IT'S ALL ABOUT STRENGTH AND LIGHTNESS

DOCOL®

SSAB SWEDISH STEEL

A scrap bos from Materia Klaesson, one of the leading
design producers in Scandinavia.

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DOCOL INTRODUCTION

Docol from SSAB is not only strong, it is also green. By using advanced high strength steels, such as Docol, products can be made lighter, stronger and have a longer life cycle than traditional steels. The benefits from using Docol AHSS are obvious in almost every application.

A lighter car has a lower fuel consumption.

A truck or railcar can carry a larger payload and needs less maintenance.

Household appliances and furniture can be designed in a completely new and lighter way.

Cranes and construction equipment can carry higher loads and have increased reach and range.

The scope for improvement with Docol Advanced High Strength Steel is very large. Not only do the end-products become lighter, safer, more efficient and have reduced impact on the environment; less steel also has to be produced in the world.

Less steel needed for a given purpose means less steel has to be transported. Reduced amounts of steel simplify the production process and less energy is needed in many stages of the process.

Of course, steel also has the advantage of being one of the most recycled materials in the world. It requires less energy during production than other alternatives, such as aluminium.

The strength and other benefits of Docol AHSS can be achieved without any radical changes in the production process or large investments in new equipment and machinery.

In most cases, it is 'production as usual'. And, in many cases, switching to Docol AHSS even simplifies design, forming and welding.

Figure 1. The extremly light weight wood chip container from CMT.

The following examples have all been nominees for the Swedish Steel Price:

The crash-proof road post

AHSS offers unlimited possibilities, not only in large and complex applications such as trucks, construction equipment and cars but also in simple and uncomplicated products. A road post made by the Australian company Dura-Post is an excellent example.

The post has a semi-circular, dished design and the Docol 1400 steel used is only 1.2 millimetres thick. In spite of being very thin, it can withstand impacts by vehicles. When struck, the post simply folds out of the way and then rises again. This is due to the high spring back properties of AHSS, combined with the dished profile.

Light truck, heavy load

A new design, switching to AHSS and more advanced welding – these three measures cut the weight of the body of a light truck, made by V.N. Automoveis in Portugal, by almost 30 per cent. The lower weight means increased payload and less maintenance.

Three different AHSS products are used in the body. Hot-rolled AHSS with a strength of 600 MPa and a thickness of 2 mm was used for the frame. The floor is made of 2 mm thick abrasion-resistant Docol with a strength of 1400 MPa. The frame and floor were joined together by MIG welding. The sides of the body are made of 1 mm thick Docol with a strength of 500 MPa.

One millimetre of steel is all that is needed

The Swedish company CMT manufactures one of the strongest and lightest containers in the world. Docol AHSS, with a minimum tensile strength of 1400 Mpa, is the predominant material used for the containers.

In the CMT wood chip container, the walls are only 1 mm thick and the floor is 2 mm thick. The same grade of steel, but 2 mm thick, is used for the walls of an all-round model. In this container, the floor is made of 3 mm thick hot-rolled steel with a strength of 650 MPa.

In both models the design has been extremely important. The smooth design reduces wear and tear as well as aerodynamic drag.

A five-star success for safety

When Italian automaker Fiat designed the Grande Punto the demands were very high. The car was to be technically innovative, with excellent safety and unique exterior design. All safety aspects were highly prioritized. The car was awarded the maximum of five stars for occupant safety in the Euro NCAP test. Thus, high-energy absorption capacity and compact design characterize the side impact beam in the doors of the car.

The beam is made from Docol with a strength of 1000 MPa. The roll-formed beam was developed in close cooperation between Fiat and its supplier Wagon Automotive.

Saving weight and time

Trailers and tippers are much more cost-effective when AHSS is used in the design. The Brazilian company Pastre has developed a lightweight semi-trailer for agricultural products such as sugar. By using AHSS the weight of the semi has been cut by 20 per cent, or around 2.5 tonnes. Load capacity is increased and fuel consumption lowered.

The trailer has two separate bodies on one chassis. The two bodies are made of Docol AHSS with a strength of 1000 MPa. In addition to lower weight, the switch to AHSS has enabled improvements of the entire trailer design: unloading is now much faster and maintenance has been reduced.

Figure 2. The side impact beams of Fiat Grande Punto are made from Docol 1000 and an important factor behind the five star Euro NCAP rating of the car.

THE DOCOL PRODUCT RANGE

The Docol range of steels have all been developed with specific applications and demand in mind. Whatever your needs are, you can be sure that there is Docol grade that can fulfill them.

High-strength, low alloyed steels – Docol LA

The micro alloyed cold-forming steels derive their high strength from the addition of very small quantities of micro-alloying elements such as niobium. These steel grades are designated according to the lowest guaranteed yield strength. The difference between their yield strength and tensile strength is small.
The high-strength low alloyed steel grades belonging to the advanced high strength steels, are suitable for bending, flanging, roll forming and simple pressing operations as well.

Figure 3. An armature from Fagerhult, the largest lighting group in the Nordic region and a leading force in Europe.

Table 1. Chemical composition (typical values)

Steel grade	C %	Si %	Mn %	P %	S %	Al_{tot} %	Nb %
Docol 420 LA	0.05	0.20	0.60	0.01	0.01	0.040	0.04
Docol 500 LA	0.06	0.40	1.20	0.01	0.006	0.040	0.06

Table 2. Mechanical properties

	Yield strength R_{eL} (N/mm^2)		Tensile strength R_M (N/mm^2)		Elongation, A80%	Min. bending radius
Steel grade	min.	max.	min.	max.	min.	90° bend
Docol 420 LA	420	520	470	590	17	0,25xt
Docol 500 LA	500	620	570	710	14	0.50xt

t = sheet thickness
The mechanical properties are valid in the transverse direction of rolling

Dual Phase steels – Docol DP/DL

Dual phase steels consist of a ferritic matrix containing a hard martensitic second phase in the form of islands. Ferrite, which is soft, contributes to good formability and martensite to the strength of the material. Increasing the volume fraction of hard second phases generally increases the strength. Dual phase steels are produced by controlled cooling from the two-phase, ferrite plus austenite phase, to transform some austenite to ferrite before a rapid cooling transforms the remaining austenite to martensite. Depending on the chemical composition and process parameters, dual phase steels with different mechanical properties can be achieved.

Dual phase steels are characterized by a low yield ratio (YS/TS), high strain hardening and high uniform elongation, resulting in a material with very good formability. Parts with complex geometries can be formed. Apart from strain hardening during pressing, the final strength of the finished parts is achieved also by bake hardening in conjunction with painting.

Docol DL, a low yield ratio type of dual phase steel, has even better formability compared to corresponding Docol DP. The figures in the steel grade designation specify the minimum tensile strength.

On request, DP steels adapted to car manufacturers' own standards can be achieved e.g. Toyota TSG3100G, Honda HES C052-00, Nissan M 2032, Fiat 52815, Renault RNUR 11-04-002 and GMW 3399M-ST-S. DP grades, with designations based on US unit ksi, can also be achieved for the US market.

Table 3. Chemical composition (typical values)

Steel grade	C %	Si %	Mn %	P %	S %	Al_{tot} %	Nb %
Docol 500 DP	0.08	0.30	0.65	0.010	0.010	0.040	-
Docol 500 DL	0.05	0.20	1.50	0.010	0.002	0.040	
Docol 600 DP	0.10	0.20	0.80	0.010	0.002	0.040	0.015
Docol 600 DL	0.10	0.40	1.50	0.010	0.002	0.040	-
Docol 800 DP	0.13	0.20	1.50	0.010	0.002	0.040	0.015
Docol 800 DL	0.14	0.20	1.50	0.010	0.002	0.040	0.015
Docol 1000 DP	0.15	0.50	1.50	0.010	0.002	0.040	0.015
Docol 1000 DPZE	0.15	0.50	1.50	0.010	0.002	0.040	0.015

Table 4. Mechanical properties

Steel grade	Yield strength R_{eL} (N/mm^2) min.	max.	Yield strength after bake hardening	Tensile strength R_M (N/mm^2) min.	max.	Elongation, A80% min.	Min. bending radius 90˚ bend
Docol 500 DP	290	370	400	500	600	20	0xt
Docol 500 DL	230	300	350	500	600	24	0xt
Docol 600 DP	350	450	500	600	700	16	0xt
Docol 600 DL	280	360	450	600	700	20	0xt
Docol 800 DP	500	650	600	800	950	10	1.0xt
Docol 800 DL	390	540	550	800	950	13	1.0xt
Docol 1000 DP	700	950	850	1000	1200	7	2.0xt
Docol 1000 DPZE	700	950	850	1000	1200	7	2.0xt

The mechanical properties are valid in the transverse direction of rolling
t = sheet thickness
ZE = electrogalvanized material
1) BH = bake hardening after 2%

Martensitic steels – Docol M

Docol M are cold reduced fully martensitic steels. To create martensitic steels, the austenite that exists during annealing is transformed to martensite in the cooling section of the continuous annealing line. Docol M is characterized by a very high strength, high-yield ratio (YS/TS) combined with moderate formability. Martensitic steels are most suitable for bending, roll-forming, simple pressing operations and tube making.

On request, martensitic steels adapted to car manufacturer's own standards can be achieved e.g. GMW 3399 M-ST-S and also grades with designations based on US unit ksi, intended for the US market only.

Table 5. Chemical composition (typical values)

Steel grade	C %	Si %	Mn %	P %	S %	Al_{tot} %	Nb %	Ti %
Docol 900 M	0.05	0.20	2.00	0.010	0.002	0.040	-	-
Docol 900 MZE	0.05	0.20	2.00	0.010	0.002	0.040	-	-
Docol 1200 M	0.11	0.20	1.70	0.010	0.002	0.040	0.015	0.025
Docol 1200 MZE	0.11	0.20	1.70	0.010	0.002	0.040	0.015	0.025
Docol 1400 M	0.17	0.20	1.40	0.010	0.002	0.040	0.015	0.025
Docol 1400 MZE	0.17	0.20	1.40	0.010	0.002	0.040	0.015	0.025
Docol 1500 M	0.21	0.20	1.10	0.010	0.002	0.040	0.015	0.025
Docol 1500 MZE	0.21	0.20	1.10	0.010	0.002	0.040	0.015	0.025

Table 6. Mechanical properties

Steel grade	Yield strength R_{eL} (N/mm^2) min.	max.	Yield strength after bake hardening	Tensile strength R_M (N/mm^2) min.	max.	Elongation, A80% min.	Min. bending radius 90˚ bend
Docol 900 M	700	-	900	900	1100	3	3.0xt
Docol 900 MZE	700	-	900	900	1100	3	3.0xt
Docol 1200 M	950	-	1150	1200	1400	3	3.0xt
Docol 1200 MZE	950	-	1150	1200	1400	3	3.0xt
Docol 1400 M	1150	-	1350	1400	1600	3	3.0xt
Docol 1400 MZE 2)	1150	-	1350	1400	1600	3	3.0xt
Docol 1500 M 2)	1200	-	-	1500	1700	3	3.0xt
Docol 1500 MZE 3)	1200	-	-	1500	1700	3	3.0xt

The mechanical properties are valid in the transverse direction of rolling
t = sheet thickness
ZE = electrogalvanized material
1) BH = bake hardening after 2% plastic deformation and heated to 170˚C
2) Can be achived at request
3) Under development

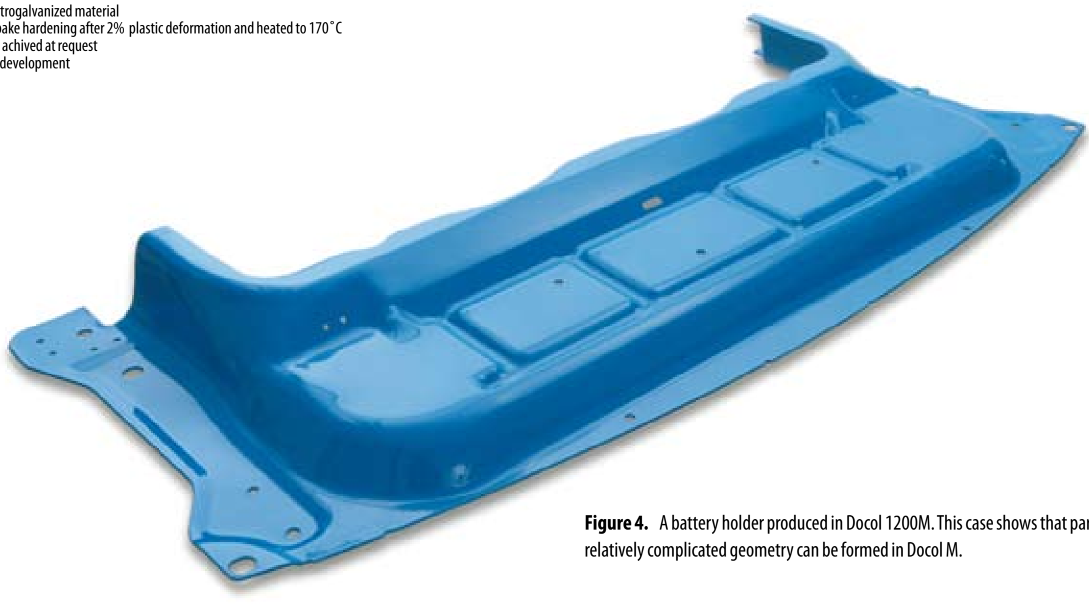


Figure 4. A battery holder produced in Docol 1200M. This case shows that parts with relatively complicated geometry can be formed in Docol M.

