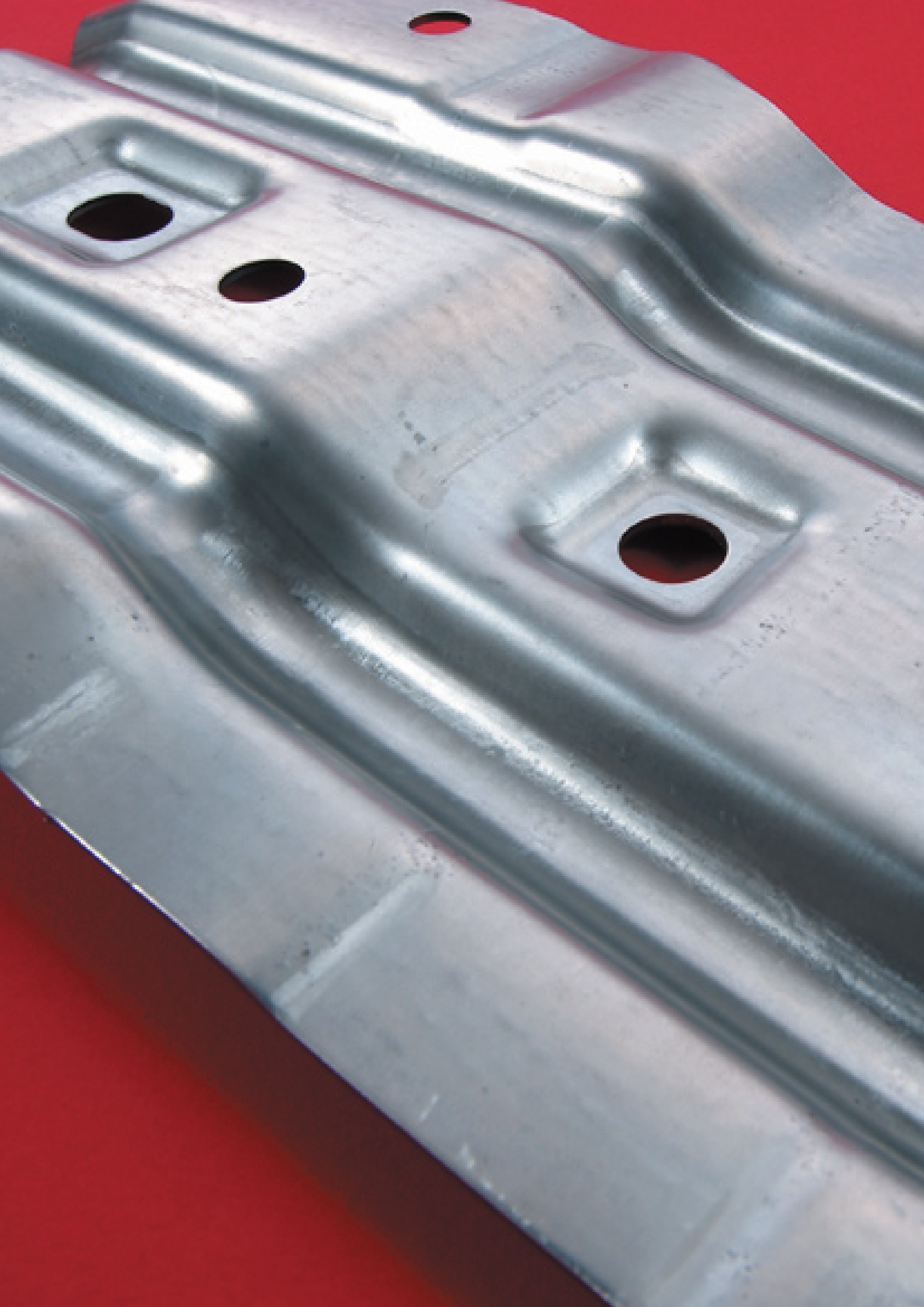
Dogal® – corrosion resistant advanced high strength steels

DOGAL®

SSAB SWEDISH STEEL



Dogal® is a hot-dip galvanised product and a registered trademark to SSAB Tunnplåt AB. SSAB Tunnplåt is the leading European producer of high strength steels.

This brochure gives a comprehensive presentation of our Dogal hot-dip galvanised extra and ultra high strength steels.

You can discover how increased strength and improved protection against corrosion result in better products, better production economy and improved competitiveness.

Dogal high strength steels offer a whole range of profitable properties.

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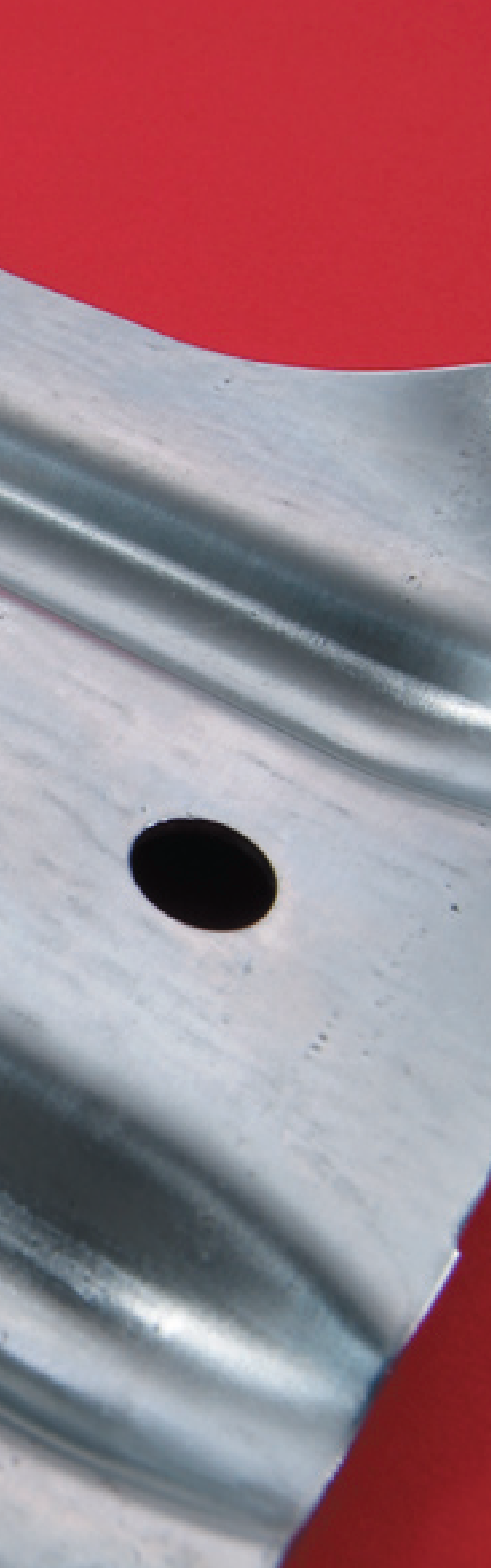


Reinforcement seat Dogal 800 DP.

Combine best corrosion resistant with highest strength

You need no longer to choose between the best corrosion resistant and the many benefits that truly high strength steels have to offer.

Dogal hot-dip galvanised steel from SSAB Tunnplåt combines good corrosion resistant with the very highest strength.

Dogal high strength steels offer a range of properties that can all contribute to improved competitiveness.

Dogal 1000 DP

Our development grade Dogal 1000 DP stretches the limits of attainability of high strength hot-dip galvanised steel. Dogal 1000 DP has a minimum tensile strength of 980 N/mm^2.

You can put the high strength of our Dogal steels to use in several ways.

You can use the high strength to reduce the material thickness and thus cut weight.

For a vehicle, this results in reduced fuel costs and great environmental benefits during the life cycle of the vehicle.

Reduced weight also reflects reduced material consumption. Since Dogal® is purchased by weight but the material is used per unit of area, the material consumption will be reduced, which means that the material costs can be lowered, while productivity is improved.

Increase safety, reduce weight

The higher strength can also yield a substantial increase in energy absorption in a vehicle.

By using high strength Dogal steel for parts such as collision absorption beams and side collision protection, the vehicle safety will be improved, without increasing the weight and perhaps even lowering it. The result is a much safer and more competitive vehicle.

High strength Dogal steels combine good corrosion resistant with the highest possible strength, lowest possible weight and high energy absorption capacity.

Stop welding, start pressing

Dogal® has the excellent cold-forming properties of high strength steels.

The unique combination of high strength and excellent formability can result in vast improvements in production economy.

Instead of welding a product from many pieces, it can be pressed and bent into a finished product in only a few operations.

The welding costs will be reduced and the quality of the finished part will be improved.

The good formability also offers greater freedom for optimising the design. An optimised design almost always results in fewer parts. This, in turn, gives logistical benefits and reduces the number of rejects. All of this contributes to better production economy.

Let the product live longer

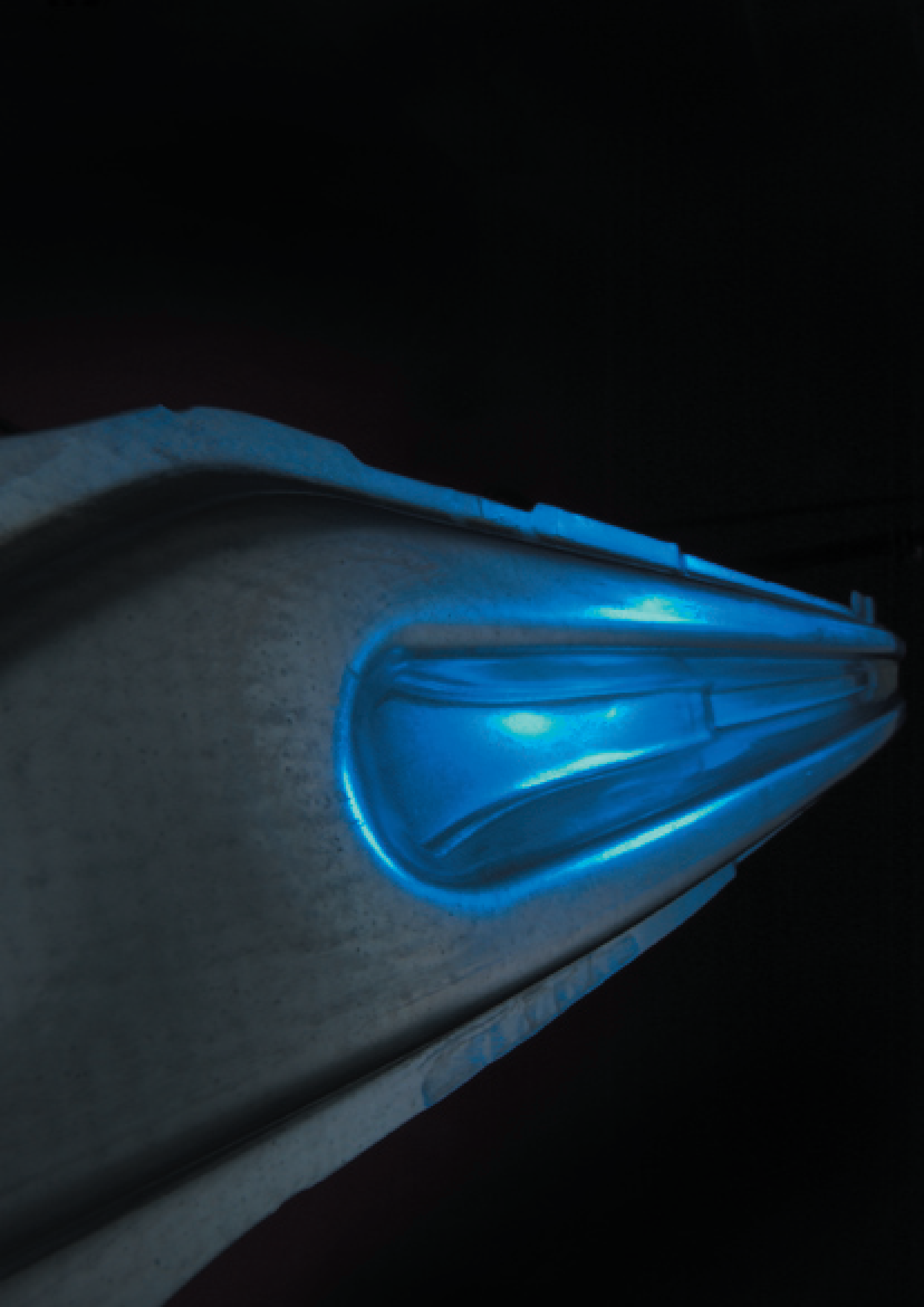
In addition to having excellent resistance to corrosion, the hot-dip galvanised surface also offers productionengineering benefits.

By using Dogal steel, you will eliminate the costs and time necessary for individual galvanising. Changing over to Dogal® often results in the price of the corrosion resistant treatment being more than halved compared to galvanising individual parts.

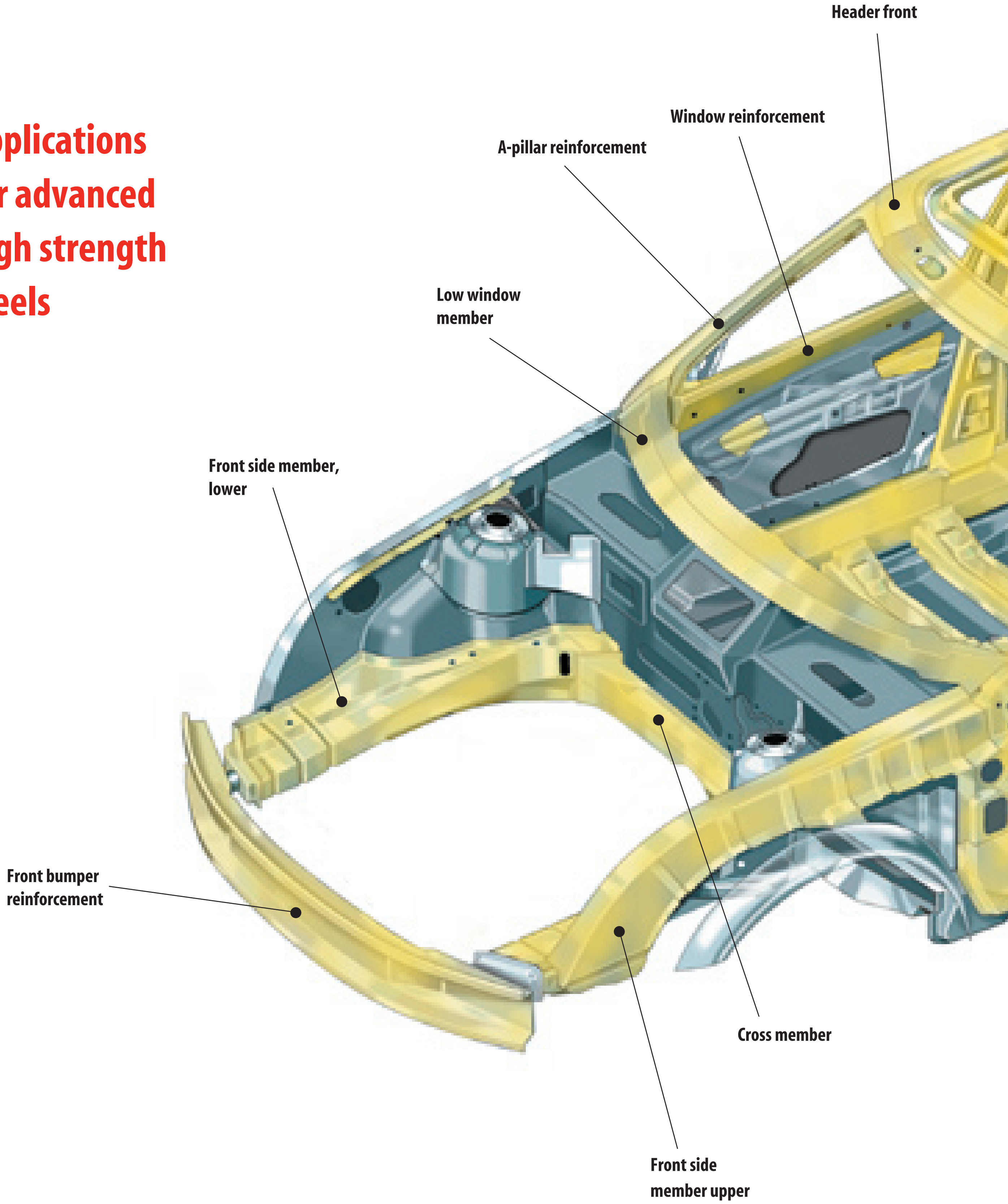
Due to the combination of good resistance to corrosion and high strength, Dogal® contributes to increasing the useful life of products, at the same time reducing the need for service and maintenance.

