euro inox
The European Stainless Steel Development Association

The Forming Potential of Stainless Steel

Materials and Applications Series, Volume 8

Euro Inox

Euro Inox is the European market development association for stainless steel.

Members of Euro Inox include:

- European stainless steel producers
- national stainless steel development associations
- development associations of the alloying element industries

The prime objectives of Euro Inox are to create awareness of the unique properties of stainless steel and to further its use in existing applications and in new markets. To achieve these objectives, Euro Inox organises conferences and seminars, issues guidance in printed and electronic form to enable architects, designers, specifiers, fabricators and end users to become more familiar with the material. Euro Inox also supports technical and market research.

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Contents

About stainless steels

Stainless steels are iron alloys with a minimum chromium content of 10.5% (by weight) and a maximum of 1.2% carbon, necessary to ensure the build-up of a self-healing oxide layer – known as the passive layer – which provides the alloy's corrosion resistance. This is the definition of stainless steels given in EN 10088-1.

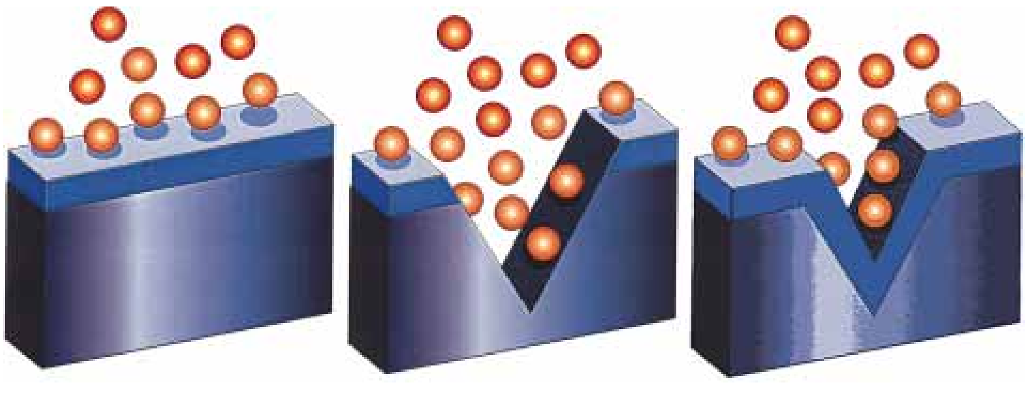
The composition of the alloying elements greatly influences the metallurgical structure of stainless steel and defines four main families of stainless steel, each with its typical mechanical, physical and chemical properties[1]:

- Austenitic stainless steels: Fe-Cr-Ni, C < 0.1 % (non-magnetic)
- Ferritic stainless steels: Fe-Cr (> 10.5 %), C < 0.1% (magnetic)
- Duplex stainless steels: Fe-Cr-Ni, combined austenitic-ferritic structure (magnetic)
- Martensitic stainless steels: Fe-Cr, C > 0.1% (magnetic and hardenable)

These families also include grades containing other elements, such as molybdenum, titanium, niobium and nitrogen. Austenitic stainless steels account for approximately two thirds of the world's stainless steel use. Austenitic grades EN 1.4301/1.4307 (AISI 304/304L) and EN 1.4401/1.4404 (AISI 316/316L), ferritic grade EN 1.4016 (AISI 430) and their variants are the best-known stainless steels and are widely commercially available.

The main properties of stainless steel can be summarised as follows:

- corrosion resistance
- aesthetic appeal
- heat resistance
- low life-cycle cost
- full recyclability
- biological neutrality
- ease of fabrication
- high strength-to-weight ratio



If the stainless steel surface is machined or accidentally damaged, the passive layer instantaneously reforms, in the presence of oxygen from air or water.

[1] Detailed information about the chemical, mechanical and physical properties of stainless steels is available from www.euro-inox.org/technical_tables (an interactive database) or from the printed brochure *Tables of Technical Properties* (Materials and Applications Series, Volume 5), Luxembourg: Euro Inox, 2005.

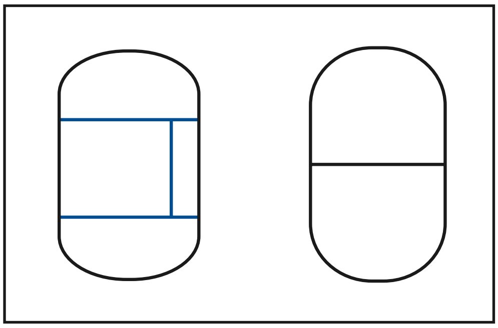
1 Introduction

Stainless steel has considerable potential in forming applications, due to its interesting range of mechanical properties. The material's high strength-to-weight ratio and considerable elongation and work hardening properties mean it can often meet the challenges of complex, three-dimensional, seamless designs.

Since its use in such designs does not impair any of its well-known corrosion resistant, heat resistant and decorative qualities, stainless steel is often the right material choice for both industrial and consumer products.

Production cost involves:
- material cost
- transformation cost

While stainless steel may not always be the cheapest material, production-process simplifications that its use may lead to can largely offset the higher material cost – for example, by reducing the number of deep drawing steps or heat treatments.



Three-piece versus two-piece design.
Photos: AEB, Vimercate (I)

Beer and beverage kegs (typically 20-70 l) can be manufactured in different ways, thanks to stainless steel's versatile mechanical properties. Three-piece designs (left-hand example) are one option, using two dished ends and cold worked stainless steel sheet for the middle section. Cold working cold rolled stainless steel enhances its mechanical properties. The use of such sheet for the middle section will improve the keg's strength or make thinner walls possible at equal strength. This design may be preferred if weight reduction is a key criterion.