Wear resistant steels – Docol Wear

Docol Wear 450 is a cold-reduced continuously annealed quenched and tempered steel with excellent wear resistance. Docol Wear can be used for components subjected to abrasive wear by hard particles such as stones, sand and grain. The figures in the steel designation specify a typical hardness value in Vickers.

Table 7 Hardness (typical values)

Steel grade	Hardness Brinell	Hardness Rockwell	Hardness Vickers	Min bending radius 90° bend
Docol Wear 450	440	43	450	3.0 xt

t = sheet thickness

Table 8 Chemical composition (typical values)

Steel grade	C %	Si %	Mn %	P %	S %	Al_{tot} %	Nb %	Ti %
Docol Wear 450	0.17	0.20	1.40	0.010	0.002	0.040	0.015	0.025

Figure 5. American Carrier uses Docol 1300M on the skin and stiffners for their bottom dumps and semi-trailers. They use 110XF in the structural parts and tail gate and 100XF tubing.

Weather resistant steels – Docol W

Docol W are corrosion-resistant steels. Such steels initially corrode in exactly the same way as ordinary carbon steels. However, after a time a uniform dense oxide film will form on the steel surface. This property is promoted by appropriate contents of Cu, Cr, P and Si in the steel. The oxide film remains firmly in place and prevents moisture from penetrating through it and causing corrosion of the steel. Docol W is available in a minimum yield strength of 700 MPa. Typical applications for Docol 700W are containers. By using this steel grade for containers great gains can be made by reducing the tare weight.

Table 9. Mechanical properties

Steel grade	Yield strength R_{eL} (N/mm²) min.	Yield strength R_{eL} (N/mm²) max.	Tensile strength R_M (N/mm²) min.	Tensile strength R_M (N/mm²) max.	Elongation, A80% min.	Min. bending radius 90° bend
Docol 700 W	700	-	800	-	5	2.0xt

t = sheet thickness
The mechanical properties are valid in the transverse direction of rolling

Table 10 Chemical composition (typical values)

Steel grade	C %	Si %	Mn %	P %	S %	Al_{tot} %	Nb %	Ti %	Cr	Cu
Docol 700 W	0.13	0.50	1.20	0.010	0.002	0.040	0.015	0.013	0.50	0.40

Packing strap steels – Docol Strap

Docol packing strap steels – designated Docol Strap 800 and Docol Strap 930 – are delivered in quenched and tempered condition. Docol Strap is characterized by high strength, combined with good formability and bendability.

Table 11 Mechanical properties

Steel grade	Tensile strength R_M (N/mm²) min.	Elongation, A5 min.
Docol Strap 800	750	15
Docol Strap 930	930	12

The mechanical properties are valid in the transverse direction of rolling
t = sheet thickness

Table 12 Chemical composition (typical values)

Steel grade	C %	Si %	Mn %	P %	S %	Al_{tot} %	Nb %
Docol Strap 800	0.15	0.50	1.50	0.01	0.006	0.040	-
Docol Strap 930	0.15	0.50	1.50	0.01	0.006	0.040	-

Figure 6. Docol Strap is ideally suited for a wide variety of packing purposes.

Steels adapted for roll forming – Docol Roll

Docol Roll is a group of steels which are primarily designed for applications where roll forming is used as a forming method. The steels are subjected to special heat treatment in the continuous annealing line, giving a material which can be roll formed into narrow radii.

Docol Roll is characterized by:

1. High yield stress – a high yield stress minimizes unflatness problems of flat areas. The plastic deformation will be confined to the radii
2. High yield ratio (YS/TS) – a high yield ratio means that stresses in highly formed regions are comparable to the stresses in slightly formed regions. Small differences in residual stresses over the cross section reduce the tendency for bending and twisting of the profile
3. High internal cleanliness and a microstructure with homogeneous hardness distribution – makes it possible to roll form into narrow radii

Ballistic protection steels – Docol Protect

Docol Protect 450 is a 450 HB ballistic protection steel with extraordinary thickness tolerances. Available in thicknesses between 1.0 – 2.1 mm.

Stand-alone capability:

- 1.5 mm EN 1522 FB1 (22LR)
- 2.0 mm EN 1522 FB2 (9 mm bullet)

Sendzimir rolled steels – Docol Hard

Docol Hard is a group of sendzimir rolled steels offering high strength combined with both thin and thick sizes to close tolerances. Docol Hard is intended for two-dimensional forming, such as bending and roll forming. Three different types of sendzimir rolled products are available:

Docol Hard 450 –750Y is a group of sendzimir rolled microalloyed steels designed for optimizing the material use in the thin segment by replacing commercial grades in the thickness range 0.50–1.00 mm. The weight can be reduced up to 50% and the cost 25% when these steel grades replace commercial grades. Typical applications are furniture, shelves, electrical fittings and white goods.

Docol Hard 850 –1000Y is a group of fine-grain treated hot rolled material followed by a cold rolling in a Sendzimir cold rolling mill. This type of sendzimir rolled products is available in thicknesses 1.50 to 4.00 mm. These steels therefore have their application in areas where hot rolled steels normally are used. Typical applications are mechanisms, lightweight containers, load-bearing beams, tubes and profiles.

Docol Hard 1500 –1700T is a group of sendzimir rolled hardened and tempered steels. These steels can withstand hard wear and rough treatment. They are used to advantage wherever the risk of deformation needs to be minimized, while using a lightweight and thin material. Typical applications are lightweight containers, safety components, beams and profiles for the building industry.

Table 13. Mechanical properties

Steel grade	Yield strength R_{eL} (N/mm^2) approx.	Tensile strength R_M (N/mm^2) approx.	Elongation, A80% approx.
Docol Hard 450 Y	450	550	3
Docol Hard 550 Y	550	650	3
Docol Hard 650 Y	650	750	2
Docol Hard 750 Y	750	850	2

The mechanical properties are valid in the transverse direction of rolling

Steel grade	Yield strength R_{eL} (N/mm^2) min.	Hardness, HV approx.	Elongation, A80% approx.	Bending radius 90° bend approx.
Docol Hard 850 Y	850	275	6	2 xt
Docol Hard 900 Y	900	300	5	3 xt
Docol Hard 1000 Y	1000	330	2	4 xt

The mechanical properties are valid in the longitudinal direction of rolling

Steel grade	Yield strength R_{eL} (N/mm^2) min.	Hardness, HV approx.	Elongation, A80% approx.	Bending radius 90° bend approx.
Docol Hard 1500 T	1500	450	2	4 xt
Docol Hard 1600 T	1600	490	2	5 xt
Docol Hard 1700 T	1700	520	1	-

The mechanical properties are valid in the transverse direction of rolling

Table 14. Chemical composition (typical values) *max value

Steel grade	C %	Si %	Mn %	P %	S %	Al_{tot} %	Nb %	Ti %	V%
Docol Hard 450 Y	0.04	0.01	0.30	0.010	0.010	0.040	-	-	-
Docol Hard 550 Y	0.05	0.01	0.40	0.010	0.010	0.040	0.03	-	-
Docol Hard 650 Y	0.05	0.20	0.60	0.010	0.005	0.040	0.04	-	-
Docol Hard 750 Y	0.06	0.40	1.20	0.010	0.005	0.040	0.06	-	-
Docol Hard 850 Y*	0.12	0.10	2.10	0.025	0.010	0.015	0.09	0.15	0.20
Docol Hard 900 Y*	0.12	0.10	2.10	0.025	0.010	0.015	0.09	0.15	0.20
Docol Hard1000 Y*	0.12	0.10	2.10	0.025	0.010	0.015	0.09	0.15	0.20
Docol Hard 1500 T	0.17	0.20	1.20	0.010	0.002	0.040	0.015	0.025	-
Docol Hard 1600 T	0.17	0.20	1.20	0.010	0.002	0.040	0.015	0.025	-
Docol Hard 1700 T	0.17	0.20	1.20	0.010	0.002	0.040	0.015	0.025	-

The alloying contents mentioned above are typical values for all grades except Docol Hard 850-1000Y. For these grades maximum alloying content is mentioned.

CONSIDERATIONS WHEN CHOOSING THE RIGHT GRADE OF DOCOL AHSS

To a degree, AHSS has different characteristics to softer steel when it comes to forming and welding. These differences must be taken into consideration when choosing AHSS, depending on the purpose intended.

Forming

Despite its high strength, cold-rolled DP and M steels offer good formability and can be formed using traditional methods. However, formability is lower compared with soft Docol steels. The outcome of forming operations can be calculated quickly and well predicted with the aid of FE simulation. The slightly poorer formability can therefore be relatively easily compensated for via tool design or detail forming, but there are a few things that need to be given special attention when forming this type of steel.

Docol DP/M is more suitable for drawn pressing than stretch pressing, which should be exploited when designing press tools. If possible, the material should be drawn into the tool rather than stretched in. Where stretching with large stretching must be done, forming may have to be done in several stages to spread the strains over a larger area.

Docol DP/M deformation hardens substantially, significantly more than soft steels and conventional strong HSLA steels. This must be taken into consideration in several stage forming in particular, as the material will flow differently depending on whether or not is has already been deformed.

At the design stage and on shaping a piece, consideration must also be given to the smallest possible bending radius. This is larger for most DP steels and all martensitic steels, compared with the soft Docol steels. Roll forming is a method that enables tighter radii than those recommended with conventional bending.

When stretching cut edges Docol DP/M should be handled with a degree of caution, as it has lower edge ductility than softer Docol steels. The cut edges must be of very high quality and the bevelled cutting edge should be towards the side with the lowest strains. If possible the piece should be cut after the forming stage to avoid straining the cut edge. Here too, the sheet can be formed in several stages to spread the strains.

The increased springback must also be taken into account when forming. Springback increases at higher strengths and this also affects the tools. Problems with tool wear can be avoided by choosing the right tool steel, while springback avoidance measures are more related to piece forming and tool design.

These measures are described in more detail in the respective sections on tool steels (p 28) and springback (p 18). A general recommendation is to always add a spare station in the forming tools for adjustments.

The Sendzimir processed Docol Hard products are only intended for two-dimensional forming such as e.g. bending, tube forming and roll forming. Docol Hard must not be used in details that require drawn or stretch pressing.

Welding

The table below shows how suitable different AHSS are for various types of welding methods.

Table 15.

Type of steel	Steelgrade	Resist spot welding	Arc welding	Laser welding	HF welding
HSLA steel	Docol 500 LA	Very suitable	Very suitable	Very suitable	Very suitable
Dual Phase steel	Docol 500 DL	Very suitable	Very suitable	Very suitable	Very suitable
	Docol 500 DP	Very suitable	Very suitable	Very suitable	Very suitable
	Docol 600 DL	Very suitable	Very suitable	Very suitable	Very suitable
	Docol 600DP	Very suitable	Very suitable	Very suitable	Very suitable
	Docol 800 DL	Suitable	Suitable	Suitable	Suitable
	Docol 800 DP	Suitable	Suitable	Suitable	Suitable
	Docol 1000 DP	Suitable	Suitable	Suitable	Suitable
	Docol 1000 DPZE	Suitable	Suitable	Suitable	Suitable
Martensitic Steel	Docol 900 M	Very suitable	Suitable	Very suitable	Suitable
	Docol 1200 M	Suitable	Suitable	Suitable	Suitable
	Docol 1200 MZE	Suitable	Suitable	Suitable	Suitable
	Docol 1400 M	Suitable	Suitable	Less suitable	Suitable
	Docol 1400 MZE	Suitable	Suitable	Less suitable	Suitable
	Docol 1500 M	Suitable	Suitable	Less suitable	Suitable
Wear resistant steel	Docol Wear 450	Suitable	Suitable	Less suitable	Suitable
Ballistic Protection steels	Docol Protect 450	Suitable	Suitable	Less suitable	Suitable
Weather resistant steel	Docol 700 W	Suitable	Suitable	Suitable	Suitable
Roll Forming steel	Docol Roll 800	Suitable	Suitable	Suitable	Suitable
	Docol Roll 1000	Suitable	Suitable	Less suitable	Suitable
Sendzimir rolled steel	Docol Hard 450 Y	Very suitable	Very suitable	Very suitable	Very suitable
	Docol Hard 550 Y	Suitable	Suitable	Suitable	Suitable
	Docol Hard 650 Y	Suitable	Suitable	Suitable	Suitable
	Docol Hard 750 Y	Suitable	Suitable	Suitable	Suitable
	Docol Hard 850 Y	Suitable	Suitable	Suitable	Suitable
	Docol Hard 900 Y	Suitable	Suitable	Suitable	Suitable
	Docol Hard 1000 Y	Suitable	Suitable	Suitable	Suitable
	Docol Hard 1500 T	Suitable	Suitable	Less suitable	Suitable
	Docol Hard 1600 T	Suitable	Suitable	Less suitable	Suitable
	Docol Hard 1700 T	Suitable	Suitable	Less suitable	Suitable

= Very suitable = Suitable = Less suitable = Unsuitable

DESIGN

The good combination of strength, formability and weldability of dual phase and martensitic Docol AHSS provides the possibility to reduce weight and improve performance in a cost-effective way. The high strength of AHSS is in general very favourable from a design point of view, but some factors have to be addressed to find the optimum solution.