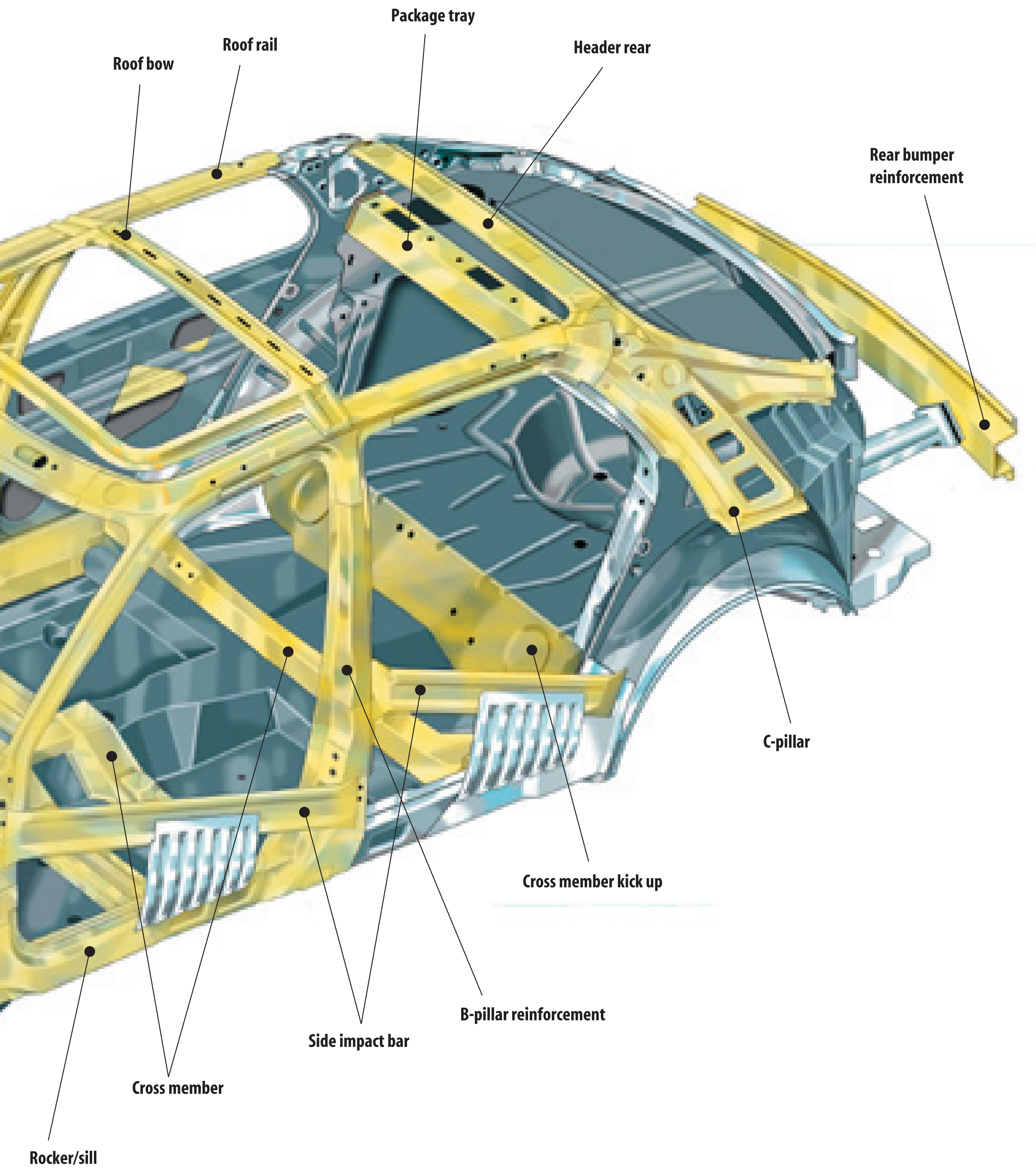
This brochure provides an in-depth explanation of the competitive properties of high strength Dogal®.

Impact member, Dogal 800 DP.



Applications for advanced high strength steels




Package tray
Roof rail
Roof bow
Header rear
Rear bumper reinforcement
C-pillar
Cross member kick up
B-pillar reinforcement
Side impact bar
Cross member
Rocker/sill

ULSAB projects

Appearance and suitability for manufacture are not the only requirements – safety, environmental demands and several other needs must also be taken into account. Against this background, the international steel industry launched a number of projects aimed at demonstrating new steel-intensive designs to meet the demands of the automotive industry.

ULSAB

The first of these projects was the Ultra Light Steel Auto Body – ULSAB – launched in 1994 to study a car body made of steel. By using a holistic approach, more than 90 percent of modern high strength steels, hydroforming and tailored blanks, the steel industry was able to demonstrate that a modern car body could be made just as strong, stiffer and also about 25% lighter than the steel bodies available on the market at that time. In addition, the project demonstrated that such a body could be mass produced at the same cost as a conventionally produced body. This project contributed to a substantial increase in the use of high strength steels and tailored blanks in the automotive industry.

ULSAC

The international steel industry then launched the Ultra Light Steel Auto Closures – ULSAC – project in 1998 in order to demonstrate that the same experience could be applied to doors and bonnets (hoods). The designs selected showed that modern, safe doors can be produced using modern high strength steels and advanced production methods. The weight is about 42% lower than that of doors made from normal mild steels. The doors can also be mass produced at reasonable cost.

ULSAS

In order to demonstrate the scope available for using high strength steels in the chassis and suspension, the Ultra Light Steel Auto Suspension – ULSAS – project was then launched. Various steel-intensive lightweight designs were also demonstrated in this project.

ULSAB-AVC

These three projects span about one third of the vehicle weight. The ULSAB-AVC project – where AVC stands for Advanced Vehicle Concepts – was then started in order to demonstrate the opportunities offered by modern high

ULSAC concept door.

ULSAB-AVC concept car.

strength steels in terms of safety, cost-effective designs, reduced fuel consumption and lower carbon dioxide emissions. This project covers the entire vehicle. The designs presented are not the only opportunities offered and are merely examples of what can be achieved by using advanced high strength steels (AHSS) in an innovative manner, in combination with modern production methods.

The body weighs only 218 kg, and this low weight has been achieved without compromising safety. The vehicle meets the safety demand made on vehicles that will be produced in 2004. The body consists of only 81 parts. 74 % of the weight consists of DP steels, and advanced high strength steels account for more than 80 % of the total weight.

The maximum carbon dioxide emissions specified by the EU are 140 g/km. ULSAB-AVC vehicles have a fuel consumption of 3.2–4.5 litres/100 km, and the corresponding carbon dioxide emissions will then be 86 to 108 g/km.

By using advanced high strength steels, ULSAB-AVC vehicles can also be cost-effectively mass produced. The production cost is estimated to be USD 10 000. The project also demonstrates the scope available for using advanced production methods comprising tailored blanks, tailored tubes, and tubes for hydroforming in conjunction with advanced high strength steels.

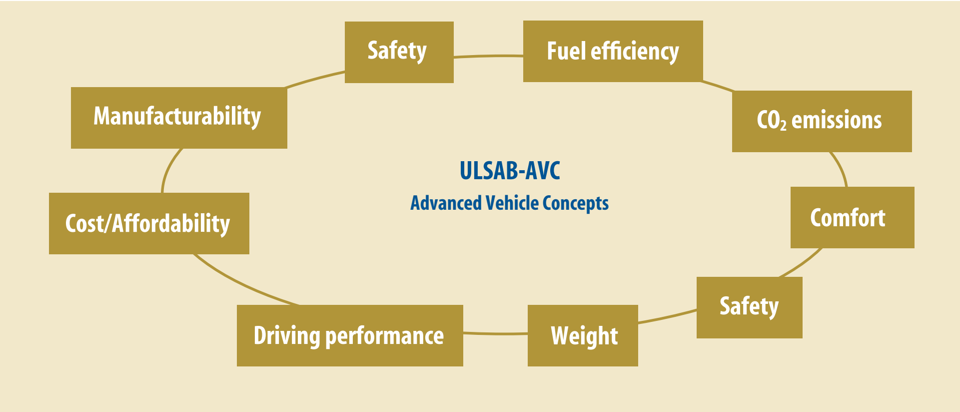


Fig. 1. The many demands of carmakers must be met.

Product programme

Dogal YP-grades

Dogal YP are micro-alloyed cold-forming steels that derive their high strength from the addition of very small quantities of alloying elements. These steel grades are designated according to their lowest guaranteed yield strength. The difference between their yield strength and tensile strength is small. YP grades have good formability and bendability in relation to their yield strengths.

Dogal DP grades

Dogal DP steel combines high strength with good stretch-forming properties.

DP steels have low yield strength in relation to the tensile strength.

Microstructure of the DP steels

The microstructure of the steels contains an amount of martensite in a multi-phase microstructure. Besides martensite, which is a hard phase, and ferrite, which is soft, bainite is also present. The strength of the steel increases with increasing content of the hard martensitic phase. The proportion of martensite is determined by the carbon content of the steel and the temperature cycle to which the steel is subjected in the continuous galvanising process.

Ageing

Dogal DP steel does not age, which is due to the structure of the material.

Work-hardening and bake-hardening

A substantial increase in yield strength can be achieved by utilising the work-hardening and bake-hardening properties of Dogal DP steels. The work-hardening caused by a strain of 2 % can increase the yield strength of Dogal DP steels by approx. 100 N/mm^2. Work-hardening is highly dependent on the amount of deformation and on the steel type. Bake-hardening by soaking the material at 170 °C for 20 minutes increases the yield strength by a further 30 N/mm^2 or thereabouts.

Pressing and painting

Whenever steel sheet parts are pressed and then painted, the work-hardening and bake-hardening properties of Dogal DP steels can be put to good use. Work-hardening occurs during pressing, and bake-hardening takes place when the paint is being cured, if the curing is done at elevated temperature.

Heat treatment

Heat treatment of Dogal® should be avoided. The heating can affect the zinc coating which can result in poor appearance and deterioration of the corrosion properties. If the material is eventually heated the temperatures should be limited to max. temp. 200 °C.

Dimensions

Dogal DP steels are available in thicknesses between 0.5 and 2.0 mm, and in widths up to 1500 mm.

Limitations may occur depending on grade and thickness.

Coating thickness

The various coating thicknesses are classified into weight in g/m^2 on both sides, as determined by means of the triple-spot test in accordance with EN 10 142.

The coating weight is not always equally distributed on both of the product surfaces. However, it may be assumed

Chemical composition (typical values)

Steel grade	C %	Si %	Mn %	P %	S %	Nb %	Cr %	Al (min)
Dogal 450 YP	0.09	0.4	1.3	0.015	0.002	0.035	–	0.015
Dogal 500 YP	0.13	0.4	1.6	0.015	0.002	0.035	–	0.015
Dogal 600 DP	0.11	0.2	1.6	0.015	0.002	–	0.45	0.015
Dogal 600 DPE	0.11	0.2	1.6	0.015	0.002	–	0.45	0.015
Dogal 800 DP	0.15	0.2	1.8	0.015	0.002	0.015	0.45	0.015
Dogal 1000 DP *								

Table 1. *) In the course of development.

Mechanical properties					
Steel grade	Yield strength, $R_{p0.2}$ N/mm² min–max	Yield strength, $R_{p2.0}$+BH 170°C for 20 min N/mm², min	Tensile strength, R_m N/mm² min–max	Elongation, A_{80} % min	Min recommended bending radius in 90° bend t=thickness, min
Dogal 450 YP	450-550	–	560-680	14	1xt
Dogal 500 YP	500-600	–	600-730	10	1xt
Dogal 600 DP	350-480	(500)	600-700	16	1xt
Dogal 600 DPE	450-530	(550)	600-750	17	1xt
Dogal 800 DP	500-640	(600)	800-950	10	1xt
Dogal 1000 DP *	660-860	–	980 (min)	6	–

Table 2. *) In the course of development.

Zinc coating			
Weight class	Coating thickness per side* µm	Weight determination on two sides, g/m² Triple-spot test	Single test
Z 100	(7)	100	85
Z 120	(8)	120	100
Z 140	(10)	140	120
Z 200	(14)	200	170
Z 275	(20)	275	235

Table 3. *) The values are calculated on the basis of the minimum values for the triple-spot test (1 µm=7.14 g/m²).

that coating weight of at least 40% of the value given in table for the single spot test exists on each surface of the product.

The weight of the coating may be checked by other methods which ensure that the requirements as to weight class are fulfilled. In the event of any dispute, however, the weight shall be determined in accordance with the above-mentioned ASTM standards.

Appearance of the surface

Dogal DP steels are produced with a skin-passed surface.

Surface quality

Dogal DP can be delivered with normal surface (A) or with improved surface (B).

