DOMEX®

Welding of Domex MC cold-forming steels

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Domex® is the brand name of hot-rolled sheet steel from SSAB Tunnplåt.

Domex MC high strength steels are low-alloy, cold-forming steels intended for the engineering and automotive industries.

Fusion welding of Domex high strength steels, has been employed for many years and does not differ significantly from fusion welding of mild steels. In order to reap the benefits of these high strength steels, the welding process must be controlled in a suitable manner.

This brochure describes welding of Domex MC cold-forming steels and includes recommendations on preparatory operations and the actual welding work. Furthermore some results of testing of fusion welded high strength, cold-forming steels are presented.

CONTENTS

Domex cold-forming steels whenever demands are strict

This technical brochure deals with the welding of Domex cold-forming steels in the form of hot rolled strip from SSAB Tunnplåt.

Manual metal arc welding and gas-shielded metal arc welding are the most common methods used for joining steel parts. Although welding is efficient, it also demands consistent properties of the steel being welded.

By using Domex cold-forming steels, SSAB Tunnplåt customers can manufacture their products more efficiently and with consistently high quality.

Optimized production

The combination of Domex cold-forming steel, appropriate welding methods and correct filler metal ensures optimized production. Low sulphur contents and low carbon equivalents make Domex steel insensitive to hot cracking and cold cracking. This also applies to the extra-high strength cold-forming steels, and preheating of the workpiece is basically never necessary.

Due to the low contents of alloying elements in Domex steels, all common welding methods and filler metals can be used.

Clear-cut benefits

The use of high strength steels usually offers clearcut benefits. As an example, by replacing a 12 mm thick standard steel with 8 mm thick Domex®, the volume of weld metal will be reduced, and the number of welding passes will also be fewer. The benefits are:

- Lower material costs
- Shorter welding time
- Simplified joint preparation

For further information on Domex cold-forming steels, please consult your SSAB Tunnplåt representative, who will also be able to provide more detailed information on the material.

Steels of lean compositions are easier to weld

Fusion welding

All common fusion welding methods can be used for welding Domex cold-forming steels, including various types of gas-shielded metal arc welding (MAG and TIG), manual metal arc welding (MMA), submerged arc welding (SAW), plasma welding and laser welding. Since the steels have very low contents of alloying elements and low amounts of inclusions (see Table 1 on the next page), there is little risk of defects such as hot cracks in the weld metal, cold cracks in the heat affected zone (HAZ) or lamellar tearing in the sheet adjacent to the weld caused by the low strength of the sheet in the thickness direction. These defect types can sometimes occur during fusion welding of steels with higher contents of alloying elements and inclusions. Cold-forming steels have such good weldability mainly because of their low contents of carbon, sulphur, phosphorus and inclusions.

In the case of a double T-joint which gives stresses in the thickness direction, it should be mentioned that when the weldment is very close to a sheared edge it is important that there are no sharp defects in the sheared surface. Otherwise cracks may propagate from these defects even if the steel has a very low amount of inclusions. An alternative to shearing is thermal cutting which gives a smoother edge surface.

Figure 1. In traditional steel grades, the slag inclusions are normally in an elongated form, which can easily lead to failure inside the sheet when a load is applied in the thickness direction.