Static strength and stiffness

Dual phase and martensitic steels are available with very high initial yield strength. In addition to this, they exhibit a pronounced work hardening and also a bake hardening effect in case of an increased temperature subsequent to deformation, i.e. painting of formed parts.

As can be seen in Figure 8 the level of work hardening is significant already at moderate levels of strain, i.e. comes into play already when forming the part. Typically the work hardening effect is about 150 MPa at a strain of two per cent and the corresponding bake hardening effect about another 50 MPa for a typical painting process.

By introducing a material which sustains greater stresses, the thickness can be reduced, maintaining equivalent performance. In Figure 9 the potential for weight reduction for two theoretical cases is shown. In many real situations the weight reduction potential is between these two extremes. The bending case is, however, not a conservative lower limit due to the fact that e.g. local buckling may occur in slender designs.

Since Young's modulus is equal for mild steel and high strength steel, stiffness of a single component is lost in about the same proportion as the reduction in gauge if all other parameters are fixed. There are, however, numerous measures to be taken in order to help the situation; the outer dimensions can be increased for components subjected to bending or torsion and local geometrical stiffeners can be introduced, such as grooves, flanging, stiffening darts, edge folds etc, c.f. Figure 7.

In many cases, the joints influence the stiffness considerably. Putting more effort in to the design of the joints, increased number of spot welds, increased number of weld planes or introducing continuous welds, will result in an improved situation. Further, closed sections show in general significant increased stiffness compared to open sections.

As mentioned above, local buckling may occur when reducing the gauges in an upgrading process. Local buckles could arise at slender compressed and sheared regions in event of stresses below the plastic limit and the full potential of the material will not be utilized. Fortunately, there are measures to be taken. Various local stiffeners may be introduced in order to reduce the slenderness and/or improve the constraint of the edges, c.f. Figure 10.

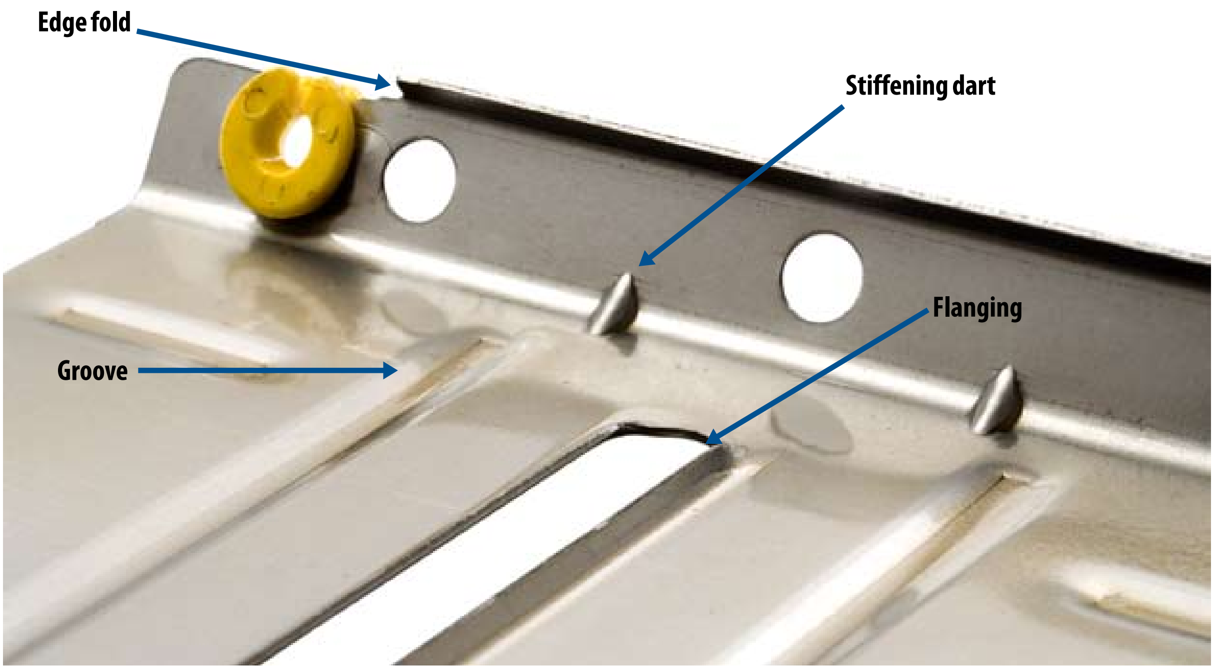


Figure 7. Examples of local geometrical stiffeners on a lump bar in Docol 1300M.

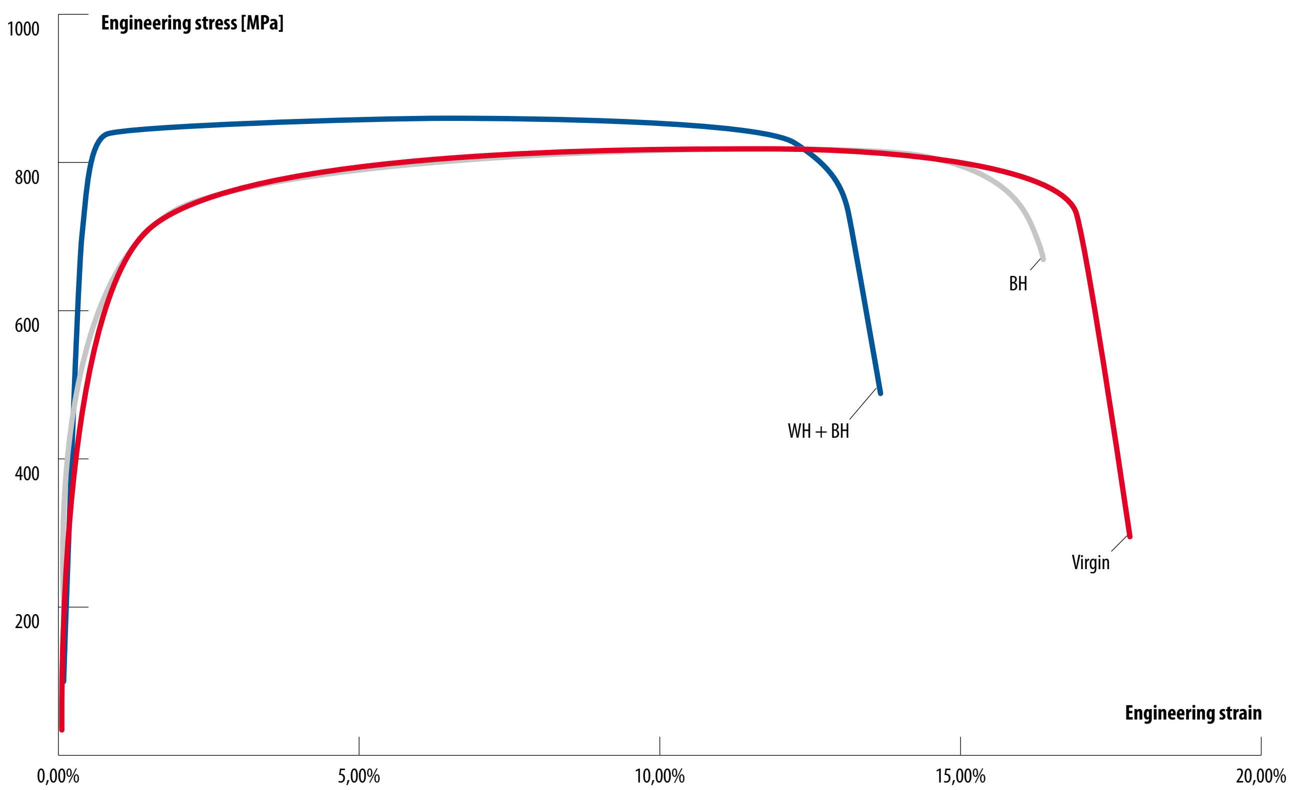


Figure 8. Engineering stress versus engineering strain for Docol 800DP. WH-Work Hardening (2% plastic deformation); BH-Bake Hardening (170° C in 20 minutes). Longitudinal testing.

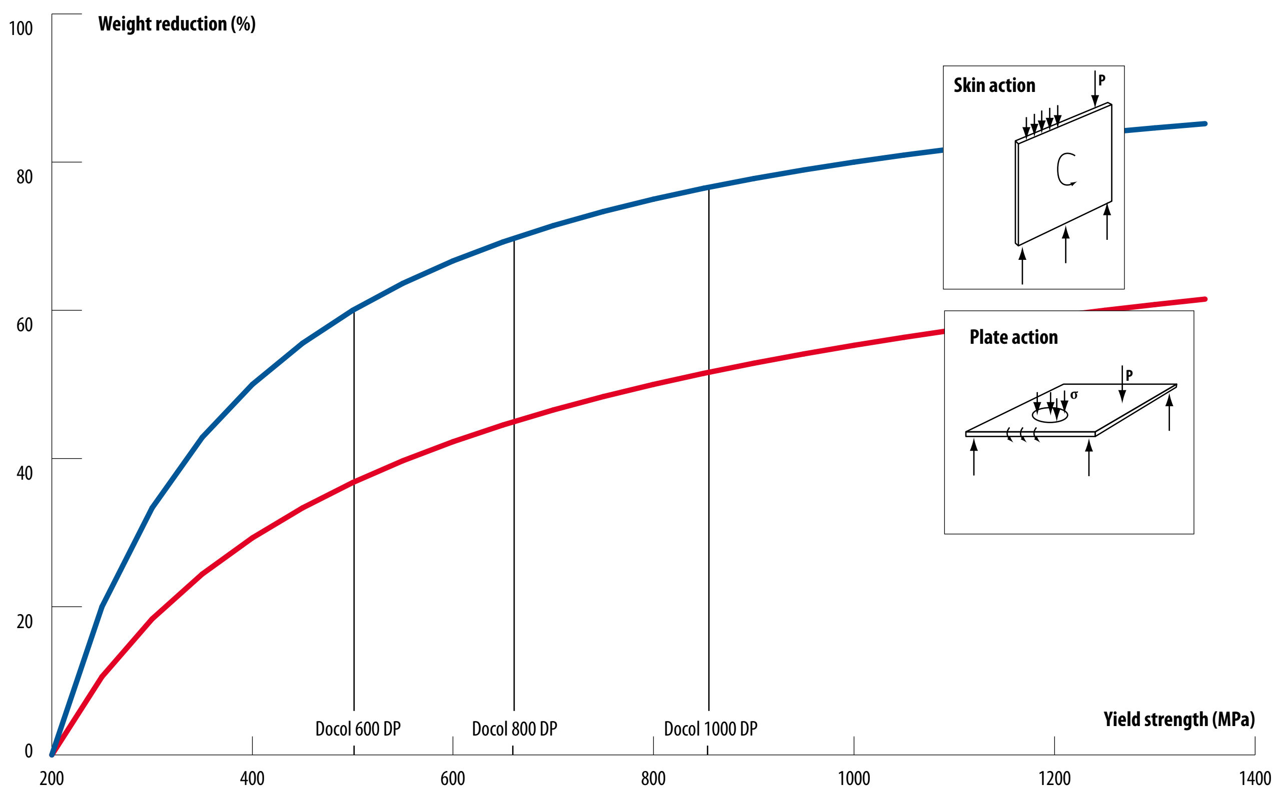


Figure 9. Example of potential for weight reduction compared to mild steel. Representative yield strengths of four Docol steel grades are shown including 2% work hardening and bake hardening.

Fatigue

Increased yield strength is positive for the fatigue strength of Docol base materials. The increase in fatigue strength is equivalent, no matter if the increase of the yield strength is due to work hardening, bake hardening or caused by upgrading the steel grade. The edge and surface conditions are of crucial importance. The most important reason for the good fatigue strength of Docol steels is the high quality of the surface.

The fatigue strength of welded joints is, however, in general not affected by the strength of the material. So allowing for higher stresses by using AHSS will result in reduced fatigue life in a case where every other parameter is kept constant.

