SCI PUBLICATION 179

ARCHITECTS' GUIDE TO STAINLESS STEEL

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Publication Number: SCI-P-179 ISBN 1 85942 049 4

British Library Cataloguing-in-Publication Data.
A catalogue record for this book is available from the British Library.

FOREWORD

The guide aims to encourage the wider use of stainless steel in architecture by providing information on the design, specification, manufacture and maintenance of stainless steel architectural components. An overview of the contemporary use of stainless steel in architecture is also given.

The authors were Rana Burgan, Dr Raymond Ogden and Nancy Baddoo of The Steel Construction Institute. The project was managed by Dr Bassam Burgan of The Steel Construction Insitute.

The preparation of this design guide was sponsored by:

- Avesta Sheffield Ltd
- The Department of Trade and Industry
- Rimex Rigidized Metals Ltd
- Nickel Development Institute

It has been prepared by The Steel Construction Institute under the guidance of a project advisory group including representatives from the sponsoring organisations and other acknowledged experts. The group contributed to the development of the work and reviewed the material in the design guide. It comprised:

Andrew Whalley, Nicholas Grimshaw and Partners
Mr Whalley acted as chairman of the group and provided material for the case studies. Nicholas Grimshaw and Partners is an architectural practice with extensive experience in using stainless steel.

Tim Childs, Rimex Rigidized Metals Ltd
Mr Childs provided technical information on surface finishes. Rimex Rigidized Metals produces patterned, etched and polished finishes on a variety of metals including stainless steel, and also chemically colours stainless steel.

Graham Gedge, Arup Research and Development
Mr Gedge provided technical input in the areas of material durability, corrosion, and grade selection. Arup Research and Development, part of Ove Arup and Partners - Consulting Engineers, provide advice on all construction related matters with particular expertise in corrosion technology and durability of materials.

Shane McAleavey, Avesta Sheffield Ltd
Mr McAleavey and colleagues provided information on costs and material for the case studies. Avesta Sheffield Ltd is one of the world's leading producers of stainless steel.

Professor Geoff Stone, Nickel Development Institute
Professor Stone provided material for the case studies and represented the Nickel Development Institute. The Institute works to develop new markets and support growth in existing markets for nickel, one of the main alloying elements of stainless steel.

John Vine, Jordan Fabrications Limited
Mr Vine provided technical advice on fabrication. Jordan Fabrications Limited is a specialist fabricator of stainless steel components for the nuclear, defence, pharmaceutical and construction industries.

CONTENTS

SUMMARY

This guide contains information on the design, specification, manufacture and maintenance of stainless steel architectural components. It is structured into two sections: *Design and Technology* and *Case Studies*.

The first section includes structural and performance information on stainless steel and reviews production and finishing processes. It focuses on those grades of stainless steel and techniques that are commonly used in relation to architectural components.

The second section provides an overview of the contemporary use of stainless steel in architecture. It comprises a broad and representative selection of building projects by leading architects and engineers.

Guide de l'acier inoxydable à l'usage des architectes

Résumé

Ce guide contient les informations nécessaires à la conception, la description, la fabrication et l'entretien des éléments architecturaux en acier inoxydable. Il est divisé en deux parties: "Conception et technologie", d'une part, et "Etudes de cas", d'autre part.

La première partie comprend des informations sur les performances structurales de l'acier inoxydable et passe en revue les différentes techniques de fabrication et de finition des produits. Ill met l'accent sur les types d'acier inoxydable et les techniques qui sont utilisées habituellement pour les éléments structuraux.

La seconde partie passe en revue les utilisations contemporaines de l'acier inoxydable en architecture. Elle contient une vaste sélection de projets réalisés par des architectes et ingénieurs de grand renom.

Edelstahl - ein laltfaden für architekten

Zusammenfassung

Dieser Leitfaden enthält informationen zu Entwurf, Spezifikation, Verarbeitung und Wartung von, "Architektur-Bauteilen" aus Edelstahl. Er enthält zwei Abschnitte: "Entwurf und Technologie" und "Fallbeispiele".

Der erste Abschnitt enthält informationen zu Konstruktion und Werkstoffverhalten von Edelstahl und gibt einen Überblick bezüglich Produktion und Oberflächenverarbeitung. Er konzentriert sich auf die Güten und Techniken, die für architektonische Bauteile meist verwendet werden.

Der zweite Abschnitt gibt einen Überblick zur zeitgenössischen Anwendung von Edelstahl in der Architektur. Er enthält eine

breite und repräsentative Auswahl von Bauten führender Architekten und Ingenieure.

Guida per architetti all'acciaio inossidable

Sommario

Questa pubblicazione, contenente informazioni sulla progettazione, sulle prescrizioni, sulla produzione e sulla manutenzione di componenti architettoniche in acciaio inossidabile, e' strutturata in due parti: "Progettazione e tecnologia" e "Applicazioni".

La prima parte contiene informazioni di carattere strutturale sulle prestazioni dell'acciaio inossidabile e analizza i processi di produzione e di finitura, con particolare riferimento a quei tipi di acciai inossidabile e a quelle tecniche maggiormente usate per la realizzazione di componenti architettoniche.

Nella seconda parte della pubblicazione e' contenuta una panoramica sull'attuale uso dell'acciaio inossidabile in architettura; nel contempo viene proposta una estesa e rappresentativa selezione di progetti di edifici eseguiti da architetti e ingegneri.

Guía del acero inoxidable para arquitectos

Resumen

Esta obra contiene información sobre el proyecto, especificaciones, fabricación y mantenimiento de componentes arquitectónicos de acero inoxidable.

Está organizado en dos secciones: "Proyecto y Tecnologia", y "Casos prácticos". La primera sección contiene información sobre estructuras de aceros inoxidables y su rendimiento pasa revista a los procesos de producción y acabado. Se concentra en las calidades de acero inoxidable y en las técnicas que son más habituales en relación con las componentes arquitectónicas.

La segunda sección ofrece una panorámica del uso del acero inoxidable en la arquitectura contemporánea. Contiene una selección amplia y representativa de proyectos de arquitectos e ingenieros eminentes.

Arkitektens guide till rostfritt stål

Sammanfattning

Den här guiden innehåller information om formgivning, projektering, tillverkning och underhåll av rostfria, arkitektoniska stålkomponenter. Den är indelad i två avsnitt: "Utformning och teknik" samt "Referensobjekt".

Det första avsnittet omfattar information om materialets statiska kapacitet och formbarhet samt beskriver produktion och ytbehandling. Den fokuserar på de typer av rostfritt stål och tekniker som är vanligt förekommande vad beträffar arkitektoniska detaljer.

Det andra avsnittet innehåller en överblick över den nutida användningen av rostfritt stål i arkitekturen. Den omfattar ett brett och representativt urval av byggprojekt av ledande arkitekter och ingenjörer.

INTRODUCTION

Overview

Stainless steel is synonymous with modern architecture. Since the early part of the twentieth century it has provided opportunity and inspiration for generations of designers. Today, in an era of architectural pluralism, and of engineering innovation, its use is being taken to new levels of expression and technical sophistication. This is in part attributable to the strides that have been made in the metallurgy and structural understanding of the material, and in production engineering; but perhaps more fundamentally it is testament to the continuing commitment and fascination of architects and engineers with the outstanding design opportunities offered by stainless steel.

The first stainless steels were developed in the early part of the twentieth century by adding chromium, and later nickel, to carbon steel. Since then, many different types and grades have been developed, each with their own performance characteristics and consequent areas of application.

Unlike carbon steel, stainless steel has a natural corrosion resistance. In the presence of air, an oxide layer forms on the surface that inhibits corrosion. The layer is thin and reinforces the natural colour without compromising the characteristic metallic lustre. Significantly, this means that the surface of the material can be exposed without any applied coatings.

Stainless steel has many appealing architectural qualities. The opportunity to develop structures in which the cross-section of the members is an accurate reflection of the forces prevalent in them can give rise to a natural vocabulary that is perhaps even clearer in stainless steel structures than in those fabricated from other steels. Cables and rods correspond to tension, broader sections to compression, bending and shear, in degrees that are proportionate to size. As a result, carefully engineered stainless steel structures often have uncommon degrees of legibility, and profound structural expression.

Similarly, and usually at a much different scale, stainless steel castings can be carefully moulded to incorporate fixings and connections, and to make the best structural use of material. The resulting forms sometimes have a quasi-anatomical quality, a clear expression of the structural and constructional rationales of the component.

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Expressive forms:

(Right) Lattice structure, Louvre Pyramid

(Below) Cast glazing fixings, Leipzig Trade Centre

Courtesy of TriPyramid Structures Inc.

Photo: Jocelyne Van den Bossche

The surface detail of stainless steel components, whether smooth and shiny, dimpled, brushed or scoured, determines the way that light is reflected. Smooth surfaces can be mirror-like, rough surfaces can be matt. By using surface treatments either singularly, or in combination, a wide variety of effects are possible.

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Visual effect:

Mirror polished cladding, La Geode, La Villette

Photo: Alain Goustard

Not least, stainless steel is appealing for its durability. The first major architectural application of stainless steel was probably the cladding on the top of the Chrysler building in New York in 1929. Today this building has become an affirmation of the longevity of the material. This longevity has gained stainless steel numerous engineering applications, sometimes seen and sometimes unseen. These range from simple and unassuming brickwork wall ties to heavy civil engineering structures, wherever the imperative to perform reliably over long periods with little maintenance dominates materials selection.

Perhaps surprisingly, and despite its robustness, stainless steel is versatile in terms of manufacturing. It can be machined or cast, folded or formed, or worked using any of a broad range of processes. As with all materials, process and form are related: geometries that are difficult to achieve using one process may be easily achieved using another. The sheer number of processes that are available in relation to stainless steel afford excellent geometric possibilities: concern with this craft of making is central to this publication.

It is apparent that architects are increasingly taking an intimate 'hands on' involvement in developing bespoke, often unique, components using stainless steel. This requires conversancy and empathy with the material, skills that Norman Foster alluded to when in 1984, on the occasion of his exhibition in Manchester, it was suggested to him that modern architecture evolved around the assemblage of standard or stock components. Foster responded:

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This is a misapprehension. In fact very little comes off the shelf. The building industry is not like the automobile industry in that sense. If you order a lot of components for a building the chances are that someone will have to go away and make them. Now if you have a thorough grasp of production processes you should be able to design something better.[1]

Durability:

Cladding dating from 1939, Chrysler building, New York

Courtesy of Avesta Sheffield Ltd

In a climate where innovation and uniqueness are valued, this remains true, and the relevance of the comment goes far beyond the so called 'high tech'. This publication seeks to provide architects and others with insight into manufacturing methods, and aspects of the design and specification of stainless steel components appropriate to the central role that many assume in terms of detailed design.

The publication also reflects a belief that 'making' is not the whole story. 'Making' follows 'choosing', and 'choice' requires appreciation of possibilities. The early part of the century gave us stainless steel, perhaps the latter part is notable as a time when

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architects and engineers earnestly began to discover the potential of its architectural usage. By way of review, this publication includes a broad range of case studies, supported by technical detail. In total, these provide an overview of current technology and indicate the practical possibilities of the material as currently understood. These case studies demonstrate that stainless steel is a material of great delight. Perhaps the greatest delight is that each decade brings new applications and demonstrates new possibilities. The future of stainless steel in architecture is exciting.

INTRODUCTION

How to Use this Design Guide

The guide is divided into two parts:

The first part ***Design and Technology*** covers aspects of the design and technology of stainless steel relevant to architectural applications. Topics are reviewed in varying degrees of detail, which generally reflect the level of understanding that is necessary to make reasonably informed design decisions.

The second part ***Case Studies*** presents a broad range of case studies that illustrate the application of various grades of stainless steel, surface finishes and manufacturing processes.

Section 1 Grades, Properties and Product Forms describes what stainless steels are, and introduces the main grades appropriate for architectural applications. It includes information on mechanical and physical properties, and product ranges. ***Appendix A*** lists national and European standards relating to stainless steel. ***Appendix B*** compares the mechanical and physical properties of selected grades of stainless steel with carbon steel, aluminium and timber. ***Appendix C*** gives further information on available products including general size ranges. ***Appendix D*** covers stainless steel woven fabric.

Section 2 Durability discusses the durability of stainless steel and provides guidance on grade selection and detailing.

Section 3 Economics discusses the economics of stainless steel, including life cycle considerations.

Section 4 Environmental Issues discusses key environmental aspects and benefits of stainless steel.

Section 5 Production and Fabrication describes production and fabrication techniques that are appropriate for manufacturing architectural components.

Section 6 Surface Finish describes surface finishing treatments. ***Appendix E*** lists the standard finishes and their corresponding process routes as set out in EN 10088.

Section 7 Joining describes techniques for joining stainless steel including welding, mechanical fastening and adhesive bonding.

How to Use this Design Guide

Section 8 Maintenance and Cleaning provides guidance on initial cleaning and subsequent maintenance.

Section 9 References lists relevant publications contain further information on the subjects covered in the guide.

Appendix F lists sources of further information on stainless steel

The 'case studies' box in the top right-hand corner of Sections 5 to 7 refers to projects included in the second part of the guide which have made use of the particular technique being described in that Section. Similarly, a 'technique' box in the top right-hand corner of each case study refers to manufacturing processes in Sections 5 to 7.

DESIGN AND TECHNOLOGY

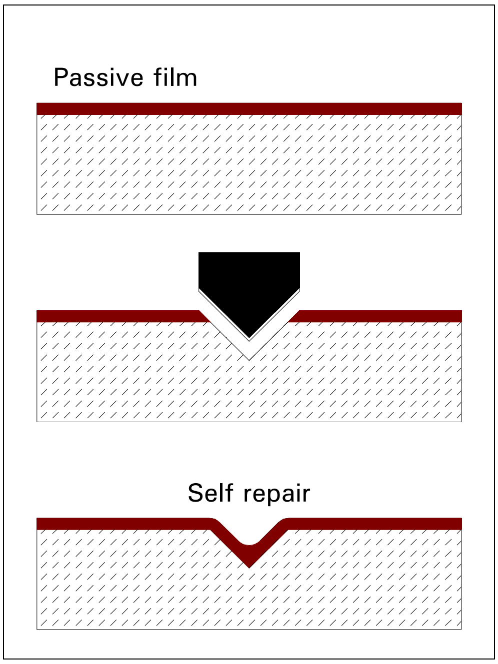
1 GRADES, PROPERTIES AND PRODUCT FORMS

1.1 An Introduction to Stainless Steel

All metals react with oxygen and water in the atmosphere to form a surface layer of oxide. The layer formed on ordinary carbon steels, known as rust, is a hydrated iron oxide which is porous and permits penetration of oxygen and water, allowing further oxidation to continue beneath it. When carbon steels are exposed to air and moisture it is necessary to provide the steels with protection. For architectural exposed steel, where appearance is important, this is usually achieved by the use of a protective coating. Such a coating will have a finite life and will therefore require infrequent but regular maintenance.

Stainless steels are alloys of iron containing a minimum of 10.5% chromium and usually at least 50% iron. Upon exposure to air or water, a thin, stable, chromium-rich oxide film forms on the surface of these metals. This film provides a high degree of protection, and if damaged by abrasion, reforms rapidly (Figure 1.1).

Figure 1.1 The corrosion protection of stainless steel



Many grades of stainless steel are available, each with different mechanical and physical properties. Generally, corrosion resistance increases with the chromium content of stainless steels.

1 GRADES, PROPERTIES AND PRODUCT FORMS

1.1 An Introduction to Stainless Steel

Austenitic stainless steels are based on 17-18% chromium and 8-11% nickel additions and are the most widely used grades of stainless steel. Compared to structural grades of carbon steel, austenitic stainless steels have:

- Excellent resistance to general or uniform corrosion.
- Different yielding and forming characteristics.
- Significantly better toughness at all temperatures.

Ferritic stainless steels contain chromium but not nickel, and have lower corrosion resistance, strength and ductility than austenitic grades; they are difficult to weld. Some grades, such as the 12% chromium ferritic steels, have relatively good wear resistance. The 17% chromium ferritic steels are occasionally used for internal applications. Since their architectural use is very limited, they are not discussed further in this guide.

Duplex stainless steels have a mixed austenitic/ferritic microstructure and are based on 22-23% chromium and 4-5% nickel additions. Grade 1.4462 (2205) has generally better corrosion resistance than the standard austenitic stainless steels due to the higher content of chromium and presence of molybdenum and nitrogen. Duplex stainless steels are also stronger than austenitic steels.

Austenitic and duplex stainless steels are readily welded.

Table 1.1 gives examples of austenitic and duplex stainless steels, their compositions and attributes.

Austenitic stainless steel grades 1.4401 (316) or 1.4301 (304) are frequently used for architectural applications. These designations are explained in more detail in Section 1.2.

1 GRADES, PROPERTIES AND PRODUCT FORMS

1.1 An Introduction to Stainless Steel

Table 1.1
Typical content of main alloying elements in the principal grades of stainless steels (The grades most widely used for architectural applications are shown in bold.)

Family	EN 10088 designation	Popular name[1]	Weight (%)					Attributes
			Cr	Ni	Mo	N	Others	
Austenitic	**1.4301**	**304**	18	9	-	-	-	Good range of corrosion resisting and fabrication properties; readily available in a variety of forms, *e.g.* sheet, tube, fasteners, fixings *etc.* 1.4401 (316) has better pitting corrosion resistance than 1.4301 (304). Low carbon (L) grades should be specified where extensive welding of heavy sections is required.
	1.4307	304L	18	9	-	-	Low C	
	1.4401	**316**	17	12	2	-	-	
	1.4404	316L	17	12	2	-	Low C	
	1.4541[2]	321	18	10	-	-	Ti	
Duplex	1.4362	2304	23	4	-	0.1	-	Higher strength and wear resistance than standard austenitic grades with good resistance to stress corrosion cracking. Grade 1.4462 (2205) has better corrosion resistance than 1.4362 (2304).
	1.4462	2205	22	5	3	0.15	-	

Notes:
1) The popular name originates from the (now partly superseded) British Standards and AISI system.
2) Titanium is added to stabilise carbon and improve corrosion performance in the heat affected zones of welds. However, except for very heavy section construction, the use of titanium stabilised austenitic steels has been superseded largely by low carbon grades.

1.2 Specification and Designation Systems

The new material standard for stainless steels is BS EN 10088: 1995, *Stainless Steels*. It is sub-divided as follows:

- Part 1, *List of stainless steels.* This sets out the chemical compositions of particular grades of stainless steel and reference data on physical properties such as density, modulus of elasticity and thermal conductivity.
- Part 2, *Technical delivery conditions for sheet, plate and strip for general purposes.* This sets out the chemical compositions and surface finishes for the materials used in flat products and mechanical properties such as proof strength.
- Part 3, *Technical delivery conditions for semi-finished products, bars, rods and sections for general purposes.* This sets out the chemical compositions and surface finishes for the materials used in long products and mechanical properties such as proof strength.

Stainless steel producers and suppliers throughout Europe are now following this standard.

The designation systems adopted in the European standard are the **European material number** and a **material name**.

The material number comprises three parts, for example 1.4401, where:

1.	**44**	**01**
Denotes steel	Denotes one group of stainless steels	Individual grade identification

The material name system provides some indication of the steel composition, for example X5CrNiMo17-12-2, where:

X	**5**	**CrNiMo**	**17-12-2**
Denotes high alloy steel	100 x % of carbon	chemical symbols of main alloying elements	% of main alloying elements

Each stainless steel material name has a unique corresponding material number.

1 GRADES, PROPERTIES AND PRODUCT FORMS

1.2 Specification and Designation Systems

In this guide, the designation system adopted is the European material number, followed in brackets by a 'popular name' *e.g.* 1.4401 (316). This popular name originates from the (now partly superseded) British Standards and AISI system, and is included here to help those familiar with the older naming convention.

Appendix A lists national and European standards covering other stainless steel product forms, *e.g.* castings, fasteners, piping, wire *etc*.

1.3 Mechanical and Physical Properties

The shape of the stress-strain curve for stainless steel differs from that of carbon steels. Whereas carbon steel typically exhibits linear elastic behaviour up to the yield stress and a plateau before strain hardening, stainless steel has a more rounded response with no well-defined yield stress. This results in a difference in structural behaviour between carbon steel and stainless steel and consequently different design rules apply in certain cases[2].

Stainless steel 'yield' strengths are generally quoted in terms of a proof strength defined for a particular offset permanent strain, conventionally the 0.2% strain. EN 10088 quotes 0.2% proof strengths of around 220 N/mm^2 for the grades of austenitic stainless steel typically used for architectural applications. This strength relates to material in the annealed condition. In practice, these values will be exceeded if the material is cold worked. There is provision within EN 10088 for supply of certain steels (including austenitic steels 1.4301 (304) and 1.4401 (316)) as cold rolled strip with 0.2% proof strengths up to four times greater than those of the annealed material.

Austenitic stainless steels have thermal expansion coefficients 30-50% greater than those for carbon steels, and thermal conductivities of less than 30% of those for carbon steels. This has implications for detailing and in welding where suitable expansion allowances should be made.

Austenitic stainless steels are essentially non-magnetic whereas duplex grades are magnetic.

Appendix B gives room temperature mechanical and physical properties quoted in EN 10088 for four grades of stainless steel. Equivalent properties for carbon steel, aluminium and timber are also shown.

1.4 Products

Most grades of austenitic stainless steels are available in the following forms:

- Plate, sheet, strip, pipe and tube (welded and seamless).
- Bar, rod, wire and special wire sections.
- Cold formed structural sections (*e.g.* channels, angles).
- Hot rolled sections (*e.g.* equal and unequal angles).
- Extruded sections.
- Castings.
- Fasteners, fixings and fittings.
- Woven fabric.

Sheet, strip and plate are commonly used for structural and cladding components. Hot rolled sections are available, but structural sections are generally fabricated by either welding together cold formed plate, sheet and strip or by roll forming.

Appendix C gives further details of the products available with approximate size ranges. Appendix D contains information on stainless steel woven fabric.

2 DURABILITY

2.1 Introduction

Stainless steels have a record of highly satisfactory performance in many different environments. However, to ensure good performance, it is essential that the correct grade is selected and appropriate design, fabrication, installation and maintenance practices followed.

The selection of a particular grade of stainless steel is influenced by a number of factors including structural performance, production and manufacturing issues, cost and durability. However, it is the durability given by its resistance to corrosion which is often the key factor in its selection.

For architectural components exposed to naturally occurring atmospheres and waters, the conventional austenitic and duplex stainless steels are resistant to general or uniform corrosion. However, there are three areas where an understanding of the ways in which stainless steel can be attacked is necessary. These are: weathering and surface discolouration; the risk of localised attack from chemical microclimates (*e.g.* salt deposits in marine locations); and lastly, the special case of structures in chemically aggressive environments. This Section discusses forms of corrosion attack relevant to stainless steels and how they can be avoided. Practical design guidance on detailing to optimise durability is also presented.

Weathering of stainless steel is extremely important, particularly where components are visible. Cladding panels, for instance, should generally be designed to avoid staining, which can occur if an inappropriate grade is selected, or if the surface becomes contaminated with carbon steel during fabrication or installation. There are certain principles that should be followed where stainless steel is used in conjunction with other materials. These are presented in Section 2.3.

Cladding fixings also warrant special consideration. Stainless steel cladding attachments are increasingly used to support brickwork and curtain walls, whilst mechanical screw fastenings are used in relation to sheet cladding systems. The design and specification criteria surrounding the use of these components are presented in Section 7.2.

2 DURABILITY

2.2 The Durability of Stainless Steel

The corrosion resistance of stainless steels arises from the passive, chromium-rich, oxide film that forms on the surface of the steel. Unlike rust that forms on carbon steels, this film is stable, non-porous and adheres tightly to the surface of the steel. It is usually self-repairing and resistant to chemical attack. If the film is scratched or broken, the exposed surface tends to react with oxygen, thereby renewing the oxide layer (Figure 1.1). The material therefore has intrinsic self-healing properties.

The presence of oxygen is essential to the formation of the oxide film. Deposits that form on the surface of the steel can reduce the access of oxygen to the surface of the steel and can therefore compromise corrosion resistance.

The stability of the oxide film is dependent upon several factors including:

- The alloying elements present in the material.
- The corrosive nature of the environment.

Further detailed guidance on the corrosion resistance of stainless steels in different environments is given in the *Avesta Sheffield Corrosion Handbook for Stainless Steel*[3].

Since the alloying elements are expensive, there is a relationship between corrosion resistance and cost. For example, the cost of grade 1.4401 (316) stainless steel, which contains molybdenum as well as chromium and nickel, is approximately 40% more than grade 1.4301 (304), which only contains chromium and nickel as the main alloying elements and is less resistant to corrosion. The correct grade specification for a given environment is therefore a balance between cost and performance.

2.3 Types of Corrosion

The types of corrosion that can affect stainless steel building components are most commonly:

- Pitting corrosion
- Crevice corrosion
- Galvanic corrosion
- Stress corrosion cracking.

2.3.1 **Pitting**

Pitting is a localised form of corrosion that generally results in small depressions on the surface of the material. It is often associated with exposure to chlorides or salts that penetrate the oxide film where it is weakest, and is a particular consideration in marine environments. Generally, pitting does not significantly reduce the cross-sectional area of components and tends to have little effect upon structural performance. However, the corrosion products from the pits can cause staining on the surface which spreads to an extent far beyond the pit sites. The staining can usually be removed by cleaning, leaving only minor dulling of the surface by the micropits. However, in regions inaccessible for cleaning and in severe cases of attack, this can have a serious detrimental effect on the appearance of components such as cladding panels.

Regular washing of the surface can reduce susceptibility to such corrosion. Grades of stainless steel that contain molybdenum are more resistant to pitting.

2.3.2 **Crevice corrosion**

Corrosion can initiate more easily in narrow crevices than on a freely draining surface, because the diffusion of oxidants necessary to maintain the oxide film is restricted and the crevice tends to trap corrosive deposits. In terms of corrosion, a crevice is defined as an opening between 0.025 and 0.1 mm, and should not be confused with wider openings that are commonly encountered in engineering structures.

Crevice corrosion is only likely to be a problem if a build-up of chlorides occurs in a stagnant solution within a crevice. Severity of corrosion will then be dependent on the geometry of the crevice; the narrower and deeper it is, the more severe corrosion tends to become. Crevices may occur at joints, such as under washers or bolt heads, in the threads of bolts, beneath deposits on the surface of stainless steel, beneath absorbent gaskets, or as a result of surface damage such as deep scratches. Every

2.3 Types of Corrosion

reasonable effort should be made to eliminate details which retain stagnant water.

2.3.3 **Galvanic corrosion**

Care should be taken whenever dissimilar metals are in contact. Galvanic (bimetallic) corrosion can occur when different metals are in electrical contact and are both immersed in the same solution (electrolyte). If an electric current flows between the two, the less noble metal (the anode) corrodes at a faster rate than would have occurred if the metals were not in contact. In the case of architectural components, the electrolyte is normally water.

It is difficult to assess the rate of corrosion between dissimilar metals, and especially the point at which the corrosion risk becomes significant for components only subjected to periodic moisture or modest dampness. Factors such as the relative areas of the different metals, the type of electrolyte and the required service life are all significant. Small carbon steel components in stainless steel assemblies are generally more susceptible to galvanic corrosion than larger carbon steel assemblies used with small stainless steel components.

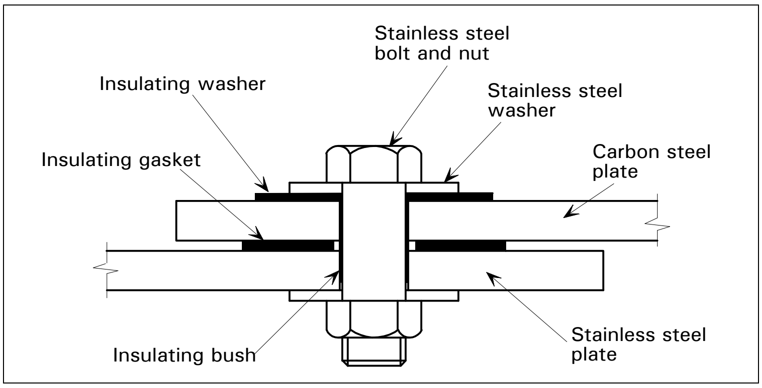
PD 6484[4] gives guidance on galvanic corrosion based on practical experience in a range of environments.

Stainless steels are the most noble of the common engineering and construction metals and therefore usually form the cathode in a bimetallic couple, and thus rarely suffer from galvanic corrosion. An exception is the couple with copper, which should generally be avoided except under benign conditions. Contact between stainless steel and zinc or aluminium may result in some additional corrosion of the latter two metals. This is unlikely to be significant structurally but the resulting white/grey powder may be deemed unsightly.

Galvanic corrosion may be prevented by isolating dissimilar metals, and by excluding water or any other fluid that might act as an electrolyte. Isolation around bolted connections can be achieved by non-conductive plastic/rubber gaskets, or nylon/Teflon washers or bushes (Figure 2.1). When painted carbon steel is joined to stainless steel, it is good practice to paint over the joint and to cover a few centimetres of the stainless steel to prevent the possibility of galvanic corrosion of the carbon steel.

2.3 Types of Corrosion

Figure 2.1 Avoiding galvanic corrosion when connecting dissimilar materials



2.3.4 Stress corrosion cracking

Stress corrosion cracking (SCC) is a form of localised attack which can lead to rapid crack growth and loss of load bearing capability. It occurs under the simultaneous presence of tensile stresses, an aggressive, usually chloride-bearing, environment and metal temperatures above about 60°C. (In certain cases, SCC can occur at lower temperatures, see Section 2.5.) Tensile stresses can arise not only from applied loads, but also from residual stresses left after cold working or welding. However, SCC is unlikely to be encountered in normal building atmospheres.

2.4 Grade Selection to Prevent Corrosion

In most normal practice, the environments determining durability issues are those external to the building and those specified to be maintained within it. Often the internal environment will be related to the needs of human occupants.

The table below gives guidance on grade selection for a range of service environments[5]. The information contained within the table is based on long term exposure tests (around 50 years).

Table 2.1
Suggested grades for atmospheric applications

Stainless steel grade	Location											
	Rural			Urban			Industrial			Marine		
	L	M	H	L	M	H	L	M	H	L	M	H
1.4301 (304)	✓	✓	✓	✓	✓	❢	❢	❢	×	✓	❢	×
1.4401 (316)	★	★	★	★	✓	✓	✓	✓	❢	✓	✓	❢
Special high alloy grades	★	★	★	★	★	★	★	★	✓	★	★	✓

L - Least corrosive conditions within that category, *e.g.* by low humidity, low temperatures.
M - Fairly typical of that category.
H - Corrosion likely to be higher than typical for that category, *e.g.* increased by persistent high humidity, high ambient temperatures, particularly aggressive air pollutants.

✓ - Probably the best choice for corrosion resistance and cost.
★ - Probably over-specified from a corrosion point of view.
❢ - Worthy of consideration if precautions are taken (*e.g.* specifying a relatively smooth surface and regular washing to be carried out).
× - Likely to suffer severe corrosion.

Adapted from Advantages for Architects, Nickel Development Institute, 1990

2.5 Corrosion in Aggressive Environments

The environmental categories given in Table 2.1 refer to general atmospheric conditions at a site. However, there are certain cases where specific chemical corrosion risks need to be considered.

One example is in enclosed swimming pool buildings. Here a combination of temperature, humidity and corrosive agents originating from the reaction of pool water disinfection additions, can produce an aggressive internal environment. Corrosion attack or degradation has been observed for several building materials in these conditions. In particular, the standard grades of stainless steels may be subject to stress corrosion cracking. However, specific guidance on grade selection and maintenance for stainless steels is available for these circumstances(6).

An example of localised conditions affecting materials selection may arise near to chimneys, stacks or flues which might discharge traces of chemicals. Where chemical processes are involved, expert assistance should be sought.

2.6 Detailing to Prevent Corrosion

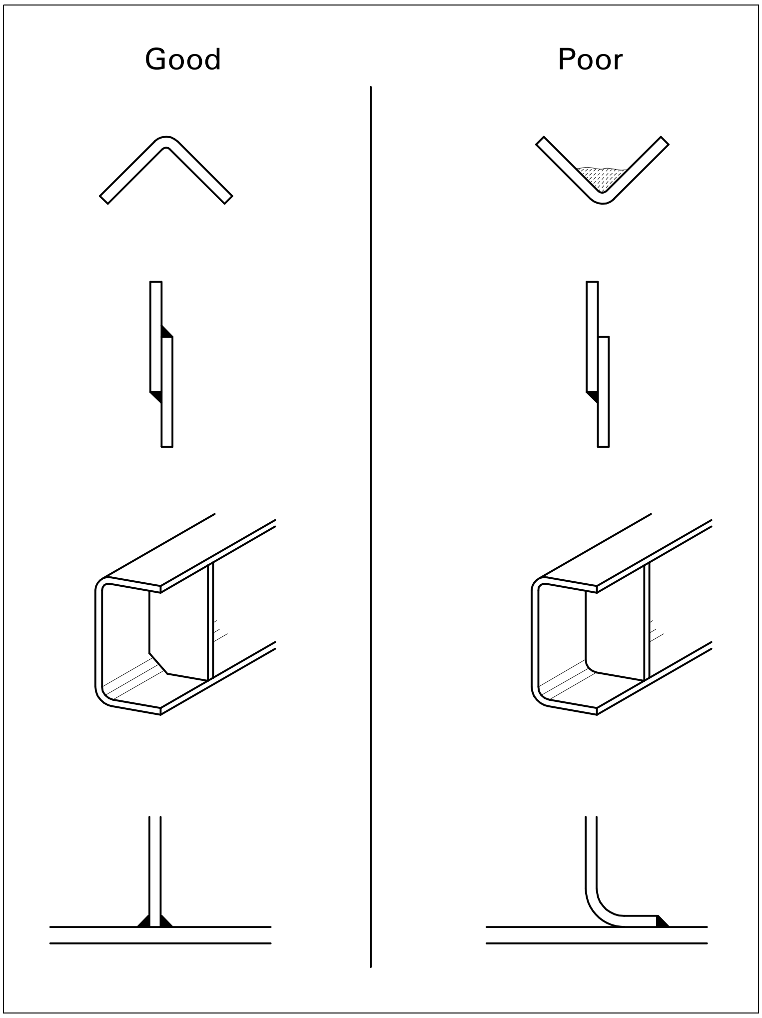
The following points summarise recommendations for good detailing to maximise durability:

- Avoid arrangements which allow dirt entrapment or chemical concentration.
- Provide clear drainage paths.
- Avoid gaps, ledges, slits and crevices.
- Specify smooth contours and radiused corners to facilitate cleaning.
- Avoid sharp changes in section and other stress raisers.
- Avoid details which create access problems for welding to achieve the optimum geometry of weld and ease of final finishing.
- Aim for conditions allowing full penetration welded joints with smooth contours and weld bead profiles.
- Insulate at connections with other metals.

Figure 2.2 illustrates selected good and poor design features.

2.6 Detailing to Prevent Corrosion

Figure 2.2
Design features to prevent corrosion



3 ECONOMICS

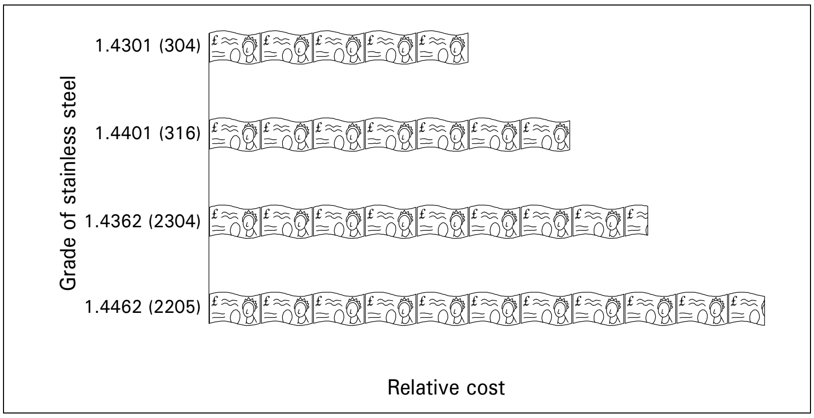
3.1 Introduction

The cost of a stainless steel component can be broken down as follows:

- Design
- Material
- Fabrication
- Surface finish
- Inspection and testing.

The material cost of stainless steel is between four and six times that of carbon steel. Grade 1.4401 (316) costs about 40% more than grade 1.4301 (304), as illustrated in Figure 3.1. Duplex stainless steels cost about twice as much as grade 1.4301 (304).

Figure 3.1
Relative costs of different grades of stainless steel material



A stainless steel component may cost slightly more to fabricate than an identical carbon steel component because:

- welding is slower
- machining is more difficult
- more controlled cleaning procedures are required.

The type of surface finish has a significant effect on the final cost of a component. Figure 3.2 indicates the cost of cold rolled stainless steel sheet in a variety of surface finishes relative to the cost of material with a basic mill finish (2B or 2D).

3 ECONOMICS

3.1 Introduction

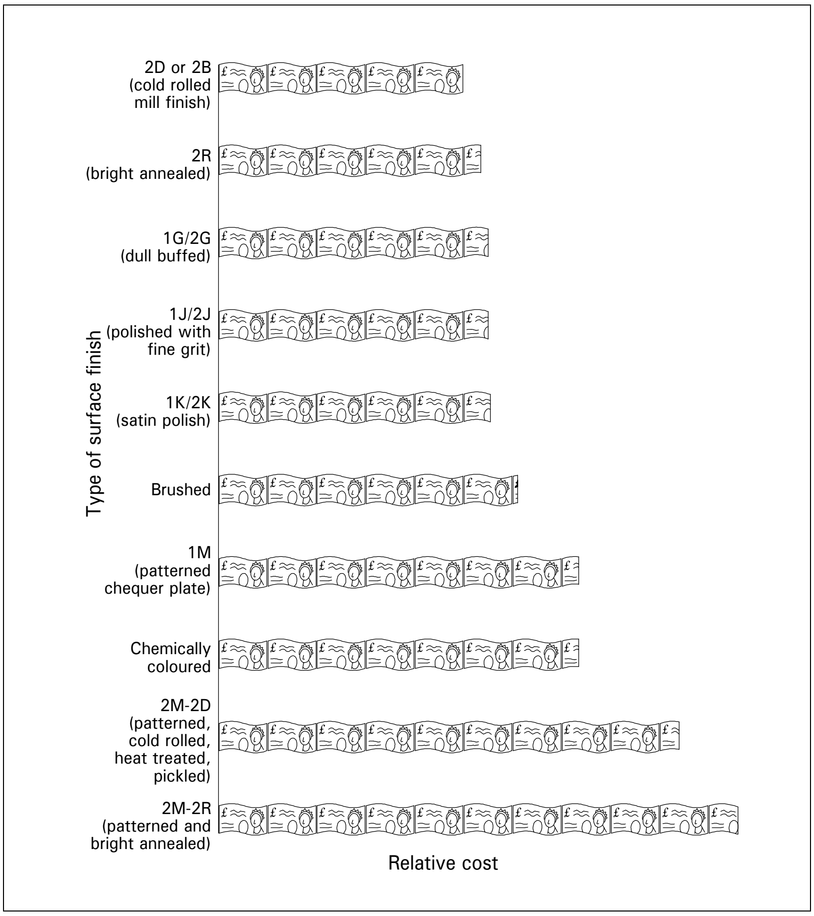


Figure 3.2
Relative costs of grade 1.4401 (316) stainless steel with different surface finishes

The costs of design and inspecting and testing a stainless steel component are essentially similar to those of a carbon steel component.

3.2 Economic Benefits of Using Stainless Steel

3.2.1
Initial costs

Whilst the material cost of stainless steel is higher, weight for weight, than some alternative materials, the overall installed cost of a stainless steel component may be less. Savings can arise for various reasons, including the omission of surface coatings.

3.2.2
Operating costs

The excellent corrosion resistance of stainless steel can offer many benefits including:

- Reduced inspection frequency and costs
- Reduced maintenance costs
- Long service life.

3.2.3
Life cycle costs

There is increasing awareness that life cycle (or whole life) costs, not just initial costs, should be considered when selecting materials. Life cycle costs take account of:

- Initial costs
- Operating costs
- Residual value (at the end of the structure's life).

For ease of comparison, it is usual to adjust all the future costs to present day values using a discount rate which encompasses inflation, bank interest rates, taxes and possibly a risk factor (in the event that the structure will be obsolete before the end of its design life).

Viewed in this way, stainless steel can often be an economical choice, since the savings in operating costs often far outweigh any higher initial costs. Although stainless steel has a high residual value, this is rarely a deciding factor for a structure with a long projected life (for instance over 50 years) as the discounted value is then very small.

The two main difficulties with carrying out a life cycle cost study are determining the future operating costs and selecting the discount rate. The calculations thereafter are straightforward, and a simple computer program[7] is available from the Avesta Sheffield Technical Advisory Centre and the Nickel Development Institute.

4 ENVIRONMENTAL ISSUES

Whilst it is entirely possible to produce stainless steel from iron ore, production is generally from scrap carbon steel or scrap stainless steel. The use of scrap reduces the energy necessary to produce new material (generally termed embodied energy), reduces waste and production emissions (including carbon dioxide), and has other important environmental benefits.

Energy and emissions

In the UK, stainless steel is produced using electric arc furnaces. Production from recycled scrap uses energy at the rate of approximately 11 GJ/tonne as compared to approximately 25 GJ/tonnes for production from iron ore by a basic oxygen process. (These numbers depend on the precise information included in any energy inventory calculation for production of the material.) Of this 11 GJ/tonne, about 80% is attributable to melting and refining, and 20% to the collection of scrap and distribution of stainless steel after production.

About 1.6 tonnes of carbon dioxide are emitted for each tonne of stainless steel produced from recycled scrap using electric arc furnaces, as opposed to approximately 3 tonnes for basic oxygen routes.

As production methods become more energy efficient, energy requirements and carbon dioxide emissions are both likely to reduce considerably.

Resources

The principal alloying elements of stainless steel are chromium and nickel. There are ample proved reserves of these materials to meet foreseeable needs, even allowing for exponential increase in demand for stainless steel. Similarly, there is an abundance of iron ore, the basic mineral used to produce new carbon steel, a proportion of which becomes the scrap from which stainless steel is made.

Recycling

Since stainless steel has a relatively high scrap value, a considerable proportion is recycled. Advantages of recycling, apart from those already cited, include reduced resource depletion, and reduction of the volume of metallic, mineral and manufacturing waste that would otherwise be sent to landfill.

5 PRODUCTION AND FABRICATION

5.1 Introduction

A wide range of production engineering techniques are available for shaping stainless steel. There is inevitably a relationship between process and form. Geometries that are difficult to achieve using one process may be easily achieved using another. For instance, castings are often characterised by flowing, rounded geometries, whilst simple folded sheet metal components tend to be angular. Normally the final selection of techniques will depend upon a range of criteria including:

- The geometry and size of the component
- The tolerances that are required
- The numbers of components to be produced
- Structural considerations
- Cost.

The most significant processes used in relation to stainless steel are presented in the following sections.

5 PRODUCTION AND FABRICATION

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5.2 Profile Cutting Techniques

5.2.1
Introduction

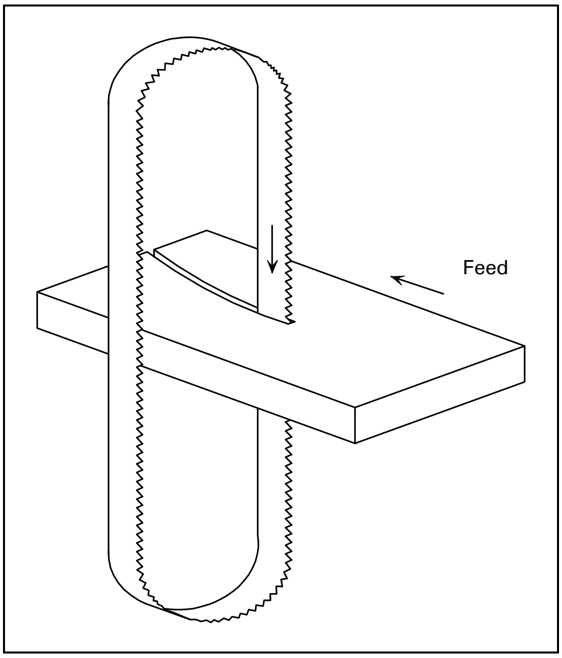
Profile cutting may be done using a variety of techniques including: bandsawing, guillotining, punching, water jet cutting, plasma arc cutting and laser cutting. Conventional flame cutting of stainless steel is not possible, unless a powder fluxing technique is adopted, because the flame cannot cut through the chromium oxides which form on the steel surface.

Factors affecting choice of cutting technique include material thickness, edge finish and cutting speed.

5.2.2
Bandsawing

A bandsaw has a continuous loop blade driven by two wheels set vertically above each other (Figure 5.1). The technique is commonly available and is flexible. The size of sheet or plate that can be profiled is limited by the bed size of the machine, and the weight that can be safely manipulated by the operatives. The depth of the blade and tooth design determines the minimum radius and tightness of arc that can be profiled.

Figure 5.1
Profile cutting using a bandsaw



The technique is better suited to sweeping profiles than those with tightly rounded corners, although difficult features can be achieved by other profiling methods after the basic shape is cut. The hardness of stainless steel requires the use of alumina or silicon carbide coated blades.

