acom

3 - 2005

A corrosion management and applications engineering magazine from Outokumpu Stainless

Utilization of the Material Strength for Lower Weight and Cost with LDX 2101®

Dear Reader

As you may realise, we continue our crusade for duplex stainless steel and once again we want to emphasise our latest development, LDX 2101®, which not only we, but also a number of our customers, have found being an extremely interesting stainless steel grade. It has twice the strength of an austenitic grade such as 316L (1.4404), it has much better corrosion resistance than 304L (1.4307), it is actually very close to 316L, and there is a price tag saying something just above the level of 304L.

No wonder why our customers are interested.

This paper contains a listing of possible applications rather than actual references, but amongst those proposed applications there are also some large orders hidden. And there is another application with a tremendous potential, not even mentioned in the paper, desalination plants.

It should be an ideal grade for evaporator vessels in MSF (multi stage flash) distillation plants and also for storage tanks for the water.

Apart from the potential cost savings due to low price and reduced weight there is also an environmental friendly aspect on this stainless steel when compared to mild steel. No need for coatings implies no emissions of solvents or pollution by residues from metal treatment baths.

Yours sincerely

Jan Olsson

Technical editor of Acom

Utilization of the Material Strength for Lower Weight and Cost with LDX 2101®

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Summary

Traditionally, stainless steel has been regarded as too expensive to be used in load carrying structures. However, there are a few exceptions, either when corrosion resistance is a critical issue, e.g. for pressure vessels and storage tanks in the process industry, or for railway car bodies in the transportation sector where life-cycle cost analyses and experiences have clearly shown that stainless steel is a cost effective alternative to painted or zinc coated carbon steel and aluminium alloys.

In the structural design today there is a strong driving force, along with utilizing higher strength, also to reduce maintenance costs for coated carbon steel structures. In addition to costs, emissions from these coating systems have a negative impact on the environment.

Introduction

The austenitic stainless steel grades 304 and 316 are well established for architectural applications in the building industry. Properties, such as the great variety of surface textures and patterns and the almost maintenance free surface, have among others led these grades to exterior claddings of many prestigious buildings around the world.

However, the moderate strength of the common austenitic steels have limited their use in structural applications, even though there are exceptions where corrosion resistance, hygienic surfaces, low maintenance costs etc. are of major importance. Typical applications where austenitic steels are used are process vessels, structures in hollow sections for maintenance walkways in the process industries and machine frames in the pharmaceutical industries.

In the mid 1980's the duplex stainless steels began their crusade as an alternative material to austenitic steels. The applications were mainly process vessels and storage tanks in the pulp and paper industry and chemical tankers. The attractiveness with duplex stainless steel is found in their good combination of strength and corrosion resistance – the stress corrosion resistance in particular is much better than for the austenitic grades. The thickness and weight reduction obtained by using duplex steels in pressure vessels or storage tanks could be up to 50% compared to austenitic grades. However, the alloying designs of the duplex grades up to then were targeting the corrosion resistance of the high performance austenitic grades e.g. 904L and 254 SMO® rather than the conventional grades such as 304 and 316. This limited their use in general constructions, where high strength is emphasized rather than high corrosion resistance. There are a few exceptions – duplex grades have been used as structural material in footbridges in both Sweden and Spain.

A stainless steel grade with high strength and corrosion resistance on the same level as the conventional austenitic grades would be attractive for construction purposes – a material which provides an almost maintenance free surface in most atmospheric environments, where carbon steel has to be carefully protected with painting systems or galvanizing with the risk of emissions and metal release. Cold worked austenitic grades e.g. 301, 304 fulfil these requirements for the thinner gauges, and are also used in rail vehicle car bodies. However, the relatively high content of expensive alloying elements, such as nickel, results in fluctuating price level for the austenitic grades, which is undesirable for a material to be used in cost-sensitive constructions.

The new duplex steel LDX 2101® is the contribution from Outokumpu for load carrying structural applications in moderate corrosive environments.

General characteristics – LDX 2101®

LDX 2101® has a leaner composition than the most common duplex grade 2205 [1]. Most striking is the low nickel content of 1.5% compared to 5%, typical of 2205, and 9% for 304 (Table 1). Instead of nickel LDX 2101® is alloyed with manganese and nitrogen. Nickel is not just an expensive alloy element; its price level also fluctuates heavily in time, which affects the cost of these grades in proportion to the nickel content.