Alternatively, stainless steel's forming capacity allows two-piece designs (right-hand example), composed of two identical deep drawn halves. This design is preferable when reduction of welds is the driving parameter. Apart from its forming potential, stainless steel is often the most appropriate material for contact with food, as it easily complies with European Food Safety Regulations.

2 Mechanical properties

Assessing the forming potential of any material requires understanding its mechanical properties. The most commonly used mechanical evaluation criteria are:

Strength: the degree of resistance of a material to deformation. Depending on structural considerations, deformation can be defined as either:

- "yielding" or permanent plastic deformation (hence "yield strength" R_p), or
- "breaking" or rupture (hence "tensile strength" R_m)

Hardness: the degree of resistance to permanent indentation by an applied load.

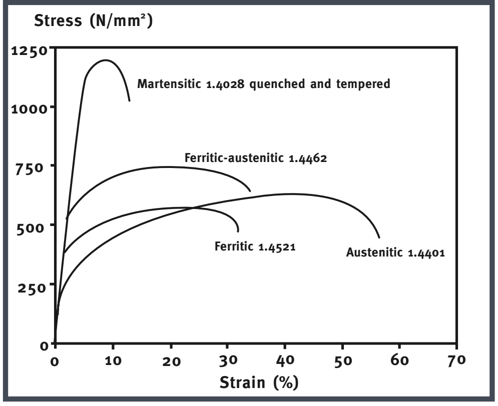
Toughness: the capacity to absorb deformation energy before fracture.

Ductility: the ability to deform plastically without fracturing.

The concepts "strong" and "weak", "hard" and "soft", "tough" and "brittle" define different aspects of a material's mechanical properties and should not be confused. Some of these properties can be measured by a tensile test. A typical plot of the results of a tensile test for various stainless steels measures stress (related to "strength") according to the amount of strain applied.

The end point of the curves corresponds to the degree of elongation at fracture and is a measure of the material's ductility. The area below each curve indicates how much energy the material absorbs before it breaks — and is thus a measure of its toughness.

Stress-strain curves for different types of stainless steel.



Martensitic steels have high strength and rather low ductility (or formability) whereas austenitic steels have lower strength and high ductility. Ferritic-austenitic (or duplex) and ferritic steels occupy an intermediate position. The yield strength of ferritic steels is generally higher than that of austenitic steels, while the yield strength of duplex is considerably greater than that of both ferritic and austenitic grades. Ferritic and duplex steels have similar ductility[2].

With the exception of martensitic stainless steels, the typical relationships shown in the graph are valid for the annealed condition, in which stainless steels are usually supplied. For completeness' sake and in order to fully grasp the forming potential of stainless steel, it should be noted that the material's mechanical properties depend on:

- chemical composition
- heat treatment (for martensitic stainless steels)
- cold working (for austenitic and duplex stainless steels)

The latter property refers to the fact that high levels of strength can be reached by

[2] More information about the specific testing of hardness and toughness (also referred to as "impact resistance") of stainless steels can be found in: CUNAT, Pierre-Jean, *Working with Stainless Steel* (Materials and Applications Series, Volume 2), Paris: Sirpe, 1998.

cold working stainless steels. Indeed, this "strain hardening" behaviour distinguishes these steels from most other metallic materials. Cold worked austenitic and duplex stainless steels therefore generally offer an interesting combination of strength and formability, in terms of weight-saving potential.

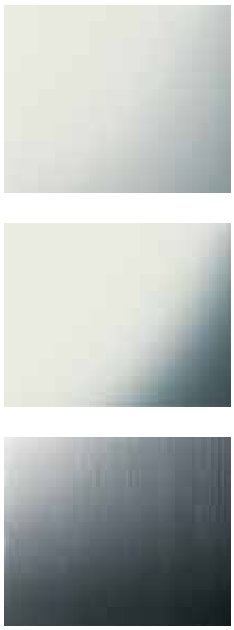
3 Forming potential

To illustrate the forming potential of stainless steel, we present nine case studies of domestic and industrial stainless steel designs. Each case study briefly describes:

- the principles of the forming operation
- the material requirements of the designed product
- the properties that make stainless steel eligible
- the actual fabrication of the product using stainless steel

4 Surface finish

Usual finishes suitable for forming: 2B, 2R and 2G/2J.



European Standard EN 10088-2 gives information about available finishes (and their terminology) for stainless steel. The most commonly found finishes and their typical thickness ranges in forming applications are:

- cold rolled slightly reflective 2B (0.40 – 8.00 mm)
- cold rolled highly reflective (bright annealed) 2R (< 3.00 mm)
- cold rolled polished (2G) or brushed (2J)

Hot rolled (1D; > 2.00 mm) and cold worked (2H; < 6.00 mm) finishes are also used.

Strong deformation typically destroys decorative surfaces. In the case of stainless steel, however, relatively complex shapes can often be achieved without the need for post-fabrication dressing (mechanical finishing). For instance, some low-cost stainless steel sinks are made directly from bright-annealed (2R) stainless steel sheet without any additional polishing. The fact that the surface finish survives the forming operation makes the combination of the material and the forming-technique cost-effective.

[3] This publication is intended to indicate selected processes that make optimum use of stainless steel's forming potential. Information about companies that can carry them out is available from Euro Inox or its members.

[4] See Annex B of *Guide to Stainless Steel Finishes* (Building Series, Volume 1), Luxembourg: Euro Inox, 2000.