However, there are several actions to be taken in order to use Docol AHSS also in fatigue-loaded applications. There are several aspects, such as smart design (changing from plate- to skin action, placing joints at lower stressed regions etc), increased spot weld density and/or diameter, improved weld quality and/or post treatment for continuous welds and the usage of alternative joining methods (laser, adhesives, weld bonding).

Tubes

The good combination of strength, formability and weldability offers great scope for producing tubes and roll formed profiles out of Docol AHSS. For instance, a High Frequency (HF) welded tube enables the use of Docol AHSS also in heavily fatigue-loaded applications due to its good fatigue resistance. The reasons for the good fatigue resistance of HF-welded Docol tubes is the fact that the quality of the weld is very good due to the possibility of performing flash trimming and the fact that there are no exposed edges.

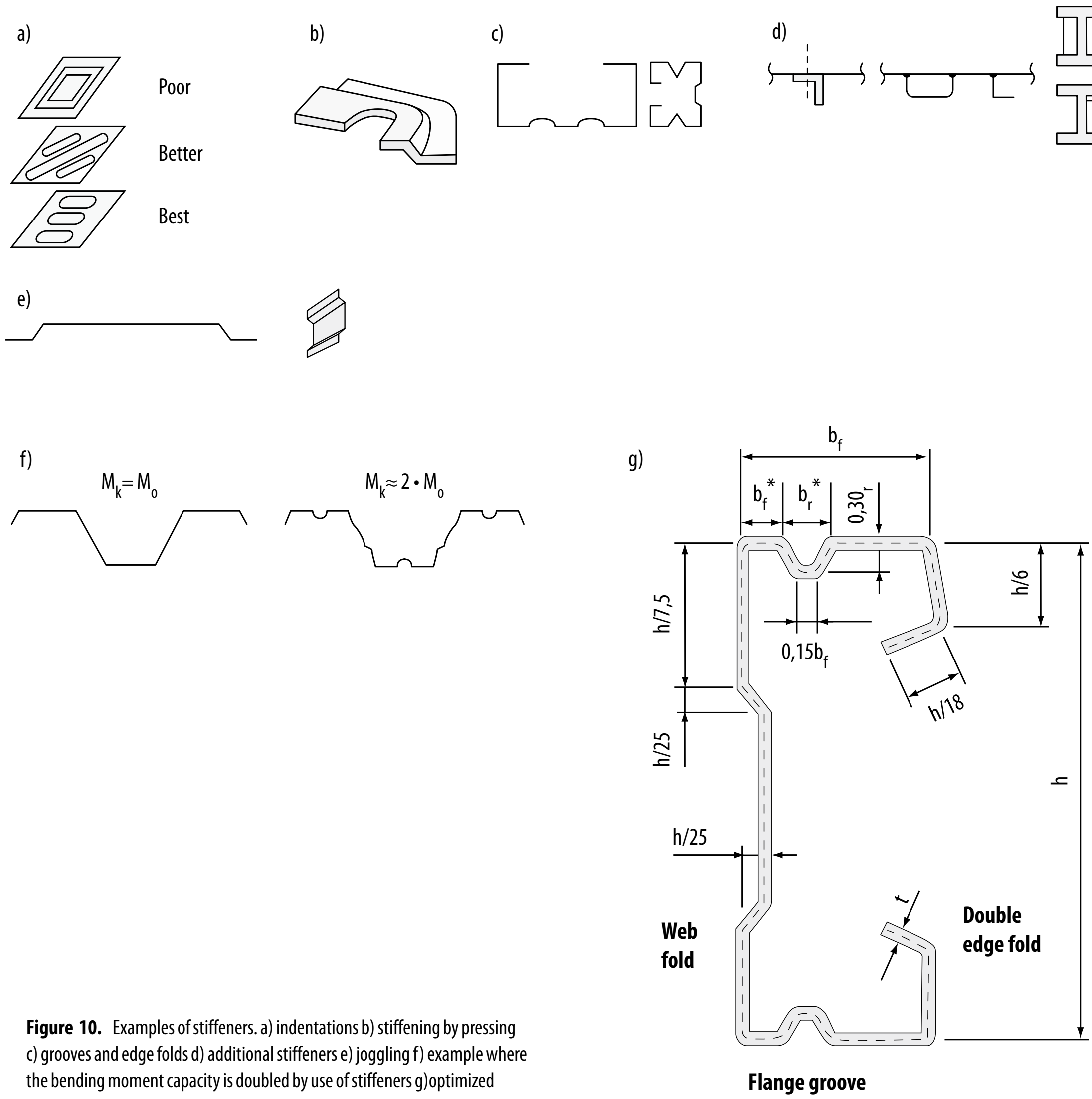


Figure 10. Examples of stiffeners. a) indentations b) stiffening by pressing c) grooves and edge folds d) additional stiffeners e) joggling f) example where the bending moment capacity is doubled by use of stiffeners g)optimized C-profile.

CUTTING AND FORMING

SSAB´s advanced high strength steels can be cut and formed in the traditional way, despite their high strength. The somewhat poorer formability compared to mild steels can almost always be compensated by modifying the design of the component or the forming process, e.g. enlarging tool radii in combination with an optimized blank shape. Regarding the shearing process, the fact is that the shearing forces do not need to be significantly increased when converting from mild steels to advanced high strength steel grades.

Shearing and punching

When shearing and punching AHSS it is important to adapt the process to the strength and thickness of the sheet and the design/stability of the shears or machinery. It is particularly important to have the correct cutting clearence between the shears. The choice of cutting clearance is dictated by the sheet thickness, strength and cut edge appearance requirements. The cutting clearence for straight shearing will also differ from the cutting clearence for punching, as the geometry will also be significant. For straight cuts, tests have shown that a cutting clearence of 5% of the sheet thickness and a cutting angle of 1° ought to be used for all Docol DP and martensitic steels, for the best results in terms of cutting force and edge quality. The cutting force can be calculated using the following equation:

$$F = A \cdot K_{sk} = \frac{K_{sk} \cdot t^2}{2 \cdot \tan\alpha} (N)$$

where:
F = cutting force (N)
A = cutting area
α = cutting angle (°)
t = sheet thickness(mm)
K_{sk} = cutting shear strength (N/mm2) = e*R_m

The factor e that is required to calculate the cutting shear strength is reduced the higher the tensile strength of the material. It is therefore not certain that the cutting force will increase when shearing materials with higher strength. An illustration of this can be seen in figure 11, where the cutting force has been measured when cutting Docol Form 04 and Docol 1400M with the same sheet thickness. The same cutting angle and cutting clearance have been used for both materials and despite a difference of around 1100 Mpa in tensile strength, the results show that the cutting force was slightly lower for Docol 1400M.

When punching Docol DP and martensitic steels the cutting clearance should be greater than on straight cuts. The general rule is that the cutting clearance should increase with increased strength and sheet thickness. However when punching the highest strength levels, too big a cutting clearance can generate high bending stresses on the punch edge and increase the risk of chipping. For tensile strengths above 1000 MPa the cutting clearance should therefore not be increased for increased strengths.

The cutting angle influences the cutting force both on straight shearing and when punching. It is possible for example, to reduce the cutting force when punching by up to 50% by employing a phased punch. The cutting force on punching can be calculated using the same equation as for straight shears, but the cutting area is determined on the punch diameter and possible phase grinding.

(The tabulated values for the e factor and guide values for cutting clearances on punching can be found in our brochure ”Tooling solutions for advanced high strength steels”.)

Laser cutting

A part made of Docol AHSS may often be of a complex geometrical shape. This geometrical shape can be produced directly by laser cutting, without any additional work after the cutting. 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 laser equipment, the cutting parameters and also on the sheet steel.

The surface cleanliness is one of the most important factors for achieving high quality of the cut surface, i.e. a smooth surface of the cut and a small angular deviation. The inner cleanliness (amount of non-metallic inclusions) is also an important factor for achieving a good result. A clean surface and a low amount of non-metallic inclusions produce the best cutting properties as regards both cut quality and production economy.

SSAB Tunnplåt has undertaken studies of the laser cutting properties of Docol AHSS, both through own investigations and by gathering the experience accumulated in companies that use laser cutting.

The results of these studies can be summarized as follows:

- Docol AHSS steels conform to the standard for one of the highest classes in accordance to EN ISO 9013. This applies to

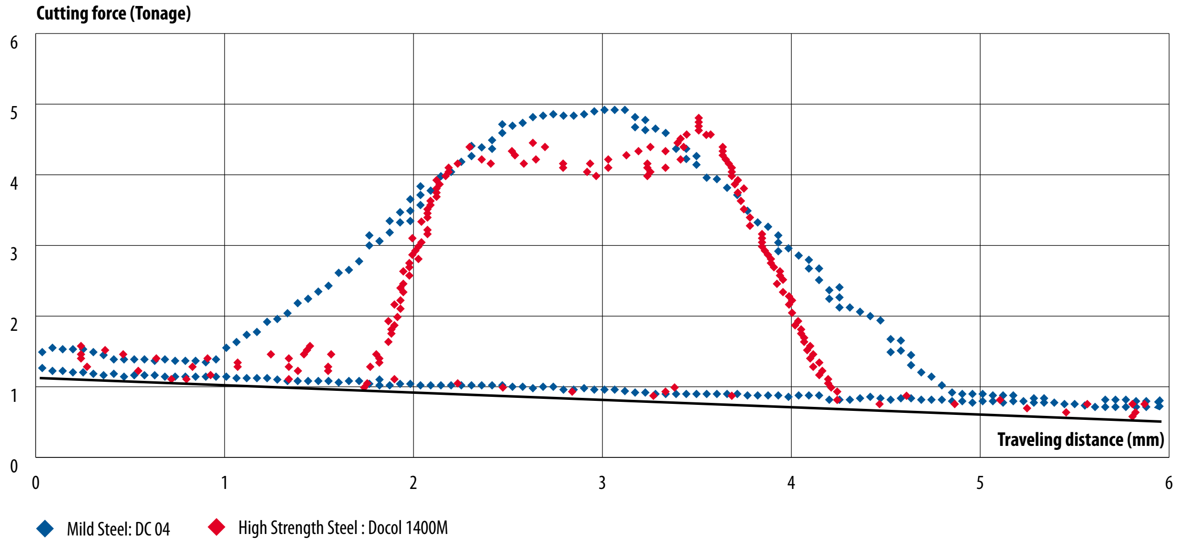


Figure 11. Measured shearing force for Docol Form 04 and Docol 1400M with a sheet thickness of 2 mm. The blade gap was 5 % of the sheet thickness and the shearing angle was 1°.

both surface smoothness and angular deviation.

- for uncoated Docol AHSS the same cutting parameters can be used as for conventional mild sheet steels
- for Docol ZE steels, the best results are obtained by using the same cutting gas (N_2) and parameters as those used for stainless steel
- Docol AHSS 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 cut edge. The heat affected zone from laser cutting is narrow. The zone is so close to the edge and is so narrow that it will be eliminated by the subsequent welding operation.

Stretch forming

Stretch forming entails holding the material in place between the blankholder and the die and then all plastic deformation is done over the punch. The material is subjected to biaxial stretching resulting in a thickness reduction. Fracture occurs when the local deformation becomes too great. Stretch formability primarily depends on the capacity of the material to distribute strains. There is a close connection between a material's stretch formability and its work hardening, i.e. the more powerful the material's work hardening the better its stretch formability. As Docol DP and martensitic steels work harden strongly, the material also possesses better stretch formability than steels of comparable strength.

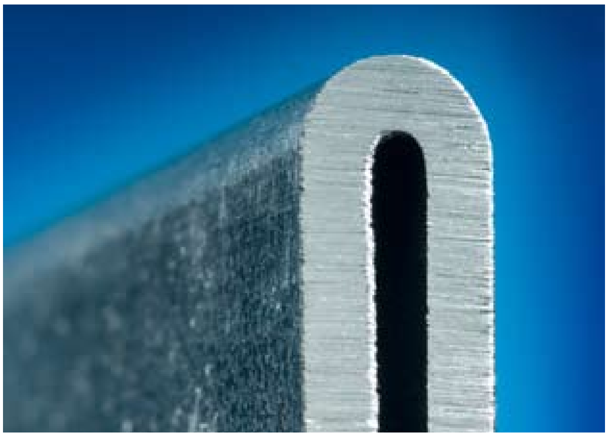


Figure 12. Docol Roll 1000 allows for extremely tight bending radii during roll-forming.

Drawing

Drawing is characterised by all or most of the material following with the punch through the die and where the blankholder force is set to prevent wrinkling. Two factors determine a material's drawability:

- Plastic deformation capability in the sheet's plane. i.e. how easy the flange material flows and becomes side wall material during drawing.
- Capability of the side wall material to resist thinning to reduce the risk of fracture.
- Docol DP and martensitic steels have very good drawability compared with other steels of the same strength.

Flanging

The process of expanding a punched hole with a conical tool is called flanging. The ratio between the punch diameter and the initial hole diameter is used to describe the flanging properties of a material.

