alform®

alform® LASER

Processing

voestalpine
ONE STEP AHEAD.

Index

The steel grades of the ALFORM® and LASER ALFORM® series are thermomechanically rolled or normalized hot-rolled steels. ALFORM® steels are available in yield strength classes from 180 to 900 N/mm²; the LASER-ALFORM® steels currently available have minimum yield strengths up to 420 N/mm².

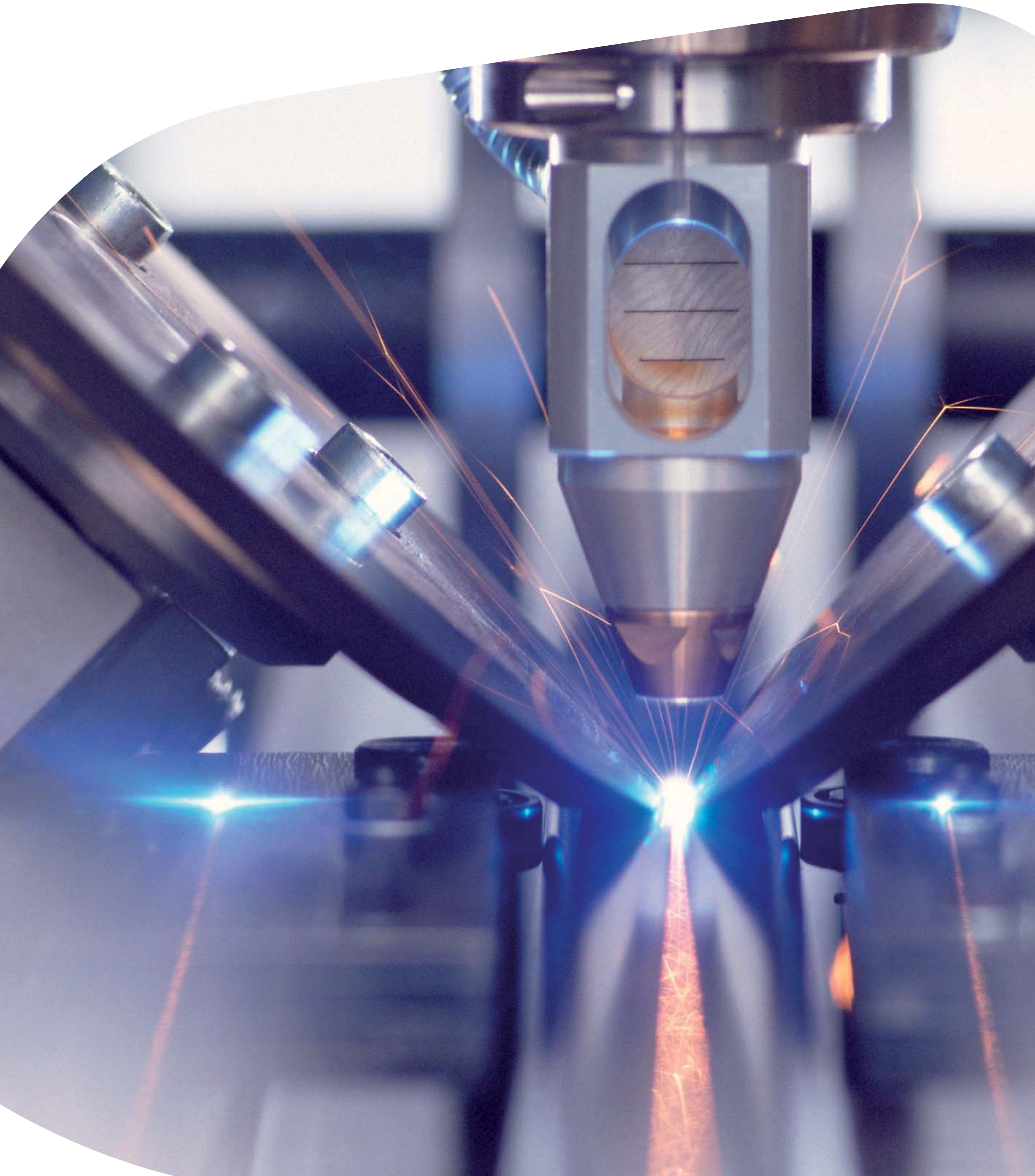
ALFORM® and LASER-ALFORM®

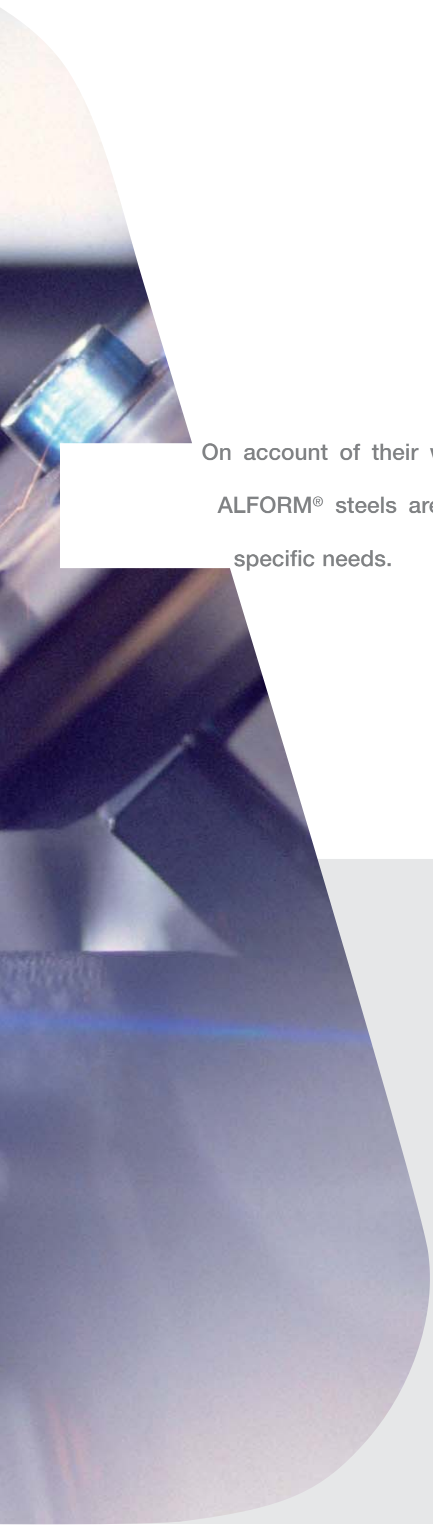
The use of ALFORM® steels has proven successful in applications where excellent processing properties such as good formability and optimum weldability are required and high strength is also essential.

- Pipe, tube and section industry
- Construction of cranes
- Automotive manufacturing
- Steel structures
- Agricultural machines
- Construction of containers

Owing to their extended processing properties, LASER-ALFORM® steels are especially suitable for laser cutting and can be used in fields of applications where extremely precise cuts, burr-free cut edges and parts free of distortion are required.

- General structural steel engineering
- Mechanical engineering (crane construction and automotive manufacturing)





1. Advantages of ALFORM® and LASER-ALFORM®

On account of their wide range of product properties, ALFORM® and LASER-ALFORM® steels are usable in a wide range of applications tailored to your specific needs.

ALFORM®

- Excellent cold formability
- Excellent weldability
- Highly uniform mechanical properties
- Optimum cutting and blanking capabilities
- High degree of purity
- High surface quality

Extended properties of LASER-ALFORM®

- Optimum laser-cutting capabilities
- Limited flatness tolerances for cut strip
- Guaranteed low silicon content

1.1 Product advantages in respect of processing

Excellent Cold Formability

Optimum forming properties are ensured by the fine grained low pearlite microstructure, the high degree of purity and the high degree of constancy of the mechanical properties. As a result, considerably narrower bending and edging radii compared with structural steels and standard steels of the same strength class can be applied, even if extremely high demands are made on the yield strength (700 N/mm² and over).

- Excellent Cold Formability

Excellent Weldability

A low C equivalent, in particular a low carbon content, is essential to achieve:

- a large field of welding parameters (processing range)
- simple weld seam preparation (no preheating)
- low tendency towards excessive hardening and excellent mechanical-technological properties in the heat affected zone
- cold cracking resistance without preheating
- excellent formability of the welds (see Fig. 1)

Upsetting test to demonstrate the forming behavior of the base material and the weld

Material:
ALFORM 355M
strip thickness: 5 mm
Section dimension:
100 x 100 mm

Optimum cutting and blanking capabilities

ALFORM® steels are ideally suited for mechanical cutting and blanking as well as for all thermal cutting processes (e.g., plasma and oxy-gas cutting).

- Uniform mechanical properties result in minimum residual stress of the strip and serve to prevent distortions during cutting.
- The high degree of purity with respect to non-metallic inclusions results in vertical cut edges without undercuts.

To meet highest standards in laser cutting capability we also supply the steel grades of the LASER-ALFORM® series. The materials have the following advantages:

- Highest cutting speeds at optimum shape of the cut edges
- Extremely narrow dimensional tolerances (if necessary, 2/3 of the thickness toleran-ces can be kept compared to EN 10051; upon request, even narrower thickness tolerances for an extra charge) and exceptional flatness (guaranteed flatness devia-tions of 3 mm over 1 m length) are achieved by optimized production conditions in the hot strip mill and special inspections carried out during cutting to length and leveling.
- A homogeneous, uniform secondary scale layer ensures trouble-free operation of laser cutting units and fine drag lines of small depth of roughness.

High Surface Quality

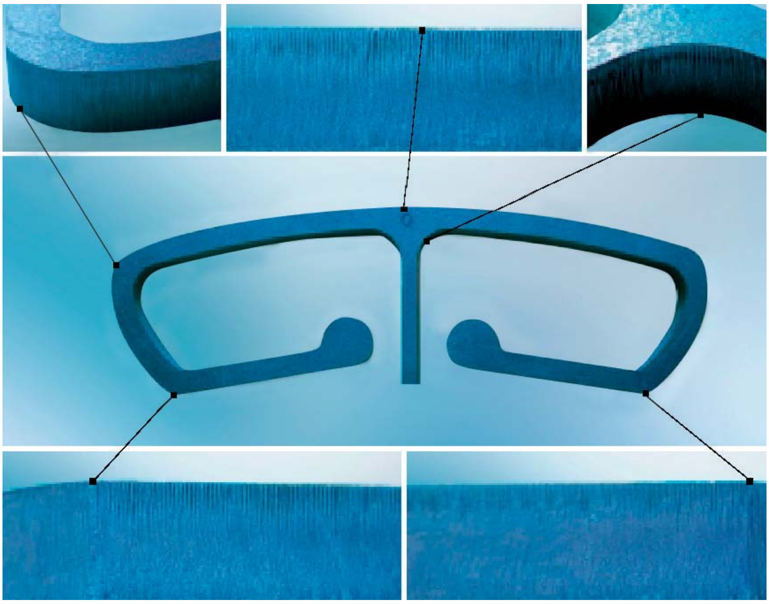
A high surface quality is achieved by a thin, uniform scale layer as a result of thermomechanical or normalizing rolling. This makes thermal cutting possible in even the case of scaling and guarantees perfect visual appearance even after painting.

Additionally, ALFORM® grades suitable for galvanizing are available.

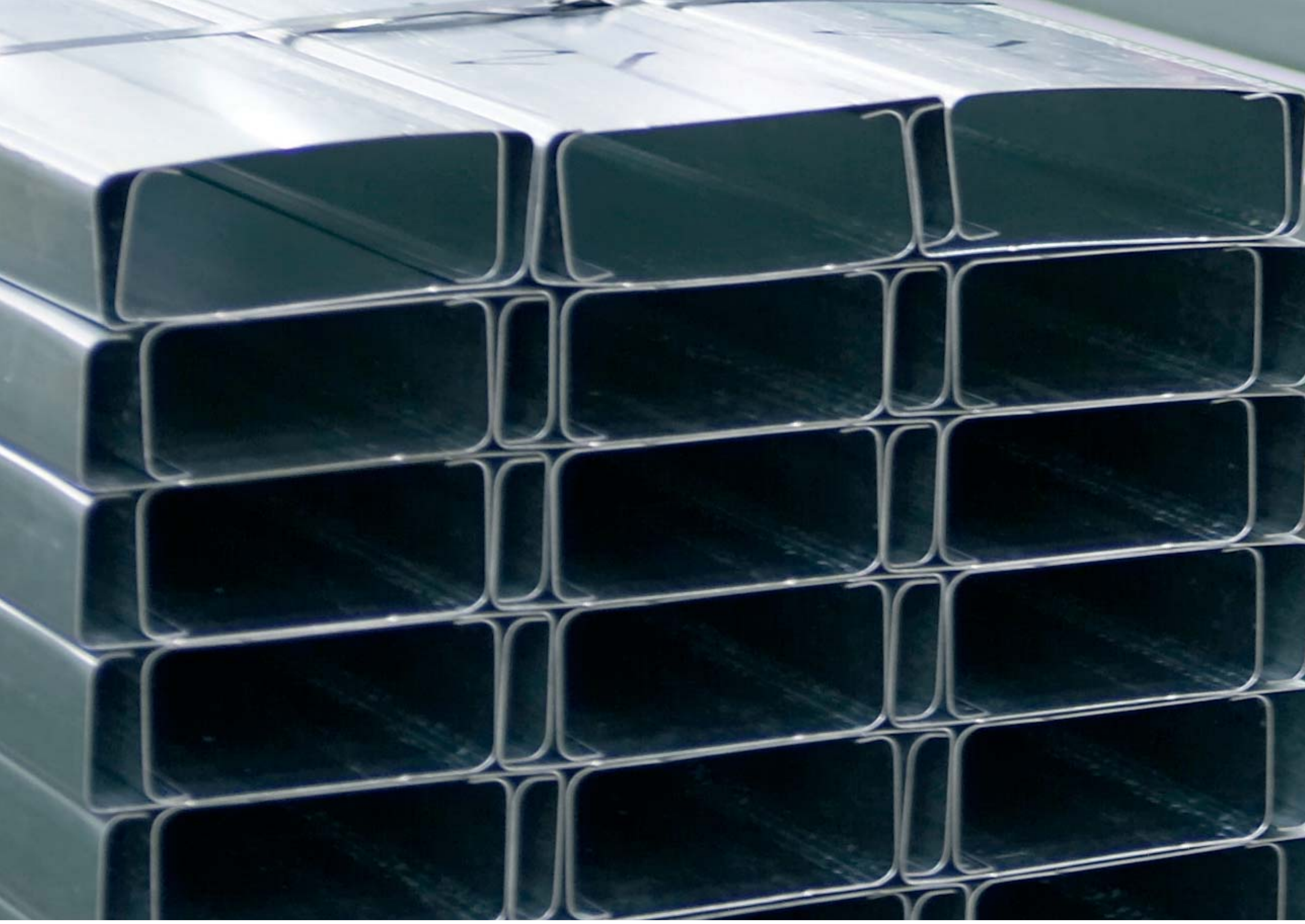
Mechanical Properties

The ALFORM® series of steel grades comprises a wide range of yield strength classes.

- Steel grades with minimum yield strength limits from 180 N/mm^2 to 900 N/mm^2 are available.
- The high degree of purity, the low contents of phosphorus and sulfur in addition to the fine grained microstructure yield optimum notched bar impact strength values and excellent formability.



Sample cut of
LASER-ALFORM 355 M,
thickness 10 mm



1.2 Example of practical application of ALFORM® steels

Advantages of ALFORM®, taking rectangular sections as an example

The use of high-strength ALFORM® steels instead of structural steels offers substantial advantages for the user. These advantages are illustrated in the graph below, which shows the maximum bending moment that can be tolerated by a rectangular section (constant outside dimensions: 120 x 80 mm) when the yield point is reached at the boundary fiber as a function of the yield strength for different wall thicknesses.

These reflections are based on conventional S235 structural steel with a nominal minimum yield strength of 235 N/mm^2. If a maximum tolerable bending moment of, e.g., 3.6 mt is to be achieved for a rectangular section, the section must have a wall thickness of 17 mm. When using higher strength ALFORM® steels, however, such as ALFORM 500 M or ALFORM 700 M, the thickness can be reduced to 6 mm and 4 mm, respectively, with the tolerable bending moment remaining the same. In this way the weight can be reduced by about 65 % and 76 %, respectively.

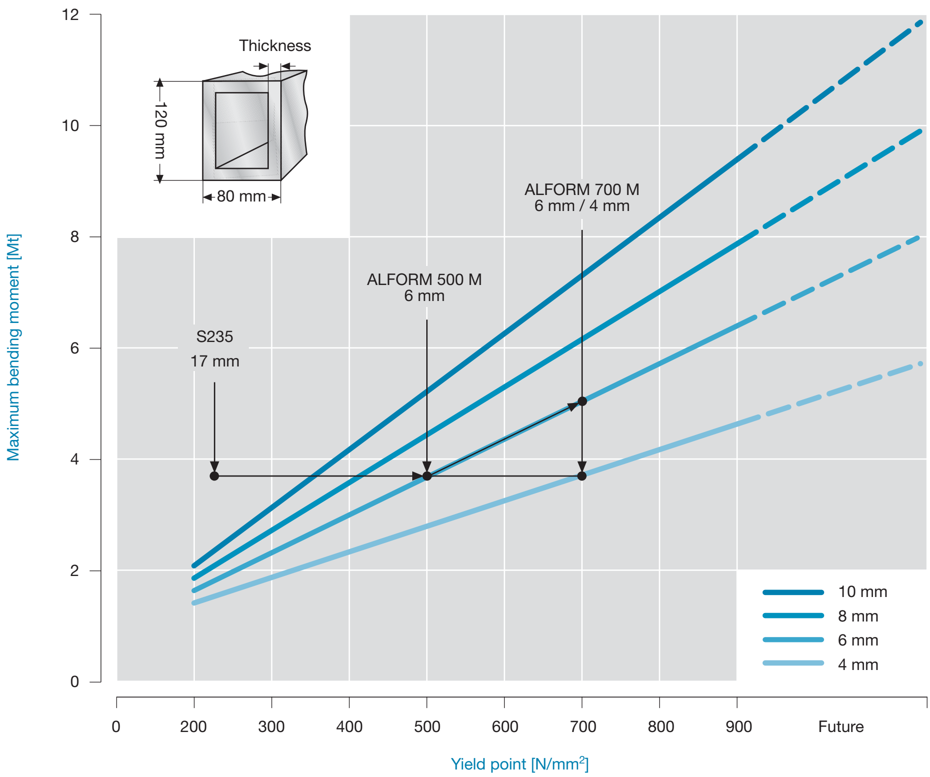
Building components must meet ever more stringent performance requirements, meaning that they have to lift or convey higher and higher loads. As shown by the example of the rectangular section, the maximum tolerable bending moment can be increased by about 45 % when using a high strength ALFORM 700 M instead of an ALFORM 500 M grade, with the thickness remaining the same.

Based on the above example, the following advantages can be derived when using higher and highest strength ALFORM® steels for the actual application:

- gain of bearing load and/or horizontal reach (cranes, supporting structure, structural steel work)
- gain of carried/useful load (mobile cranes, vehicle construction, containers)

Furthermore, a reduction in component thickness results in

- lower material input
- cost advantage in spite of higher price
- reduction of filler metals and shortening of welding time
- lower machining costs in weld seam preparation
- improved handling in processing (e.g., during cutting and edging)
- narrower edging radii



Weight savings achieved by using ALFORM 700 M and 900 M, taking a concrete pump as an example

In view of the maximum total vehicle weight of 48 tons as specified in the Road Traffic Regulations for carriage without special authorization, a manufacturer of concrete pumps cannot increase the horizontal/vertical reach of a truck mounted concrete pump unless higher strength materials are increasingly used. The advantages of ALFORM 700 M and 900 M compared to S355J2 structural steel with regard to the key efficiency characteristics of a concrete pump are illustrated by the following theoretical considerations.

SCHWING, a manufacturer of concrete equipment, has manufactured a truck mounted concrete pump with a total weight of less than 48 tons and a vertical reach of 61 m using mainly ALFORM 700 M and 900 M. If such a machine were made of S355J2 its total weight would amount to about 100 tons.