Chemical composition. Table 1

Grade	EN	ASTM	Typical composition [%]					
			C max	N	Cr	Ni	Mo	Mn
LDX 2101®	1.4162	S32101	0.03	0.22	21.5	1.5	0.3	5
SAF 2304®	1.4362	S32304	0.02	0.10	23	4.8	0.3	–
2205	1.4462	S32205	0.02	0.17	22	5.7	3.1	–
304L	1.4307	304L	0.02	–	18.3	9.2	–	–

LDX 2101® is a trademark of Outokumpu
SAF 2304® is a trademark of Sandvik AB

The corrosion resistance of LDX 2101 is governed by its high contents of chromium and nitrogen, 21.5 and 0.22% respectively, and the duplex microstructure. The content of molybdenum is quite low, around 0.3%, the level commonly attributable to cost efficient scrap practice, which also contribute to a more stable material price. The high chromium content improves the resistance to all types of corrosion in all environments and the high content of nitrogen contributes to better resistance to mainly pitting and crevice corrosion in comparison to that of conventional 304. The duplex structure has also far better resistance to stress corrosion cracking (SCC) then conventional austenitic grades such as 304 and 316.

Fabrication and especially weldability and formability are crucial properties of materials to be used in constructions. LDX 2101 can easily be welded with good results using similar methods as for austenitic and other duplex stainless steels, either with over alloyed duplex 2205 filler [2] or the newly developed LDX 2101 filler [3]. The high strength implies larger forces for bending operations and the spring back is more pronounced than for the austenitic steels. With proper tools and knowledge it is not more expensive or difficult to manufacture a vessel in high strength duplex steel than in a standard austenitic steel. Machining operations, such as drilling, are in fact easier to manage with LDX 2101 than conventional austenitic grades – especially concerning tool wear. LDX 2101 is available in a variety of product forms ranging from cold rolled sheets of 0.5 mm to hot rolled plate with thickness up to 75 mm. Welded tubes, bars and fasteners, etc. are under development.

LDX 2101 is developed for multi purpose and constructional use and is a high strength alternative to:

- Austenitic 304 types of grades
- 201, 301 and nitrogen alloyed, e.g. 301LN
- Ferritic stainless steels
- Paint, epoxy and zinc coated carbon steel

Utilize strength

Mechanical and physical properties

The mechanical properties of LDX 2101 together with SAF 2304, 2205 and 304L are listed in Table 2.

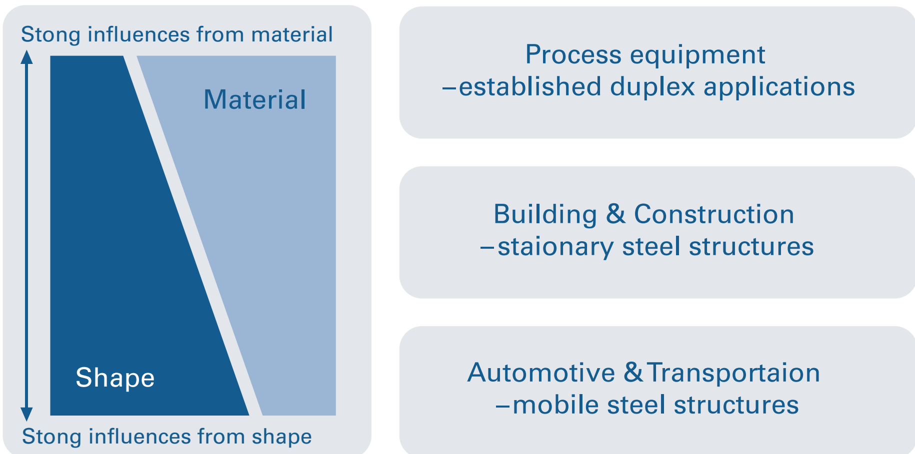
Mechanical properties, hot rolled plate, min values at room temperature. Table 2

Grade	EN	ASTM	EN, min values			ASTM, min values		
			Rp0.2 [MPa]	Rm [MPa]	A5 [%]	Rp0.2 [MPa]	Rm [MPa]	A5 [%]
304L	1.4307	304L	200	500	45	170	485	40
LDX 2101	1.4162	S32101	4501[1]	650[1]	30[1]	450[2]	650[2]	30[2]
SAF 2304	1.4362	S32304	400	630	25	400	600	25
2205	1.4462	S32205	460	640	25	450	640	25

1) Values still not officially approved, but no deviations according the ASTM values are expected.
2) According to ASTM A240 for hot rolled plate. For cold rolled sheet, Rp0.2 min 530 MPa and Rm min 700 MPa.

For heavy structures with relative simple shape e.g. storage tanks, the influence from the material is strong and its strength can easily be utilized with only minor optimization of the design. For lightweight complex automotive structures made of thin gauges, the shape of the component becomes very important to how much of the material strength can be utilized. In between these two application segments, the building and construction segment can be positioned, Figure 1.