To achieve the best results, the burred edge of the workpiece should be turned towards the punch. This is because the outer fibres of the material are subject to the greatest strains. If the burr is turned outwards, away from the punch, there is a risk of micro cracks in the burr acting as break lines.

As the outer fibre in a thin material is deformed less than in thick material, with the same inner diameter of the flanged hole, thinner material can withstand higher flanging relationships than thicker material

The foot radius on flanging of a specific material should not be less than its recommended bending radius.

Bending

In bending operations the sheet is formed by a bending moment. Tensile stresses are induced on the outside of the bend and compressive stresses on the inside.

The bendability falls as the material strength increases. The difference in bendability lengthways and crossways respectively to the rolling direction is relatively substantial for Docol AHSS. Bendability is always slightly poorer in the rolling direction and bending should therefore be down crossways to the rolling direction where possible. The minimum guaranteed bending radii for Docol AHSS apply for bending lengthways in the rolling direction and are therefore conservative values for crossways bending.

Forming limit curves

The forming limit curve, FLC, shows how much deformation a material can withstand for different strain paths. FLC is therefore very appropriate to use as a fracture criterion and is a good aid when resolving difficult pressing operations. If the strains during a pressing operation are known, e.g. via simulation or measuring, these can be compared with the FLC of a specific material. If the FLC is higher than the measured values the material can be used in the pressing operation without risk of fracture. FLC should however not be used as a fracture criterion for stretching cut edges, as FLC does not take into account edge ductility.

If the strains are positive in both directions in the graph, then it is stretch forming which is marked to the right of the zero line in the FLC graph. Points that have one negative and one positive principal strain are marked to the left of the zero line, which means it is a drawing operation of the forming limit diagram (FLD), FLC is at its lowest point at the zero line, i.e. at plane strain, and this point is called FLD_0. Both engineering and true strains can be used to describe an FLC. The curves depend on the thickness of the material.

Several different tests are required to describe a material's formability. However FLC is the testing method that provides the best overall description of the formability of a material.

Too often the elongation value from a tensile test is used to describe a material's formability, which gives a conservative and inaccurate picture of formability.
Docol 1200M for instance has a guaranteed elongation value (A80) of 3% and in a forming operation 3% strain is a very low value. This value also includes strains after necking, which are not desirable when forming. From a forming perspective, the value should therefore be even lower. On the other hand, FLD_0 for Docol 1200M, which is the lowest value of the FLC, is around 10% depending on sheet thickness and this value does not include strain after necking. A material can therefore be deformed in a forming operation at significantly higher strains than during a tensile test, without breaking.

Springback

Springback means that when the load is removed from a material after a deformation, the material changes its shape due to residual stresses that arose in the material. To achieve the correct final geometry on a component during forming, springback has to be taken into account. Springback increases when switching from mild steel to AHSS. In addition to material strength, springback is also influenced by sheet thickness, component geometry and tool design.

Springback is usually differentiated into two types. One is caused by the residual stress distribution through the thickness of the sheet, while the second is caused by the residual stress distribution in the plane of the sheet. The first type of springback results in e.g. angle deviations when bending and curved profile walls when deep drawing. The second type results in e.g. distortion or unevenness in the part. Both types of springback increase at higher strengths and reduced sheet thickness.

There are various methods of minimising springback and the most suitable method can differ from case to case. When bending for example, springback can be compensated for relatively simply by overbending. However, as a general rule, it is better to try to change the residual stress distribution so springback is minimised. The distribution of residual stresses can be affected by e.g. increased blankholder force, drawing beads in the tools or a modified geometry of the blank etc. Geometric stiffening of the component is also a way of minimising springback.

Figure 13. FLC - True Strain

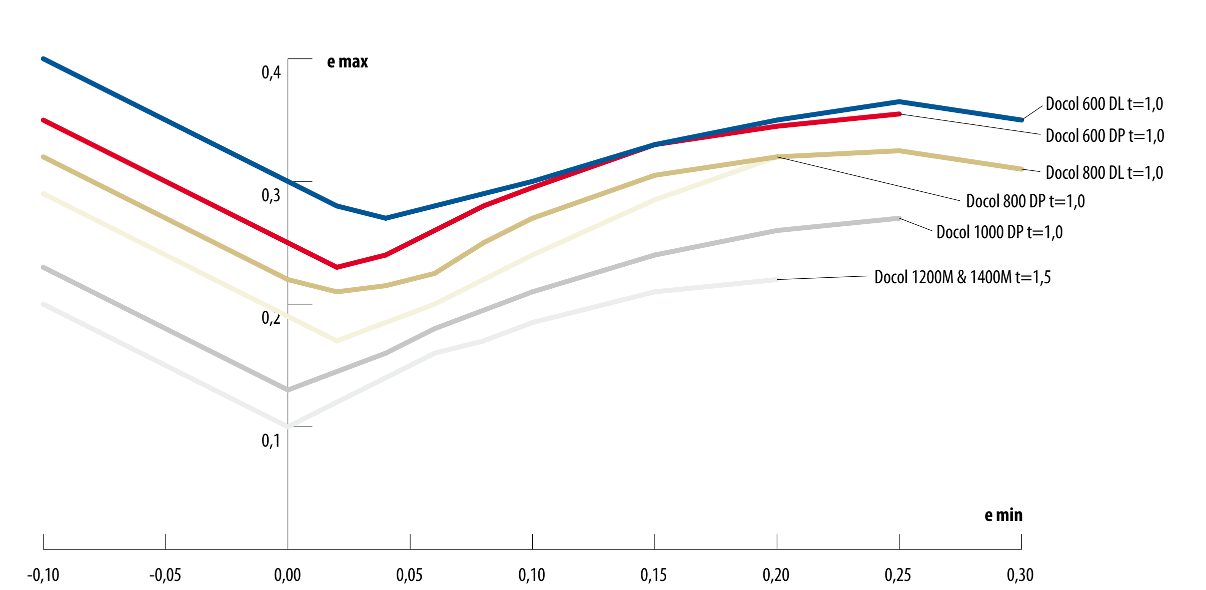


Figure14. Sledge runners in Docol Hard 900Y on their way in the South Pole.

HOT STAMPING OR COLD FORMING

Cold forming of AHSS is a well-proven method. The technology has been widely used for a long time and production costs and return on investments are easily calculated.

Hot stamping of boron steel has grown rapidly in recent years, but the number of producers using the method is still small compared to cold forming specialists. One reason for this is that cold forming is a competitive and efficient method of forming all but the most demanding automotive components such as parts with complicated geometry and extremely high strength.

For most other applications all arguments are in favor of cold forming. The same strength is achieved with both methods, but the cost advantage of cold forming is very significant.

In fact, hot stamping, on average, is 40–60 per cent more expensive than cold forming. One of the factors behind the great price difference is the fast production cycle for each coldformed part. No major investments have to be made in machinery and tooling, which makes it swift and simple to convert the production to AHSS.

ROLL FORMING AND TUBE PRODUCTION

Roll forming and tube production are methods in which the ability of Docol AHSS to work harden is put to use. In these processes, controlled deformation of the material takes place and leads to an increase in the yield strength and tensile strength of the finished part. The increase in strength can be used in the design of the finished part. If the finished part is heat-treated, e.g. during painting, the strength will increase further.

Tubes

Due to the good combination of strength, formability and weldability, DP steels are well suited for tube production and represent an excellent structural element whenever structures are required to be able to withstand high loads. Tubes are used in frameworks, furniture and seats for cars and buses. The tubes produced are typically circular, although there is ample scope for also producing square, oval and crescent-shaped tube sections in subsequent stages in a tube mill.

Since DP steel tubes can be hydroformed, the opportunity arises for using these tubes also for other components in order to reduce the weight of component parts. Cold-formed tubes are made by continuous roll forming of flat sheet into a tube, and then making the joints by high-frequency welding. Since high-frequency welded tubes of DP steel have excellent fatigue properties, scope is also available for using these tubes in parts that are subjected to fatigue stresses. The challenge is to ensure good fatigue properties when joining the tubes to other parts.

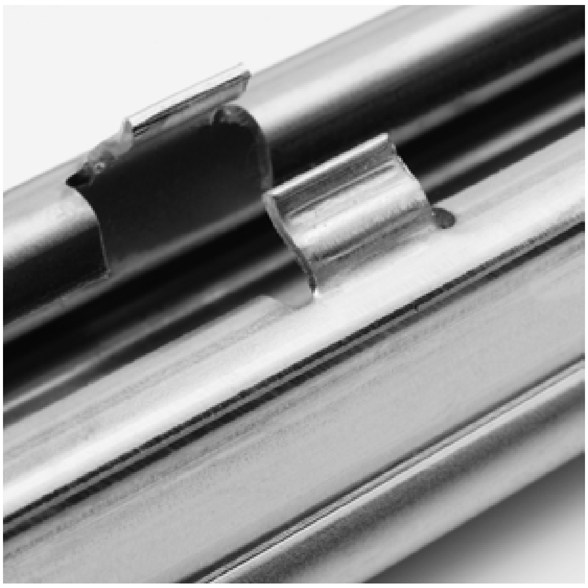


Figure 15. Docol Roll allows multiple forming without any difficulties. Seat rails made from Docol Roll 800. Manufactured by Johnson Controls, South Korea.

Another challenge in the production of high-frequency welded tubes from AHSS with strengths of ≥ 1000MPa, i.e. dual-phase steels or fully martensitic steels, is to restrict the heat supply. Controlled heat supply and the fact that the tube is usually subjected to a principally longitudinal load mean that with such high strength levels can also be used for tube production.

Roll formed profiles

Roll formed and profiles of AHSS can be used in many different applications e.g safety components in cars and furniture. Roll forming is a very cost-effective method of forming and results in low per-item prices, particularly in long production runs.

Roll forming is a forming method which has proven to be less sensitive to the formability and springback issues of AHSS. For instance, it has been seen that significantly sharper bending radi without material fracture can be obtained in roll forming, compared to conventional bending.

The problem with springback is also reduced and even eliminated in some cases. Generally, less problems with dimensional tolerances are seen compared to bending or stamping, even if the scatter in the mechanical properties of the material is large. Roll forming also allows for calibration steps to be added after the final forming step in order to further reduce dimensional deviations, or to introduce a curvature to the profile. The good behaviour in roll forming has been seen for AHSS in general, but perhaps even more significantly for AHSS at the highest available strength levels. The reason for this good behaviour is in part due to the roll forming process itself, but there are also material aspects which influence the results.

Material aspects in roll forming

As mentioned above, AHSS have been found to perform well in roll forming. This is even more so for the highest available cold forming steels, with tensile strength up to 1500 MPa and above, where the contrast to other forming methods is striking.

Bending radius

Internal bending radii in the order of the sheet thickness have been achieved in roll forming of ultra high strength steels, while the same material requires radii of three to four times the sheet thickness in V- bending to avoid fracture. Very stiff profiles can therefore be made in roll forming, which makes further weight reduction possible. The sharper radii are made possible in part by the roll forming method as such, but it is also helpful if the material does not have a significant work hardening. In this case the strip conforms better to the forming rolls and has less tendency to "bend ahead". A sharp bending radius of course also requires that the micro structural cleanliness of the material is high.

Straightness of profile

The straightness of the roll formed profile has been seen to improve with the material strength.

The reason for the better straightness of the high strength profile is mainly that the plastic deformation in this profile is confined to the radius. High yield strength is thus beneficial to prevent plastic deformation of the "legs". This can lead to less twisting and bending of the finished profile. It can also lead to fewer problems with "oil canning", since the residual forces will be lower. Finally, there will be less problems with waviness of the edges.

Another aspect which has to do with the straightness of the roll formed profile is the ratio between yield strength and tensile strength, in other words the work hardening of the material. A profile, which has a complex cross section, with heavily as well as slightly deformed areas, will exhibit a large difference in residual stress levels if the material has a high work hardening. If the ratio of yield stress to tensile strength is close to unity, there will only be small differences in residual stresses between heavily and slightly deformed areas, and therefore not as high tendency for the finished profile to bend or twist.

Micro structural aspects

Roll forming is virtually always done in the same direction as the rolling direction of the strip, therefore the inclusions in the material will be oriented in the same direction as the bends. This increases the risk of fracture. From a metallurgical viewpoint, it is therefore important that the material has the highest possible cleanliness, which means absence of slags and inclusions. The microstructure should be as homogeneous as possible, or else there is a risk that deformation is concentrated in certain micro structural phases, which can lead to crack initiation.

Strip thickness tolerances

As in most forming methods, dimensional tolerances of the finished part depend on the sheet thickness tolerances. Roll forming is no exception – narrow strip thickness tolerances contribute to process stability and a high accuracy of the manufactured parts.

Docol Roll

Docol Roll is a group of steels adapted to roll forming. Docol Roll makes it possible to roll form profiles in very high strength combined with narrow radii and good accuracy in terms of size.