5 Hydroformed nodes for automotive frames

Hydroforming makes it possible to create complex shapes from tubes. It involves:

- inserting a stainless steel tube in the die
- sealing both ends
- filling the tube with fluid (usually water or oil)
- exerting pressure on the stainless steel through the combined effect of the (radial) fluid pressure and (axial) compression of the tube ends

The process, which can be used to form almost any complex shape, has the following advantages over conventional techniques:

- intact part surface (no galling from punch or staining by lubricant)
- tighter shape tolerances

The assembly advantages of hydroformed nodes include:

- replacement of conventional welded assembly of complex cut tubes
- separation of welded seam and cutting (metallurgical variation and mechanical variation are thus in separate areas)

Benefits include:

- standardization of manufacture
- modular solutions
- higher stiffness and strength leading to weight reduction
- cost reduction

Manufacturing automotive frame nodes

Metallic "space frames" (top left-hand image) are being considered as solutions for building car bodies. In fact, bus manufacturers have been applying this principle for years, using a frame of welded stainless steel tubes. Traditionally, this has involved the use of joints made by bending, cutting and welding (top right-hand image).

Model: P-J Cunat, Joinville-le-Pont (F)

Photo: HDE Solutions, Menden (D)

Hydroforming tool and photograph: Arcelor Centre Auto-Applications, Montataire (F)

New space frame parts with hydroformed nodes Photo: Ugine & ALZ, La Plaine Saint-Denis (F)

Deformation behaviour of stainless steel during hydroforming

During hydroforming, some areas become widely deformed, leading to “strain hardening” of the metal. This extra benefit of stainless steel enhances the mechanical properties of the component, improving both its static and its fatigue behaviour.

The deformed areas, where stress is maximal, are located away from the welded areas. This is the exact opposite of classical assembly, where the welded areas are also the most critical areas.

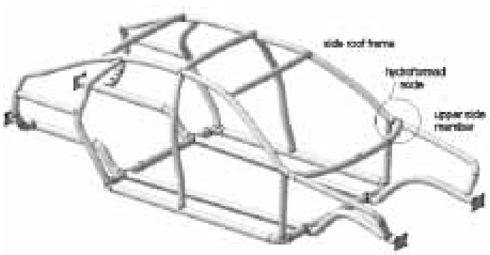
Hydroformed node
Photo: HDE Solutions, Menden (D)

Advantages of the hydroformed stainless steel node

The assets of combining hydroforming and stainless steel include:

- better axial alignment
- perfect perpendicularity (no risk of thermal distortions following welding)
- possibility of automated welding (to the node rather than within the node)
- better thickness/geometric accuracy
- better distribution of tensions

Result: fewer parts, less scrap, fewer dies and less material, leading to cost reduction.



Model and photograph: Ugine & ALZ, La Plaine Saint-Denis (F)

6 Hygienic design through seamless surfaces

Design requirements applicable to kitchen utensils intended for contact with food include:

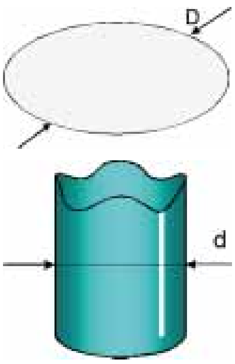
- hygienic, easy-to-clean surfaces
- efficient heat distribution (for cooking), yet burn-free handgrips
- resistance to impact and wear

Beyond technical aspects, lifestyle considerations add finish and shape requirements to the list. The fabrication process of a designer cooking pot illustrated below shows why stainless steel has been the material of choice to meet these challenges for decades.

Transformation of a flat metallic disc into a hollow body

Surprisingly enough, the fabrication of this elegant container starts from a flat disc, 1 mm thick and about 400 mm in diameter. Grade EN 1.4301 with a cold rolled 2B surface (as supplied by the mill) will absorb the considerable strain applied by the press or presses involved. The diameter of the disc is reduced by half during this process – which is roughly the limit of the material's forming capacity[5].

Stainless steel can accommodate deeper shapes, provided its plastic deformation capacity is restored. This is done through an intermediate heat treatment (annealing) above 1000° C. At these temperatures, stainless steel surfaces are oxidised. As this blackened surface would contaminate tooling downstream of the presses and make polishing more difficult, a chemical surface treatment is carried out to remove it and restore the passive state of the surface. The restored cylindrical shape can now be deep drawn into greater lengths.



The Limiting Drawing Ratio (LDR) = D/d. Typical LDR values for stainless steels are between 1.8 and 2.

[5] Limiting Drawing Ratio (LDR) refers to the quotient of the maximum blank diameter (D) that can be deep drawn into a cylinder in one step and the diameter (d) of that cylinder.

From shaped volume to designer item

To make it suitable for induction heating, the bottom of the pan is fitted with a disc of ferritic (Cr) stainless steel. The latter is magnetic, unlike the austentic (Cr-Ni) stainless steel of which the body is made.

For optimum heat distribution, an aluminium disc is inserted between them. The three parts are tightly fixed together by a punching and brazing operation.

Although the matt appearance of the starting disk has none of the glossy look of designer cookware, its surface roughness is sufficiently low to make post fabrication finishing efficient.

Once the main assembling steps are completed, the pan body can be ground and polished. A variety of abrasive grain media, Scotch-Brite™ pads and buffing pastes (for final finishing) are available.

The forming of stainless steel is not limited to cylindrical shapes. A more complex, curved profile (left of picture) can be given to the cylinder (right) with the help of a two-piece metal die, of the required final shape, and a punch (centre) made from a series of hard polymer discs of varying properties.