Surface treatment

Dogal® is always provided with surface protection in the production process, unless

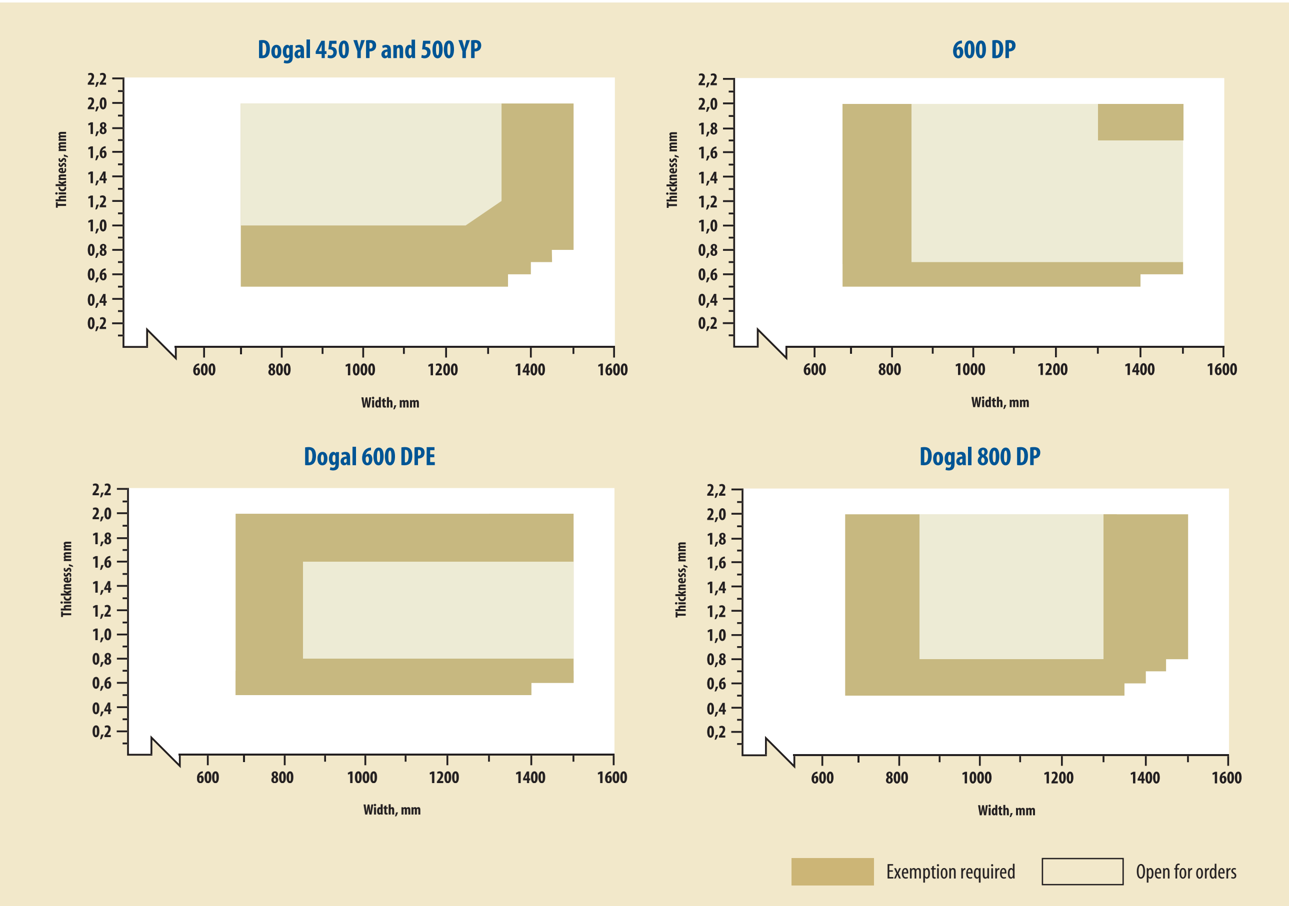
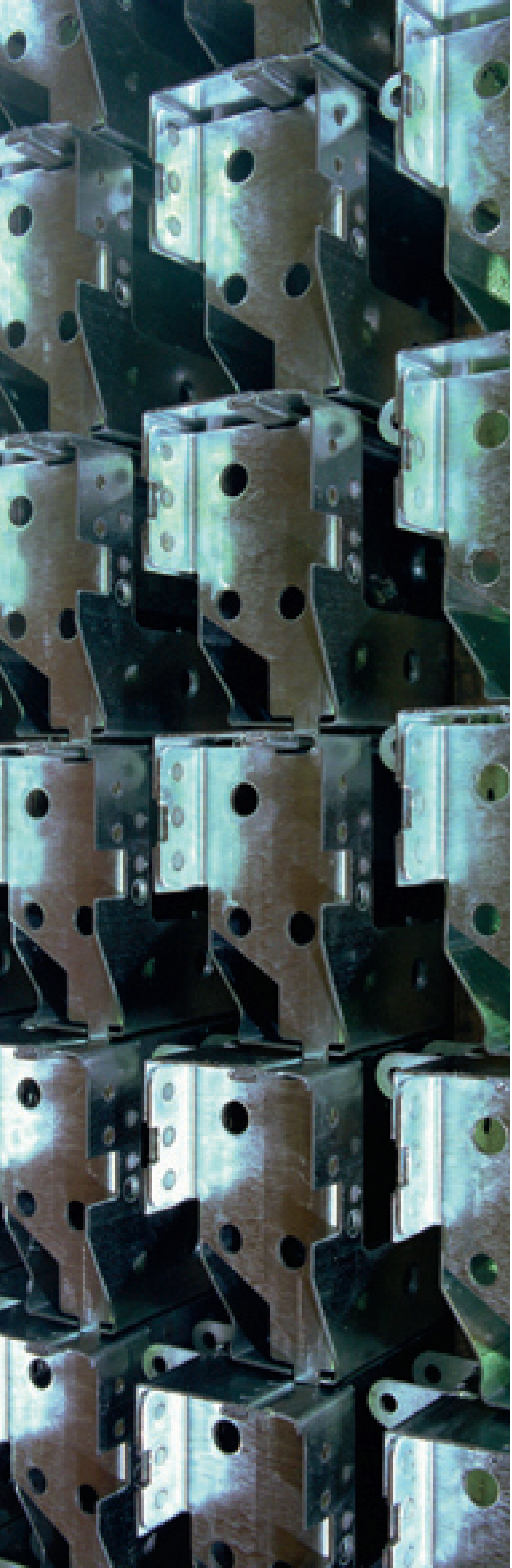


Fig. 2.



otherwise specified. The durability of the protection is dependent on the ambient conditions during storage and transport.

There are four types of surface protection.

Chemical passivation (C) protects the surface against moisture and reduces the risk of white rust occurring during storage and transport. Chemical passivation may sometimes cause discolouration and patches, which is permissible since it does not affect the quality.

Oiling (O) reduces the risk of white rust, but to a much lesser extent than chemical passivation. The oil film can be removed by a degreasing agent which will not damage the surface.

Chemical passivation and oiling (CO) is a surface treatment combination that improves the protection

Tolerance on width

Sheet cut to size and coils. Acc. to EN 10 143/93.

Nominal width mm	Tolerance, mm Standard	Special
650-1200	0/+5	0/+2
1201-1500	0/+6	0/+2

Table 4.

Edge camber

acc. to EN 10 143/93.

Gauge length mm	q, mm max
2000	6

Table 5. For lengths less than 2 m the edge camber shall not exceed 0.3% of the actual length.

Out-of-squareness

Sheet cut to length (u). Acc. to EN 10 143/93.

Maximum deviation = 1% of sheet width

Table 6.

Flatness

Maximum deviation between the sheet and flat surface on which it is resting. Acc. to EN 10 143/93.

Nominal thickness mm	Width mm	Max. deviation mm
–0.70	<1200	8
	1200–1500	9
(0.70)–1.20	–1200	6
	(1200)–1500	8
(1.20)–2.00	–1200	5
	(1200)–1500	6

Table 7. The tolerance also applies to sheet cut to length from a coil at the purchaser´s plant if straightening is carried out in suitable straightening equipment.

against corrosion and is available by agreement.

Dogal steels can also be supplied *untreated (U)*. However, since this involves the risk of white rust, SSAB Tunnplåt offers this option only if specified by the purchaser and at the purchaser's own risk.

Tolerance on thickness (including metal coating)

Nominal thickness	Normal tolerance on nominal widths		Special tolerance on nominal widths	
	≤ 1200	> 1200 ≤ 1500	≤ 1200	> 1200 ≤ 1500
≤ 0,40	±0,06	±0,07	±0,04	±0,05
> 0,40 ≤ 0,60	±0,07	±0,08	±0,05	±0,06
> 0,60 ≤ 0,80	±0,08	±0,09	±0,06	±0,07
> 0,80 ≤ 1,00	±0,09	±0,11	±0,07	±0,08
> 1,00 ≤ 1,20	±0,11	±0,12	±0,08	±0,09
> 1,20 ≤ 1,60	±0,13	±0,14	±0,09	±0,11
> 1,60 ≤ 2,00	±0,15	±0,15	±0,11	±0,12

Table 8. Applicable to steels with a yield point of ≥ 280 N/mm^2. As per EN 10 143/93.

Tolerance on length

Sheet cut to length. Acc. to EN 10 143/93.

Nominal length (L) mm	Normal		Special (S)	
	minus mm	plus mm	minus mm	plus mm
< 2000	0	6	0	3
≥ 2000	0	0.003 x L	0	0.0015 x L

Table 9.

Coatings

Weight class	Weight thickness per side * µm min	Weight determination both sides, g/m^2	
		Triple-spot test min	Single-spot test min
Z 100	(7)	100	85
Z 140	(10)	140	120
Z 200	(14)	200	170
Z 275	(20)	275	235

Table 10. The material must be coated according to one of the weight classes of the following tables.
* The figures are calculated on the basis of minimum values for the triple-spot tests. (1 µm = 7.14 g/m^2)

Technical properties

Shearing and punching

When a high strength material is sheared, the shearing operation must be adapted to suit the hardness, thickness and shear strength of the steel, and the design, rigidity and wear of the power shears or machine being used. Correct cutting clearance of the power shear blades is particularly important. Cutting clearance is governed by the sheet thickness, strength of the steel and demands on the appearance of the sheared edge. The thicker the material and the higher the strength, the larger the cutting clearance must be. A cutting clearance of 6% of the sheet thickness is normally used for mild steels and medium-strength steels. A cutting clearance of about 8-10% of the sheet thickness is recommended for Dogal DP steels. A larger cutting clearance gives a neater cut surface, but a somewhat larger rollover zone.

The cutting force in Newton can be calculated from the following equation:

$$F = \frac{K_{sk} \cdot t^2}{2 \cdot \tan ß}$$

F = cutting force (N)
K_{sk} = cutting strength
(e times tensile strength)
ß = cutting angle in power shears
t = sheet thickness

The factor e varies with the tensile strength of the material. Mild steels such as Dogal F 30 have e = 0.8, while Dogal 800 DP has e = 0.6. The necessary cutting force increases with the tensile strength. Changing to a steel with a higher strength usually leads to reduced thickness, and the necessary cutting force is thereby substantially reduced. A chamfered punch can reduce the necessary force by up to 50%.

The cutting clearance is very important to wear during punching. A smaller clearance increases the tool wear, and the tools must therefore be sharpened more often.

Laser cutting

A part made of Dogal DP steel may often be of complicated geometric shape. This geometric shape can be produced directly by laser cutting, without any additional work after the cutting process. Laser cutting produces very high cutting quality in terms of edge quality and dimensional accuracy. To achieve good cutting performance, strict demands must be made on the equipment, the cutting parameters, and also the workpiece material.

Test results

Cutting by laser has grown in popularity in recent years. SSAB Tunnplåt has therefore undertaken studies of the laser cutting properties of Dogal 800 DP, both through our own research and by gathering the experience accumulated in companies that use laser cutting.

The results of these studies can be summarised as follows:

- on Dogal DP steels, the best results are achieved by using the same cutting gas (N_2) and parameters as those used for stainless steel
- Dogal DP steels conform to the standard for one of the highest classes in accordance to EN ISO 9013. This applies to both surface and conicity
- Dogal DP steels contain no macro-inclusions that could have a detrimental effect on the cutting results
- changes in hardness occur only in a narrow zone nearest to the edge. The heat-affected zone from laser cutting is narrow (see Fig. 3). The zone is so close to the edge and is so narrow that it will be eliminated by the subsequent welding operation.

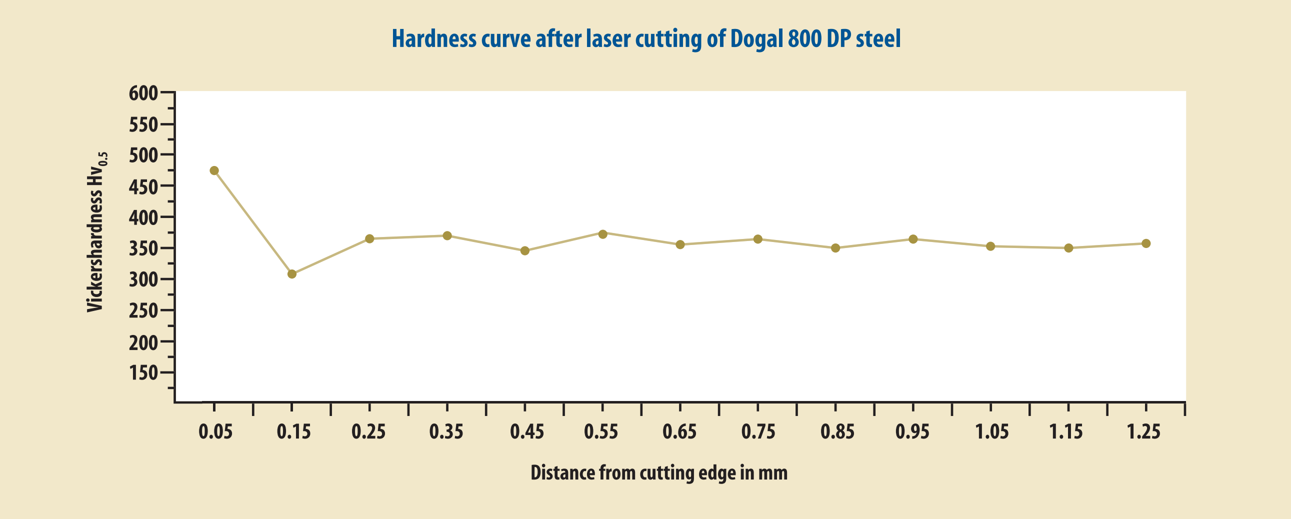


Fig. 3.

Forming

In spite of their high hardness, Dogal DP steels have good formability and can be formed in the traditional way. The somewhat poorer formability compared to mild steels can almost always be compensated for by modifying the design of the component.

Dogal DP steels have very good work-hardening properties, and this is the most important reason for the good formability of these materials. Comparing Dogal DP with Dogal YP in the same strength range (even with better tensile elongation), you will find that Dogal DP steels have equal or better formability.

The edge ductility of YP steels can be expected to be somewhat better than that of DP steels.

Stretch-forming

In stretch-forming, the material is clamped by the blankholder, and all plastic deformation occurs over the punch. The material is subjected to a biaxial strain, which results in a thickness reduction. Failure will occur if local deformation is excessive. The stretch-forming properties depend mainly on the capability of the material to redistribute strain.

There is a close relationship between the stretch-forming properties of the material and its work-hardening properties, i.e. the greater the work-hardening of the material, the better the distribution of strains and thus the better the stretch-forming properties. Since Dogal DP steels undergo high work-hardening, the material also has better stretch-forming properties than other steels of comparable strength.

Deep drawing

Deep drawing is characterised by the whole of the blank or most of it being forced through the die, and the blankholder pressure being set so that wrinkling will be prevented.