Figure 16. Wagon Automotive, Italy

JOINING

All common joining methods can be used for joining of Docol AHSS, e.g. resistance spot welding, arc welding, laser welding, mechanical joining and adhesive bonding. Often the same joining parameters as for mild steels can be used for joining Docol AHSS but in some cases the joining parameters should be changed to ensure the best results.

Resistance spot welding

Resistance spot welding is the most common welding method for Docol AHSS. Both AC and MFDC spot welding machines can be used. Conventional single pulse welding can normally be used and the best results are obtained if the electrode force is somewhat increased compared to what is normally used for mild steels. It is also beneficial to use slightly longer weld times. Weld growth curves (weld size vs. weld current) and weldability lobes form the basis of weldability studies. These give a means of comparing the welding current range capable of producing acceptable welds for a particular welding schedule (electrode force/weld time combination) for different steels. The width of the weldability lobe gives information about the anticipated tolerance of a particular welding schedule in production. The aim is to maximise the welding range to achieve the greatest safety margin on weld quality.

In Table 16 results from weldability studies are shown for some of the Docol AHSS. These results show that wide welding current ranges can be obtained for Docol AHSS when optimised welding parameters are used.

In the tests described in the table, plug failures were obtained for all steels tested. Plug failure is the type of failure aimed for when testing resistance spot welded sheet steels. In general, plug failures are always obtained for Docol 600 DP/DL, Docol 800 DP/DL and Docol 900 M if optimised welding parameters are used. For the other Docol DP and Docol M steels, of higher strength, plug failure is also normally obtained but in some cases also partial plug failures are observed. Especially for sheets of thickness greater than 1.7 mm it can be difficult to always achieve plug failures for this type of steels.

The strength of a spot weld increases with increasing sheet thickness and increasing weld size. The material strength also has an influence on the weld strength. The influence is different for shear and cross tension loading. This is demonstrated in Figure 17. where the shear strength and cross tension strength is plotted vs. material strength for three Docol DP steels and two reference steels of lower strength. The shear strength increases with increasing material strength. For the cross tension strength the influence of material strength is much less. These results demonstrate that the greatest benefit of spot welds is obtained in shear and in the design work peel or tension loading should therefore if possible be avoided.

High Frequency Welding (HF)

HF welding is the main welding process for the manufacturing of cold-formed welded steel tubes. Such tubes are used in many different applications. During HF welding the sheet edges are quickly heated to a high temperature. When the edges are then pressed together at high pressure a strong joint is obtained.

HF welding can also be used for Docol AHSS and the properties of the joint are mainly determined by the properties in the heat-affected zone (HAZ). For Docol AHSS of low strength the hardness of the weld area exceeds the hardness of the base material and there is a limited or no soft zone in the transition from HAZ to base material. For Docol AHSS of high strength there will be a hardness drop in HAZ. In most cases this hardness drop is not any problem.

Arc welding

For Docol AHSS all common arc welding methods (GMAW,

Table 16. Available welding current ranges (ΔI) for resistance spot welded Docol AHSS (cross tension tests, single pulse welding, electrode type B).

Steel 1 / steel 2 (thickness, mm)	Welding data	ΔI[3] (kA)	Maximum plug diam[4] (mm)	Fracture mode
Docol 600 DP (1.0) / Docol 600 DP (1.0)	5/3.4 /13/10[1]	2.0	7.2	Plug failure
Docol 800 DP (1.5) / Docol 800 DP (1.5)	6/4.0/15/10[1]	2.0	8.0	Plug failure
Docol 1000 DP (1.2) / Docol 1000 DP (1.2)	6/4.0/14/10[1]	2.1	7.2	Plug failure
Docol 900 M ZE100 (1.2) / Docol 900 M ZE100 (1.2)	6/3.5/340/200[2]	2.0	7.3	Plug failure
Docol Roll 800 (1.25) / Docol Roll 800 (1.25)	6/4.0/300/200[2]	2.0	7.0	Plug failure
Docol 1200 M (1.6) / Docol 1200 M (1.6)	6/3.5/16/10[1]	2.5	8.0	Plug failure

1) AC machine. Electrode tip diam (mm) /electrode force (kN)/welding time (cycles) / hold time (cycles)
2) MFDC machine. Electrode tip diam (mm)/electrode force (kN)/welding time (ms)/hold time (ms)
3) Available welding current range (minimum plug diameter = $4\sqrt{t}$ mm).
4) Plug diameter close to the splash limit

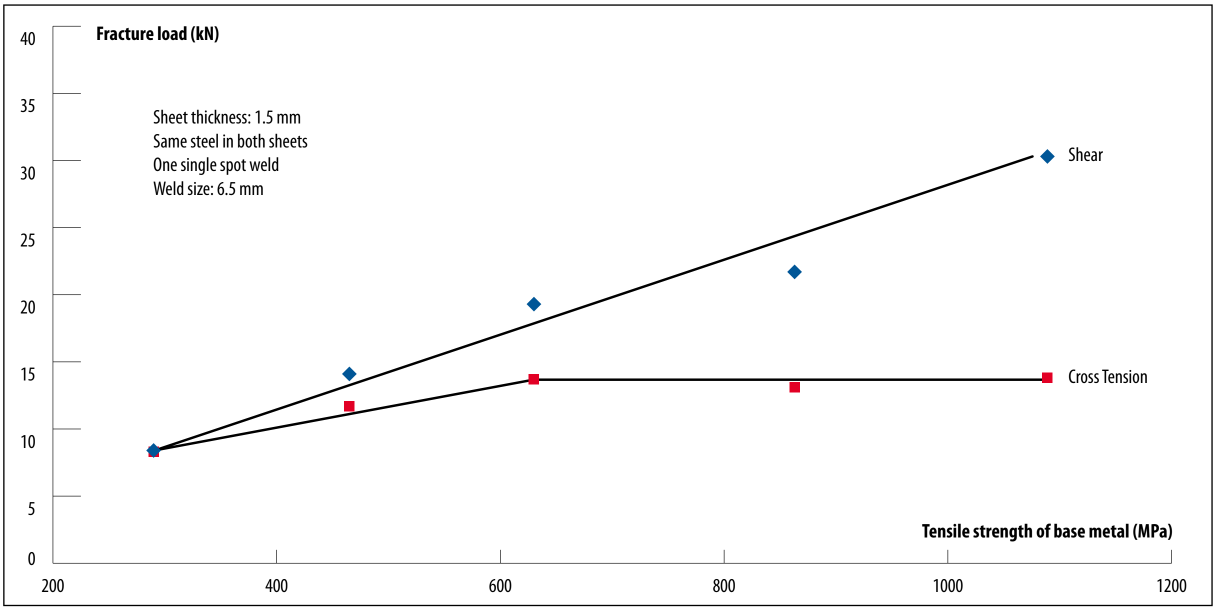


Figure 17. Fracture load of spot-welds for Docol DP steels (600DP, 800DP, 1000DP). Two steels of lower strength included as reference.

TIG and plasma) can be used. The same shielding gases can be used for Docol AHSS and Docol mild steels. Despite the higher alloying content for Docol AHSS there are no increase in welding imperfections compared with mild steel arc welds.

The strength of the welds for Docol AHSS increases with increasing base metal strength (see Figure 18.). For Docol AHSS of very high strength (e.g. Docol 1000DP, Docol 1200 M, Docol 1400 M) the strength of the arc welds may be reduced in comparison to the base metal strength. The reason is small soft zones in the heat-affected zone (HAZ).

In most applications single-sided welded lap joints are often used. The strength of a lap joint is lower than the strength of a butt joint. This is due to the unsymmetrical loading and the extra bending moment associated with this type of loading for the lap joint. This extra bending moment increase the stresses near the weld toe.

In Figure 18. the influence of filler metal strength is shown for some Docol AHSS steels of different strength levels. These results show that an increased strength of the filler metal increases the strength of the lap welds for Docol AHSS of very high strength levels.

In the automotive industry arc welds are normally used in local areas of the vehicle where the loads are high. The length of the arc welds is in this case often quite short. The reduction in weld strength for the Docol AHSS of very high strength can be compensated by increasing the length of the weld.

Laser welding

Laser butt-welding can be used for Docol AHSS. Some examples of butt-welding are the production of tailor-welded blanks and in the roll forming process when closing the profile in the roll forming line. The requirements for edge preparation of Docol AHSS are similar to those for Docol mild steels. In both cases a good quality edge and a good fit-up are needed to obtain good

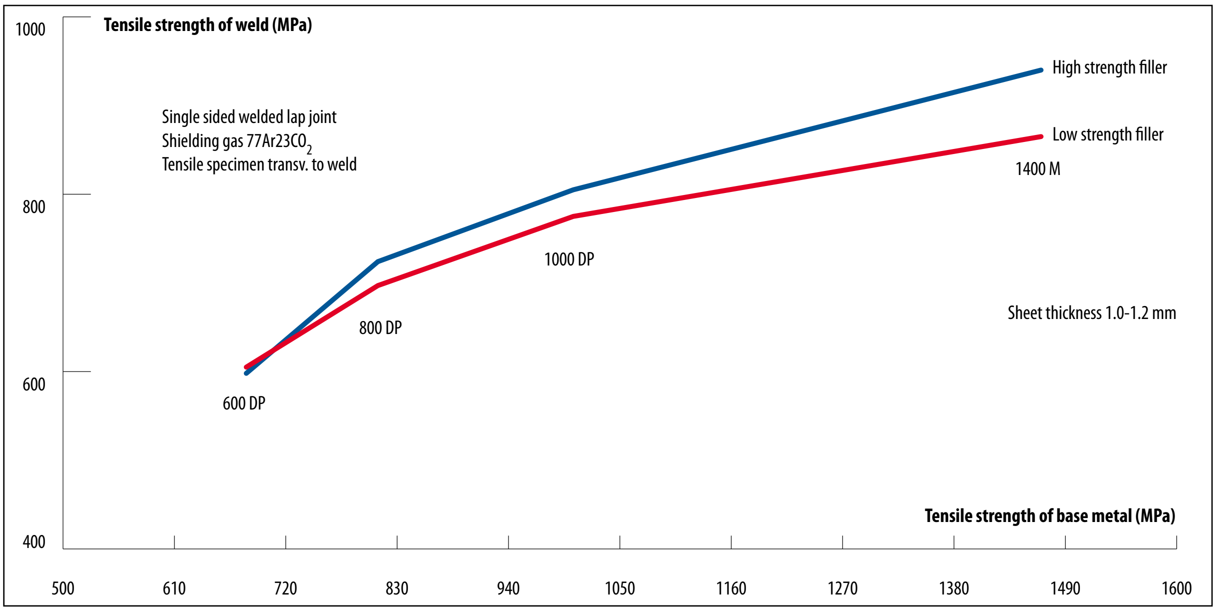


Figure 18. Influence of filler metal strength in GMAW of Docol DP and Docol M. Tensile strength is 560 MPa for the low strength filler and 890 MPa for the high strength filler.

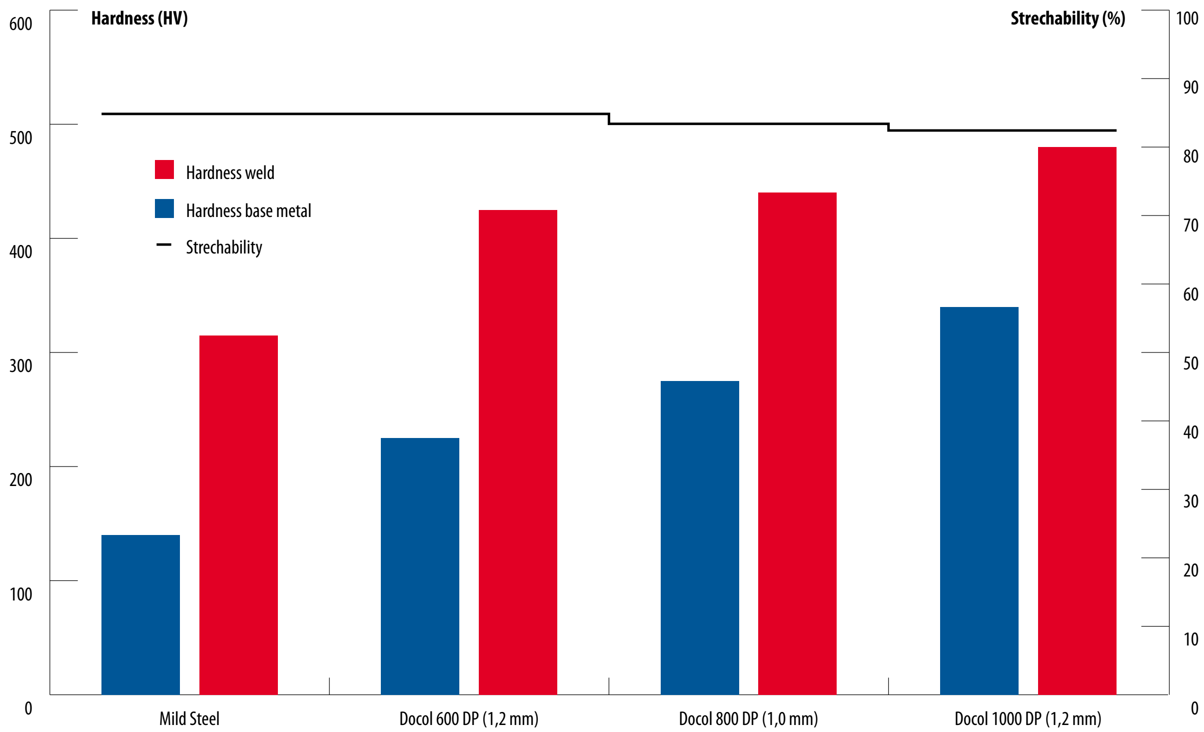


Figure 19. Hardness and stretchability of laser welds for Docol DP steels. Butt welds with both sheets of the same thickness (1.0-1.2 mm). The Erichsen test is used for describing the stretchability.

results after laser welding. A too large gap between the sheet edges can create an undesirable underfill on the topside of the weld or lack of fusion in the weld seam. Depending on the sheet thickness, the maximum allowable edge separation is of the order of 0.1 to 0.2 mm.