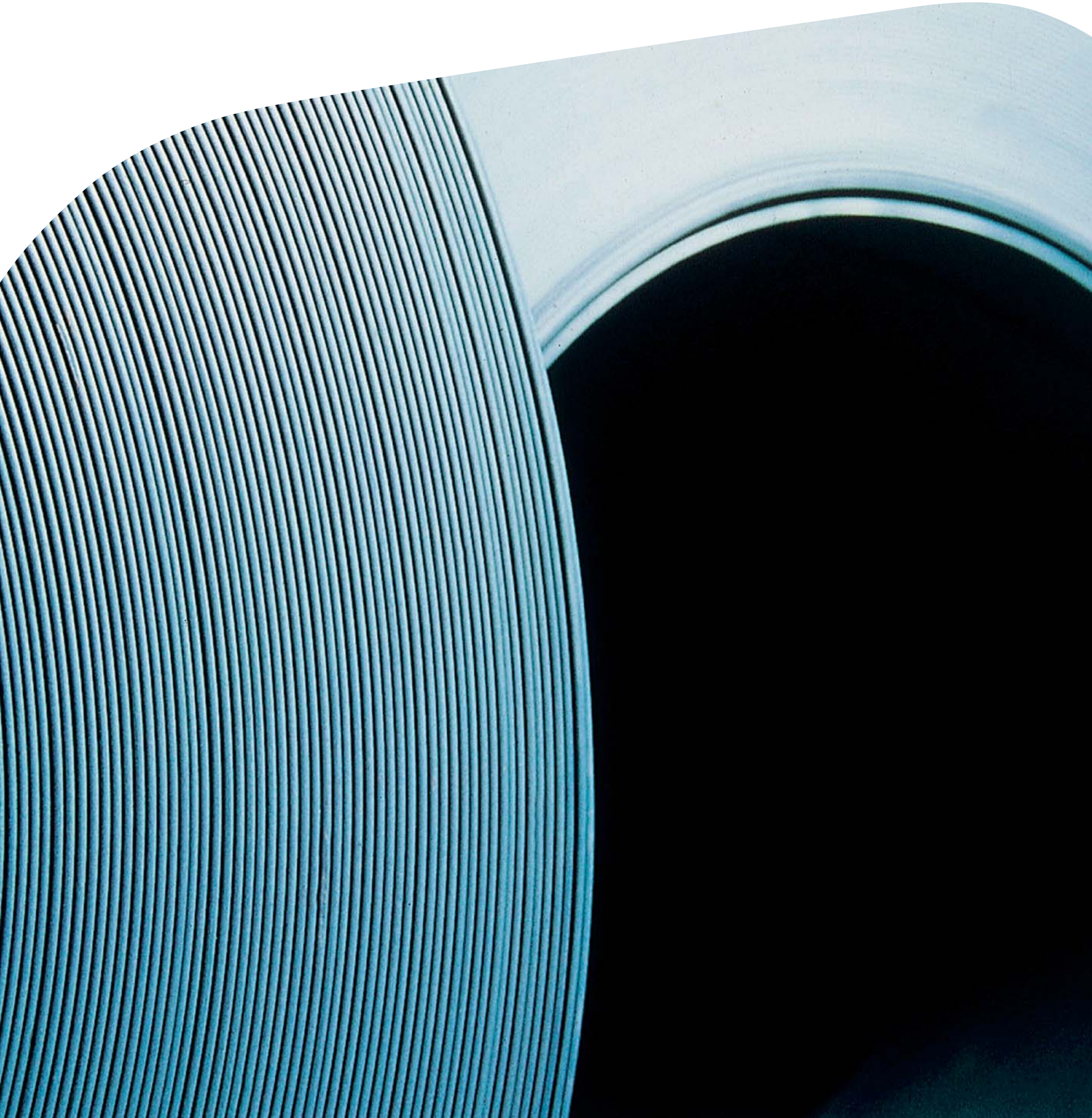
NOTE

Material (cost) can be saved by using a material of higher strength. The improved suitability of ALFORM® steels for welding and edging offer additional savings potentials in processing.

As a result, the maximum load moment in the bearing point would increase by a factor of three. Because of the larger supporting width required the net horizontal reach, with the boom laterally telescoped, would be about 5 m shorter. Moreover, roughly 20 % material (cost) could be saved by using a material of higher strength.

Theoretical sample calculation

	ALFORM 700 M and 900 M	S355J2
Weight	48 t	100 t
Max. load moment of the jib	100 %	296 %
Max. height	61 m	61 m
Net horizontal reach of the jib	54 m	49 m
Supporting width of the vehicle	9 m	16 m



2. The ALFORM® and LASER-ALFORM® products

The following is an extract from the range of ALFORM® and LASER-ALFORM® products. The full range of products is available in the technical terms of delivery or in the Product Configurator of voestalpine Stahl GmbH. Please find more detailed information in the Appendix.

The ALFORM® series of voestalpine is a high quality product family of hot-rolled steel strips and cut plates. The thermomechanical production process, combined with a sophisticated QM system, ensures constantly high product quality in addition to excellent processing properties.
ALFORM® steels are also available in highest strength classes and are suitable for a wide range of applications. LASER-ALFORM® steels additionally offer extended properties with regard to their laser cutting capabilities.

2.1 Product Description / Delivery Specifications

ALFORM 380 M / ALFORM 380 N

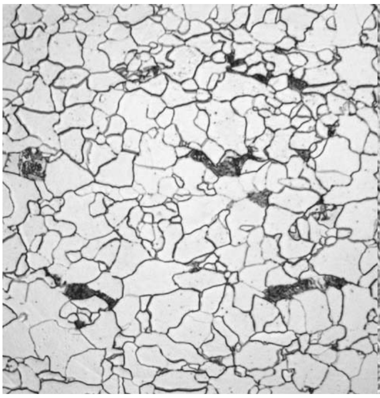
ALFORM	brand name at voestalpine Stahl GmbH
380	Minimum yield strength in N/mm^2
M	Thermomechanically rolled
N	Normalized rolled

Comparison with Standard Steels

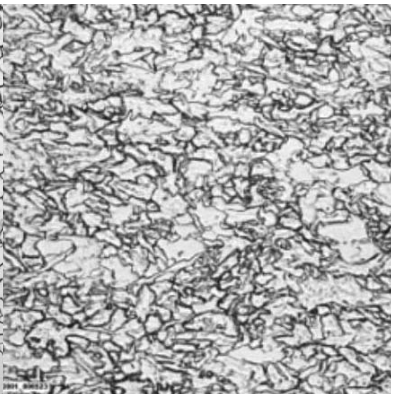
The M series of the ALFORM® grades is based on EN10149/2 yet, unlike this standard, features limited tolerances in the chemical analysis, the mechanical properties, and the bending and edging radii. The reference standards of the N series are EN10111, EN10025 and EN10149/3.

Difference between thermomechanically rolled and normalized rolled

ALFORM® is available both in normalized and in thermomechanically rolled condition. When thermomechanically rolled steels are heat treated above 580°C (e.g., normalizing), the minimum yield strength will decrease (M series). In such a case it is advisable to use normalized rolled steels (N series). Thermomechanically rolled steels can also be subjected to flame leveling, with local short-term heating up to 800°C.



Normalized rolled microstructure



Thermomechanically rolled microstructure

The figures show the difference in microstructure between normalized and thermomechanically rolled grades, the latter (figure on the right) being characterized by a
particularly fine grained low pearlite microstructure.

Surface appearance: pickled or unpickled

ALFORM® and LASER-ALFORM® steels are available with pickled or unpickled surfaces. In general, pickled grades are supplied with oiled surfaces, whereas unpickled grades are usually supplied with unoiled surfaces only.

Hot-rolled steel strips, cut plates and slit strips

ALFORM® steels are available as hot-rolled steel strips, slit strips and cut plates. The steel grades of the LASER-ALFORM® series are available as hot-rolled cut plates only. ALFORM® in larger thicknesses and widths (larger than 12 mm in thickness and larger than 1,625 mm in width) are supplied by voestalpine Grobblech GmbH. More information about the individual sources is available on the last few pages in the annex.

Dimensions apply to unpickled products. Other product variants and a detailed list of the dimensions available are provided in the current sales brochure and in the technical terms of delivery.

Dimensions

Thickness [mm]	ALFORM 180 N LASER-ALFORM 180 N	ALFORM 200 N 240 N LASER-ALFORM 200 N 240 N	ALFORM 380 N LASER-ALFORM 380 N	ALFORM 280 M 315 M 340 M	ALFORM 355 M 380 M LASER-ALFORM 355 M 380 M	ALFORM 420 M LASER-ALFORM 420 M	ALFORM 460 M	ALFORM 500 M 550 M	ALFORM 600 M	ALFORM 650 M 700 M	ALFORM 900 M
1.50	1,100	1,250	–	1,000	1,000	–	–	–	–	–	–
1.75	1,200	1,360	–	1,120	1,050	–	–	–	–	–	–
1.90	1,260	1,440	1,100	1,200	1,120	1,000	1,000	1,000	–	–	–
2.25	1,625	1,625	1,180	1,460	1,340	1,150	1,150	1,130	–	–	–
2.50	1,625	1,625	1,240	1,625	1,625	1,300	1,300	1,240	–	–	–
2.75	1,625	1,625	1,300	1,625	1,625	1,550	1,550	1,360	–	–	–
3.00	1,625	1,625	1,350	1,625	1,625	1,625	1,625	1,530	1,400	1,400	–
3.25	1,625	1,625	1,410	1,625	1,625	1,625	1,625	1,625	1,480	1,480	–
3.50	1,625	1,625	1,475	1,625	1,625	1,625	1,625	1,625	1,530	1,530	1,300
3.75	1,625	1,625	1,540	1,625	1,625	1,625	1,625	1,625	1,530	1,530	1,380
4.51	1,625	1,625	1,625	1,625	1,625	1,625	1,625	1,625	1,530	1,530	1,435
8.01	1,625	1,625	1,625	1,625	1,625	1,625	1,625	1,625	1,530	–	–

Upon ordering, the notch impact energy is determined on Charpy-V samples for thicknesses of 6 mm and higher.

Mechanical properties LASER-ALFORM® Steel Series

Steel grade	Testing direction tensile test	Yield strength [N/mm²] ReH	Tensile strength [N/mm²] Rm	Fracture elongation [%] min. A80	A5
LASER-ALFORM 180 N	transverse	180 – 290	280 – 360	32	38
LASER-ALFORM 200 N	transverse	200 – 320	320 – 400	28	34
LASER ALFORM 240 N	transverse	240 – 360	360 – 440	26	32
LASER-ALFORM 380 N	transverse	380 – 520	510 – 610	20	25
LASER-ALFORM 355 M	longitudinal	355 – 480	430 – 530	20	25
LASER-ALFORM 380 M	longitudinal	380 – 510	450 – 550	20	24
LASER-ALFORM 420 M	longitudinal	420 – 550	480 – 580	18	22

Mechanical properties ALFORM® Steel Series

Stahlsorte	Testing direction tensile test	Yield strength [N/mm²] ReH	Tensile strength [N/mm²] Rm	Fracture elongation [%] min. A80	A5
ALFORM 180 N	transverse	180 – 290	280 – 360	32	38
ALFORM 200 N	transverse	200 – 320	320 – 400	28	34
ALFORM 240 N	transverse	240 – 360	360 – 440	26	32
ALFORM 280 N	transverse	280 – 420	430 – 530	21	28
ALFORM 380 N	transverse	380 – 520	510 – 610	20	25
ALFORM 280 M	longitudinal	280 – 400	370 – 470	24	28
ALFORM 315 M	longitudinal	315 – 440	390 – 490	22	26
ALFORM 340 M	longitudinal	340 – 465	420 – 520	20	25
ALFORM 355 M	longitudinal	355 – 480	430 – 530	20	25
ALFORM 380 M	longitudinal	380 – 510	450 – 550	20	24
ALFORM 420 M	longitudinal	420 – 550	480 – 580	18	22
ALFORM 460 M	longitudinal	460 – 590	520 – 640	16	20
ALFORM 500 M	longitudinal	500 – 650	550 – 680	15	19
ALFORM 550 M	longitudinal	550 – 700	600 – 740	15	18
ALFORM 600 M	longitudinal	600 – 750	650 – 800	13	16
ALFORM 650 M	longitudinal	min. 650	700 – 850	12	15
ALFORM 700 M	longitudinal	min. 700	750 – 930	11	14
ALFORM 900 M	transverse	min. 900	930 – 1,100	–	10

Chemical Composition of the LASER ALFORM® Steel Series

Guaranteed values of heat analysis in %

Steel grade	C max.	Si max.	Mn max.	P max.	S max.	Al min.	Nb [1] max.	V [1] max.	Ti [1] max.
LASER-ALFORM 180 N	0.08	0.03	0.35	0.018	0.020	0.020	–	–	–
LASER-ALFORM 200 N	0.10	0.03	0.45	0.018	0.020	0.020	–	–	–
LASER-ALFORM 240 N	0.12	0.03	0.70	0.018	0.020	0.020	–	–	–
LASER-ALFORM 380 N	0.18	0.03	1.60	0.018	0.012	0.015	0.05	0.05	0.05
LASER-ALFORM 355 M	0.10	0.03	1.20	0.018	0.010	0.020	0.05	0.05	0.05
LASER-ALFORM 380 M	0.10	0.03	1.20	0.018	0.010	0.020	0.05	0.05	0.05
LASER-ALFORM 420 M	0.10	0.03	1.40	0.018	0.010	0.020	0.05	0.05	0.05

[1] The total of Nb, V and Ti may not exceed 0.22 %.

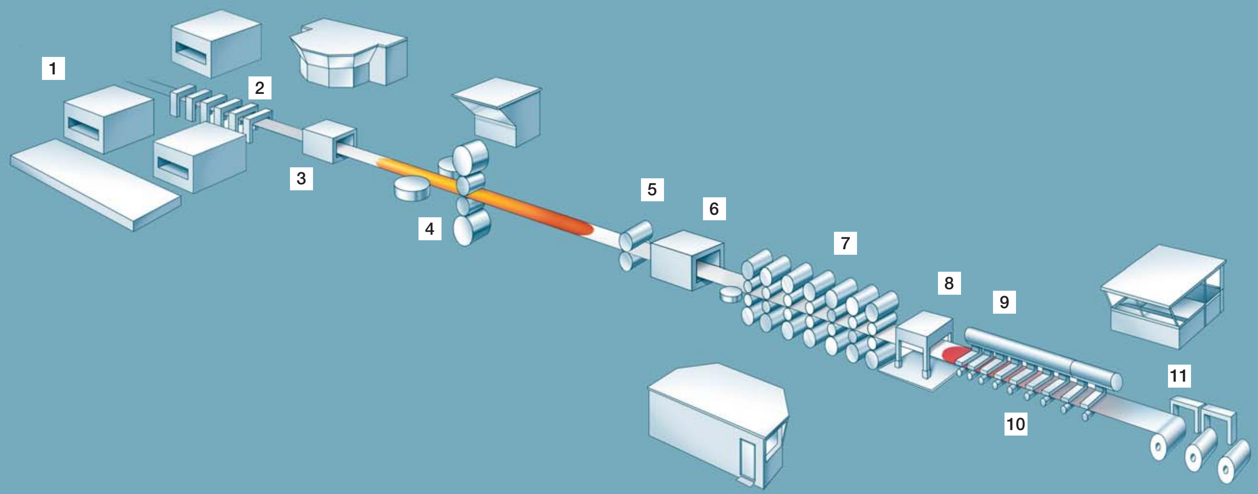
Chemical Composition of the ALFORM® Steel Series

Guaranteed values of heat analysis in %

Steel grade	C max.	Si max.	Mn max.	P max.	S max.	Al min.	Nb [1] max.	V [1] max.	Ti [1] max.	Mo max.	B max.
ALFORM 180 N	0.08	0.05 [2]	0.35	0.025 [2]	0.020	0.020	–	–	–	–	–
ALFORM 200 N	0.10	0.05 [2]	0.45	0.025 [2]	0.020	0.020	–	–	–	–	–
ALFORM 240 N	0.12	0.05 [2]	0.70	0.025 [2]	0.020	0.020	–	–	–	–	–
ALFORM 280 N	0.16	0.05 [2]	1.20	0.025 [2]	0.015	0.020	0.05	0.05	0.05	–	–
ALFORM 380 N	0.18	0.30	1.60	0.025	0.012	0.015	0.05	0.05	0.05	–	–
ALFORM 280 M	0.10	0.05 [2]	0.70	0.020	0.010	0.020	0.05	0.05	0.05	–	–
ALFORM 315 M	0.10	0.05 [2]	0.90	0.020 [2]	0.010	0.020	0.05	0.05	0.05	–	–
ALFORM 340 M	0.10	0.05 [2]	1.20	0.020 [2]	0.010	0.020	0.05	0.05	0.05	–	–
ALFORM 355 M	0.10	0.05 [2]	1.20	0.020 [2]	0.010	0.020	0.05	0.05	0.05	–	–
ALFORM 380 M	0.10	0.05 [2]	1.20	0.020 [2]	0.010	0.020	0.05	0.05	0.05	–	–
ALFORM 420 M	0.10	0.05 [2]	1.40	0.020 [2]	0.010	0.020	0.05	0.05	0.05	–	–
ALFORM 460 M	0.10	0.05 [2]	1.50	0.020 [2]	0.008	0.020	0.07	0.07	0.07	–	–
ALFORM 500 M	0.10	0.05 [2]	1.60	0.020 [2]	0.008	0.020	0.07	0.07	0.07	–	–
ALFORM 550 M	0.12	0.05 [2]	1.70	0.020 [2]	0.008	0.020	0.07	0.07	0.07	–	–
ALFORM 600 M	0.12	0.30	1.80	0.020	0.008	0.020	0.07	0.07	0.15	0.3	0.005
ALFORM 650 M	0.12	0.30	1.80	0.020	0.008	0.020	0.07	0.07	0.15	0.3	0.005
ALFORM 700 M	0.12	0.30	2.00	0.020	0.008	0.020	0.07	0.07	0.15	0.3	0.005
ALFORM 900 M	0.18	0.50	2.10	0.020	0.008	0.020	0.07	0.07	0.24	0.8	0.005

[1] The total of Nb, V and Ti may not exceed 0.22 % (not applicable to ALFORM® 900 M).

[2] If these steel grades are to be galvanized, the following restrictions apply:
Maximum of Si 0.03 % and a maximum of P 0.18 %.



Schematic design of the hot-rolling line

2.2 Production Process

The figure shows the schematic layout of the hot strip mill of voestalpine Stahl GmbH. The hot rolling process basically starts with the heating of the slabs to approx. 1,200°C. After high pressure descaling, the slab is rolled in the roughing stand in the reversing mode until the transfer bar has a thickness of approx. 40 mm. Subsequently, following another descaling treatment, the strip is rolled to its final thickness in the seven-stand finishing train. The strip is cooled in the cooling line according to exactly defined cooling patterns, and coiled on a coiler.