The ability of the material to withstand drawing is determined principally by two factors:

- ability of the material to deform plastically in the plane of the sheet, i.e. how easily the flange material flows and changes over into side-wall material during drawing

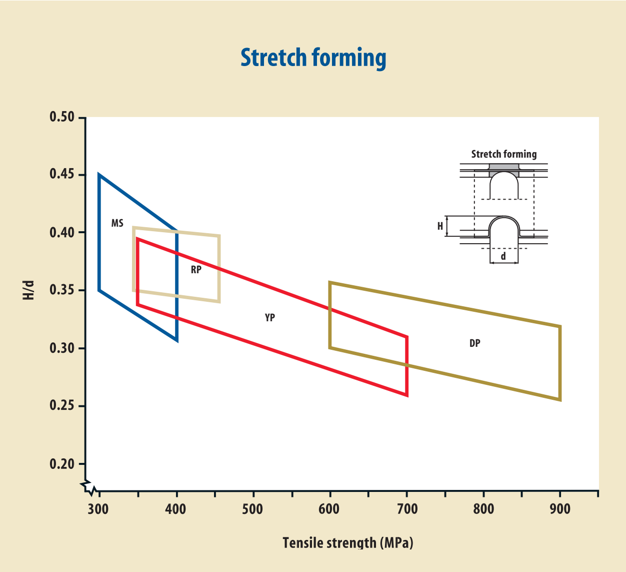


Fig. 4. Stretch-formability, H/d, as a function of the tensile strength of mild steels (MS) and Dogal YP, RP and DP steels. The figure shows the good stretch-formability of Dogal DP steels.

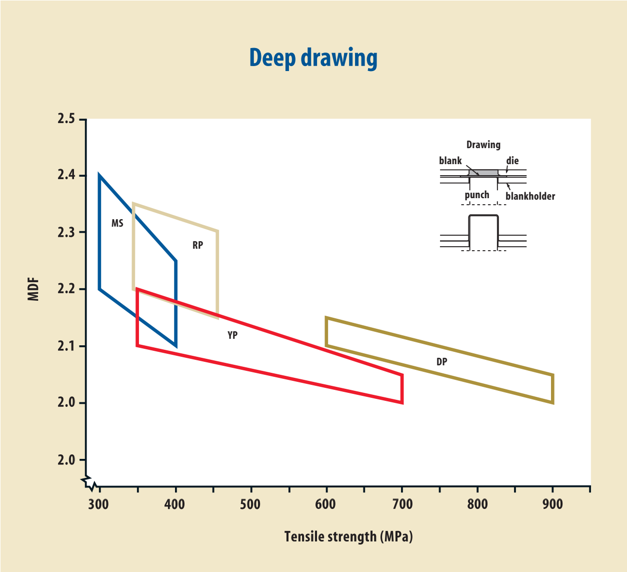


Fig. 5. Limiting Drawing Ratio (LDR) as a function of the tensile strength of mild steels (MS) and of Dogal YP, RP and DP steels.

The pictures shows the good drawability of Dogal DP steels.

- the side-wall material must be able to withstand plastic deformation in the thickness direction, so that the risk of failure will thus be reduced. The drawability of Dogal DP steels is as good as, or somewhat better than, that of other steels of comparable strength.

Flanging

The ratio of hole diameter before and after flanging is known as the flanging ratio.

The blanks should be positioned so that the shearing burr faces towards the punch. This is because the outer fibres of the material sustain the heaviest deformation and because cold working during shearing lowers the ductility of the cut edge.

Since the outer fibre of a thin material deforms less than that of a thick material, a thinner material can withstand a higher flanging ratio than a thicker material at the same inside diameter of the flanged hole.

Bending

In bending, a bending moment is applied to the sheet, and the outside of the sheet then experiences tensile strain while the inside undergoes compression. The bendability of Dogal DP steels is good, being equal to or better than that of other materials of equivalent strength. If possible, try to avoid bending and re-bending Dogal 800 DP steel, since this operation increases the risk of fracture.

Roll forming

Roll forming is a method of forming that is well suited for Dogal DP steels. The process is less demanding on the material than pressbrake bending, and therefore enables profiles of complicated cross-sections and with tight radii to be produced.

Roll forming can be combined with simultaneous or subsequent operations such as punching, welding and bending.

Due to the high strength of Dogal DP steels, their springback is larger than that of mild steels, and this also applies to roll forming. If used for Dogal DP steels, a production line originally intended for a soft material must therefore generally be adapted to suit the higher strength of Dogal DP grades.

Tensile test curves

Curves from conventional tensile testing are usable for various types of Finite Element Method (FEM) analysis, e.g. calculations for the loadcarrying capacity or energy absorption of a part being designed. In true stress/strain curves, the stress and strain levels are compensated for the reduction in area during testing. Steel of higher strength will have a higher level of stress for a given strain.

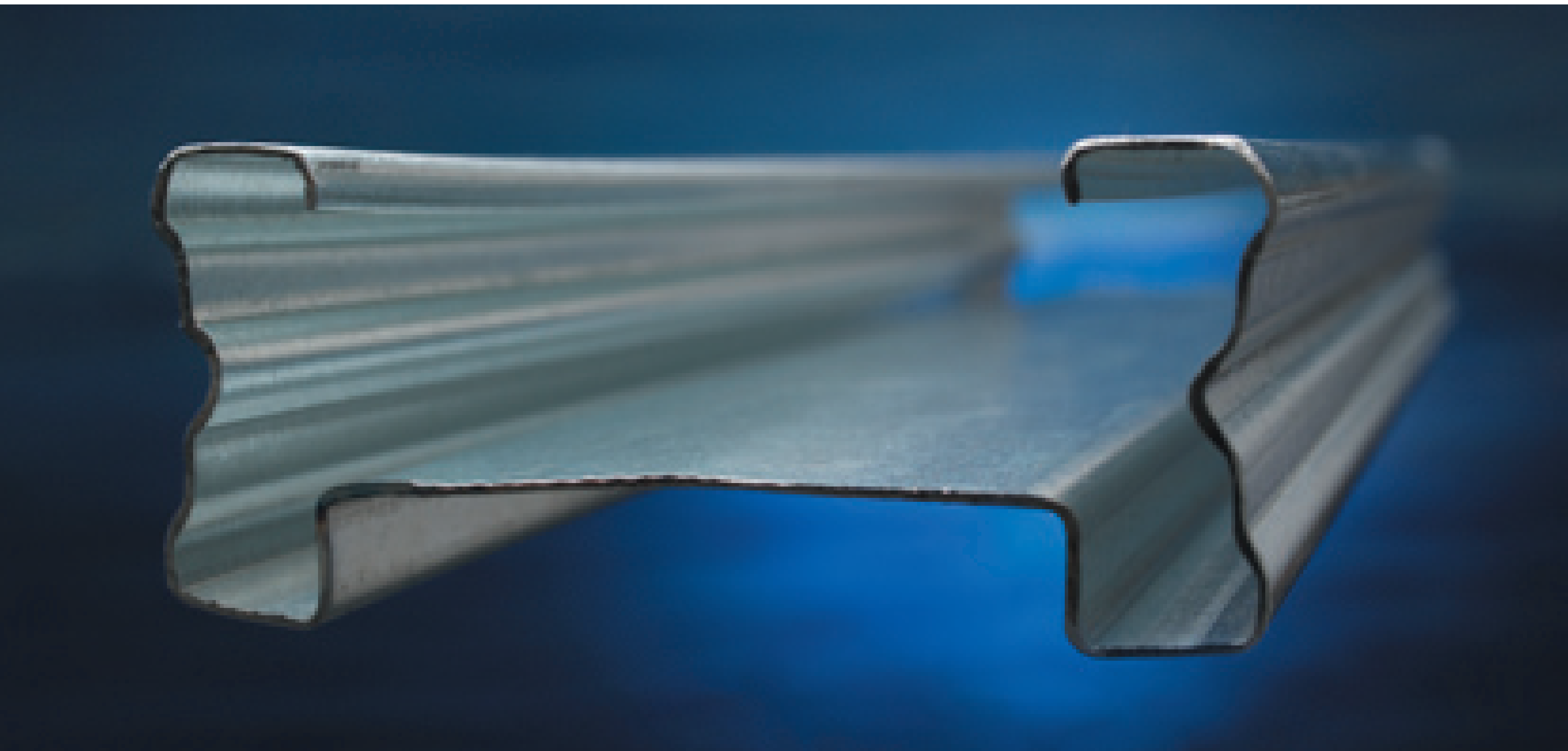
Forming limit curves

The forming limit curve (FLC) shows the amount of deformation that the material can withstand at a certain deformation path or a certain deformation condition.

The FLC can be used for documentation or as an aid in solving difficult pressing operations.

A square grid pattern is etched on a sample of the material, which is then pressed. The change in size is

Roll-formed profile in Dogal DP.



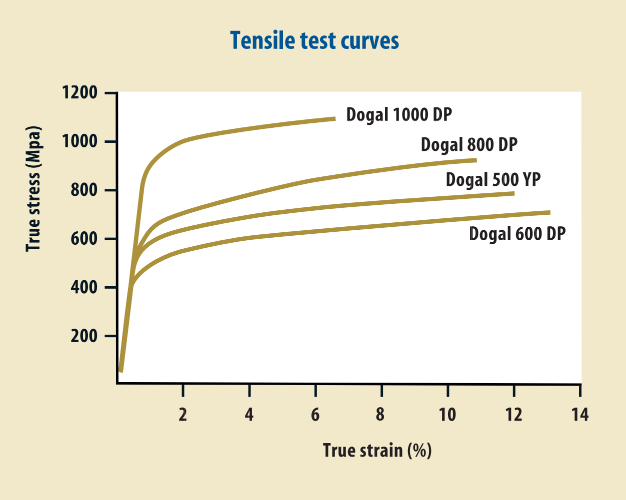


Fig.6. The effect of work hardening is different between YP and DP steel grades. For example, Dogal 800 DP and 500 YP have approximately equal yield strength, while there is a significant difference in tensile strength. This will affect the energy absorption capacity and formability among other things.

measured in two directions, i.e. that which is biggest, designated ∑-max, and that at right angles to this direction, designated ∑-min.

If a positive change has occurred in both directions, the process is stretch-forming, which is plotted to the right of the zero line in the FLC graph. The values that have a negative ∑-min and a positive ∑-max are plotted to the left of the zero line, which denotes a drawing process.

The curves are dependent on the thickness of the material, and must therefore be recalculated to the relevant thicknesses. The results for a given pressing operation are plotted on the graph and are compared with the material curve. If the result is below the curve, the relevant material can withstand the deformation.

Springback

The springback will increase on change-over from mild steel to a steel of a higher strength. Springback is affected not only by the strength of the material, but also by the tooling used. An increase in strength, punch radius (R) or die opening width (W) will cause increased springback. A decrease in thickness will also increase the springback for a given radius.

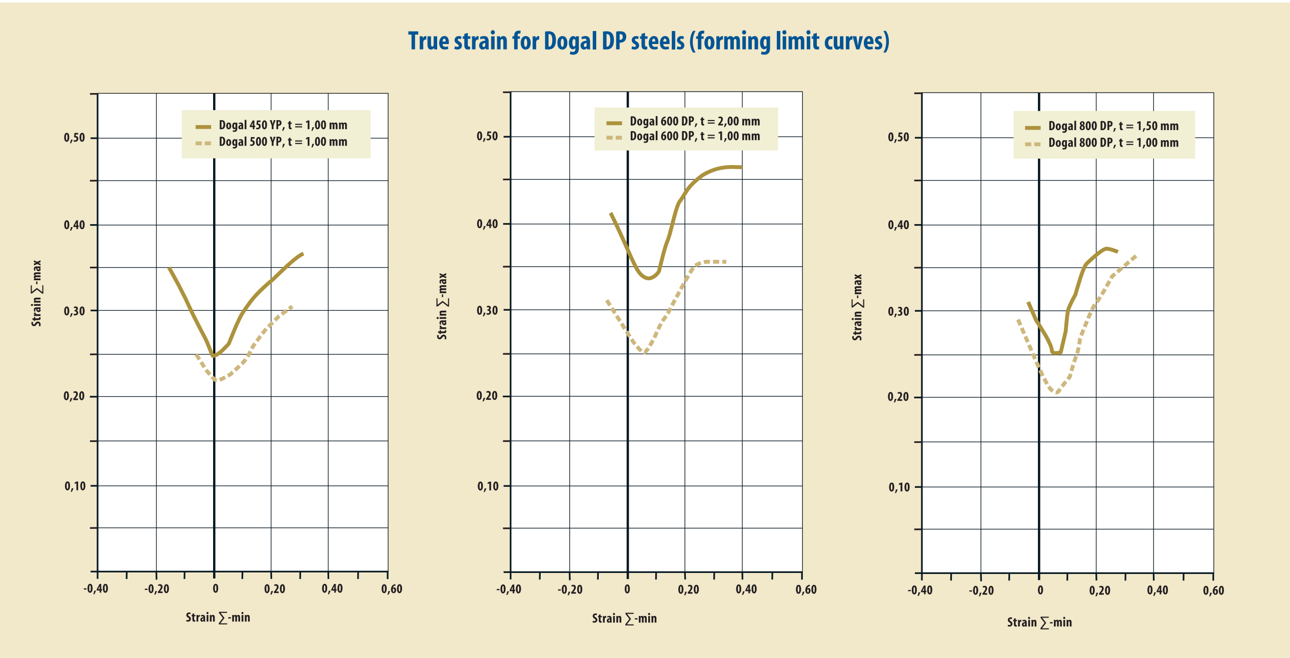


Fig. 7. t = thickness

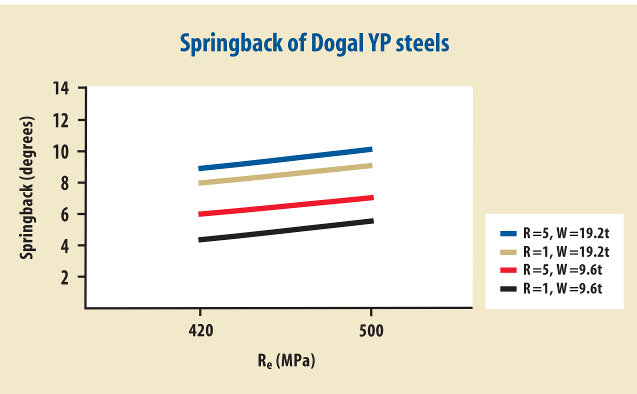


Fig. 8. Bending through 90 degrees (t=1.25 mm).

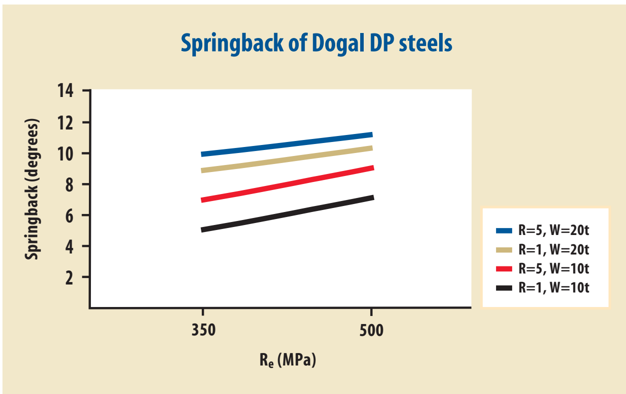


Fig. 9. Bending through 90 degrees (t=1.20 mm).