Fig. 1 Influence from material and shape on design for different application segments.



Other properties

With the high strength of LDX 2101 compared to the austenitic grades other properties than just for structural utilization can be improved. Higher hardness is often important in order to increase wear resistance. The dent resistance is also improved by higher strength.

High strength in combination with high ductility and pronounced work hardening behaviour has promoted duplex steels for structures requiring high-energy absorption [4]. One good example of that are blast walls on offshore platforms, which are often made of duplex SAF 2304. High-energy absorption capacity is also important in different road equipments and crash absorbing automotive components.

Fatigue strength is closely related to strength. In structures where dynamic loads are present, the fatigue strength becomes an important material property at design. Especially for applications in the transport sector fatigue is a crucial parameter. The fatigue strength of a material increases with higher static strength and LDX 2101 has consequently higher fatigue strength than 304L [2]. However, in welded structures the structural geometry is much more important for the fatigue life than the strength of the material itself.

It is important to consider the total life cycle cost when discussing the potential of stainless steel as load carrying material, especially for the building and construction field. For moderately corrosive environments, LDX 2101 provides a sustainable surface without the need for a protective coating, which periodically requires maintenance. In addition to that, the coating material is often hazardous to the environment. At the end of the lifetime, the scrap is highly valuable and can easily be re-used when producing new materials – the ability to recycle stainless steel is very high due to scrap-based production.

Cost effectiveness

The argumentation so far has been to reduce thickness and weight of the structure, but in the end it is the total costs for a given performance that counts. Today with the high nickel price the price for LDX 2101 is on the same level as for 304 depending on product. The fluctuating nickel price makes it difficult for a fabricator to estimate the total cost of a construction in austenitic steel – but with LDX 2101 with a low nickel content the situation is similar to using carbon steel. This is advantageous for fabricators using long-term contracts.

Hence, by just looking at the weight saving potential due to the higher strength of LDX 2101, it will be possible to do a cost comparison between LDX 2101 and 304.

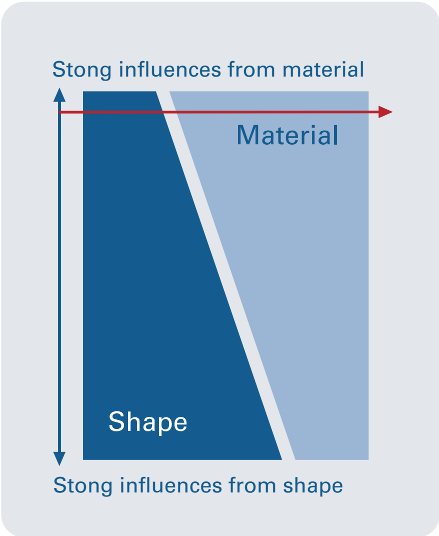
When a structure is optimized with a thinner section of a high strength material, and the component shape is modified to utilize its properties, the fabrication costs will also be affected. The use of thinner gauges often requires more stiffening elements to deal with deflection and instability issues. The stiffeners add to the fabrication costs, and conflicting arguments arises. Therefore, thickness and weight reduction given by the higher strength must be related to possible higher fabrication cost. It is important to remember that using thinner sections, in high strength material requiring less welding preparation and less volume of welding material, can also reduce fabrication costs. For large structures, such as bridges, high strength steel facilitates the use of simpler component shapes requiring less fabrication.

Potential applications – LDX 2101

Process equipment – Established duplex applications

Duplex steels have successfully replaced austenitic steels in storage tanks and pressure vessels in the process industry e.g. pulp and paper industry, and are now an established material type. The most common grade is 2205 – combining high strength and very good corrosion resistance. It is no coincidence that duplex steels have been successfully implemented in tank and pressure vessel applications. First of all they have better stress corrosion resistance than most austenitic grades. Secondly, tanks and pressure vessels can simply be regarded as a cylinder with internal pressure, and therefore their shape is one of the best for utilizing strength without having to optimize the shape, Figures 2a-b.

Fig. 2 Process equipment – storage tanks and pressure vessels. The pictures show a white liquor tank in LDX 2101 (Courtesy of YIT), left and the world's largest continuous digester in duplex 2205 (Courtesy of Kvaerner Pulping), right.