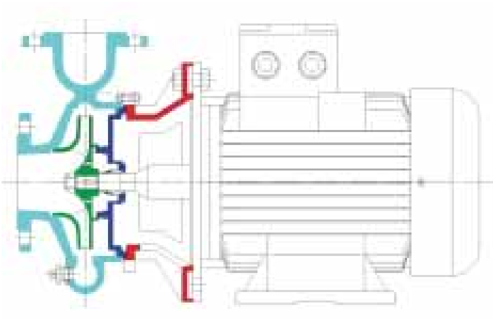
A versatile material for hygienic designs

Thanks to its welding, forming and finishing properties, stainless steel easily meets the requirement that cooking utensils feature seamless (hygienic) design, non-stick surfaces, long-term rigidity, suitability for induction heating, etc. The use of such shapes can be extended beyond kitchenware into other applications of hygienic design.

Handgrips, made from round or flat bar, are welded to the pan's body. By minimising the contact surface and using austenitic stainless steel (which has lower thermal conductivity than other steels) they are optimised for safe, burn-free use.

Photos: Zani Serafino, Lumezzane (I)

7 Pump efficiency through hydroformed casings



The main parts of a typical centrifugal pump

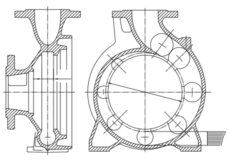
A centrifugal pump increases the energy (created by a motor) of the fluid running through it, displacing the fluid and increasing its pressure. Its main parts are:

- an electric motor and a shaft
- a fixed casing (light blue)
- a rotating impeller (green)
- a seal (blue) and a support (red)

The impeller transforms the energy of the motor into the energy of the fluid (the latter being the sum of pressure, kinetic energy and potential energy).

The hydraulic purpose of the casing is to guide the fluid into the impeller on the inlet side, separate the low pressure from the high pressure zone and guide the fluid leaving the impeller to the outlet, further increasing its pressure through decreasing its speed. From a mechanical point of view, the casing has to resist the operating pressure, support the pump (depending on the model) and accommodate strains from the connected piping.

The role of the spiral case



Spiral case design

In order to further increase the pressure of the fluid as it leaves the impeller blades, the casing features a spiral case, the cross-section of which grows as the spiral develops. This allows the fluid's speed to decrease (necessary to increase its pressure) with the least possible friction loss. Fabricating a metallic spiral case that respects these complex design principles appears quite challenging.

From castings to deep drawn casings

The traditional approach is to use cast iron, steel or bronze castings for the casing. Recently, casings made by deep drawing stainless steel have become available, combining the superior strength-to-weight ratio and excellent forming properties of stainless steel to produce a lightweight yet mechanically resistant product.

Cast iron casing

Stainless steel casing involving deep drawing

Benefits of using stainless steel

Stainless steel casings ensure:

- absence of contamination (e.g. of drinking water) by the casing material

Centrifugal pump with stainless steel casing

- corrosion resistance in a wide range of mildly aggressive media

- reduced weight through enhanced mechanical properties (resulting in compact, easy-to-handle pumps)
- attractive surface appearance and ease of maintenance
- higher pump efficiency through smooth surface

Benefits of using hydroforming

Pump casing made from a deep drawn stainless steel blank. The inlet is located on the front and the fluid leaves the casing through a hydroformed orifice at the top.

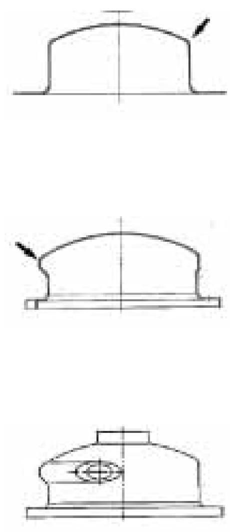
Casing designs can range from very simple (a circular cross-section) to quite complex (incorporating the spiral case). The latter, usually fabricated by welding two halves together, offer improved pump efficiency. Hydroforming, however, makes it possible to integrate the spiral case into a stainless steel casing design and have only one part – thus avoiding welds and lowering the risk of corrosion.

The spiral case is integrated into the pump casing by hydroforming. The outlet orifice is carefully finished to improve operating efficiency.

Production of a hydroformed stainless steel pump casing

Starting with a circular, stainless steel blank (from 1.5 to 3 mm thickness, depending on the model), the following operations complete the casing:

- deep drawing, to give the casing the necessary volume
- hydroforming the spiral case using >1000 bar water pressure
- drilling and milling the orifices
- welding the fittings and support to the outside



Casing manufacturing steps: deep drawing, hydroforming, drilling and dressing, fitting

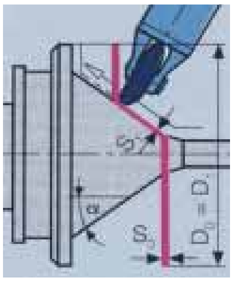
8 Metal spinning for exclusive designs

Metal spinning is a forming process involving no material loss. It requires:

- a circular metal blank or a deep drawn preform
- a spinning roller
- a lathe-mounted die of circular symmetry

The blank is stretched over the die in stages while both die and blank are being driven by the lathe. Because of the high pressures involved, lubrication is important, to prevent the workpiece sticking to the die, which can cause surface damage.

Diagram: Leifeld Metal Spinning, Ahlen (D)



This lathe spinning process generally involves less capital investment, less tooling, set-up and switching costs and less energy consumption than does the drawing press process. However, since its productivity is low, it is more suitable for prototyping and small series. The process is carried out without any attempt to thin the metal.