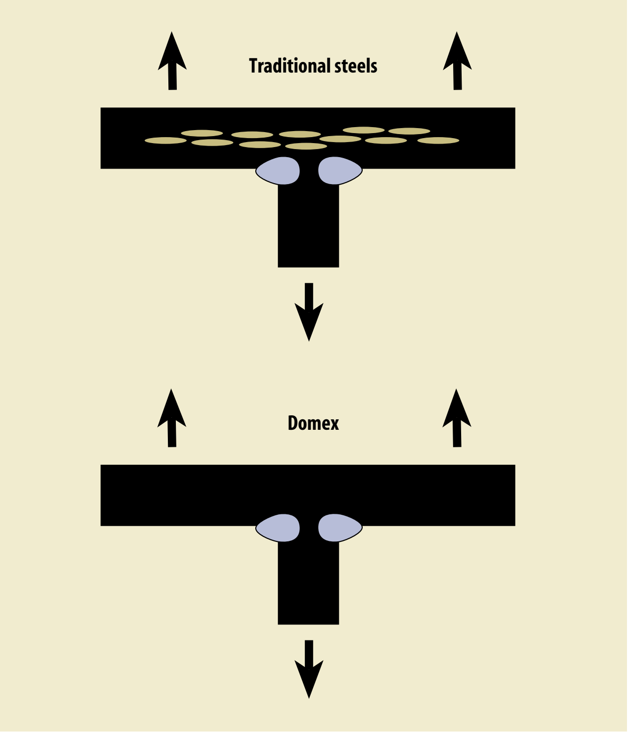
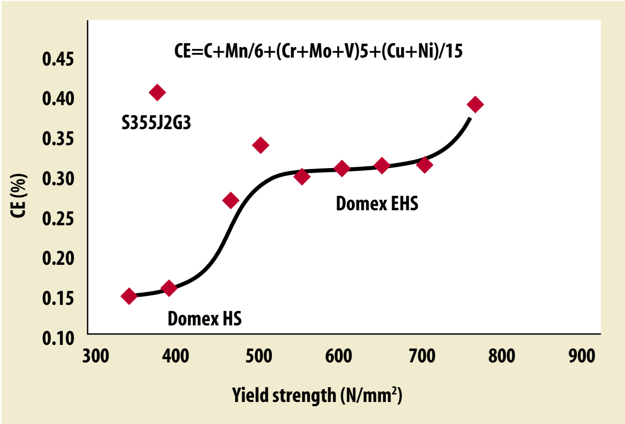


Figure 2. Due to the limited amount of slag inclusions, the strength of Domex is high, also in the thickness direction.

Figure 3. Carbon equivalent values against typical yield strengths of Domex cold-forming steels (HS and EHS steels) and S355J2G3, in a thickness of 6 mm.



Insensitive to cold cracking

The risk of cold cracking, which is a form of cracking that is caused by hydrogen embrittlement and occurs at fairly low temperatures (below 200°C), is very low in cold-forming steels. This is because the microstructure formed in the HAZ as a result of welding is insensitive to cold cracking. The reason that harmful microstructures do not occur is partly due to the fact that the cooling rate is normally low since the material is usually thin, and partly because the composition of the steel is so lean.

Carbon equivalent formulas are available for grading steels with regard to the risk of cold cracking. The most common carbon equivalent formula is **CE=C+Mn/6+(Cr+Mo+V)/5+(Cu+Ni)/15.** The CE values for the high strength (HS) and the extra-high strength (EHS) cold-forming steels (6 mm thick) are plotted in Figure 3 against typical yield strength values for the various steels. The ordinary structural steel S355J2G3, formerly designated St 52-3, has been plotted as reference. This clearly illustrates that the cold-forming steels have very lean compositions in relation to their strengths.

No preheating

No preheating is normally needed before welding, and preheating should not normally be employed unless it is absolutely essential, since the toughness and strength of the cold-forming steels could otherwise be impaired.

High strength in the weld

It is easy to produce high strength joints by fusion welding of Domex cold-forming steels, since matching filler metals are available for all of the various strength grades (see also Table 4 on page 9 concerning filler metals). The same strength requirements as those applicable to the parent material will then apply to the weld. This also applies to the EHS steels which have the highest strength of all the steels in the cold-forming range. In many cases, undermatched filler metal can also be used for welding EHS steels, e.g. if the weld is in a low-stress region. These filler metals are often less expensive and the range available is also greater. There is a rule of thumb which states that the strength of the weld is roughly mid-way between the strength of the steel sheet and the strength of the filler metal obtained from the data sheets of the filler metal manufacturer.