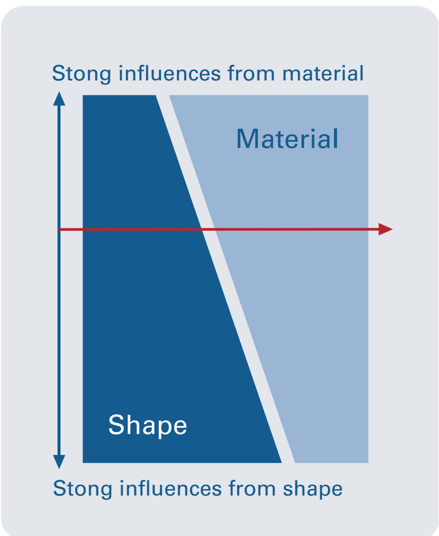
Building and construction – Stationary steel structures

In the building and construction sector a growing attention is directed to life cycle analyses – both cost and environmental aspects – with the objectives to reduce maintenance costs and lower emissions from toxic coating materials and metal deposition to the nature. The possibility to recycle scrap from stainless steel is also an important issue. There is also a growing interest for using stainless steel as a load carrying material in footbridges and general steel structures, and not only for cladding of buildings.

The aesthetical aspect of stainless steel is a key factor, but together with high strength, as is the case for LDX 2101, new possibilities are opened in structural design. High strength in combination with a sustainable surface, not requiring any protective coating and future maintenance, makes it a good candidate to provide cost effectiveness. Fabrication, e.g. welding and forming, do not deviate from fabrication of other duplex grades on the market – the same methods can be used.

However, it is important to point out that both austenitic and duplex stainless steel behave somewhat differently to carbon steel regarding structural design, particularly regarding instability and local buckling. Design recommendations for stainless steel are available, such as Design Manual for Structural Stainless Steel, published by Euro Inox [5].

Fig. 3 Stationary steel structure – maintenance platform with hollow sections of austenitic stainless steels (Courtesy of Stålmonteringar AB STÅLAB).



Maintenance platforms and walkways

Austenitic grades 304 and 316 are often used in hollow sections for frame structures, and in the platform gratings around process equipments in industrial plants, Figure 3. By using a high strength stainless steel such as LDX 2101 there is a great potential to reduce the wall thicknesses and material costs of the sections compared to 304. To tackle the stiffness-deflection dilemma for thinner gauges, the height of the section shape profile has to be increased to keep the stiffness on the same level as for the thicker section. If it is not possible to optimize design, weight saving is limited. However, the wear and dent resistance of the structure will always be better using a high strength steel, although thickness reduction is limited.

Footbridges

There are today several installations of duplex stainless steels as load carrying material for bridges. One footbridge in Bilbao, Spain, is made of SAF 2304, and another in Stockholm, Sweden, of 2205. Other examples are a traffic bridge in Minorca, Spain, and Stonecutters Bridge in Hong Kong where the pylons are made of concrete with a skin of 2205. Strength, aesthetics and sustainability are the properties making duplex steel the winning concept for bridges.

In Italy close to Siena a footbridge with a span of 50 meters will be built in LDX 2101. The bridge was originally specified for carbon steel. This urban/rural environment does not require the higher corrosion resistance of the other duplex grades. The bridge will be completed in 2005, Figure 4.

In comparison with tanks and pressure vessels, bridges requires more from the shape to fully benefit strength, when stiffness and deflection often become the critical constraints. However, with an optimized design, the weight saving potential compared to austenitic grades or conventional mild steel is around 30%.

Floodgates

The manufacturer of the floodgate, Stålmonteringar AB in Sweden, decided to use LDX 2101instead of 304 for a fresh water floodgate, Figure 5. The sheet thickness could be decreased from 8 to 6 mm, i.e. a thickness reduction by 25%. The shape was slightly

Fig. 4 Stationary steel structure – footbridge to be manufactured in LDX 2101, Ruffolo Bridge, Siena Italy. (Courtesy of SETCO).

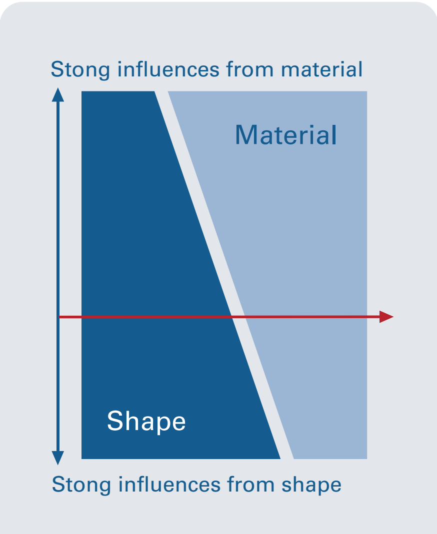
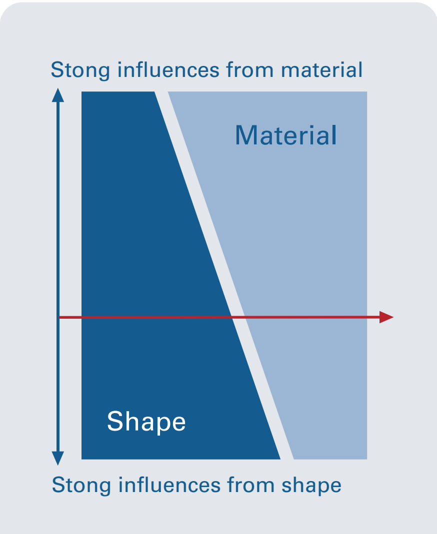