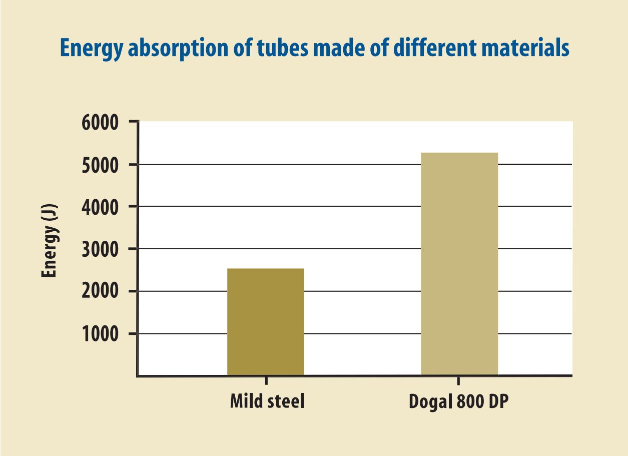
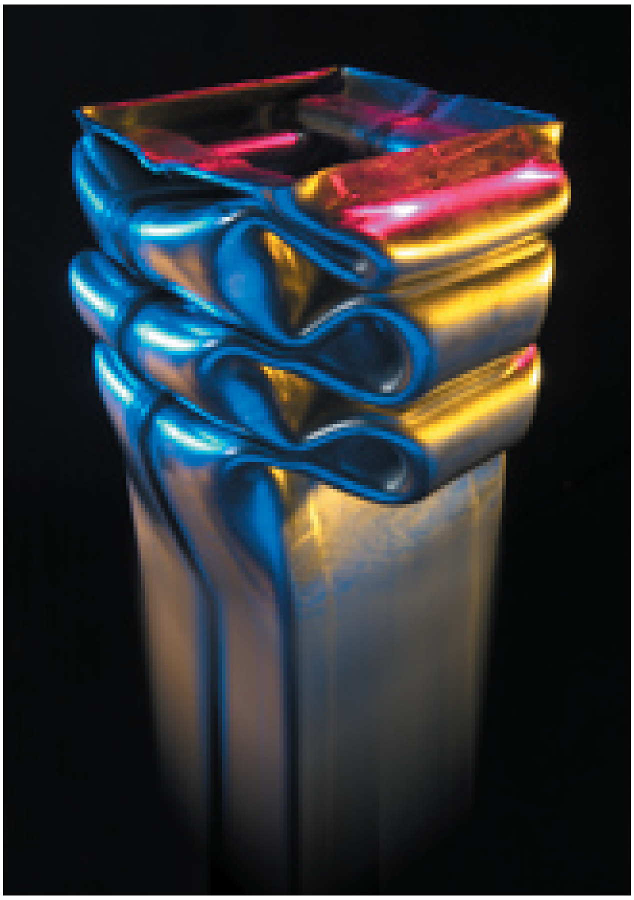


Fig. 10. The chart shows the energy absorption capacity of 60x60x1.2 mm thick rectangular tubes. The tube has been compressed 150 mm at low speed. It absorbed 5200 J, which corresponds to the energy of a 100 kg mass falling from a height of 5.3 metres.



Crushed beam in Dogal 800 DP.

The springback can be compensated by increasing the plastic deformation of the material at the bend. This can be done by over-bending the material or by reducing the punch radius or die opening width. It can also be reduced by the introduction of stiffeners.

Tube forming and roll forming

Tube forming and other roll forming are typical operations in which the work-hardening properties of Dogal DP steels can be put to good use. Controlled deformation of the material takes place in these operations, which leads to an increase in the yield strength and tensile strength of the finished part.

Since the magnitude of the deformation is known and controlled, the increase in strength can be used in the design of the finished part. If the finished parts are heat treated, e.g. in conjunction with surface treatment, a further increase in strength can be expected.

Energy absorption

Dogal DP steels are suitable for components designed to absorb energy. Compared to a mild steel, the sheet thickness can be reduced, which offers economic and environmental benefits.

The cross-sectional geometry, material strength and sheet thickness are the main factors that jointly determine the energy absorption capacity. Replacement of a lower grade material by a high strength steel should be combined with optimisation of the cross-sectional geometry and the sheet thickness in order to put the properties of the material to full use.

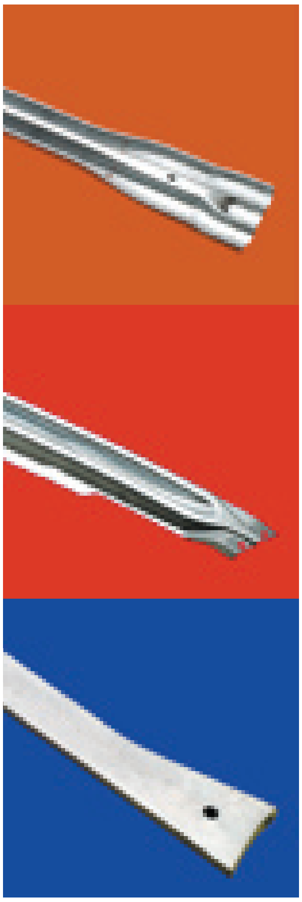
Since Dogal DP steels have high work-hardening properties, the strength of the material increases during forming operations. This has a beneficial effect in a low-speed crash of a road vehicle when energy is absorbed by elastic deformation of the material. The strength of the material also increases at high deformation rates.

The energy absorption capacity of a component or a system can be estimated by means of finite element analysis (FEA). This enables the influence of various factors to be investigated in order to optimise the system. Effects such as work-hardening, bake-hardening and strain rate effects can be included in order to improve the accuracy of the simulation. Stress-strain curves for Dogal DP steels for use as input in crash simulations can be downloaded from SSAB Steelfacts at www.ssabdirekt.com.

The energy absorption capacity should always be verified by testing of single components or the whole system.

Resistance to shocks and impact

Large areas of steel sheet subjected to shock and impact incur serious risk of permanent deformation. A car door, for example, must be able to withstand moderate shock and impact load without permanent deformation. The yield strength of the material determines the resistance of the sheet area to impact. The figure shows the relative thickness at which Dogal



Side impact beams in Dogal 800 DP.

DP steel has equivalent or the same shock and impact resistance as a mild steel (yield strength of 220 N/mm²), i.e. indirectly how much material can be saved by changing over to Dogal DP steels.

Fatigue

Good utilisation of the properties of high strength steels must be based on careful analysis of the fatigue load, i.e. the form and number of loading cycles in the load spectrum, together with good design, e.g. low stress-raiser effects in joints.

If the load amplitude is assumed to be constant at the maximum value, substantial oversizing would result, since real-life components are usually subjected to loads of varying amplitude (narrow spectrum load). The milder the load spectrum and the fewer the number of load cycles, the more beneficial it will be to use high strength steels, even in welded structures. Good design:

- use the stressed skin effect wherever possible
- ensure uniform load distribution throughout the structure
- avoid sudden stiffness changes or abrupt changes in cross-section
- the manner in which the load is applied is often critical – design with care
- ensure that welded joints are correctly located and designed
- accumulations of stress raisers must be avoided in all structures
- ensure that the weld quality is good (the actual production quality must be kept under close control).

For thin sheets of materials such as Dogal DP steels, a typical good design will include:

- using reinforcements (such as flutes and edge reinforcements) in order to counteract buckling and thus improve material utilisation
- using reinforcements to prevent local bending of the sheet, e.g. at load application points
- increasing the spotweld nugget diameters and reducing the spacing of the spot welds in order to lower the stress in the weld and thus raise the fatigue strength of the entire structure
- using spot welds in combination with bonded joints (weld-bonding) in order to increase the fatigue strength
- using laser welded joints, since these have much higher fatigue strength than spot welds.

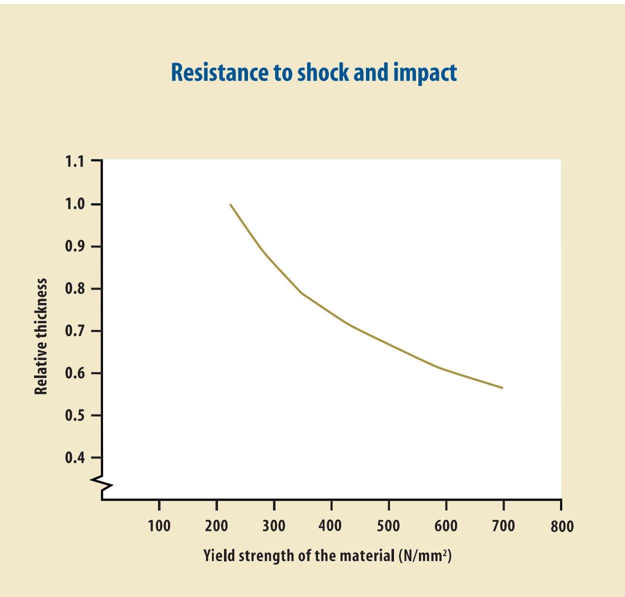


Fig. 11.

Welding of Dogal high strength steels

The welding methods that can be used for zinc-coated steels are almost the same as those used for welding cold-reduced steels. To ensure the best possible results, one of the factors that must be changed are the welding parameters. In the automotive industry, resistance welding, and especially spot welding, is the most common welding method.

Nowadays, mechanical joining is becoming increasingly common because of the surge in the development of these new joining methods. MAG welding is the fusion welding method that is most common when welding zinc-coated steels.

Spot welding

For spot welding Dogal high strength steels, we recommend the same type of Cu Cr Zr electrodes as those used for uncoated steels (A2 according to ISO 5182). In the same way, following a change in welding parameters, what is recommended for mild zinc-coated steels is also recommended for the high strength Dogal steels:

- increased electrode force (approx. 20-70%)
- increased welding time (approx. 20-50%)
- increased welding current (up to 50%).

The difference between high strength steels and mild zinc-coated steels is that the electrode force and welding time must be increased more for the high strength steels.

Results from the measured allowed current range (see table 11) that produce good

quality spot welds in Dogal steels are shown in the table below.

Strength of spot welds

The shear strength of spot welds in Dogal DP steels is higher than that of spot welds in steels of lower strength. The shear strength increases with increasing strength of the steel being welded. The peel strength of spot welds is lower than the shear strength, and it is therefore best to design the product for shear load if the product is to be spot welded. The higher strength of Dogal steels can then be put to good use.

Fusion welding

The most common welding method for zinc-coated steel is MAG welding. MMA welding can sometimes also be used. In the automotive industry, laser welding is also commonly used. TIG welding may be difficult since the zinc oxide from the fumes may adhere to the electrode and cause poor arc stability and weld quality.

The best solution from the welding point of view is to grind away the zinc coating locally. To maintain the corrosion resistance after welding, regardless of whether or not the coating has been ground away, some kind of anti-corrosion treatment will be needed after welding, such as painting with a zinc-rich paint.

If it is not possible to grind away the coating, one or more of the following measures is recommended:

- use as thin a coating as possible
- decrease the welding speed
- when MAG welding, use a gas with a high content of CO_2
- use a narrow gap between the sheets
- spray the sheets with an anti-spatter oil before welding
- when MAG welding, use flux-cored wire intended specifically for welding zinc-coated steels
- use MIG brazing with copper wire.

Strength of MAG welds

When MAG welding zinc-coated steel, the weld quality is one of most important factors that determines the strength of the welded joint.

Measured allowed current ranges in spot welding of Dogal high strength steels

Steel 1	Steel 2	Thickness Steel 1/Steel 2 (mm)	Welding data						Allowed current range[1)]		Type of failure
			Electrode diameter (mm)	Electrode force (N)	Squeeze time (cycles)	Cooling time (cycles)	Welding time (cycles)		range kA	min-max kA	
Dogal 450 YP[2)]	Dogal 450 YP	2.0/2.0	8.0	5000	30	10	20		1.5	9.4-10.9	Full plug
Dogal 500 YP[2)]	Dogal 500 YP	1.5/1.5	6.0	4000	99	10	23		1.2	6.2-7.4	Full plug
Dogal 600 DP[2)]	Dogal 600 DP	1.0/1.0	6.0	3500	99	10	14		1.3	7.6-8.9	Full plug
Dogal 600 DP[2)]	Dogal 600 DP	1.5/1.5	6.0	4500	30	20	19		2.0	6.9-8.9	Full plug
Dogal 800 DP[2)]	Dogal 800 DP	1.2/1.2	6.0	4000	99	10	18		1.7	6.7-8.4	Full plug
Dogal 800 DP[3)]	Dogal 800 DP	1.5/1.5	8.0	4000	30	10	17		3.0	9.8-12.8	Full plug

Table 11. [1)] Min. value: Plug dia. = 70% x electrode tip dia. Max value: Highest value without spatter. [2)] Coating thickness Z100, 7 µm (both steels). [3)] Coating thickness Z140, 10 µm (both steels).

Results of MAG welding of overlap joint in Dogal advanced high strength steels									
Grade	Sheet thickness mm	Zinc thickness µm	Filler metal	Volt V	Current A	Weld speed cm/min	$Rp_{0.2}$ MPa	R_m MPa	Remarks
Dogal 450 YP	2.0	7	OK Autrod 12.51	18.1	91	36	342	509	Matching
Dogal 500 YP	1.5	7	OK Autrod 12.51	18.1	89	50	446	567	Matching
Dogal 800 DP	1.2	7	OK Autrod 12.51	15.8	62	25	586	838	Undermatching
Dogal 800 DP	1.2	7	OK Autrod 13.31	17.6	84	43	486	766	Matching
Dogal 450 YP	2.0	7	Safdual Zn	15.2	122	50	330	500	Tubular wire
Dogal 500 YP	1.5	7	Safdual Zn	15.3	121	60	493	541	Tubular wire
Dogal 600 DP	1.2	20	Safdual Zn	14.7	132	80	500	628	Tubular wire
Dogal 800 DP	1.0	20	Safdual Zn	14.6	129	80	590	725	Tubular wire
Dogal 600 DP	1.2	20	OK Autrod 19.40	15.4	80	43	220	258	MIG brazing
Dogal 800 DP	1.0	20	OK Autrod 19.40	15.4	74	43	269	403	MIG brazing

Table 12.

The porosity of the weld increases with increasing thickness of the zinc layer, and it is therefore important to use a filler metal that gives low porosity and a minimum of spatter. This is more important than using a matching filler metal.

The table above shows the results of using different filler metals for MAG welding of Dogal steels.