Either rutile electrodes or basic electrodes can be used for manual arc welding. For the steel grades Domex 315 MC-Domex 420 MC rutile electrodes are recommended for short welds, if little spatter and fine transitions between the weld metal and the parent material are required. Basic electrodes are recommended in all other cases and if high toughness of the weld is required, and for position welding. The electrodes should be stored so that they will not absorb moisture. Impurities on the surface, such as rust, paint and moisture, must be removed before welding is started. Pure carbon dioxide or a mixed gas (around 80 percent argon and 20 percent carbon dioxide) is used for MAG welding, and pure argon is most commonly employed for TIG welding.

Table 1. Chemical composition of Domex cold-forming steels

Chemical composition									
Steel grade	C (%) max	Si % (%) max	Mn% (%) max	P % (%) max	S % (%) max	Al (%) min	Nb (%) max	V (%) max	Ti (%) max
Domex 315 MC	0.10	0.03	1.30	0.025	0.010	0.015	0.09	0.20	0.15
Domex 355 MC	0.10	0.03	1.50	0.025	0.010	0.015	0.09	0.20	0.15
Domex 420 MC	0.10	0.03	1.50	0.025	0.010	0.015	0.09	0.20	0.15
Domex 460 MC	0.10	0.10	1.50	0.025	0.010	0.015	0.09	0.20	0.15
Domex 500 MC	0.10	0.10	1.60	0.025	0.010	0.015	0.09	0.20	0.15
Domex 550 MC	0.12	0.10	1.80	0.025	0.010	0.015	0.09	0.20	0.15
Domex 600 MC	0.12	0.10	1.90	0.025	0.010	0.015	0.09	0.20	0.15
Domex 650 MC	0.12	0.10	2.00	0.025	0.010	0.015	0.09	0.20	0.15
Domex 700 MC	0.12	0.10	2.10	0.025	0.010	0.015	0.09	0.20	0.15

Some thicknesses of these steel gr
maximum Si content of 0. ed in the order.

Table 2. Mechanical properties of Domex cold-forming steels

Mechanical properties							
Steel grade	Yield strength Re_h (N/mm²) min	Tensile strength R_m (N/mm²) min	Elongation min % A_{80} t<3	A_5 t≥3	Practical application Minimum recommended bending radius (≤90°) for nominal thickness (t) in mm t≤3	3>t≤6	t>6
Domex 315 MC	315	390-510	20	24	0.2xt	0.3xt	0.4xt
Domex 355 MC	355	430-550	19	23	0.2xt	0.3xt	0.5xt
Domex 420 MC	420	480-620	16	20	0.4xt	0.5xt	0.8xt
Domex 460 MC	460	520-670	15	19	0.5xt	0.7xt	0.9xt
Domex 500 MC	500	550-700	14	18	0.6xt	0.8xt	1.0xt
Domex 550 MC	550	600-760	14	17	0.6xt	1.0xt	1.2xt
Domex 600 MC	600	650-820	13	16	0.7xt	1.1xt	1.4xt
Domex 650 MC	650[*]	700-880	12	14	0.8xt	1.2xt	1.5xt
Domex 700 MC	700[*]	750-950	10	12	0.8xt	1.2xt	1.6xt

[*] For thicknesses >8 mm, the minimum yield strength may be 20 N/mm² lower.

Soft zones

When cold-forming steels of the highest strengths – from Domex 550 MC upwards – are welded, soft zones will form in the HAZ. These will occur as a result of changes in the microstructure. The width and hardness of the zone are determined by the sheet thickness, working temperature and the heat input. (Q = U x I/v, where U = voltage, I = current and v = travel speed.) High heat input and thin sheet result in lower hardness and a wider zone. However, these zones have proved to be of no significance if normal heat inputs are used. When a load is applied across the weld, a triaxial stress condition will quickly occur in the soft zone, which will prevent further deformation. Failure will thus not occur in the soft zone, but in the parent material or in the weld metal, depending on whether the filler metal is under-matched or matched, and whether or not the weld reinforcement has been ground away.