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5.2 Profile Cutting Techniques

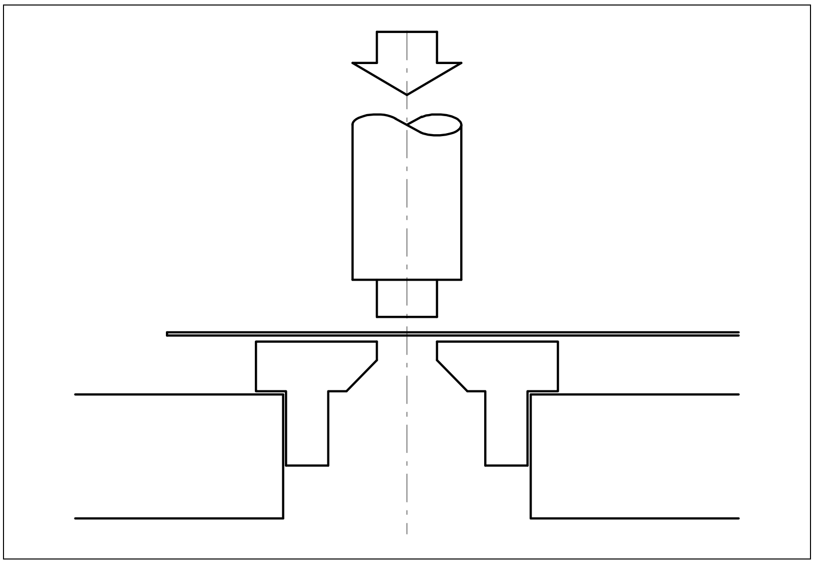
5.2.3 Guillotining and punching

Guillotines, simple blade-type cutting machines, may be used for shearing stainless steel along straight lines. They are particularly useful for sheet reduction and for preparation of simple blanks. Machines (commonly known as *quickworkers*) based upon small rotary cutting wheels are used for shearing curves; these allow the orientation of the sheet to be adjusted as the shearing operation progresses.

Holes can be punched by forcing a male die through sheet, plate or other material into an open-ended female die, such that the material shears (Figure 5.2). The diameter of holes should generally be greater than 5 mm and at least 2 mm greater than the thickness of the stainless steel; anything smaller should be drilled. The maximum thickness of stainless steel that can be punched is about 20 mm, but it should be noted that thicknesses greater than 10 mm may be prone to cracking on shear lines, encouraging corrosion.

On thin material (up to about 3 mm), holes can be simultaneously punched and the edges turned in using a female die that is larger than the male die; some metal is drawn down into the gap between the two dies during the punching process.

Figure 5.2
Punching



Profiles can be punched out of stainless steel sheet using NC (numerically controlled) punching machines. In this process the workpiece is held under a repeating punch, using a clamp that repositions the workpiece between every punch stroke.

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5.2 Profile Cutting Techniques

5.2.4 Water jet cutting

A water jet cutter uses a narrow, high pressure water jet to propel abrasive particles. The abrasive is entrained into the stream of fast moving fluid in the cutting nozzle. It strikes the workpiece at close to the speed of sound, chipping away small particles (Figure 5.3). Abrasive particle size governs cutting speed and cut smoothness, with smaller particles giving a slower smoother cutting action. Stainless steel up to 75 mm thick can be cut using this technique.

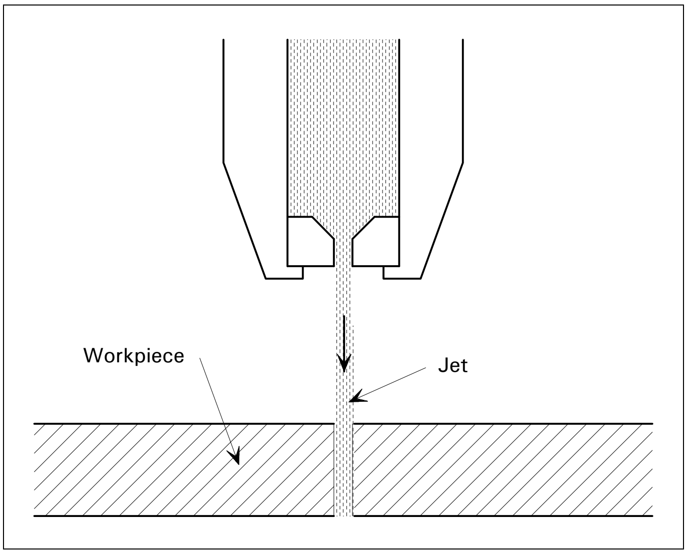

Figure 5.3 *Profile cutting using a water jet cutter*

Water cutting does not heat, distort or change the properties of stainless steel, and is safe to use in environments where flame cutting would be hazardous (*e.g.* in fire risk zones). The use of water jet cutting is increasing, and costs are falling.

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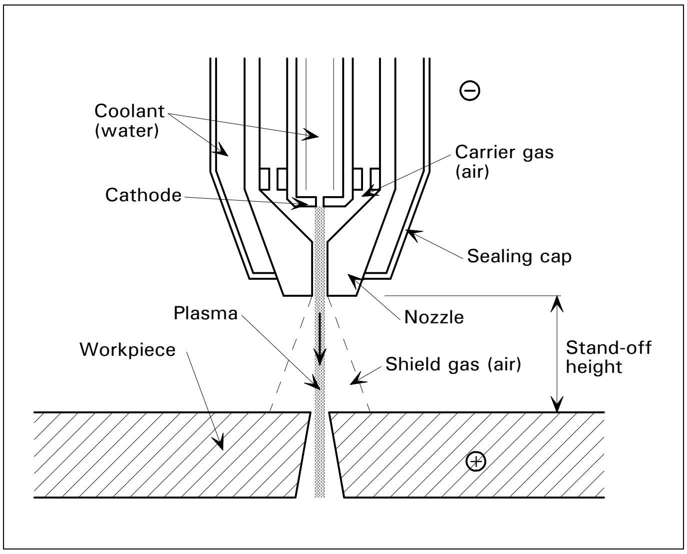
5.2 Profile Cutting Techniques

5.2.5
Plasma arc cutting

A plasma arc (a mixture of neutral atoms, free electrons and positive ions) is produced by electronically ionising a suitable gas or mixture of gases. The plasma torch and the workpiece are charged to opposite polarities, causing a plasma arc to be formed between them (Figure 5.4). The arc reaches temperatures of up to 28,000°C and the particles move at a high velocity; they blow away molten material as it is produced.

Smooth-sided cuts can be produced in stainless steel up to 125 mm thick, but the heat of the plasma arc results in the formation of a heat affected zone and some distortion of the steel. Carbonisation in the heat affected zone may lead to corrosion problems later, and the cut edges should be either machined (removing approximately 3 mm of steel) or acid pickled. Plasma arc cuts are about 8 mm wide and the cut edges, particularly on thick material, tend to be slightly sloping.

Figure 5.4
Profile cutting using a plasma arc cutter



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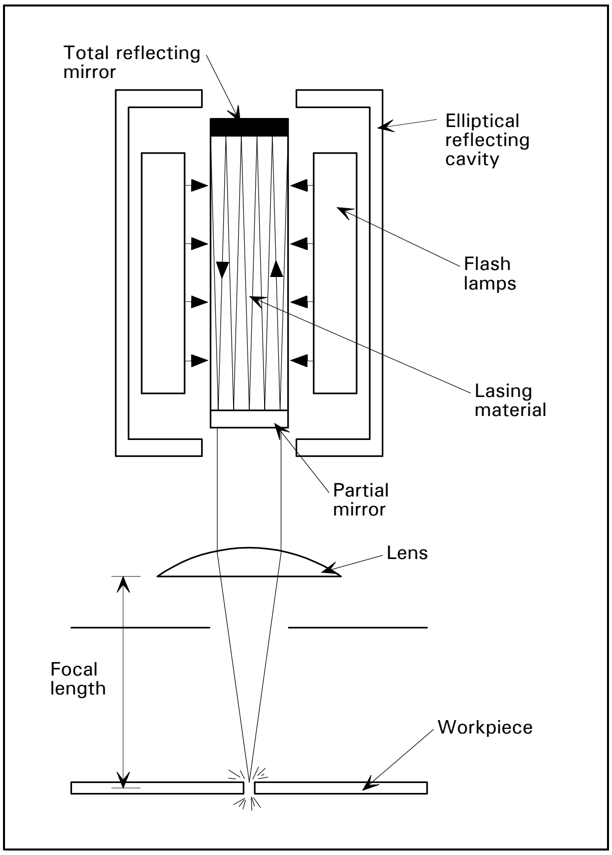
5.2 Profile Cutting Techniques

5.2.6 Laser cutting

Stainless steel up to about 8 mm thick can be cut using a laser (Figure 5.5). This technique is very precise, and there is little excess heat, so distortion and heat affected zones are minimal. Gas may be supplied at the cutting point either to increase the cutting rate (using oxygen) or to shield the workpiece and help purge vaporised material (using argon or nitrogen).

Figure 5.5 *Profile cutting using a laser cutter*



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5.3 Forming Techniques

5.3.1 Introduction

Folding is a means of bending stainless steel sheet in two dimensions, producing linear deformation. Complex forms can be produced by multiple folding operations. Folding does not generally require special tooling and so tends to be a particularly economic method of producing geometrically simple components.

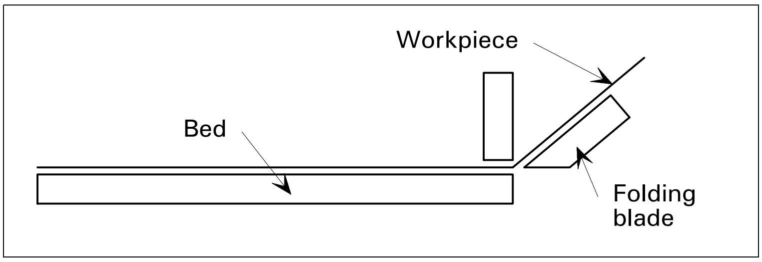
Cold forming austenitic stainless steels results in greater work hardening, so power requirements will be higher than for carbon steel. Furthermore, stainless steel has a greater tendency to 'spring back' than carbon steel, and so must be overbent.

The high ductility of stainless steel allows small radii to be formed. However, as a general rule, bend radii should not be less than twice the thickness for grades 1.4301 (304) and 1.4401 (316), or two and a half times the thickness for 1.4462 (2205).

5.3.2 Sheet metal folding

Sheet metal folding machines comprise a flat bed and a pivoting block or plate tool. The workpiece is sandwiched between the tool bed and a clamping plate such that the leading edge of the tool bed and clamp lie along the line where folding is required. Metal protruding beyond the leading edge of the clamp is then bent upwards by the action of the folding blade (Figure 5.6).

Figure 5.6
Simple folding machine



5.3.3 Brake pressing

A brake press is simply a wide press with a relatively narrow bed and ram (the moving part of the press that normally holds the upper tool of a matched die set), as shown in Figure 5.7. Brake presses can be used to form single wide sheets or plates, or can accommodate several dies such that a number of small pieces can be bent in one operation. Brake presswork is the most widely used technique for the production of architectural panels, flashings and similar components.

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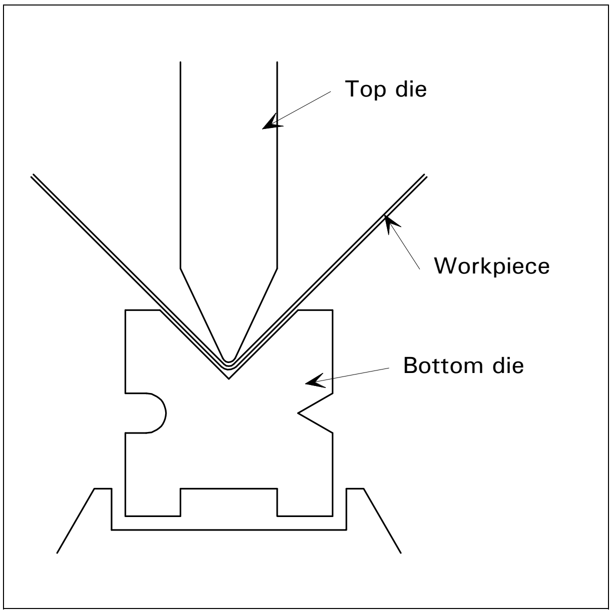
5.3 Forming Techniques

Single strike techniques are often used to produce simple L shaped flashings, whilst multiple bending operations are used to produce Z, C, S, I, T, and even O profiles, or to corrugate sheets. Brake presses may also be used to produce light impressions in different directions across metal sheet, improving rigidity (cross swaged cladding panels, for example).

Brake presses are commonly available up to 4 m in bed length, although larger machines are in existence.

Figure 5.7 *Brake presswork*



5.3.4 Roll forming

In the roll forming process, steel strip is fed through several pairs of cylindrical tools arranged serially. Each of these progressively forms the strip material until the desired profile is achieved (Figure 5.8) Machine set-ups are longer and more complicated than for press braking, and tooling is rather more involved. Hence the process only becomes economic for large production runs. Library tools are available for standard L, C, and T sections. These can be augmented by special tooling to produce minor variations (such as swages in standard sections).

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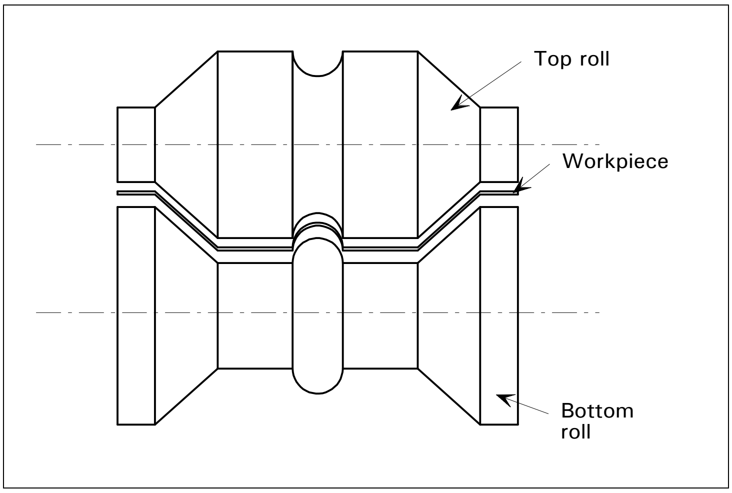
5.3 Forming Techniques

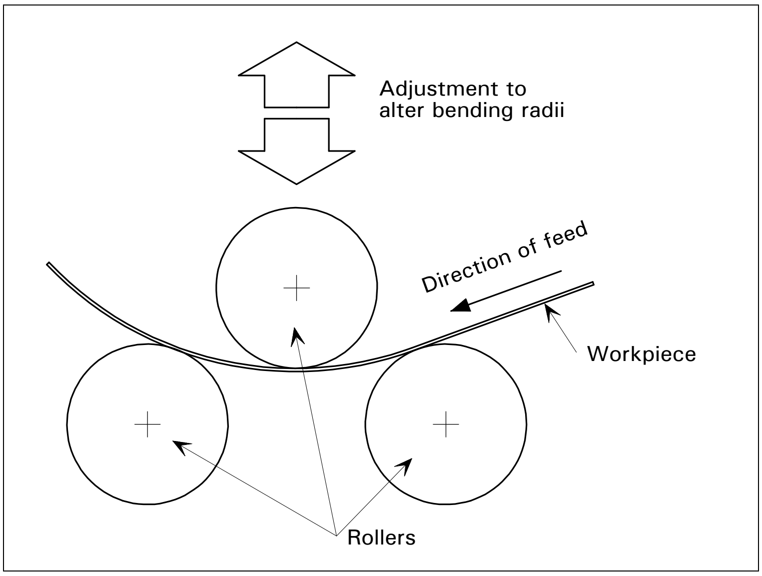
Figure 5.8
Roll forming



5.3.5
Roller bending

Bending rollers comprise three cylindrical formers arranged in a triangular fashion (Figure 5.9). The workpiece is fed beneath the top roller such that it is pinched against both of the bottom rollers. This causes the component to deform plastically. The radius of bending can be adjusted by raising or lowering the top roller. Spirally wound tubes can be produced by introducing strip metal at an angle to the rollers. Truncated cones can be rolled by splaying the rollers or by using conical rollers.

Figure 5.9
Bending rollers



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5.4 Stretch/Draw Forming Techniques

5.4.1
Introduction

Unlike folding and similar sheet metal forming techniques, stretch/draw forming relies upon three dimensional (non-linear) deformation of sheet material. The thickness of the sheet will generally be altered as a result of stretching or shrinkage. There are two primary methods of stretch/draw forming: matched die and single die.

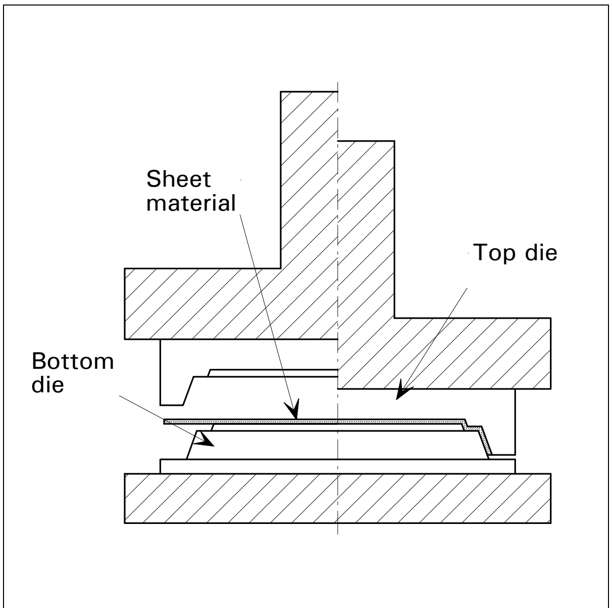
Matched die sets are expensive to produce because of the exact tolerances required, but are perhaps more competitive than is generally appreciated, particularly where the tooling is relatively simple. However, single die processes still generally afford overall cost savings for low volume production.

Single die processes are principally distinguished on the basis of the mechanisms by which pressure is applied. Techniques include fluid and rubber forming, stretch forming and spinning.

5.4.2
Matched die forming

Matched die presswork involves closing together dies on either side of the stainless steel sheet, plastically deforming the sheet to the approximate topology of the matched die faces (Figure 5.10).

Figure 5.10
Matched die forming



Due to the high cost of tooling, these processes are generally best suited to high volume production runs, but may become economic on smaller runs if the shape of the die is simple. Dies

Case Studies

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5.4 Stretch/Draw Forming Techniques

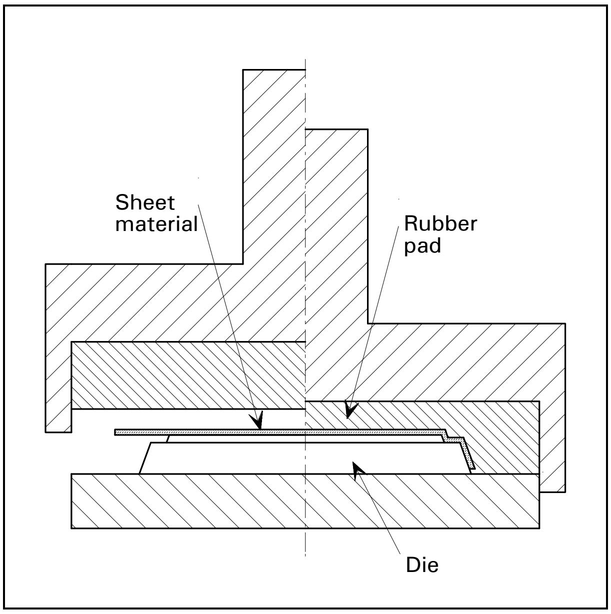
have to be made to close tolerances and, due to the pressures involved, must generally be very durable. Behaviour of the stainless steel in the die must be accurately predicted to control thinning, wrinkling and springback.

Advances in tool-making technology and a fall in the real cost of tooling have made this an increasingly viable option especially for small components such as pressed cover plates for balustrade fixings *etc*.

5.4.3 Fluid and rubber die forming

One of the rigid tool parts of a matched die set can sometimes be replaced by a flexible 'die'. This may consist of a solid rubber pad (suitable for reasonably shallow pressings) or a volume of oil sealed by a rubber membrane (fluid or hydro-forming). Figures 5.11 and 5.12 illustrate these techniques. In operation, the soft die exerts pressure uniformly over the surface of the sheet metal, deforming it to the shape of the rigid die beneath. Typically, stainless steel sheet up to 1 mm thickness can be formed by this process.

Figure 5.11 *Rubber die forming*



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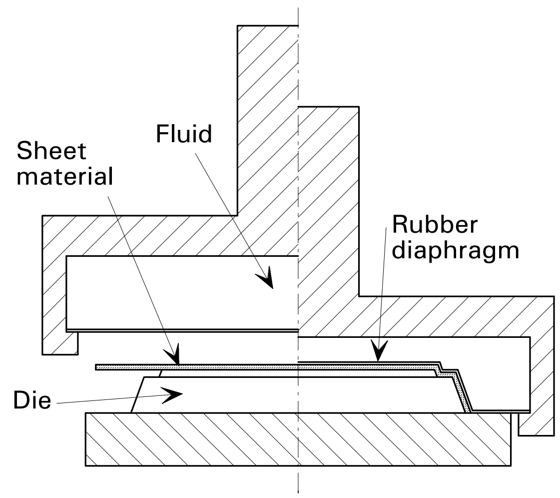
5.4 Stretch/Draw Forming Techniques

Figure 5.12
Fluid forming



Considerable savings can be made for low to medium volume production runs as the rigid die does not have to exactly match an opposing die, and is not subject to high impact stresses. Rigid dies can therefore be made from a range of easily worked materials such as plastics, composites, timber, aluminium, softer grades of steel and special re-usable alloys.

Another advantage is that certain re-entrant features (recesses hidden when the component is viewed from the direction of the press stroke) are possible. At high pressures the rubber flows elastically, filling lateral recesses (within certain limits) and then recovering as pressure is released, permitting removal of the component.

5.4.4 **Stretch forming**

In the stretch forming process, sheet material is plastically deformed over a stretch block to produce a three-dimensional wholly convex or concave panel of non-constant radius (Figure 5.13). Almost any depth of section can be produced on a single, relatively inexpensive machine, but the technique is generally limited to two dimensional forming. Constant radius panels can be produced, but this is more simply done using bending rollers. Tooling costs are low as only one form block is needed, and this can normally be made from timber or resin-bonded plywood. The workpiece sheet will be work hardened and dimensionally altered in this process; its length will increase whilst its width and thickness decrease.

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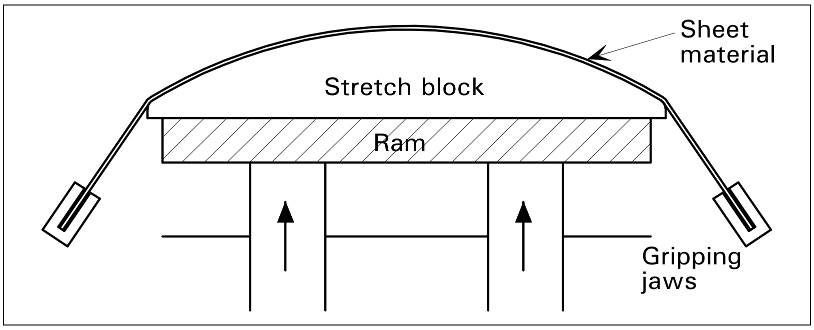
5.4 Stretch/Draw Forming Techniques

Figure 5.13
Stretch forming



In simple stretch forming the sheet material is clamped down at two opposite edges and a moulded stretch block is slowly raised in the centre on hydraulic rams, such that the metal takes on the shape of the former. Three dimensional curvature is possible using the simple stretch forming technique by restraining the material around its entire perimeter. However, problems with thinning of the material and a tendency to wrinkle restrict the technique to shallow circular or near-circular pressings that have few practical applications.

A variation on simple stretch forming is stretch-wrap forming. The material is stretched beyond its yield point whilst still straight, and then wrapped around the form block. The stretch-wrap forming technique allows more accurate control of metal thinning, and sliding of the sheet metal over the forming block (as the metal yields under tension) is minimised.

5.4.5
Spinning

Metal spinning involves plastically deforming sheet metal onto a rotating former using a rigid tool. A circular sheet is attached to a lathe or spinning machine with its centre point on the axis of rotation. A hardwood former is attached to the lathe and, whilst the lathe is spinning, a lever-like tool is used to bend and stretch the metal onto the surface of the former (Figure 5.14). Stainless steel of up to 3 mm thickness can be spun with a maximum sheet diameter of 2.5 m. Simple forms (shallow parabolic dishes, for example) can be made in one operation, but more complex shapes often require two or more formers.

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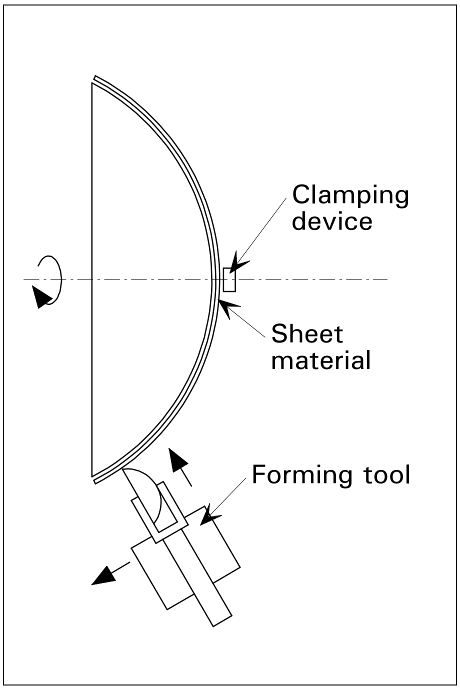
5.4 Stretch/Draw Forming Techniques

Figure 5.14
Metal spinning



Tooling is inexpensive, but the process is labour intensive, making it most suitable for low volume production runs. The range of shapes that can be achieved is limited (all objects require one axis of rotational symmetry).

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Sackler Galleries

5.5 Tube and Section Bending

5.5.1
Introduction

Several techniques exist to bend tubes and sections. These are more specialised operations than simple sheet bending due to problems with distortion, thinning and induced stresses. Tight radii may require hot bending, larger radii can be bent cold.

Tube and section bending operations should not produce significant distortion on the inside radius or thinning on the outside, nor should they leave excessive compressive or tensile stresses in the material. For tubes it is generally accepted that the minimum bending radius is three times the diameter, measured from the centre line. Other ratios apply to other sections. In practice, the minimum bending radius is dependant on wall thickness, the amount of distortion that is acceptable and the type of bending equipment that is used.

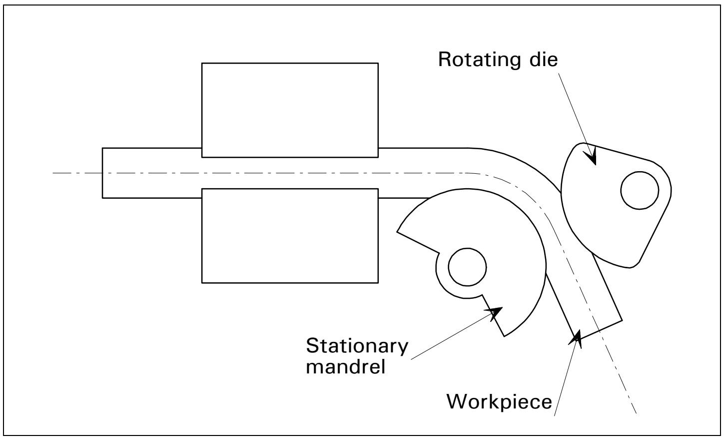
5.5.2
Roller bending

Cold bending of tubes and sections using bending rollers is common. Bending rollers are essentially as described in relation to sheet and plate forming (Section 5.3.5), but rollers tend to be narrower and may be shaped to suit particular tubes and sections. Very heavy bending rollers are available for bending large tubes and sections.

5.5.3
Rotary bending

Tubes of 114 mm diameter or less are commonly bent using rotary machines. The tube is drawn around a stationary mandrel or bending shoe by a rotating die (Figure 5.15). Multiple bending operations can be carried out on one length of tube and each bend can be in a different plane. Distortion is reduced in this process because the tube is confined around its entire circumference at the point of bending.

Figure 5.15
Rotary section bender



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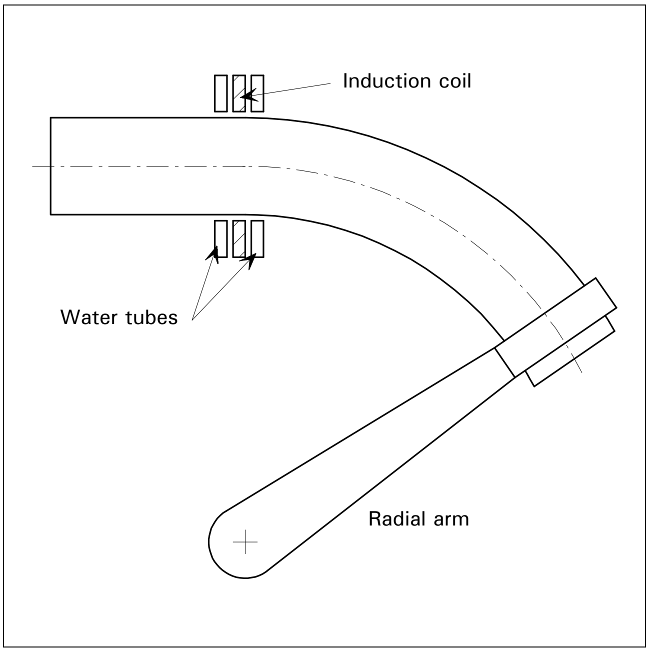
5.5 Tube and Section Bending

5.5.4 **Induction bending**

Induction processes are able to achieve tight radii and are often used to bend large tubes to relatively tight tolerances. The heat also helps to minimise residual stresses. A small section of the workpiece is heated to a forging temperature using an induction coil (Figure 5.16). The surrounding material is cooled by circulating water. A radial arm attached to the workpiece bends the heated section whilst hydraulic rams advance the workpiece through the machine. The narrowness of the heated zone (approximately 13 mm) eliminates wrinkling, and as the process requires no dies or formers, it is potentially very flexible.

Figure 5.16 *Induction bender*



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East Croydon Station
Leipzig Trade Fair
Reina Sofia
School of OT&P
Serres at La Villette

5.6 Machining Techniques

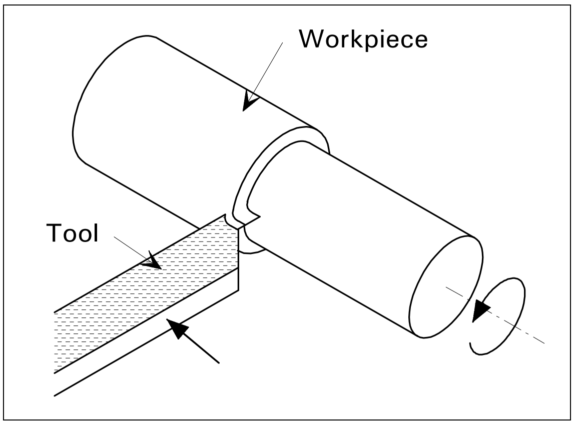
5.6.1 **Introduction**

Machined components are produced by mechanically removing material from a workpiece until the desired shape is achieved. Although all machining processes used for carbon steel can be used for stainless steel, the relative hardness of the material means that slower cutting speeds are necessary to avoid work hardening.

5.6.2 **Turning**

Turning is the most widely used machining process. The workpiece is mounted on a lathe and the cutting tool moves progressively along its length (Figure 5.17).

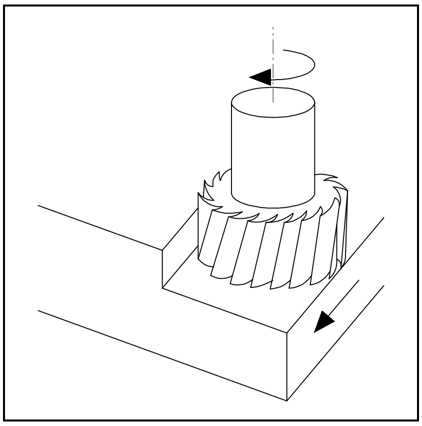
Figure 5.17
Turning



5.6.3 **Milling**

The tools used in these processes have more than one cutting edge, cutting action being provided by rotation of the tool and feed by translational movement of the workpiece (Figure 5.18).

Figure 5.18
Milling



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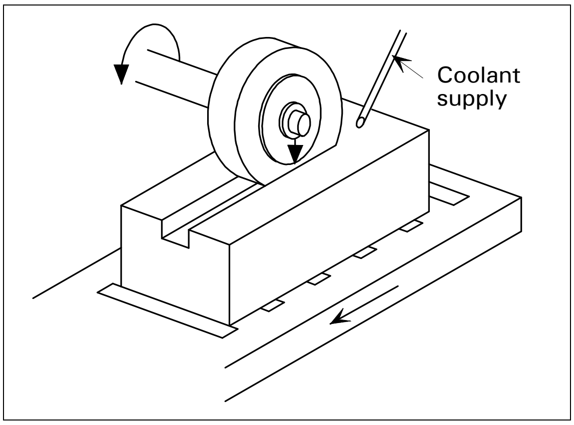
5.6 Machining Techniques

Milling machines can generally accommodate workpieces up to 1 m square. The tool can be any shape or size to generate flat, curved or irregular surfaces. Form cutters, shaped exactly to clone the part being produced, can make irregularly shaped components and are appropriate for large production runs.

5.6.4 **Grinding**

Conventional grinding can offer an alternative to turning and milling (Figure 5.19). However, the hardness of stainless steel means that grinding is usually restricted to the production of precision engineered components and surface finishing. Surface grinding machines which hold the workpiece on a magnetic table cannot be used for non-magnetic grades of stainless steel; conventional mechanical restraint is required.

Figure 5.19
Grinding



5 PRODUCTION AND FABRICATION

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5.7 Casting Techniques

5.7.1
Introduction

Whilst there are exceptions, casting techniques can generally be divided into two classes: those suited to geometrically simple or large components, and those intended for accurate components requiring fine tolerances and good surface finishes.

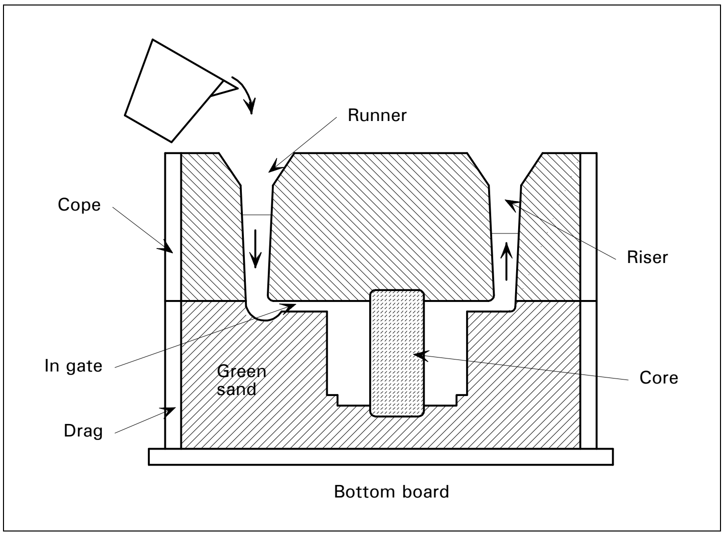
Large castings have many architectural applications, including structural connections, staircase components and balustrades. Components can have excellent structural characteristics, and often have pleasing sculptural forms. The most common method of producing these is sand casting.

Smaller or more accurate castings may be produced by a variety of techniques, including resin shell and investment casting.

5.7.2
Sand casting

Traditionally, large architectural components have been sand cast. Sand is moulded by hand, or machine, around a wooden or metal pattern. The pattern is subsequently withdrawn, leaving a cavity into which molten metal is poured. Complex three dimensional shapes may be made by using two or more moulds in a combined fashion, typically with one mould (the cope) set above another (the drag), Figure 5.20. Separate cores are used to form holes in the castings.

Figure 5.20
Section through sand casting box



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5.7 Casting Techniques

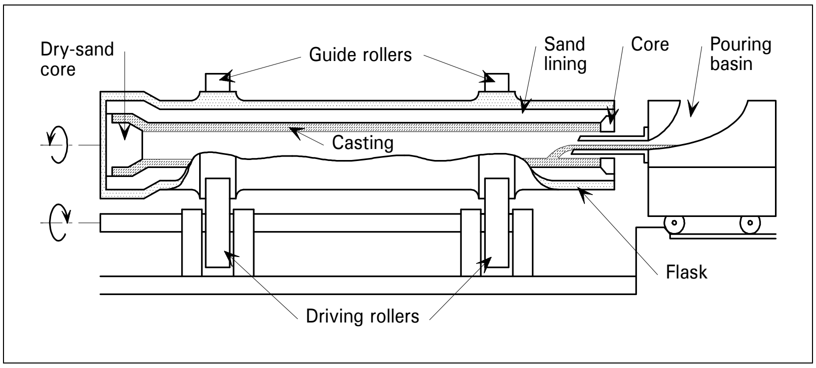
A great variety of components may be produced by sand casting. Components from 100 g to 100 tonnes are possible, and mould costs are very low. Sand casting is the only practical method of casting particularly large components. Careful quality control is essential where dimensional accuracy and surface flatness are important. Critical surfaces may require machining. Split lines can occur at mould faces and components normally require finishing (fettling).

5.7.3 Centrifugal casting

Centriufgal casting is a technique used to produce hollow cylindrical components such as structural sections. Molten stainless steel is poured into a mould which rotates at sufficient speed to produce centrifugal accelerations of between 60 and 80g (Figure 5.21). Moulds may be made from sand, metal or ceramic materials. Sand moulds are commonly used for long castings. Centrifugal castings can have excellent mechanical properties, however care should be taken that laps do not form in the casting as a result of imperfect flow.

The typical maximum length of centrifugally cast components is 10 m, maximum outside diameter is approximately 1.75 m, and maximum weight is generally of the order of 36 tonnes.

Figure 5.21 *Centrifugal casting using a sand mould*



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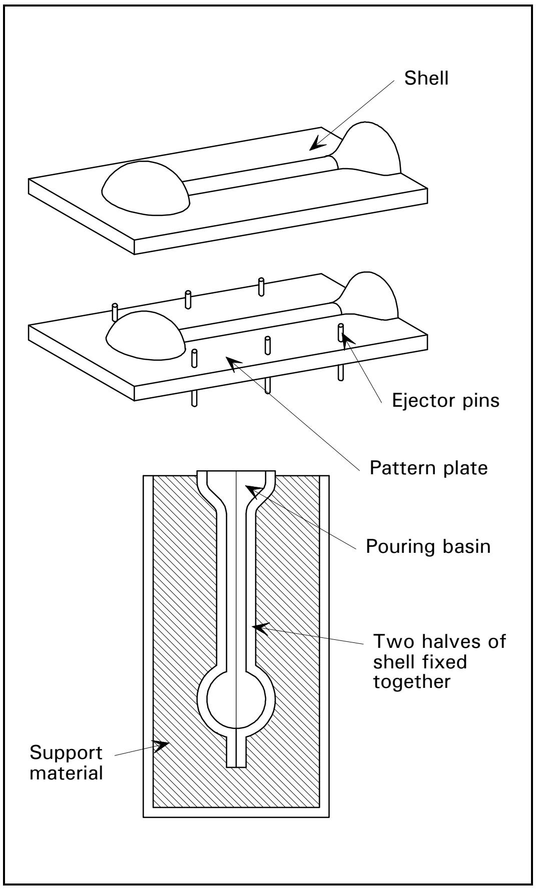
5.7 Casting Techniques

5.7.4
Resin shell casting

Resin shell casting uses sacrificial moulds made from resin-bonded sand. Sand and resin mixture is melted onto a heated steel pattern plate and then hardened by oven curing. The mould is made in two halves, which are then joined with bolts or adhesive (Figure 5.22).

Figure 5.22 *Manufacture and placement of resin shell casting moulds*



Compared to sand casting, the resin casting process gives higher degrees of accuracy, and better surface finishes are possible by using fine grained sand. Less finishing tends to be required than for sand casting and this may compensate for higher mould costs. Where components are symmetrical, one pattern plate may be used for both halves of the mould.

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5.7 Casting Techniques

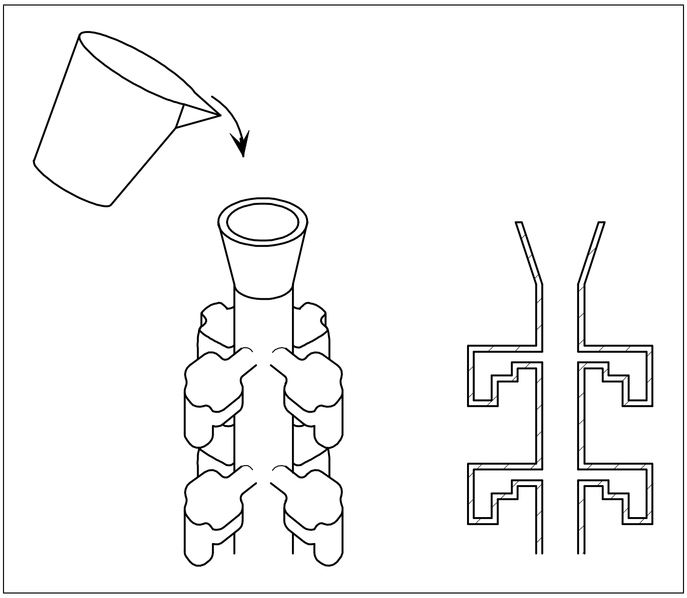
5.7.5
Investment casting

The use of investment or 'lost wax casting' as a means of producing bespoke architectural components has increased significantly in recent years. In particular, it has become the standard method of producing fixings for 'planar' type glazing. Other uses include specialist ironmongery and small structural components.

In this process, wax patterns are assembled into a tree like structure which is coated in a refractory material (Figure 5.23). The wax is then melted and drained, leaving a hollow shell into which the stainless steel is cast. Upon solidification the shell is broken away. The resulting components accurately clone the original patterns.

Since the process involves many stages, it has tended to be expensive. However, high levels of automation have now been achieved in many foundries, and the approach is becoming increasingly viable. Components are typically up to 1 kg, but heavier items (sometimes in excess of 30 kg) can be produced.

Figure 5.23 *Refractory moulding for investment casting*



6 SURFACE FINISH

6.1 Introduction

A wide range of surfaces and finishing techniques is available for stainless steels. Appreciation of the range and the methods used is important, since selection of the final finish applied will have a major effect on appearance, corrosion resistance, ease of cleaning and resistance to damage.

Steel producers offer material with a variety of finishes in large, consistent quantities, from basic mill finishes to finishes optimised for architectural applications.

Specialist finishers and fabricators also offer a range of finishes, on volume production of coil or sheet, on individual panels or on components with complex decorative patterns.

A combination of several finishing operations may be specified to achieve the desired end effect.

The specification and designations for surface finish of stainless steel is covered in European Standard EN 10088. Appendix E lists the types of surface finish for flat products with corresponding process routes given in EN 10088: Part 2. Generally, the designation is a number and a letter, for example 1D and 2G. The number denotes either hot rolled (1) or cold rolled (2) material. The letter denotes the type of finish.

Surface finishing is not an exact science; there is no way of specifying a finish in precise numerical terms. EN 10088 provides little more than an approximate guide.

Surface finish of castings is specified using visual or tactile replicas of a standard range of actual cast surfaces[8].

Many finishes are on offer and, particularly in the case of polished finishes, specialist finishers will have their own internal standards and methods of production. Materials from two different suppliers are therefore unlikely to have identical appearance, even if they have the same nominal designated finish. Where finish consistency is important, the specifier should provide the polisher with a sample of the finish required. Once a finish has been agreed, a reference sample and a record of agreed viewing/inspection conditions should be retained, to allow for subsequent matching.

6 SURFACE FINISH

6.1 Introduction

Surface finishes may either be imparted onto the material prior to fabrication (either by the fabricator or the materials supplier), or may be post-worked onto components after manufacture (by the fabricator). Finishes imparted prior to fabrication are known as pre-production finishes; finishes imparted after manufacture are known as post-production finishes.

6.1.1 Pre-production finishes

It is often economic to use pre-finished material rather than post-finish components after fabrication. Pre-finished material may however be marked by manufacturing processes, or may be cut or joined in such a way that components require a degree of post-finishing at cuts, edges or welded joints. Certain pre-production finishes have been specifically designed to be easily reproduced if damaged. Many other surfaces can be approximately matched.

Pre-production surface finishes may be protected using plastic films applied to the surface of the material. These are frequently used where sheet materials are brake pressed or folded, since the press tools or blades can impair the finish (particularly when producing acute angular folds).

Pre-production finishes are generally more consistent than post-production finishes. The consistency of finish is particularly important if the material is covering large, flat areas (as often occurs in cladding for instance), because inconsistencies may give an unexpected chequerboard effect where some panels appear darker than others.