Laser welding

Laser welding can be used for joining Dogal steels, both for assembly welding and for use as tailored welded blanks. Overlap joints are normally used for assembly welding. The type of weld is either a conventional weld with 100% penetration in both sheets, or an edge weld. Laser welding of Dogal steels is done in the same way as for mild steels, but the clamping forces needed for a good joint set-up are often somewhat higher for Dogal steels than for mild steels. To achieve good results in laser welded overlap joints in Dogal steels, a narrow gap of 0.1–0.2 mm is recommended between the sheets, in the same way as for zinc-coated mild steels. This will enable zinc fumes to escape from the weld pool, and porosity and other defects will thereby be avoided. An excessively large gap should be avoided in order to eliminate the risk of undercut on the top side of the weld.

Dogal steels can be used in tailor-welded blank applications. Laser butt welding is used in this case. The edge preparation on Dogal steels is then the same as for zinc-coated mild steels. In both cases, high quality of the edges and good set-up are needed to achieve good results in laser welding. If the tailor-welded product is intended for use in a forming operation, a stretchability test (Erichsen cup test) is normally used for assessing the formability of the laser weld. All Dogal steels record high Erichsen numbers (Erichsen number = stretchability of weld/ stretchability of parent metal). See table 13 below.

MIG brazing of zinc-coated DP steels

MIG brazing can be used for joining zinc-coated high strength steels. The same equipment as for MIG/MAG welding can also be used for MIG brazing. A copper-based wire with a low melting point

Formability of laser welds in Dogal advanced high strength steels (Erichsen tests)				
Grade	Sheet thickness mm	Laser power kW	Welding speed m/min	Erichsen number[1)]
Dogal 450 YP	1.9	2.6	2.0	0.78
Dogal 600 DP, Z 140	1.2	6.0	5.5	0.82
Dogal 800 DP, Z 100	1.2	6.0	10.0	0.82

Table 13. [1)] Erichsen number = stretchability of weld/stretchability of parent metal

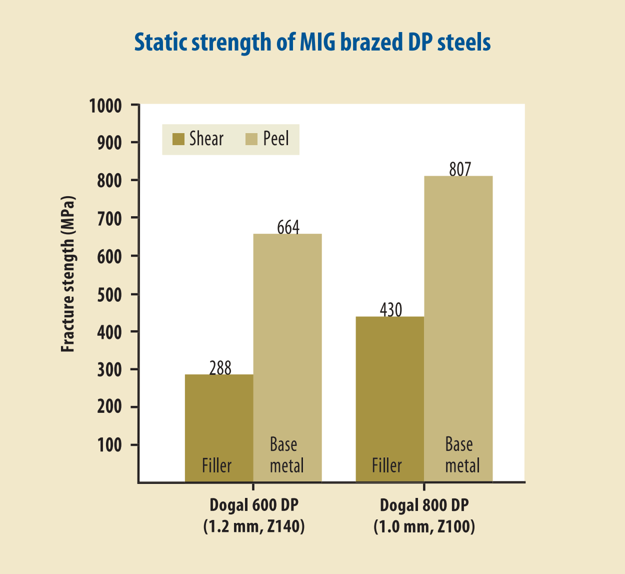


Fig. 12. Tensile shear (fillet in lap joint) and tensile peel tests (flange joint) on MIG brazed Dogal 600 DP and Dogal 800 DP. Filler metal/shielding gas: SG-CuSi3/Ar.

is used as filler metal, together with an inert shielding gas. The most common filler metal for MIG brazing of zinc-coated steels is SG-CuSi3 (DIN 1733). This is due to its low hardness and wide melting point range, which reduce the risk of defects during brazing. Some of the advantages of MIG brazing compared to MAG welding are:

- lower heat input
- less deformation of the sheets
- less spatter and better appearance.

One disadvantage of MIG brazing is the sometimes low strength of the filler metal. The results of tensile shear testing and peel testing of Dogal 600 DP Z140 (1.2 mm thick) and Dogal 800 DP Z100 (1.0 mm thick) are shown in Fig. 12. The strength of the flange joints (peel tests) is very good and the fracture is located at the parent metal. The strength of the lap joints (shear tests) is lower than the strength of the parent metal due to the low strength of the filler metal.

Corrosion

Introduction

Metals are generally exposed to the atmosphere more frequently than to any other corrosive environment. Atmospheric corrosion is a process that takes place in a film of water on the surface of the metal. The film may be so thin that it is invisible to the naked eye.

The main atmospheric components that cause corrosion are oxygen (approx. 20 %), water (2.3 % at 20°C) and carbon dioxide (0.03 %). Other corrosive components often also occur due to natural processes or human activities, e.g. sulphur dioxide, soot, hydrogen sulphide, ozone, sodium chloride, nitrogen oxides, etc. Factors such as direction of the prevailing wind, temperature, rainfall and solid particles also play an important role.

The corrosion rate is increased by the following factors:

- increase in relative humidity
- occurrence of condensation (when the surface is at or below the dew point)
- increase in the amount of pollution in the atmosphere.

Experience has shown that significant corrosion takes place if the relative humidity is above 80 % and the temperature is above 0°C. However, if pollutants and/or hygroscopic salts are present, corrosion will also occur at lower humidity levels.

Zinc-coatings have been used for more than a hundred years to protect steel from corrosion. The coatings are fairly effective and have a two-fold action – as a barrier and as galvanic protection of the steel surfaces. The corrosion properties of Dogal DP steels are determined by the corrosion resistance of the zinc-coating, which is exactly the same as that of hot-dip galvanised mild steels. Dogal DP steels thus have the same corrosion resistance as other hot-dip galvanised steels. The coatings are effective in a broad pH range between about 4 and 12 (see Fig. 13), which make them useful as protection both in atmospheric environments and in various aqueous solutions.

Atmospheric corrosion

The Swedish Corrosion Institute has investigated the long-term anti-corrosion properties of Dogal® in various environments. The results are shown in Fig. 14. The test sites used are classified in accordance with SS EN ISO 12 944-2 by 1-year exposure of steel and zinc panels. The classification according to the latest data is shown in table 15.

The SS EN ISO 12944-2 standard describes different environments in more detail (see table 16).

The environment is divided into 5 categories, ranging from very low corrosivity (C1) to very high corrosivity (C5). Mass loss and average thickness reduction values are also given for each category. These figures can be used for determining the life in a certain corrosivity category (see table 16).

In standard SS EN ISO 14 713 continuously hot dip galvanised steel, Z 275, with a coating thickness of 20 µm/side is approved in category C2, which means at least 15 years life span.

Corrosion rate of Dogal® as a function of pH in aqueous solutions

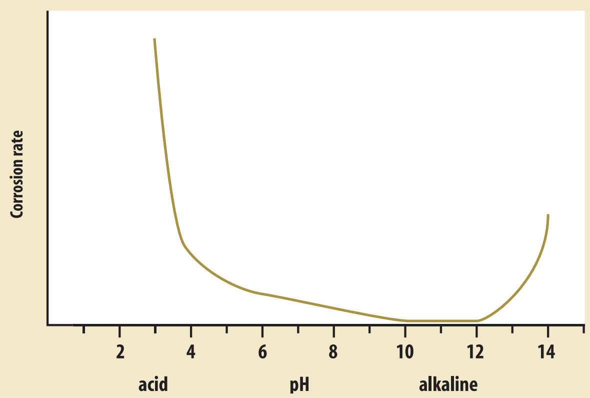
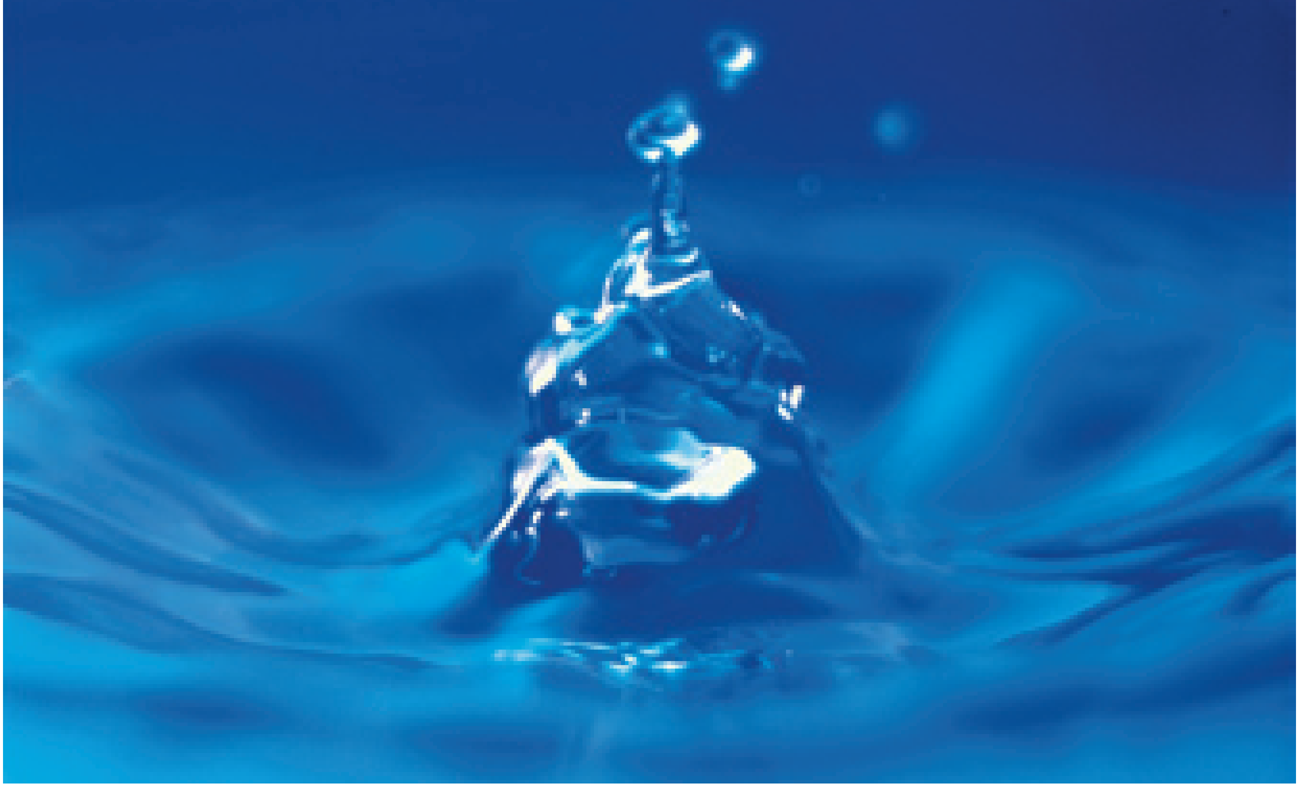


Fig. 13.



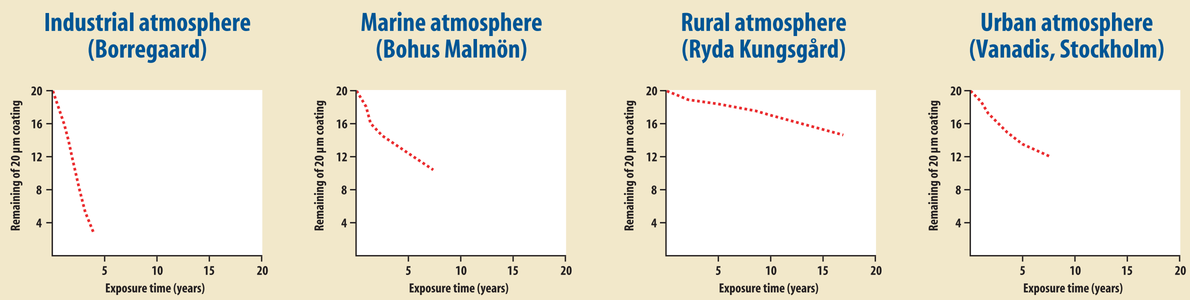


Fig. 14.

Classification of the corrosivity of the field stations

Field station	Environment	Carbon steel	Zinc
Ryda	Rural	C2	C2
Stockholm, Vanadis	Urban	C2	C2
Borregaard	Industrial	C3	C4
Bohus Malmön	Marine	C5	C3

Table 14. Data based on 2002 exposure, except Borregaard, which is based on the values from 1995.

Estimated life of Dogal Z275

Grade	Estimated lifetime (years)									
	C1		C2		C3		C4		C5	
	min	max	min	max	min	max	min	max	min	max
Dogal Z 275	∞	∞	18	130	6	18	3	6	1	3

Table 15.

Atmospheric corrosivity categories

Corrosivity category	Mass loss/unit area, thickness loss after 1 year			
	Steel		Zinc	
	Mass loss (g/m^2)	Thickness loss (µm)	Mass loss (g/m^2)	Thickness loss (µm)
• C1 (very low) Indoor	≤ 10	≤ 1.3	≤ 0.7	≤ 0.1
• C2 (low) Mostly rural areas	>10 to 200	>1.3 to 25	>0.7 to 5	>0.1 to 0.7
• C3 (medium) Urban areas with low to moderate pollution	>200 to 400	>25 to 50	>5 to 15	>0.7 to 2.1
• C4 (high) Industrial and coastal areas with moderate pollution	>400 to 650	>50 to 80	>15 to 30	>2.1 to 4.2
• C5 (very high) Industrial and coastal areas with high humidity and aggressive atmosphere	>650 to 1500	>80 to 200	>30 to 60	>4.2 to 8.4

Table 16.

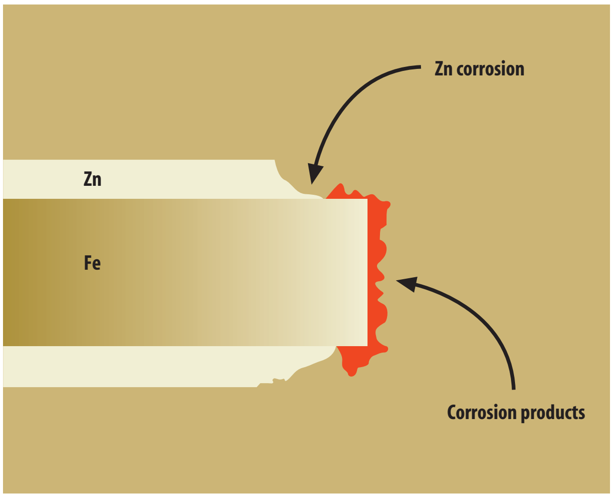


Fig. 15. Edge corrosion on Dogal®.

NOBLE ↑ / LESS NOBLE ↓

- **Gold**
- **Graphite**
- **Silver**
- **Stainless steel (passive*)**
- **Copper**
- **Nickel**
- **Tin**
- **Stainless steel (active*)**
- **Lead**
- **Steel**
- **Cadmium**
- **Aluminium**
- **55 Aluminium-zinc (Aluzink)**
- **Galvanised steel (Dogal®)**
- **Zinc**
- **Magnesium**

* In the passive state, the material has an inhibiting oxide film on the surface. This is not the case in the active state.

Table 17. Electrochemical series of metallic materials.

Corrosion at cut edges

A cut edge on Dogal® is shown schematically in Fig. 15. The zinc coating is less noble than the steel edge and thus becomes the anode in the galvanic couple, while the steel edge is the cathode. The protection of the edge depends on the aggressiveness of the environment, i. e. the conductivity of the wet film at the edge, the coating thickness and the steel thickness.