As an example of heat inputs, for a butt weld a maximum heat input of around 1.0 kJ/mm can be used for 8 mm thick Domex 700 MC if normal tensile strength demands are applicable to the welded joint. With this heat input, 8 mm thick plate can be welded with two beads. For fillet welds which are the most common type of welds higher heat inputs can be used (approx 30-40 %).

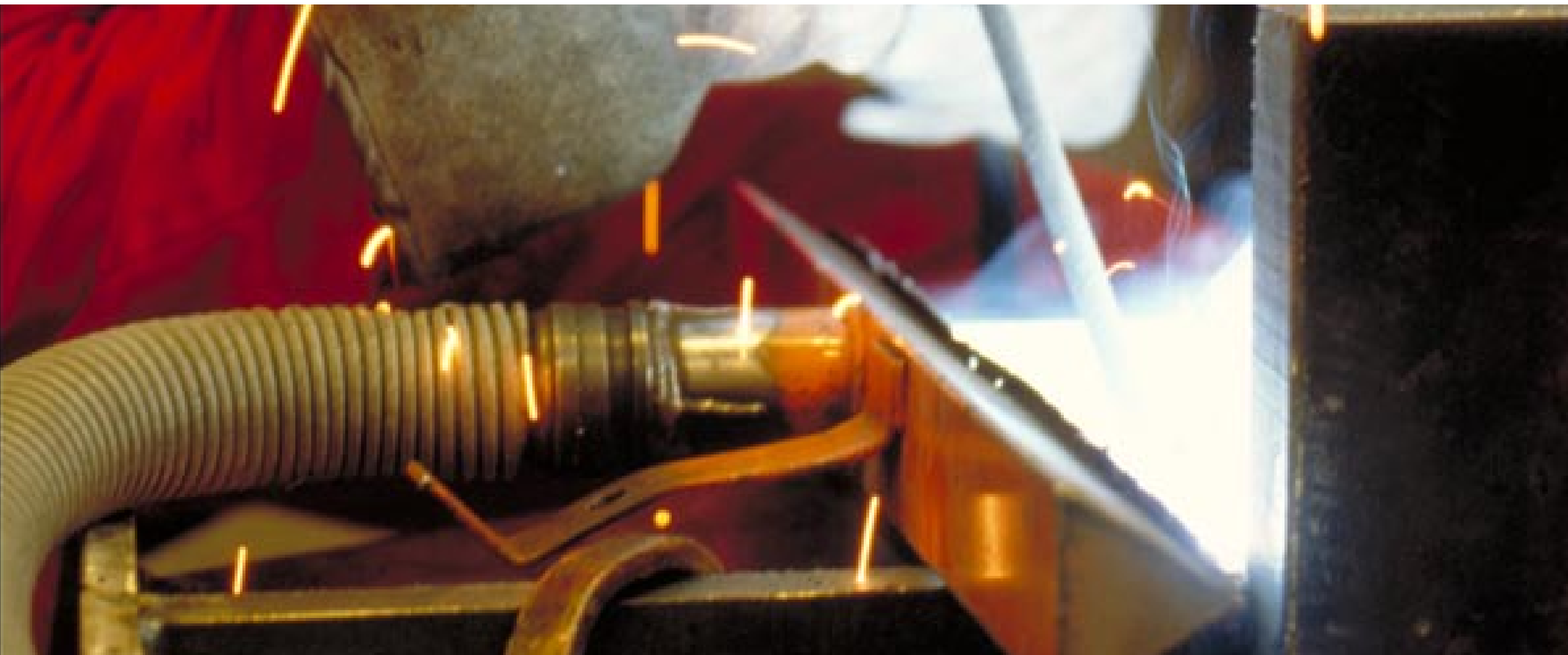
High toughness of welded joints

It is important that the impact toughness of a welded structure is high enough so that brittle fracture will not occur. The impact toughness of both the parent material and the weld metal must then be high. In the case of Domex cold-forming steels, the impact toughness properties guaranteed for the parent material can also be met by the welded joint.

To ensure that the impact toughness requirements will be met by the weld metal, it is important to select a filler metal which has sufficiently good impact toughness. However, the experience gained in fusion welding of cold-forming steels indicates that the impact toughness of the weld metal is often found to be appreciably higher than the values specified in the catalogues of filler metal suppliers.