6.1.2 Post-production finishes

Post-production finishes are used both as a means of finishing components manufactured from unfinished material, and to repair finishes on components manufactured from finished material. Generally there are two reasons why post-production finishes might be used rather than pre-production finishes:

Whilst most pre-production finishes can be successfully matched, certain post-production finishes (such as mirror polished) can be difficult to match. Obvious blending marks can occur between pre- and post-finished areas. Therefore, it is often appropriate to finish components requiring 'difficult to match' visible surfaces after manufacture. Post-production finishing may also be necessary to ensure good corrosion resistance; contamination of the passive film on the surface of stainless steel by weld spatter or by deposition of carbon steel (filings for instance) can leave unsightly rust staining. Some finishing techniques (for example electropolishing) can be used to combine remedial clean-up work with production of the final surface. Alternatively, components may be finished and then 'passivated' whereby ferrous material and other substances are removed by immersing the component in dilute nitric acid.

6.1.3 Weld finishing

The heat produced in welding can discolour stainless steel by forming thin layers of oxide (heat tint) on the surface. It is good practice to remove heat tint, but general experience indicates that unless the environment is particularly aggressive, the discolouration is only an aesthetic problem. If necessary, heat tint can be removed using light abrasives, pickling paste or by wire brushing.

Welds may be ground in the conventional way to improve appearance and achieve smooth seamless surfaces. The weld surface is usually then finished to match the adjacent surfaces. When welds are difficult to access, in an internal corner for instance, it may not be possible to use mechanical finishing devices, and finishes may need to be applied manually.

6 SURFACE FINISH

6.2 Basic Mill Finishes

All hot and cold rolled material is heat treated and given a basic finish by the rolling mill. These basic mill finishes may be sufficient for the required use or may be the basis for further finishing, either by the steel producer, or by a polisher or during fabrication.

A minimum specification for material leaving the rolling mill or foundry would be that it is to be free from significant surface defects and the surface shall offer the level of corrosion resistance expected from the grade selection. Achievement of good corrosion resistance requires removal of both high temperature oxides and of any surface layers of metal depleted in chromium by oxidation. The most commonly used method of achieving this is to 'pickle' the surface with an appropriate acid solution. For hot rolled plate products, heat treated and pickled, EN 10088 designates the finish 1D.

Compared with hot rolling, cold rolling improves smoothness and dimensional tolerances. The cold rolled equivalent of the 1D finish is 2D, denoting material cold rolled, heat treated and pickled. This gives a uniform matt finish with some susceptibility to finger marking. It is often used for industrial plant.

A smoother surface is given by the 2B finish, material cold rolled, heat treated, pickled and skin passed. This material has a smooth, pearly, semi-lustrous appearance. It is brighter than 2D and is also susceptible to fingerprints. It is produced using the same techniques as 2D, but with an additional final light rolling process using polished rollers. The surface is difficult to match using manual techniques. Applications include industrial cladding and roofing. It is the most common form of stainless steel, and the basis for many other finishes.

A highly reflective finish is produced on a large scale by using a heat treatment in a controlled atmosphere, rather than a conventional furnace. The cold rolled, bright annealed finish, 2R, has a highly reflective, mirror-like surface produced by basic cold rolling, bright annealing and subsequent cold rolling using polished rollers. Scratches can be removed by skilled polishing, but the care required means that the material is generally only used where damage is unlikely.

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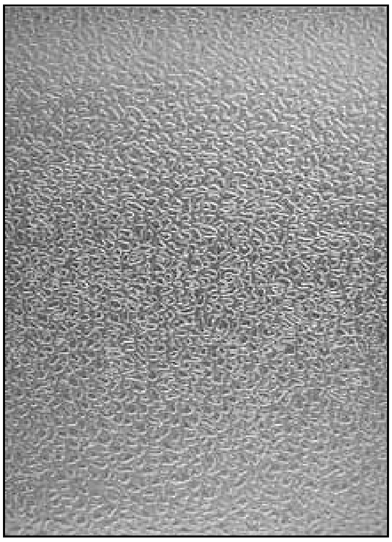
6.3 Patterned Finishes

Embossed, three-dimensional patterns may be rolled onto or into strip by cold rolling, either by steel producers in the course of manufacture, often referred to as 'special mill finishes' or by specialist finishers.

Patterned or textured rolls are used to impart surface features by cold rolling. These may be applied to one or both sides of the strip. Designs include low reflective surfaces, produced using lightly roughened rolls ('matt rolled' finishes) and deeper 'random' (within the limits of roll repeat) and regular patterns. These may be abstract, or simulate other materials such as leather grain, or woven fabrics (Figures 6.1 and 6.2). The patterns are usually applied to cold rolled material bearing the basic mill finishes 2D, 2B and 2R. Matt rolled surfaces are designated 2F and the heavier patterns, embossed on one side only, leaving the second surface flat, are designated 2M. The discontinuous, work-hardened surfaces of the 2M finishes help to mask scratches and marks, making them suitable for contact areas such as lift doors, fascias and linings.

Figure 6.1 *Single-sided pattern finishes on material with basic mill finish 2D*



Courtesy of Avesta Sheffield Ltd

Deeper, three-dimensional patterns can be developed by rolling between pairs of rolls with a matched, male-female pattern (Figure 6.3). Presses may also be used to pattern sheets. Symmetrical designs are available giving significant panel stiffening, which may allow the use of lighter gauge material. The greater displacement of the surface can also help suppress the visual impact of out-of-plane effects ('oil canning') in sheets.

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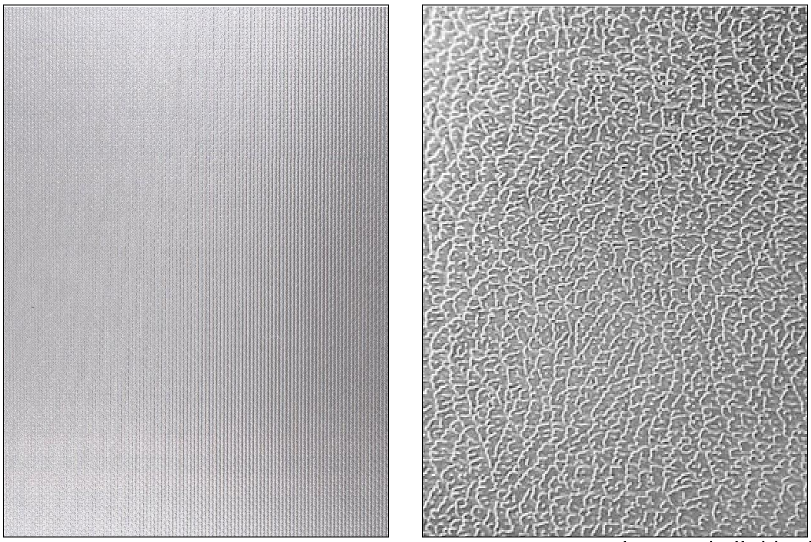
6.3 Patterned Finishes

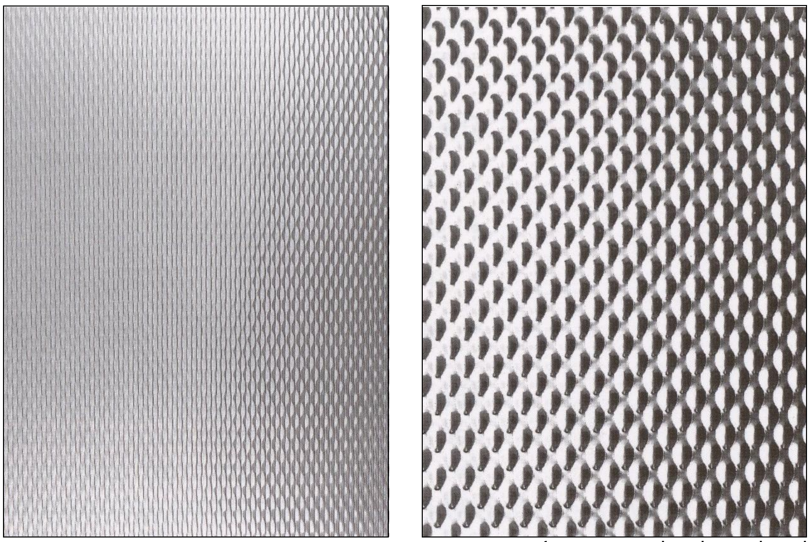
These deeply patterned surfaces are also a good basis for the development of special aesthetic finishes. Corrugated patterned finishes are designated 2W.

Figure 6.2
Single-sided pattern finishes on material with basic mill finish 2R



Courtesy of Avesta Sheffield Ltd

Figure 6.3
Three-dimensional pattern finishes



Courtesy of Rimex Rigidized Metals Ltd

Facilities exist for rolling stainless steel in thicknesses from 0.1 mm. Various lengths can be produced, although fabrication and handling of lengths over 4000 mm is difficult.

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6.4 Mechanically Polished and Brushed Finishes

The wide range of mechanically polished finishes involve cutting or polishing the surface with an abrasive medium or a sequence of media, using belts, wheels, brushes or mops. The finishes may be applied to any starting surface, as a pre- or post-production finish. Although much material is polished in coil or sheet form as a finishing operation in the steel plant, or by specialist polishers or fabricators, the same general principles and techniques apply to post-fabrication work on components or installations.

The cutting action in polishing imparts uni or multi-directional striations (depending upon the direction of the abrasion) or a smooth reflective surface (where a fine abrasive is used). Figures 6.4 and 6.5 illustrate brushed and polished finishes.

Brushed striated finishes are susceptible to damage, but scratches can be readily abraded out. Surfaces do not fingerprint easily and therefore can be used successfully in areas of high contact such as doors or windows. Atmospheric deposits and other forms of surface soiling are generally washed away most easily if any uni-directional polishing or grinding marks are oriented vertically, in the direction of water run off. Polished reflective surfaces are also susceptible to damage; remedial polishing is possible but is more complex than restoring a striated surface.

The major classes of finish listed in EN 10088 are:

- coarse (1G and 2G)
- smoother (1J and 2J)
- smooth with controlled cutting action (1K and 2K)
- mechanically polished (non-directional) (1P and 2P)

The surface appearance, corrosion resistance and dirt retention can vary widely within each class, depending upon the nature of the abrasive medium used and the polishing practice. (Factors influencing the polishing action include the type of abrasive, the grit size, dry or wet conditions, belt contact pressure, speed and material feed rate.) The1K/2K finish gives a fine, clean cut with minimal microcrevices, thereby optimising corrosion resistance and minimising dirt retention. It is therefore more suitable for external applications, whereas 1J/2J is more suited to internal applications.

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6.4 Mechanically Polished and Brushed Finishes

Figure 6.4
Polished finishes

(Left) 2G, ground or coarse polished

(Right) 2J, dull polished

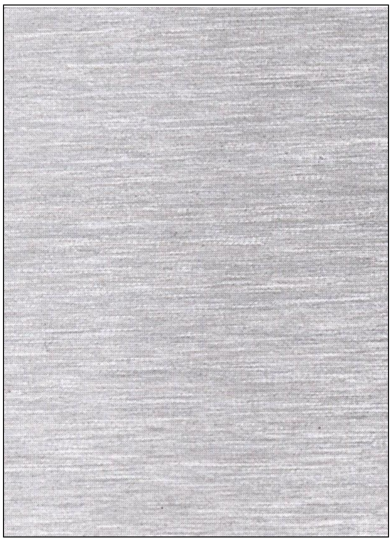
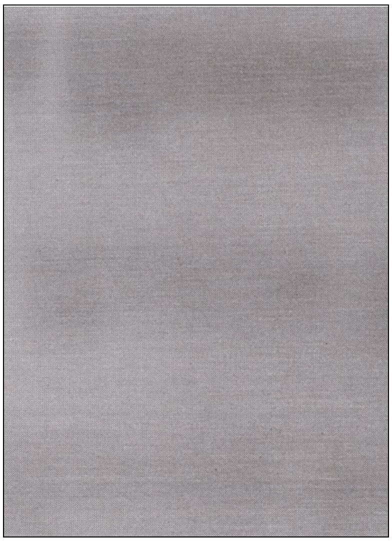


Figure 6.5
2K, satin or fine polished



Courtesy of Avesta Sheffield Ltd

However, all of the finishes described above may be subject to specific requirements agreed between manufacturer and purchaser, such as grade of grit, polishing sequence and surface roughness. Major steel producers and polishers have a range of process route options available and can advise on the selection of a finish.

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6.4 Mechanically Polished and Brushed Finishes

In all grinding and polishing operations on stainless steel, it is essential to avoid iron contamination. Only iron-free media should be used and these media should be kept free from contamination by iron debris. If this is not observed, iron particles transferred to the stainless steel surface may lead to rust staining. Finishing materials that have been used previously on carbon steels must not be used subsequently for stainless steel surfaces. Control of this aspect is particularly important for operations carried out manually or on site.

6 SURFACE FINISH

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6.5 Bead Blasted Finishes

Non-directional, matt surface finishes can be developed by the impact of a hard, inert medium onto the steel surface. The technique can be used in the shop and under site conditions.

Blast finishes are produced by spraying sand, glass or lead bead, silicon carbide, aluminium oxide, stainless steel shot or ground quartz onto the surface of stainless steel. A non-directional texture with a soft satin reflection can be created in a range of coarsenesses, depending upon the media and the thickness of the material utilised. Unlike acid etching, no material is removed from the surface during the blasting process, although the character of the surfaces produced by the processes are similar. Bead blasted surfaces have low reflectivity, and work well when applied over satin or mirror polished finishes.

The nature of the surface created by bead blasting depends on the medium that is sprayed (Table 6.1).

Table 6.1 *Surface finishes created by different media*

Medium	Surface finish
Sand	Dark, coarse
Glass bead	Light, smooth
Silicon carbide	Very dark, coarse
Stainless steel shot	Honed
Ground quartz	Shiny, coarse

Glass beads tend to be preferred because shot and grit abrasives can become contaminated with abraded material. Contamination can cause excessively rough surfaces that are prone to crevice corrosion.

Blasting can take place before or after fabrication, but the process work hardens the surface and can cause distortion. For this reason blast finishes should not be applied to stainless steel thinner than 0.4 mm. To avoid surface distortion, blasting can be carried out on both sides of sheet material. The surface of the material should be cleaned before and after blasting.

A similar finish can be obtained by acid etching (Section 6.8). Blasted material can be chemically coloured, combined with

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6.5 Bead Blasted Finishes

rolled patterns, masked and polished or acid etched to create standard or bespoke designs.

For optimum corrosion performance, fine media should be used which do not embed into the surface. As with other mechanical finishes, media must be kept free of iron contamination.

6 SURFACE FINISH

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6.6 Electropolished Surfaces

Electropolishing is used to enhance the reflectivity of stainless steel and to provide smooth surface finishes. It is commonly used for intricate components that are difficult to polish by mechanical techniques, including textured surfaces such as chequer plate flooring.

The process relies on creating an electrochemical cell. The work to be polished is the anode in a cell containing a suitable electrolyte. The flow of electric current results in the removal of a thin surface layer of the stainless steel component. Loss of material is greatest at high spots. This preferential erosion results in a general smoothing of the surface as the peaks and troughs are levelled out.

The amount of material that is removed and the original surface characteristics determine the quality of the finish. Electropolishing imparts good corrosion resistance because the process leaves the surface smooth and free from any irregularities.

Electropolishing is normally carried out using a diptank process prior to fabrication. Components can, however, be electropolished after fabrication.

Note that electropolishing, although smoothing out rough features, will not alone provide a geometrically flat surface.

6.7 Coloured Finishes

Stainless steel can be coloured either by the application of paint or by chemical treatments. Both are durable in normal service, but damage can be difficult to repair, especially for finishes produced by chemical treatment. Paint systems rely upon introducing a second layer of material onto the surface of the stainless steel. Chemical systems rely upon altering the nature of the passive film.

6.7.1 **Painted finishes**

Steel producers in Europe and Japan have developed coil coating routes to produce painted stainless steels. The coatings include primers and pre-paint systems and also architectural finishes based upon both acrylic and PVF systems. The main applications are roofing and siding sheets. Stainless steel sheeting is also available part-painted to facilitate welding of fully supported roofing.

6.7.2 **Chemically coloured finishes**

Stainless steel can be coloured blue, black, bronze, charcoal, gold, green and red/violet by immersion in a solution of chromic and sulphuric acids. The various colours are produced by controlling the build-up of the thickness of the passive film that causes interference effects in reflected light.

The induced thickness of the passive film ranges from 0.02 microns to produce a bronze colour to 0.36 microns to produce green. The sequence of colours is bronze, blue, black, charcoal, gold, red-violet and green. Intermediate colours are possible, but obtaining good consistency can be problematic.

The colours noted above can be produced on 1.4301 (304) and 1.4401 (316) material. Ferritic grade 1.4016 (430) material is generally used to achieve good quality black, although a bluey/black colour can be produced on austenitic material. Charcoal is produced by colouring satin polished material to a shade of blue.

An attraction of chemically coloured stainless steel is that it appears to change colour under different shades and angles of artificial and natural light.

Most chemical colouring is applied to stainless steel sheet, but it is possible to colour fabricated components. Only the finest quality stainless steel can be successfully chemically coloured. To ensure a good match between panels, material should be used from the same mill supplier and batch run.

6 SURFACE FINISH

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6.7 Coloured Finishes

Coloured stainless steel is difficult to repair if scratched; it is therefore best suited to cladding and roofing where major scratches and abrasion are relatively unlikely. Coloured stainless steel can be combined with rolled, acid etched or blasted finishes to produce different textures. With a rolled pattern, stiffness and strength can be improved.

6.8 Specialist Decorative Finishes

A range of techniques is available to develop unusual finishes and incorporate graphic design elements into decorative panels. They include:

- acid etching
- the use of masks or resists to transfer patterns and designs onto surfaces
- combining different, compatible surface treatment methods.

6.8.1 **Acid etched surfaces**

Acid etching removes a thin layer of surface material, and is used to produce standard and bespoke finishes (Figure 6.6). It is carried out on sheet material only. The area etched away becomes frosted in appearance (and similar to the finish created by blasting), while the unetched sheet surface can be mirror or satin polished. Acid etched sheets can also be chemically coloured, either before or after the etching process has taken place. The pattern depth of the etch is controlled by the length of exposure of the stainless steel to the acid. The thinnest material that can be etched is generally 0.8 mm. Thick materials are not a problem, apart from the aspect of handling.

Figure 6.6 *Acid etched finish*

Courtesy of Rimex Rigidized Metals Ltd

6.8.2 **Masking**

Both blasting with a suitable medium (Section 6.5) and acid etching can be used to modify surface appearance, either locally using masking techniques or over entire regions.

There are two widely used methods of transfering images to form masks for selective surface treatment:

6.8 Specialist Decorative Finishes

Silk screen process

In this process a mask is used to define the area to be etched. The component is then dipped or sprayed with acid, subsequently cleaned and the mask removed to reveal the etched pattern. The method is generally restricted to patterns, and is not suitable for the entire surface of a large sheet, since it is difficult to obtain a clear etch on a large area without blemishes.

Photoresist process

This process involves the creation of the pattern/design from computer generated graphics which are transferred to a photographic negative. The stainless steel sheet (up to a size of 2440 × 1220 mm) is then laminated with a photosensitive film and exposed to ultraviolet light passed through the negative to produce the required design. The sheet is then developed so that unexposed areas are dissolved by treatment with sodium carbonate. The sheet is then drawn through sprays of hydrochloric acid and ferric chloride to create the required etched design. This process is suitable for fine and detailed patterns.

6.8.3 Combinations

Table 6.2 describes the types of finishes which can be obtained by combining surface finishing processes.

6.8 Specialist Decorative Finishes

Table 6.2
Surface finishes obtainable by combining finishing processes

Combination	Description
Polished and patterned finish	Satin and brush finishes (selected to remove glare from mill finished stainless steel) can be subsequently rolled to produce a patterned finish.
Coloured and patterned finish	Chemically coloured stainless steel can be subsequently rolled to produce a patterned finish (Figure 6.7). Areas of coloured material can be removed by polishing.
Patterned and polished finish	Three-dimensional patterned or coloured and patterned finish with pattern 'peaks' highlighted by polishing
Coloured mirror finish	Chemically coloured stainless steel with a clear reflective finish (Figure 6.7).
Coloured satin finish	Chemically coloured stainless steel with a grain texture.
Coloured blasted finish	Chemically coloured stainless steel with a coloured random frosted texture.
Coloured, patterned blasted finish	As above but with a rolled pattern.
Coloured acid etched finish	Unique finishes of custom designed coloured patterns, in mirror or satin finishes (Figure 6.8).

6.8 Specialist Decorative Finishes

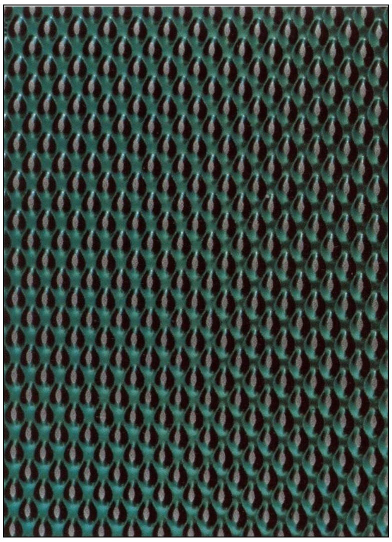

Figure 6.7
Combinations -

(Left) Coloured patterned finish

(Right) Coloured mirror finish

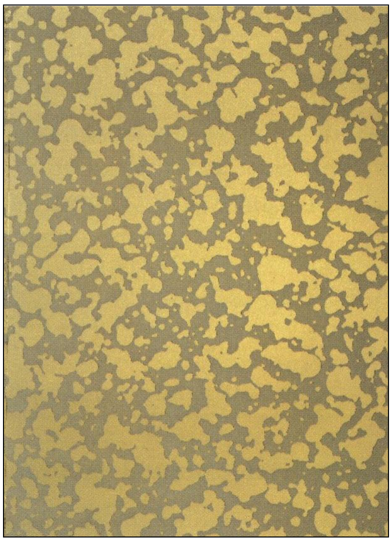

Figure 6.8
Combinations - Coloured acid etched finish

Courtesy of Rimex Rigidized Metals Ltd

7 JOINING

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7.1 Welding

7.1.1 Introduction

Austenitic stainless steels are easily welded using either manual or automated techniques. As with carbon steel, it is essential that correct welding procedures are observed. These should reflect the particular joint configurations, steel chemistry *etc*.

Generally, since stainless steels are non-hardenable, neither pre- nor post-heating of the workpiece is necessary.

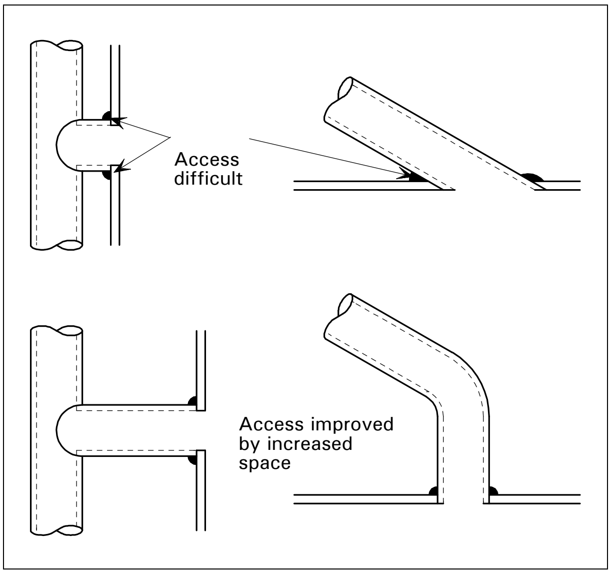
Choice of welding process and consumables

The main factors affecting the choice of welding process are the type, thickness, shape and location of joints. In order to preserve the corrosion resistance of the weld metal and the adjacent area, the welding consumables should have an equal or superior corrosion resistance to that of the base metal. Correct selection of consumables is also important in achieving optimum mechanical properties. Specialist advice can normally be obtained from manufacturers of the welding consumables.

Weld detailing

Good weld detailing is important to avoid defects such as crevices, undercuts and poor weld penetration that can lead to corrosion problems. Adequate access must be provided for the welding equipment (Figure 7.1) and the edges of the pieces to be welded must be prepared appropriately: for example, thick sections (>5 mm) must be chamfered. Where welds can be hidden, the need for post-fabrication surface finishing is reduced.

Figure 7.1
Design with welder access in mind



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7.1 Welding

Corrosion resistance

Slag from coated electrodes, arc strikes and weld spatter can adversely affect corrosion resistance (and joint strength). Where necessary, a comprehensive weld cleaning procedure should be agreed with the fabricator.

Heat tint

Heat tint forms on the surface of steels after heat treatment or welding (Section 6.1.3). If required, pickling and passivation procedure should be used to remove this. Local heat tint can be removed by polishing.

Inspection

Whilst there are various methods of inspecting welds, visual and dye penetrant methods are most common. Sophisticated techniques using X-rays and gamma rays can be adopted although use of these is rare in construction. Magnetic particle inspection (MPI) and ultrsonic testing cannot be used successfully on austenitic stainless steel.

Distortion

Stainless steel has a lower thermal conductivity and higher thermal expansion than carbon steel, which increases the tendency to distort during welding. Distortion can, however, be minimised by symmetrical welding and by the use of jigs to support and confine workpieces during welding.

Welding stainless steel to other metals

It is possible to weld stainless steel to other metals, provided that appropriate filler is used. The accepted procedure is to use an over-alloyed austenitic electrode to ensure adequate mechanical properties and corrosion resistance. Dissimilar joints are only very rarely made without a filler metal, since even in thin sheets the weld quality can be poor.

When painted carbon steel is welded to stainless steel, it is good practice to paint over the joint and to cover a few centimetres of the stainless steel to reduce the risk of galvanic corrosion.

7.1.2 Manual metal arc (MMA) welding

MMA welding is the common stick electrode process known to all fabricators. An electric arc is produced between the workpiece and a metal electrode. A small area of the workpiece is brought to its melting point and at the same time the end of the electrode is melted. Droplets of molten metal pass though the arc and are deposited on the workpiece. A flux coating to the electrode vaporizes in the heat of the arc, forming a gaseous shield which protects the weld from oxidization. The flux also contains slag forming ingredients that produce a coating over the weld as it cools.

MMA welding is simple, fast, versatile and causes minimum distortion to the welded parts. However, the process necessitates good quality control; weld spatter and slag should be removed.

7.1.3 Tungsten inert gas (TIG) welding

In the TIG process, an arc is formed between the workpiece and a non-consumable tungsten electrode. The weld is formed by the local melting of the components being joined. Weld filler metal can be provided, if necessary, by feeding a filler rod into the arc. The weld is shielded by an inert gas shroud (*e.g.* argon or helium, but not carbon dioxide which could lead to carbon pick-up).

Stainless steel sheet of between 0.5 and 4 mm thickness can be welded by the TIG process. Sheet of less than 3 mm thickness can be welded successfully without the need for additional filler metal. TIG welding gives a high quality, clean, smooth weld. The inert gas shields the weld from oxidation without producing slag, so remedial surface treatment requirements are reduced.

7.1.4 Plasma arc welding

Plasma arc welding is a similar process to TIG welding, except that the arc is constricted through a small orifice before it reaches the workpiece. This is done by placing the tungsten electrode in a nozzle which also directs a plasma gas. An inert shielding gas shrouds the plasma arc.

The plasma arc welding process is suitable for stainless steel of thicknesses from foil up to about 8 mm, using a plasma gas of argon and shielding gas of argon with 5 - 8% hydrogen. Weld appearance is excellent. Plasma arc is generally used for fabricating tube and box sections using automated welding systems.

7.1.5 Metal inert gas (MIG) welding

In the MIG welding process an arc is formed between the workpiece and a consumable wire electrode. The wire may be solid or flux cored. As in TIG welding, the weld is shrouded by an inert gas.

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MIG welding produces a clean, essentially slag and flux free weld at high speeds. Heat distortion of the workpiece can be controlled. Stainless steel up to around 30 mm thickness can be welded by this process.

A variant of the MIG process is to shroud the weld with an active gas (Metal Active Gas or MAG welding). For stainless steel, a mix of argon with 1% oxygen is used. The oxygen increases the fluidity of the weld pool, permitting smoother transfer of weld metal.

7.1.6 Submerged arc welding (SAW)

In the submerged arc process, the welding is carried out under a blanket of granular flux material. The flux melts in the heat of the arc and shields the weld from oxidation, helping to purify and strengthen the weld metal. Welding is carried out in the flat position and movement of the electrode is mechanically controlled.

High quality, uniform welds are achievable, at high speed and with no smoke or arc flash. The SAW process is used to weld thick stainless steel plate.

7.1.7 Resistance welding

Resistance welding is suitable for joining stainless steel less than 3 mm thick. The components to be joined are sandwiched between two electrodes. Mechanical pressure is applied, and current is passed between the electrodes. Heat builds up at the point of greatest electrical resistance (the surface between the two components), melting the metal of both surfaces to form a weld nugget. For this process, the surface of the stainless steel must be clean since it is not normally possible to weld through contamination, paint, *etc*.

Weld shape is governed by a number of factors, including the shape and size of the electrodes. Spot resistance welding joins the material with a series of separate ‘spot’ welds. Seam welds are produced by overlapping a series of spot welds or by using wheels/rollers rather than discrete electrodes. Seam welding is usually highly automated, and best suited to high volume, high speed repetitive production work. Spot welding is a manual process and much slower.

7.1.8 Stud welding

Studs can be used to join components when bolts (which penetrate the material and are visible on the other side) are impractical or undesirable, for example secret fix cladding attachments. The stud is welded to one component and fixed to the other using a mechanical fastening.

Stud welding techniques involve drawing an arc between the stud and the surface to which it will be joined. This brings the end of the stud and a spot on the surface up to melting point. The stud is then fired at the surface such that a weld is formed over the area of the end of the stud.

One type of stud has a small nipple at the weld end which melts in the heat of the arc. When the stud is fired onto the surface the nipple explodes, the material spreading out between the stud and the surface to form a weld. This process uses minimal heat, so it is suitable for fixing small, low strength studs to thin sheet material. The minimum thickness of stainless steel sheet to which studs can be welded without marking the opposite surface depends on a number of factors, including the stud size and discharge current, but typically lies between 1-1.5 mm.

Higher strength stud welding techniques are available for thicker stainless steel sheet. One such technique uses studs that are flux-cored at the weld end. These studs have a length of sacrificial material around the flux core that forms the weld material. The disposable ceramic collars used with this type of stud eliminate weld spatter. High strength welds can be formed, but remedial surface treatment may be required.

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7.2 Mechanical Joints

7.2.1 Introduction

Mechanical joints are formed using fasteners or fixings; they are commonly used to assemble components and systems on site. The joints can be detailed to enable relative movement of the components being joined.

In exposed locations or under circumstances where galvanic corrosion is likely to occur, it is important to ensure that the fastener is at least as corrosion resistant as the components being joined. To prevent the possibility of rust stains appearing at joints, carbon steel fasteners should never be used to join stainless steel components, even if the fasteners are isolated from the components.

Stainless steel fasteners and fixings are widely used to:

- connect stainless steel components to each other, *e.g.* to form lap joints between profiled sheeting for cladding,
- connect stainless steel components to components made from other materials *e.g.* bolts connecting stainless steel masonry support angles to a steel or concrete structure,
- connect components made exclusively from materials other than stainless steel, *e.g.* to form joints between corrosive timber components such as oak heartwood, or aluminium, copper or zinc roofing.

A wide selection of screws, bolts, washers, nuts, studs, rivets, clips, brackets and other fastening hardware is available in various grades of stainless steel.

7.2.2 Specification of stainless steel fasteners

Stainless steel fasteners are covered by BS 6105. Each fastener is designated by a four character identifier consisting of a letter followed by three digits, *e.g.* A2-70. The letter indicates the general composition of the stainless steel (A for austenitic, C for martensitic and F for ferritic).

The first digit indicates the type of alloying elements present (or grade) and hence the corrosion resistance of the fastener. Three grades of austenitic stainless steel fasteners are widely available. In increasing order of corrosion resistance they are designated A1, A2 and A4. A1 fasteners contain sulphur which is added to improve machining. This, however, reduces their corrosion resistance and renders them unsuitable except in rural and benign environments. A2 fasteners are equivalent in corrosion resistance to grade 1.4301 (304) stainless steel, and are suitable for urban

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and lightly industrial sites. A4 fasteners are equivalent in corrosion resistance to grade 1.4401 (316) stainless steel, and are suitable for industrial and marine sites.

The last two digits indicate the property class or strength. Three property classes exist: 50, 70 and 80, which correspond to ultimate tensile strengths of 500, 700 and 800 N/mm^2. The property class of a bolt has no significant effect on its corrosion resistance. Property class 70 is the most widely available strength class.

Thus the designation A2-70 denotes a bolt having the same corrosion resistance as 1.4301 (304) stainless steel and an ultimate tensile strength of 700N/mm^2.

7.2.3 Choice of fasteners and fixings in design

The type of fastener used depends on the size and form of the components to be joined.

Self drilling screws are particularly suitable for light components such as roofing and cladding panels. In carbon steel sheeting, they are installed in one operation: they have a drill point which forms its own pilot hole through which the screw enters and cuts a thread in the sheet. However, self drilling screws are generally not hard enough to drill stainless steel; they should be installed through pre-drilled clearance holes in the stainless steel sheet, self-drilling a hole into the member (normally carbon steel) behind.

Self tapping (or thread forming) screws and rivets are also used to join light components. Stainless steel self-tapping screws are mostly used in aluminium, plastic or wood.

Bolts are suitable for joining heavier components. Washers under both the bolt head and the nut are recommended, to ensure weather tightness. The correct tightening of bolts is important. Torque wrenches should be specified and used.

Wall ties, dowels and anchorages are frequently made from stainless steel because they are usually difficult to inspect and replace, yet corrosion resistance must be assured. Some codes of practice specifically recommend the use of stainless steel fixings in certain situations. For example, stainless steel, copper and copper-based alloys are the only recommended materials for

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fixings in masonry buildings over three storeys (BS 5628: Part 3) and for fixings to natural stone cladding and lining (BS 8298).

7.3.1
Introduction

Adhesives can offer substantial economic, performance and design advantages over conventional methods of joining. However, they are subject to limitations. Table 7.1 summarises these advantages and limitations.

Table 7.1
Advantages and limitations of adhesive bonding

Advantages	Limitations
Ability to join dissimilar materials	Surface pretreatments normally required, particularly with a view to maximum joint strength and durability
Ability to join thin sheet material efficiently	Fairly long curing times frequently involved
More uniform stress distribution in joints leading to enhanced fatigue resistance	Poor resistance to elevated temperature and fire
Weight savings over mechanical fastening	Brittleness of some products, especially at low temperatures
Smooth external surfaces are obtained	Poor creep resistance of flexible products
Corrosion between dissimilar metals may be prevented or reduced	Poor creep resistance of all products at elevated temperatures
Glueline acts as a sealing membrane	Toxicity and flammability problems with some adhesives
No need for naked flames or high-energy input during jointing	Equipment and jigging costs may be high
Capital and/or labour costs are often reduced	Long-term durability, especially under severe service conditions, is often uncertain

Adapted from Adhesives, by A R Hutchinson, Mechanical Engineer's Reference Book, 12th Edition, Section 16.4, Butterworth Heinemann, 1994

There is increasing interest in bonding stainless steel structures, notably sheet metal components, where the ability to attach dissimilar materials (*e.g.* cladding to core materials), and the wish to avoid mechanical face fixings, makes adhesives particularly desirable. Best experience has so far been in relation to interior claddings, where the service environment is relatively benign, and in specialist applications such as the bonding of pipework connections in the water and chemical process industries.

7.3.2
Design considerations

Adhesive bonds are comparatively weak in tension, particularly when compared with welded joints, but strong in shear and compression. Load-bearing bonded joints require careful design: detailed guidance on joint design is contained in specialist literature[9][10].

7.3.3
Types of adhesive

Many types of engineering adhesive are available. Correct selection and specification is essential, and specialist advice should normally be sought.

Engineering adhesives may be categorised into four main groups:

- Epoxy: these comprise an epoxide resin and a reactive hardener. They tend to be used on large components where gap-filling, strength, creep, moisture and heat resistance are required.
- Polyurethane: isocyanate resin is combined with hardeners similar to those used in epoxies. Unlike epoxies, these materials harden quickly. However, they are generally weaker and more susceptible to moisture than other structural adhesives. They are frequently used for bonding large sandwich panels.
- Phenolic/resorcinolic: these were amongst the first structural adhesives, and are rarely encountered outside the aircraft and timber industries.
- Acrylic: this group includes: anaerobic adhesives, sometimes used for locking, sealing and retaining closely fitting metal parts; and toughened acrylic adhesives, used for bonding sheet and coated metal. This latter class has good environmental resistance, peel and impact strength.

7.3.4
Adhesion and surface pre-treatment

Adhesives may be used on their own or in conjunction with other materials. Adhesive bonding normally involves the following stages:

1. Preparation of the surface to be bonded.
2. Application of primer (if needed).
3. Mixing, dispensing and application of adhesive.
4. Curing.

Inadequate surface pre-treatment is a common cause of durability problems. Whilst adhesives are available that can absorb oily films and slight surface contamination, pre-treatment is normally essential. Pre-treatment typically involves cleaning, removal of weak surface layers and recleaning. The usual methods of pretreating surfaces are: solvent degreasing, mechanical abrasion and chemical treatments. The degree of surface preparation required will generally depend upon the adhesive used, the necessary bond strength, the initial level of contamination and the service environment. Bonding should be carried out as soon as possible after cleaning, preferably within one or two hours.

Surface primers can significantly improve bond strength. These provide particularly good interface conditions, and in the future it may be commonplace to bond pre-primed stainless steel. Primers and adhesives must be properly compatible.

Generally for stainless steel, dry wiping, followed by abrasion and then solvent wiping, appears sufficient. However, grit-blasting followed by priming with a silane solution or with a chromate based solution has been reported to be particularly effective.

There is a relationship between surface roughness and bond strength, whereby the rougher the surface, the better the bond. Stainless steel can be supplied with a range of surface finishes, and the roughness of these is an important consideration. Bright annealed finishes are more difficult to bond effectively than finishes such as 2D (acid pickled).

Adhesive mixing, dispensing and application has to be carefully controlled. Single part adhesives can be applied by spraying, brushing, rolling, or by direct extrusion from containers. Two part systems must be carefully mixed before application. Large bonded areas may require holes or passages for air to escape from between the surfaces during the lay-up process. Jigs or permanent mechanical fixings may be required to restrain components whilst the adhesive cures.

Correct curing conditions are important. Components may need to be heated using appropriate methods. Care should be taken however that curing temperatures do not have any adverse effect upon materials to which stainless steel is bonded, such as insulation or backing boards.

8 MAINTENANCE AND CLEANING

8.1 Component Design

Maintenance and cleaning can be minimised or simplified by the use or avoidance of particular details:

- The effects of rainwater run off from horizontal surfaces that may harbour dirt should be considered.
- The beneficial effect of rain may be optimised by ensuring that run off is as uniform as possible. Concentrated flows of rain water should generally be avoided to prevent localised streaking.
- Grooves, recesses and complex contours can hamper manual cleaning.
- Joints should generally be designed to avoid dirt entrapment. Capillary draw should be eliminated by using sealants or by having a gap large enough to permit effective drainage.
- Run off from other materials should not be allowed to contaminate stainless steel surfaces. This is a particular issue where run off is from materials such as carbon steel, weathering steel, chloride bearing cements, mastics, sealants *etc*.
- Bright annealed and bright/mirror polished surfaces tend to show scratches more readily than embossed or dull brushed finishes, whilst mill finishes 2B and 2D are extremely difficult to reproduce if they are scratched. Careful selection of finish in relation to service conditions is recommended.
- It is often preferable to have the grain of unidirectional finishes running vertically, since this improves self cleaning and reduces dirt entrapment, particularly where coarser finishes are used.

Section 2.6 gives recommendations for good detailing to maximise durability.

8.2 Storage and Site Erection

Care is required in storing and handling stainless steel to avoid damaging the surface finish (especially bright annealed, polished and chemically coloured/painted finishes) and to avoid contamination by carbon steel and iron.

Where necessary, a means of protecting the surface of stainless steel components during transportation, storage and erection should be given in the specification. Dry storage under cover is preferred, particularly if a wrapping that might absorb water and stain the surface, such as cardboard, has been used. It is preferable for sheet and plate to be stored upright in racks.

A plastic film can be specified to protect the surface and prevent the deposition of airborne dirt and debris generated during construction. This is particularly relevant to chemically coloured or painted surfaces and will minimise (in many instances completely eliminate) the need for cleaning before handover. The film should be kept in place for as long as possible. By starting to strip the film at the top of the building and working down to the base, any dirt and debris falls onto the protected lower layers. The film manufacturer's advice should be sought on the choice of film material, type of adhesive and the maximum time that can be allowed before removal of the film. The reason is that prolonged exposure to heat, sunlight or pressure can make stripping the film difficult and cause adhesive to be retained on the stainless steel surface, leading to consequent cleaning problems.

Steel should be inspected immediately after delivery for any surface damage.

When carbon steel lifting or handling equipment such as strapping, crane hooks, chains or rollers are being used, appropriate protective material should be placed between the stainless steel and carbon steel to prevent damage. Clean, heavy cardboard or light plywood are suitable materials for this purpose. Grinders should be reserved for exclusive use on stainless steel.

8.3 Cleaning before Handover

If stainless steel surfaces have not been protected by an adhesive film, then they should generally be cleaned prior to handover. Different cleaning procedures are followed depending upon the surface finish, and where necessary these should be set out in the specification.

8.3.1 Bare stainless steel

A typical procedure for cleaning bare stainless steel would be:

1. Rinse with water to remove loose dirt.
2. Wash with water containing soap, detergent or 5% ammonia, using a soft, long fibre brush if necessary.
3. Rinse with water.
4. If required, remove the water with overlapping strokes, working from top to bottom.

When cleaning brushed surface finishes, the cleaning movement should be in the same direction as the grain.

If iron contamination is suspected, it can be detected and removed on site; ASTM 380[11] gives a suitable detection method. Embedded iron can be removed by either pickling or passivation. Both are carried out after degreasing (removing oil, grease and other organic contamination).

Table 8.2 gives a method for removing mortar or cement splashes.

8.3.2 Chemically coloured/painted stainless steel

Many of the cleaning techniques used for bare stainless steel should not be used on chemically coloured/painted stainless steel, as the colouring systems are more delicate than the steel surface. Specific advice on cleaning should be sought from suppliers. Site repair is usually not possible.

8.4 Maintenance and Cleaning During Service

Exterior and interior building components require routine cleaning, the frequency of which is dependent upon environmental conditions and aesthetic requirements.

8.4.1 Bare stainless steel

Rain can wash well-designed facades quite effectively. However, it is usually recommended to supplement this natural process by washing the stainless steel once or twice a year. For instance, a stainless steel curtain wall may be washed at the same time as the windows.

However, in areas where severe environmental conditions exist, such as coastal regions with high temperatures, high humidity and severe air pollution, more frequent washing may be necessary. The procedure used for cleaning before handover can be adopted.

In some locations, heavier soiling may occur as a result of local conditions, such as splashing at ground level from road surfaces. In such cases, pressure jet cleaning with hot water to remove material adhering to the surface, followed by rubbing with a suitable mild-abrasive cleaner, a water rinse and drying, is usually adequate. Domestic cleaners that contain harsh abrasives should be avoided since they will alter the surface appearance. Many also contain chlorine compounds which, if left on the surface, may cause corrosion.

Table 8.1 provides an overview of some common cleaning methods and the circumstances in which each should be selected.

8.4.2 Chemically coloured/painted stainless steel

The four stage cleaning regime suggested in Section 8.3.1 for the cleaning of bare stainless steel before handover can be adopted, but special care must be taken not to damage the surface. This is particularly important when dealing with heavily soiled, painted stainless steel. For instance, pressure jet cleaning may damage the paint; hosing with water containing a detergent is preferable. If the soiling still remains, gentle rubbing with a soft cloth sprinkled with fine calcium carbonate powder, *i.e.* 200 mesh or finer, could be tried - but this could take the gloss off the paint if done too vigorously or frequently. Overall, it is advisable to seek advice from the painted stainless steel producer or a specialist cleaning company.

8.4 Maintenance and Cleaning During Service

Table 8.1 *Cleaning methods for bare stainless steel*

Requirement	Suggested Method[1)]	Comments
Routine cleaning of light soiling	Soap, detergent or dilute (1%) ammonia solution in warm clean water. Apply with a clean sponge, soft cloth or soft-fibre brush then rinse in clean water and dry.[2)]	Satisfactory on most surfaces
Fingerprints	Detergent and warm water. Alternatively, hydrocarbon solvent	Proprietary spray-applied polishes available to clean and minimise re-marking
Oil and grease marks	Hydrocarbon solvent	Alkaline formulations are also available with surfactant additions.[3)]
Stubborn spots, stains and light discolouration. Water marking. Light rust-staining.	Mild, non-scratching creams and polishes. Apply with soft cloth or soft sponge, rinse off residues with clean water and dry.	Avoid cleaning pastes with abrasive additions. Cream cleaners are available with soft calcium carbonate additions. **Avoid chloride containing solutions.[4)]**
Localised rust stains caused by carbon steel contamination	Proprietary gels, or 10% phosphoric acid solution (followed by ammonia and water rinses), or oxalic acid solution (followed by water rinse).	Small areas may be treated with a rubbing block comprising fine abrasive in a hard rubber or plastic filler. Carbon steel wool should not be used, nor should pads that have previously been used on carbon steel. A test should be carried out to ensure that the original surface finish is not damaged.