Fig. 5 Stationary structure – floodgate manufactured in LDX 2101 during installation. (Courtesy of Stålmonteringar AB STÅLAB).



modified by adding an extra stiffener to control the local buckling resistance. One additional stiffener increases the fabrication cost slightly but that is more than well compensated by the overall lower welding costs, and less material due to the thinner sections.

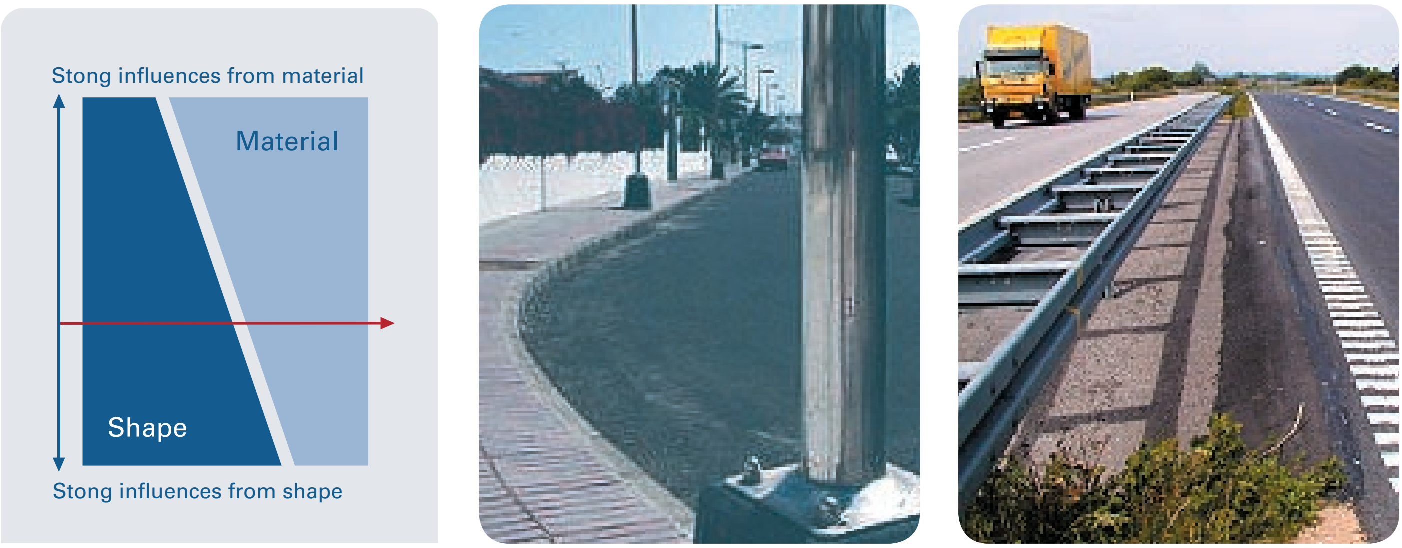
Buildings

For special purpose buildings, such as timber drying kilns or storage buildings for nuclear waste, LDX 2101 could be an interesting alternative to both austenitic steels and aluminium alloys. For timber kilns both 304 and 316 are used. 2 to 3 mm cold rolled material is typically used for timber kilns. Section shape has to be optimized to control stability and buckling, which are the critical constraints to take advantage of the strength. For storage buildings thicker material is also of interest for the load carrying sections in the frame structure.

Road equipments

The aesthetical aspects of road equipment are growing in importance, and so are life cycle cost and life cycle analyses. The most common material for these applications is today galvanised or coated mild steel, but LDX 2101 will add strength, energy absorption and sustainability. One possible application of LDX 2101 is road and bridge crash barriers. Trials are also running for using 0.9 mm cold rolled LDX 2101 in "crash forgiving" lampposts. The properties for these types of applications are very much dependent on the section shape, but 10–20% thickness and weight reduction is possible compared to ordinary austenitic and mild steels, Figure 6.