1 Heating:
2 Pusher-type furnaces
1 Walking-beam furnace (2007)

2 Skidmark compensation

3 Descaling box

4 Roughing stand with edging stand

5 Cropping shear

6 Descaling box

7 Finishing line

8 Messgeräte

9 Measuring devices

10 Cooling line

11 Downcoilers

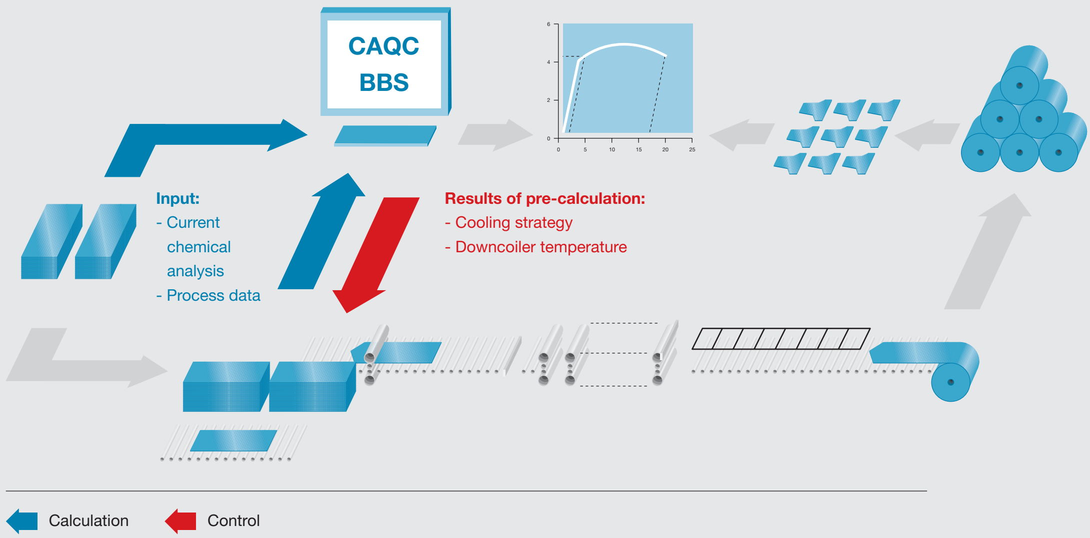
Hot-strip rolling mill of voestalpine Stahl GmbH

Technical Specification

General Data:

Capacity:		4,200,000 t/y
with walking beam furnace (2007)		4,800,000 t/y
Dimensions:	Thickness:	1.5 mm to 15 mm
	Width:	900 mm to 1,635 mm
Coil weight:		max. 32 t
		(19.6 kg/mm strip width)

The outstanding property profile of ALFORM® and LASER-ALFORM® is a result of the accurate matching of the production parameters of the hot strip mill with the chemical composition. Specific alloying with so-called micro alloying elements, i.e., niobium, titanium and vanadium, causes extremely fine precipitations to be formed during hot rolling, which inhibit the recrystallization of the microstructure. This process is referred to as thermomechanical rolling and is the first prerequisite for the adjustment of the fine grained microstructure typical of ALFORM®. The second essential process step, i.e., temperature control in the cooling line, determines the types of the microstructural phases. Controlled forming and temperature control during rolling and cooling within extremely narrow tolerances ranges are a prerequisite for achieving excellent and uniform product properties.



CAQC process to ensure highest quality

2.3 Product Quality

Quality control is implemented by a computer aided quality control system (CAQC) installed in the hot strip mill. This system predicts the mechanical properties to be expected as a function of the analysis and the hot rolling parameters. To compensate for any variations in analysis the coiling temperature can be adjusted accordingly during rolling. In this way uniform mechanical properties are achieved for the hot-rolled steel strip. Fig. 3 shows the schematic control diagram of the CAQC system.

Apart from the mechanical properties, which are primarily determined by the chemical composition and temperature control, the main quality characteristics are dimension, flatness and surface finish. Particular attention is therefore given to adhering to the rolling temperatures, thickness tolerances, flatness and surface quality. The process temperatures are determined at the roughing stand, downstream of the first stand and the last stand of the finishing train by means of pyrometers and temperature scanners, and another ten pyrometers along the cooling line. The thickness is determined using X-ray measuring instruments, and the strip width is determined using a profile sensor. The strip flatness is monitored by means of a laser system. The quality of the strip surface is monitored in the hot strip mill and in the pickling line using a surface inspection system for the automatic detection and classification of the most common defects by pattern recognition.

NOTE

You will find detailed information on ALFORM® in the form of heavy plate as well as differences to ALFORM® as a hot-rolled strip on the homepage of voestalpine Grobblech GmbH. http://www.voestalpine.com/grobblech/en.

2.4 Differences to other hot-rolled products

ALFORM® AS HEAVY PLATE

The information provided in this User Manual is primarily related to hot-rolled steel strip and hot-rolled cut plates made of ALFORM® steel.

As described in the preceding chapter, these products are manufactured in the hot strip mill in thicknesses up to 12 mm and widths up to 1,625 mm. ALFORM® in larger thicknesses and widths is supplied by voestalpine Grobblech GmbH. These products are available in the form of heavy plates in thicknesses up to 25 mm, widths up to 3,000 mm and lengths up to 12,000 mm. The minimum yield strength limits range from 355 N/mm^2 to 960M Pa. The product advantages described in Chapter 2 of this User Manual basically also apply to heavy plate ALFORM® grades.

DIFFERENCES TO THE OTHER HOT-ROLLED STEEL GRADES OF voestalpine STAHL GMBH

voestalpine Stahl GmbH offers other hot-rolled steels in addition to the ALFORM® steel series. These are discussed in more detail in the following.

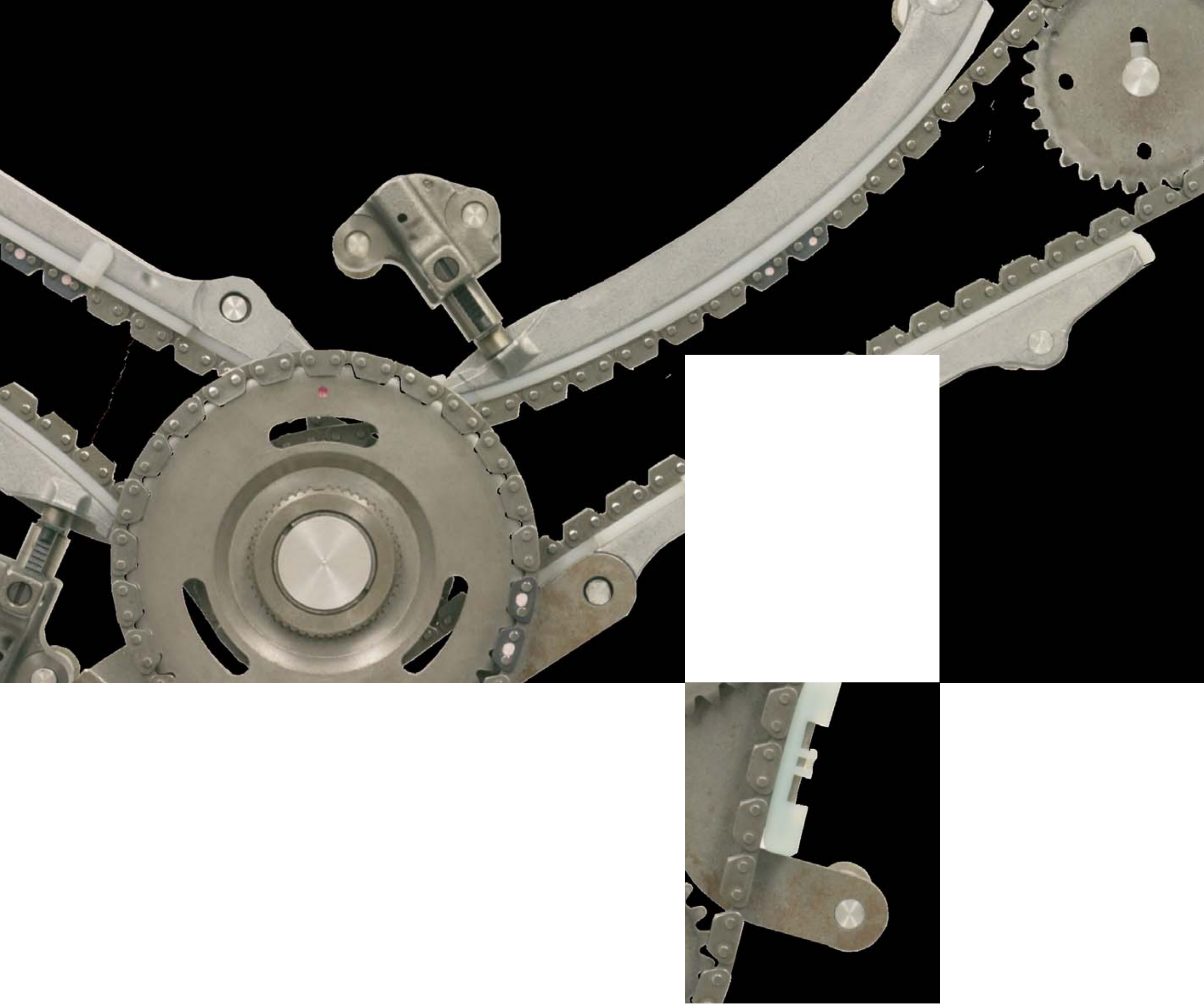
1) Low carbon steels for cold forming

These steels are supplied in accordance with EN 10111 and are used for manufacturing components that require a great deal of forming work, such as compressor casings, coupling parts or sections and tubes with extremely narrow edging radii. For this field of application, the steel grades DD11 (drawing quality), DD12 (deep drawing quality) and the extra deep drawing qualities DD13 and DD14 are available.

Upon request, we supply steels for cold rolling analogous to the retracted norm DIN 1614-86, Part 1. This includes steel grades St22 (drawing grade), RRSt 23 (deep-drawing grade) and St24 (special deep-drawing grade).

2) Unalloyed structural steels

These steels are included in EN 10025 and are mainly used in general mechanical engineering. The steels are used for slight drawing stress application as well as for shaping and edging. Typical grades are, for example, S235JR, S275JR and S355JR.



3) Case hardening and heat treatable steels

Case hardening steels as defined by the EN 10084 standard are steels with a comparatively low carbon content that are used for components whose cases are usually carburized or carbonitrided and subsequently subjected to hardening treatment in a medium. The chemical composition is guaranteed for such steels. Typical grades are, for example, C10, C15 or HC16. These steels are used for parts subject to high wear and high impact loads, such as gears or snow chains, and are delivered in hot-rolled condition or in hot-rolled and soft annealed condition.

Heat-treatable steels are steels for mechanical engineering which as a result of their chemical composition are suitable for hardening and in heat-treated condition show good toughness characteristics for a given tensile strength. These steels are generally used in soft hot-rolled or hot-rolled and soft-annealed condition for manufacturing parts which are subsequently heat treated, i.e., hardened and tempered, in order to obtain the desired properties for use. The series of unalloyed heat treatable steels includes standard steel grades in accordance with EN 10083 and a number of special steel grades, in particular boron alloyed heat treatable steels.

4) Steels for the production of gas cylinders

P245NB, P265NB, P310NB and P355NB are steel grades optimized for the production of gas cylinders. These steels are particularly characterized by a good deep drawing behavior, high ageing resistance and high cold cracking resistance when being worked.

5) Dual phase steel DP600

The special properties of this steel result from its two phase microstructure of soft ferrite and hard martensite. This microstructure yields a low yield strength and good work hardening during forming. The DP600 grade is thus characterized by high tensile strength values and extremely high values of elongation after fracture. The yield strength of this steel grade can be significantly increased by paint baking (e.g., at 170°C/20 min); this is referred to as the bake hardening effect. The DP600 grade has an excellent cold formability (especially with respect to stretch forming stresses), good weldability and high fatigue strength. Wheel discs in wheel rim production are a typical application of this grade.

You will find further information on the above-mentioned hot-rolled products, as well as other products by voestalpine Stahl GmbH, on our home page:
http://www.voestalpine.com/stahl/en

DIFFERENCES BETWEEN THERMOMECHANICALLY ROLLED AND HEAT-TREATED (QT) HOT-ROLLED PRODUCTS

The highest strength ALFORM® steel grades are produced by thermomechanical (TM) rolling and subsequent accelerated cooling in the cooling line. After hot-rolling, the material is tempered in order to achieve the specified material properties. Hardened and tempered material of similar strength (S890Q in accordance with EN 10025-6) by contrast is subjected to multi stage heat treatment comprising hardening (= austenitizing + quenching) und tempering (QT) in order to obtain the specified properties.

2.5 Research & Development Outlook

As shown below by the development of the load moment and the boom length of mobile cranes, the application of high and highest strength ALFORM® steels facilitates development and improvement for the benefit of the customer. In order to be able to continue to provide a competitive edge for our customers by using highest strength steels, we are focusing our research and development activities on the development of new highest strength steels. In the specific case of ALFORM® steels, we are making every effort to increase the highest strength limit beyond the ALFORM 900 M grade.

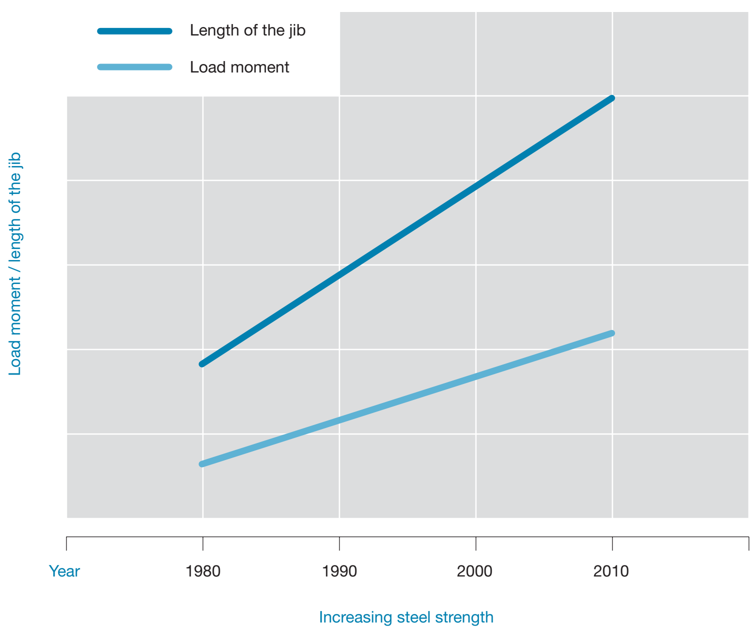


Figure 4: Development of the load moment and the boom length of mobile cranes

Another focal point in research and development is to optimize the existing steel grades. The continuous development of production know-how (e.g., computer-aided quality control system and new cooling line models) will guarantee the high degree of constancy and extremely narrow tolerances of our products.

NOTE

Matching the material with the intended purpose of high and highest strength steels is a key factor for success. We therefore provide our customers with professional advice on how to apply our products in order to achieve the best possible results.

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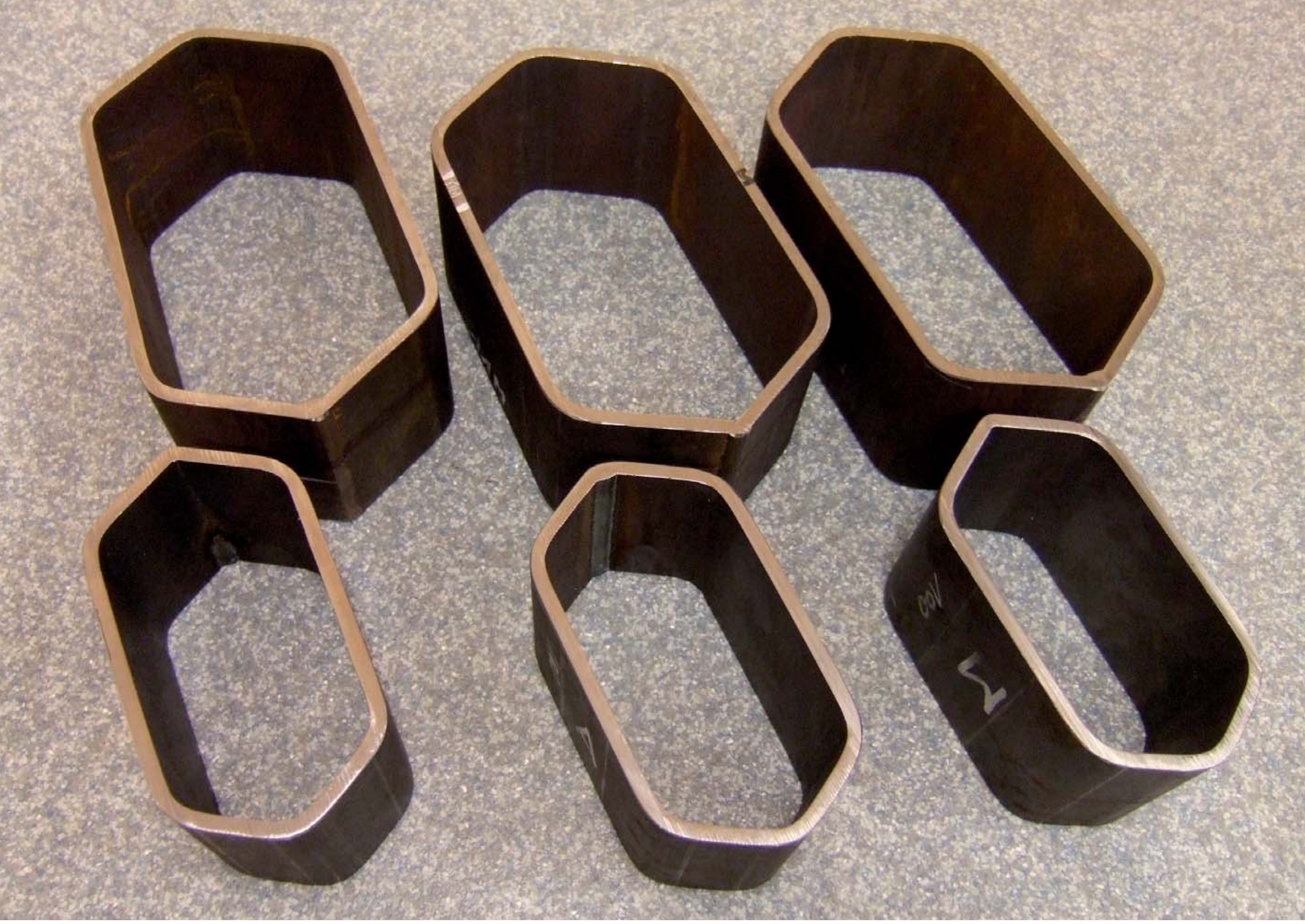
3. Application Engineering

The steel grades of the ALFORM® and LASER-ALFORM® series are very versatile in application. The properties of the materials in respect of processing and use are described in detail on the basis of specific applications and symbolic representations as shown below.

These examples from the wide range of applications of ALFORM® and LASER-ALFORM® steels are intended to give a survey of the variety of possible and optimum applications of these innovative steel grades.



3.1 Forming

Cold forming

The special steel grades of the ALFORM® series have been specially developed for applications where good cold formability is required. Low strength ALFORM® steels, in particular ALFORM 180 N and ALFORM 200 N, are primarily designed for conventional deep drawing applications.

Higher strength grades are designed for special applications where high yield and tensile strengths are required in addition to good cold formability. Particularly the thermomechanically rolled ALFORM 315 M to ALFORM 900 M grades have a high strength as well as excellent forming properties.

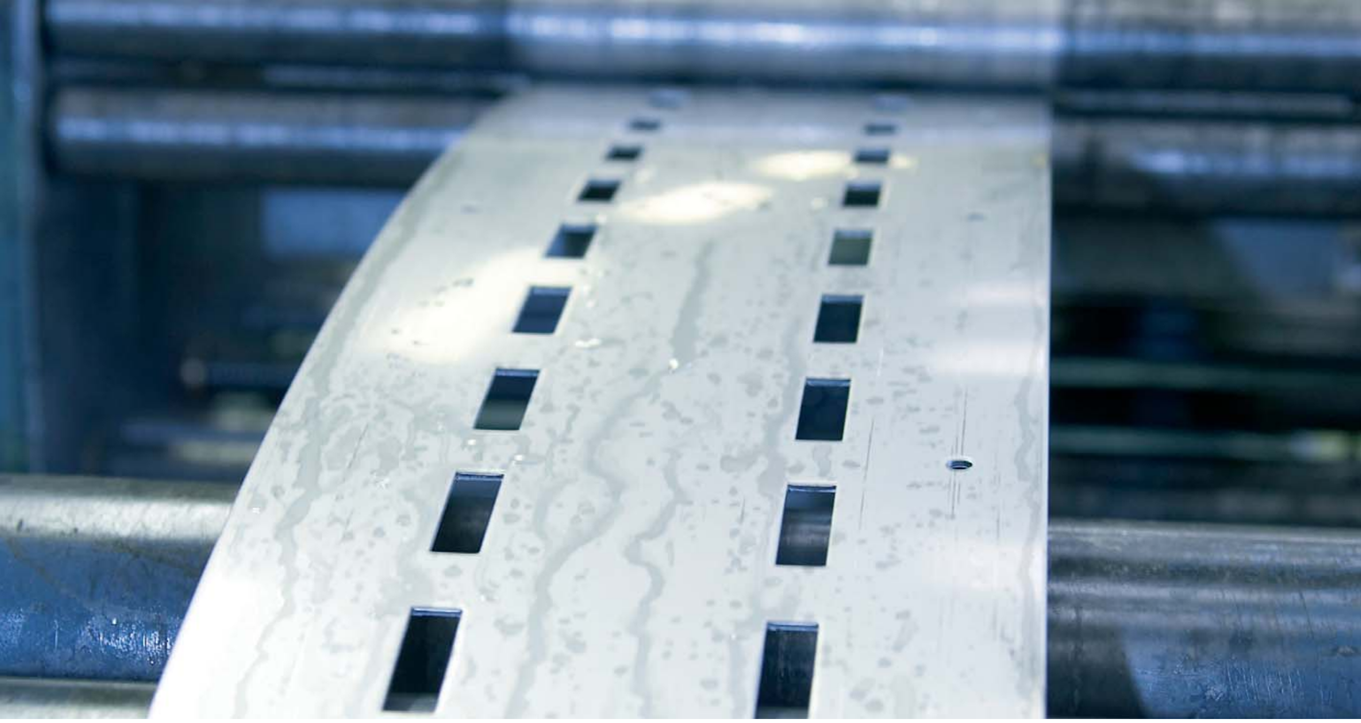
NOTE

As a general rule, the higher the yield strength of the steels, the poorer their cold forming properties. Hence the forming conditions must be adjusted to the respective yield strength level. The minimum bending radii specified in the relevant standards and guidelines are to be complied with.