Notes:

1) Cleaning agents should be approved for use under the relevant national environmental regulations and should be prepared and used in accordance with the company or suppliers' health and safety and application instructions. Non-aromatic hydrocarbon solvents which are substitutes for 1,1,1-Trichloroethane are available for degreasing.

2) Rinse water should be clean, equivalent to a reasonable quality potable water, and leave no deposits. To avoid drying marks, use an air blower or clean, soft, disposable wipers.

3) When using potentially aggressive formulations, for example mortar cleaners and caustic, concentrated degreasants or paint strippers, a small hidden area of the surface should be cleaned first, to assess any changes in appearance. The products must be removed by thorough rinsing after application.

4) Chloride-bearing solutions, including hydrochloric acid-based mortar cleaning agents and hypochlorite bleaches should not be used in contact with stainless steels, as they can cause unacceptable surface staining and pitting. However, if in unusual circumstances, the use of a bleach solution cannot be avoided, it should be fully diluted, in accordance with suppliers' instructions, with contact times kept to a minimum and with thorough rinsing after use. **Under no circumstances should concentrated bleaches contact decorative stainless steel surfaces.**

8.5 Vandalism, Accidents and Remedial Cleaning

8.5.1
Bare stainless steel

Stainless steel is highly durable. Graffiti can often be removed and surface damage repaired by following recommended procedures. Table 8.2 provides an overview of some cleaning methods and the circumstances in which each should be selected.

Table 8.2 *Cleaning methods for bare stainless steel following vandalism, accident or neglect*

Requirement	Suggested Method[1)]	Comments
Adherent hard water scales and mortar/cement splashes	10-15% volume solution of phosphoric acid. Use warm, neutralise with dilute ammonia solution, rinse with clean water and dry.	Proprietary formulations available with surfactant additions. **Avoid the use of hydrochloric acid-based mortar removers**.
Heat tinting or heavy discolouration[2)]	a) Non-scratching cream or polish. Apply with soft cloth or soft sponge, rinse off residues with clear water and dry. b) Nylon-type pad.[3)]	a) Suitable for most finishes. b) Use on brushed and polished finishes along the grain.
Badly neglected surfaces with hardened, accumulated grime deposits	A fine, abrasive paste as used for car body refinishing.[3)] Rinse clean to remove all paste material and dry.	May brighten dull finishes. To avoid a patchy appearance, the whole surface may need to be treated.
Paint, graffiti	Proprietary alkaline or solvent paint stripper depending upon paint type. Use soft, nylon or bristle brush on patterned material.	Apply as directed by manufacturer.[4)]

Notes:

1) See Note 1 in Table 8.1

2) Heavy oxidation of stainless steel surfaces is unlikely to be encountered in normal architectural use. In exceptional cases, for example after a repair requiring welding, or after fire damage, it may be necessary to clean and repassivate areas using a nitric acid-hydrofluoric acid pickling paste pack. A change in surface appearance will result.

3) Nylon abrasive pads should be adequate for dealing with most deposits. If a more severe treatment is needed to mask coarse scratches or physical damage on a surface, use the finest abrasive medium consistent with covering the damage marks. With directional brushed and polished finishes, align and blend the new scratch pattern with the original finish, checking that the resulting scratch pattern is aesthetically acceptable.

Silicon carbide media may be used, especially for the final stages of finishing. Ensure that all abrasive media used are free from sources of contamination, for example iron and chlorides. If wire brushes are used, these should be made of a similar or better grade of stainless steel.

4) See Note 3 in Table 8.1

8.5 Vandalism, Accidents and Remedial Cleaning

8.5.2
Chemically coloured/painted stainless steel

Techniques exist to remove paint and ink marks from chemically coloured and painted stainless steels, but any attempt to remove this type of graffiti should be left to specialist cleaning companies, otherwise the surface may be irrevocably damaged.

Graffiti scratches on painted stainless steel have the same visual effect as on painted carbon steel, but the advantage is that the scratch mark does not subsequently enlarge by corrosion. Clearly, it is possible to repaint the scratched area and restore the surface of a painted stainless steel. In the case of chemically coloured stainless steel, however, site rectification is not possible as the colour depends on the electrolytic production of an oxide film.

Mortar and cement splashes should be washed off immediately, as satisfactory removal when dry is impossible. In the extreme, stainless steel wool could be used to remove the accretion from painted stainless steel, but this would also remove the paint and repainting the affected area would be required.

Oil stains should not be removed with an organic solvent, like a thinner, as this could upset the colour tone. It is preferable to use a soft cloth wetted with a neutral detergent diluted with hot water, followed by a cold water rinse and drying with a soft cloth.

It is important to avoid scratching the surface. A metallic brush or coarse abrasive compound should never be used and, ideally, iron particles should be removed before they start to rust, by wiping gently with a soft cloth.

Large scale, remedial cleaning should be done by a competent, specialist cleaning company.

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CASE STUDIES

Matrix showing the stainless steel components used in each case study

CASE STUDY	Structure	Cladding	Glazing fixings	Handrails/Balustrades	Staircases	Kitchen/Bathroom equipment	Ironmongery	Flooring	Louvres	Sculpture
Avesta Sheffield Finishing Department, Sheffield		✦								
B8 Building, Stockley Park			✦						✦	
Bilbao Metro Railway Stations	✦			✦	✦					
British Pavilion, Seville			✦					✦		✦
East Croydon Station			✦							
European Court of Human Rights, Strasbourg		✦								
Hartcliffe Mini Town Hall, Bristol		✦					✦			
La Geode, Parc de la Villette		✦								
La Grande Arche, Paris	✦									
Leipzig Trade Fair - Central Hall			✦							
Lowe Flat, London				✦	✦	✦				
Museum of Science & Industry, Tampa		✦								
One Canada Square, London		✦								
Petronas Towers, Kuala Lumpur		✦								
Reina Sofia Museum of Art, Madrid			✦							
Sackler Galleries, London				✦	✦					
School of OT & P, Southampton	✦									
Serres, Parc de La Villette	✦		✦							
Tension Net Staircase, Chicago				✦	✦					
Thames Tower, London	✦	✦	✦							
Waterloo International Terminal		✦	✦	✦			✦	✦		

AVESTA SHEFFIELD COIL PRODUCTS - SHEFFIELD FINISHING DEPARTMENT

Sheffield, UK, 1992

Architect: *HLM Architects, UK*
Engineer: *White Young, UK*

✦Cladding

Techniques
Roll forming Patterned finish Mechanical joints

Figure 1
General view of Finishing Department

Courtesy of Avesta Sheffield Ltd.

Figure 2
Aerial view of Finishing Department

Courtesy of Avesta Sheffield Ltd.

General

The Finishing Department of Avesta Sheffield Coil Products Division was constructed on a prime site adjacent to the forthcoming Sheffield Airport and Sheffield Ring Road (Figure1, Figure 2). It is an example of how stainless steel can be used effectively in a simple utility building, using standard proprietary profiled sheet cladding systems.

AVESTA SHEFFIELD COIL PRODUCTS - SHEFFIELD FINISHING DEPARTMENT

Technique
Roll forming Patterned finish Mechanical joints

The building has a floor area of approximately 30,000 m^2, comprising 25,000 m^2 of factory area and a 5,000 m^2 automated dispatch bay. It has a steel structure with lattice columns and trusses. The factory area comprises 5 bays containing a sophisticated automatic storage and retrieval (ASR) system.

Cladding

Roofs are clad in 0.7 mm profiled stainless steel sheet grade 1.4301 (304) with a 2B basic mill surface finish. Walls are clad in 0.8 mm bright annealed profiled stainless steel grade 1.4401 (316). The profiles were produced by roll forming and are former British Steel 'longrib' types 1000R and 1000W (1000 mm roof and wall profiles). The 4600 m^2 sidewalls have a patterned 'linen' finish on the outside face which gives them a pleasing satin-like appearance when viewed from a distance, and a 'grain' when viewed close to. Wall flashings are designed to match the wall cladding.

The building has approximately 1.4 km of gutters. These are fabricated from 4 mm thick stainless steel grade 1.4301 (304) with a 2B basic mill surface finish.

Stainless steel cladding sheets were predrilled and screwed to angle spacers between the cladding and the internal liner sheets using conventional stainless steel topped, carbon steel bodied, self-tapping fixings.

B8 BUILDING, STOCKLEY PARK

Uxbridge, UK, 1990

Architect: *Ian Ritchie Architects, UK*
Engineer: *Ove Arup & Partners, UK*

Techniques
Punching Machining

✦ Glazing fixings ✦ Louvres

Figure 1
B8 Building at Stockley Park

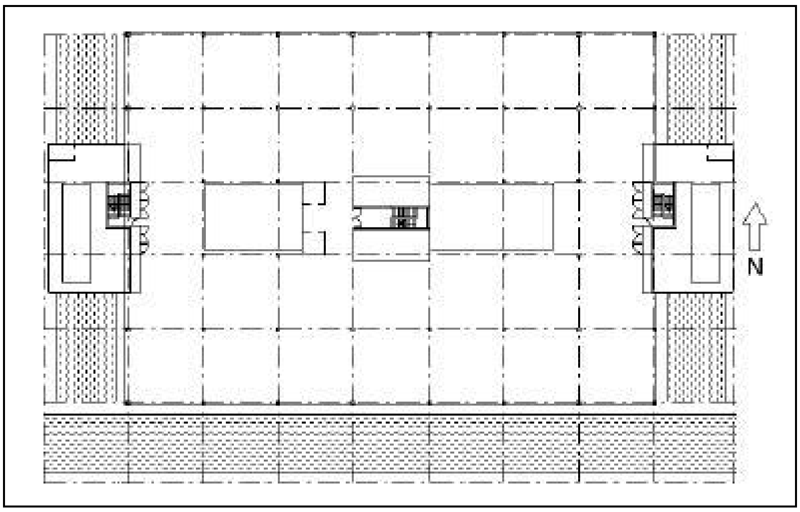
Photo: Jocelyne Van den Bossche

General

The building provides office accommodation on three floors (Figure 1), with the 45 m x 64 m plan organised on a 9 m x 9 m structural grid (Figure 2). Two plant zones located at the east and west sides of the rectangular plan provide the building with its mechanical and electrical services. The cladding is a double-glazed planar system supported on extruded aluminium posts.

The architects used grade 1.4401 (316) stainless steel for the planar glazing supports, the external sun screen and the cladding to the plant rooms. Stainless steel was selected for its durability, appearance and ease of maintenance.

Figure 2
Typical floor plan



Techniques
Punching Machining

Glazing supports

Stainless steel (grade 1.4401 (316)) glazing supports comprise a 180 mm long machined arm and a conical machined collar, with 90° turn locking nuts at the connection to the aluminium mullion. The glass panels (2988 mm x 1346 mm) are fixed at each of the corners using a conventional planar detail. The arm picks up the fitting at one end and screws into the stainless steel machined conical collar at the other end (see Figure 3). The complete assembly is shown in Figure 4.

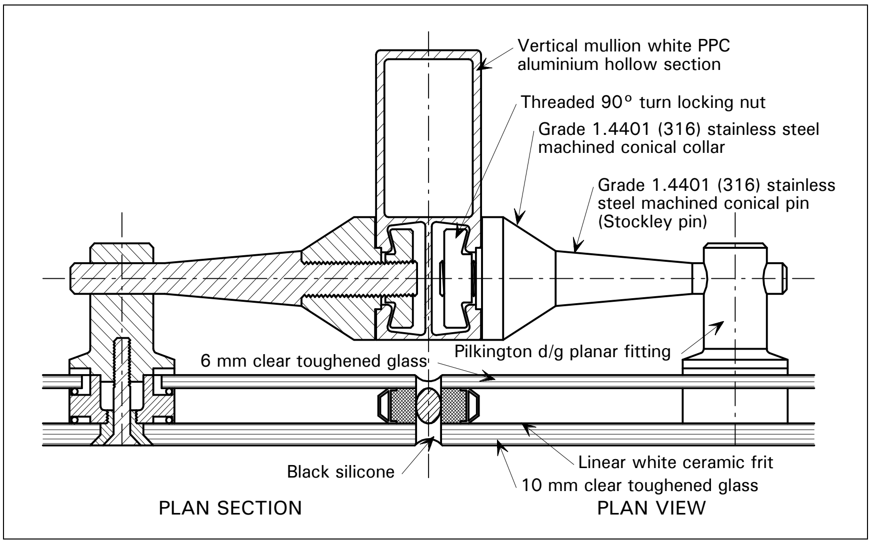


Figure 3 *The stainless steel 'Stockley pin' connects the glass (through the planar fittings) to the aluminium mullions*

Figure 4 *The Stockley pin assembly*

Photo: Jocelyne Van den Bossche

Techniques
Punching Machining

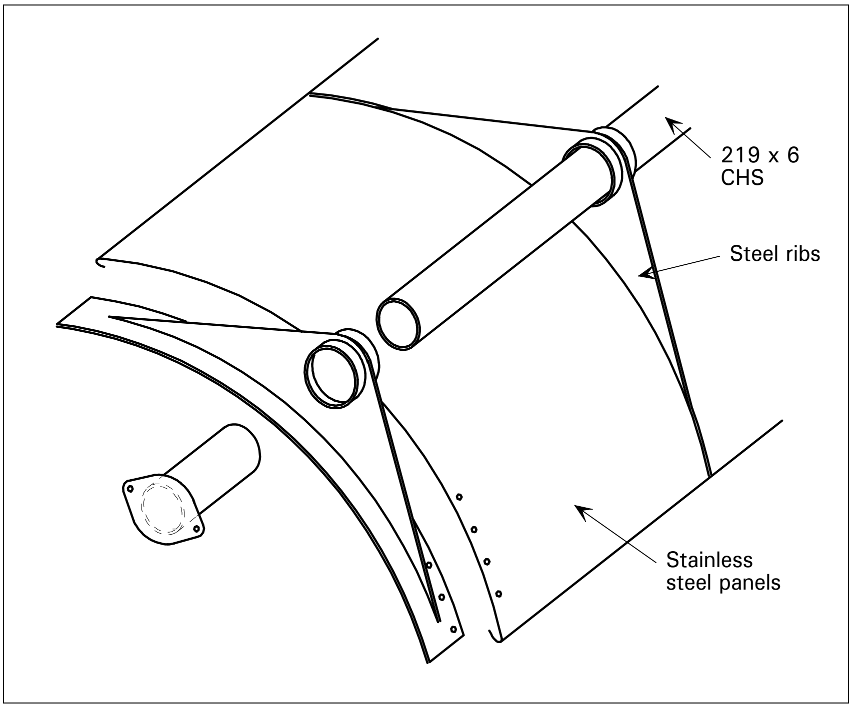
Horizontal thermal movement and construction tolerances are accommodated by allowing the planar fixing to slide along the machined arm. Vertical adjustment is provided by the continuous groove in the aluminium mullion.

Sun screens

The external stainless steel sun screens reduce solar gain and glare. They extend from the building on the south, east and west sides (Figure 2). This results in an attractive and dynamic change in the patterns of light and shade cast on the building during the course of the day.

The screen is made of 540 custom punched perforated curved stainless steel panels each 1500 mm wide. These were pre-assembled onto pressed stainless steel brackets which were then bolted onto the circular hollow section (CHS) support structure (Figure 5 and Figure 6). The total length of the screen on the three sides of the building is 136 m.

Figure 5
Custom-punched panels are mounted on pressed steel ribs bolted to CHS support structure



Techniques
Punching Machining

Figure 6
Four curved panels constitute the sun screen on the east, west and south of the building

Photo: Jocelyne Van den Bossche

Louvres

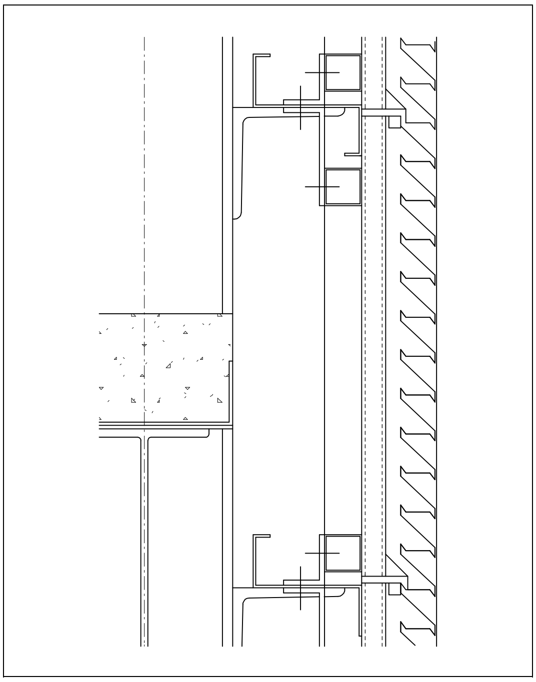
The two plant rooms are clad with 50 mm grade 1.4401 (316) pressed stainless steel louvres (Figure 7). The louvres are clipped to vertical stainless steel support rails and transoms fixed to the steelwork (Figure 8). Fire escape and plant access doors are incorporated into the system.

Figure 7
Side view showing louvre cladding to one of the plant rooms

Photo: Jocelyne Van den Bossche

Techniques
Punching Machining

Figure 8
Cross-section through the louvres



BILBAO METRO RAILWAY STATIONS

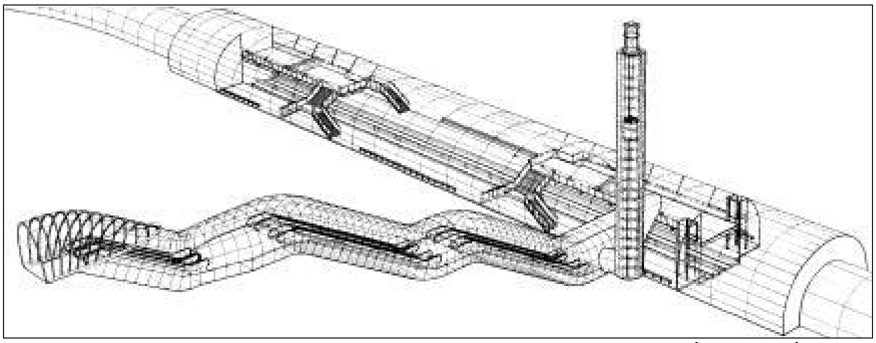
Bilbao, Spain, 1996

Architect: *Foster and Partners, UK*
Engineer: *Sener, Spain (Mezzanines)*
Saitec, Spain (Entrance enclosures)

Techniques
Laser cutting Tube bending Machining Polished finishes, (satin mirror) Welding Mechanical joints

✦ Structure ✦ Handrails/Balustrades ✦ Staircases

Figure 1
Axonometric view of a bored tunnel station



Courtesy of Foster and Partners

General

The Bilbao Metropolitan Railway is part of an urban regeneration programme planned for the city of Bilbao and the surrounding area.

The first stage of the project comprised eleven underground stations. Figure 1 is an axonometric view of a typical station. Escalators carry passengers directly to a mezzanine level which is linked to the platform by two sets of gently curving staircases (Figure 2).

Figure 2
The mezzanine provides the link between the platform and the access tunnels

Photo: Richard Davis

Stainless steel grade 1.4404 (316L) was used in the entrances to the stations, the stairs, and the furniture. It was selected for its ease of maintenance, visual appearance and corrosion resistance. In the case of the mezzanine support structure, a special heat-resisting grade, 1.4845 (310) (to be covered in forthcoming EN 10095), was used to give the required fire resistance without the need to protect the structure.

Techniques
Laser cutting Tube bending Machining Polished finishes (satin, mirror) Welding Mechanical joints

Entrance canopies

The metro is identified at street level by glass and stainless steel enclosures (Figure 3). Apart from the signage, these are the only visible elements at street level.

Figure 3
Stainless steel and glass entrance canopy

Photo: Richard Davis

The canopies are designed in curved toughened glass supported on grade 1.4404 (316L) stainless steel frames. Each frame is a different size and constructed from a curved circular hollow section (CHS) (Figure 4). The CHS frames are connected to curved rectangular hollow section (RHS) members that carry the glazing bars. The connection between the CHS and RHS members is made using fin plates (Figure 4, Section A-A). The glass panels are mounted on the RHS and fixed using 60 mm wide, 2 mm thick stainless steel strip. The base of the canopy is clad in 1.5 mm grade 1.4404 (316L) stainless steel sheets with a 15 mm wood backing fixed to the concrete (Figure 5).

Techniques
Laser cutting Tube bending Machining Polished finishes (satin, mirror) Welding Mechanical joints

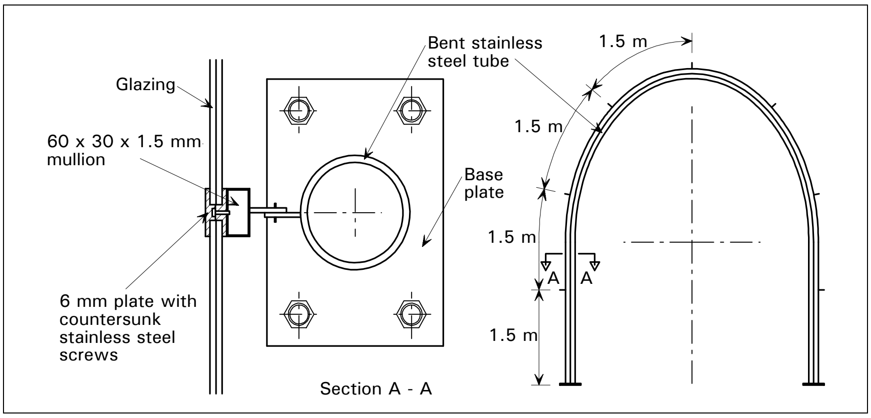


Figure 4
Curved frames support the glazing to the entrance canopy

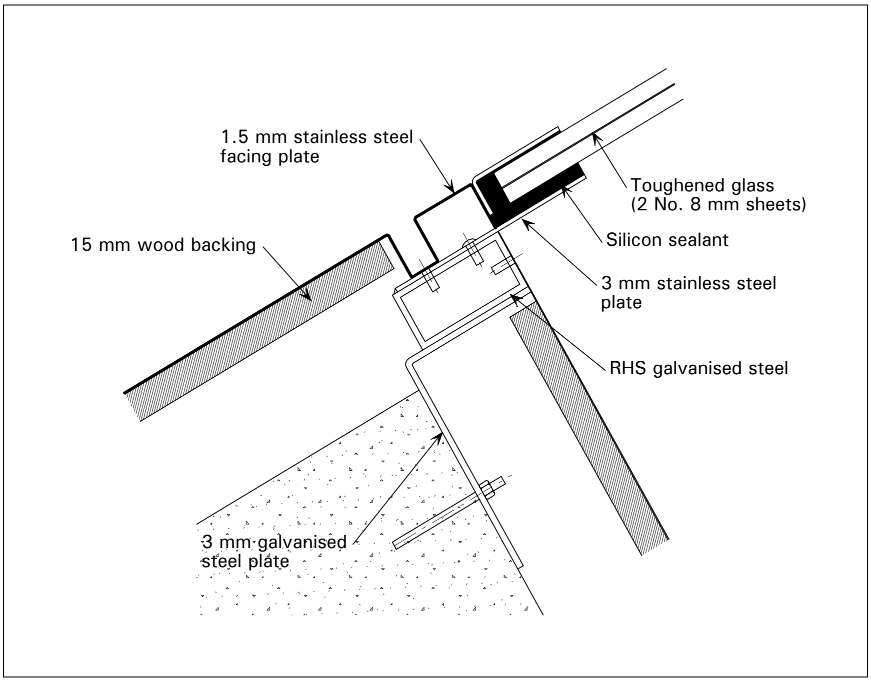


Figure 5
Cladding detail at the base of the canopy

Mezzanine

The mezzanine floors at either end of the station are suspended from the cavern roof by stainless steel hangers and braced laterally against the cavern sides using stainless steel struts (Figure 6). The structure of the mezzanine comprises primary stainless steel I-section beams fabricated from plate. Secondary stainless steel I-beams span between the primary beams (Figure 7). These support a reinforced concrete slab with a terrazzo floor finish.

Techniques
Laser cutting Tube bending Machining Polished finishes (satin, mirror) Welding Mechanical joints

Photo: Richard Davis

Figure 6 *Stainless steel hangers and struts support the mezzanine*

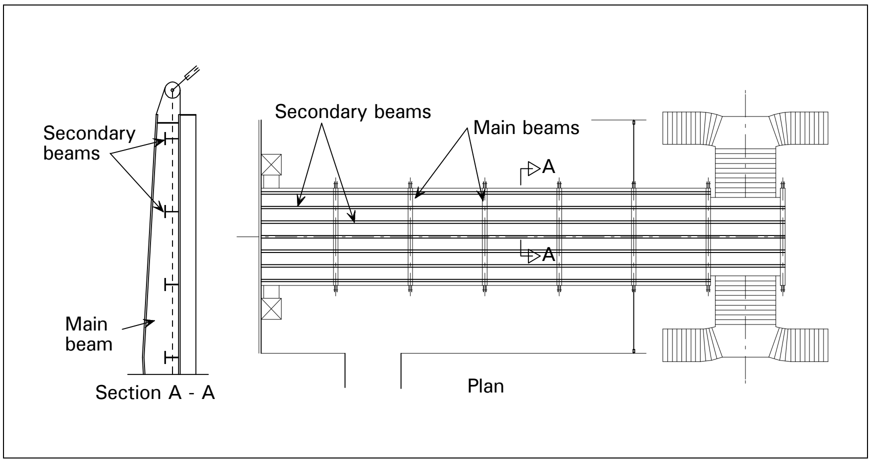


Figure 7 *Grid of stainless steel beams supports the mezzanine*

140 × 10 mm stainless steel CHS are used as hangers for the mezzanine. The main beam is pin connected to a stainless steel machined head, which is welded to the tubular hangers (Figure 8). Machined stainless steel hangers provide the connection to the roof via 30 mm thick stainless steel plates anchored by grouted hammer head bolts (Figure 9).

Techniques
Laser cutting Tube bending Machining Polished finishes (satin, mirror) Welding Mechanical joints

Photo: Alfredo Aldai

Figure 8
Mezzanine main beam is pin connected to stainless steel hanger

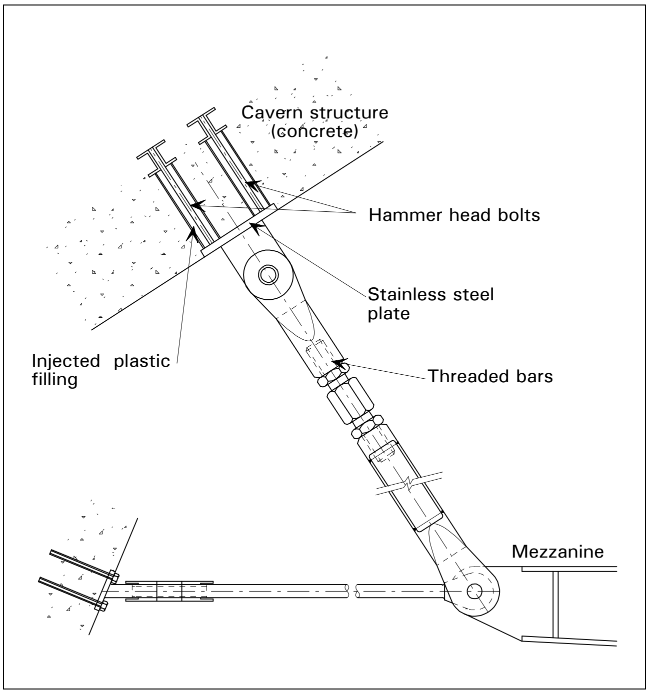


Figure 9
Support to the mezzanine structure

Techniques
Laser cutting Tube bending Machining Polished finishes (satin, mirror) Welding Mechanical joints

Stairs

Treads are fabricated from 8 mm thick stainless steel plates. The plates are welded to form a V shaped cross-section with the top of the V closed to form a 'tray' that receives the concrete infill. The treads are welded at each end to a stainless steel stringer. Stringers are also fabricated from welded plates, 16 mm and 10 mm thick (Figure 10).

Figure 10 *Stair details*

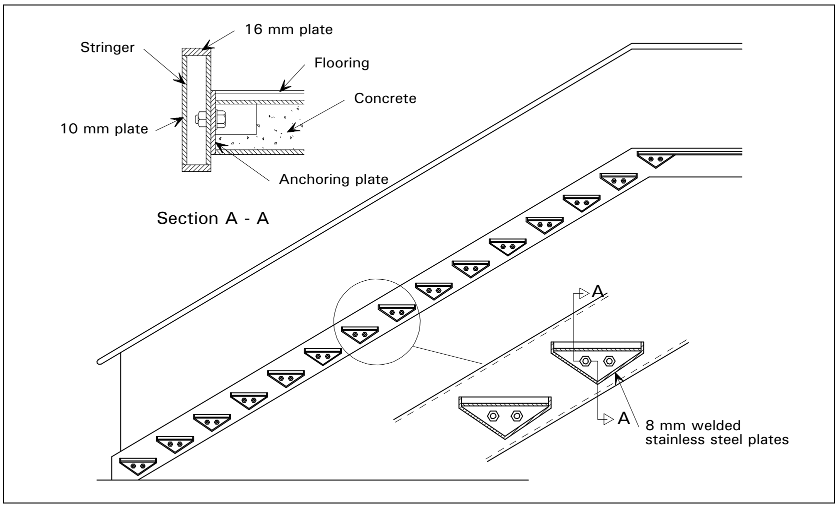


Figure 11 *Treads are welded to stringers (all fabricated from stainless steel plates)*

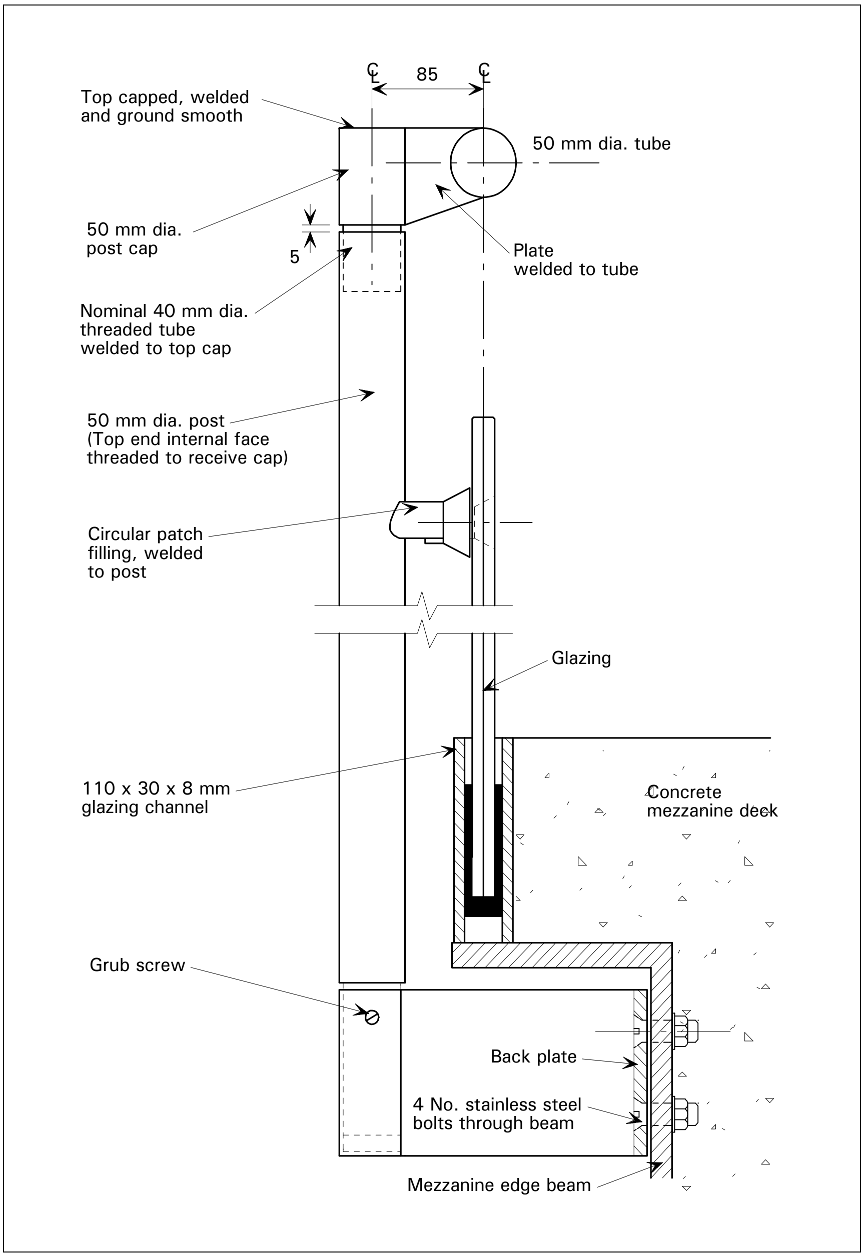
Photo: Alfredo Aldai

Handrails to the staircase and mezzanine areas are fabricated from 50 mm stainless steel tubes, polished to a mirror finish. These are fixed to balusters at 1.2 m centres by a welded 10 mm plate projecting from a post cap (Figure 12). A threaded spigot joins the post cap to the

Techniques
Laser cutting Tube bending Machining Polished finishes (satin, mirror) Welding Mechanical joints

satin finished stainless steel baluster. A stainless steel bracket bolted to the mezzanine edge beam provides support to the baluster. Balustrade glazing is also supported on the edge beam and restrained by each baluster using a stainless steel glazing bracket.

Figure 12
Stainless steel handrail and baluster details



Techniques
Laser cutting
Tube bending
Machining
Polished finishes (satin, mirror)
Welding
Mechanical joints

Seating

The seats (Figure 13) were designed by Michael Weiss Associates in keeping with Foster and Partners concept design. They are fabricated from curved 1.5 mm thick stainless steel sheets. Rigidity is provided by internal tubes, spot welded to brackets which in turn provide the support points for the seats. All components (including the laser cut plates that support the seats) are in grade 1.4404 (316L) stainless steel. A typical section through the seat is shown in Figure 14.

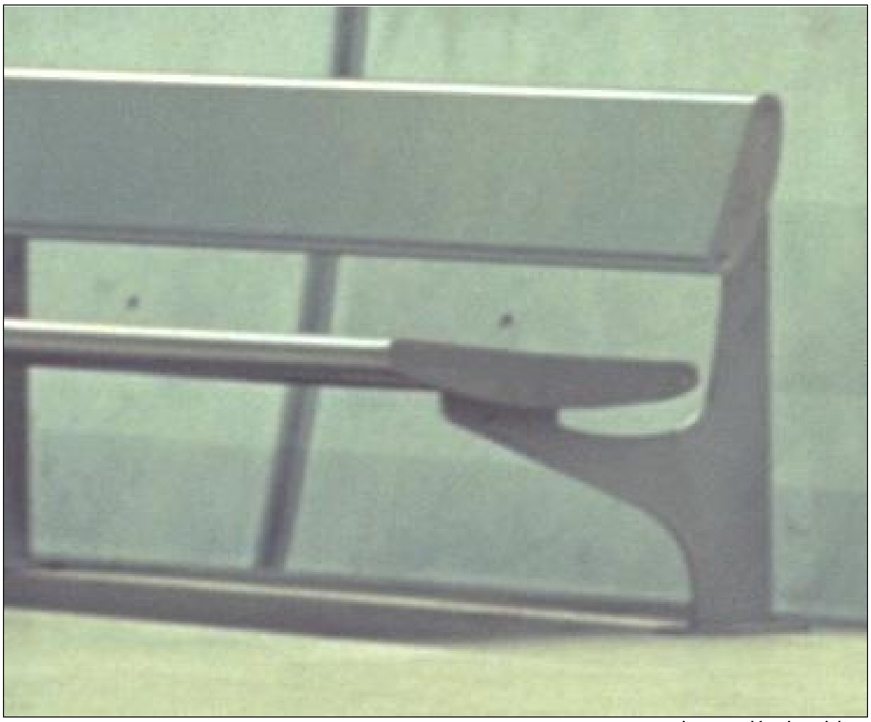
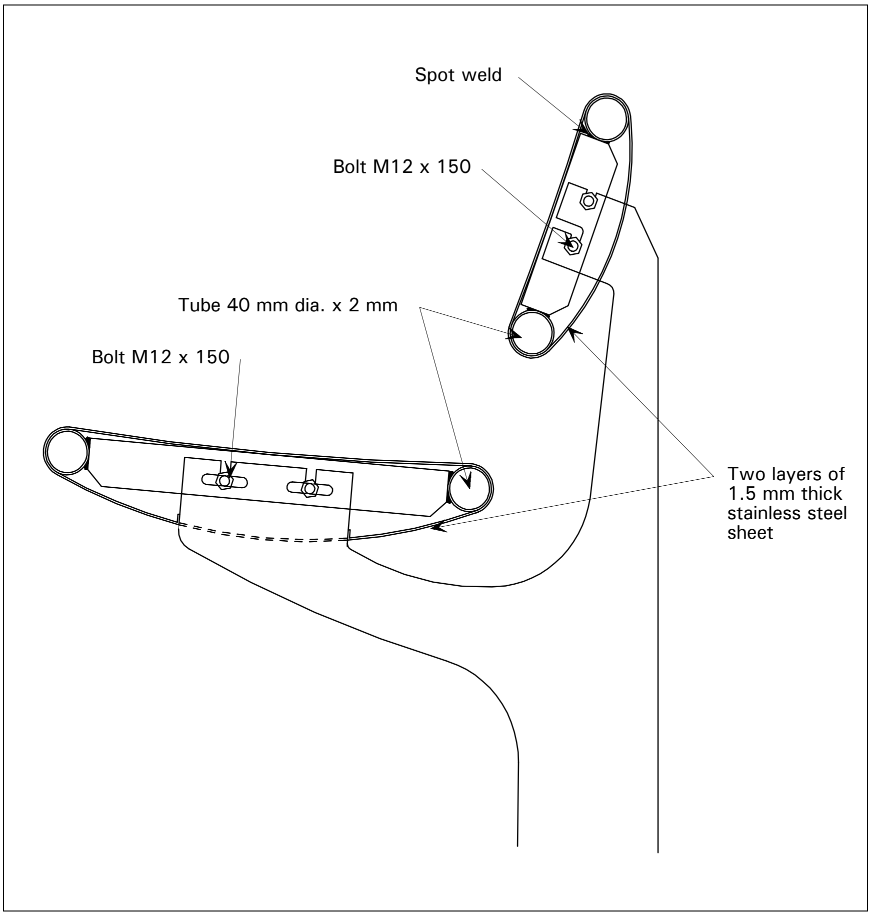


Figure 13 *Purpose designed stainless steel seating*

Photo: Alfredo Aldai

Techniques
Laser cutting Tube bending Machining Polished finishes (satin, mirror) Welding Mechanical joints

Figure 14
Typical cross-section of stainless steel seating



BRITISH PAVILION

Seville, Spain, 1992

Architect: *Nicholas Grimshaw and Partners, UK*
(Water features designed by William Pye Partnership)
Engineer: *Ove Arup & Partners, UK*

✦ Glazing fixings ✦ Flooring ✦ Sculpture

Techniques

- Punching
- Tube bending
- Machining
- Polished finish (mirror)
- Welding

Figure 1
General view of the pavilion

Photo: Jo Reid and John Peck

General

The British Pavilion at Expo' 92 provided an imaginative exhibition space within a steel and glass envelope (Figure 1). The structure was pre-fabricated in the UK, erected at the exhibition site in Spain and subsequently dismantled after the exhibition.

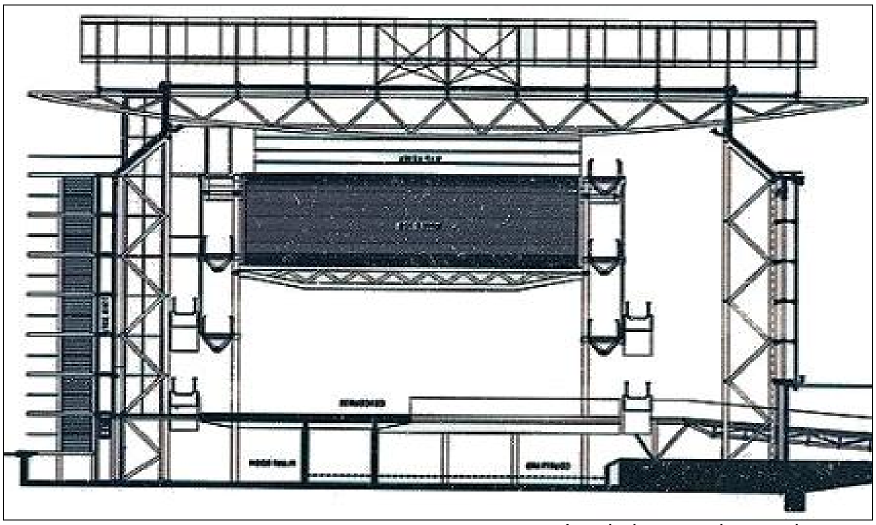
The building responded to the hot climate in several ways. The external envelope comprised a series of ten identical 22 m high tubular steel frames and roof trusses, which supported shading devices (Figure 2).

Techniques
Punching
Tube bending
Machining
Polished finish (mirror)
Welding

The east wall was the public face of the building. It comprised a striking 65 m long, 12.5 m high, glass wall and a public entrance via a footbridge across a small pool. A continuous curtain of water ran down the glass to the main concourse level where it fell into the pool. A water sculpture by the entrance bridge enhanced the effect of cascading water. The water curtain and sculpture were designed by the William Pye Partnership.

Stainless steel was used in the supports for the water wall, the water sculpture, the gutters which collected the water as it cascaded down the wall and for internal flooring.

Figure 2
Cross-section



Courtesy of Nicholas Grimshaw and Partners

Glazed water wall

The water wall is hung like a curtain from steel framework. It is based upon Pilkington's Planar system. The glass is braced horizontally by purpose-made aluminium extrusions independently suspended on stainless steel rods. Adjustable stainless steel connectors were used to attach the aluminium extrusions to machined stainless steel planar fixings.

Stainless steel gutters

The water was pumped up to the top of the glass where it was distributed evenly along the surface via hundreds of small nozzles. It was then gathered in the stainless steel gutter, from where it ran into the pool (Figure 4, Figure 6). The pool extended to the interior of the building and the water fell over an internal stainless steel weir adjacent to the restaurant where it was collected and re-circulated.

Techniques

- Punching
- Tube bending
- Machining
- Polished finish (mirror)
- Welding

Figure 3
Detail section through glass suspension

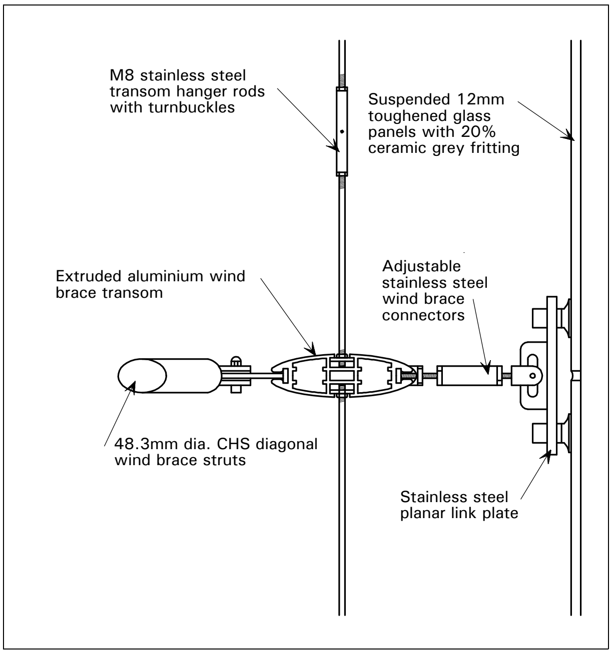


Figure 4
Water curtain

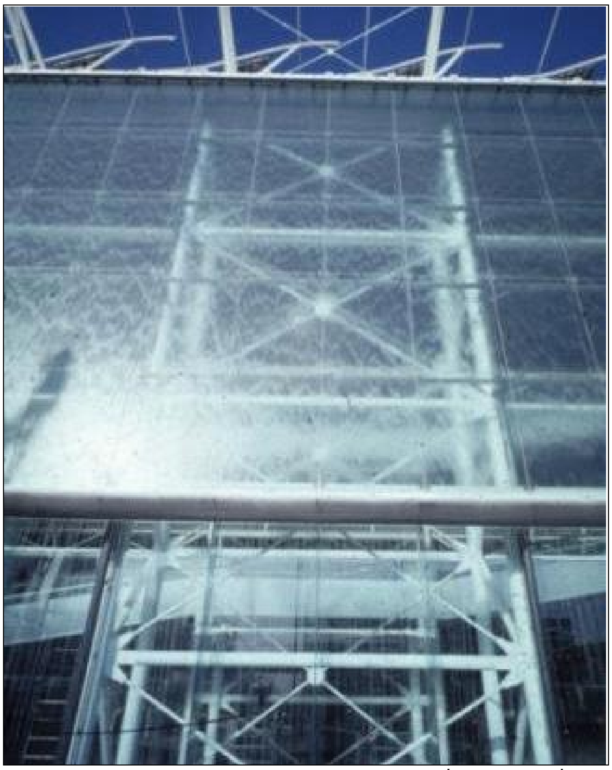


Photo: Ben Johnson

Techniques
Punching
Tube bending
Machining
Polished finish (mirror)
Welding

Internal flooring

Panels of stainless steel with rubber studs provided a novel non-slip and durable flooring (Figure 5). A CNC (Computer Numerically Controlled) system was used to punch almost one million 30 mm diameter holes in the stainless steel sheet through which rubber studs projected. These were positioned to an accuracy of better than 0.1 mm.