A general stretchability test such as the Erichsen cup test can be used for assessment of the formability of a laser butt weld. All Docol DP steels show good stretchability values (see Figure 19. stretchability=100 x the ratio of stretchability of weld to stretchability of base metal). The hardness of the laser welds for DP steels is higher than for mild steels (see Figure 19.) but, despite this fact, good stretchability values can be achieved for the DP steels. The reason is that the factor which mainly determines the stretchability is the difference in hardness between weld metal and base metal and these values are not so much higher for dual phase steels compared to mild steels.

In the production of laser welded, roll-formed profiles Docol AHSS can be used. If the hardness of the laser weld is considered to be too high for some reason a post- heat treatment can be used to reduce the hardness. For the heat treatment a high frequency induction device is recommended.

One of the benefits of laser welding is that the strength of the laser weld in Docol AHSS of very high strength steels can be increased in comparison with ordinary gas metal arc welding. The reason for this is that the heat input is much lower for laser welding and the material is therefore less affected by heat.

Docol AHSS is also well suited to laser lap welding. In assembly laser welding different kind of lap welds are often used. It can be a lap fillet weld (edge weld) or a conventional penetration lap weld. For lap welds of thin sheets full penetration in the lower sheet is often utilized due to an easy quality control process in this case. For lap welds of thicker sheets, approx. 50% penetration in the lower sheet can be recommended.

Mechanical joining

The mechanical joining methods of clinching and self-piercing riveting can be used for Docol AHSS. These methods have some benefits in comparison with resistance spot welding e.g. there is

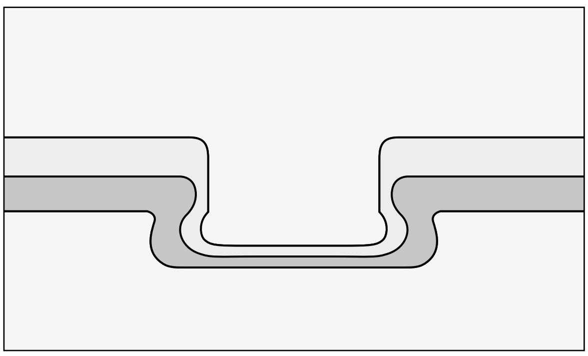


Figure 20. Two sheets joined by clinching

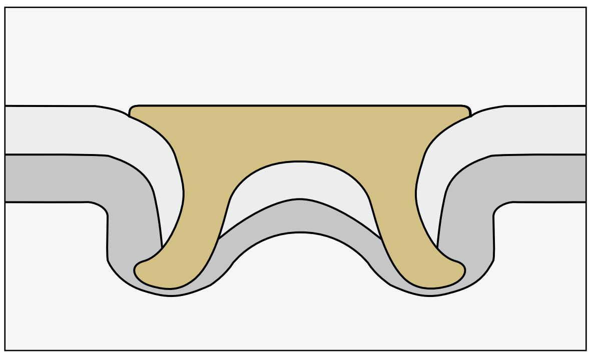


Figure 21. Self-piercing riveting with a semi-tubular rivet.

no heat involved which alters the mechanical properties and it is possible to join completely different materials. In the case of zinc coated steels, the corrosion resistance is also better with these mechanical joining methods.

In clinching no additional joining element is used. The sheets are formed together in cold condition so that they are locked mechanically (see Figure 20). The tools used for clinching consist of a punch and a die. Clinched joints should be designed for shear loading as the peel strength of clinched joints is quite low. The static strength of a clinched joint increases with increasing strength of the clinched sheets. Other factors, which are important for the strength, are sheet thickness and joint size. Clinching performs well in sheet strengths up to DP 600. Also DP 800 can be clinched if it is in combination with another steel of lower strength.

In self-piercing riveting with a semi-tubular rivet the rivet is pressed through the upper sheet by means of a punch. The die forces the tubular part of the rivet to expand and form the sheets (see Figure 21). Self-piercing riveting with a solid rivet avoids flaring on the die side. The rivet punches a hole in both sheets and securing then takes place by the material being cold formed onto the rivet. In the same way as for clinching, the static strength increases with increasing strength of the sheets and the shear strength is higher than the peel strength. Conventional self-piercing riveting can be used for sheet strengths up to DP 600. With modifications of the equipment, also Docol DP 800 can be self-piercing riveted.

Adhesive bonding

The use of adhesive bonding and weld bonding has increased in recent years. Docol AHSS in combination with a high strength structural adhesive will result in higher bond strength than for mild steels if the same sheet thickness is applied. If higher joint strengths are needed the overlapped area may be enlarged.

Joining of Docol AHSS with adhesive bonding is a good method to improve fatigue strength and stiffness in comparison with other joining methods (arc welding, laser welding, resistance spot welding). Due to the larger bonding area with adhesive bonding the local stresses are reduced and therefore the fatigue strength is increased. The most common structural adhesive used today in the automotive industry is one-component epoxy resin.

TECHNICAL CONSIDERATIONS

Docol AHSS can be designed, formed, joined and treated in much the same way as other steels. But there are a few considerations that have to be made when it comes to surface treatment and heat treatment – hot processes should be avoided so as not to impair the strength of the material. Stress corrosion cracking should also be considered.

Surface treatment

Docol AHSS can be protected against corrosion in the same way as mild steels, i.e. by painting, electrogalvanizing or other types of metallic coatings. However, hot processes, above 200 °C, should be avoided because they can have a negative influence on the material strength.

In electrogalvanizing, or other hydrogen generating processes, the sensitivity of the steel to hydrogen embrittlement must be taken into account. Hydrogen atoms are released during the coating process and enter the steel. The hydrogen-generated fracture usually occurs after some time when the product has undertaken several more production steps or, even worse, when it is taken into operation. The risk for hydrogen embrittlement problems is increased as the strength level of the steel rises and must be investigated carefully for all materials with a tensile strength above 1000 MPa. SSAB has developed Docol AHSS to improve the resistance to hydrogen embrittlement.

Docol AHSS can be continuously electrogalvanized without risk if the right process parameters are chosen. However, for Docol 1200M and products with even higher strength levels, careful testing and evaluation is necessary in all plants where production is planned to take place. This action will provide the producer with all data necessary for a safe and stable production of the product.

Surface treatments in acid solutions are other examples of processes that can be a potential risk for hydrogen embrittlement in AHSS. We have observed this effect when materials have been phosphated in processes not operating properly. Normally, modern phosphating processes generate no, or very small, amounts of hydrogen but if the process control is unsatisfactory the produced amount of hydrogen increase and can cause hydrogen embrittlement. Thus, phosphating processes treating AHSS need to be run with a careful production control.

Figure 22. By using Docol AHSS the weight of a gas cylinder can be reduced by 50 percent without impairing safety. Since gas cylinders are refilled over and over again, costs of transportation are reduced.

When surface treatment and corrosion protection of processed parts are of interest there are some alternatives to zinc plating on the market. Geomet and Delta MKS are treatments that eliminate the risk of hydrogen embrittlement. However, these processes include a curing stage for the coating, and the maximum recommended heat treatment temperature for the relevant steel grade must be taken into account if the steel is to retain its high strength.

Heat treatment

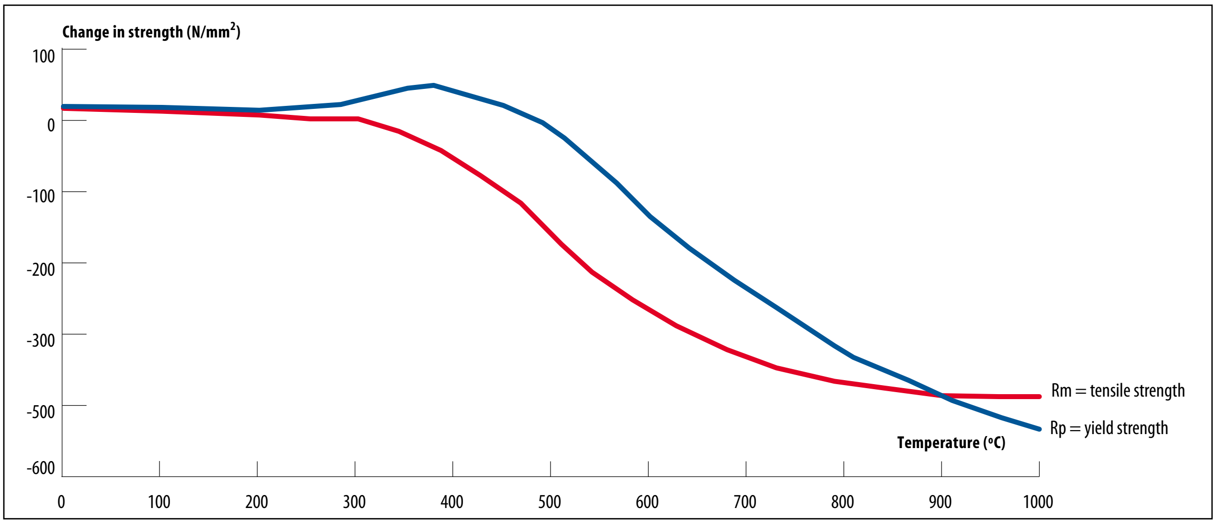
When Docol AHSS are heated their strength properties can be impaired. Maximum heating temperature, without loss in strength, varies between 200–400° C depending on the steel grade. Table 17 shows the maximum heating temperature that is allowed without loss in strength.

Martensitic steels can be heated at temperatures of up to about 200° C without loss in strength. If heated to above 200° C the strengths of these steels will decrease by more than those of dual phase steels.

Table 17.

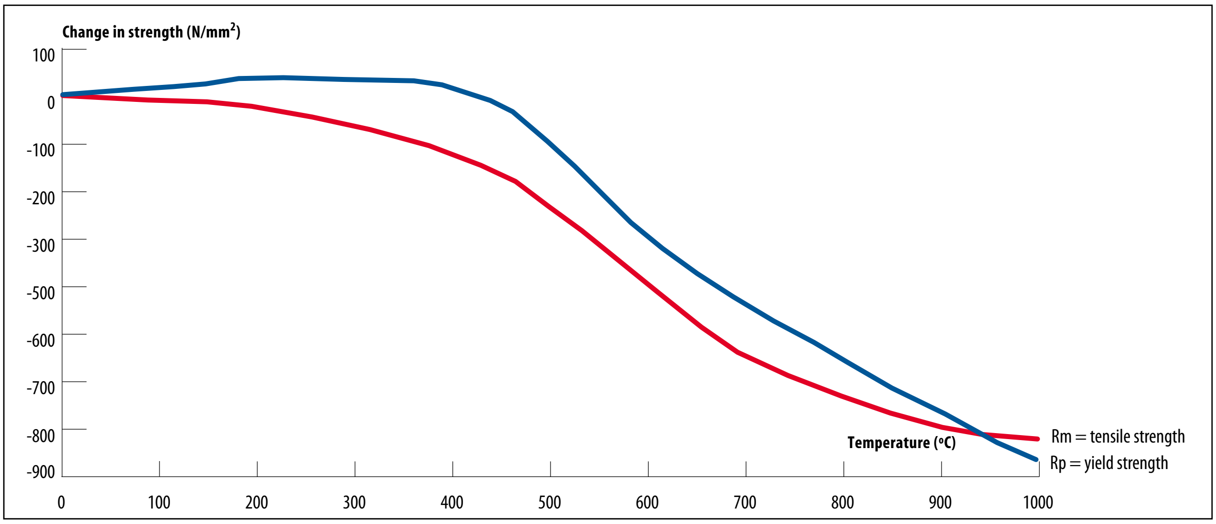
Type of steel	Steelgrade	Max heating temperature
Dual Phase steel	Docol 500 DL	200°C
	Docol 500DP	300°C
	Docol 600 DL	200°C
	Docol 600 DP	300°C
	Docol 800 DL	200°C
	Docol 800 DP	300°C
	Docol 1000 DP	300°C
	Docol 1000 DPZE	300°C
Martensitic steel	Docol 900 M	200°C
	Docol 1200 M	200°C
	Docol 1200 MZE	200°C
	Docol 1400 M	200°C
	Docol 1400 MZE	200°C
	Docol1500 M	200°C
Wear resistant steel	Docol Wear 450	200°C
Weather resistant steel	Docol 700 W	400°C
Roll forming steel	Docol Roll 800	400°C
	Docol Roll 1000	400°C

Figure 23. Heat tratment of Docol 1000 DP



The graph shows how the strength of Docol 1000 DP is changed by heating

Figure 24. Heat tratment of Docol 1200/1400 M



The graph shows how the strength of Docol 1200 DP and Docol 1400 DP are changed by heating

Stress corrosion cracking

Stress corrosion cracking (SCC) is the formation of brittle cracks in a normally sound material through the simultaneous action of a tensile stress and a corrosive environment. SCC is strongly affected by the microstructure of the steel, the concentration of specific corroding species, and, to a lesser degree, the stress intensity.