Alternatively, conical shapes can be formed in a single step, provided there is a minimum opening angle of about 12° (less, if more steps are involved). The diameter of the open end of the cone corresponds to the initial diameter of the disc, so a degree of wall thinning (depending on the angle) takes place. This process is referred to as power spinning, shear forming or flow turning.

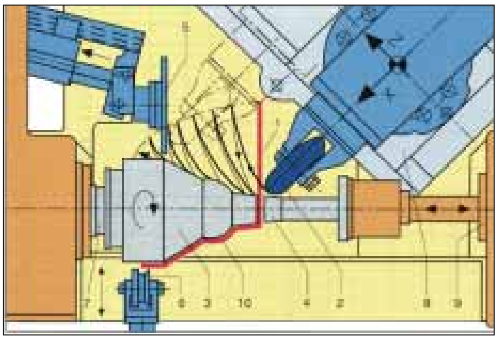


Diagram: Leifeld Metal Spinning, Ahlen (D)

As an alternative to classical forming processes such as deep drawing or stretching, spinning is ideal for conical or cylindrical shapes. Such shapes are commonly found in everyday domestic items and even in industry. Considerable height/diameter ratios can be obtained, starting from just a two-dimensional stainless steel disc.

Photo: ThyssenKrupp Nirosta, Krefeld (D)

Lathe spinning stainless steel

The force exerted by the tool results in compressive stresses in the stainless steel blank, causing rapid work hardening and consequent reduced formability. Spinning is therefore mainly used with only limited thicknesses. The process ideally suits grades with low yield strength and a low work hardening rate, which is the case of ferritic grades (e.g. EN 1.4016) and some austenitic steels (referred to as "stable" austenitics) that work harden slowly, such as EN 1.4301 or, to a higher degree, EN 1.4303.

Lathe spinning produces stainless steel shapes with a high degree of circular symmetry. As a consequence, post fabrication polishing of these workpieces can usually be carried out cost-effectively.

A designer stool foot made of stainless steel

A bar stool is a product with high circular symmetry. Since the stool's foot must be heavy enough to provide stability, ferrous metals (mild or stainless steel) are more suitable for this part than aluminium, which has a density of only one third that of steel alloys. The foot being a part requiring regular cleaning, painted-steel feet tend not to last very long: regular use of cleaning products causes the paint to wear off, resulting in unsightly pieces of designer furniture.

Making stool feet by metal spinning of stainless steel has proved an excellent solution to this problem. The high circular symmetry of spun stainless steel products facilitates automated post fabrication polishing or buffing, as shown by the stool foot illustrated.

Finishing the smooth, cold rolled surface of stainless steel does not require costly preparation.

A bar stool has high circular symmetry. The stainless steel foot is resistant against aggressive cleaning products.
Photo: Thate, Preetz (D)

Photo: Thate, Preetz (D)

9 Decorative wheel rims made by spinning

Car owners with a penchant for the exclusive are increasingly seeking to customise their vehicles to personal taste. Designer wheel rims are just one expression of this trend. Lathe spinning being an appropriate forming process for small series, stainless steel rims made using this technique offer the following advantages:

- high strength-to-weight ratio (enabling light structures)
- increased strength through cold working
- smooth cold rolled surface, facilitating polishing

- higher corrosion resistance than traditional metals
- absence of painted coating (which can chip)

Assembly of a typical designer wheel

Designer wheel made of three parts: the star hub (top), the inner rim (middle) and the outer rim (bottom). The latter is made of stainless steel, which offers a combination of high-strength, light weight and surface smoothness.

Decorative car wheels can be made from two or three parts, depending on the model. A three part model features:

- a star hub (mostly in cast aluminium)
- an inner rim (mostly in cast aluminium)
- an outer rim (potentially in stainless steel)

The star hub is bolted to the inner rim through the outer rim, using noble alloy bolts to avoid galvanic corrosion.

The stainless outer ring is formed through lathe spinning, followed by automated polishing. Apart from providing a visually attractive surface, the polishing

Assembly of the star hub through the stainless outer rim onto the inner rim.

increases the corrosion resistance of this part, which will be exposed to varying atmospheric conditions, potentially including salt spray.

For the manufacturer, using stainless steel avoids having to carry out an environmentally unfriendly final surface treatment of the outer rim.

Spinning of the outer stainless steel rim

The outer rim is shaped from a circular stainless steel blank. These can be bought directly from the supplier or cut from square blanks.

For ease of fabrication, assembly holes are made before spinning takes place. The blank is mounted on a lathe against a circular die. The forming roll exerts pressure on the blank, which increasingly adopts the shape of the die. Progressively, more rings are added to the lathe, enabling the blank to be increasingly formed. Appropriate lubricants must be used.

During cold forming, stainless steel gets stronger (a phenomenon known as work hardening). While too much of this effect will make spinning difficult, work hardening contributes more than the properties of any other traditional alloy to the strength of the outer rim, which will have to absorb shocks from hitting unexpected bumps while driving.



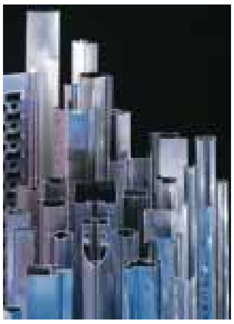

Lathe spinning of the outer stainless rim. The stainless steel will increase in strength during forming, offering interesting potential for shock absorption.