Hot Forming

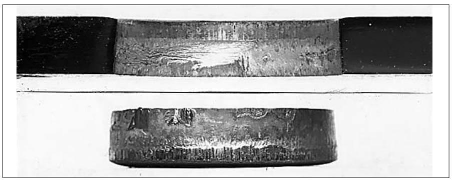
Steels supplied in normalized rolled condition (N series) are also suitable for hot forming.

Thermomechanically rolled steel grades are not designed for processing by hot forming. The mechanical properties of steel grades where the material condition cannot be achieved and restored solely by heat treatment are affected by hot forming in processing.

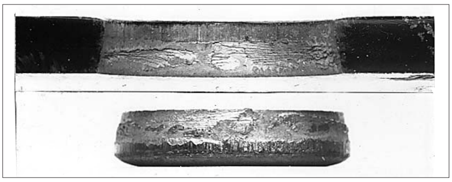


3.1.1 CUTTING AND PUNCHING

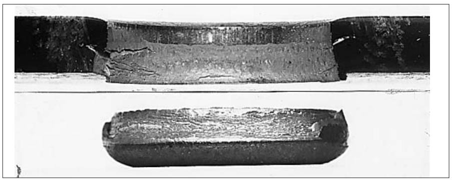
Blade clearance: 6 % of the strip thicknesses



Blade clearance: 15 % of the strip thicknesses



Blade clearance: 25 % of the strip thicknesses



Influence of the blade clearance on the form of the cut surface of ALFORM 700 M during punching, 3 mm thickness

Influence of the blade clearance on the form of the cut surface of ALFORM 700 M during punching, 3 mm thickness

The steels of the ALFORM® series are most suitable for cutting with shears and punching. An essential parameter in cutting with shears and punching is the selection of the blade clearance. The blade clearance influences both the quality of the cut surface and the required amount of force and work. Larger blade clearances require a smaller amount of cutting force and cutting work and therefore a lower tool wear as well. If the blade clearance is too large, the form of the cut surface is significantly worse, as shown in the photographs in Figure 5 of punched holes with the respective punching stamps. As the blade clearance increases, strong deviations from the shape occur and the stampings become dirty.

Furthermore, the required size of the blade clearance is determined by the material and the strip thickness. Mainly with the higher-strength steel grades a too large blade clearance may cause incipient cracks parallel to the surface due to unfavorable strain ratios in the blade clearance.

Blade Clearance Reference Values

The following reference values for the blade clearance are given to achieve proper interfaces for punchings and perforations in accordance with VDI 3368 (up to a thickness of 5 mm with break-through by cutting strip without clearance angle):

TIP

It is important that the width of the blade clearance is completely uniform at all points.

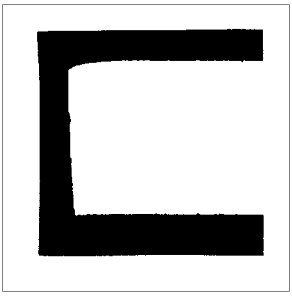
Recommended Blade Clearance

Shear strength (approx. 0.8 x tensile strength)	250 – 400 N/mm²	400 – 600 N/mm²	> 600 N/mm²
Ratio of blade clearance to strip thickness	0.04	0.05	0.06

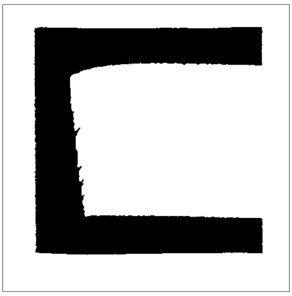
The form of the cut edge is determined by the strip thickness, the blade angle, the blade clearance and the material also during cutting on gate shears. When the blade clearing is too large, defects of form such as dented edges and burr height increase. In addition, the portion of the shearing zone in the total fracture surface is reduced.

The cut edge becomes more and more frayed. Figure 6 shows the influence of the blade clearance on the cut-section geometry for the steel grade ALFORM 700 M.

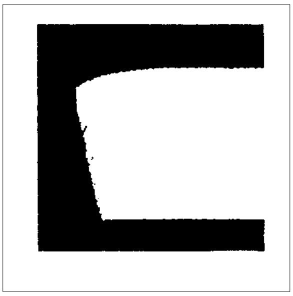
Influence of blade clearance with strip shears on the form of the cut surface of ALFORM 700 M, 3 mm thickness



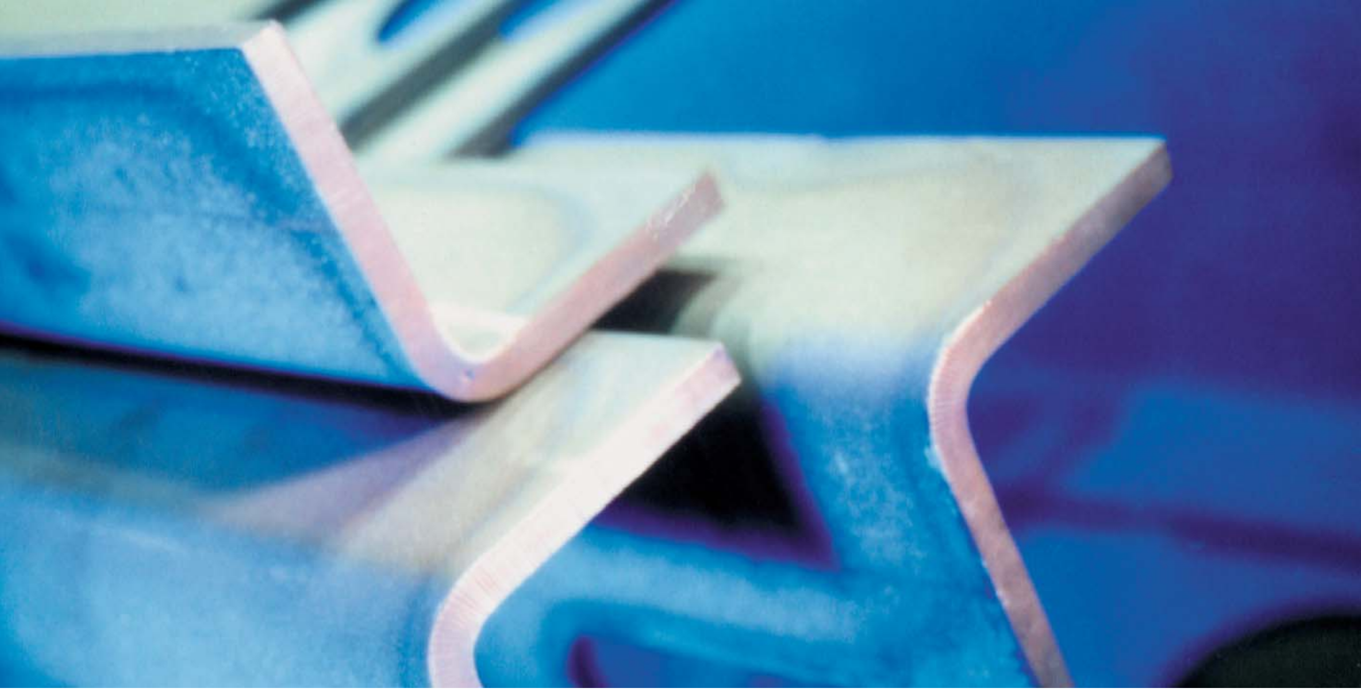
Blade clearance: 4 % of the strip thicknesses



Blade clearance: 10 % of the strip thicknesses



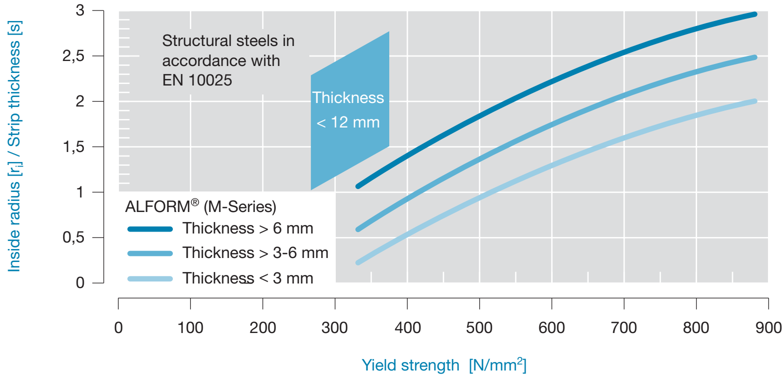
Blade clearance: 16 % of the strip thicknesses



3.1.2 EDGING AND BENDING

The micro alloyed ALFORM® series has a significantly better forming behavior than conventional structural steels. This is clearly demonstrated in Figure 1, where the minimum bending radii are shown as a function of the minimum yield strength for the respective steel grades. Although the minimum yield strength is twice as high as that of structural steels of strength classes S235 to S355 in accordance with EN 10025, the minimum inside edging radius is about the same for these steels. The values of the minimum permissible inside edging radius on the finished component as guaranteed for ALFORM® steels are much better than those of structural steels and even better than those of thermomechanically rolled steels in accordance with EN 10149.

Figure 1: Comparison of minimum yield strength and guaranteed minimum edging radii for ALFORM® TM steels and conventional structural steels.



The edging radii mentioned below are guaranteed without crack formation, provided edging has been performed properly, e.g. with appropriate form of the top and bottom tools as well as deburring of the cut edges/removal of flash from the cut edges.

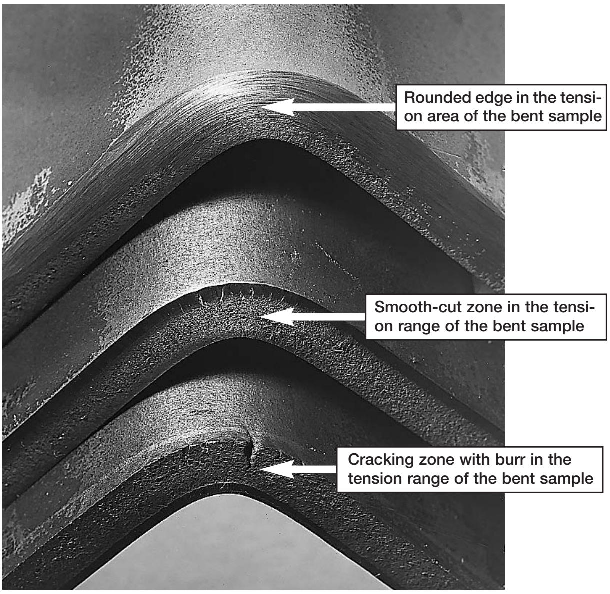
Guaranteed edging radii

Steel grade	s < 3 mm	s = 3 – 6 mm	s > 6 mm
ALFORM 180 N	0.25 s	0.5 s	1.0 s
ALFORM 200 N	0.25 s	0.5 s	1.0 s
ALFORM 240 N	0.25 s	0.5 s	1.0 s
ALFORM 280 N	0.25 s	0.5 s	1.0 s
ALFORM 380 N	0.25 s	0.5 s	1.0 s
ALFORM 280 M	0.25 s	0.5 s	0.8 s
ALFORM 315 M	0.25 s	0.5 s	0.8 s
ALFORM 355 M	0.25 s	0.5 s	0.8 s
ALFORM 380 M	0.25 s	0.5 s	0.8 s
ALFORM 420 M	0.5 s	1.0 s	1.0 s
ALFORM 460 M	0.5 s	1.0 s	1.4 s
ALFORM 500 M	1.0 s	1.2 s	1.8 s
ALFORM 550 M	1.0 s	1.2 s	1.8 s
ALFORM 600 M	1.0 s	1.5 s	1.8 s
ALFORM 650 M	1.0 s	1.5 s	2.0 s
ALFORM 700 M	1.0 s	1.5 s	2.0 s
ALFORM 900 M	2.0 s	2.5 s	3.0 s

90° edging

s = nominal thickness

minimum inner edging radius



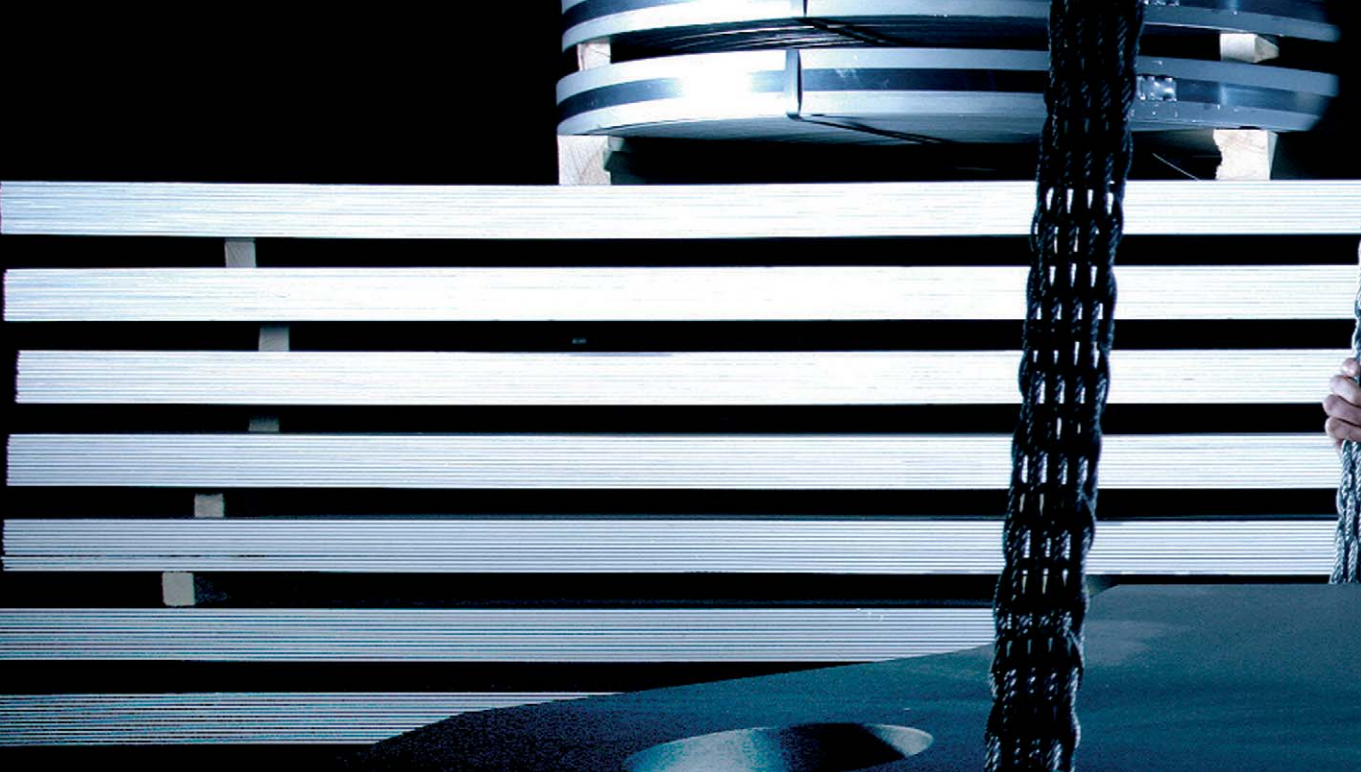
Influence of cut edge formation on the bending properties of a hot-rolled strip of steel grade S355JOC

Cutting Edge and Burr

The cut edges are a preferred starting point for incipient cracks. Mainly the burrs favor the formation of cracks. Therefore the edges should be broken or, even better, rounded at the top.

If machining of the cut edges is not possible, bending must be performed so that the burr is positioned in the pressure zone, i.e. the inner side of the edge (Fig. 2).

For the uppermost edging angle the edges were rounded at the top. For the middle edging angle, the smooth-cut zone is on the outer side of the edge, whereas for the lowest edging angle the cracking zone of the cut is positioned with the burr in the tension zone, thus favoring or leading to crack formation.



Adjusting Edge Radii

Increasing the die width usually results in the formation of larger inner radii during free bending. For this reason, the desired edge radius can easily be adjusted by means of the die width. This effect diminishes as the yield strength increases. Figure 3 shows the occurring inside edge radii as a function of the die width related to the strip thickness. Local necking occurs in grades with a high minimum yield strength (above 500 N/mm²) in certain geometrical relationships between the edging tools. This means that the inside edge radii can be adjusted smaller than the top tool radii. Local necking results from extreme local elongation below the vertex of the tool.

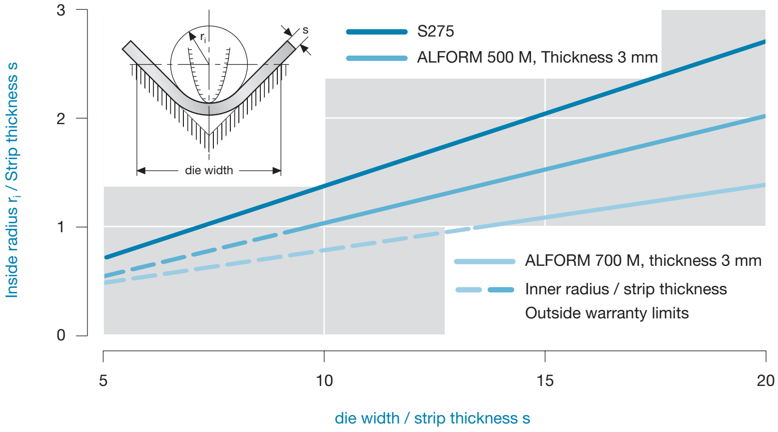


Figure 3: Influence of the steel grades on the forming bending radii during free bending in dependence on the die width

Figure 4 shows comparative elongation measurements on the outer surface on edging angles of S235 and of the high-strength grade ALFORM 700 M under identical forming conditions. It is clear that the elongation of ALFORM 700 M is localized within a narrow range. Bending punches with respectively larger tool radii must be used in order to achieve the guaranteed inside edge radii in high-strength steels. This distributes the deformation to a larger component area.