The conductivity of the film covering the edge is governed by the amount of dissolved salts. A high conductivity increases the protection of the cut edge and a thicker steel sheet can then be protected. A pure water film, e.g. water condensate, has very low conductivity, which results in a poor protection of the edge. Red rust will then be formed on the cut edge after a short time. This effect can be observed when a product has been exposed to high humidity or condensation during storage or transport.

A zinc coating cannot protect a cut edge that is thicker than 1 or 2 mm. The lower limit of 1 mm applies in environments in which the edge is exposed to a high humidity or water condensate (i.e. low conductivity conditions). In more polluted or salt-rich environments (i.e. high conductivity conditions), protection may be extended to 2 mm thick edge.

As a consequence of the protection mechanism described in Fig. 15, the metallic coating starts to dissolve in the vicinity of the edge. A thicker layer would obviously give protection for a longer time because more material is available. The width of the dissolved area is determined by the conductivity of the wet film and the ability of the object to keep the area in humid condition, e.g. the lower edge of a vertical panel or a horizontally exposed perforated panel.

Material compatibility

Galvanic corrosion can occur if Dogal® is in direct electrical contact and completes an electric circuit with another metal or alloy. As the zinc-coating is usually the less noble in such a couple (see table 17), it will become the anode and will corrode faster than in an uncoupled situation. Table 17 is a ranking of some common materials from noble to less noble and when two materials are connected the anode becomes the less noble and corrodes faster.

Severe combinations with Dogal® are those in which it is coupled to the noblest materials. In such a case, the driving force for corrosion is very strong and the attack on the anodic material (Dogal®) is much faster than in an uncoupled condition.

Dogal® should not be used together with lead or copper, including various alloys containing these elements, such as brass. Water run-off from a part containing copper onto Dogal® should also be avoided, since corrosion and discolouration may be encouraged. Combinations with stainless steel or nickel in aggressive environments may also be risky.

Wood is a material that can absorb much water and retain high humidity for a long period of time. The contact area between wood and Dogal® forms a crevice and white rust will occur. This process is similar to the formation of white rust between sheets during storage or transport in humid conditions.

Impregnated wood is even worse, because the impregnation chemicals usually contain copper salts that, to some extent, are dissolved and leak out of the wood. The solution is thus fairly aggressive and causes severe attack on Dogal . If wood is used in storage and transport, these aspects must be taken into account and the necessary measures must be taken to prevent damage to the product. For further details, see the section dealing with transport and storage.

Table 18 shows that graphite is a very noble material and can therefore substantially increase the corrosion of Dogal® if the two materials are in contact. Carbon black is sometimes used as a pigment in various types of rubber. Carbon black is chemically the same as graphite. So if a rubber material containing carbon black is in contact with Dogal®, it can significantly increase the corrosion rate.

Various sealing and roofing felt materials are petrochemical products and contain bitumen. If the sealant or roofing material is exposed to UV radiation, some of the components may decompose and may be leached out by rain or water condensate, thus producing an acidic solution. If this solution comes into contact with Dogal®, it will cause increased corrosion in those areas. Make sure that no corrosive chemicals are leached out of the sealant or roofing material and that it contains a UV stabiliser or is covered with a radiation-proof surface layer.

Protection of welds

During welding, most of the zinc-coating is vaporised and the corrosion protection in the weld is very limited. The spot welds are usually too large to gain complete galvanic protection from the surrounding coating (Fig. 16). Red rust will thus form in the spot welds, regardless of the size of the spots. A zinc-rich paint or a zinc spray can be applied to the spot welds to improve the protection against corrosion.

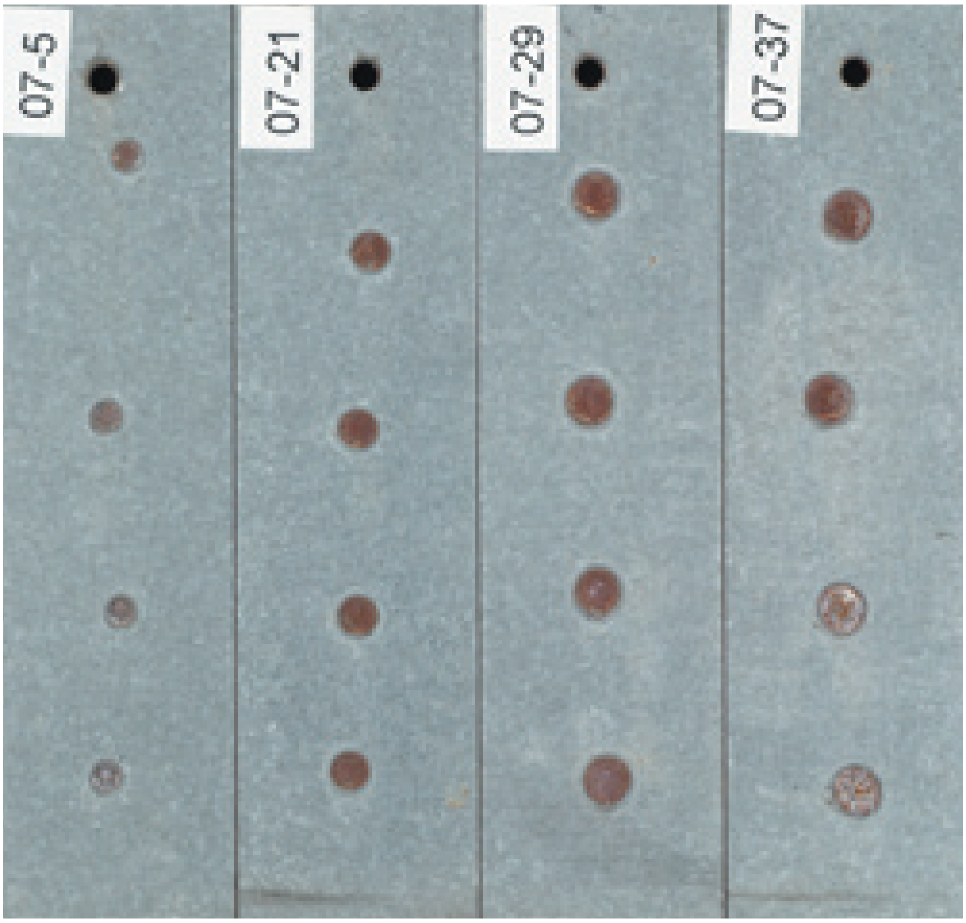


Fig. 16. Spot-welded Dogal® with various diameters of spot welds after 5 years exposure to an urban atmosphere. The diameters of the spots increase from left to right. It will be noted that, regardless of the sizes of the spots, red rust occurs in the spots.

Surface treatment

The appearance and functionality of Dogal® can be enhanced by surface treatment. Many pre-treatment and coating systems are available for application to hot-dip galvanised steel. The choice of system is determined by the combination of the demands on the product and the aggressiveness of the environment to which the product will be exposed.

Cleaning

The metal surface must be clean before the paint is applied, since it will otherwise be impossible to achieve a good coating system. The most common cleaners used today are aqueous, alkaline solutions applied by spraying or dipping. The formulation of the cleaner depends on the type and amount of dirt on the surface. For recommendations in these matters, consult a supplier of pretreatment chemicals.

If the product is to be used indoors or in a mild outdoor environment, cleaning before paint application is sufficient. In more aggressive environments, a chemical conversion coating will be needed before painting.

Chemical conversion coating

A common surface conversion process is iron phosphating, either combined with cleaning or with a separate cleaning process. Iron phosphating produces a thin (less than 1 µm) coat of zinc phosphate on the galvanised surface.

Another surface conversion process is zinc phosphating, with or without the addition of nickel and manganese. The zinc phosphating bath requires more attention and stricter control than an iron phosphating bath and produces a thicker crystalline coating. This process is used if very strict demands are made on paint adhesion and anti-corrosion properties.

All phosphating coats improve the paint adhesion and reduce the risk of underfilm corrosion (i.e. corrosion under a paint coat).

Paint systems

There are two major types of paint systems for continuously hot-dip galvanised steel, i.e. solvent-borne or water-borne paints and powder paints. A rule of thumb is that the thicker the paint coat, the better the protection against corrosion. In aggressive environments, the paint system must include a primer coat with a corrosion inhibiting pigment. In order to optimise the life of the product, it is essential for the top coat to have good outdoor stability.

Primer

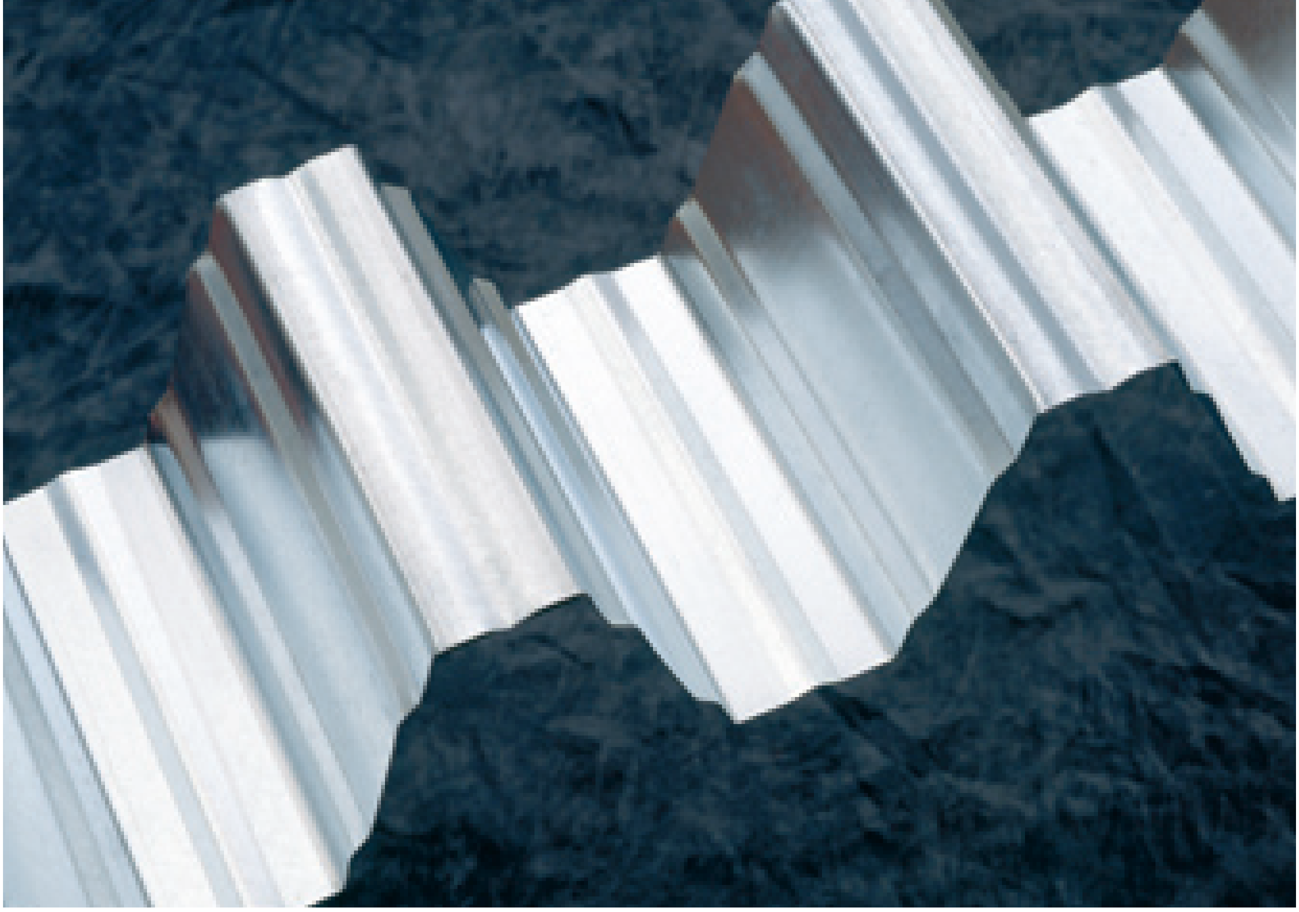
The function of the primer is to provide good adhesion to the metal and good protection against corrosion. It should contain an anti-corrosion pigment, such as zinc phosphate. Suitable primers are alkali-resistant alkyd and epoxy paints. Since epoxy is degraded by sunlight, the top coat must be applied to an epoxy primer before the product is exposed to sunlight. The primer can be omitted for painted products that are used in environments that have low aggressiveness.

Top coat

The purpose of the top coat is to give the painted surface the required aesthetic appearance, and enhanced resistance to scratching and impact. It can also add a technical value, such as electrical shielding or anti-slip properties. A brief summary of paints according

Binder	Properties
Acrylic	Good outdoor stability, colour fastness and good mechanical properties. Limited resistance to solvents. Air-dried or oven cured.
Alkyd	Alkyds are not recommended for Dogal®.
Epoxy	Not for use outdoors, due to the risk of chalking. Good mechanical properties and good resistance to chemicals. Available as powder and solvent-borne coatings (oven cured).
Polyester	Common binder for powder coating. Good outdoor stability and mechanical properties.
Polyurethane (PUR)	Excellent resistance to chemicals and outdoor stability. Available as water-borne or solvent-borne, or as powder coating.

Table 18.



to their binders and the main properties of the binders in table 18.

Recommended coating systems for Dogal®

On the basis of the corrosivity categories, table 19 gives some recommendations of suitable protective coating systems for Dogal®. For a complete selection of systems, consult a paint supplier.

Transport and storage

To ensure trouble-free manufacture and surface treatment of the end product, it is important to protect the products from water and moisture throughout the handling, production and storage chain, all the way from the steel mill to the end user.

If the coils or sheets are exposed to water or moisture during transport or storage, wet storage staining may occur. This form of corrosion produces a white or grey appearance on the surface when coils or tightly packed sheets or panels are exposed to water or moisture. Water can enter between the coil laps or sheets by capillary action and will then cause corrosion attack and discolouration of the surface.

Small damaged areas can be repaired by a light blast-cleaning. Some pretreatments that can remove the corrosion products are also available. In such cases, the surface can be painted in the usual way. However if the corrosion products cannot be removed, do not attempt to paint the surface, since the adhesion will always be unsatisfactory.

Corrosivity category	Pretreatment	Paint system
C2	Degreasing	Powder coating , epoxy* or polyester. Film thickness at least 60 µm.
	Degreasing + iron phosphate	Powder coating , epoxy* or polyester. Film thickness at least 40 µm.
C3	Degreasing	Water-borne acrylic primer with active anti-corrosion pigment + polyester powder coating, at least 60 µm thick.
	Degreasing + iron phosphate	Powder coating , polyester. Film thickness at least 60 µm.
C4	Degreasing + iron phosphate	Water-borne acrylic primer with active anti-corrosion pigment + polyester powder coating, at least 60 µm thick.
	Degreasing + zinc phosphate	Powder coating , polyester. Film thickness at least 80 µm.

Table 19. * Indoor use only.

Recommendation for tool steels

Punching and forming of Dogal high strength steels

As in all industrial production, it is important that the forming and shearing operations on steel sheet parts should be trouble-free. The chain from tool design to tool maintenance comprises many stages, as illustrated by the schematic below.