Fig. 6 Stationary structure – lampposts made of duplex stainless steel, left, and crash barriers in galvanized steel, right.



Automotive and transportation – mobile steel structures

Aluminium alloys are often regarded as the light metal in modern lightweight vehicle design. That is true when only density is regarded, but the relative strength and relative stiffness show that the performance of a structure in LDX 2101 or 6000 series aluminium is comparable. However, optimization of section properties is the most important factor needed to fully utilize the unique properties of the material, especially for thin sections. For mobile structures with dynamic loads, fatigue performance of the joints is often the critical property rather than the static strength of the material. And the fatigue strength of carbon and stainless steel joints is far better than for similar joints in aluminium.

Another important property emphasised by the automotive and railroad industries is high energy absorption for increased impact safety. High strength, strain hardening and plastic deformability are then important properties to consider.

Barge tankers

Duplex 2205 are today an established material for different types of cargo tanks in ship transportation, but its high corrosion resistance is not always required. One such case is for cargo tanks to a barge for containing calcium carbonate where LDX 2101 has been chosen. Along with strength, dent and wear resistance are important properties for this type of applications.

Tank trailers and chassis

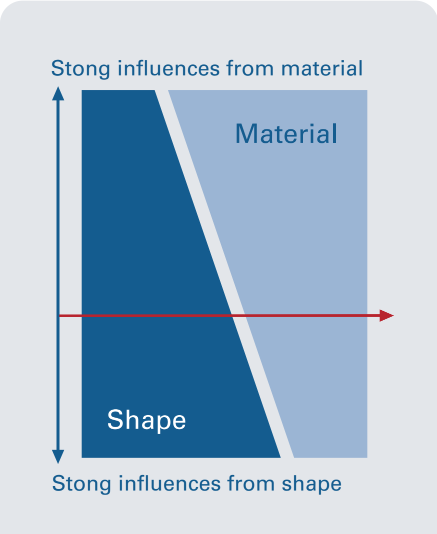
Mobile tanks are often manufactured in type 316, and duplex steels are mainly chosen for high-pressurised tanks, when high mechanical strength is required. One Finish and one German manufacturer of mobile tanks also use duplex 2205 in the trailer chassis where high strength is required, and 304 for the other parts. LDX 2101 could be an interesting alternative, for both the high-pressurized tanks and the chassis – one single material will simplify manufacturing.

Rail vehicle car bodies

Austenitic steels with enhanced mechanical properties by temper rolling have been used in railroad car bodies in United States since the 1940's. Energy absorption, sustainability and fire resistance are important properties. Aluminium alloys have made a great impact into this business especially for long distance trains, although, stainless steel has also been used for the high-speed train in Sweden, Figure 7. For commuter rail vehicles e.g. subways, trams – having car bodies with many large openings for doors and windows requiring a lot of joining – high strength stainless steel is still the preferred material. Coating for corrosion protection is not needed - which save weight and lowers maintenance costs.

The strength of fusion or spot-welded joints in LDX 2101 is better than for temper rolled austenitic steels. The temper rolled material is also limited to thicknesses below 3–5 mm depending on the strength class.

Fig. 7 Mobile structure – rail vehicle car body. The photo shows the car body of the Swedish high-speed train X2000 in temper rolled austenitic stainless steel.