Figure 5
Non-slip rubber and stainless steel floor

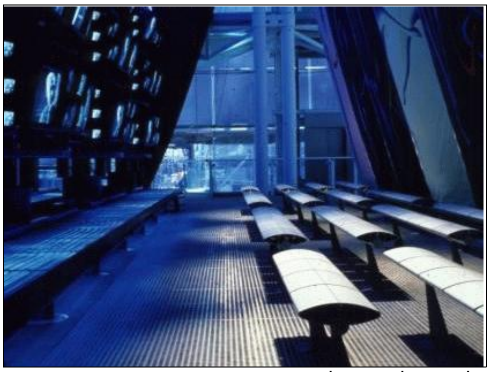


Photo: John Linden

Water sculpture

The bridge which provided the public entrance to the building through the water wall was flanked on either side by a free-standing stainless steel water sculpture (Figure 6). This comprised two arcs formed out of curved stainless steel circular hollow sections, sculpted in mirror finished stainless steel. Each arc was cantilevered from a single vertical stainless steel pole using tensioned cables. The cables were fixed to shaped plates which were welded to both sides of the pole, ground flush and polished.

Figure 6
Water sculpture

Photo: John Linden

EAST CROYDON STATION

Croydon, UK, 1992

Architect: *Brookes Stacey Randall Fursdon in conjunction with Network SouthEast Architecture and Design, UK*
Engineer: *Anthony Hunt Associates, UK*

✦ Glazing fixings

Techniques
Machining
Investment casting
Brushed finish
Bead blasted finish
Mechanical joints

Figure 1
General view of the station

Photo: John Linden

General

The re-development of the Victorian station at Croydon started in 1990 and was completed in 1992 (Figure 1). The new building spans 55 m between brick abutments. A column-free interior includes an entrance concourse, ticket area, retail facilities and offices (Figure 2). High levels of transparency are achieved by the use of a light cable-stayed steel frame, full height glazed walls and glass rooflights. A glass canopy extends beyond the front glass wall to shelter the entrance area. It relates the entrance to the concourse, from where ramps descend to the platforms below.

Stainless steel components were used intensively in the roof and wall glazing systems. All were made from grade 1.4401 (316) stainless steel. Cast components were made by the lost wax process, a form of investment casting. Stainless steel castings and other components were passivated and blasted with stainless steel shot to give a natural polished surface.

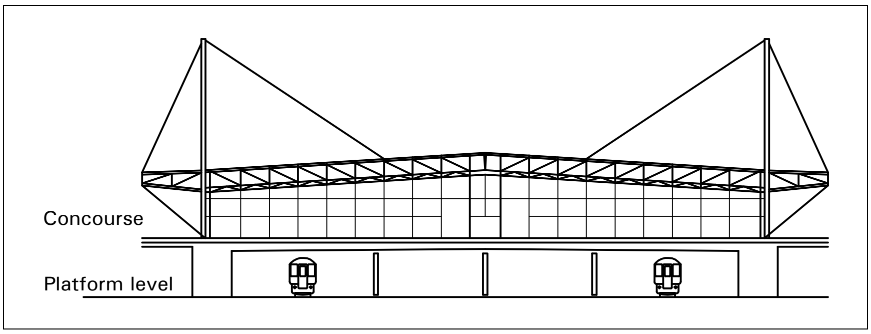


Figure 2
Long section

Techniques
Machining
Investment casting
Brushed finish
Bead blasted finish
Mechanical joints

Roof glazing

The roof is clad using profiled steel decking and glazing. Decking covers the ticket offices and retail kiosks. Glazing to the central area comprises 10 mm thick toughened 1.5 m square sheets supported by planar fittings, suspended from stainless steel twin-armed castings (Figure 3).

Figure 3
Roof glazing suspended by stainless steel castings

Photo: John Linden

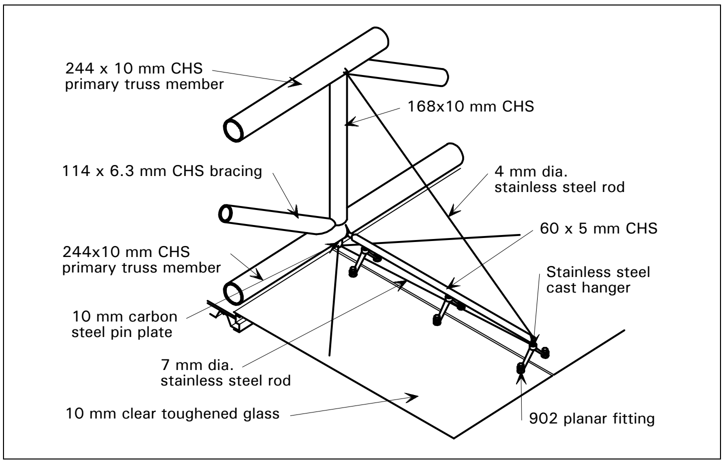


Figure 4
Isometric of glazed end to canopy

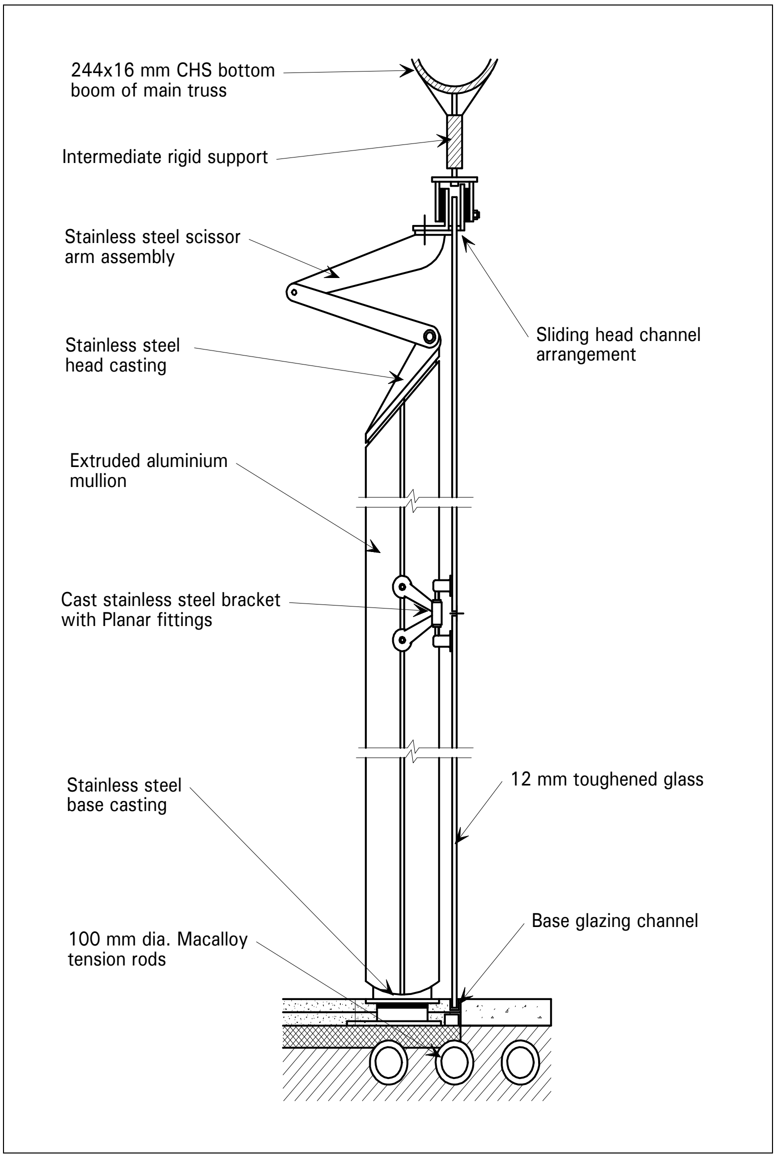
The 3 m wide canopy is suspended using stainless steel tie rods and turnbuckles, and similar castings to those used in the main roof.

Techniques
Machining
Investment casting
Brushed finish
Bead blasted finish
Mechanical joints

Wall glazing

The station walls are clear toughened full-height glass restrained by purpose made extruded aluminium mullions. The mullions, which were specifically developed for the project, have an elliptical form (Figure 5 and Figure 7).

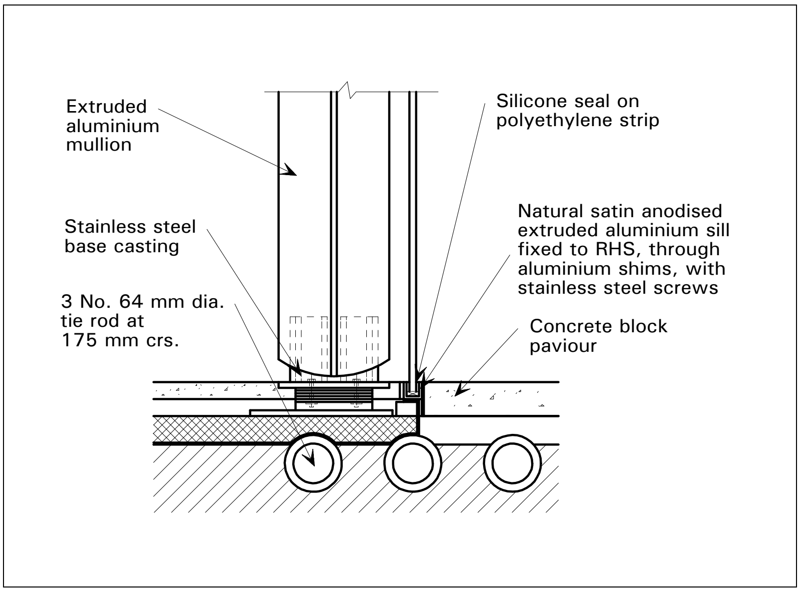
Figure 5
Wall glazing assembly



Techniques
Machining
Investment casting
Brushed finish
Bead blasted finish
Mechanical joints

The base and head details of the mullions are designed to accommodate movement of the primary structure. At the top, a stainless steel casting slots into the mullion and is fixed to the roof structure by means of a pin-jointed scissor arm arrangement comprising two pivoted 6 mm stainless steel plates and a 10 mm stainless steel top arm (Figure 5). The resulting articulated head accommodates vertical movement of the primary structure of +57 - 48 mm and allows for tolerance in assembly. Differential movement between the primary structure and glazing is accommodated at the top of the glass which slides between two back-to-back angles fixed to the structure. At the bottom end, a radiused base detail accommodates movement at 90° to the wall. Here, the mullion slots over a stainless steel base casting bolted to the floor (Figure 6).

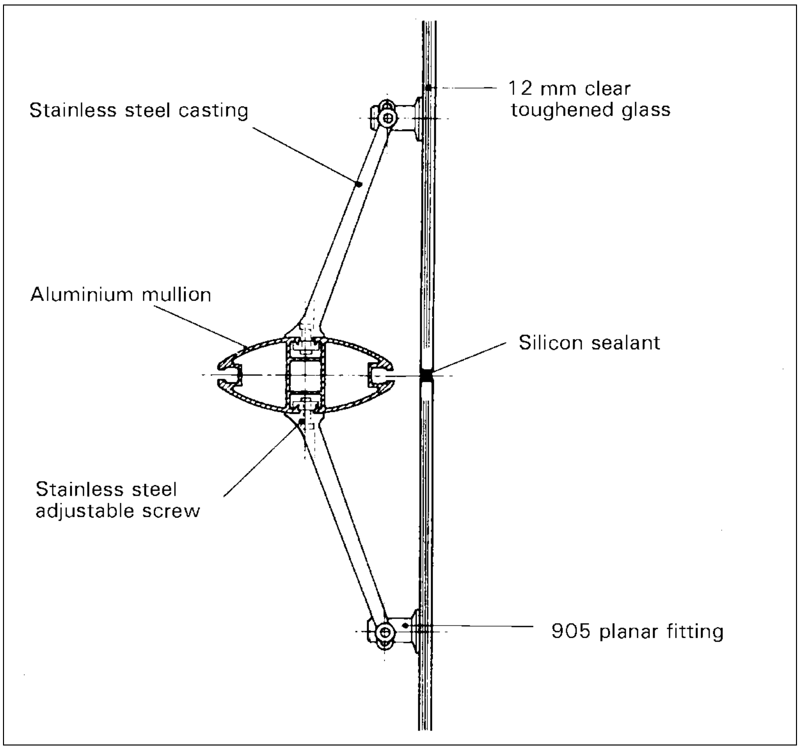
Figure 6
Mullion base detail



Each of the 2.84 m x 2.10 m panes of 12 mm thick glass sheets is supported at four points by planar fittings on cast stainless steel arms (Figure 7). These are located 300 mm in from each corner, thus reducing the effective span of the panels to 2.24 m and the maximum wind deflection to 25 mm.

Techniques
Machining Investment casting Brushed finish Bead blasted finish Mechanical joints

Figure 7
Connection of cast arms to mullions



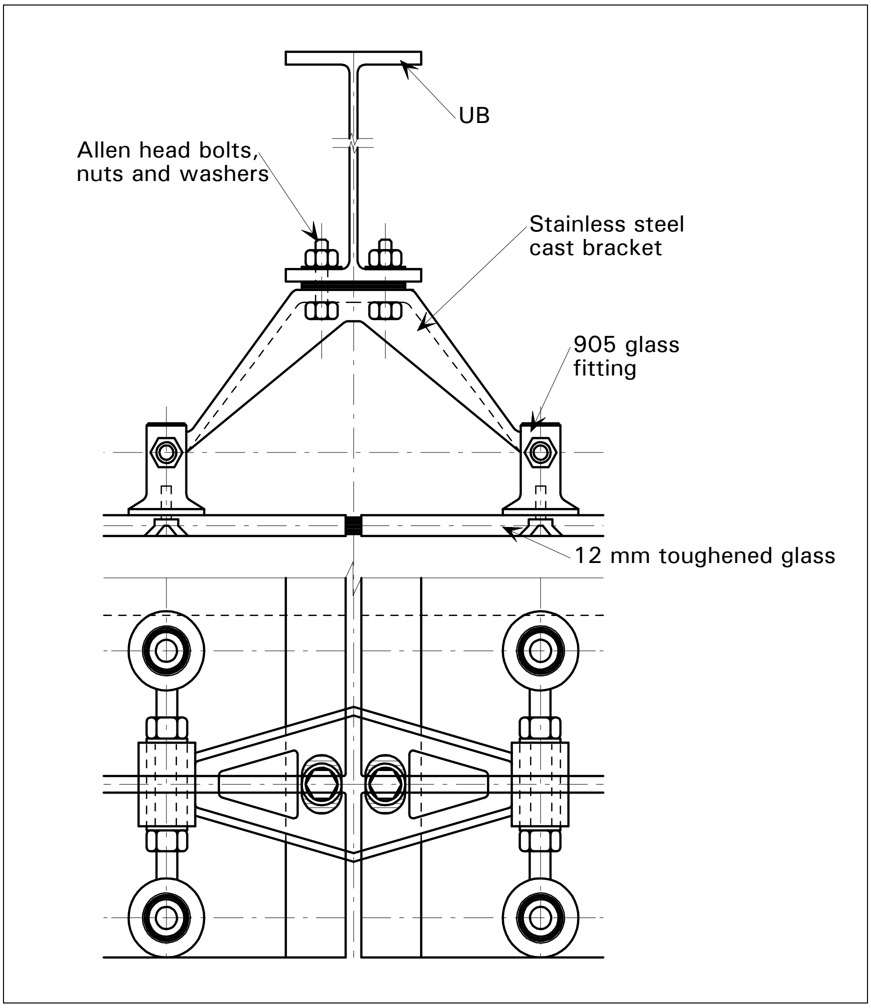
Ramps

Timber and brick tunnel-like ramps that led down to the platforms were replaced with light steel and glass designs. The steel frames are perpendicular to the slope, producing a cascade effect.

Similar planar fittings and stainless steel castings to those in the concourse building were used to support the glazing to the ramps. The three 60 m long structures are framed in steel portals pinned at the base. Twin-armed stainless steel castings are fixed to the carbon steel I-beams using stainless steel nuts and washers (Figure 8). The upper area of the glazing pivots into the ramps on machined stainless steel rods with a brushed finish. This enables the glazing, which is inaccessible from above, to be cleaned from the inside.

Techniques
Machining
Investment casting
Brushed finish
Bead blasted finish
Mechanical joints

Figure 8
Detail of ramp glazing



EUROPEAN COURT OF HUMAN RIGHTS

Strasbourg, France, 1994

Architect: *Richard Rogers Partnership, UK*
Engineer: *Ove Arup & Partners, UK*

Technique
Patterned finish

✦ Cladding

Figure 1
The building is descibed as having a head and tail

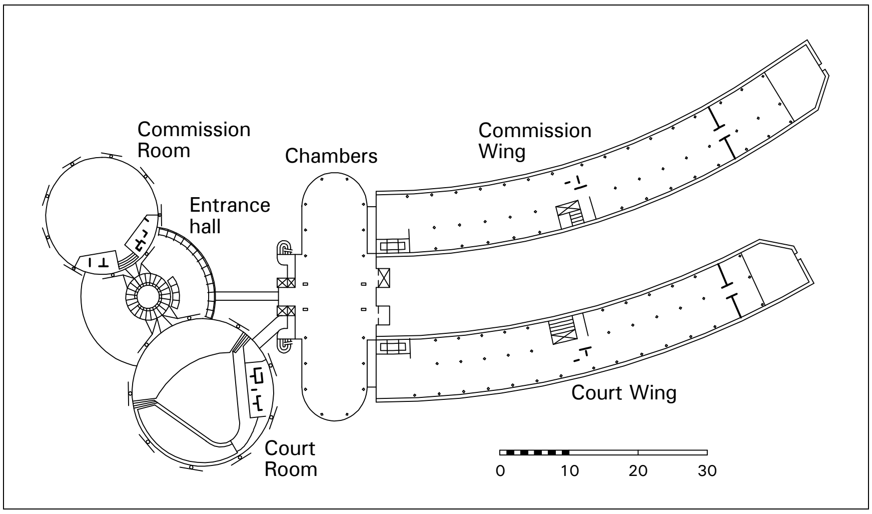


Figure 2
The 'head' comprises a pair of large stainless steel drums joined by a glass cylinder

Courtesy of Avesta Sheffield Ltd.

General

In 1989, a competition instigated by the mayor of Strasbourg for the design of the Supreme Court of the 34 nation Council of Europe was won by the Richard Rogers Partnership. The site is adjacent to a broad sweep of the River Ile in the city's green belt, with a canal to the south separating the site from the rest of Strasbourg's Euro-complex and city centre. The 30,000 m^2 building occupies half of the site, while the rest is landscaped.

The architects describe the building as having a 'head' and 'tail', with the principal functions expressed clearly in the form of the building (Figure 1, Figure 2). The head comprises a pair of large drums which

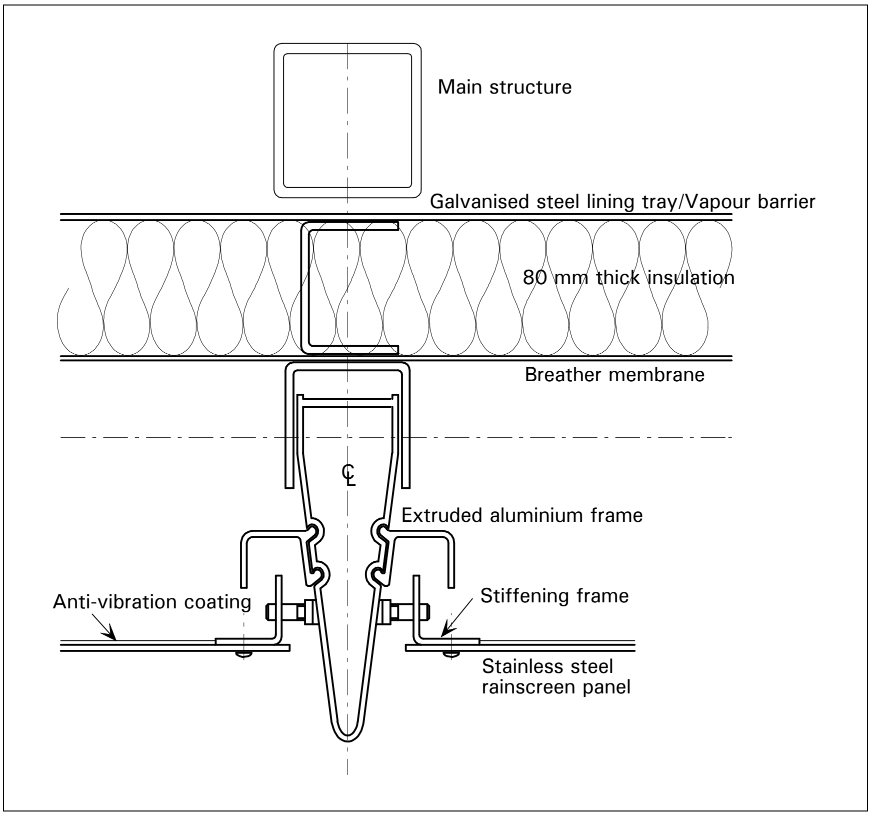
Technique
Patterned finish

overlap with and are joined by a glass cylinder which forms the entrance block). The larger of the two drums (facing the park) is the chamber of the European Court of Human Rights while the smaller (facing the river) is the formal meeting place of the Commission.

Cladding

The two drums at the end of the building are clad in 5000 m^2 of grade 1.4401 (316) stainless steel. 2 mm thick panels form a ventilated rainscreen that is supported on vertical extruded aluminium mullions (Figure 3). Stiffening frames are attached to the sides of the panels. These frames provide the point of attachment to the mullions. An anti-vibration coating applied to the rear of the panel provides additional stiffness and suppresses rain drumming.

Figure 3
Horizontal section at mullion



HARTCLIFFE MINI TOWN HALL

Bristol, UK, 1995

Architect: *Hallett and Pollard, UK*
Engineer: *Ian Duncan Associates, UK*

Techniques
Punching Polished finish Bead blasted finish Welding

✦Cladding ✦Ironmongery

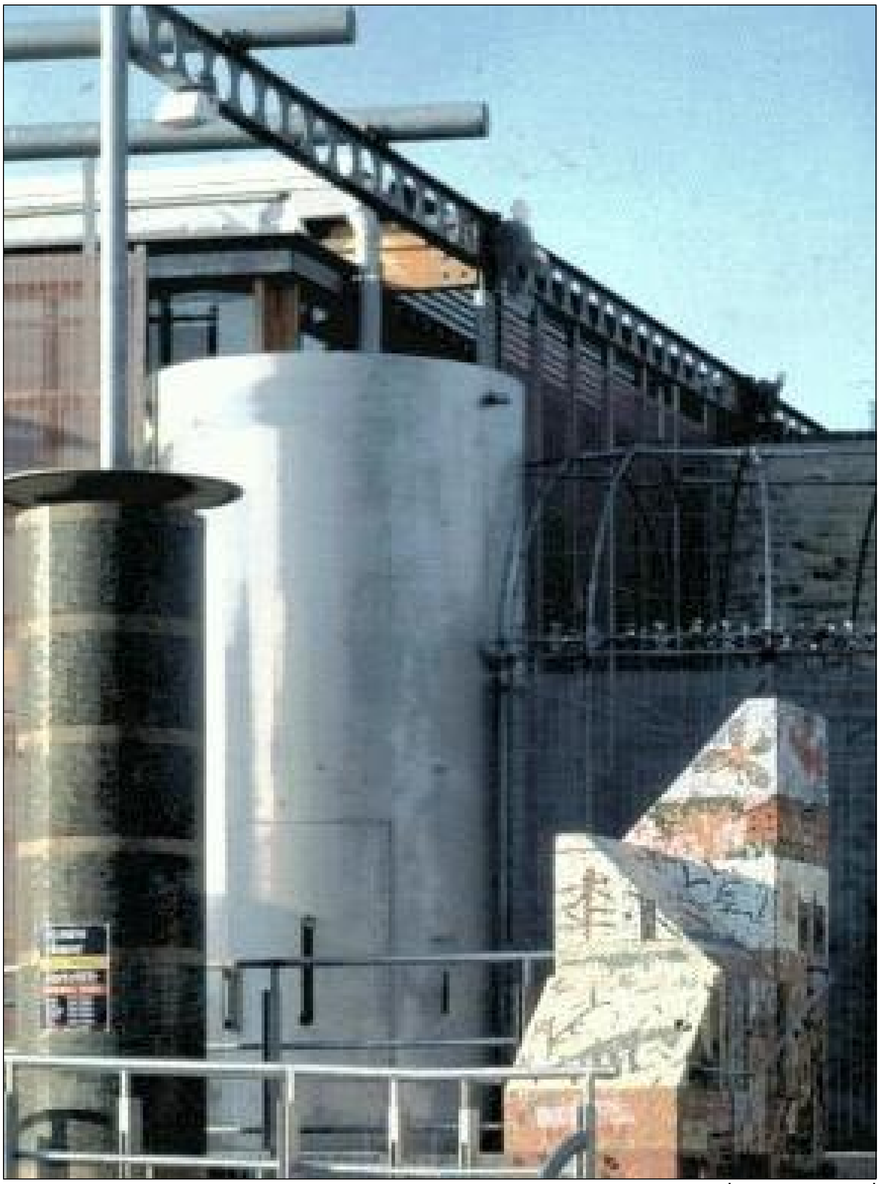


Figure 1
General view of the building

Photo: Peter Cook

General

The Hartcliffe Council Housing Services Office in Bristol is located adjacent to the existing public library on Peterson Square, south of Bristol.

The main elevation is windowless rubble-stone in response to local pleas for traditional material. The construction is strong, secure and awkward for graffiti (Figure 1).

Techniques
Punching Polished finish Bead blasted finish Welding

Entrance

The main entrance had to be designed for security, vandal and fire resistance. Inspired by grain silos at a local factory, it was conceived in the form of a stainless steel drum-shaped enclosure (Figure 2). Grade 1.4401 (316) was used for durability because the entrance is exposed to the external environment.

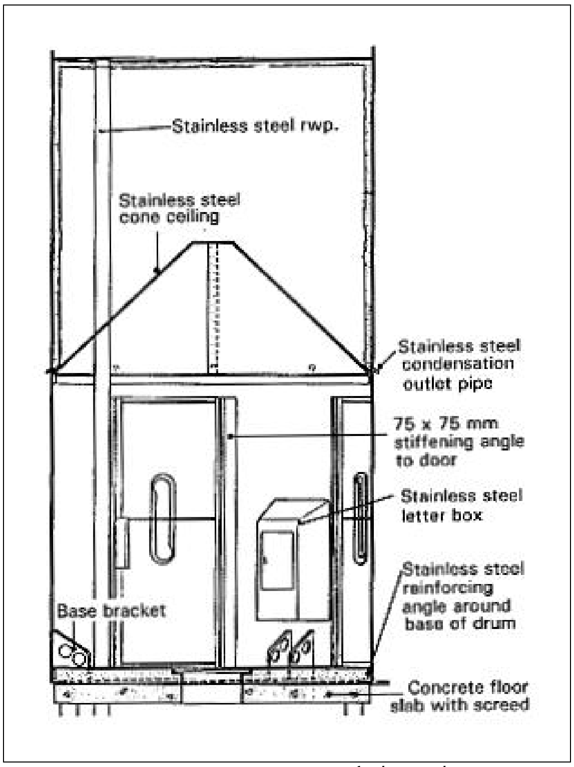
Photo: Peter Cook

Figure 2
Stainless steel entrance

The entrance is constructed from three stainless steel cylinders welded together. Each cylinder is 2.5 m in diameter and is formed from 10 mm thick sheet. The circumferential welds between the cylinders were ground flush offsite and the surface given a bead blasted finish for mark and vandal resistance. The bottom cylinder is reinforced at the base by a stainless steel ring beam welded at the cylinder base and buried in the floor screed. It is fixed to the ground by three base brackets with holding down bolts. The 5.1 m high entrance unit came to site virtually complete, with the roof, rainwater down-pipe, letterbox, stiffening angles and fixing brackets all welded offsite (Figure 3). The only exception to this was the cone-shaped ceiling (common to grain silos) which was installed on site and made out of pop-rivetted sections. One of the cone sections is removable to gain access to the roof space above.

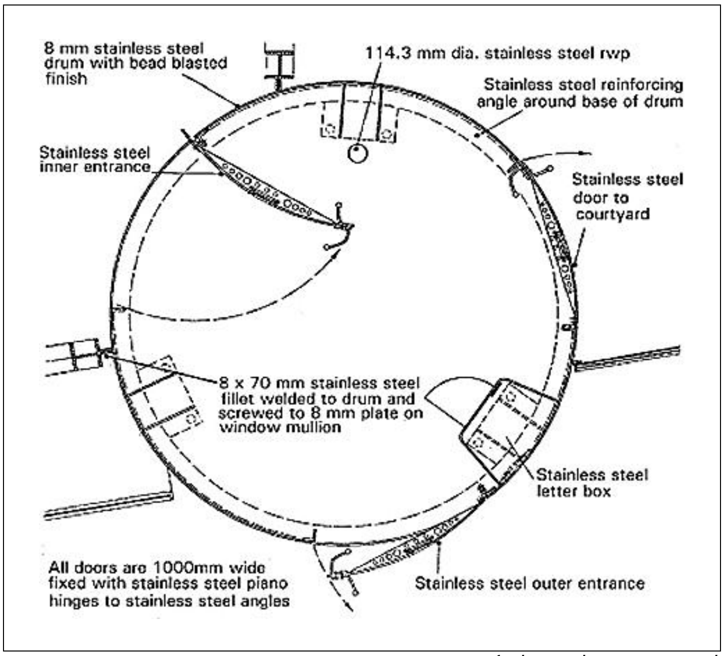
Techniques
Punching Polished finish Bead blasted finish Welding

Figure 3
Section through entrance drum



Courtesy of *The Architects' Journal*

Figure 4
Plan of entrance drum



Courtesy of *The Architects' Journal*

Techniques
Punching
Polished finish
Bead blasted finish
Welding

There are three 1 m wide doors leading in and out of the drum (Figure 4). They are fabricated from the cut-out pieces of the main stainless steel drum which had been cut for the door spaces (Figure 5). These pieces are stiffened with three punched perforated curved stainless steel plates. Stainless steel backing plates bolted to the doors reinforce the vertical edge. The doors swing on full height stainless steel piano hinges that are fixed to angles with security bolts and shear-off nuts. Figure 6 shows a detail part plan of the drum and door.

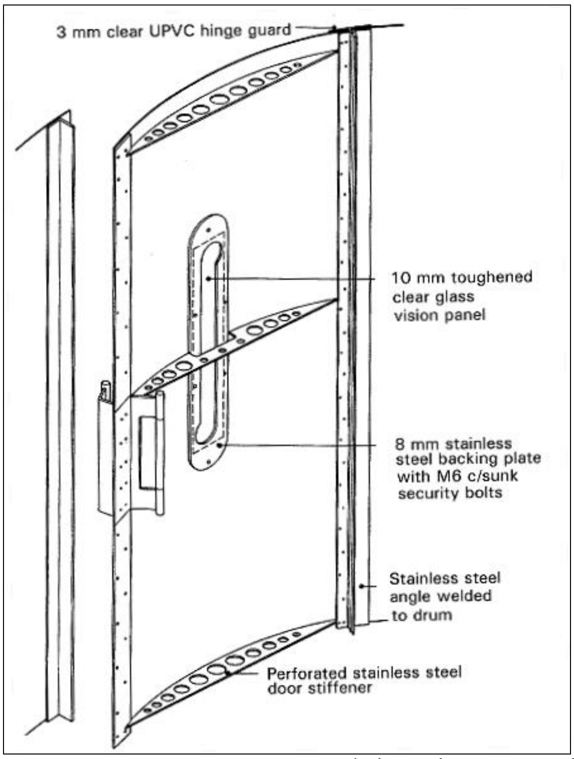


Figure 5
Isometric of stainless steel door

Courtesy of *The Architects' Journal*

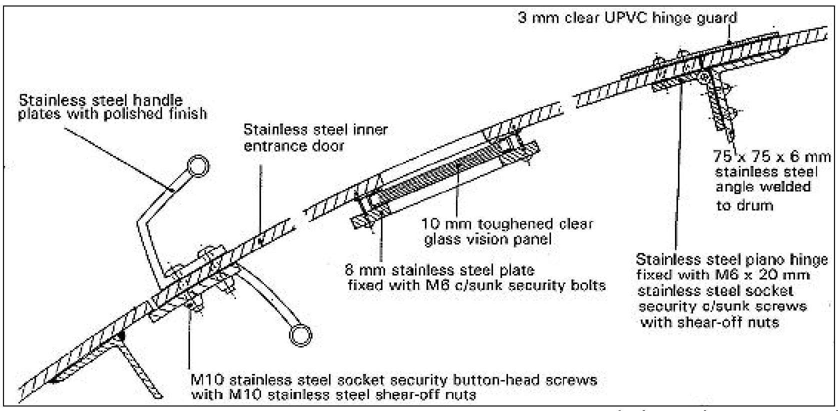


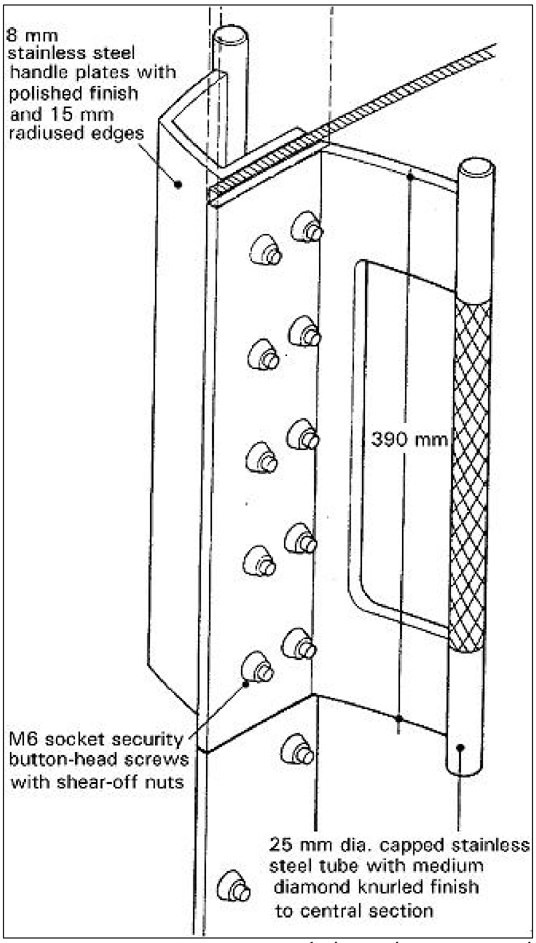
Figure 6
Part plan of drum and door

Courtesy of *The Architects' Journal*

Techniques
Punching Polished finish Bead blasted finish Welding

The doors have specially designed handles (Figure 7) fabricated from 8 mm stainless plates. These are polished and fixed to the door using security button-head screws and shear-off nuts. A 25 mm diameter capped stainless steel tube (with a diamond knurled finish to the central section) is welded to the plate to form the door handles.

Figure 7
Door handle detail



Courtesy of *The Architects' Journal*

LA GEODE, PARC DE LA VILLETTE

Paris, France, 1985

Architect: *Adrien Fainsilber with Sylvain Mersier, France*

Engineer: *Multicub/Acieroid, France*

Techniques
Rubber die forming Polished finish (mirror)

✦ *Cladding*

Figure 1
General view of La Geode

Photo: Alain Goustard

General

La Geode is an ultra modern cinema facing the south facade of the City of Science at the Parc de la Villette to the north-east of Paris (Figure 1). It has a mirror-like finish and is sited at the centre of a reflecting pool. The form could tolerate no additions and hence the entrance to the sphere is located below the pool level (Figure 2). Four escalators criss-cross the space leading from the entrance hall to the auditorium. The ceiling and the whole inner structure are supported by a massive central concrete pier. The pier is extended by cantilevered arms which support transverse beams.

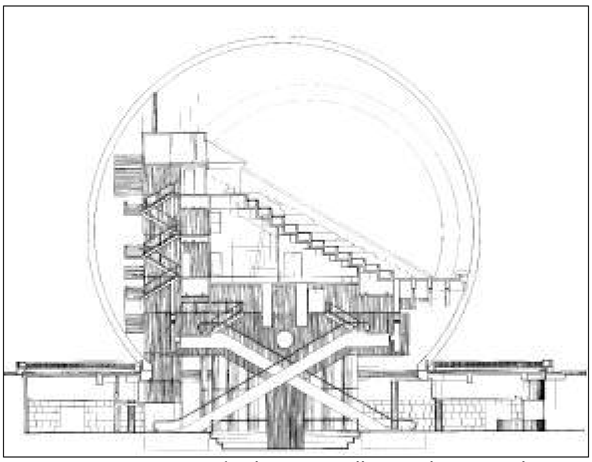


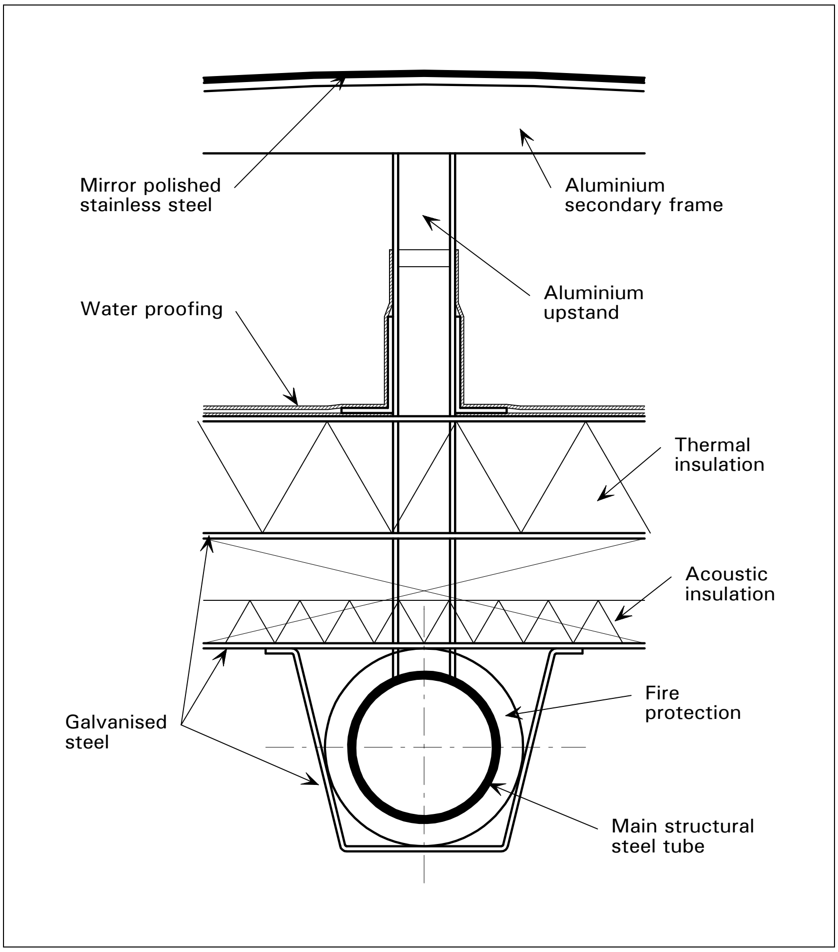
Figure 2
Section showing the main concrete pier and cantilevers

Courtesy of Adrien Fainsilber Architecte Urbaniste

Techniques
Rubber die forming Polished finish (mirror)

Stainless steel was chosen for the quality of surface finish that can be achieved and for its corrosion resistance.

Figure 3
Cross-section through roof construction



Roof construction

Figure 3 is a cross-section through the roof construction. Primary structural support to the geodesic dome is provided by a fire protected tubular steel structure. Structural members are approximately 2 m long, fabricated from 101 mm diameter tubes (Figure 4). On top of the structure are two steel skins 80 mm apart. This gap contains 30 mm of rock wool for acoustic insulation (Figure 3). A further 70 mm layer of foil-backed rock wool above the top steel skin provides thermal insulation and carries the waterproofing membrane.

Techniques
Rubber die forming Polished finish (mirror)

Figure 4
Triangles created by the primary tubular steel frame

Photo: Philippe Hurlin

A series of aluminium upstands are bolted to the nodes of the tubular steel frame and protrude through the waterproofing membrane. The upstands support a secondary triangular aluminum frame that divides each of the main frame triangles into 4 smaller equilateral triangles. Figure 5 shows part of this secondary frame. Its members have curved top edges (as shown in Figure 3) which support the stainless steel cladding.

Figure 5
View showing aluminium frame

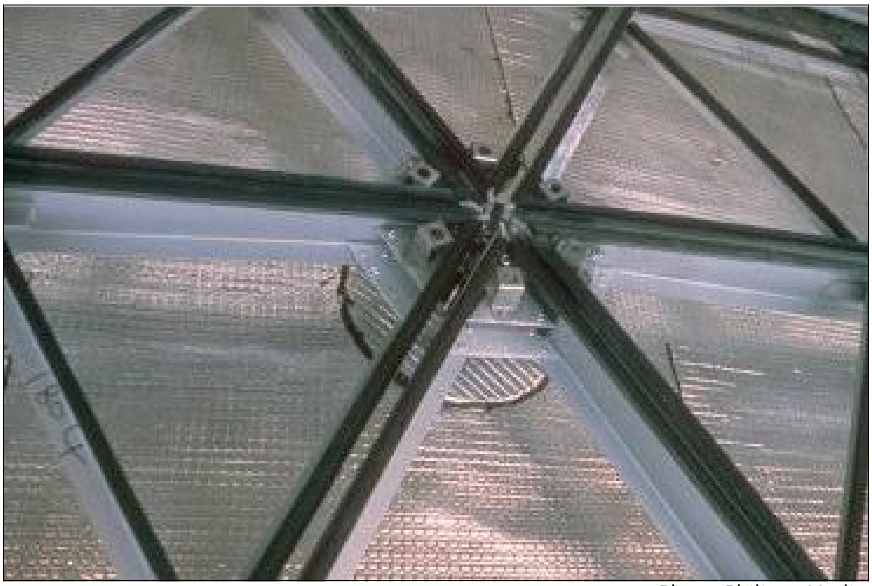


Photo: Philippe Hurlin

The cladding is a mosaic of 6433 doubly-curved triangular plates in grade 1.4401 (316) stainless steel. The plates are 1.5 mm thick and 1.2 m along their edges (Figure 6).

Techniques
Rubber die forming Polished finish (mirror)

Figure 6
Erection of stainless steel skin

Photo: Philippe Hurlin

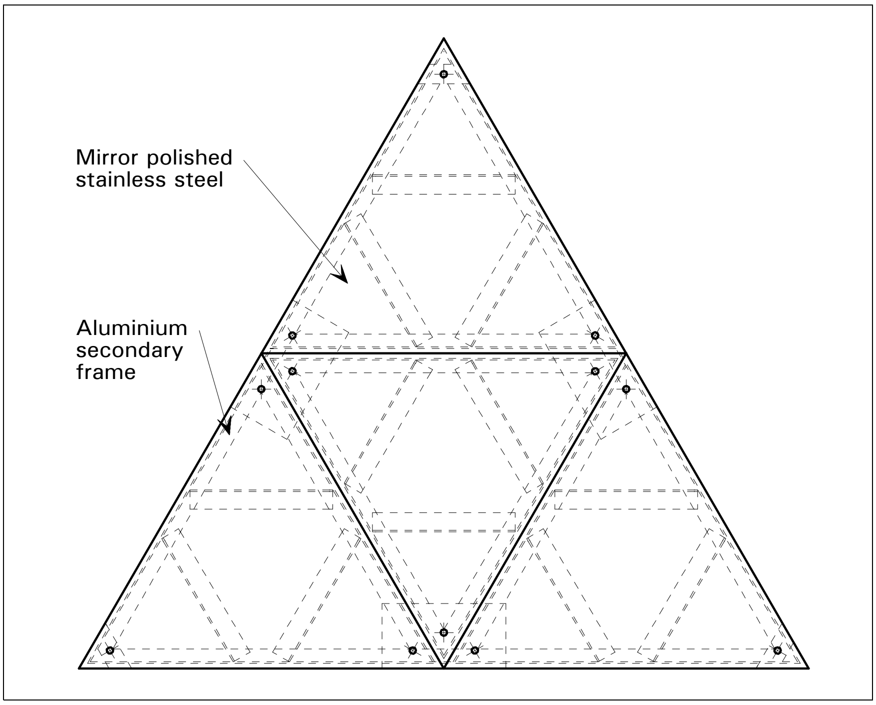
The spherical form and the choice of a mirror finish necessitated tight manufacturing tolerances. These were achieved by pressing the plates using a 2000 tonne press to a radius of 4.2 m, and then allowing them to elastically spring back to the final required radius of 18 m. To ensure consistency of surface finish, the plates were all polished in a direction parallel to what was to be the horizontal side of the triangle.