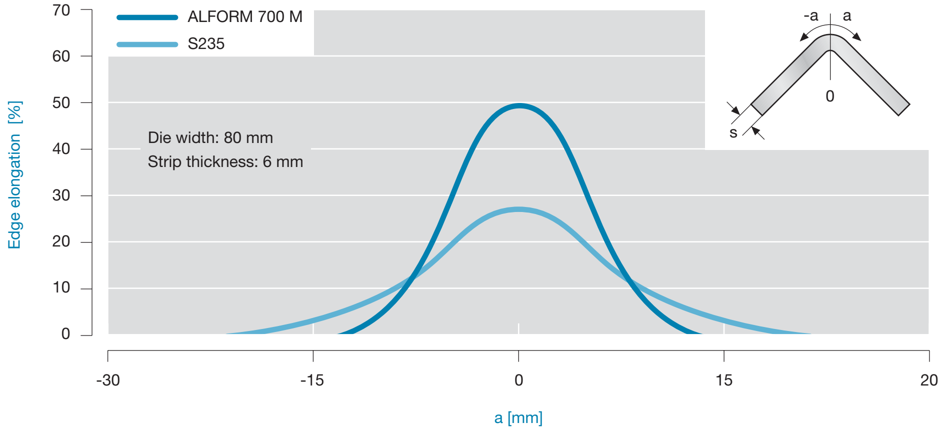
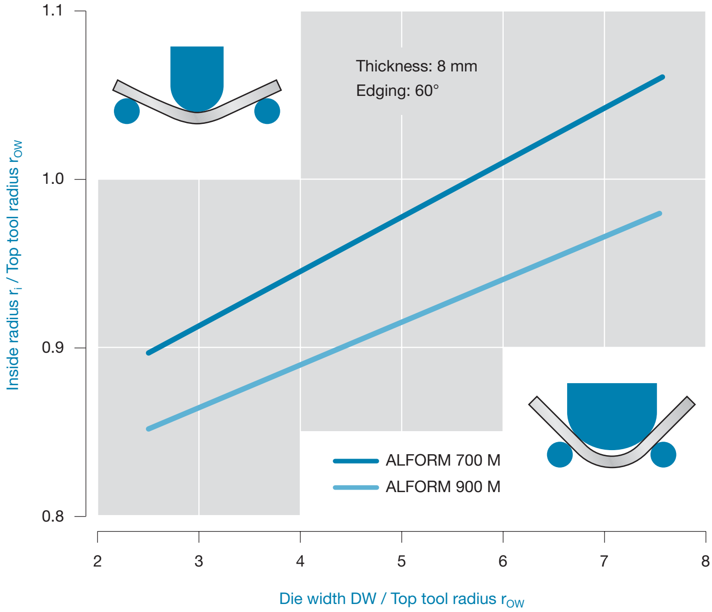


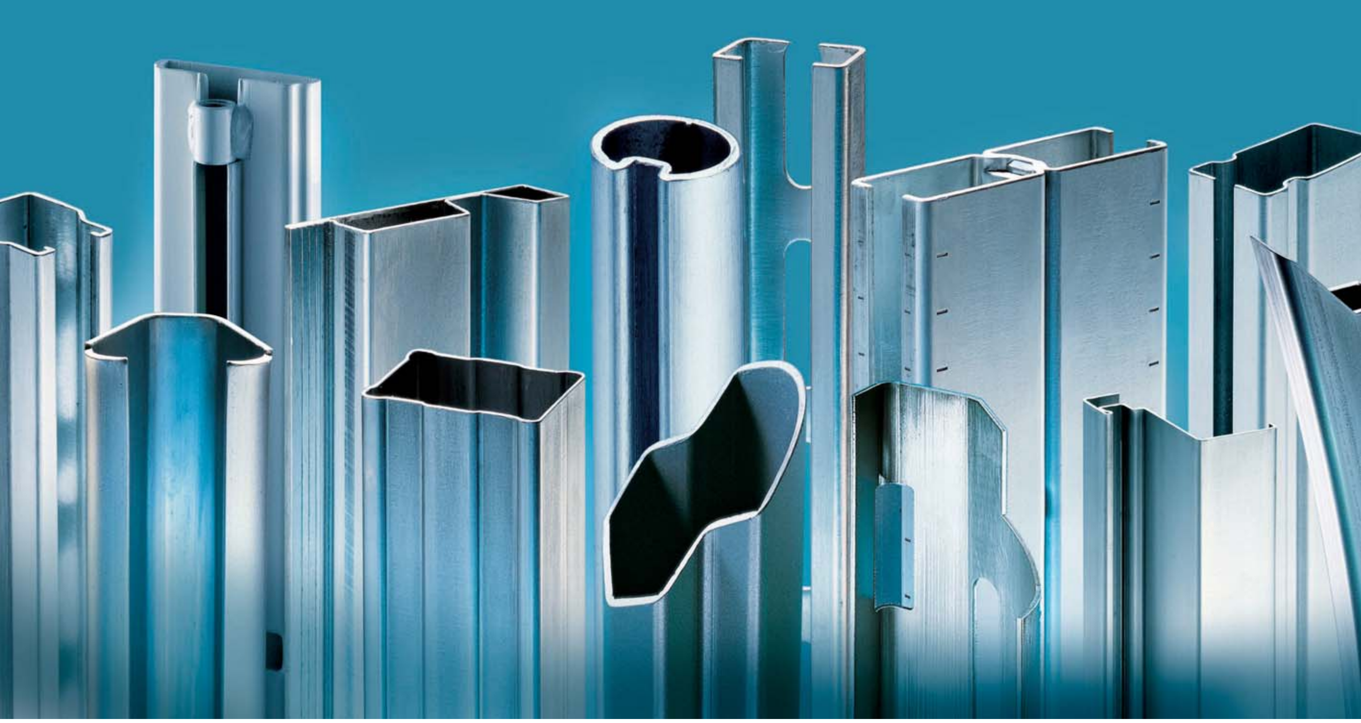
Figure 4: Edge fiber elongation in the region of the outer surface of samples edged in the V die by free bending

In the case of especially high requirements on edge geometry, the influence of die width must also be taken into consideration. The interaction between the die width and the top tool radius is shown in Figure 4a, which shows the relationship in free bending between the inside edge radius and the top tool radius in ALFORM 700 M and ALFORM 900 M with reference to the die width.

For narrow dies, this results in large top tool radii (i.e. die width/radius of top tool=2) and inside edge radii less than the top tool radii (i.e. 90 % of the top tool radius). In the reverse case, elastic recovery accounts for inside edge radii that are larger than the tool radii.

Interaction between die width and top tool radius





3.1.3 COLD FORMING

One of the most important technologies for the processing of steel strip is the manufacture of cold-formed sections and longitudinally welded tubes. The technology of cold forming optimally utilizes the cold-forming properties of the steel materials for the production of a variety of tube and section profiles. Cold forming leads to increased strength, particularly the yield strength of the material.

The relatively high number of forming steps during the profiling of high-strength ALFORM® steels allows bending radii that are smaller than those of one-step forming technologies such as bending or edging.

Because of the low carbon content, ALFORM® materials do not harden easily and so there is little cold cracking. This leads to optimum weld seam properties in closed sections even at high welding speeds and rapid cooling of the joint zone.

NOTE

ALFORM® steel grades are characterized by their excellent cold formability, which is apparent in the forming limit diagrams. Components with complex geometries can be manufactured in secure processes with ALFORM®.

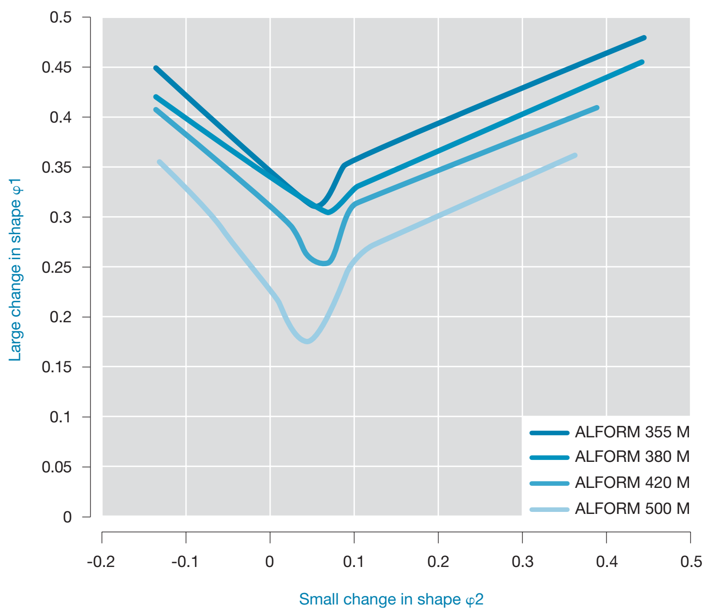
3.1.4 DEEP DRAWING

The forming limit diagrams are important aids to describe the formability of strip materials, particularly that of deep-drawn grades. The diagrams tell us which deformations can be withstood by the strip without the occurrence of any necking or cracking. Forming limit diagrams are used for evaluating the process security of forming technologies for specific components.

Samples in different formed conditions are investigated as they occur in the press shop. The elongations are evaluated to ascertain permissible forming procedures for each respective material.

The area to be formed in a specific material is the area below the forming limit curves. Material failure occurs above the forming limit curves. A higher forming limit curve allows a higher degree of freedom in the shapes that can be produced with a given material. Lower forming limit curves reduce the freedom of design.

Forming limit diagrams for ALFORM® steel grades



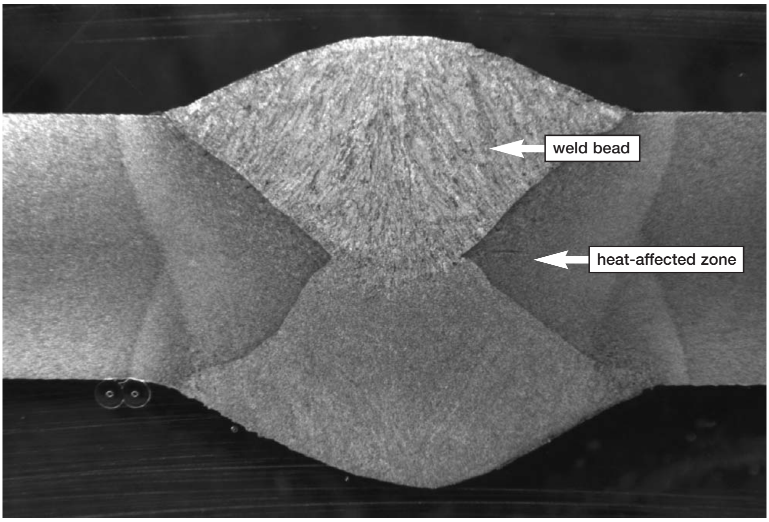
3.2 Welding

3.2.1 WELDING ALFORM® STEEL GRADES

The material composition (described by the carbon equivalent) and the time/temperature curve during welding are of decisive importance for the mechanical properties of welded joints. The time/temperature curve is determined by

- strip thickness
- weld shape
- arc energy
- preheating temperature
- weld build-up.

The cooling time $t_{8/5}$ is used to describe the temperature/time curve during welding. This is the time that is required for cooling from 800 to 500 °C in weld beads and in the austenitized heat-affected zone (HAZ) structure. This time is decisive for the formation of the weld metal and HAZ structure and its properties. The determination of $t_{8/5}$ is also described in detail in EN 1011-2 (May 2001 edition).



Macro image of a weld seam (weld bead, heat-affected zone)

NOTE

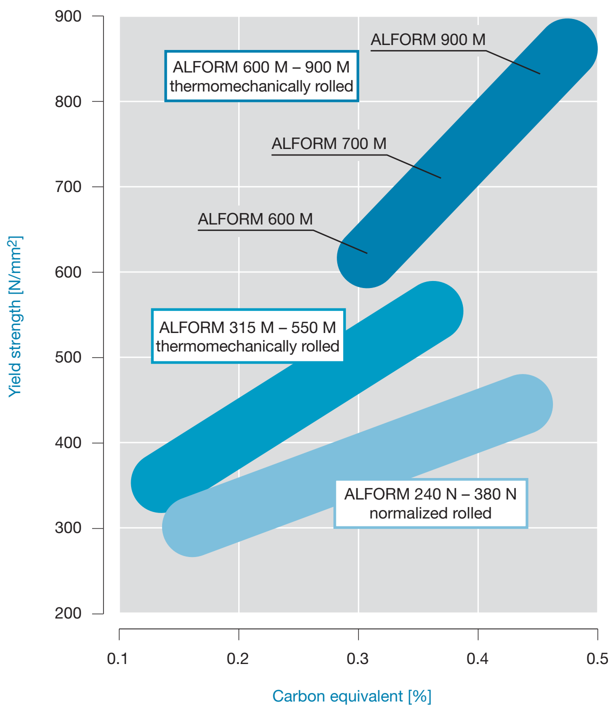
Generally, all welds in metallic materials are subject to the regulations of standard series EN 1011 (such as EN 1011-2 for electric-arc welding of ferritic steels).

C equivalent

The steel grades of the specialty steel series ALFORM® have been optimized not only with respect to their cold formability, but they have also been designed with a chemical composition that allows achieving carbon equivalents as low as possible and thus excellent weldability.

Special mention must be made of the excellent weldability of the steel grades ALFORM 280 M up to ALFORM 900 M, which achieve very low C equivalents because of the fine-grain mechanism to increase strength through thermomechanical rolling in combination with microalloying. ALFORM 180 N up to ALFORM 240 N as normalized rolled steel grades can be welded without any problem.

The diagram of the yield strength ranges of the individual steel groups in relation to the carbon equivalent shows that the TM rolled steel grades have a considerably lower carbon equivalent, relative to the same respective position of the yield strength as compared to the normalized rolled grades (Figure 1). Special mention must be made of the excellent weldability of the steel grades ALFORM 600 M up to ALFORM 900 M. In spite of values almost double the yield strength, the C equivalents of these steel grades is not significantly higher that those of the N series (i.e. 0.30 in ALFORM 355 N or 0.36 in ALFORM 700 M).

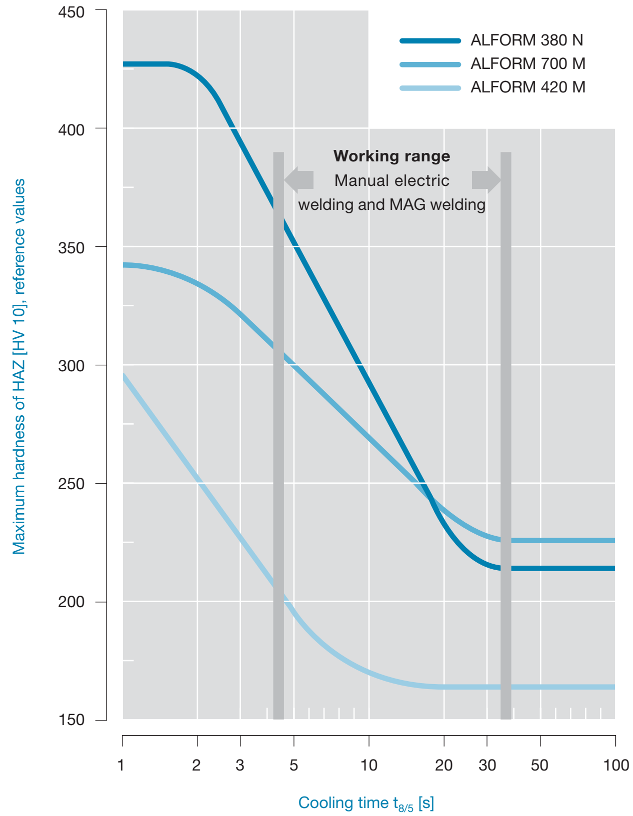


$$CEV = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15}$$

Yield strength and carbon equivalent for different manufacturing processes and steel grades

Hardening in the heat-affected zone

Hardening in the heat-affected zone (HAZ) of welded joints is very low because of the low carbon equivalent of TM steels. Even the high-strength steel grade ALFORM 700 M shows lower hardening than the normalized rolled steel grade ALFORM 380 N which has a significantly lower yield strength. Thus the risk of cold cracking in the heat-affected zone is reduced to a minimum level.



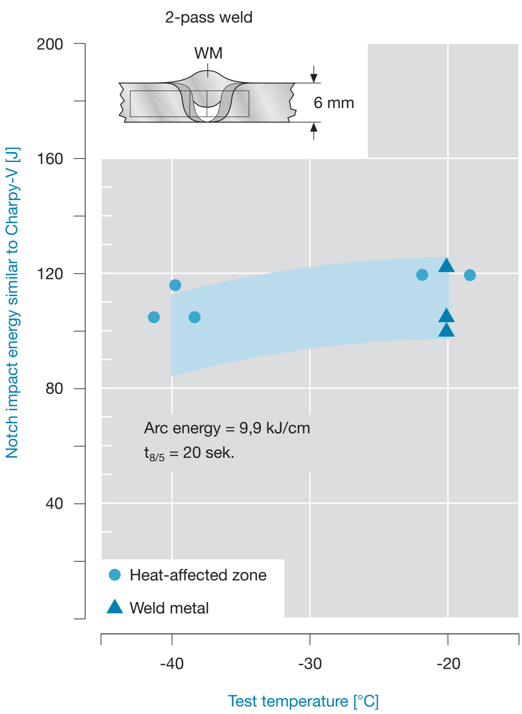
Influence of welding parameters on hardening (HAZ properties)

HAZ toughness

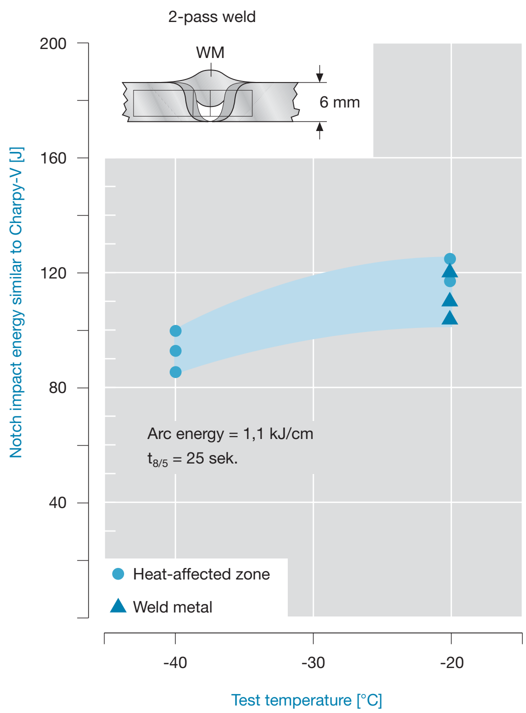
The HAZ toughness depends on the type and grain size of the microstructure in the overheated zone. Coarse grain sizes and larger fractions of embedded regions of martensite-retained austenite reduce the toughness considerably. As a result of the low pearlite fraction the amount of martensite regions in the HAZ structure is lower for the M series of the ALFORM® steels than for conventional steels. Any martensite regions that still exist are softer and tougher due to their lower carbon content. In combination with the grain-growth retarding effect of the precipitates from the microalloy, very high HAZ toughness values can therefore be achieved for TM steels.
The example of the notch impact energy/temperature curves for ALFORM 700 M (Figure 3) shows that adhering to the guaranteed standard values for toughness1) does not cause any problem even for a sample thickness of 5 mm²). This sample shape was chosen because in this case only small V-notch samples (similar to Charpy-V notch) could be examined due to the small strip thickness of 6 mm. However, the guaranteed value was also obtained using the reduced sample cross section.