Superior strength of stainless steel wheels

Austenitic stainless steels have interesting mechanical properties. Not only do they already possess high tensile (R_m) strength, but cold forming processes like spinning – plus the subsequent shaping of the edge of the outer rim – will actually increase their mechanical resistance. As well as keeping the rims free from damage by gravel projection, this feature also makes stainless steel a highly suitable material for a designer item susceptible to accidental contact with the stone pavement.


Photos: Schmidt, Bad Segeberg (D)

10 Cold rolled sections for superior strength



Section rolling is a well-known production method for obtaining long, often complex metallic shapes from metal strips. If the process is taken into account at design stage, considerable cost reductions can be achieved in production through, for example, avoiding welded assemblies of C- and/or U-shaped subsections. Section rolling is a good way to combine several functions in just one section: cable transport, cooling, fixation, etc.

Traditionally, section rolling provides solutions for the building industry (window and door frames), the transportation industry (trucks, buses and railcars) and the engineering and office-furniture industries. But other sectors (such as automotive) are also emerging, due to the remarkable capacity of section rolling to add value by integrating different functions in a single structural element.

Section rolling of stainless steel strips

The section rolling process looks quite similar to a tube mill. A line of forming units (each consisting of hard forming rolls with

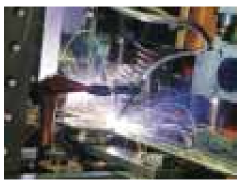
an individually machined shape) transforms strip metal (usually in widths < 1000 mm) into a section, that can be welded into a closed section or left open at the end. Stainless steel can be formed in this way in a thickness range between 0.40 and 8 mm, to gradually exploit its exceptional ability to absorb plastic deformation. This gradual forming process enhances stainless steel's mechanical properties, making possible sections of superior strength and complex shape.

The greater the number of forming stations, the more gradual is the absorption of plastic deformation and the less the tension generated in the material. This can be important for meeting dimensional tolerance requirements during assembly.

Adding value for a variety of end uses

To add value to a section, the rolling process can be completed by such operations as:

- drilling hole patterns
- welding supports
- bending or stretching to produce three-dimensional profiles



Photos and text: Welser Profile AG, Gresten (A)

Stainless steel sections for passenger railcar bodies

Passenger railcars traditionally consist of an underframe and a body. The body is made of materials such as painted carbon steel, aluminium or stainless steel. The stainless steel components can be section rolled from strips supplied by mills in thicknesses ranging from 0.40 to over 6 mm.

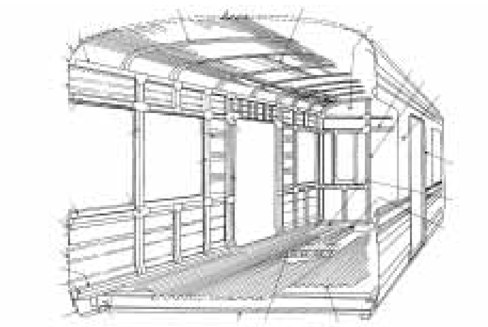


Illustration: Nickel Institute, Toronto (CDN)

Weight-saving potential of stainless steel for passenger railcars

Grade 1.4301 can be used but 1.4318 (with added nitrogen and lower nickel) offers superior initial mechanical properties. Moreover, the mechanical properties of this grade are enhanced if the stainless steel strips are strengthened (cold worked) by the mills before section rolling[6]. The use of stainless grade 1.4318 for section rolling therefore holds unprecedented weight-saving potential for railcar posts, beams and frames.

Lighter railcar bodies obviously consume less energy during acceleration and deceleration – an especially obvious asset in the case of local trains that stop and start at short intervals.

Considerable weight-saving potential is offered by the combined use of:

- stainless steel (instead of carbon steel)
- grade 1.4318 (for superior strength through work hardening)
- section rolling

Photo: Ugine & ALZ Belgium, Genk (B)

Other benefits of using stainless steel for passenger railcar bodies include:

- low maintenance (no need to paint bodies)
- long life cycle (no long-term thickness reduction through wear)
- increased fire safety compared to other (light) metals
- increased crashworthiness (due to the mechanical properties)

Photo: Outokumpu, Espoo (FIN)

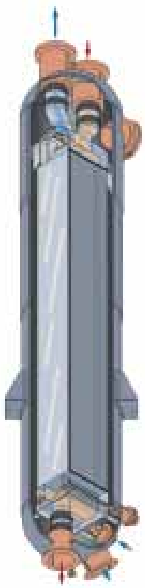
[6] Detailed information is available on the Euro Inox CD-ROM, *Stainless Steel for Structural Automotive Applications – Properties and Case Studies* (Automotive Series, Volume 1, Release 3), Luxembourg: 2006

11 *Explosion formed heat exchanger plates*

Explosion forming uses the high dynamic pressure of a shockwave to press a metal sheet into the form of a die, at high speed. The process is usually carried out with the explosive charge in water, at a certain standoff distance from the part to be formed. The shockwave acts as a punch. Compared to more traditional methods of forming, the advantages of explosive forming make possible:

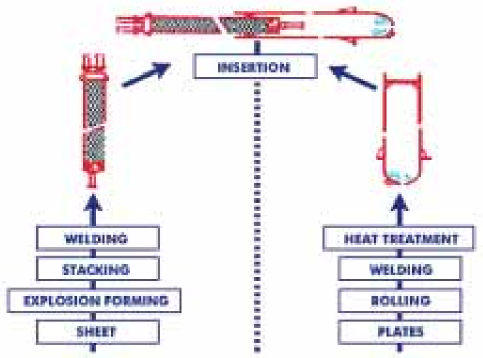
- working with large sheet sizes (thanks to the use of explosives)
- using high sheet thicknesses (> 10 mm in the case of Ni alloys)
- elaborate shaping possibilities (reducing operations such as welding and heat treatment)
- products with high mechanical resistance
- highly accurate dimensions

Large plate heat exchangers



Large welded plate heat exchangers (PHE) are typically found in oil refineries and in the petrochemical industry. Demanding heat-exchange requirements necessitate a large contact surface, combined with efficient heat transfer at high temperature. If the contact surface exceeds several thousand square meters, a single PHE of this size will prove more economical than a single shell and tube heat exchanger (or even a series of them).