The plates are arranged in groups of four (Figure 7), each fixed to the aluminium secondary frame by three loose fitting 10 mm diameter countersunk screws at the corners. Special neoprene gaskets are inserted between the aluminium frame and the stainless steel plate to isolate the two metals and eliminate noise due to wind induced vibrations. A gap of 6 mm between the plate edges allows for thermal expansion. The edges of the plates slide over a mirror polished

Techniques
Rubber die forming
Polished finish (mirror)

stainless steel splice plate system which maintains the continuity of the stainless steel surface across the joint.

Figure 7
Triangular plate arrangement onto aluminium frame



LA GRANDE ARCHE

Paris la Defense, France,1989

Architect: *Johan Otto von Spreckelsen, Denmark /Paul Andreu, France*
Engineer: *Ove Arup & Partners, UK*
Rice Francis Ritchie (RFR), UK

Techniques
Polished finish

✦ Structure

General

The 110 m high Grande Arche is the terminal point for the route that stretches from the Louvre through the Arc du Carrousel, the Tuileries, Place de la Concorde, Champs-Elysées and Arc de Triumphe (Figure 1).

Figure 1
View through La Grande Arche

Courtesy of Oxford Brookes University

The Danish architect, Johan Otto von Spreckelsen, chose to access the roof of the Arche by means of panoramic exterior lifts running within a 91 m high open stainless steel restraint structure (Figure 2). The design had to acknowledge that the venturi effect of the Arche could increase the wind speed over the lift tower by a factor of 2.35. As a result, a maximum wind speed of 78 m/s was adopted for design purposes.

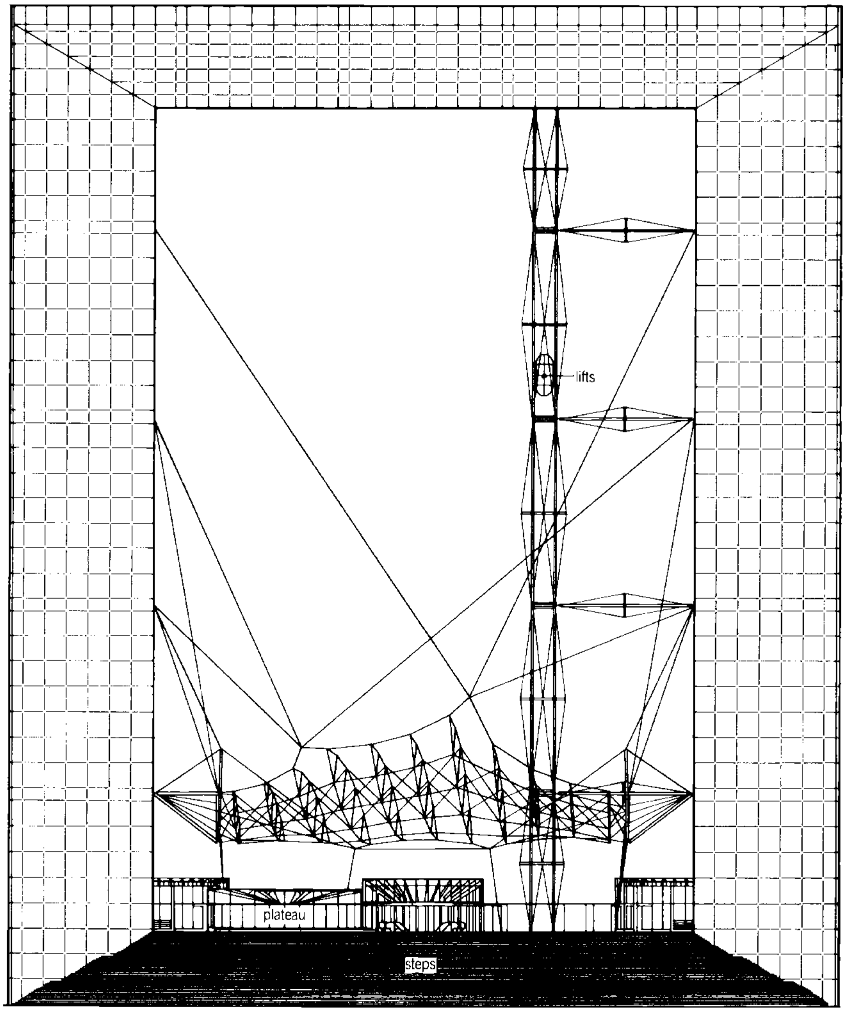
Lift structure

The stainless steel chosen for the lift structure was duplex grade 1.4462 (2205). This has excellent atmospheric corrosion resistance and a 0.2% proof strength of 460 N/mm^2, which allowed considerable weight savings to be made in comparison with other possible grades.

The lift tower was designed as a series of five 38 tonne modules constructed from seamless tubes and bars made by a hot extruded powder metallurgy process. Tube diameters varied from 60 mm to 244 mm. About 200 tonnes of stainless steel were used, all with the same polished finish.

Each of the modules, complete with lift car guide rails, was assembled at ground level before being offered to the building. Four arms, each 18 m long, connect the modules to the southern side of the Arche and the whole structure is stabilised using cables.

Figure 2
West elevation of La Grande Arche



Courtesy of *The Architects' Journal*

LEIPZIG TRADE FAIR - CENTRAL HALL

Leipzig, Germany, 1996

Techniques	
Machining	
Mechanical joints	

Architect: *Gerkan, Marg & Partners (GMP), Germany*
Ian Ritchie Architects, UK
Engineer: *IPP Köln, Germany with assistance to Ian Ritchie Architects by Ove Arup & Partners, UK*

✦ *Glazing fixings*

Figure 1
Internal view of the glass hall

Photo: Jocelyne Van den Bossche

General

The centrepiece of the Leipzig Trade Fair site is a glass barrrel vault shaped entrance hall measuring 79 m by 244 m and 28 m high (Figure 1). The building is a huge conservatory (described by the architect as a landscaped valley) designed to accommodate a wide variety of functions. It accommodates reception and information points, spaces designed for rest and relaxation and glass bridges leading to the surrounding conference halls.

Glass suspension system

The glass skin is formed from toughened, low-iron laminated glass panels, each measuring 3.1 m x 1.5 m. They are suspended from the main steel tubular arches by stainless steel 'fingers' attached to cast steel arms (Figure 2, Figure 3). Each glass panel is fastened at four points. Adjustable screws at the connection accommodate out-of-plane tolerances, whilst adjusting plates accommodate in-plane tolerances.

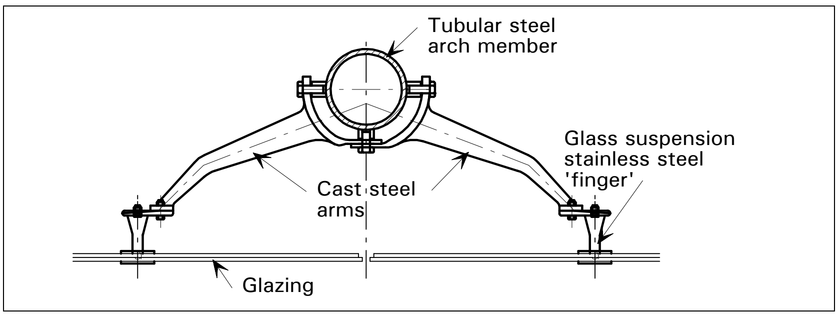


Figure 2
Cast arms connect the stainless steel point supports to the tubular grid shell vault

Techniques
Machining Mechanical joints

Figure 3
Cast arms and stainless steel point supports

Photo: Jocelyne Van den Bossche

The fingers contain a spherical bearing (three-dimensional pin joint) in the plane of the glass to eliminate local out-of-plane bending stresses in the glass. Other out-of-plane deflections are catered for by specially developed silicone seals between panes which act as hinges. In order to accommodate significant deformations of the steel supporting structure parallel to the glass plane, whilst maintaining support of the glass, three suspension details were developed. These are used in an appropriate combination for each glass panel. The first gives fixity about both in-plane axes of the glass panel, the second allows movement about one axis only and the third has two degrees of freedom, about both in-plane axes (Figure 4, Figure 5). This arrangement also prevents transfer of stresses from the structure to the glass panels.

Techniques
Machining Mechanical joints

Figure 4
Types of stainless steel point suspension 'fingers'

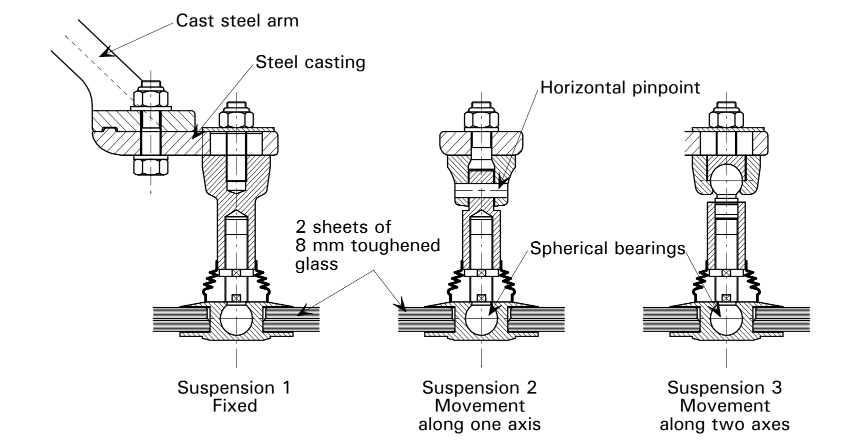
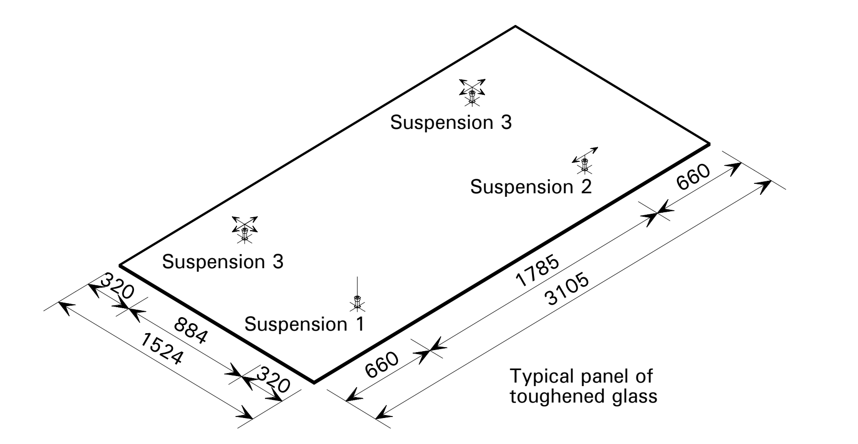


Figure 5
Point suspension fingers give appropriate degrees of freedom to each glass panel



The point support fingers are CNC (Computer Numerically Controlled) machined from grade 1.4401 (316) stainless steel. They are isolated from the carbon steel cast arms by a 0.5 mm dense polymer composite foil, washers and bushes. Stainless steel was used for its durability and corrosion resistance and to eliminate any need for repainting close to the glass.

LOWE FLAT

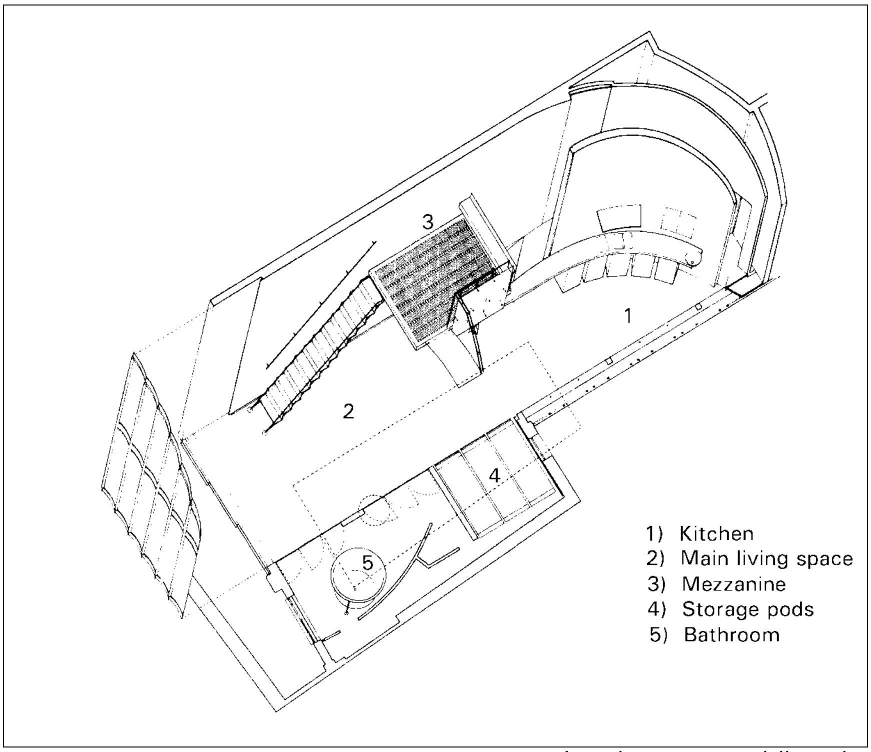
London, UK, 1996

Architect: *Brookes Stacey Randall Fursdon, UK*
Engineer: *Dewhurst MacFarlane and Partners, UK*

Techniques
Laser cutting
Spinning
Tube bending
Sand casting
Brushed finish
Welding

✦ Handrails/Balustrades ✦ Staircases ✦ Kitchen/Bathroom equipment

Figure 1
Axonometric view of the flat



Courtesy of Brookes Stacey Randall Fursdon

General

Chris Lowe of the Pet Shop Boys commissioned Brookes Stacey Randall Fursdon to design a flat within a converted warehouse (Figure 1).

The function of the main space can change depending on the particular facilities brought into use. The small side space is split into a storage area and a bathroom. The storage area houses three large pull-out 'pods'. The first is designed to store kitchen and dining items, the second provides hanging and shelf space for clothes and bedding and the third accommodates a mixing deck, hi-fi and record/CD storage. Each pod cantilevers out on a purpose designed triple extending mechanism, thus leaving no visible tracks or floor wear marks. When all three pods are retracted, the volume is maximised as one large living space.

The flat has many innovative stainless steel features. Stainless steel is used in the staircase, the window screens, the bathroom, the kitchen partition and the handrails to the mezzanine. Kitchen furniture and storage cabinets are purpose designed using carbon steel skeletons and stainless steel surfaces. Grade 1.4401 (316) stainless steel is used throughout, including the bathroom, where high levels of humidity are likely.

Techniques
Laser cutting
Spinning
Tube bending
Sand casting
Brushed finish
Welding

Staircase

The staircase leads from the lounge to the mezzanine. Glass treads and risers minimise visual interruption of the overall volume. These consist of 10 mm toughened glass bonded to 12 mm laminated toughened glass (Figure 2).

Figure 2
View showing the glass staircase

Courtesy of Brookes Stacey Randall Fursdon

The top and bottom corners of each step are held by hand finished stainless steel sand castings (Figure 3). These are welded to continuous 20 mm diameter stainless steel rods that run along the staircase creating a truss like structure on each side of the staircase (Figure 4, Figure 5).

Techniques
Laser cutting
Spinning
Tube bending
Sand casting
Brushed finish
Welding

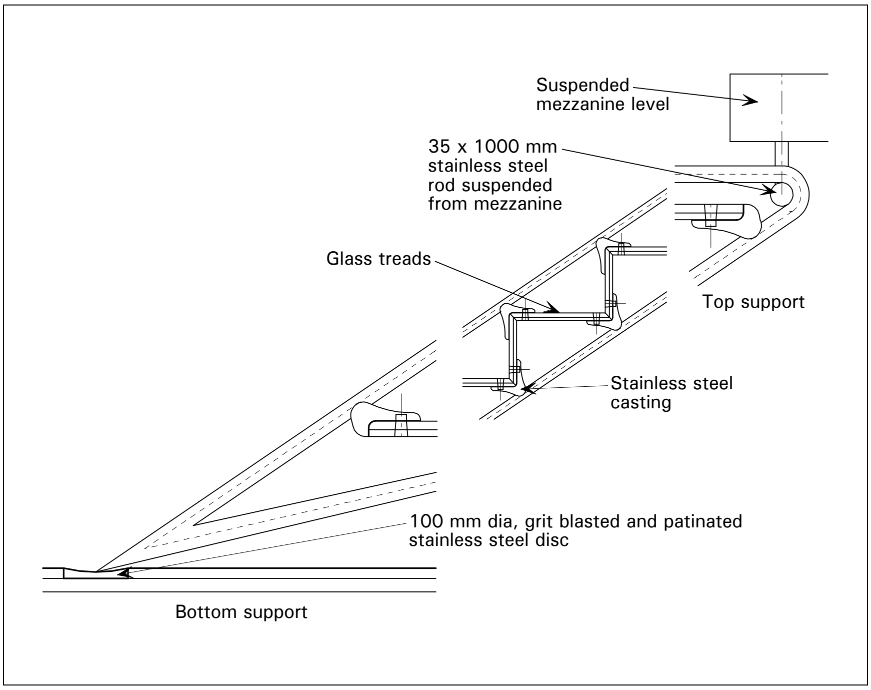
Figure 3
Steps held by castings

Courtesy of Brookes Stacey Randall Fursdon

Figure 4
Glass and stringer 'truss'

Courtesy of Brookes Stacey Randall Fursdon

Figure 5
Stair support arrangement



Techniques
Laser cutting
Spinning
Tube bending
Sand casting
Brushed finish
Welding

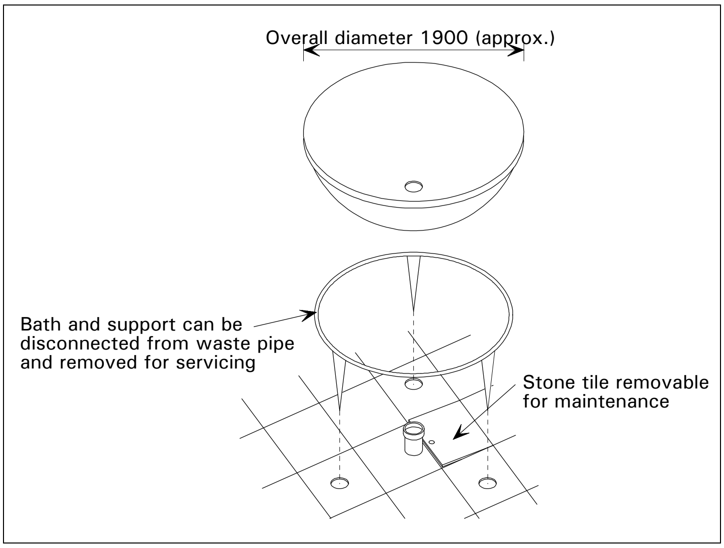
The trusses land on 2 mm stainless steel discs bolted to carbon steel discs embedded in the floor slab. The top of the truss is welded to a 35 mm diameter stainless steel rod attached to the bottom of the mezzanine floor (Figure 5).

Bathroom

The bathroom furniture (bath, basin, special light fittings and shower head) have a brushed finish.

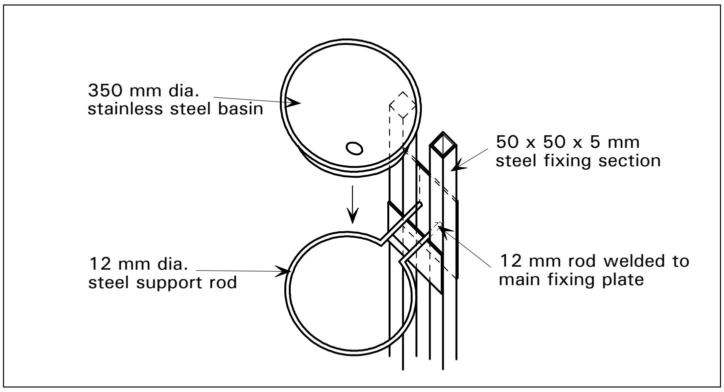
The bath was specially fabricated from stainless steel plate and is supported on a frame of curved stainless steel circular hollow sections. The bottom of the bath was spun to achieve the necessary dish shape.

Figure 6
Bath construction



The bathroom basin was also spun and is supported on a stainless steel frame (Figure 7).

Figure 7
Basin details

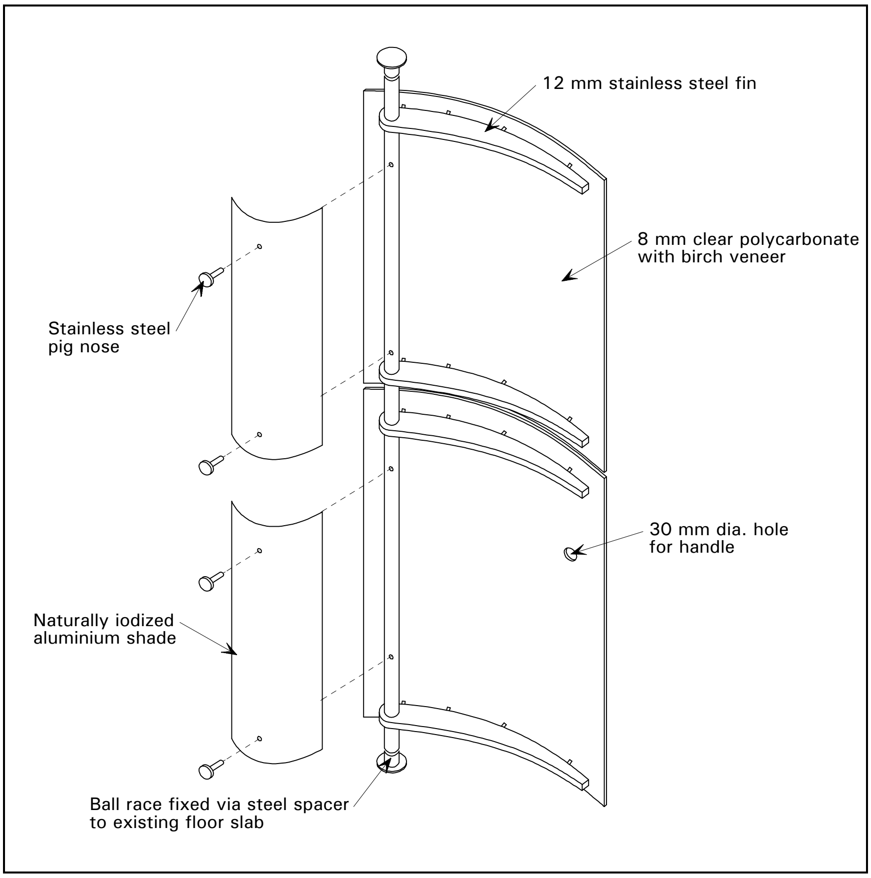


Techniques
Laser cutting
Spinning
Tube bending
Sand casting
Brushed finish
Welding

Front screen

Privacy to the main living area is provided by six pivoting curved glass screens faced with a thin veneer of birch wood. These are supported by a stainless steel frame with a pivoting mechanism. This consists of 6 mm laser cut fins welded to 40 mm diameter stainless steel tubes rotating on a ball race mechanism (Figure 8).

Figure 8
Front screen arrangement



Techniques
Laser cutting
Spinning
Tube bending
Sand casting
Brushed finish
Welding

Kitchen and dining areas

The kitchen and dining areas are flanked by an acid etched glass screen on slim stainless steel supports. The glass is bonded using an epoxy based resin adhesive to 100 x 8 x 6 mm laser cut stainless steel fins welded to an oval stainless steel tube. This is attached with pig nose fixings to a round floor plate (Figure 9).

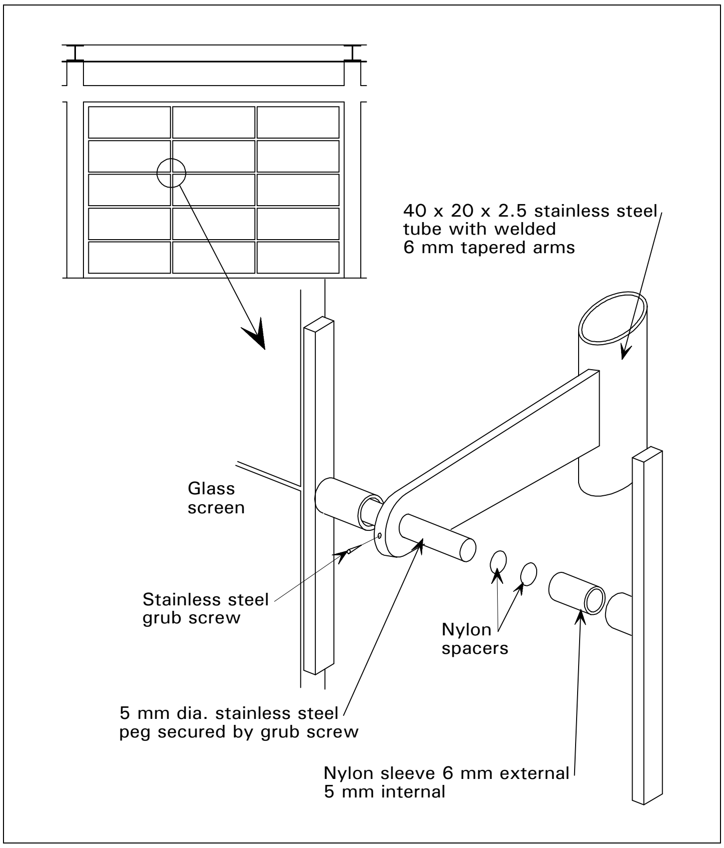


Figure 9
Support to kitchen glazed screen

The cabinets are cantilevered above the floor. They are made from stainless steel sheets bonded to medium density fibreboard and bolted to a carbon steel carcase. The top is a solid 22 mm thick counter, made by side laminating birch strips to a curve with a recessed stainless steel cable tray at the rear. The tray is fabricated from three flat stainless steel strips welded together.

MUSEUM OF SCIENCE AND INDUSTRY

Tampa, Florida, USA, 1996

Architect: *Antoine Predock Architects, USA /Robbins, Bell & Kreher, USA*
Engineer: *Paulus Sokolowski & Sartor*

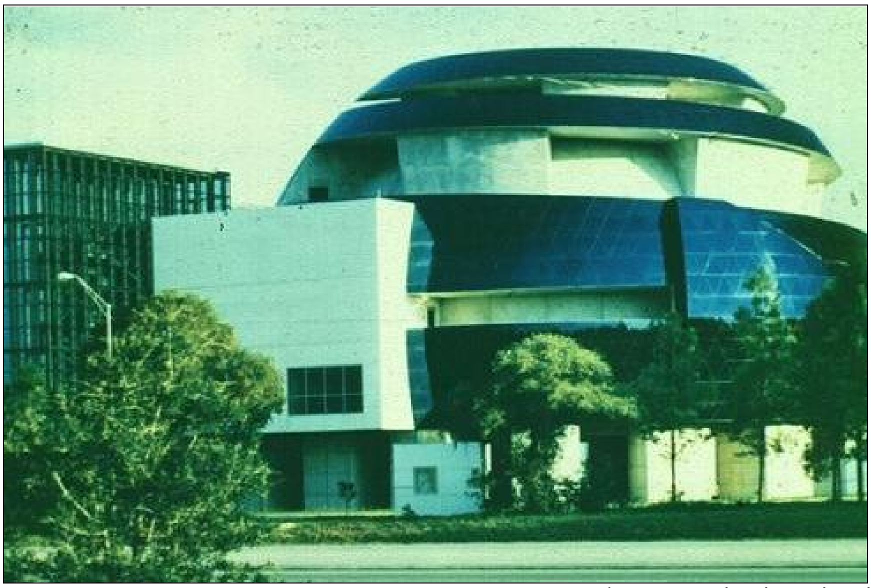
Techniques
Polished finish (mirror) Coloured finish Mechanical joints

✦Cladding

General

The Museum of Science and Industry in Tampa covers an area of approximately 11,000 m^2. The building is notable for its contrasting geometric forms and for its bold external use of colour (Figure 1).

Figure 1 *General view of Museum of Science and Industry*



Courtesy of Rimex Rigidized Metals Ltd

Exhibition halls and related spaces are flat sided or rectilinear volumes that contrast with an essentially spherical omnimax theatre at one end of the building. The theatre dominates the composition and is clad in coloured stainless steel. It has a truncated flattened top and spiralling walkways set behind reveals in the outer wall that appear to have been 'peeled' away, rather like skin from an orange. The resulting form is complex and striking.

Cladding

The cladding system used on the omnimax theatre was custom designed. The curved walls are clad using simple triangular coloured stainless steel panels attached to tubular aluminium subframes. Panels are face fixed using stainless steel screws, and have simple cut edges. Screws are coloured to match the panels.

Approximately 29 tonnes of 1.6 mm thick grade 1.4301 (304) bright annealed stainless steel sheet was used in the cladding system.

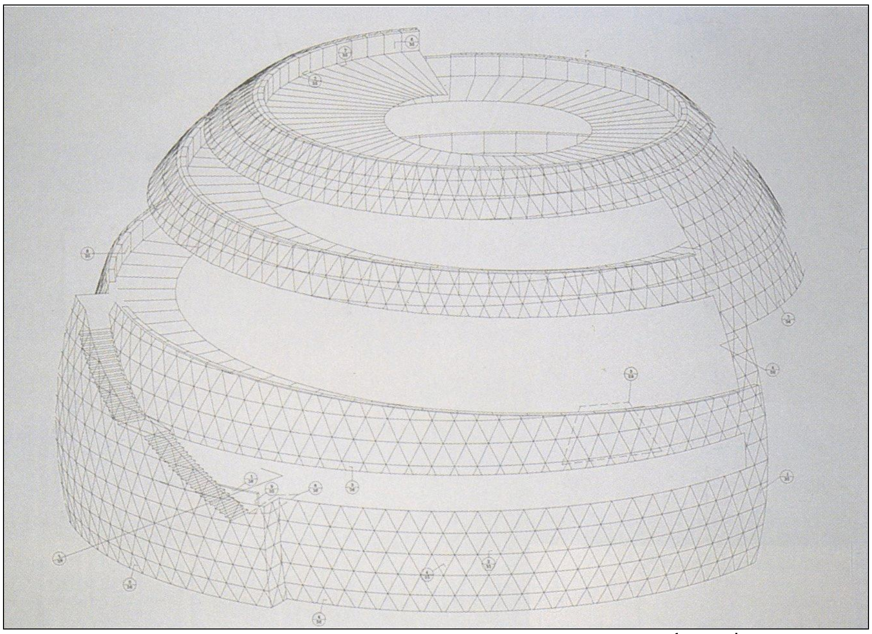
The sheet was manufactured in the UK in a single batch. Great care was taken to achieve particularly high standards of consistency in the composition of the material and good surface quality, *i.e.* free from blemishes, marks, dwell lines, *etc.* As a result, there is markedly little variance in the colour shade. Material was first polished to a mirror

Techniques
Polished finish (mirror)
Coloured finish
Mechanical joints

finish and then coloured using a chemical process. Colour samples were agreed in advance and the finish matched against these samples. After colouring, the sheet was coated in PVC to avoid damage during transit and fabrication.

The fabricator resolved the complex geometry of the cladding system using computer modelling (Figure 2).

Figure 2
Axonometric view of sphere



Courtesy of A. Zahner Company

ONE CANADA SQUARE

London, UK, 1990

Architect: *Cesar Pelli & Associates, USA*
Engineer: *M S Yolles and Partners Ltd, Canada*

Techniques
Patterned finish Stud welding

✦ *Cladding*

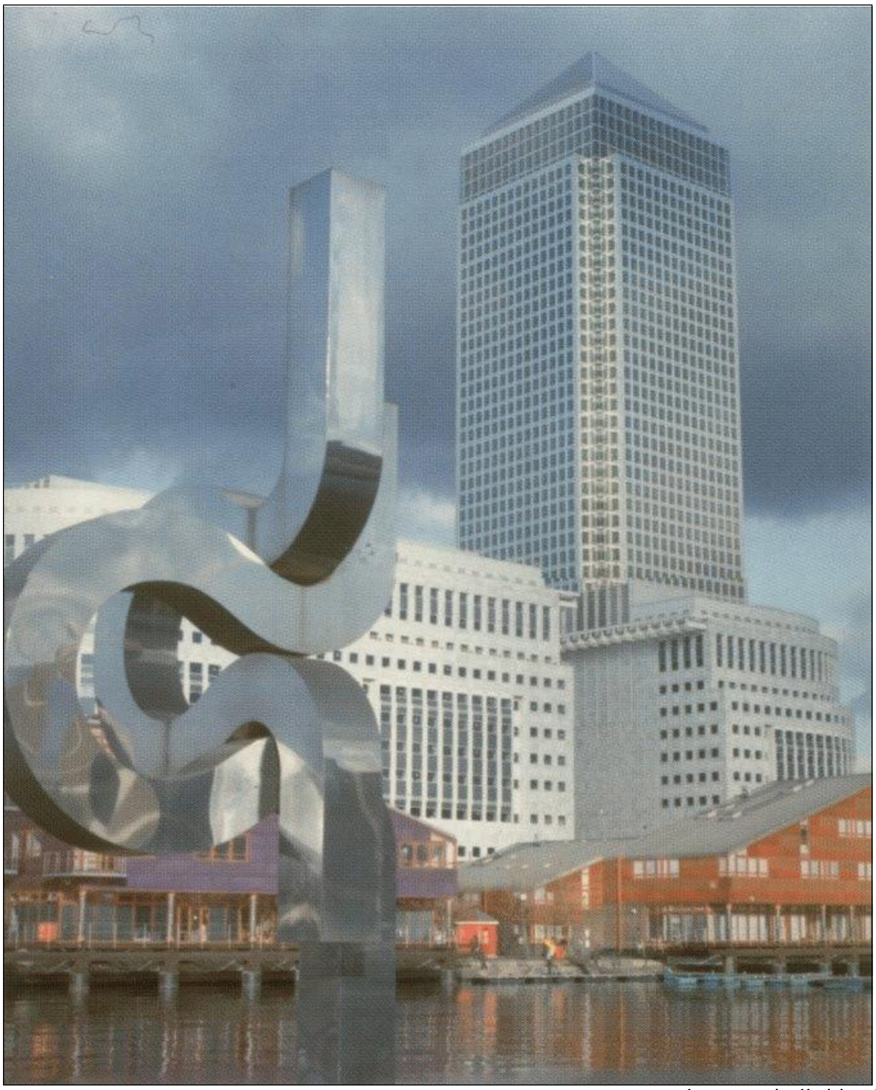


Figure 1 *One Canada Square*

Courtesy of Avesta Sheffield Ltd

General

One Canada Square has become the symbol of the Canary Wharf complex in London (Figure 1). The forty-eight storey tower is 245 m high, making it the UK's tallest building and Europe's second.

Building cladding

The building is clad in stainless steel. The reflective quality of the panels is central to the architectural expression of the building. "It's a glowing display," noted Pelli, "a display that changes from blue to white to orange to red during the course of the day."

Techniques
Patterned finish Stud welding

Grade 1.4401 (316) stainless steel panels with a single-sided textured surface finish (Figure 2) were used to clad the 34,000m^2 of facade area. The cladding system consisted of small rectangular panels, none larger than 1.5 m in any dimension. The small panel size effectively hides slight variations in the colour and reflectivity of the stainless steel.

Figure 2
Single-sided textured stainless steel cladding is used for the external envelope

Photo: Charles Birchmore

Panels were formed from a flat sheet of stainless steel 2.5 mm thick with anchoring studs welded to one side (Figure 3). The panels hang from the top of a lightweight aluminum curtain-wall frame, which in turn is anchored to the composite floor slab. At each floor level, a horizontal stainless steel bullnose moulding conceals the joint between the panels, while each window bay is separated by vertical stainless steel window-washing tracks (Figure 4).

Techniques
Patterned finish Stud welding

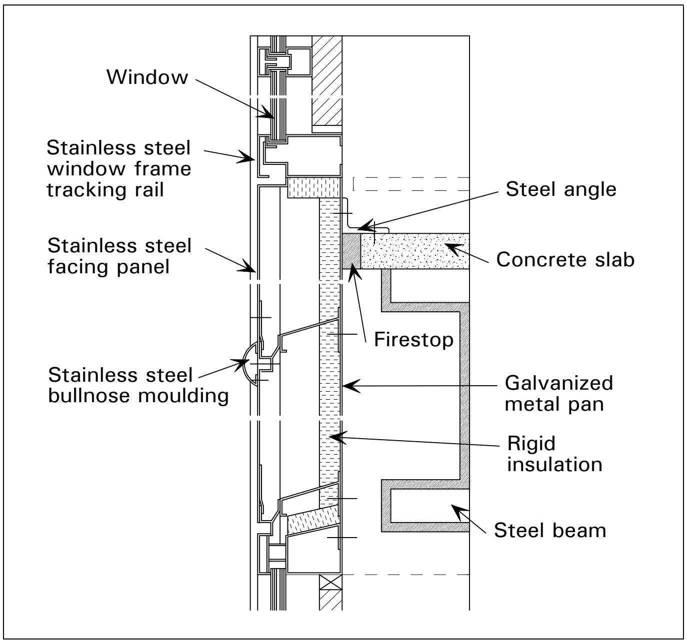


Figure 3
Section through wall cladding

Figure 4
Bullnose mouldings conceal horizontal panel joints

Photo: Charles Birchmore

PETRONAS TOWERS

Kuala Lumpur, Malaysia, 1996

Architect: *Cesar Pelli & Associates, USA*
Engineer: *Thornton-Tomasetti, USA*

Techniques
Patterned finish
Polished finish (satin)

✦ Cladding

Figure 1 *Twin towers under construction*

Courtesy of Avesta Sheffield Ltd

General

The Petronas Towers are located in the centre of Kuala Lumpur. The twin 88-storey towers (Figure 1) stand as a gateway to the 97 acre Kuala Lumpur City Centre project. A double-decker walkway links the two buildings at the 41st and 42nd floors giving the appearance of a huge portal.

Technique
Patterned finish Polished finish (satin)

The cladding of the towers consists of ribbons of glass and stainless steel (Figure 2). Grade 1.4401 (316) material was used throughout. Flat panels and column covers are 2.5 mm thick bright annealed stainless steel with a roll-textured finish. Tubular features have a satin polished finish. The two different surface finishes give the building distinctive reflective qualities.

Figure 2
Cladding consists of ribbons of stainless steel and glass

Courtesy of Avesta Sheffield Ltd

REINA SOFIA MUSEUM OF MODERN ART

Madrid, Spain, 1991

Architect:	*Ian Ritchie Architects, UK, in association with Iñiguez & Vazquez, Spain*
Engineer:	*Ove Arup & Partners, UK*

✦ *Glazing fixings*

Techniques
Laser cutting Machining Mechanical joints

Figure 1
The external towers

Photo: Jocelyne Van den Bossche

General

The conversion of the 17th Century hospital to the Reina Sofia Museum of Modern Art involved the addition of three new lift towers to the exterior of the existing building. The two towers on the main facade to the front of the building are for visitor circulation; the third incorporates a goods lift and is located on the west elevation.

Each of the 36 m high front towers (Figure 1) is conceived as a transparent envelope of frameless glazing. The glass separates the internal steel frame from an external stainless steel structure. The architect selected stainless steel for its corrosion resistance, appearance and for the different coefficients of expansion provided by the different alloys.

Techniques
Laser cutting Machining Mechanical joints

External support system

A total of twelve sets of stainless steel rods run down the outer face of the glass envelope. Each set comprises two basic mill finished, lightly ground rods (Figure 2). The inner 'suspension' rod (nearer to the glass) is 28 mm in diameter and made from duplex stainless steel. The outer 'tie-down' rod is 20 mm in diameter and made from grade 1.4401 (316) stainless steel. Duplex stainless steel has a smaller thermal coefficient of expansion than grade 1.4401 (316) (see Appendix B); thus the thermal movement of the two rods are to some extent self compensating. This leads to smaller thermal movement of the glass panels than if similar metals had been used (Figure 3).

Each rod is storey-height and is connected by cylindrical couplers to internally threaded blocks which receive the pivot pins for the support brackets. Each bracket is connected at its middle to the suspension rod and at the far end to the tie-down rod (Figure 4).

Figure 2
Tie-down rods

Photo: Bruce Gibbons

Techniques
Laser cutting Machining Mechanical joints

Figure 3
Tie-down system

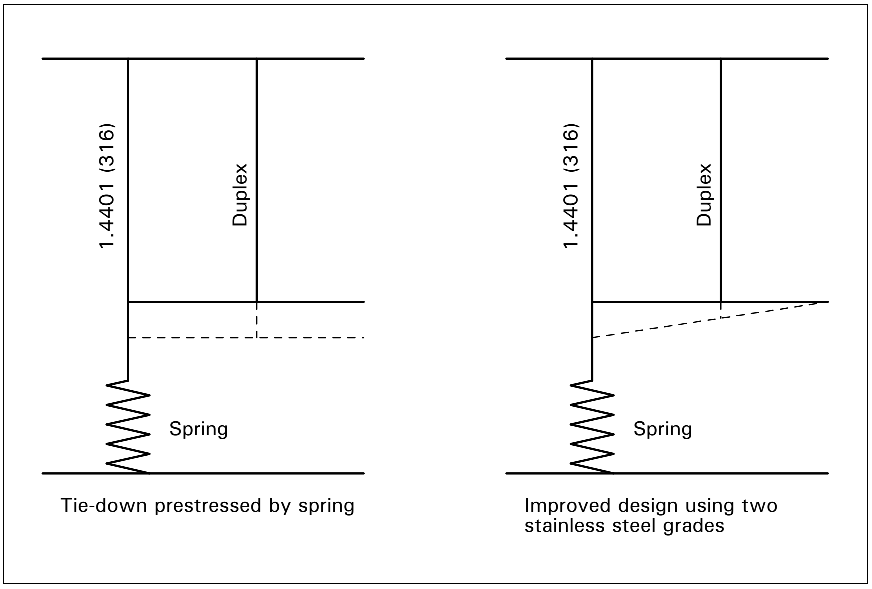
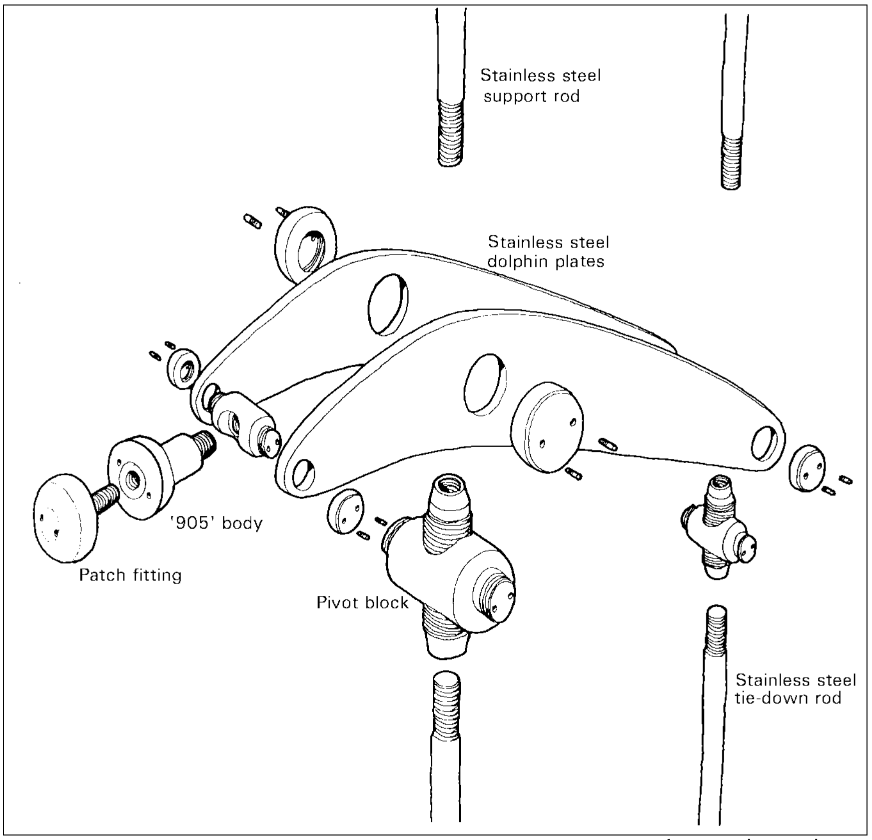


Figure 4
Connection of rods to support brackets



Courtesy of Ian Ritchie Architects

Techniques
Laser cutting Machining Mechanical joints

The dolphin shape stainless steel laser cut brackets are made from grade 1.4401 (316) stainless steel (Figure 5). This process allowed the sculptural forms (inspired by Picasso's 'Guernica') to be produced to high tolerance, rapidly, and with minimal remedial treatment. The frameless sheets of toughened glass are 2966 mm × 1833 mm x 12 mm panes. Each is suspended from one central stainless steel patch fitting on its top edge which is picked up by the bracket.