1) 40 J at –20 °C in accordance with EN 10149 in the Charpy V full test

Wire/gas combination: Böhler X70 IG / Corgon 18
Condition: as-welded condition, Weld shape: V-type weld



Wire/gas combination: Böhler X70 IG / Corgon 18
Condition: as-welded condition, Weld shape: V-type weld

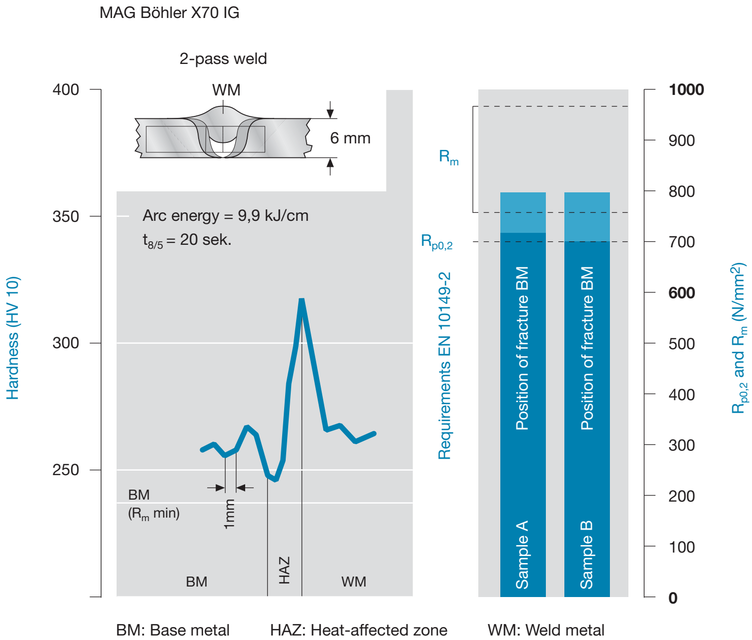


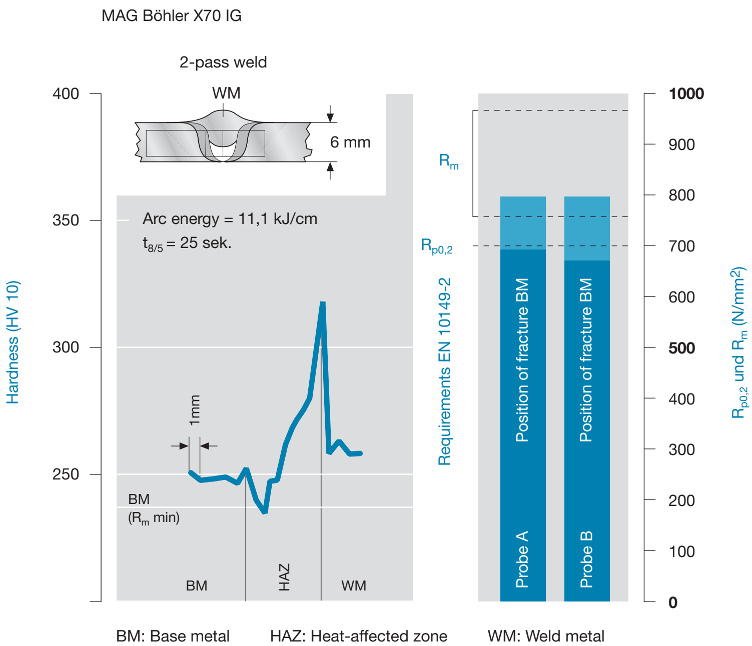
Toughness properties in the HAZ of ALFORM 700 M as shown in notch impact energy/temperature curves. The notch impact energy was determined on undersize samples and calculated to the scale of a full-size sample.

Strength properties of the welded joint

With respect to their strength transverse to the welded joint high-strength and/or ultra high-strength, heat-treatable and TM steels are characterized by the occurrence of a so-called "soft zone“ in the intercritically heated (partially austenitized) area of the heat-affected zone, which becomes broader with increasing heat input (equivalent to a longer cooling time $t_{8/5}$). As a consequence of their alloy design ALFORM® steel grades have high tempering resistance and thus a reduced susceptibility to this decrease in strength. For the steel grade ALFORM 700 M this is shown by the variations in hardness and the strength properties transverse to weld seams as illustrated in Figure 4. Practically no remarkable softening zone and thus no reduction of the strength below the guaranteed values for the base metal occur up to a very long cooling time $t_{8/5}$ of 20 seconds. In case of stringent requirements, longer cooling times and/or higher arc energies should not be chosen because this causes the losses in strength to continually increase as a result of the soft zone becoming too broad in relation to the strip thickness due to the thermal overload of the material. The time $t_{8/5}$ must be limited to 10 seconds for the steel grade ALFORM 900 M in the case of stringent requirements because of the increased utilization of the hardening effect to raise the strength.

These upper limitations of $t_{8/5}$ are also necessary with respect to satisfactory strength properties in the weld and requirement-specific toughness properties in welded joints (weld metal and HAZ) (see Arc Energies – Number of Weld Passes).





ALFORM 700 M, variation of hardness across the welded joint and strength properties transverse to weld seam

3.2.2 GENERALLY APPLICABLE WELDING INSTRUCTIONS

Weld Seam Preparation

Weld preparation can be in the form of machining or thermal cutting. During thermal cutting (oxy-gas cutting, oxy-laser cutting, plasma cutting) a heat-affected zone occurs adjacent to the cut surface which, however, is not broader than approximately 2 mm when cutting parameters are optimally adjusted to the strip thickness. Hardening is recognizable in a very narrow area of several tenth of one mm directly adjacent to the cut edge. The hardening depends on the carbon equivalent and roughly corresponds to the hardening in the heat-affected zone during welding. As a result of the low carbon equivalent (especially due to the reduced carbon content) hardening is clearly lower for TM rolled ALFORM® grades when compared to normalized steels or heat-treatable steels of the same yield point.

Welding Process

Both fusion welding with all proven fusion welding techniques (manual and machine-type) and flash butt welding, high-frequency welding and resistance welding can be employed for the ALFORM® and LASER-ALFORM® steel grades, provided the indicated welding instructions are observed.

Filler Materials and Welding Conditions

The selection of the filler materials should result in a weld that matches the mechanical-technological properties of the base metal (tensile strength, yield strength and notch impact toughness). Filler materials which cause unnecessarily high strength in the weld metal should be avoided.

Preheating Temperature

As a rule, preheating for welding is not required due to the upper limit (≤ 12 mm) of the as-delivered thickness. At outside temperatures of less than +5 °C or in the event of damp welding edges, the welding edges should be dried by preheating to a temperature of 80 – 100 °C to prevent cold cracking. For steel grades with a yield point of ≥ 500 N/mm^2 welding techniques (Hg method according to ISO 3690) are preferred which allow to achieve a low hydrogen content in the weld of DHM ≤ 5 ml/100 g of weld metal. This is guaranteed by inert gas-shielded welding with solid wire. Basic electrodes, flux-cored wires and/or welding powder for submerged arc welding must be subjected to secondary drying according to the manufacturer's instructions.

Arc Energy – Number of Layers

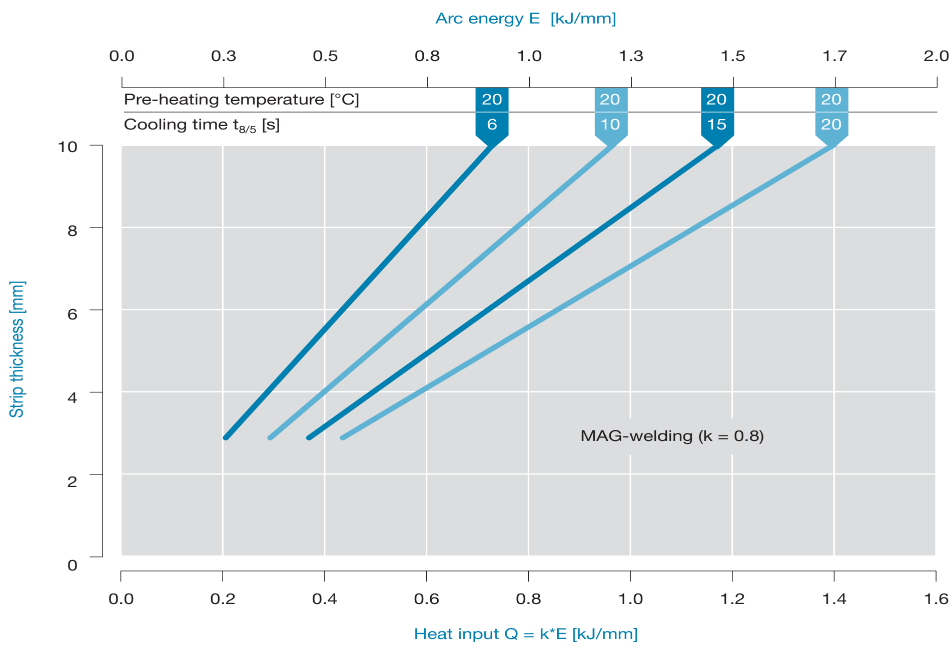
With respect to the toughness properties of the weld metal and/or heat-affected zone it is taken into consideration that decreasing the yield point results in an increase in toughness of the weld. In addition, higher strength values transverse to the weld are achieved. For higher requirements on the strength and toughness, the arc energy must be limited and the stringer bead technique must be employed.

For lower requirements on the welded joint (strength and toughness), the number of layers may be reduced in some cases. Welding conditions resulting in cooling times $t_{8/5}$ of 7 to 25 seconds have proved successful for the indicated steel grades. The time $t_{8/5}$ should be limited to 20 seconds to achieve the standard strength values for the TM rolled high-strength steel grades ALFORM 550 M to ALFORM 700 M. The following diagram (Figure 5 or EN 1011-2) can be used to determine the admissible arc energy at a given strip thickness for compliance with this prescribed standard.

TIP

The following approximation can be selected to achieve high strength and notch impact energy for standard structural steels (N, TM) and fine-grain structural steels (N, TM) up to yield strengths of $R_{p0,2} \leq 500$ N/mm²:

$$\text{Minimum number of layers} = \frac{\text{Strip thickness [mm]}}{3}$$



You will find a summary of the welding instructions for the most important steels of the ALFORM® series, including recommended filler materials, in the following table.

Hot-Rolled Strip

Material	Method	Filler Materials	Gas	Preheating [°C]	Interpass Temperature [°C]	$t_{8/5}$-Range [s]
ALFORM 380 M	MAG (GMAW)	ER 70S-6 wires (acc. to AWS A 5.18) such as Böhler EMK 6	M21	60 – 80 [1)]	≤ 180	3 – 25
	Manual electric welding (SMAW)	E 7018-G electrodes (acc. to AWS A 5.1) such as Böhler FOX EV 50	–			
ALFORM 460 M	MAG (GMAW)	ER 90S-G wires (acc. to AWS A 5.28) such as Böhler NiMo 1-IG	M21	60 – 80 [1)]	≤ 150	3 – 25
	Manual electric welding (SMAW)	E 7018-G electrodes (acc. to AWS A 5.5) such as Böhler FOX EV 55	–			
ALFORM 500 M	MAG (GMAW)	ER 90S-G wires (acc. to AWS A 5.28) such as Böhler NiMo 1-IG	M21	60 – 80 [1)]	≤ 150	3 – 20
	Manual electric welding (SMAW)	E 8018-G electrodes (acc. to AWS A 5.5) such as Böhler FOX EV 60	–			
ALFORM 550 M	MAG (GMAW)	ER 90S-G wires (acc. to AWS A 5.28) such as Böhler NiMo 1-IG	M21	60 – 80 [1)]	≤ 120	3 – 20
	Manual electric welding (SMAW)	E 8018-G electrodes (acc. AWS A 5.5) such as Böhler FOX EV 65	–			
ALFORM 700 M	MAG (GMAW)	ER 110 S-G wires (acc. AWS A 5.28) such as Böhler X70-IG	M21	60 – 80 [1)]	≤ 80	3 – 20
	Manual electric welding (SMAW)	E 11018-G electrodes (acc. AWS A 5.5) such as Böhler FOX EV 85	–			
ALFORM 900 M	MAG (GMAW)	ER 120 S-G wires (acc. AWS A 5.28) such as Böhler X90-IG	M21	60 – 80 [1)]	≤ 80	3 – 12
	Manual electric welding (SMAW)	E12018-G electrodes (acc. AWS A 5.5) such as Oerlikon Tenacito 100	–			

[1)] When the workpiece temperature lies below +5 °C, the welding edges should be dried by preheating them to a temperature of 60 – 80 °C.

3.3 Oxy-Laser Cutting

Modern and fully automatic manufacturing methods call for materials with the highest possible uniformity of properties.

Under the brand name LASER-ALFORM® voestalpine Stahl GmbH offers strip with a yield strength ranging between 200 and 380 N/mm^2 and that are especially suitable for laser and plasma cutting. The strip is characterized by an extremely uniform surface and homogeneous microstructure across the entire cross section of the strip. This is obtained by a thin and uniform scale layer resulting from thermomechanical or normalized rolling, special emphasis on a high degree of purity with respect to non-metallic inclusions during melting and a special alloy design. The strip production technologies are designed to minimize residual stresses and to avoid distortions during cutting.
Significant improvements of the quality of the cut and cutting speed can be achieved by optimizing processes and materials. Perfectly adapted cutting devices and parameters are a prerequisite to utilizing the advantages of the materials.

3.3.1 INFLUENCES ON THE QUALITY OF THE CUT DURING OXY-LASER CUTTING

NOTE

The mode of a laser beam is decisive for the quality of the flame cut.

MACHINE-RELATED INFLUENTIAL VARIABLES

Laser Radiation

Depending on the focal distance of the focusing optics, the radiation (with an average diameter of 15 – 20 mm) caused by the CO_2 laser is bundled to 200 – 300 µm to achieve the required power density which allows fusing of the metal to be cut.

The intensity of the beam shows a characteristic distribution over the cross section, called the mode. Rotational symmetry of this distribution is necessary to obtain satisfactory cutting results. The most frequent distribution used for industrial lasers is the so-called doughnut mode = TEM 01 (Figure 1). The mode can easily be quantified by using the so-called quality code K, where 1 designates the best possible mode. Figure 2 shows the quality codes currently employed for industrially used CO_2 laser cutting devices.

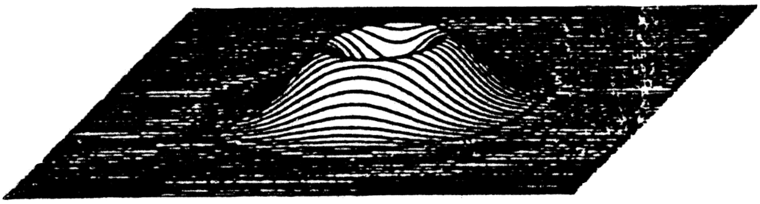
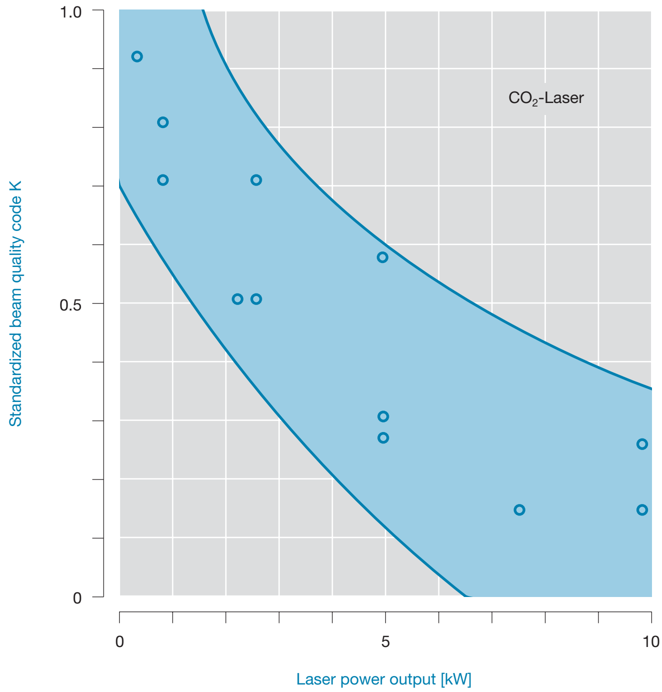


Figure 1: Intensity distribution of laser radiation (TEM 01)

Figure 2: Beam quality codes for currently employed industrial lasers of different power categories 0.5



Cutting gas O_2

Oxygen has two functions in oxy-laser cutting:

- The oxygen reacts with the iron to form iron oxide. During this reaction heat arises which contributes to the total fusion efficiency at least as much as it contributes to the laser radiation.
- The oxygen expels the iron-iron oxide mixture from the gap of the cut.

When using oxygen, care must be taken to ensure a minimum purity of 99.59 % (3.5 O_2). Reducing the purity by only a few tenths of a percentage point results in a decrease of the maximum cutting speed of 10 to 30 %. The reason is that contamination in the oxygen retards the oxidation reaction.

Cutting Gas Pressure

The oxygen pressure must also be reduced in case of decreasing cutting speeds and/or increased strip thickness. Irregularities in the oxidation reaction and thus an irregular cut will result if the oxygen pressure is too high. Figure 3 shows standard values for oxygen pressure at different strip thicknesses, based on experiments and practical results, for cutting S235 (St 37-2). An additional reason to reduce the pressure is the supersonic phenomena at pressures higher than 0.9 bar (greater strip thicknesses).

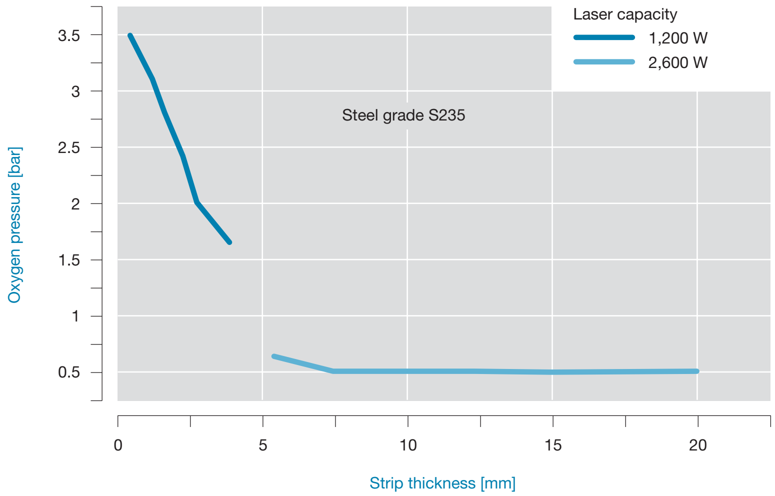


Figure 3: Dependence of cutting gas pressure on the strip thickness

Cutting speed

After optimizing the mentioned parameters, the cutting speeds that depend on the laser power, as represented in Figure 4, can be achieved for LASER ALFORM®. For this purpose, laser powers are respectively allocated to different strip thickness ranges. Cutting thin strip by using very high power would not make much sense because the major part of the laser energy passes the gap of the cut and quality code K decreases as the power increases.

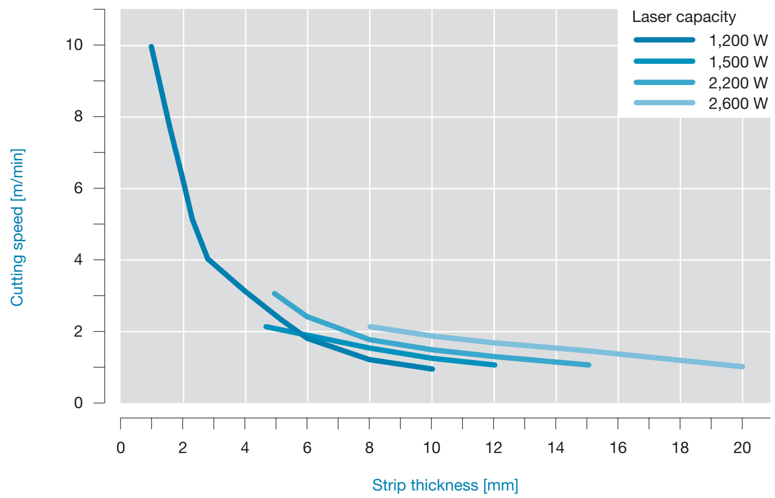


Figure 4: Achievable maximum cutting speeds after optimization of cutting parameters

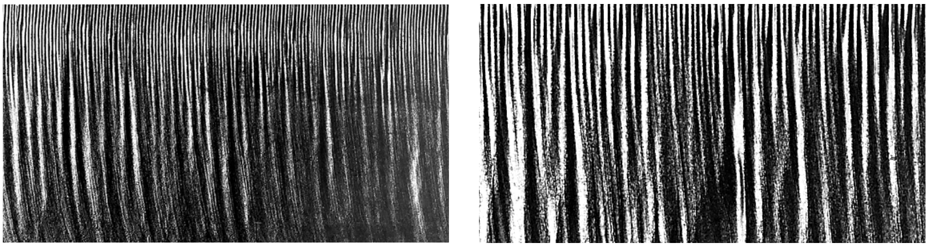
MATERIAL-RELATED INFLUENTIAL VARIABLES

Chemical Composition

A prerequisite for improved cutting behavior is an excellent degree of purity with respect to non-metallic inclusions and a low content of undesired accompanying elements.

Furthermore it has been proven that the silicon content influences the quality of the cut surface via the depth of roughness Rz and the drag for strip with a thickness of roughly 12 mm and higher. The cut surface is mainly characterized by the appearance of the drag lines running from top to bottom and their depths. As is recognizable from Figure 5, the higher silicon content results in clearly larger drags for sample B for cutting experiments on 20 mm strip of S235J2G4 under otherwise identical conditions. At the same time the drag periodicity measured by the number/length of the drags changes.