A prerequisite for achieving good productivity and production economy is that all stages are correctly performed. It is therefore vitally important to select the right tool steels for a given cutting or shearing operation.

To be able to select the correct steel, it is important to identify the failure mechanisms that may arise during shearing and/or forming and that may lead to the tool becoming unusable or breaking down after only a short period of use. There are basically five failure mechanisms that may occur in the active parts of the tool:

- **wear,** either abrasive or adhesive, associated with the workpiece material, the type of forming operation and the frictional forces in sliding contact
- **plastic deformation** may occur in the event of an inappropriate relationship between the stresses and the compressive yield strength (hardness) of the tool material
- **edge chipping** may occur as a result of an inappropriate match between the stresses and the ductility of the tool material
- **cracking** may occur as a result of an inappropriate match between the stresses and the toughness of the tool material
- **pick-up** may occur as a result of an inappropriate match between the workpiece material and the frictional forces occurring on sliding contact. The pick-up mechanism is closely related to adhesive wear.

Plastic deformation, edge chipping and cracking are forms of failure that often result in serious and costly production stoppages. Wear and pick-up are more predictable and can largely be handled by systematic maintenance of the tools. A consequence of this is that it may be advisable to allow more wear than to get chipping or cracking.

The special feature in forming and shearing Dogal DP steels is that, for a given sheet thickness, the forces must be higher than for mild steels, since the higher yield strength must be overcome during forming and the higher shear strength must be exceeded during shearing. This means that the stresses increase and the demands on the wear resistance and strength of the tool material thus also increase. The shearing operation is most sensitive, since it demands a combination of high wear resistance and high resistance to edge chipping/tool breakage, while the forming operation demands only wear resistance.

A relative comparison between cold working steels

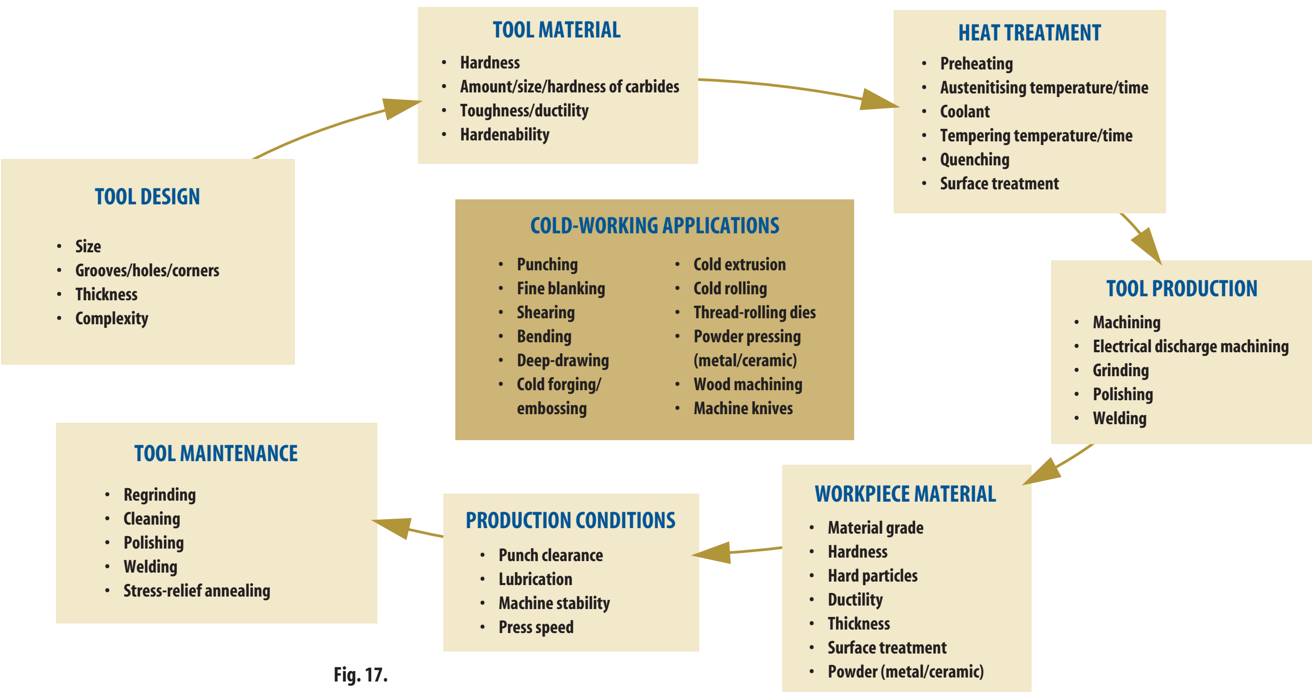


Fig. 17.

Tool steel grade	SS	ISO	DIN	Hardness – Plastic deformation	Wear resistance – Abrasive	Wear resistance – Adhesive	Resistance to fatigue – Crack initiation (Ductility – resistance to chipping)	Resistance to fatigue – Crack propagation (Toughness – resistance to total breakage)
Arne	2140	W.-Nr. 1.2510	AISI 01					
Calmax		W.-Nr. 1.2358						
Rigor	2260	W.-Nr. 1.2363	AISI A2					
Sleipner								
Sverker 21	2310	W.-Nr. 1.2379	AISI D2					
Sverker 3	2312	W.-Nr. 1.2436	AISI D6					
Vanadis 4								
Vanadis 23		W.-Nr. 1.3344	AISI M3:2					
Vanadis 6								
Vanadis 10								

Table 20. Relative resistance to failure mechanisms

from Uddeholm Tooling as regards resistance to these particular damage mechanisms on tools is shown in the above table.

Production conditions

Compared to other steels, VANADIS steels have a good combination of wear resistance and resistance to edge chipping. The reason is that the steels are produced by powder-metallurgical methods, while others are produced by conventional metallurgical methods. The difference in properties is due mainly to the fact that the powder-metallurgical method produces small, uniformly distributed carbides that protect against abrasion. Moreover, by being small, the carbides are less dangerous as initiation points for fatigue cracks. As opposed to this, conventional steels with good wear resistance have large carbides that are arranged in streaks and that impair the mechanical strength of the material.

Steel selection guide for shearing Dogal high strength steels

It is difficult to give accurate advice for the selection of tool steels for a specific production situation, since no production system is exactly the same as the next. If possible, a better approach is to try to build on past experience from in-house production in the same mechanical equipment, and gradually improve the choice of steel by comparing the performance of different steels. If the user has no in-house experience, the table on page 32 may be used as a guide.

All tool steels in the table 20 can be used for the lower strength grades of Dogal DP steels, thinner sheet and simpler geometries, whereas only a few of the steels are usable for the highest strength grades, mainly due to the risk of early tool breakage caused by edge chipping.

In tool design and production, it is important to avoid sharp corners, small radii and poorly machined surfaces. The high working stresses combined with the high hardness of tool steels give rise to stress concentrations in such areas.

Steel selection guide for forming Dogal high strength steels

Wear, which is mainly abrasive in nature, is the main damage mechanism in forming operations, although adhesive wear may also occur due to the high frictional forces involved in the forming of Dogal steels. Powder steels have the best performance, but no special information other than that included in the failure mechanism table above (table 20) and the tool steel guide on page 33 are necessary for selecting tool steels. Due to the fact that ultra-high strength steels are not as formable as mild steel, the parts produced cannot be given radii that are as tight as those in mild steel sheet, which is beneficial in the context of tools.

Punching high strength steels
Guide for tool steels

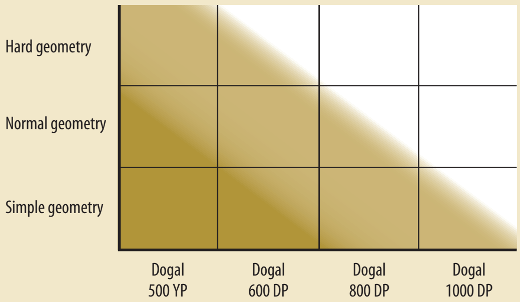


Fig. 18.

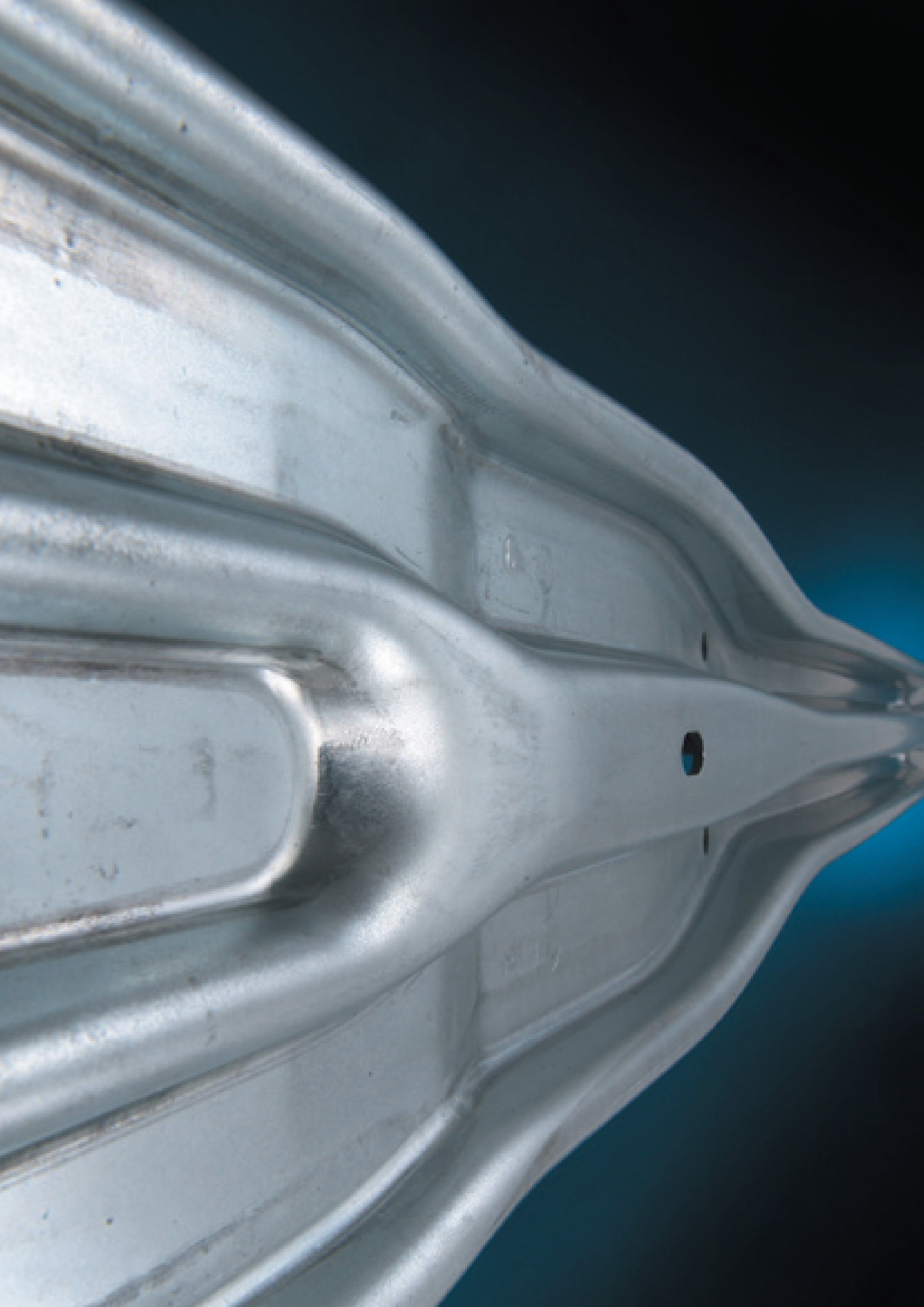
Short- and middle long lengths of series	Sleipner Rigor Calmax Sverker 21	Sleipner Rigor Calmax	Sleipner Rigor Vanadis 4
Long length of series	Vanadis 10 Vanadis 6 Vanadis 4 Vanadis 23 Sleipner Sverker 21	Vanadis 6 Vanadis 4 Vanadis 23 Sleipner	Vanadis 6 Vanadis 4 Vanadis 23 Sleipner

Table 21. In all cases, the hardness should be at least 58 HRC, since the risk of plastic deformation could otherwise be present.

Steel selection guide for forming
Guide for tool steels

Length of production run	**Dominating type of wear** **Adhesive wear**	**Mixed wear**	**Abrasive wear**
Short	Arne 54-56 HRC Carmo* 54-61 HRC	Arne 54-58 HRC Calmax 54-59 HRC	Arne 54-60 HRC
Medium	Calmax 54-58 HRC Sleipner 56-62 HRC	Rigor 54-62 HRC Sleipner 58-63 HRC	Sverker 21 58-62 HRC Sleipner 60-64 HRC
Long	Vanadis 4 56-62 HRC	Vanadis 6 60-64 HRC Vanadis 23 60-65 HRC	Sverker 3 58-62 HRC Vanadis 6 60-64 HRC Vanadis 10 60-64 HRC

Table 22. * Flame-/induction hardening.



What should the designer bear in mind?

The advanced high strength steel of Dogal® offer scope for designing lightweight, thin-wall products. However, bear in mind that the ultimate properties of the product are determined by the geometrical design in combination with the properties of the material. The ability to carry loads and the stiffness in bending of beams, profiles, etc., are significantly affected by the section height and various reinforcements.

Reinforcements such as flutes and folded edges are used for thin steel sheet components, since they reduce the buckling tendency, add rigidity and enable the material to be put to full use. Reinforcements are particularly important in the design of energy-absorbing parts, in which buckling or folding should be restrained or controlled, even during plastic deformation. Flutes and reinforcements can be pressed directly into parts made of Dogal high strength steels.

The pressability of these materials is good in relation to their high strength. However make sure that edge radii are sufficiently large and the drawing depth is moderate. Roll forming is particularly well suited for producing profiles in long production runs. In roll forming, flutes and edge folds can be located in suitable areas directly in the forming process. When forming parts of Dogal high strength steels, thought should be given to producing the design so that adequate compensation can be made for springback. This is also important in the design of the forming tools. Using stressed skin action in steel sheet parts enables the material to be put to better use. Try to avoid structural parts of steel sheet acting as plates with local deflections and consequently high bending stresses.

SSAB Tunnplåt AB is the largest Scandinavian sheet steel manufacturer and a leader in Europe in the development of high strength, extra-high strength and ultra-high strength steels.

SSAB Tunnplåt is a member of the SSAB Swedish Steel Group, has a turnover of SEK 10 billion, and has around 4400 employees in Sweden. The company produces about 2.8 million tonnes of sheet steel annually.

Our environmental policy involves continual improvements to the efficiency of production processes and environmental care plants, and development of the environmental properties of our products from the life cycle perspective.

We produce the following steels in our modern, high-efficiency production lines and rolling mills for strip products:

DOMEX®
hot-rolled steel sheet

DOCOL®
cold-reduced steel sheet

DOGAL®
metal-coated steel sheet

PRELAQ®
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