Figure 5
Glazing bracket

Photo: Jocelyne Van den Bossche

Figure 6
Glazing horizontal support arm

Photo: Jocelyne Van den Bossche

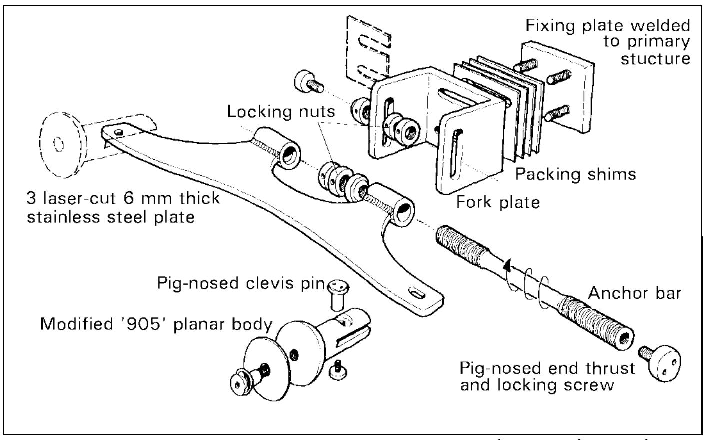
A standard stainless steel tie (Figure 6) connects the glass back to the steel frame and provides bracing against wind loads. The main components of the tie are a 6 mm thick laser cut arm (a variant of a Planar 905 fixing) and a machined threaded bar which passes through the tie and locates within the slots of a U-shaped painted carbon steel bracket fixed back to the structure (Figures 7 and 8). The arrangement allows vertical movement of the glass whilst transferring horizontal forces to the structure.

Techniques
Laser cutting Machining Mechanical joints

Figure 7
Glass horizontal bracing

Photo: Jocelyne Van den Bossche

Figure 8
Horizontal bracing - schematic



Courtesy of Ian Ritchie Architects

SACKLER GALLERIES

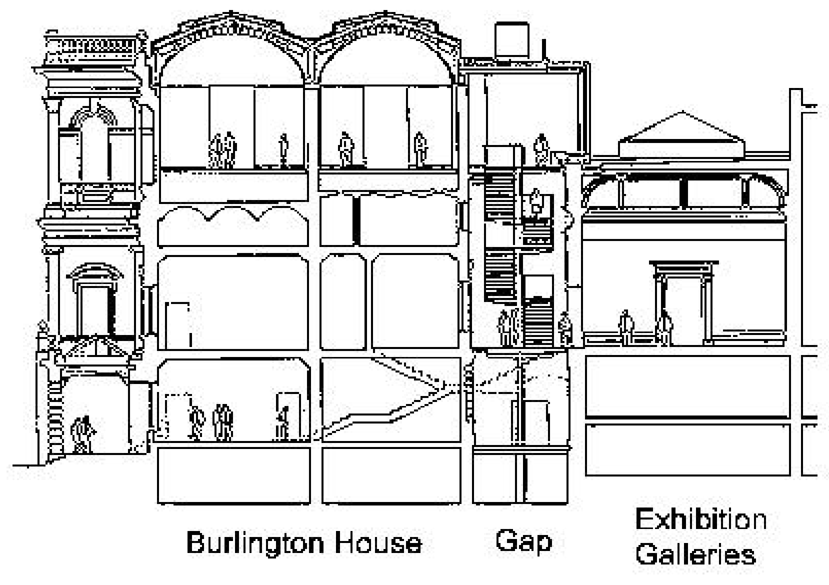
Royal Academy of Art, London, UK, 1991

Architect: *Foster and Partners, UK*
Engineer: *Anthony Hunt Associates, UK*

Techniques
Tube bending
Bead blasted finish
Mechanical joints

✦ *Handrails/Balustrades* ✦ *Staircases*

Figure 1 *North-south section showing the new staircase*



Courtesy of Foster and Partners

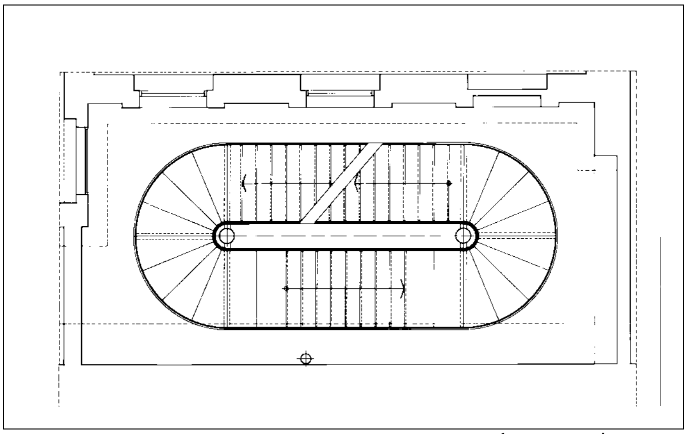
General

Foster and Partners' masterplan for the Royal Academy provides a new suite of galleries for small international travelling exhibitions and improves circulation through the building.

The scheme includes a new staircase that connects all five floors of the building and gives direct access to the Diploma Galleries (now the Sackler Galleries), the library and the restaurant (Figure 1). Interference with the existing buildings is minimal. The staircase is supported by two circular columns which take loads to the ground and from which cantilevered tapered arms support the flights and landings (Figures 2 and 3).

Techniques
Tube bending
Bead blasted finish
Mechanical joints

Figure 2
Structurally independent stairs supported on circular columns with outstretched arms



Courtesy of Foster and Partners

Figure 3
Glass treads and balustrades create a high degree of transparency

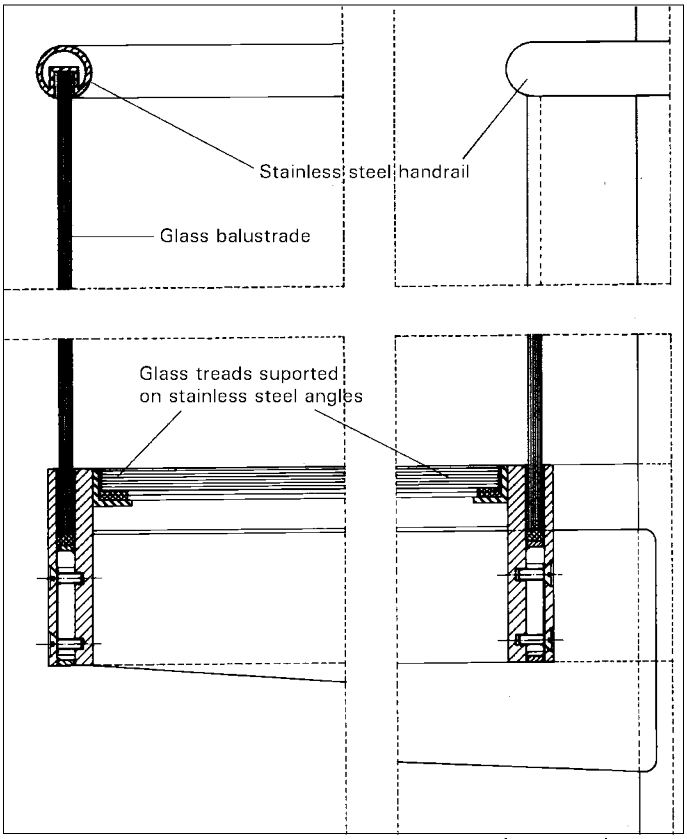
Photo: Dennis Gilbert

Techniques
Tube bending
Bead blasted finish
Mechanical joints

Treads and balustrades are made from glass and allow light to flood through from above. A 40 mm stainless steel handrail is fixed to the top edge of the glass balustrade by means of a rebate (Figure 4). The handrail has a bead blasted finish that is tactile and avoids fingerprints. It is bent to a radius of 200 mm on the inside and 1400 mm on the outside of the semi circular half landings (Figure 5).

A stainless steel pressure plate arrangement is used at the base of the glass balustrade to provide the necessary clamping action. Both the pressure plate and the stair edge stringer are fabricated from stainless steel plate and are attached using countersunk stainless steel bolts. Support angles on the inside of the stringer provide bearing for the glass treads and half landings.

Figure 4 *Detail of stainless steel handrail and tread support*



Courtesy of Foster and Partners

Techniques
Tube bending
Bead blasted finish
Mechanical joints

Figure 5
Bead blasted stainless steel handrail

Photo: Dennis Gilbert

SCHOOL OF OCCUPATIONAL THERAPY & PHYSIOTHERAPY

Southampton, UK, 1996

Architect: *Foster and Partners, UK*
Engineer: *Ove Arup & Partners, UK*

✦*Structure*

Techniques
Machining Electropolished surface Welding

General

The School of Occupational Therapy and Physiotherapy at Southampton (Figure 1) was designed to be constructed on a very low budget. It has a square plan to optimise wall to floor area ratios, with a central gymnasium located diagonally across the plan. Offices and other areas are located in triangular areas either side of the gymnasium.

The building takes maximum advantage of self finished materials and is designed for minimum maintenance. Facades are engineering brick on exposed stainless steel channels. Window frames are exposed galvanised steel.

Figure 1
Corner elevation

Photo: Dennis Gilbert

Cladding Supports

Approximately 40 tonnes of grade 1.4404 (316L) stainless steel were used in the cladding supports, all of which were electropolished prior to delivery.

Exposed fabricated stainless steel channels, oriented with their toes projecting outwards, are strapped onto the floor edge. These are expressed on the outside of the building to create a layering of the 3-storey facades (Figure 2). They receive gravity loads from grey stack bonded engineering brick panels. The web of the channel is 8 mm plate; the flanges are 15 mm plate and are machined to create a taper toward the toe in order to improve drainage. The finish on the stainless steel was preserved by welding the channel from the rear and by designing the flanges such that the machined face is adjacent to the brickwork, with the preserved finished face exposed on the inside of the section.

Wind restraint is provided by vertical T-sections that span between floor edge channels. These are attached to the channels using simple

Techniques
Machining Electropolished surface Welding

cleats, the uppermost of which are slotted to provide dimensional tolerance.

The forward leg of the T-section is expressed as a pinline on the facades, dividing them into regular 1145 mm modules.

The corner detail is specially fabricated in stainless steel. It acts as a wind restraint and provides an elegant solution for turning the facade ends through 45°.

Figure 2 *Exposed stainless steel channels support brick panels*

Courtesy of Avesta Sheffiled Ltd

SERRES, PARC DE LA VILLETTE

Paris, France, 1986

Architect: *Rice Francis Ritchie (RFR), UK*
Engineer: *Rice Francis Ritchie (RFR), UK*

Techniques
Machining
Centrifugal casting
Investment casting
Polished finish
Electropolished surface
Welding
Mechanical joints

✦ *Structure* ✦ *Glazing fixings*

Figure 1
View of the main facades - The Serres

Photo: Jocelyne Van den Bossche

General

An architectural competition for the design of the National Museum of Science, Technology and Industry was won by Adrien Fainsilber in 1980. The scheme includes glazed facade elements (or Serres), later designed by RFR. The Serres act as a transition between the museum and the park (Figure 1).

From outside, the glazed plane is a perfectly smooth uninterrupted skin. Inside, the support members and cables have a sculptural quality (Figure 2). All the metallic components making up the Serres are made from stainless steel, mostly grade 1.4401 (316).

Techniques
Machining
Centrifugal casting
Investment casting
Polished finish
Electropolished surface
Welding
Mechanical joints

Figure 2
The support structure to the Serres

Photo: Jocelyne Van den Bossche

Structural framework

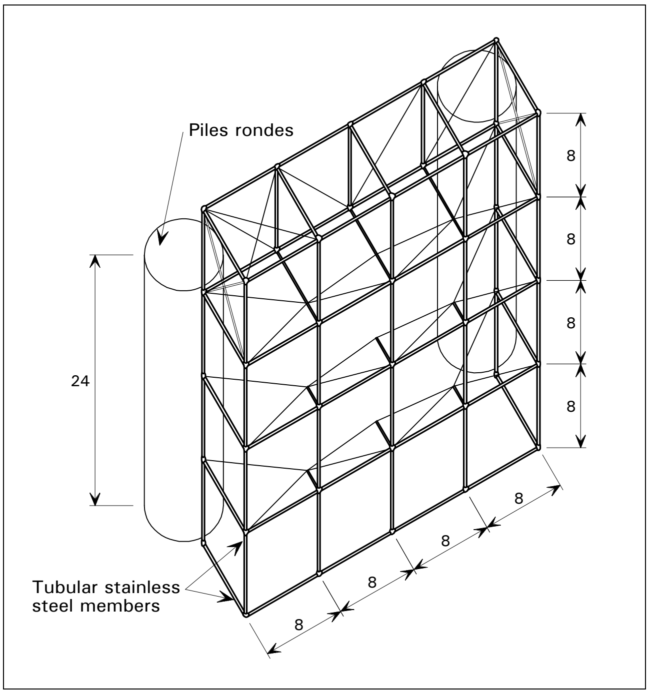
The elevation of each Serre is 32 m x 32 m. The supporting framework is fabricated from tubular stainless steel members on an 8 m x 8 m grid. The structure is attached to the main building by two 24 m high concrete cylinders (known as *piles rondes*) clad in 1.5 mm polished stainless steel sheet.

Tubular members

Tubes were manufactured by centrifugal casting, which allows the outer diameter to be kept constant (300 mm in this case) while varying the inside diameter. This technique was used because the material thickness required in certain parts of the structure rendered normal fabrication techniques (seam welding, followed by grinding and polishing of the welds) uneconomical. The tube wall thickness varied from 35 mm for the most stressed members to 6 mm for the least stressed.

Techniques
Machining
Centrifugal casting
Investment casting
Polished finish
Electropolished surface
Welding
Mechanical joints

Figure 3
Schematic of a Serre also showing the piles rondes



Each 8 m member was cast in four 2 m long sections which were butt welded together. The tubes were machined on a lathe along their length giving a striated appearance (Figure 4). A relatively roughened surface finish was sought to blend with an orange-peel finish on the nodes.

Figure 4
Striated finish to tubulars

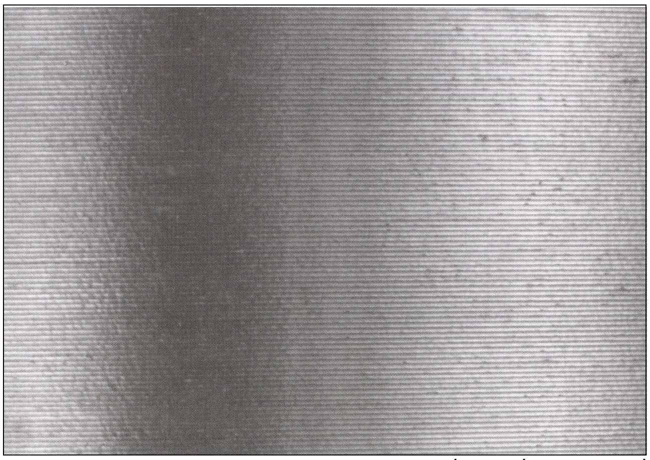


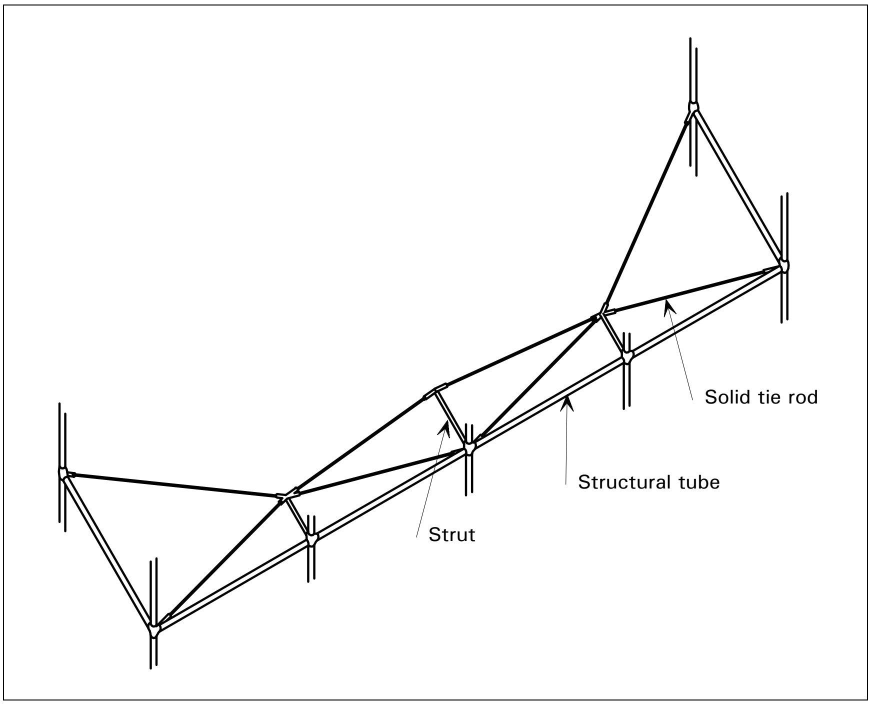
Photo: Alain Goustard

Techniques
Machining
Centrifugal casting
Investment casting
Polished finish
Electropolished surface
Welding
Mechanical joints

Wind bracing

Wind bracing is present at each of the first three 8 m levels (Figure 5). It takes the form of two faceted parabolae of solid tie rods, prestressed one against the other and separated by tubular struts. The tie rods are fitted with forged ends and are joined through cast pieces either to each other or to the main tubes (Figure 6).

Figure 5
Wind bracing at horizontal tube levels



Cast nodes

Stainless steel nodes (Figure 7) that connect the tubular members were cast in ceramic moulds. They were then cleaned by blasting with a fine grit and were machined at their contact points with the tubular members or any other connection requiring tighter tolerances than those offered by the castings. The castings were then electropolished to give them a slightly roughened but shiny orange-peel finish.

Techniques
Machining
Centrifugal casting
Investment casting
Polished finish
Electropolished surface
Welding
Mechanical joints

Figure 6
Tie rods are joined through their forged ends by castings

Photo: Stéphane Couturier, Courtesy of Archipress

Techniques
Machining
Centrifugal casting
Investment casting
Polished finish
Electropolished surface
Welding
Mechanical joints

Figure 7
Cast stainless steel nodes

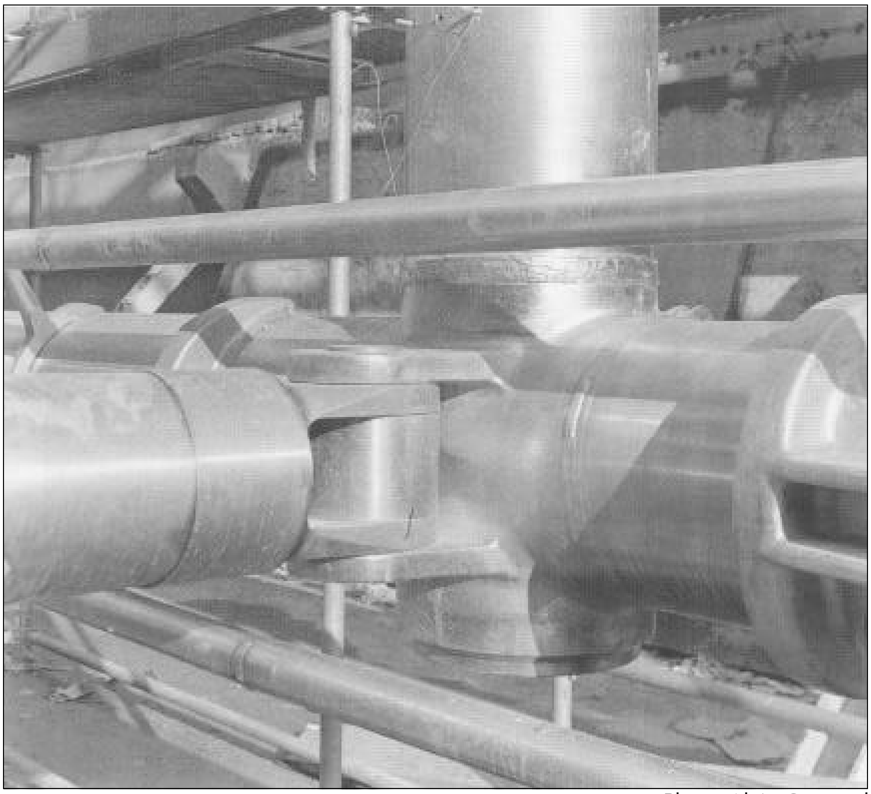


Photo: Alain Goustard

The cast nodes and the centrifugally cast tubes were welded together. No attempt was made to disguise the welds as these delineated the boundary between the two components. Three types of welding were employed; the first (used on certain horizontal tubes) was a form of shop welding, where the tube is moved relative to a fixed electrode. The second (used on other horizontal tubes) was site welding where the tube remained stationary while the electrode moved. A circular weld is very difficult to achieve when executed by hand. The vertical tubes were welded on site, again with the electrode moving relative to the tube and only small fillets of weld applied, because gravity tends to deform larger fillets while the metal is still liquid.

Each of these three types of weld has its own appearance: the horizontal shop welds are very smooth and even, the on-site horizontal welds are rougher and their finish includes slightly irregular grooves, and the vertical on-site welds have the appearance of bands of string, one above the other (Figure 8).

Techniques
Machining
Centrifugal casting
Investment casting
Polished finish
Electropolished surface
Welding
Mechanical joints

Figure 8
Effects achieved by different welding techniques

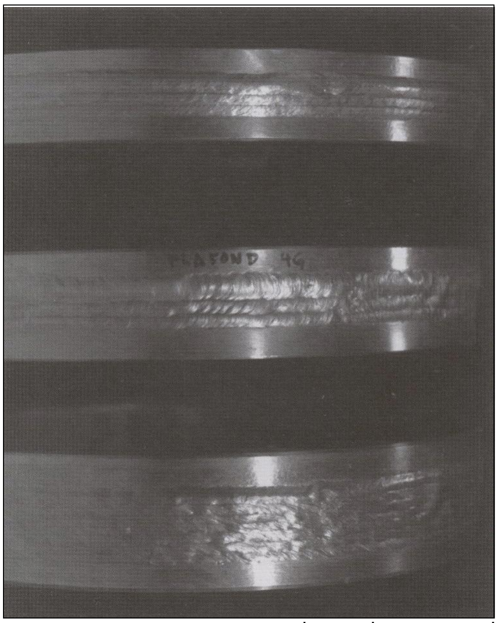
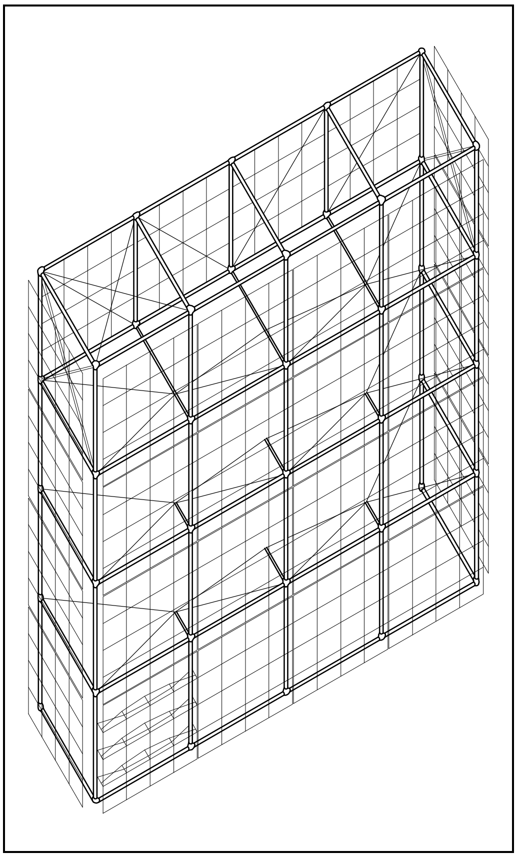


Photo: Alain Goustard

Figure 9
Structural hierarchy of the Serres; the cable trusses are shown in bottom left hand panel (but repeat in every 8 m panel)



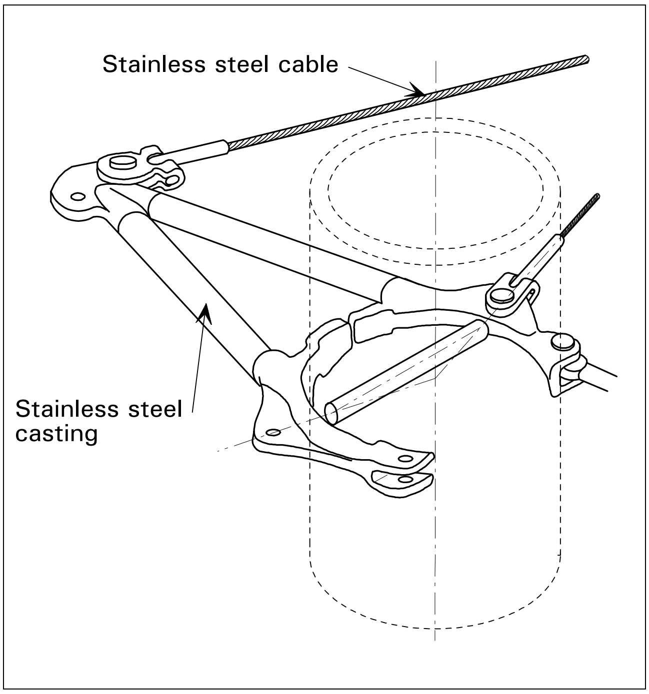
Techniques

- Machining
- Centrifugal casting
- Investment casting
- Polished finish
- Electropolished surface
- Welding
- Mechanical joints

Cable trusses

The cable truss is the only horizontal support system for the glass and it repeats throughout the entire facade (Figure 9). The cable truss consists of two single strand stainless steel cables, 12.7 mm in diameter made of 19 wires with turnbuckles and fork ends for tensioning and fixing. The cables are pre-tensioned one against the other into a parabolic shape in a manner similar to that used for the main wind bracing system. The ends of the cables are supported by V-brackets. These are lost wax castings, shop welded to the tubular columns (Figure 10).

Figure 10
V-bracket fixing the cable truss to the tubular frame



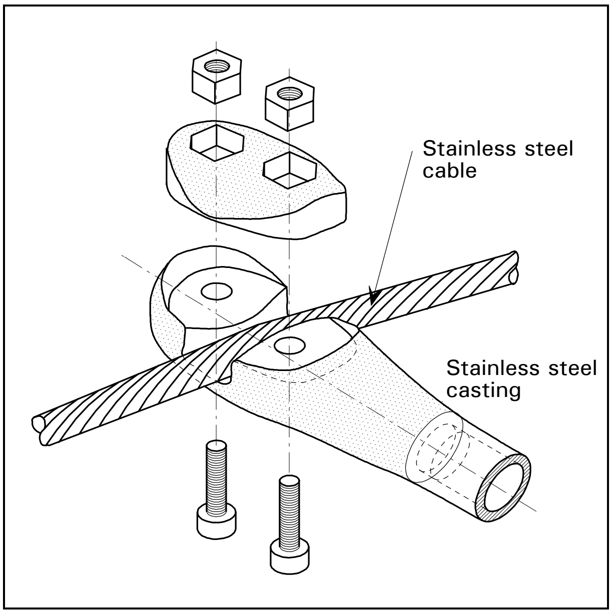
Strut attachments in the corners of the glass panels hold the panels in the vertical plane. The continuation of these struts into the plane of the cable truss transfer wind loads from the glass into the cables and also act as cable spacers, enabling the cables to take their twin parabolic shape (Figure 11). These struts are stainless steel tubes with cast cable clamps welded to their ends. The cable clamps are stainless steel lost wax castings formed in two halves and bolted together. One half of the casting ensures continuity of the strut through the connection whilst the other is a capping which clamps down onto the first (Figure 12).

Techniques
Machining
Centrifugal casting
Investment casting
Polished finish
Electropolished surface
Welding
Mechanical joints

Figure 11
Struts maintain the cables in their parabolic form

Photo: Jocelyne Van den Bossche

Figure 12
Cable clamp

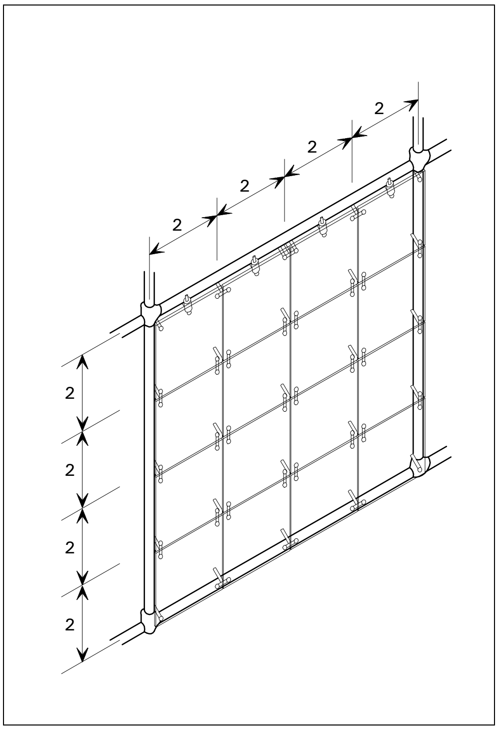


Techniques
Machining
Centrifugal casting
Investment casting
Polished finish
Electropolished surface
Welding
Mechanical joints

The glass suspension system

The design strongly emphasizes the expression of a glass curtain. The glass panels are suspended in vertical independent columns each comprising four 2 x 2 m sheets. The uppermost sheet is suspended at the centre of its top edge by a spring support assembly (Figure 13). Lower sheets are hung from the sheet above using corner attachments.

Figure 13
Glass panel assembly



The suspension connection is a stainless steel lost wax casting which is machined to receive mechanical components such as the articulated bolt connected to the glass sheet and the eye bolts that connect the assembly to the structural tube (Figure 14, Figure 15).

Other components of the glass suspension system include a stainless steel four hole connection assembly used to attach the glass to the cable truss. The connection takes the form of an articulated H composed of three castings (Figure 16).

Techniques
Machining
Centrifugal casting
Investment casting
Polished finish
Electropolished surface
Welding
Mechanical joints

Figure 14
Sprung suspension

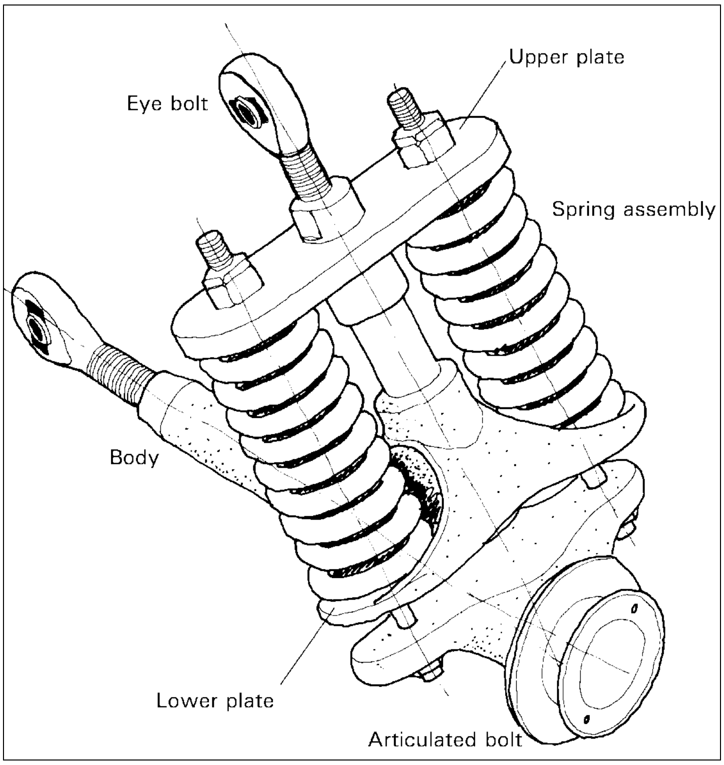


Figure 15
V-shape created by the casting transfers load tangentially to the tube

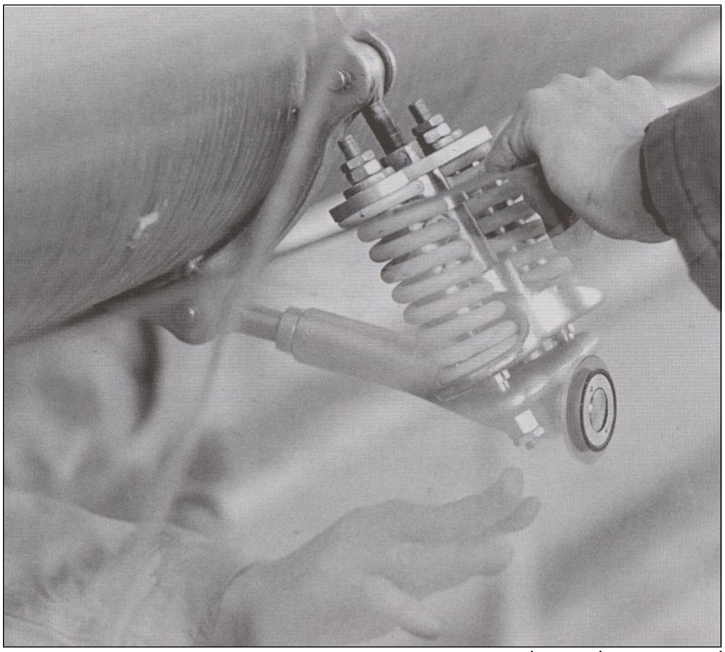
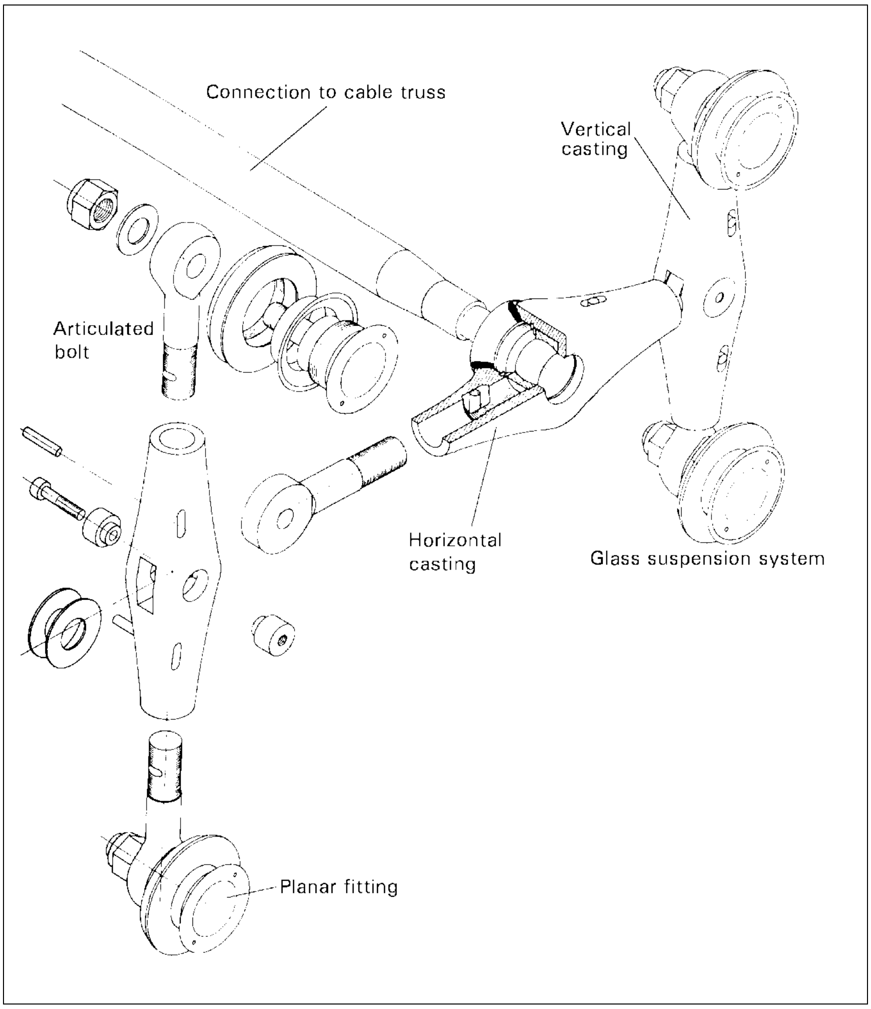


Photo: Alain Goustard

Techniques
Machining
Centrifugal casting
Investment casting
Polished finish
Electropolished surface
Welding
Mechanical joints

Figure 16
Four hole glass fixing assembly



TENSION NET STAIRCASE

Chicago, USA, 1996

Architect: *James Carpenter Design Associates Inc, USA*
Engineer: *Dewhurst Macfarlane and Partners, UK*

Technique
Mechanical joints

✦ *Handrails/Balustrades* ✦ *Staircases*

Figure 1 *Translucent glass treads spiral round the slender cone of stainless steel mesh*

Photo: Brian Gulick

General

The Tension Net Staircase (Figure 1) is the sculptural centrepiece and the only staircase within the penthouse apartment of a mixed-use 67 storey tower in downtown Chicago.

The thin floor slab of the building could not support loads from an equivalent slab bearing staircase and so the design team chose to suspend the innovative structure from the reinforced concrete ceiling.

Technique
Mechanical joints

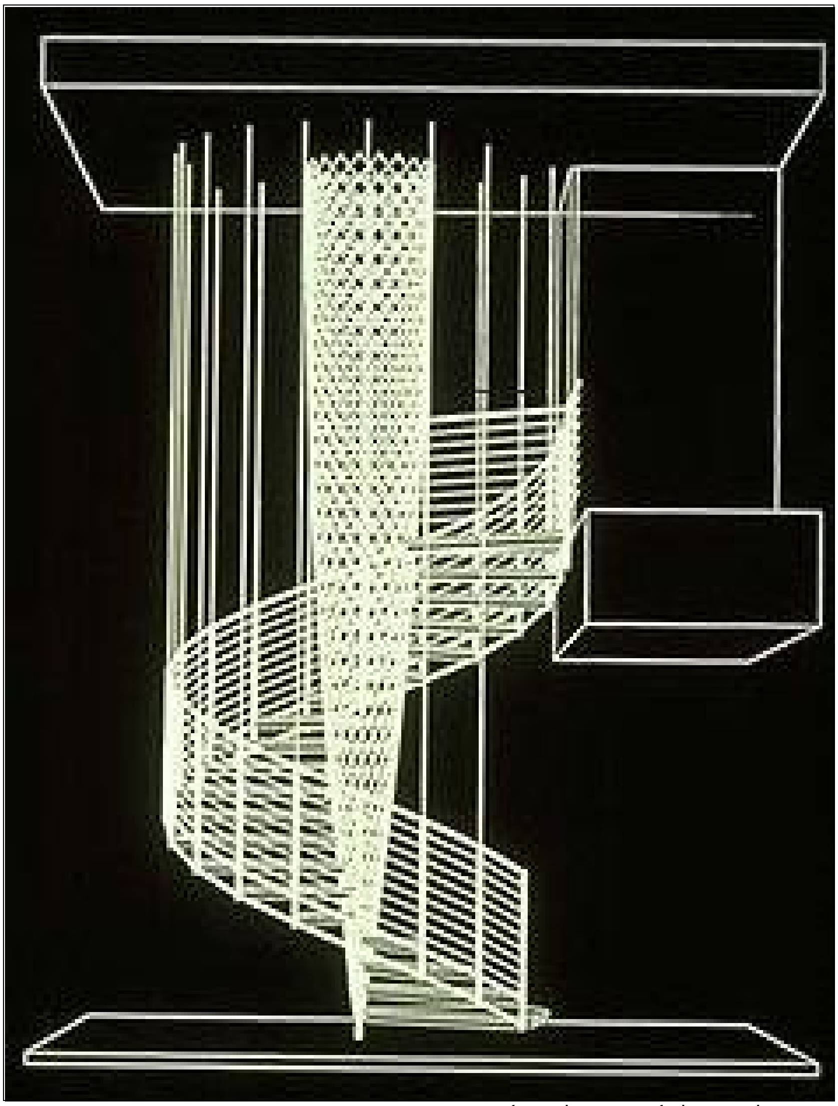


Figure 2 *Structurally independent stairs supported on a conical stainless steel tension net*

Courtesy of Dewhurst Macfarlane and Partners

Staircase structure

The main structure of the staircase is a slender filigreed cone of stainless steel mesh made of a double layer of 3 mm rods spiralling in both directions (Figure 2). The mesh is stiffened by post-tensioning against the floor and by a series of compression rings set horizontally at 185 mm intervals. The mass of the glass treads also contributes to stiffening the net. The cone was fabricated offsite as a single unit, with coupling points in each rod. This enabled the structure to be divided into three parts for transportation. Once in place, the cone was made properly vertical using the single turnbuckle at the base (Figure 3) and tensioned by tightening the 10 bolts at the top. The structure, with its delicate spiralling rods, suggests a vortex around which are spun the luminous glass planes of the treads and fine balustrading.

Technique
Mechanical joints

Figure 3
Stairs are aligned and tensioned with a single turnbuckle at the cone base

Photo: Brian Gulick

Each tread comprises three layers of laminated annealed and acid etched glass (Figure 3). The etched surfaces of the treads capture the light and shadowy patterns thrown by people and the structure itself. The treads are supported on two of their three sides by nylon strips on aluminium bars. Previous attempts to use glass in the treads have usually relied on four-sided support or back-up members.

THAMES TOWER

London, UK, 1995

Architect: *Brookes Stacey Randall Fursdon, UK*
Engineer: *SMP Atelier One, UK*

Techniques
Machining Sand casting Polished finish (brushed, mirror) Welding

✦ *Structure* ✦ *Cladding* ✦ *Glazing fixings*

Figure 1
General view of the tower

Photo: Moreley von Steinburg

General

The Thames Water Tower (Figure 1) is a commemorative monument to the engineering feat which went into the design and construction of the 80 km London ring main. It is one of three large diameter pipes which rise above ground level to accommodate water surges in the ring main. It takes the form of a giant public barometer conceived by Damien O'Sullivan and Tania Doufa of the Royal College of Art in an ideas competition commissioned by Thames Water in 1992. Brookes Stacey Randall Fursdon were commissioned to consider and advise on the feasibility of constructing the scheme and to identify alternative design options that could satisfy this concept. The most appealing of these involved the use of water sprayed from within the tower onto the inside surface of a glass enclosure.

The 16 m high tower is subdivided into five sections each with its own arrangement of water nozzles. The change in climatic pressure is detected by an electronic barometer which sends a signal for translation by a microprocessor to activate sprays of blue coloured water at varying levels within the tower. The water forms a thin film on the inside face of the toughened glass cylinder. The barometer and control panel are solar powered from photovoltaic panels mounted at the top of the tower on the solar vane.

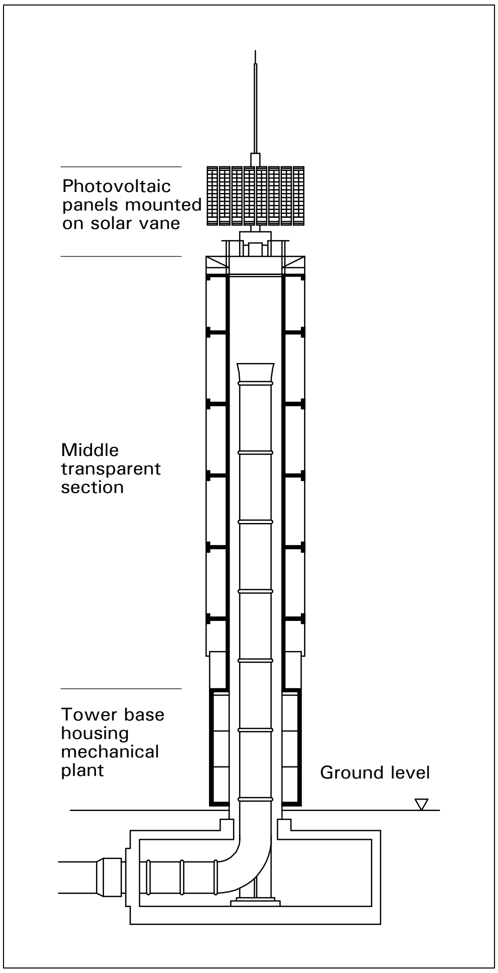
Stainless steel was a natural choice for appearance, corrosion resistance and robustness.

Techniques
Machining Sand casting Polished finish (brushed, mirror) Welding

The tower base

Figure 2 is a vertical cross-section through the tower. The tower base is a 4 m high, 1.5 m diameter cylinder. The void within the base contains the plant and pumps necessary to run the barometric tower. This part of the enclosure is fabricated from robustly detailed 4 mm thick matt finished grade 1.4401 (316) stainless steel plate (Figure 3). The choice of material and surface finish was made to maximize 'vandal resistance' whilst capitalising on the harmony between glass and stainless steel. The plates are fixed with dome headed bolts to a substructure of 'T' and 'L' fabricated stainless steel sections.