Figure 5: Quantitative correlation between number of drags/length and strip thickness.



Sample A (0.017 % Si)   Sample B (0.18 % Si)

[1] Cut evaluation criterion according to DIN 2310, Part 5

Coarser drag lines result in a greater depth of roughness[1] of the cut edge. This silicon-related change of the configuration of the cut causes additional problems on edges and narrow radii of profiles due to slag adhering to the bottom side of strip with a thickness above 12 mm.

3.3.2 STRIP SURFACE

Scale

A solid scale layer (tight scale surface) has no negative impact on the cutting result. Problems may occur with hematite-rich fissured scale surfaces because the capacitative distance control reacts sensitively.

Organic Coatings

Combustion gases arise from paper, bonding agents or paint that contaminate the cutting oxygen and lead to interruptions of the cut. With increased coating thickness, primers have an adverse influence on the quality of the laser cut and should be avoided.

Oil

A thin oil film has no negative effect.

3.4 Flame Straightening

The oxyacetylene torch is mainly used to as a straightening method to eliminate welding distortions in components caused by tensions or to remove poor fit-ups during assembly of steel components. Wedge-type straightening is used to remove or produce curvatures. This makes flame straightening one of the most important processing technologies for structural steels.

Depending on the type of straightening work that must be performed, either line-type straightening (where the material is only heated near the surface down to a depth of roughly one third of the strip thickness) or wedge-type straightening (where the material is heated thoroughly to remove or produce curvatures) is applied. Straightening by line-type heating serves primarily to remove bulges and ripples or level the distortion of the fillet weld angle in components, and wedge-type straightening is used to remove or produce curvatures.

In the time/temperature curve, cooling times $t_{8/5}$ for wedge-type straightening, due to the thorough heating (Figure 1), are roughly four times longer than for straightening by line-type heating (with subsequent cooling). Strength is lost in the material if the straightening temperature is too high. For this reason, and also because of its effect throughout the entire strip thickness, requirements for application of wedge-type straightening are stricter. In contrast to straightening by line heating, a reduction of the admissible maximum straightening temperatures is required.

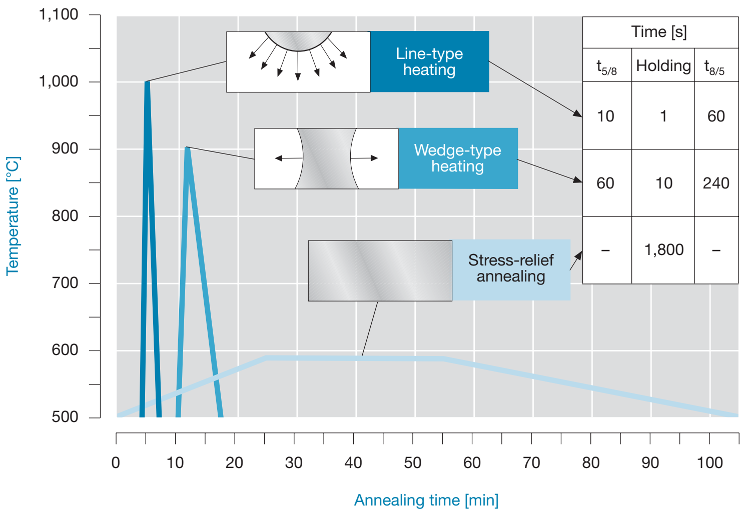
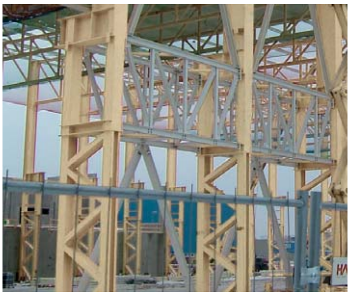


Figure 1: Temperature-time cycles during straightening by line-type/wedge-type heating and/or during stress-relief annealing



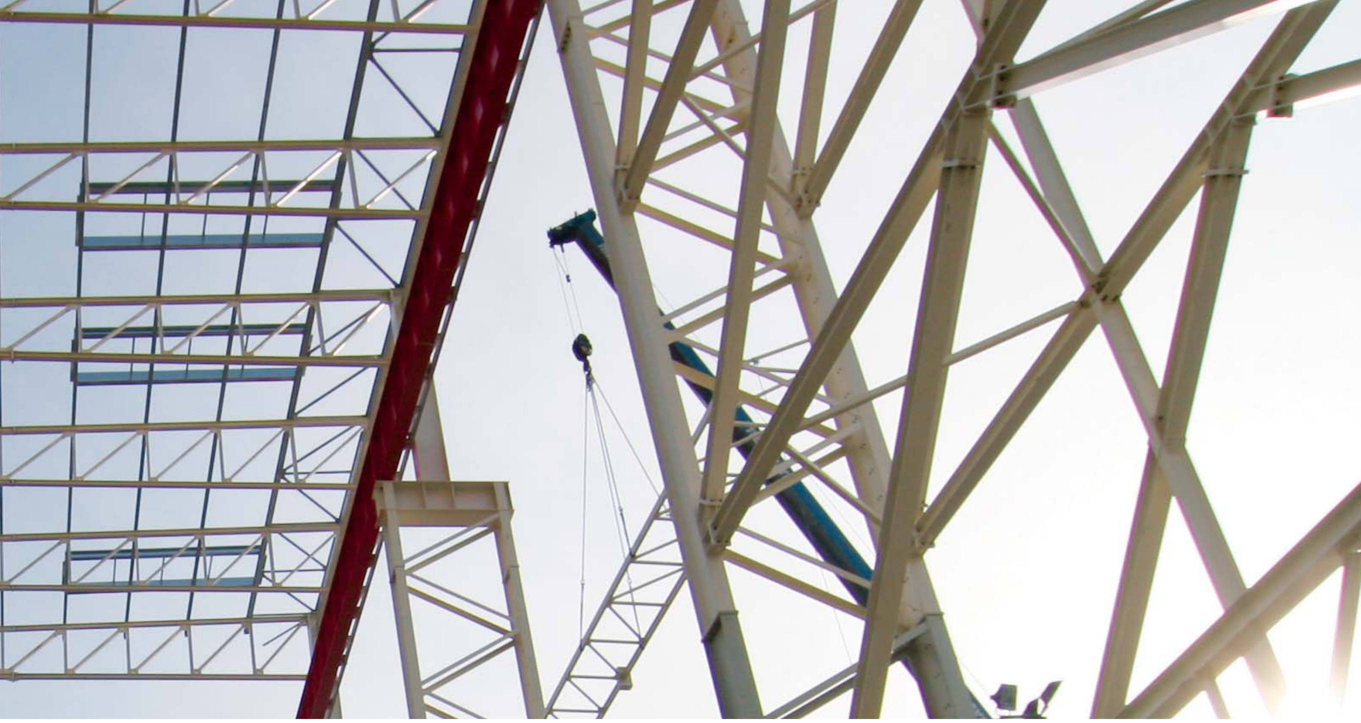
3.4.1 SELECTION OF TORCH AND GAS MIXTURE

It is common practice to use large torches (torch size = 2 – 2.5 x strip thickness) and acetylene as fuel gas and setting the flame at excess oxygen ($O_2:C_2H_2 = 1.4$). This selection of the process parameters causes an especially rapid heating of the spot to be straightened and minimizes the heat input.

3.4.2 MAXIMUM ADMISSIBLE STRAIGHTENING TEMPERATURES

Comprehensive in-house analyses conducted on steels from the voestalpine Stahl GmbH product range have shown that normalized steels and TM rolled steels of identical yield point demonstrate almost the same behavior in the analyzed straightening temperature range with respect to strength loss at increasing straightening temperature.

Figure 2 shows the maximum admissible straightening temperatures for standard steel S355J2G3 in accordance with EN 10025 and some steel grades of the ALFORM® specialty steel series as a function of the yield point for line-type and wedge-type heating. With strip of a thickness below 5 mm it should be noted that, even when line-type heating is used, the material is always thoroughly heated and therefore achieve time-temperature-time cycles corresponding to those of thicker strip. Temperature checks performed by operators during straightening work confirm that these higher temperatures are applied in common practice.



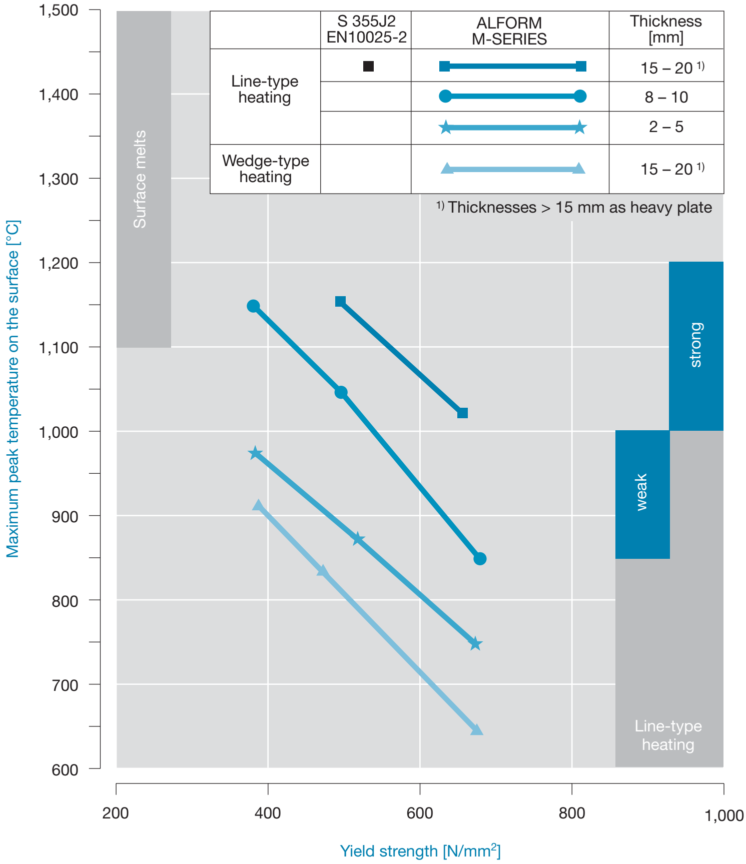


Figure 2: Upper limit for peak temperatures during flame straightening as a function of yield point and strip thickness for line-type and wedge-type heating.

3.4.3 MONITORING STRAIGHTENING TEMPERATURES

NOTE

In addition to the observance of annealing colors in accordance with Figure 3, direct temperature measurements immediately after removal of the flame can also be used to check peak temperatures.

In the case of line-type heating, the annealing colors in the color table have proven to be unsuitable for checking the straightening temperature since no red heat was observed for measured line heating temperatures up to 700 °C (light-red annealing color in accordance with the table). In the experiments, a small dark-red to dark-cherry-red spot with a diameter of roughly 5 mm and approximately 15 mm behind the peak of the flame was apparent at temperatures of 800 °C and higher. This spot was larger at temperatures of up to 900 °C (with a diameter of approximately 1 cm). At 1,000 °C the color spread to the peak of the flame. In our opinion, observation of the size of the red spot and its distance from the peak of the flame is a good method of estimating the peak temperature for line heating (Figure 3). Because of the rapid dissipation of heat into the base metal and the retarded response of the named measuring devices, the temperature measurements immediately after removal of the flame by means of a heat-sensitive crayon or electronic thermometer do not allow concrete analysis of the peak temperatures actually achieved.

Annealing colors

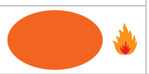
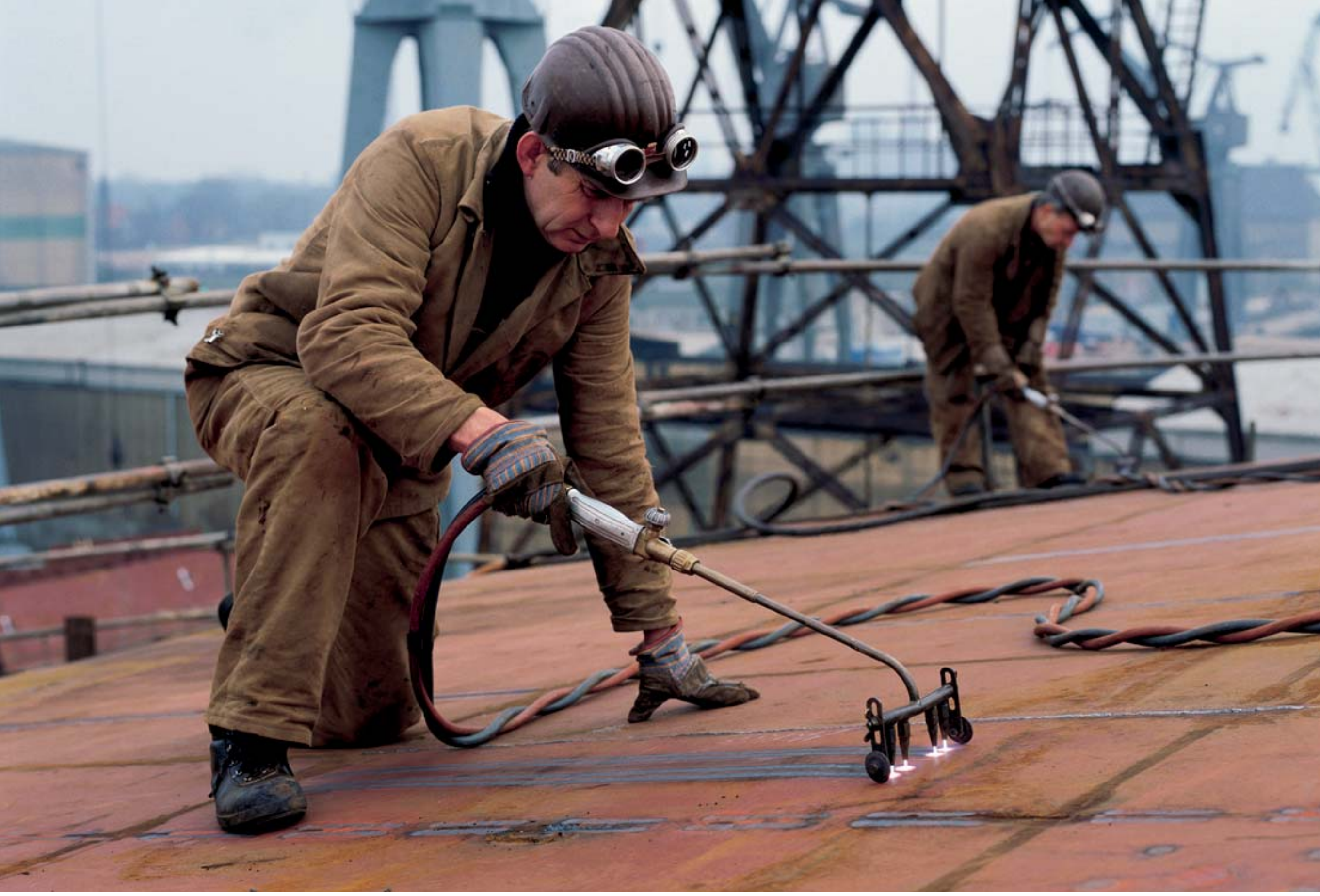
Peak temperature (°C) in 1 mm depth	Line-type heating on surface		Wedge-type heating
	bright finished	scaled	
600	grey	grey	–
700	grey	grey	grey?
	Feed → bright spot / flame wedge		
800		larger, brighter than on bright finished surface	red
900			yellow-red
1,000			
1,250	Surface melts		

Figure 3: Comparison of temperature in a depth of 1 mm (measured by means of welded-in thermocouples) with annealing color as observed during flame straightening



3.5 Fatigue Strength of ALFORM® Steels

3.5.1 BASE MATERIAL

Detailed analyses have been conducted with respect to the fatigue strength of hot-rolled strip. Woehler tests using different mean stresses have been performed on longitudinal samples with as-rolled skin.

The following stress relationships were analyzed:

- S = minimum/maximum stress = –1 (tension-compression),
- S = +0.1 (fatigue under pulsating tensile stresses) and for high strength
- S = +0.5 (fatigue under pulsating tensile stresses with high mean stress)

Examples of Woehler diagrams for ALFORM® grades are shown in the following figures. A statistical interpretation was also carried out and the result was presented in the form of three curves for a 10, 50 and 90 % probability of survival (Pü).

The figure demonstrates how the fatigue strength increases parallel to the yield point. This effect is particularly evident if Smith's diagrams are derived from the data (Figure 5). Especially with greater mean stresses the increase in fatigue strength is extremely high for grades in the higher strength range.

Figure 1: Fatigue strength of hot-rolled strip ALFORM 355 M, base metal, t = 5 mm, as-rolled under reversed tension-compression stresses and/or pulsating tensile stresses

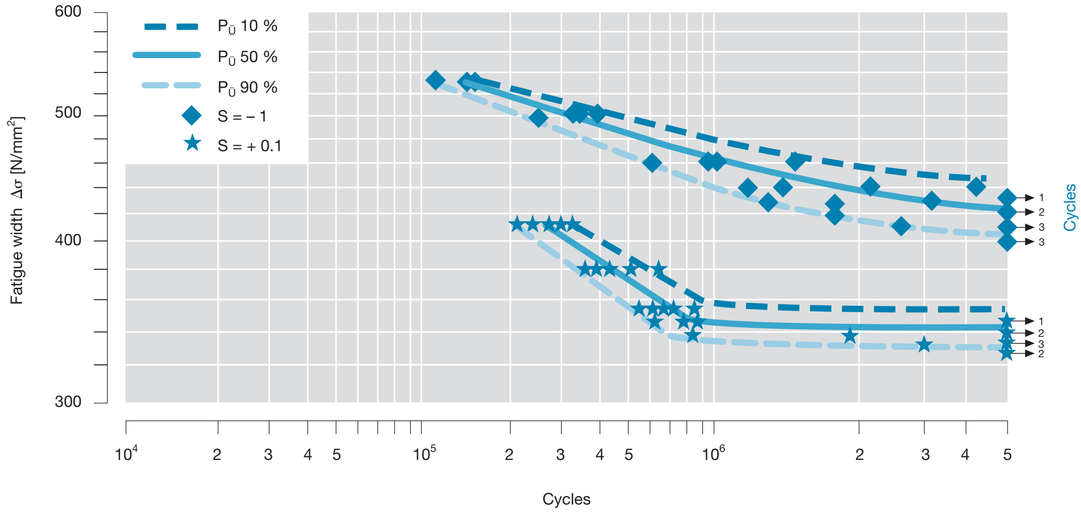


Figure 2: Fatigue strength of hot-rolled strip ALFORM 500 M, t = 6 mm, base metal, as-rolled under reversed tension-compression stresses and/or pulsating tensile stresses

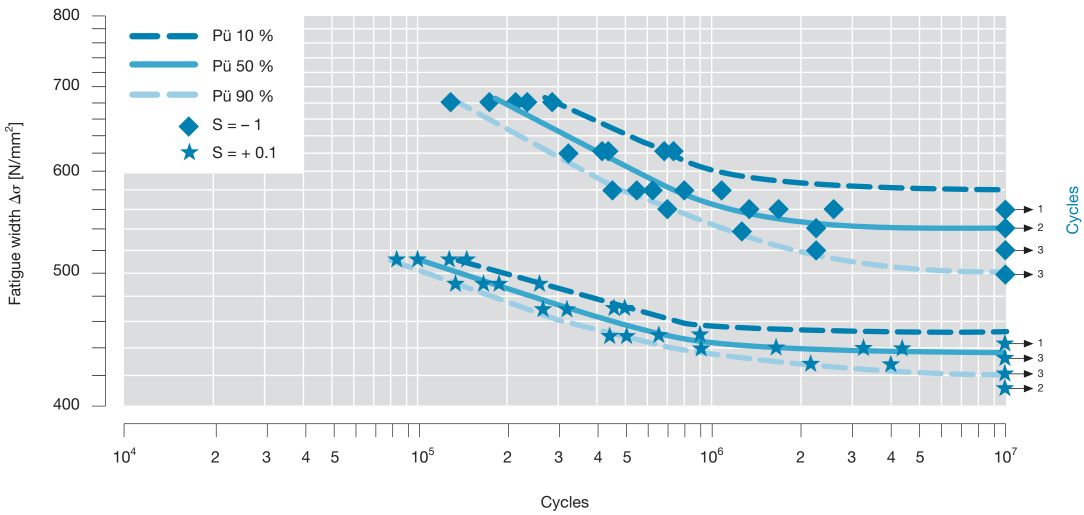


Figure 3: Fatigue strength of hot-rolled strip ALFORM 700 M, t = 0.28 in, base metal, as-rolled under reversed tension-compression stresses and/or pulsating tensile stresses