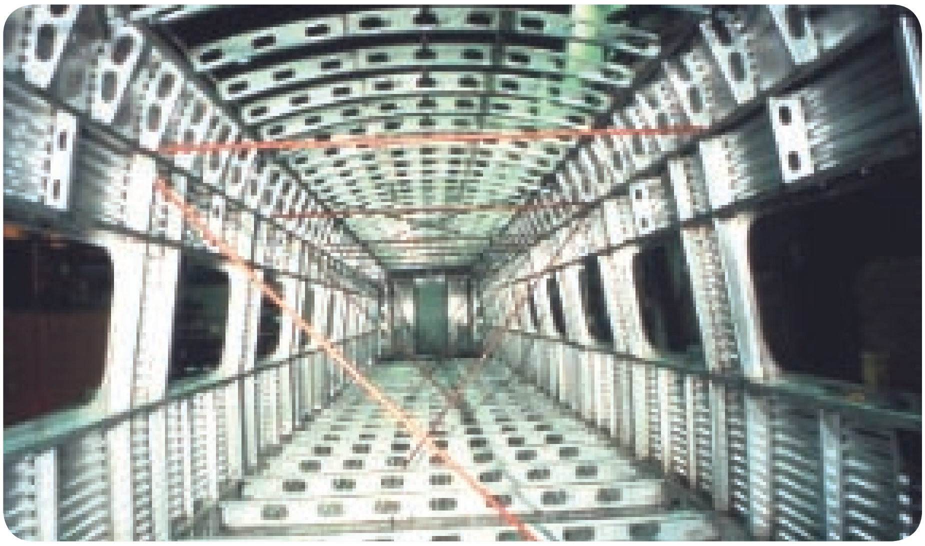
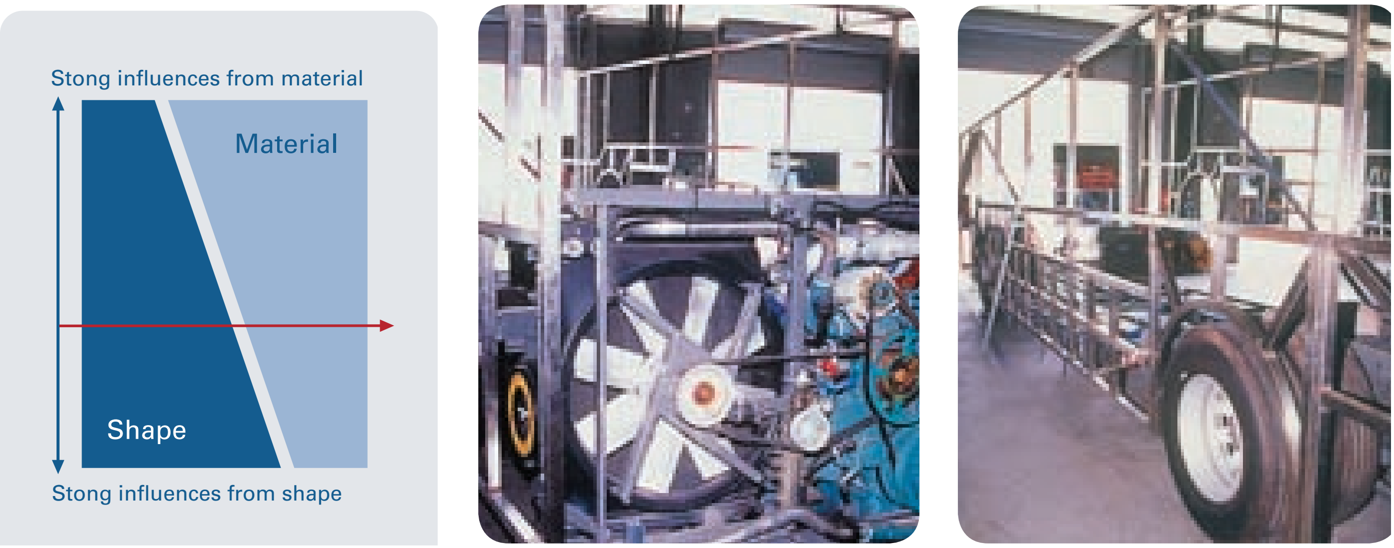


Fig. 8 Mobile structure – bus bodies. The photos show a prototype bus with grade 304 stainless steel body shell manufactured by Gold Coast-based company, Bus Tech Pty Ltd. (Courtesy of Australian Stainless Steel Development Association).



Bus bodies – Framework and skin panel

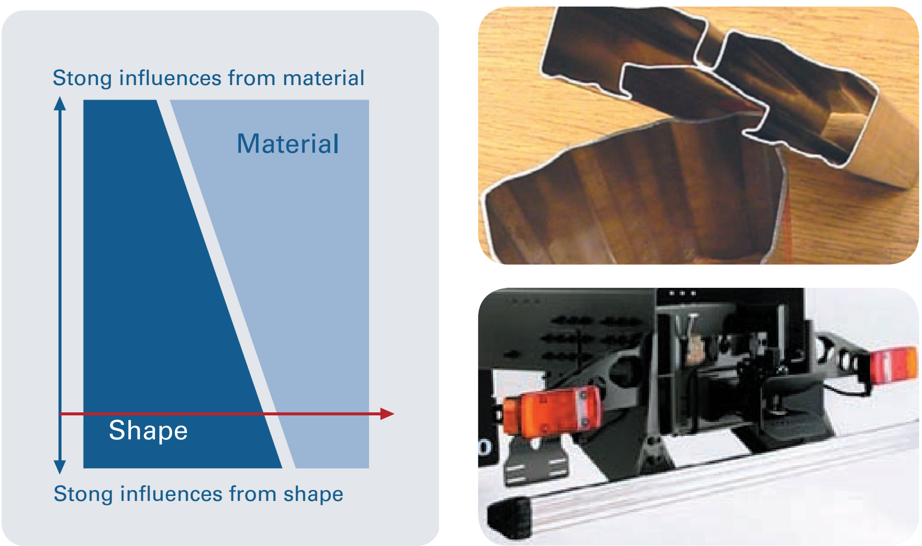
Ferritic stainless steel of type 12Cr-steel and austenitic grade 304 are used in hollow sections for both the body framework and skin panels, Figure 8. Recently requirements due to European standardisation regarding overturn safety, side and frontal collision and fire resistance, have enhanced the driving force of using stainless steel. Both austenitic and duplex steels have very good energy absorption abilities, which is needed in the deformation zones of the body. If higher strength is required, either temper rolled austenitic steels or duplex steels e.g. LDX 2101 can be used. As for railroad car bodies, the main advantage with the duplex steels is the mechanical properties of welded joints – the material will stay elastic to higher strength levels.