The impact toughness in the HAZ is determined by the microstructure of the steel which, in turn, varies with the composition of the steel, the plate thickness working temperature and the heat input during welding. The HAZ consists of different zones, and the lowest toughness is normally in the coarse-grained zone immediately adjacent to the fusion boundary. However, the weld can meet the requirements applicable to the parent material, including the HAZ in cold-forming steels. To enable EHS steels with the highest strength values to meet the impact toughness requirements in the HAZ at -20°C for a butt weld the heat input must be limited. In the case of 6 mm sheet, the heat input must not exceed around 0.7 kJ/mm, and the corresponding value for 8 mm thick material is 0.75 kJ/mm. With these heat inputs the 6 and 8 mm thick plates can be welded with 3 beads. For fillet welds higher heat inputs can be used.

For Domex cold-forming steels, the impact toughness properties guaranteed for the parent material can also be met by the welded joint. It is important to select a filler metal that has sufficiently good impact toughness.



Joint preparation

Joint preparation in Domex cold-forming steels can be done by milling, grinding or thermal cutting such as gas, plasma or laser cutting. On thin sheet (≤4 mm) and pure I joints, ordinary shearing can be used if the quality of the cut surface is good. The low contents of alloying elements in these steels eliminates the need for preheating before thermal cutting. As mentioned earlier, there is very little risk of cold cracking.

Many different gases or gas mixtures can be used in thermal cutting. However, if plasma cutting is employed for joint preparation, some care should be taken when using air or nitrogen as the plasma gas. This is because nitrogen absorption could take place at the cut surfaces of the steel, which may give rise to porosity of the weld metal during subsequent fusion welding. This problem can be avoided by using a different plasma gas, or by grinding around 0.2 mm off the cut surfaces before welding.

Welding sequences

The forces to which a welded structure is subjected consist of the external applied loads and the internal stresses caused by welding (residual welding stresses). The residual stresses are normally high and are on a level with the yield stress.

It is often important to minimize the residual welding stresses and welding deformations in a structure. Before welding is started, a welding plan should therefore be drawn up. The following recommendations apply:

- Welding should be carried out in a direction away from the most firmly restrained parts of the structure towards the less restrained parts.
- Avoid starting or finishing a weld in very highly stressed areas.
- If possible, use a filler metal which has low trength but otherwise conforms to the demands made on the welded joint.
- Build up the weld symmetrically.
- Minimize the cross-sectional area of the welds.

Results of mechanical testing of welded joints

Over the years, many welding studies have been carried out on cold-forming steels. Different heat inputs and different filler metals (matched, undermatched and over-matched) have been tested. All joints have been radiographed to determine whether the weld quality is satisfactory. The testing to which welded joints were subjected included strength, impact toughness at various temperatures (in the various zones of the weld metal and the HAZ), bendability and hardness.

Some examples of the mechanical properties (tensile strength and impact toughness) obtained on MAG welded cold-forming steels (butt welds) are tabulated below. All of the filler metal wires used in the welds reported in Table 3 are matched or overmatched. A mixed gas consisting of 80 percent argon and 20 percent carbon dioxide was used throughout. The results of plasma and laser welding are also included in the table. Before tensile testing, the weld reinforcements were ground down.

The results demonstrate that the tensile strength requirements applicable to the parent material (see Table 2) can also be met in a direction across the welded joint. The weld is thus at least as strong as the steel sheet. The impact toughness of the weld metal and the HAZ (tested at -20°C and/or -40°C) is also good. All joints have also been subjected to bending tests with a bending radius of 2 x sheet thickness, with satisfactory results.

forming steels. MAG welds (butt welds, mixed gas, weld reinforcement ground away before testing, V joints in 6 and 8 mm test pieces), as well as laser and plasma welds.