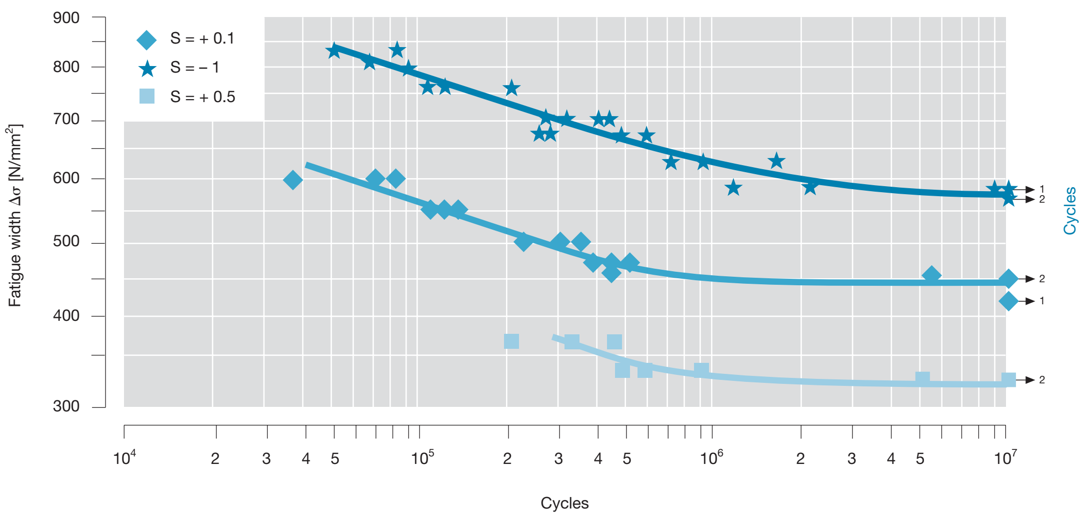


Figure 4: Fatigue strength of hot-rolled strip ALFORM 900 M, t = 0.20 in, base metal, as-rolled under reversed tension-compression stresses and/or pulsating tensile stresses

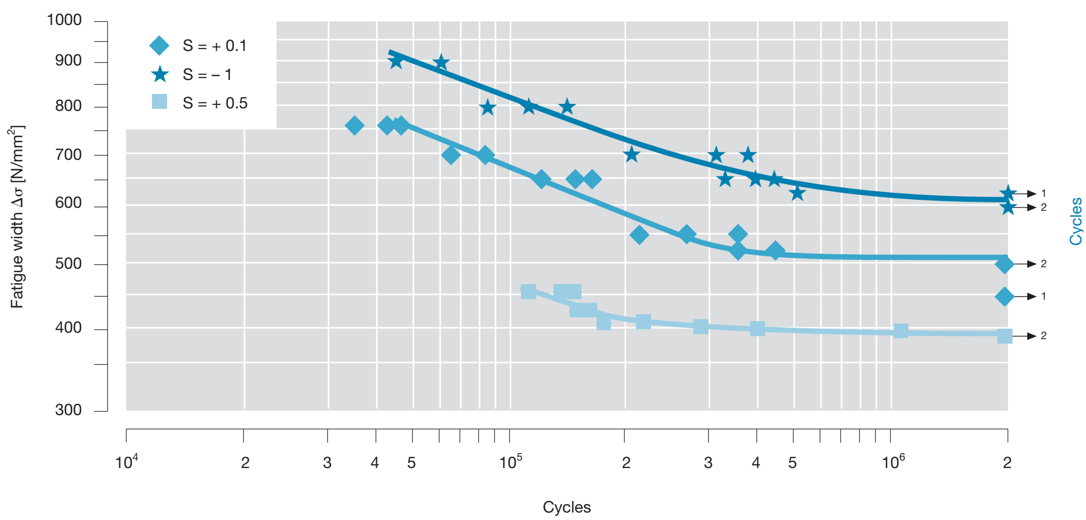
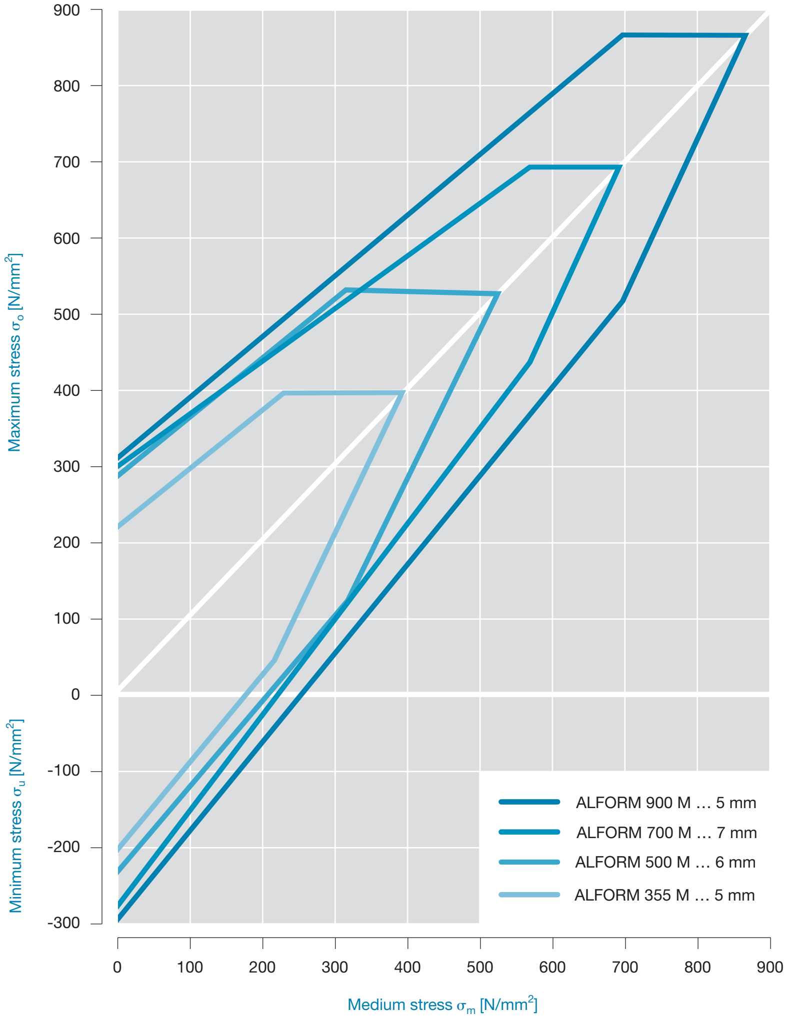


Figure 5:
Fatigue strength
according to
SMITH (2 x 10⁶ cycles),
base metal, as-rolled



3.5.2 WELDED JOINTS

Special attention must be paid to the notch effect of the welds when applying high-strength steels in welded structures under dynamic stress. Apart from constructive measures (positioning the welds in areas with lowest possible stress), a notch-free execution of the weld is of great importance (flat weld, avoidance of undercuts, possibly notch-free grinding etc.).

NOTE

The resistance of notch-containing structures to dynamic stresses does not increase to the same extent as the yield point does.

The following test results can be used to determine the fatigue strength of welded structures. Butt welds were analyzed in Alform 700 M strip at a thickness of 7 mm. Woehler tests were performed on untreated welds, using alternating tensile and compression strengths. The butt welds showed a satisfactory fatigue strength, which can be increased considerably even by sandblasting (Figure 6).

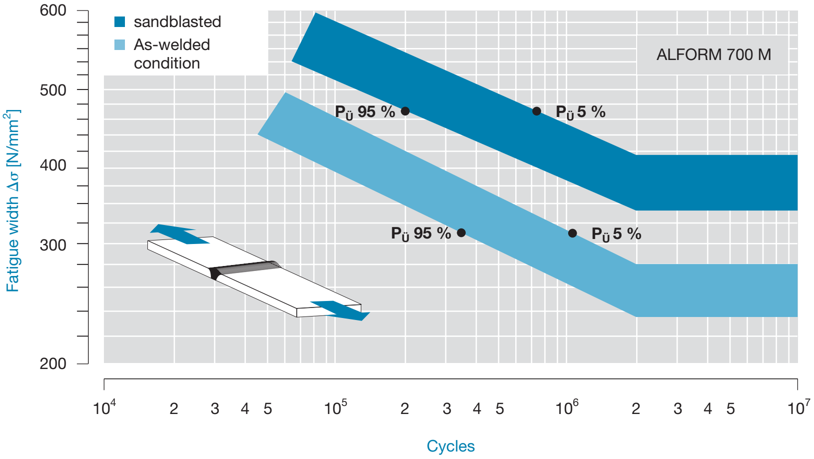


Figure 9: Fatigue strength of butt welds (under reversed tension-compression stresses, S = –1)

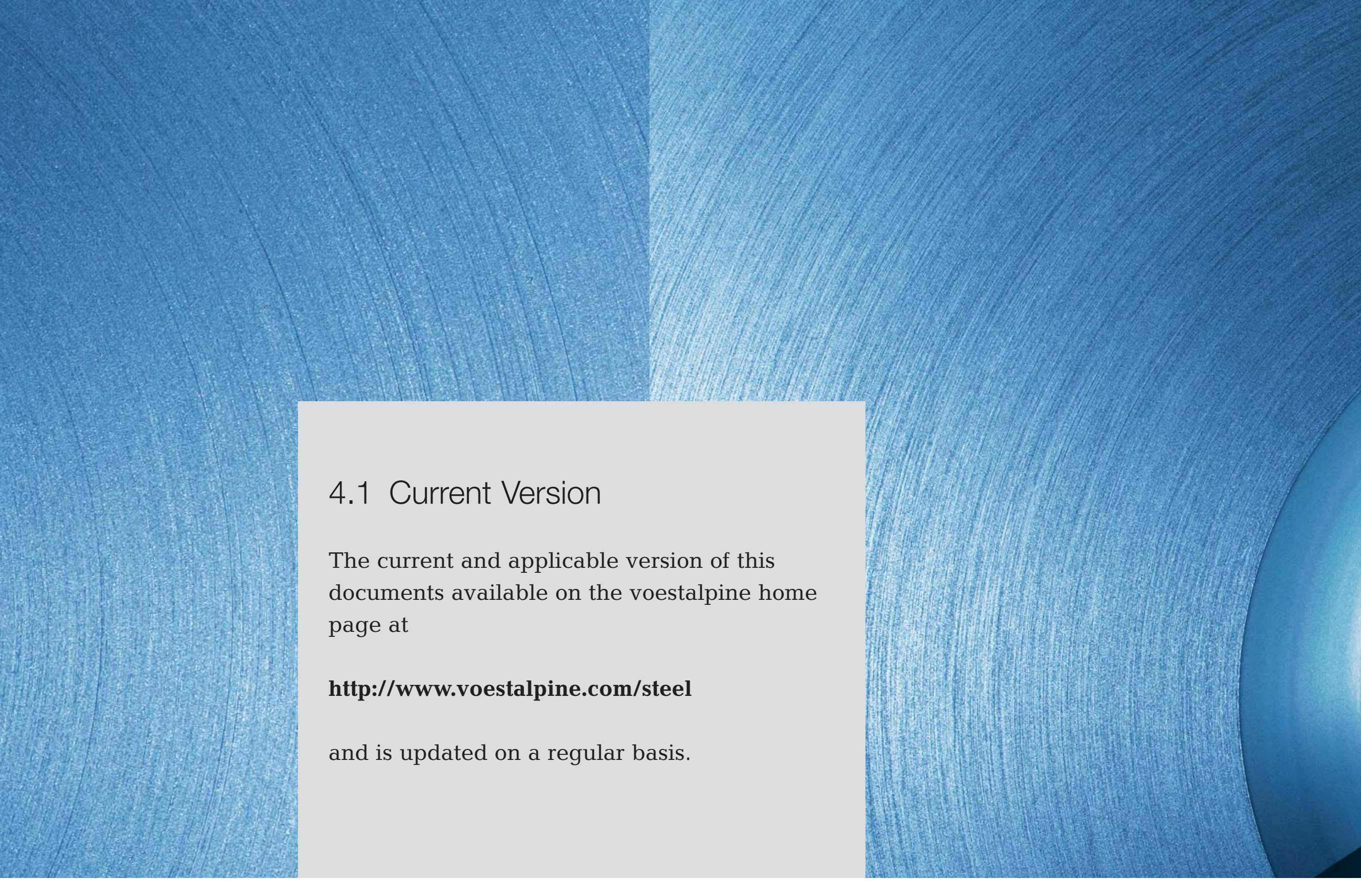
You will find further information as well as further examples of Woehler diagrams for ALFORM grades in the Technical Terms of Delivery for Hot-Rolled Strip, Chapter 10, Processing Instructions.

4. Appendix

This manual provides you with the most comprehensive information concerning ALFORM. It is not possible to cover the entire spectrum of possible applications in greater detail in this document. Please refer to other sources of information on the Internet or contact our specialists at voestalpine Stahl.

Overview

- Current Version
- Order Data
- Technical Terms of Delivery, Warranties and Standards
- References and Links
- Customer Service Representatives



4.1 Current Version

The current and applicable version of this documents available on the voestalpine home page at

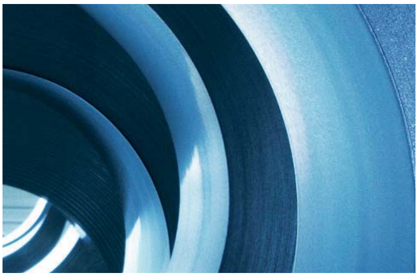
http://www.voestalpine.com/steel

and is updated on a regular basis.

4.2 Order Data

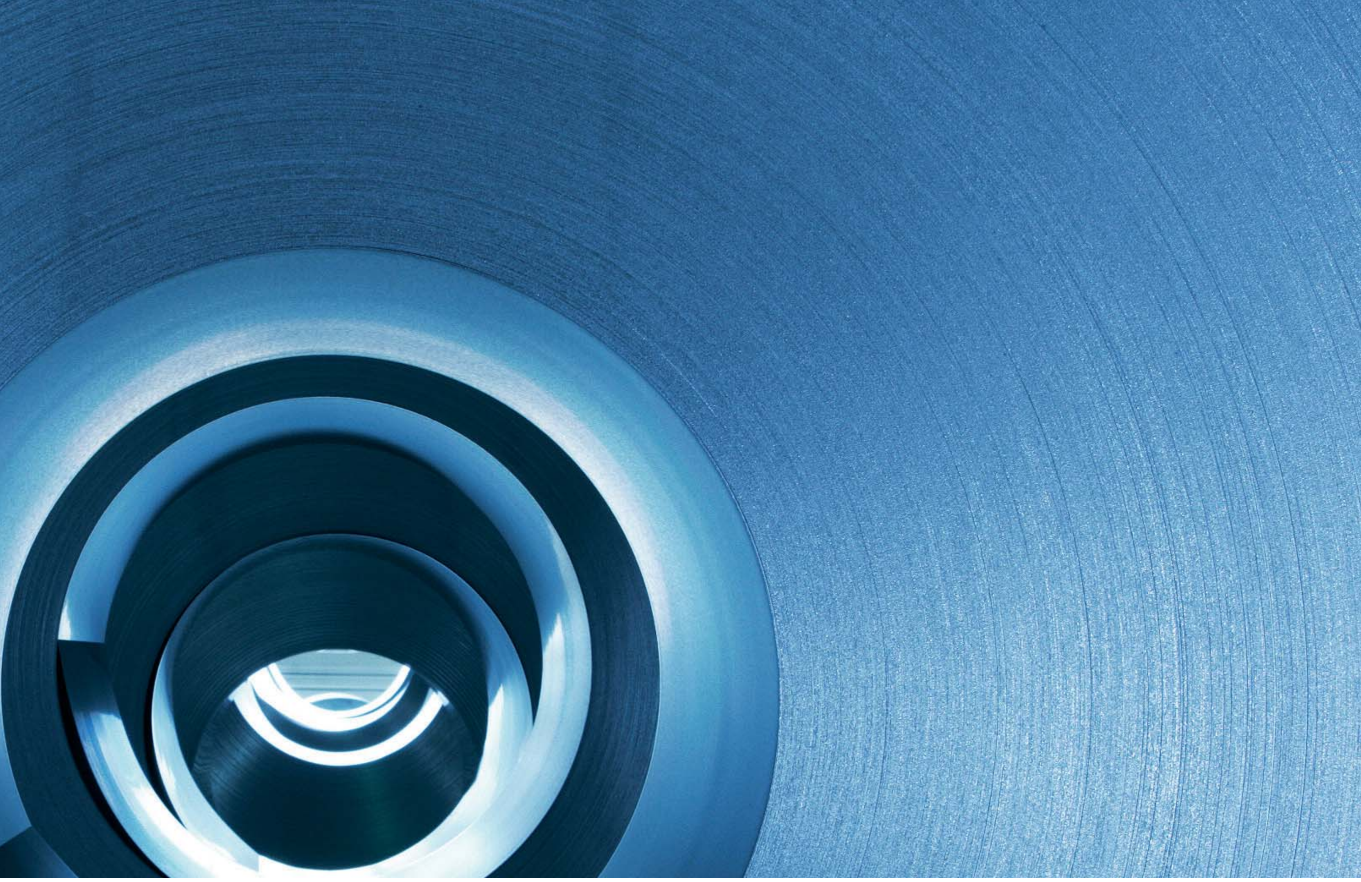
ALFORM® is delivered in compliance with the applicable Technical Terms of Delivery published by voestalpine Stahl GmbH as well as in accordance with applicable European standards. Limitations, particularly those that go beyond these Technical Terms of Delivery or the European standards, shall be indicated at the time the goods are ordered by the customer.

An order will not be considered to be complete until all of the necessary order details have been received.



NOTE

Complete customer orders can be processed without any delays.



Obligatory Order Data

- Desired delivery quantity and customer receiving date
- Designation of the steel grade in accordance with the Technical Terms of Delivery
  - Alternative steel grade designation in accordance with the European standard
- Dimensions (thickness, width and length)
- Order Data
  ... for coils:
  - Inside diameter
  - Min./max. outside diameter or Min./max. coil weight
  - Specific coil weight in kg/mm strip width

  ... for bundles
  - Min/max. bundle weight
- Type of surface
- Packing type
- Data for transportation

Specific Order Data

- Acceptance test and test certificates upon request
- Additionally limited tolerances with regard to flatness and thickness
- Narrowed tolerances with regard to dimensions
- Data on application
- Special requirements in mechanical features
- Special requirements with regard to packing upon special request
- Special requirements with respect to labeling or marking, including information on the desired location
- Special requirements on welding seams or weld seam designation when delivered in coils

4.3 References

TECHNICAL TERMS OF DELIVERY, WARRANTIES AND STANDARDS

ALFORM® und LASER-ALFORM® are delivered in compliance with the applicable Technical Terms of Delivery for Hot-Rolled Strip published by voestalpine Stahl GmbH. You will find these terms on our home page at www.voestalpine.com/steel.

Links on the Internet

Home page of voestalpine Stahl
http://www.voestalpine.com/steel

Product information from voestalpine Stahl
http://www.voestalpine.com/Stahl-Produktkonfigurator

SUBSIDIARIES WHO OFFER ALFORM® AND LASER ALFORM®

Processing of hot-rolled steel strip
voestalpine Anarbeitung
http://www.voestalpine.com/anarbeitung/en

Steel product warehousing
voestalpine Stahlhandel
http://www.voestalpine.com/stahlhandel/en

ALFORM® as heavy plate
http://www.voestalpine.com/grobblech/en

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