Automotive components

The automotive industry is showing great interest in high strength stainless steels, both temper rolled austenitic steels and duplex steels. For different types of impact members, bumper beams etc., the formability and excellent energy absorption capability of stainless steel challenge both high strength carbon steel and aluminium alloys. Substantial weight reduction without increasing cost is possible with an adapted design, which benefits most of the materials.

In Figure 9, an example of a shaped section, optimized to give highest local buckling resistance, is shown. The section is manufactured in temper rolled ultra high strength austenitic steel – the replaced section was made of aluminium.

Fig. 9 Automotive structures – optimized cross sections of under run protection beams for Volvo trucks in temper rolled austenitic stainless steel.



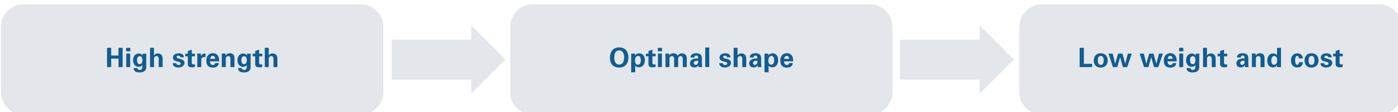
Discussion and Conclusions

The weight and cost reduction potential by using the new leaner alloyed duplex grade LDX 2101 as load carrying material in construction has been described. Depending on the field of application and the nature of the structure, potential weight savings up to 50% are possible by using LDX 2101 instead of the austenitic grade 304.

With roughly the same price level per ton – although more stable price level for LDX 2101 due to the lower nickel content – the utilization of higher strength sets the "saving potential". Therefore, LDX 2101 is a very attractive material for applications in the process industry where strength easily can be utilized, in storage tanks and pressure vessels, in the construction field, for footbridges and special purpose buildings and in the transportation industry, for different kinds of body structures.

However, to utilize the majority of the material's unique properties it is very important to optimize the component shape to "fit" the material for its structural function, Figure 1. This is particularly important for applications in the thinner thickness range. For certain applications LDX 2101 can challenge other types of materials – low nickel austenitic steels (e.g. 200 series), ferritic 12Cr-steel, galvanized steel and aluminium alloys. High strength along with highly competitive life cycle capabilities are the strongest arguments for choosing LDX 2101for structural applications.

Fig. 10 The design philosophy for the best utilization of LDX 2101.



References

[1] P. Johansson, M. Liljas, "A New Lean Duplex Stainless Steel for Construction Purposes", 4th European Stainless Steel Science and Market Congress, Paris, France, 2002.

[2] C. Ericsson, P. Johansson, M Liljas, E.M. Westin, "Mechanical Properties of Welds in the New Lean Duplex Stainless Steel LDX 2101 (EN 1.4161, UNS S32101), Stainless Steel World Conference, Maastricht, The Netherlands, 2003.

[3] B. Holmberg, M Larèn, "Welding and applications of the new Lean Duplex Steel, LDX 2101" IIW Annual Meeting, Prague, Czech Republic, 2005

[4] H.L. Groth, R.E. Johansson, H. Lundh, "Energy Absorption in Stainless Steel Structural Members", Nordic Symposium on Mechanical Properties of Stainless Steels, Sigtuna, Sweden, 1990.

[5] "Design Manual for Structural Stainless Steel" (Second Edition), Euro Inox, Building Series, Vol. 3, 2002. Available online via the Euro Inox web site www.euro-inox.org.

Acknowledgement
This article has been published in
Stainless Steel World, June issue, 2005

1278EN-GB. Graphic Concept. November 2005

Outokumpu is a dynamic metals and technology group. Focusing on our core competences, that is, extensive knowledge of metals and metals processing, we aim to be leaders in all of our key businesses: stainless steel, copper and technology. Customers in a wide range of industries use our metals, metal products, technology and services worldwide.

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