The stress can be either an external stress or residual stresses from the fabrication of the material or product. Under certain conditions and in contact with some chemicals AHSS can develop SCC. The risk increases with tensile strength, but so far occasional problems have only been observed on steel at the 1400 MPa level.

AHSS can develop SCC in contact with certain chemicals. It is recommended not to use materials with a tensile strength of 700 MPa or higher in contact with the following chemicals without additional corrosion protection:

- Concentrated salt solutions, especially presence of chloride, sulphide or ammonia
- Mixed strong acids (e.g. hydrochloric acid, sulphuric acid)
- Acidic sulphide solutions
- Calcium, ammonium, or sodium nitrate solutions
- Strong alkali like caustic soda (sodium hydroxide)
- Anaerobic (free from oxygen) environments

Resistance to shock and impact

Large areas of steel sheet subjected to shock and impact incur serious risk of permanent deformation. A car door or a container, 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.

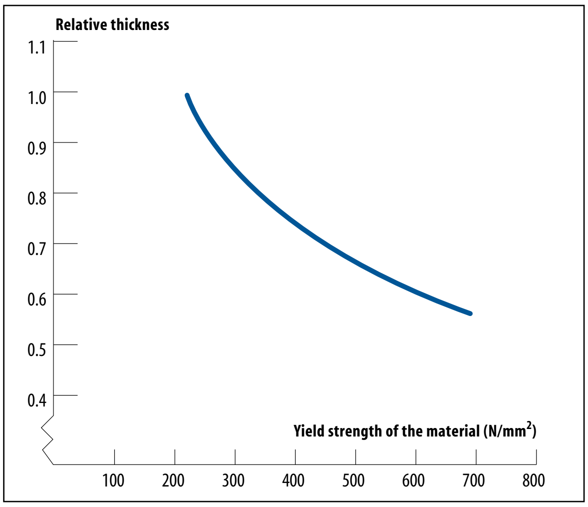


Figure 25.

TOOL STEELS

When forming and cutting sheet profiles, the entire chain from tool design to tool maintenance must be problem free. The chain includes several different steps and every step must be correctly performed to ensure good productivity and production economy. This makes it very important to select the right tool steel for a given forming or cutting operation.

To select the right steel you need to be able to identify the damage mechanisms that can arise when shearing and/or forming and that can lead to a tool becoming unusable or failing quickly. In principle, there are five damage mechanisms that can arise in the active parts of the tool:

- Wear, abrasive or adhesive, that is associated with the material being worked, type of operation and friction forces in the sliding contact.
- Plastic deformation, that arises when the tension level arising exceeds the hardness limit of the tool material.
- Burring, as a result of high tensions in comparison with fatigue resistance of the tool material.
- Crack formation as a result of high tensions in comparison with the fracture toughness of the tool material.
- Build up, that is a result of high friction forces in the sliding contact with the material being worked. The build up mechanism is closely related to adhesive wear.

Plastic deformation, burring and crack formation often result in serious and costly production downtime. Wear and build up are more predictable and can be addressed to an extent by regular tool maintenance. One consequence of this is that it can be worth accepting more wear than getting burrs or cracks. When forming and shearing Docol AHSS the tools are subjected to higher forces locally compared with softer steels, which makes it necessary to have higher specifications for durability and strength in the tool material.

Shearing operations are the most sensitive as these require a combination of high durability and high resistance to burring and crack formation, while forming operations are mostly a matter of durability.

As a rule, powdered metal steel offers a good combination of durability and resistance to burring compared to other tool steels. The difference in properties mainly depends on powder metallurgy producing small and evenly distributed carbides that protect against wear. And the fact that these carbides are also tiny makes them less of a hazard as initiation points for fatigue cracks. In contrast, conventional steels with good durability have large carbides that form together and so reduce mechanical durability.

Steel selection guide for shearing

No two production situations are exactly alike, and as such, the choice of tool steel must be made in terms of the process specific circumstances. Where possible experience from earlier production with the same machinery should be utilised. Starting from there, the choice of steel can be successively improved by relative comparisons between different steels.

SSAB and Uddeholm Tooling have produced a guide for choosing tool steels for shearing and punching tools, that can be used in the absence of in house experience. The guide is included in our brochure "Tooling solutions for advanced high strength steels".

When designing and manufacturing tools, it is important to avoid sharp corners and acute radii and poorly worked surfaces. The high tensions in combination with the high hardness of the tool steel can give rise to concentrated tensions in the event of such defects.

Steel selection guide for forming

The limited damage mechanism when forming is mainly wear and this wear is mainly abrasive. However adhesive wear also arises and build up also appears, as high friction forces are created when forming Docol AHSS. SSAB and Uddeholm have produced a guide for choosing tool steels when forming Docol AHSS. The guide is included in our brochure "Tooling solutions for advanced high strength steels".

SSAB – A PLAYER IN THE MOST ADVANCED MARKET

SSAB is one of the world's most successful and respected steel companies. By focusing on AHSS, both strip and plate, we have become a leading producer of these steels.

Our position as a highly specialized producer in our niche ensures that we are well tuned to the needs of our customers – and can take quick action. The automotive industry is one of our most important customers.

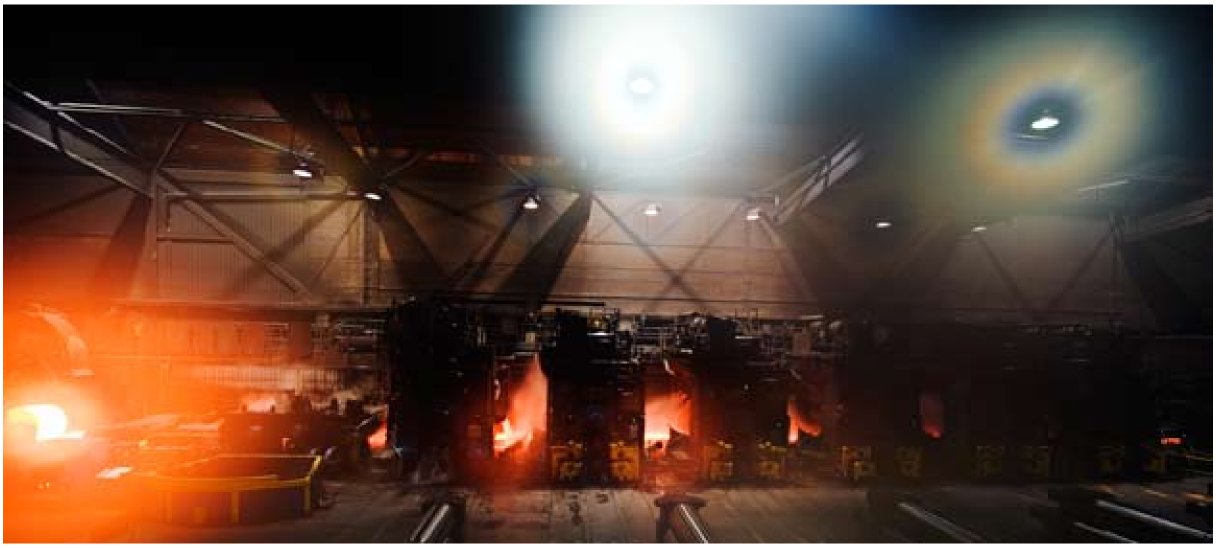
The SSAB Swedish Steel Group had annual sales (2007) of more than SEK 47,000 million, with sales to more than a hundred countries all over the world and offices in more than 40 of them.

The SSAB Swedish Steel Group has a total of around 10,000 employees worldwide, of whom the Strip Products Division (formerly SSAB Tunnplåt) employs 3,800. The Strip Products Division produced more than 2.7 million tonnes of strip during 2007.

SSAB was formed in 1988 by the merger of three steelworks in Sweden. In 2007 the group expanded by acquiring IPSCO, a leading producer of advanced high strength steel and other steel products in Canada and the U.S.

Environmental policy of the SSAB Group

Within the SSAB Group, all operations shall be conducted in a resource-effective and efficient manner in respect of the use of raw materials, energy and other natural resources. The commercial operations are based on environmental work which contributes to permanent and sustainable development of the use of steel in society. It is SSAB's aim to maintain a leading position within the steel industry in the environmental performance of products and processes.



THE KNOWLEDGE SERVICE CENTER

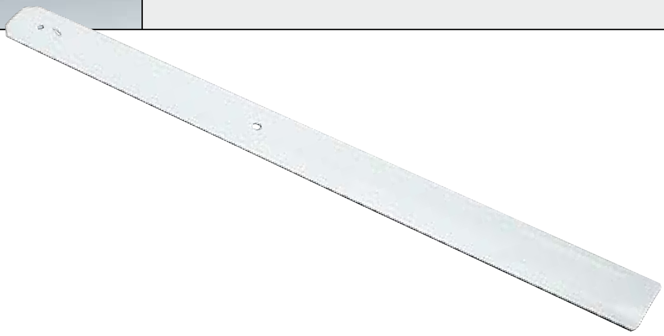
The SSAB Knowledge Service Center puts our extensive knowledge of Docol AHSS, and how they are best used, at the full disposal of all our customers through personal contact with our application engineers and materials experts.

Through the Knowledge Service Center helpdesk (+46 243 700 00), or e-mail, we provide assistance and technical support in all areas of importance – choice of material, designing for optimum performance and all aspects of the production process from forming to tooling and joining.

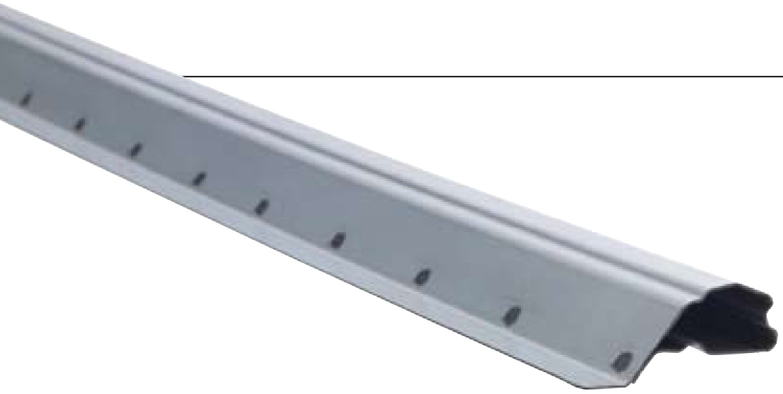
Instant support around the clock is also available on the web at www.ssabdirect.com. This is a very comprehensive database containing detailed product facts, downloadable auxiliary programs, material graphs and other information that simplifies analysis and design work.

For those who prefer complete printed matter and manuals, these can be ordered from the Knowledge Service Center or via www.ssabdirect.com.

APPLICATIONS



Highway Post
Docol 1400 M



Waist Reinforcement
Docol 1000 DP+ZE

Lightning Armature
Docol Hard 450Y

Door Beam
Docol 1400M

Waste Basket
Docol Hard 550Y

Battery Holder
Docol 1200 M

Door Beam
Docol 1200 M

Amurons Pipe In
Docol 1400 M

SSAB Tunnplåt AB is the largest Scandinavian steel sheet manufacturer and a leader in Europe in the development of Advanced High Strength Steels.

SSAB Tunnplåt is a member of the SSAB Swedish Steel Group, has a turnover of SEK 14 billion, and employs more than 4000 people in Sweden. We produce around 2.7 million tonnes of sheet steel every year.

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

DOMEX®
Hot-rolled strip steel

DOCOL®
Cold-reduced sheet steel

DOGAL®
Hot-dip galvanized sheet steel

PRELAQ®
Prepainted sheet steel

Registered trademarks for SSAB Tunnplåt AB.

We assist our customers in selecting the steels that are best able to improve their competitiveness. Our strength lies in the quality of our products, the reliability of our supplies, and our flexible Knowledge Service Center.

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