Figure 2
Vertical cross-section



Techniques
Machining
Sand casting
Polished finish (brushed, mirror)
Welding

Figure 3
Tower base

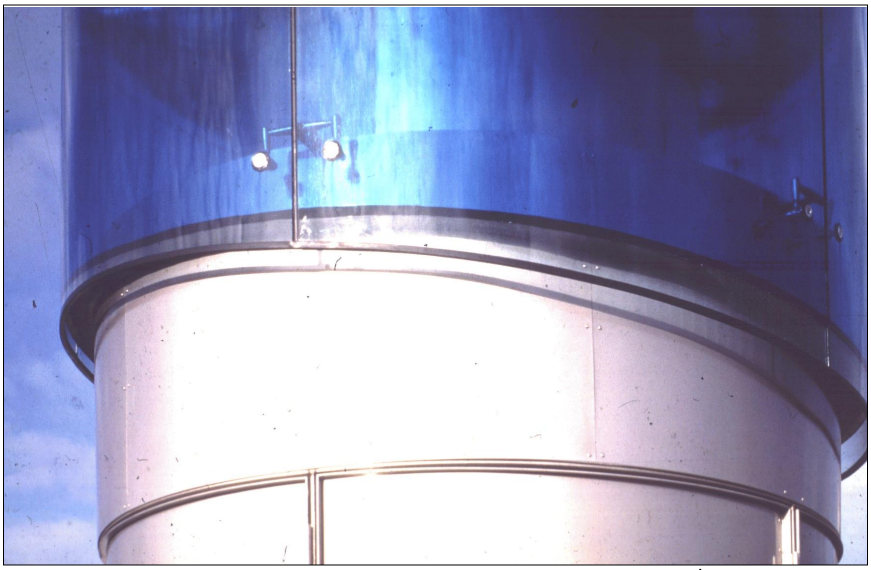


Photo: Peter Durant

The middle section

The main middle section is a transparent tube of 12mm glass. Within this enclosure, stainless steel grillages at 2 m intervals define the horizontal calibration marks of the barometer. The grillages are fabricated from 30 mm x 2 mm bars, welded together and brush finished. Figure 4 shows a typical plan at the grillage level. These grillages provide access for maintenance at each level, supplemented by an integral ladder (Figure 1) which also acts as part of the vertical calibration of the tower by providing the 'minor' scale. The grillages are supported by cantilever stainless steel sand castings (Figure 5) that incorporate fixing plates. The castings also provide cantilevered support at 2 m vertical intervals to the suspended glass enclosure. The glass skin is held using machined countersunk flush stainless steel fixings and black silicon sealant between glass sheets. Black silicone was used to impart a graphic quality to the glazed assembly when viewed in conjunction with the dyed blue water.

Techniques
Machining Sand casting Polished finish (brushed, mirror) Welding

Figure 4
Plan at grillage level

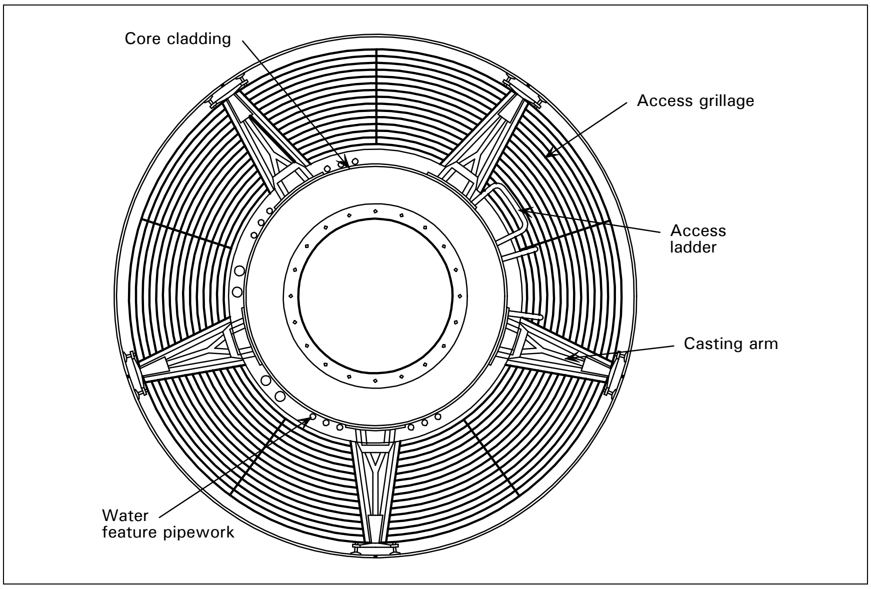
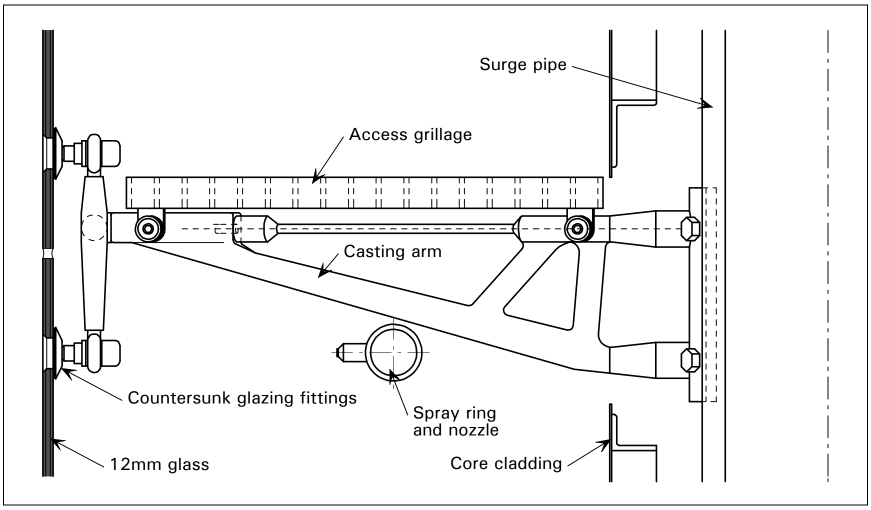


Figure 5
Section through glass fixing arrangement and grillage support



Within the glass enclosure, the surge pipe is clad using 3 mm stainless steel sheet with a mirror finish (Figure 6) which is sectioned to visually reinforce the vertical calibration of the tower.

The water is distributed in risers located within the polished stainless steel core cladding which in turn pass through a series of horizontal water rings. Water is sprayed onto the glass by an array of water nozzles spaced around the rings. Figure 7 shows a typical plan at the level of the nozzles.

Techniques
Machining
Sand casting
Polished finish (brushed, mirror)
Welding

Figure 6
Surge pipe cladding

Photo: Peter Durant

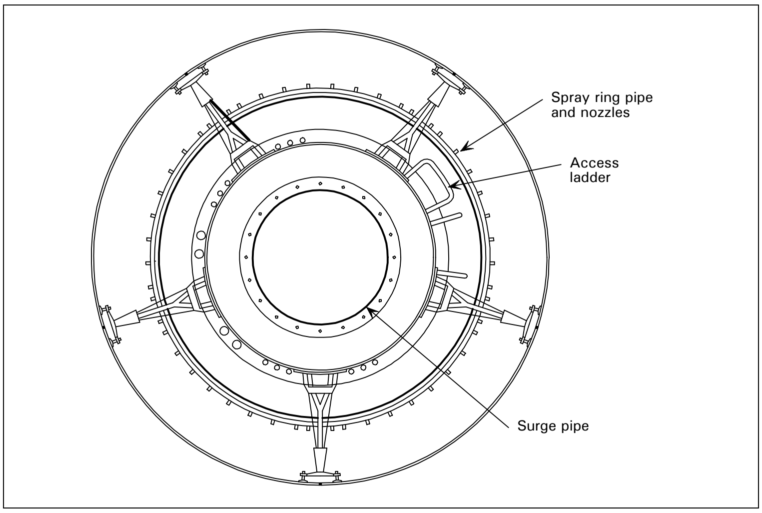


Figure 7
Plan at nozzle level

WATERLOO INTERNATIONAL TERMINAL

London, UK, 1992

Architect: *Nicholas Grimshaw and Partners, UK*
Engineer: *Anthony Hunt Associates, UK*

Techniques
Folding Brake pressing Sand & investment casting Polished, patterned, bead blasted & electropolished finishes Welding Mechanical joints Bonded joints

✦ *Cladding* ✦ *Glazing fixings* ✦ *Handrails/Balustrades* ✦ *Ironmongery* ✦ *Flooring*

Figure 1 *Waterloo International Terminal - aerial view*

Photo: Michael Dyer

General

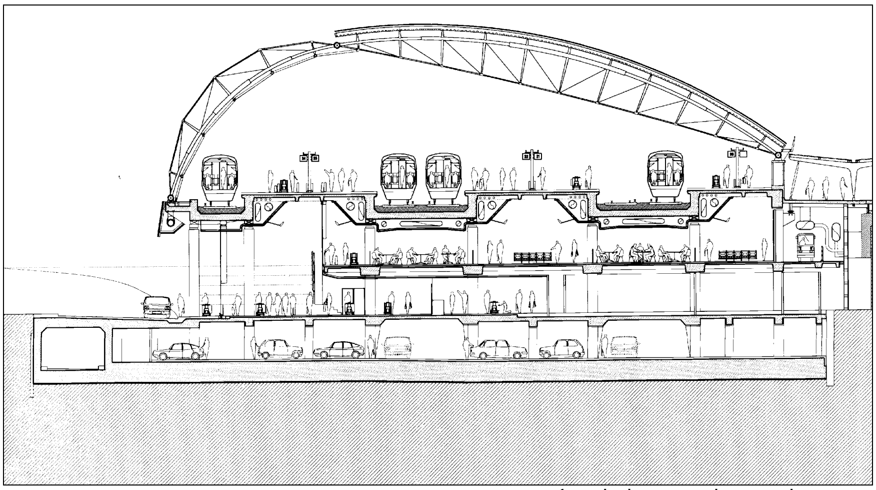
The new International Terminal at Waterloo (Figure 1) is located to the west of the existing Waterloo mainline station and replaces the old Victorian brick vaultings. It comprises a four-storey concrete viaduct accommodating an underground car park, the arrivals, departures, offices and at the top level, just under the roof structure, the train tracks (Figure 2).

The shape of the terminal was dictated by five railway tracks which replaced the old lines. The 400 m long structure (determined by the train length) follows the twisted shape of the tracks and is made up of a series of asymmetric three pinned arches, each comprising two bow string trusses, a “long truss” and a “short truss” (Figure 2).

The architects used stainless steel extensively throughout the terminal. This choice stemmed from the desire to have ‘self finished’ materials which are long lasting, able to withstand the heavy wear associated with large numbers of passengers and able to achieve design lives exceeding 125 years.

Techniques
Folding
Brake pressing
Sand & investment casting
Polished, patterned, bead blasted & electropolished finishes
Welding
Mechanical joints
Bonded joints

Figure 2
Cross section through arrival and departure hall



Courtesy of Nicholas Grimshaw and Partners

Stainless steel roof cladding

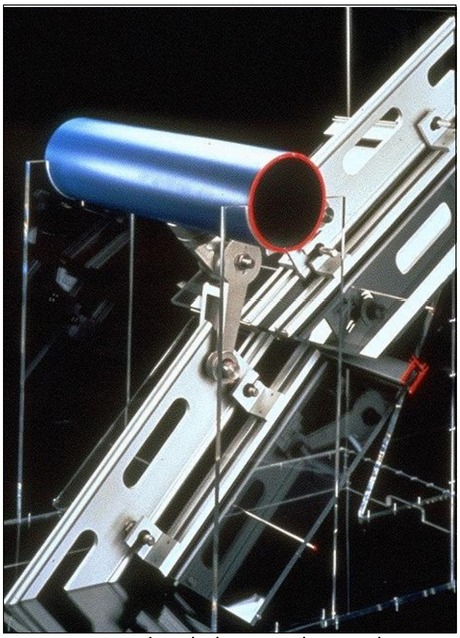
The cladding to the long trusses is formed from grade 1.4401 (316) 0.9 mm thick stainless steel sheets, brake pressed to a trapezoidal profile and laid in a herringbone pattern. The material was given a matt rolled finish prior to fabrication. The cladding spans between the trusses and falls to stainless steel gutters formed from 3 mm rolled sheet (Figure 3). Flashings and cladding fixings were also made from stainless steel.

Figure 3
Stainless steel roof cladding spans between trusses and stainless steel gutters

Photo: Brian Newton

Techniques
Folding
Brake pressing
Sand & investment casting
Polished, patterned, bead blasted & electropolished finishes
Welding
Mechanical joints
Bonded joints

Figure 4
Glazing connection used in the roof cladding



Courtesy of Nicholas Grimshaw and Partners

Glazing connections for west elevation of train shed

The short trusses of the train shed are fully glazed using panels of 10 mm toughened safety glass connected to the tubular chord of the truss. The glass panels overlap by varying amounts and are able to move independently from one another.

Structural movements are accommodated by a special connection that joins the glazing to the structure (Figure 4). The connection comprises four interconnecting grade 1.4401 (316) stainless steel castings (Figure 5). Each of the joints between them is serrated (Figure 6) in order that they can be clamped in position. Vertical movements are taken up by the brackets pivoting at the point of connection to the structure. Lateral movements are taken up at the connection between the panel and the mullion.

Castings were made using the lost wax process (a form of investment casting). They were bead blasted and electropolished to give a very smooth surface finish, ideal for weathering. The choice of grade and surface finish was based on accelerated weather tests. The basic form of the castings was developed by prototyping, first using foam models, then wooden models from which wax patterns were made and the castings produced (Figure 7).

Techniques
Folding
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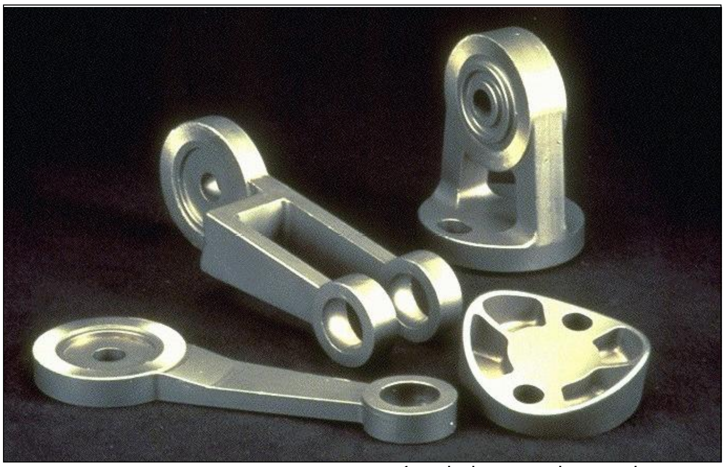
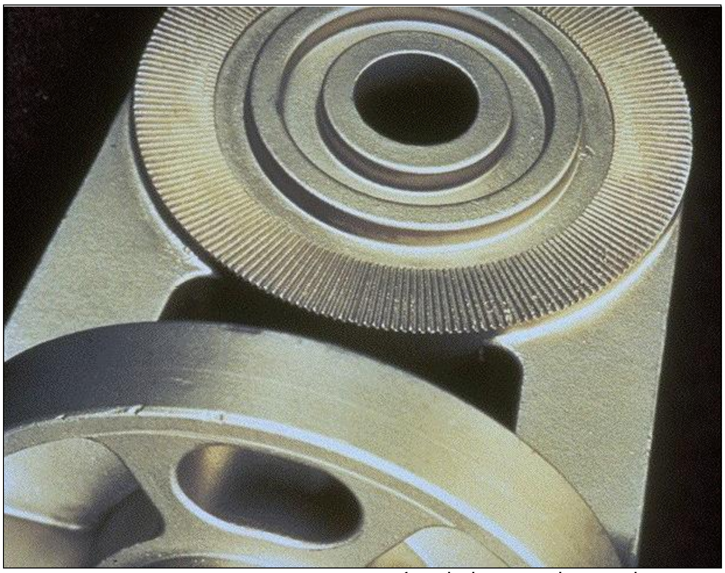
Sand & investment casting
Polished, patterned, bead blasted & electropolished finishes
Welding
Mechanical joints
Bonded joints

Figure 5
The four stainless steel cast components used for the glazing system



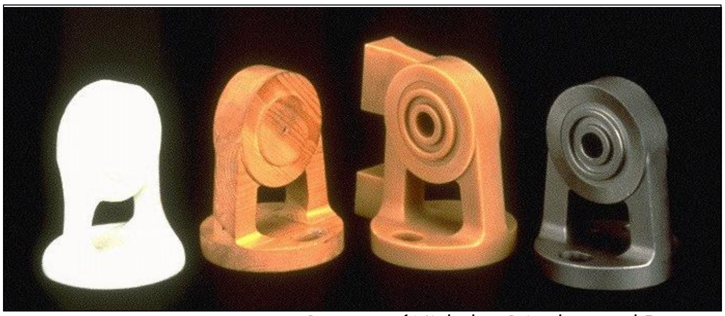
Courtesy of Nicholas Grimshaw and Partners

Figure 6
Close-up showing the serrated joints in a casting



Courtesy of Nicholas Grimshaw and Partners

Figure 7
Prototype stages of cast stainless steel elements (foam, wood, wax pattern and final casting)



Courtesy of Nicholas Grimshaw and Partners

Techniques

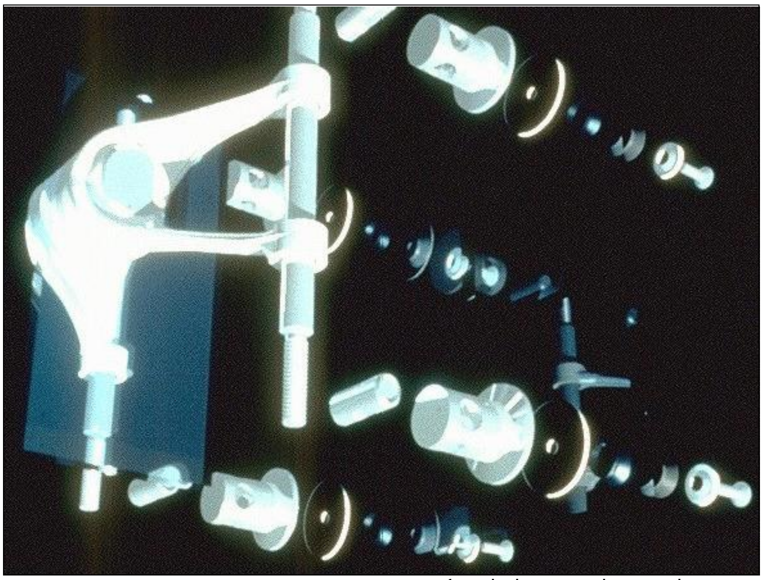
- Folding
- Brake pressing
- Sand & investment casting
- Polished, patterned, bead blasted & electropolished finishes
- Welding
- Mechanical joints
- Bonded joints

Glazing connections - front elevation

The curved wall of the viaduct is made of glass sheets hung from the concrete structure and stiffened by glass fins. This conceptually simple structure has to accommodate a series of complex deflections. These include 55 mm of thermal movement in addition to upward and downward deflections of alternating bays caused by heavy trains.

Three glazing assembly connections were developed using hand sketches and detailed computer models (Figure 8).

Figure 8 *Computer model of glass fin connection assembly*



Courtesy of Nicholas Grimshaw and Partners

The stainless steel components were cast using a lost wax technique and were electropolished. The castings are bolted to glass fins and carry stainless steel rods which can move up and down within the sleeves at the thin end of the arms. The rods are attached to the corners of each glass sheet by bolt assemblies (Figure 9).

At the top of the wall, a 'teardrop' casting allows the glass pane to move up and down and to rotate. An accordion-like gasket at the top allows for movement against the structure.

Techniques
Folding Brake pressing Sand & investment casting Polished, patterned, bead blasted & electropolished finishes Welding Mechanical joints Bonded joints

Figure 9
Glazing connection using stainless steel cast components

Courtesy of Nicholas Grimshaw and Partners

Techniques
Folding
Brake pressing
Sand & investment casting
Polished, patterned, bead blasted & electropolished finishes
Welding
Mechanical joints
Bonded joints

Balustrade

Stainless steel balustrades were specially designed for the terminal (Figure 10, Figure 11). The handrail is cantilevered out by swan neck brackets from the balusters. Brackets were cast using a lost wax process and are electropolished. The baluster has a tapered elliptical section and was sandcast. The section is hollow (cored) to reduce weight and is welded to another lost wax casting which receives the floor spigot. The latter joint is adhesively bonded. The handrail and balusters have a satin finish to avoid grease and marking. The finish was produced by first polishing and then matting down with a fine bead blasting, and coating with aircraft grade wax.

Figure 10
Balustrade

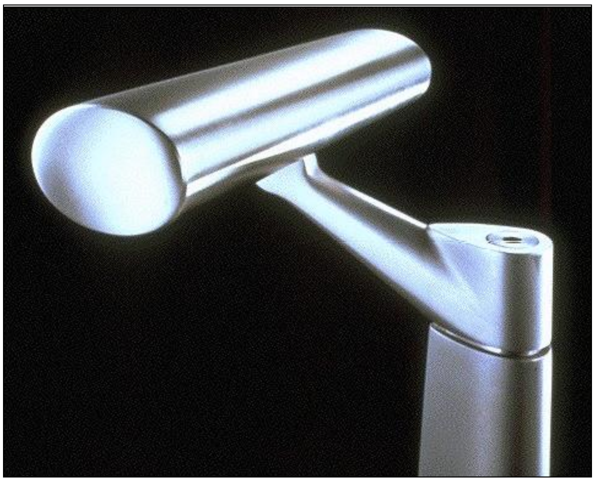


Figure 11
Lost wax casting connects the handrailing to the sand cast baluster

Courtesy of Nicholas Grimshaw and Partners

Techniques
Folding
Brake pressing
Sand & investment casting
Polished, patterned, bead blasted & electropolished finishes
Welding
Mechanical joints
Bonded joints

Ticket check booths

The ticket booths (Figure 12, Figure 13) were designed to have an 'air stream' quality. They incorporate a variety of materials including curved glass and patterned grade 1.4401 (316) stainless steel panels made by a cold rolling process which produces a three-dimensional finish. This increases strength and gives good impact and scratch resistance. The pattern also avoids problems of marking sometimes associated with stainless steel used internally.

Figure 12
Ticket check booths

Photo: Reid and Peck

Figure 13
Ticket check booths

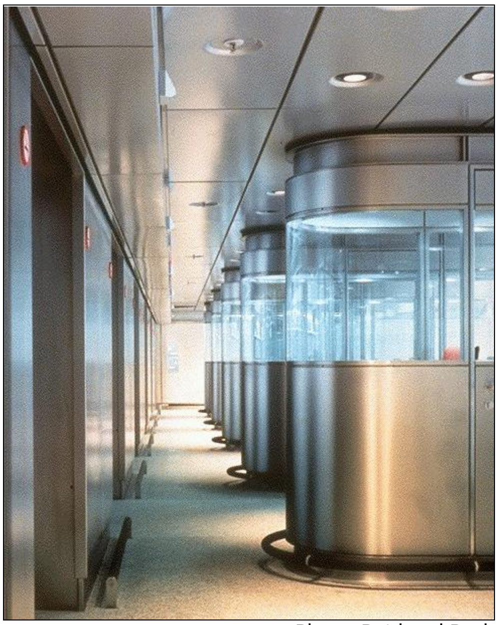


Photo: Reid and Peck

Techniques
Folding Brake pressing Sand & investment casting Polished, patterned, bead blasted & electropolished finishes Welding Mechanical joints Bonded joints

Interior fit-out

Interior doors have stainless steel hinges with concealed self-lubricating bushes. Tubular stainless steel handles were used for circulation doors (Figure 14). These were up to 1800 mm long and 25 mm in diameter. All doors are lined with patterned grade 1.4401 (316) stainless steel panels (Figure 14). Wall trims and skirtings are made from pressed stainless steel with a 240 grit brush finish (Figure 15).

Figure 14
Stainless steel lined doors and door furniture

Courtesy of Nicholas Grimshaw and Partners

Figure 15
Stainless steel wall trims and skirting

Courtesy of Nicholas Grimshaw and Partners

Techniques

- Folding
- Brake pressing
- Sand & investment casting
- Polished, patterned, bead blasted & electropolished finishes
- Welding
- Mechanical joints
- Bonded joints

Telephone

The public telephones are supported on a stainless steel frame made from folded plate with pressed front panels. These can accommodate any company's telephone equipment, allowing for a mix of different operators (Figure 16). All the stainless steel sheet has been finished with a 240 grit brush finish. Double curved toughened safety glass is used as a screen.

Figure 16
The specially designed telephone poles use stainless steel pressed sheets

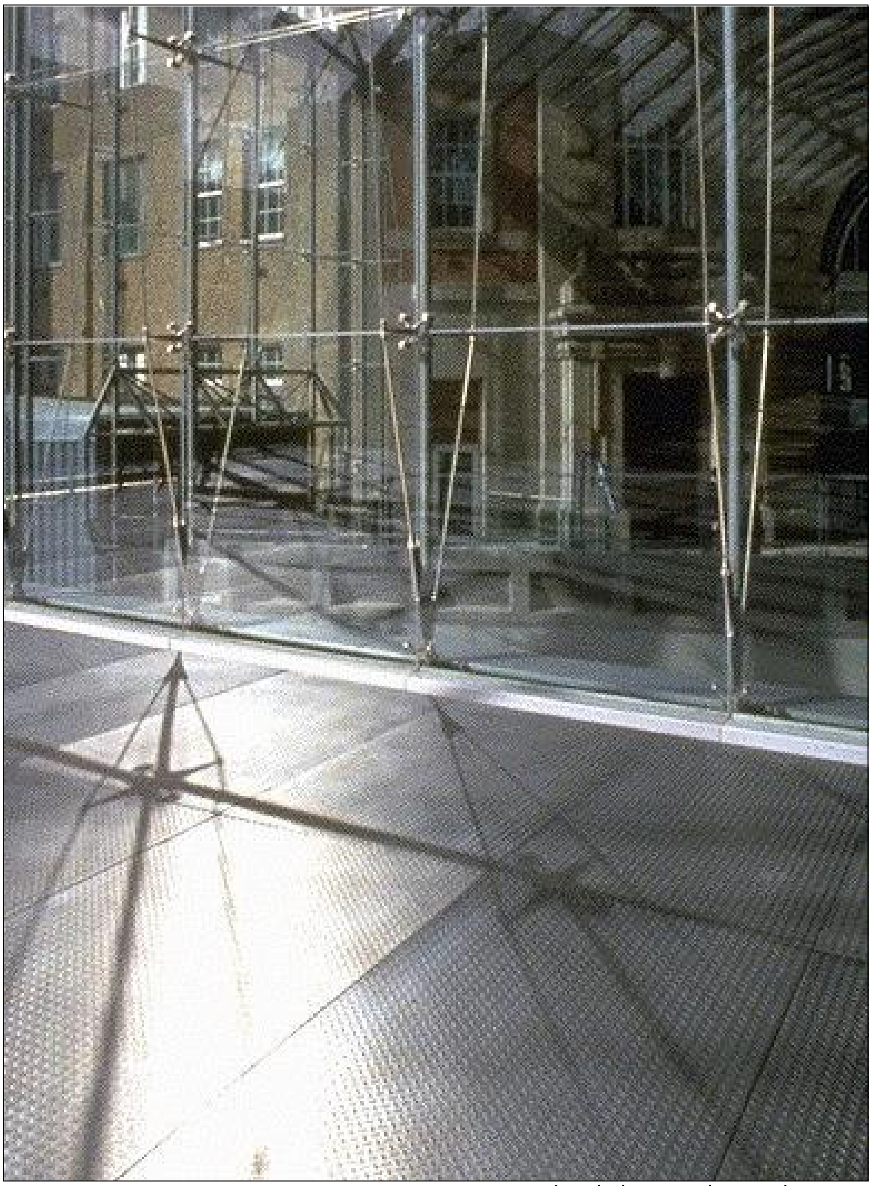
Photo: John Linden

Techniques
Folding Brake pressing Sand & investment casting Polished, patterned, bead blasted & electropolished finishes Welding Mechanical joints Bonded joints

Floor

In many areas of the building, stainless steel chequer plate floor (normally associated with industrial applications) was used (Figure 17). By electropolishing the stainless steel, a high quality, durable finish has been achieved; this looks pleasing with the granite floors and other high quality finishes used elsewhere in the building. Stainless steel flooring was also used for the staircases.

Figure 17
Stainless steel



Courtesy of Nicholas Grimshaw and Partners

Techniques
Folding Brake pressing Sand & investment casting Polished, patterned, bead blasted & electropolished finishes Welding Mechanical joints Bonded joints

Lift cars

The lift car walls are finished with single-sided textured stainless steel lining panels, providing a durable, robust and easily cleaned lift car that also has an air of elegance (Figure 18). Electropolished stainless steel plate was used for the floor of the lift cars.

Figure 18
Lift car

Courtesy of Nicholas Grimshaw and Partners

APPENDIX A. British and European Standards Relating to Stainless Steel

Table A.1 *British and European Standards relating to stainless steel*

Subject	Standard number	Title
Designation	BS EN 10027:1992	Designation systems for steel Part 1: Steel names, principal symbols Part 2: Steel numbers
Flat and long products - material	BS EN 10088:1995	Stainless steels Part 1: List of stainless steels Part 2: Technical delivery conditions for sheet/plate and strip for general purposes Part 3: Technical delivery conditions for semi-finished products, bars, rods and sections for general purposes
	EN 10095 due in 1998	Heat resisting steels and alloys (Stainless steels & nickel alloys)
	BS 970: Part 1: 1996	Specification for wrought steels for mechanical and allied engineering purposes Part 1: General inspection and testing procedures and specific requirements for carbon, carbon-manganese, alloy and stainless steels
Flat and long products - tolerances on dimension and shape	BS EN 10029:1991	Tolerances on dimensions, shape and mass for hot rolled steel plates 3 mm thick or above
	BS EN 10048: 1996	Hot rolled narrow steel strip - tolerances on dimensions and shape
	BS EN 10051:1992	Continuously hot-rolled uncoated plate, sheet and strip of non-alloy and alloy steels - tolerances on dimensions and shape
	EN 10259 due in 1997	Cold rolled stainless and heat resistant steel wide strip and sheet/plate. Tolerances on dimensions and shape.
	EN 10258 due in 1997	Cold rolled stainless and heat resistant steel narrow strip and cut length. Tolerances on dimensions and shape.
Wire	BS 3111: Part 2:1979	Steel for cold-forged fasteners and similar components Part 2: Stainless steels

Table A.1
(Continued)

Subject	Standard number	Title
Castings	BS 3100:1991	Steel castings for general engineering purposes
Wall ties	DD 140: Part 2: 1987	Recommendations for design of wall ties (Note: this publication is a draft for development and should not be regarded as a British Standard)
	BS 1243: 1978	Specification for metal ties for cavity wall construction
Wall ties, straps, hangers, dowels, masonry fixings	BS 5628: Part 3: 1985	Code of practice for masonry: Materials and components, design and workmanship
Cladding fixings, continuous support angles	BS 8298: 1994	Code of practice for design and installation of natural stone cladding and lining
Joist hangers	BS 6178: Part 1: 1990	Specification for joist hangers for building into masonry walls of domestic buildings
Lintels	BS 5977: Part 2: 1983	Specification for prefabricated lintels
Reinforcement bars	BS 6744: 1986	Specification for austenitic stainless steel bars for the reinforcement of concrete
Fasteners	BS 6105: 1981 (equivalent to ISO 3506: 1979)	Specification for corrosion-resistant stainless steel fasteners
Welding	BS 7475: 1991	Specification for fusion welding of austenitic stainless steels
Design of structural members	ENV 1993-1-4:1996	Design of steel structures Part 1.4: General rules; Supplementary rules for stainless steels
Quality Assurance	ISO 9002:1994	Quality systems - model for quality assurance in production and installation

Note:
European standards for tube, forgings, castings, welding consumables, fittings are in preparation.

APPENDIX B. Mechanical and Physical Properties of Stainless Steel Compared to Other Materials

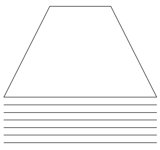
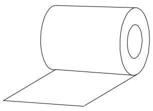
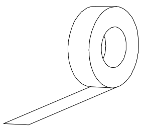
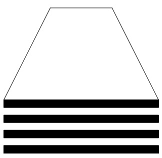
Table B.1 *Room temperature mechanical and physical properties of stainless steel, carbon steel, aluminium and timber*

Steel designation	Density (kg/m^3)	Minimum 0.2% proof strength or yield strength (N/mm^2)	Modulus of elasticity (kN/mm^2)	Thermal expansion 20 - 100°C (10^{-6}/°C)	Thermal conductivity at 20°C (W/m°C)	Heat capacity at 20°C (J/kg°C)
Austenitic stainless steel						
1.4301 (304)	7900	210-230[1)]	200	16.0	15.0	500
1.4401 (316)	8000	220-240[1)]				
Duplex stainless steel						
1.4362 (2304)	7800	400-420[1)]	200	13.0	15.0	500
1.4462 (2205)		460-480[1)]				
Other materials						
Carbon steel (grade 275)	7850	275[2)]	210	12.2	51.9[7)]	486
Aluminium (grade 5251)	2690	60.0[3)] 215[4)]	70.0	24.0	155	850-900
Timber (European beech)		65.0[5)] ('green' condition)	9.80 ('green' condition)	5.00[6)] (along grain)	0.30 (along grain)	10.0-20.0
	720 (12% moisture)	118[5)] (12% moisture)	12.6 (12% moisture)	40.0[6)] (across grain)	0.10-0.20 (across grain)	

Notes:
1) The higher value is applicable to thicknesses up to 6 mm. The lower value is applicable for thicknesses up to 75 mm.
2) Nominal thickness, t ≤ 16 mm.
3) Annealed condition
4) Temper designation H28 to BS 1470
5) Average bending strength from tests on small clear specimens
6) At 0°C
7) In the temperature range 20 - 100°C

APPENDIX C. Product Range

Table C.1 *Approximate size range: flat products*

Item	Process route	Surface finish	Approximate range of dimensions	
			Thickness (mm)	Width (mm)
Sheet, strip and coil	Hot rolled		2.0 to 8.5	1000 to 2032
	Cold rolled	soft annealed 2D	0.25 to 6.35	Up to 2032
		skin pass rolled 2B	0.25 to 6.35	Up to 2032
		bright annealed 2R	0.1 to 2.00	Up to 1250
		brushed	0.4 to 2.0	Up to 1500
		polished	0.4 to 5.0	Up to 1524
		pattern rolled	0.1 to 3.0	Up to 1350
Plate	Hot rolled		3 to 140	1000 to 3200
	Cold rolled		3 to 8	1000 to 2000

Many different companies manufacture stainless steel products and size ranges vary. For actual sizes refer to manufacturers' information.

APPENDIX C. Product Range

Table C.2 *Approximate size range: long products and structural sections*

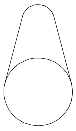
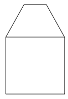
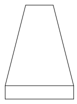
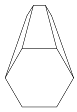
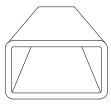
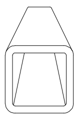
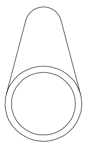
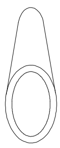
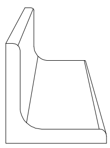
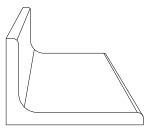
Item	Process route	Shape		Approximate range of dimensions		
				Thickness (mm)	Width (mm)	Diameter (mm)
Bar	Hot or cold finished	Rounds		-	-	2 to 450
		Squares		-	-	3 to 300
		Flats		3 to 25	12 to 150	-
		Hexagons		-	-	5 to 100 AF
Hollow sections	Seamless or welded from strip or plate	Rectangular hollow sections		1 to 8	20x10 to 250x150	-
		Square hollow sections		1 to 8	10x10 to 300x300	-
		Circular hollow sections		0.25 to 60	-	3 to 1500
		Oval hollow sections		1.5 to 3	-	61x37 to 121x76

Table C.2 *(Continued)*

Item	Process route	Shape		Approximate range of dimensions		
				Thickness (mm)	Width (mm)	Diameter (mm)
Structural sections	Hot rolled[1)]	Equal angles		2 to 20	10 x 10 to 180 x 180	-
		Unequal angles		2 to 20	20 x 10 to 200 x 100	-

Note:
1) A range of hot rolled sections (*e.g.*channels, I-sections, angles) are available, but structural sections are generally fabricated by either welding together cold formed plate, sheet and strip or by roll forming.

Many different companies manufacture stainless steel products and size ranges vary. For actual sizes refer to manufacturers' information.

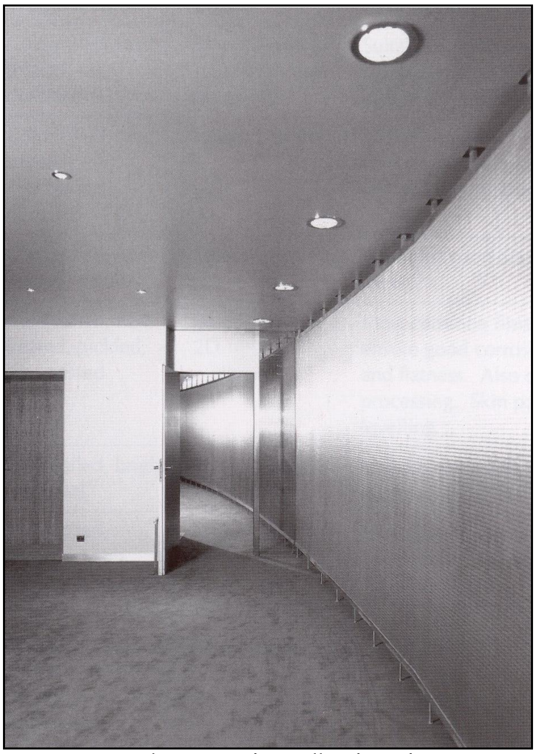
APPENDIX D. Woven Stainless Steel Fabric

Stainless steel multi-strand and single strand wire can be woven to produce fabric-like material. Fabrics are woven using proprietary processes and are available in widths up to 8 m. The weave pattern, the size of wires, the tightness of weave and the combination of wires can all be adjusted to create a wide range of textures and differing degrees of transparency. Many standard stainless steel fabrics are available. Special patterns can be produced, although early consultation with manufacturers is recommended.

Multi-strand wires are considerably more flexible than single strand wires consequently, common stainless steel fabrics tend to have either two sets of single strand wires set at 90° to each other, or one set of single strand and one set of multi-strand wires. The former type is relatively rigid in both directions, the latter is rigid in one direction but flexible in the other. Rigid fabrics can be formed to retain curvature. Flexible fabrics can be draped to curve naturally under their own self-weight.

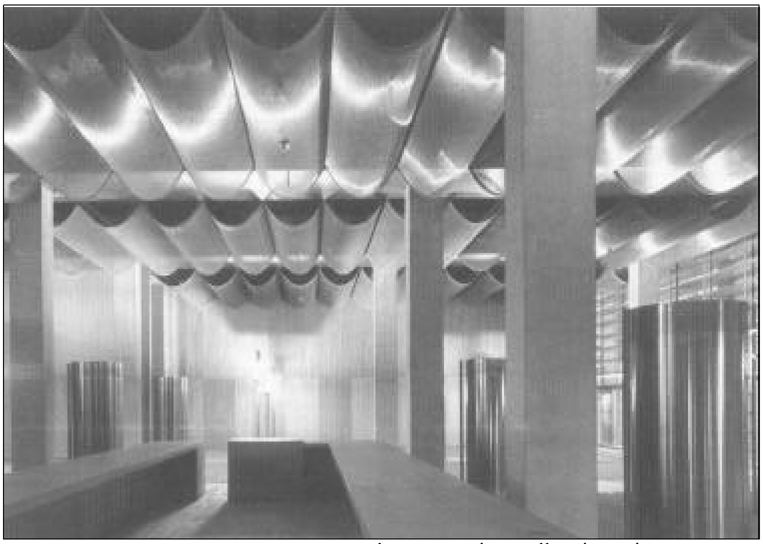
Applications include suspended ceiling and interior screens, sun shades and exterior screens, balustrades, and furniture.

Figure D.1
Wire mesh partition wall at Charles de Gaulle Airport in Paris



Courtesy of GKD - Gebr. Kufferath GmbH & Co. KG

Figure D.2
Wire mesh suspended in the form of arches at the Bibliothèque Nationale de France in Paris



Courtesy of GKD - Gebr. Kufferath GmbH & Co. KG

APPENDIX E. Surface Finish Designations in BS EN 10088

Table E.1
Type of process route and surface finish for sheet, plate and strip: standard finishes[1)]

Abbreviation		Type of process route	Surface finish	Notes
BSEN10088-2[2)]	BS 1449-2[3)]			
1U	-	Hot rolled, not heat treated, not descaled	Covered with the rolling scale	Suitable for products which are to be further worked, e.g. strip for rerolling
1C	0	Hot rolled, heat treated, not descaled	Covered with the rolling scale	Suitable for parts which will be descaled or machined in subsequent production or for certain heat-resisting applications.
1E	1	Hot rolled, heat treated, mechanically descaled	Free of scale	The type of mechanical descaling, e.g. coarse grinding or shot blasting, depends on the steel grade and the product, and is left to the manufacturer's discretion, unless otherwise agreed.
1D	1	Hot rolled, heat treated, pickled	Free of scale	Usually standard for most steel types to ensure good corrosion resistance; also common finish for further processing. It is permissible for grinding marks to be present. Not as smooth as 2D or 2B.
2H	-	Work hardened	Bright	Cold worked to obtain higher strength level.
2C	-	Cold rolled, heat treated, not descaled	Smooth with scale from heat treatment	Suitable for parts which will be descaled or machined in subsequent production or for certain heat-resisting applications.
2E	-	Cold rolled, heat treated, mechanically descaled	Rough and dull	Usually applied to steels with a scale which is very resistant to pickling solutions. May be followed by pickling.
2D	2D	Cold rolled, heat treated, pickled	Smooth	Finish for good ductility, but not as smooth as 2B or 2R.
2B	2B	Cold rolled, heat treated, pickled, skin passed	Smoother than 2D	Most common finish for most steel types to ensure good corrosion resistance, smoothness and flatness. Also common finish for further processing. Skin passing may be by tension levelling.
2R	2A	Cold rolled, bright annealed[4)]	Smooth, bright, reflective	Smoother and brighter than 2B. Also common finish for further processing.
2Q	-	Cold rolled, hardened and tempered, scale free	Free of scale	Either hardened and tempered in a protective atmosphere or descaled after heat treatment.

Notes:
1) Not all process routes and surface finishes are available for all steels
2) First digit, 1 = hot rolled, 2 = cold rolled
3) The surface finish designations in BS 1449: Part 2 (now partly superseded) are also given to help those familiar with the older designation convention.
4) May be skin passed

APPENDIX E. Surface Finish Designations in BS EN 10088

Table E.2
Type of process route and surface finish for sheet, plate and strip: special finishes[1]

Abbreviation		Type of process route	Surface finish	Notes
BS EN 10088-2[2]	BS 1449-2[3]			
1G or 2G	3A	Ground	[5]	Grade of grit or surface roughness can be specified. Unidirectional texture, not very reflective.
1J or 2J	3B/4	Brushed or dull polished	Smoother than ground.[5]	Grade of brush or polishing belt or surface roughness can be specified. Unidirectional texture, not very reflective. Typically specified for internal applications.
1K or 2K	5	Satin polish	[5]	Additional specific requirements to a 'J' type finish, in order to achieve adequate corrosion resistance for marine and external architectural applications. Transverse R_a < 0.5 μm with clean cut surface finish. Typically specified for external applications.
1P or 2P	7/8	Bright polished	[5]	Mechanical polishing. Process or surface roughness can be specified. Non-directional finish, reflective with high degree of image clarity.
2F	-	Cold rolled, heat treated, skin passed on roughened rolls	Uniform non-reflective matt surface	Heat treatment by bright annealing or by annealing and pickling.
1M	-	Patterned	Design to be agreed, second surface flat	Chequer plates used for floors
2M	-			A fine texture finish mainly used for architectural applications
2W	-	Corrugated	Design to be agreed	Used to increase strength and/or for cosmetic effect.
2L	-	Coloured[4]	Colour to be agreed	
1S or 2S	-	Surface coated[4]		Coated with e.g. tin, aluminium, titanium

Notes:
1) Not all process routes a nd surface finishes are available for all steels
2) First digit, 1 = hot rolled, 2 = cold rolled
3) The surface finish designations in BS 1449: Part 2 (now partly superseded) are also given to help those familiar with the older designation convention.
4) One surface only, unless specifically agreed at the time of enquiry and order
5) Within each finish description, the surface characteristics can vary, and more specific requirements may need to be agreed between manufacturer and purchaser (*e.g.* grade of grit or surface roughness)

APPENDIX F. Sources of Further Information

Stainless Steel Advisory Service
The Steel Construction Institute
Silwood Park
Ascot, Berks SL5 7QN
Tel: 01344 23345 Fax: 01344 22944

For queries concerning the application of stainless steel in construction.

Avesta Sheffield Technical Advisory Centre (ASTAC)
Avesta Sheffield Ltd
PO Box 161
Shepcote Lane
Sheffield S9 1TR
Tel: 0114 244 0060 Fax: 0114 242 0162

For queries concerning grade selection, corrosion, product forms and availability.

Nickel Development Institute (NiDI)
42 Weymouth Street
London, W1N 3LQ
Tel: 0171 493 7999 Fax: 0171 493 1555

Nickel Development Institute (NiDI)
European Technical Information Centre
The Holloway, Alvechurch
Birmingham, B48 7QB
Tel: 0152 758 4777 Fax: 0152 758 5562

Nickel Development Institute (NiDI)
214 King Street West - Suite 510
Toronto, Ontario
Canada
M5H 3S6
Tel: 00 416 591 7999 Fax: 00 1 416 591 7987

For queries concerning grade selection, corrosion and end-uses in all industries.

For stainless steel product suppliers, refer to ***Steel Construction Yearbook 1997***, available from SCI.

Design and page make-up by The Steel Construction Institute, Ascot, Berkshire, SL5 7QN
Printed and bound by The Nuffield Press Limited, Abingdon, Oxon, OX14 1RL
1600 - 2/97