PHEs typically consist of hundreds of explosion formed stainless steel sheets. These single sheets are between 0.8 and 1.5 mm thick and can be as wide as 2 m and as long as 15 m. After sheet-by-sheet explosion forming, they are stacked and welded



together into a bundle. The chevron-shaped corrugations of the plates create a turbulent flow pattern of crossing fluids that ensures high heat-transfer efficiency.

The bundle is inserted into a pressure vessel complying with applicable construction

codes. Connection between bundle and vessel is by expansion bellows.

Advantages of using stainless steel

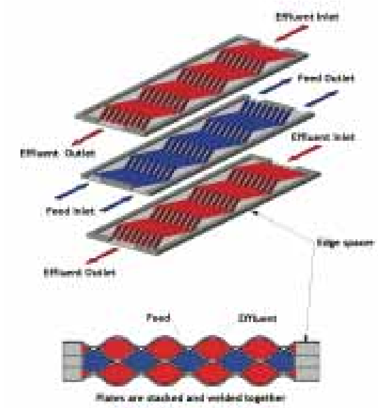
The material provides several benefits:

- Typical process temperatures in a PHE range from 300 to 550 °C (peaking at 650 °C). These present no problem for grades such as EN 1.4541 (AISI 321).
- Stainless steels resist typical intended working pressures of up to 120 bar and inlet/outlet pressure differences of 40 bar.
- The use of high forming speeds (up to 120 m/s) in explosive forming has an extra strain hardening effect on stainless steel corrugated plates.
- The corrugated pattern (causing turbulent flow) combined with low surface roughness (which is not impaired by the forming process) limits the risk of clogging ("fouling") and low heat-exchange efficiency.
- Appropriate grade selection reduces the risk of corrosion caused by, for example, sulphur-bearing fractions of oil products.
- Conventional welding techniques can be used to tightly seal the stack of corrugated plates.

A successful combination

Neither explosion forming nor stainless steel itself qualify as innovations. But the development of large plate heat exchangers that fully exploit the sizes and properties of stainless steel and the process of explosion forming is a significant cost-saving asset in the day-to-day operation of the refining, petrochemical and gas treatment industry.

This solution is beneficial both in the case of investment in new units and in process-optimization revamps.

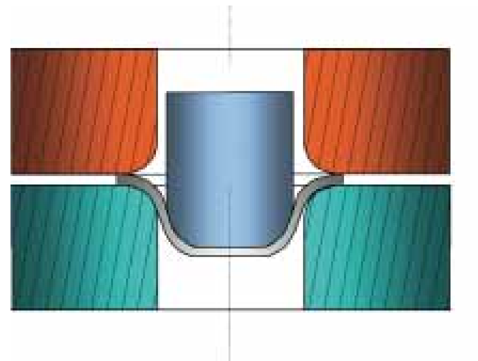


Photos: *Alfa Laval Packinox, Chalon-sur-Saône (F)*

12 Deep drawn locknuts for wheel decoration

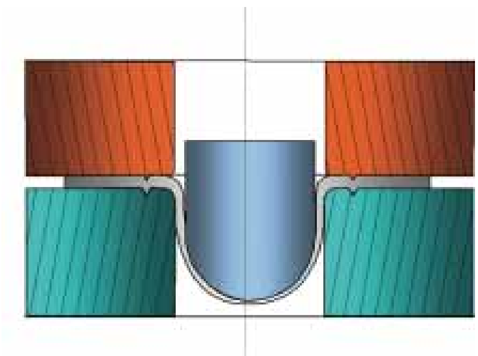
Stainless steels generally show excellent forming properties. While most forming is done with austenitic (Cr-Ni) stainless steel, ferritic (Cr) grades also qualify for certain forming operations, provided the metal is not simply being stretched. The difference between (deep) drawing and stretching is explained below.

Drawing



- metal flows freely into die
- deformation of large circle into narrow cylinder must come from width rather than thickness (= high anisotropy "r"[7])

Stretching



- metal held by the blankholder
- considerable thickness reduction
- high elongation (A%) and hardening (n) required

In practice, the forming mode is usually a combination of stretching and forming, which explains the frequent use of austenitic grades.

Drawability of ferritic grades

Ferritic grades have slightly higher LDR values (see page 8) than austenitic grades, which makes them especially suitable for drawing applications.

"Roping" is typical of ferritic grades. Special ferritic grades are available, however, that contain titanium or niobium and have been produced under strict rolling and annealing conditions to avoid roping and improve deep drawing properties.

Deep drawn cylinder in standard ferritic grade EN 1.4016 (above), showing the "roping" effect, and in austenitic grade EN 1.4301 (below). Roping is unsightly and would require post fabrication finishing. It can be avoided by selecting a "stabilised" ferritic grade (bearing Ti or Nb) and by strict control of process parameters.

[7] Anisotropy "r" is the ratio of transverse strain to thickness strain. If r > 1, the sheet stretches more than it thins.

Deep drawn automotive locknuts of ferritic stainless steel

Of all the stainless parts used for automotive and truck trim, the type of wheel fastener cover shown (right) provides one of the greatest forming challenges. The shape indicates a high degree of drawing, which, in this case, is carried out in successive steps.

Stainless steel not only meets aesthetic requirements but also offers high strength and simple design – the item being made in one part, requiring neither welding nor adhesives. Traditionally, these parts were produced using austenitic grades such as EN 1.4301 (AISI 304). The drawing properties of ferritic stainless steels are such, however, that these nut caps can also be produced from a ferritic grade (EN 1.4526 – AISI 436) containing chromium, molybdenum and niobium:

- This grade is suitable for the drawing process (anisotropy, processing).
- Ferritic grades in general show a combination of gloss and colour that appeals to manufacturers of automotive trim.
- Molybdenum contributes to resistance to pitting corrosion (from de-icing salts and humid meteorological conditions).
- Niobium helps suppress roping (thus also reducing post-fabrication polishing).

Because they are small, these fasteners are ideally suited to mass polishing in tumbler installations – which gives the stainless steel a high-gloss finish.

Stainless steel locknuts can be glued, brazed or seamed onto the nut. They are stronger than parts made of other construction materials. Stainless versions require less post fabrication treatment (such as painting or coating) and are fully recyclable at the end of the service life of the vehicle.

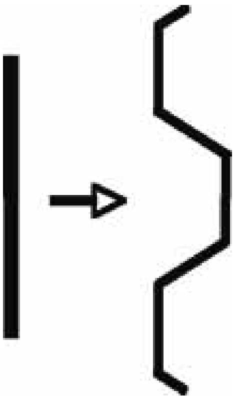
Photos: Ugine & ALZ France, Gueugnon (F)

13 Corrugated sheet for higher cargo capacity

Photo: Lincoln Smitweld BV, Nijmegen (NL)

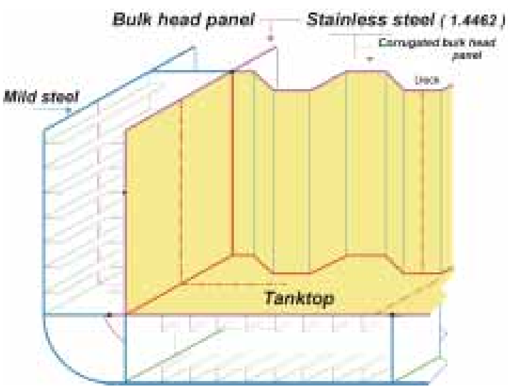
Chemical tankers transport a wide variety of liquid chemicals. Typical cargoes include chemical, petrochemical and food products, such as phosphoric acid, sulphuric acid, petroleum products, vegetable oils and molasses. At the port, the product is pumped directly into one of the ship's tanks, which can be thousands of cubic meters in size. A tanker usually contains several such compartments, so that the vessel can carry multiple cargoes.

Corrugated steel sheet for increased stiffness



The stiffness of a structural component is proportional to its moment of inertia. The latter can be increased by shifting as much mass away from the centre of gravity as possible, making a thin corrugated sheet a more interesting structural component than a thicker flat plate. A series of very large compartments made of corrugated steel walls ("bulkheads") increases the stiffness of, for example, a vessel.

Corrugated-panel bulkheads are also easier to clean, after each cargo, than traditional designs consisting of internal stiffeners.



Drawing: Lincoln Smitweld BV, Nijmegen (NL)

Corrosive liquids

Photo: Outokumpu, Degerfors (S)

Since the vessels represent a considerable investment, they have to be as versatile as possible. Austenitic grades EN 1.4406 (AISI 316LN), EN 1.4434 (AISI 317LN) or duplex grade EN 1.4462 are commonly used for this application, in order to accommodate aggressive chemicals such as those mentioned. These Cr-Ni-Mo grades are not only resistant to a greater number of corrosive products than are Cr-Ni grades, but also permit higher operating temperatures, thus increasing the operating comfort of the vessel during loading and/or discharge.

Structural integrity

Stiffness and corrosion resistance are necessary properties but they alone are not sufficient to meet the construction challenges of a 35 million dollar tanker. The storage and transportation of chemicals are subject to stringent shipbuilding codes. The failure criteria of, for example, compartment plating are associated primarily with the yielding failure mode, which means that the yield strength ($R_{p0.2\%}$) of the construction material is an important selection criterion.

Duplex stainless steels show much higher yield strength than do austenitic stainless steels and are therefore the material of choice for bulkheads. These steels make possible lighter structures, which in turn increases cargo capacity – a vital consideration in freight transportation.

Multiple benefits from duplex stainless steels

To start with, duplex stainless steels possess, to a high degree, the same unique forming properties as do austenitic stainless

Photo: Lincoln Smitweld BV, Nijmegen (NL)

Photo: Cantiere Navale De Poli, Venice (I)

steels: properties entirely suitable for corrugated structures that increase the stiffness of a tanker compartment. In addition, the high yield strength of duplex stainless steels holds considerable weight-saving potential, through allowing reduced wall thicknesses while still meeting shipbuilding structural requirements.

Finally, the combination of chromium, molybdenum and nitrogen makes this family of grades highly resistant to localised corrosion, such as pitting and crevice corrosion. This increases the number of different chemicals (with their various temperature ranges) that one vessel can transport, ultimately increasing the potential customer base for this type of investment good.

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