Weld No. (method)	Domex steel grade (thickness, mm)	Wire	Pass	Heat input kJ/mm	Tensile test across		Impact test (Chappy V)			
					R_m, MPa	Fracture location	Direction of testing	Position*)	Impact energy (J/cm²) -20°C	-40°C
1 (MAG)	Dx 355 MC (6)	OK 12.51	1	0.87	476	Parent material	Longitudinal	A B C	133 258 270	99 250 256
2 (MAG)	Dx500 MC (6)	OK 12.51	1	1.2	595	Parent material	Longitudinal	A B C	168 162 256	174 110 244
3 (MAG)	Dx 500 MC (12)	OK 12.51	1 2	1.3 1.5	636	Parent material	Longitudinal	A B C	61 138 275	42 46 120
4 (MAG)	Dx 650 MC (6)	TD-T90	1 2	0.73 0.81	810	HAZ	Transverse	A B C		207 51 107
5 (MAG)	Dx 650 MC (8)	SG 700	1 2	0.61 1.2	774	Weld metal	Transverse	A B C	176 72 89	172 46 58
6 (MAG)	Dx 700 MC (3)	OK 13.13	1	0.29	829	Weld metal				
7 (MAG)	Dx 700 MC (3)	OK 13.31	1	0.39	846	HAZ				
8 (MAG)	Dx 700 MC (8)	OK 13.31	1 2 3	0.88 0.94 0.95	836	Parent material	Longitudinal	A B C	71 80 156	52 69 61
9 (MAG)	Dx 700 MC (8)	OK 13.31	1 2	1.14 1.13	849	Parent material				
10 (Plasma)	Dx 355 MC (3)	OK 12.51	1	0.65	455	Parent material				
11 (Laser)	Dx 420 MC (8)	-	1	0.38	539	Parent material	Longitudinal	A B C	198	117 245 302
12 (Laser)	Dx 700 MC (6)	-	1	0.25	816	Parent material	Longitudinal	A B C	208 153 135	83 150 105

*) A = Weld metal, B = Fusion line, C = HAZ 1 mm from fusion line.

Table 4: Some examples of filler metals from a number of suppliers for use on Domex cold-forming steels. The filler metals are roughly matching or over-matching. Also other filler metals can be used if they fullfill the requirements of the weldment in the actual construction.

Steel grade	Manual metal arc welding, coated electrode	Gas-shielded metal arc welding Tubular electrode	 Wire electrode	Submerged arc welding Wire/power	Manufacturer
Domex 315 MC Domex 355 MC Domex 420 MC	OK 48.00 Filarc 88 S P 48 S, Maxeta 22 Supercord	OK Tubrod 15.00 Filarc PZ6103 DWA 50 Fluxofil 12	OK Autrod 12.51 Filarc PZ6000 S Elgamatic 100 Spoolcord 21	OK 12.24/ OK Flux 10.62 - - Fluxocord 40/ Powder OP 121TT	ESAB Filarc ELGA Oerlikon
Domex 460MC Domex 500 MC	OK 74.78 Filarc 88 S P 48 S, Maxeta 21 Tenacito 70	OK Tubrod 15.17 Filarc PZ6145 DWA 50, DWA 55E Fluxofil 41	OK Autrod 12.51 Filarc PZ6041 Filarc PZ6047 Elgamatic 103 Carbofil CrMo-1	OK 12.24/ OK Flux 10.62 - - Fluxocord 41/ Powder OP 121TT	ESAB Filarc ELGA Oerlikon
Domex 550 MC Domex 600 MC	OK 75.75 Filarc 108 Maxeta 110 Tenacito 75	OK Tubrod 15.27 Filarc PZ6147 - Fluxofil 42	OK Autrod 13.13 PZ 6047; PZ 6048 Elgamatic 135 Carbofil NiMo-1	OK 13.40/ OK Flux 10.62 - - Fluxocord 42/ Powder OP 121TT	ESAB Filarc ELGA Oerlikon
Domex 650 MC	OK 75.75 Filarc 118 P 110 MR; Maxeta110 Tenacito 75	OK Tubrod 15.27 PZ132; PZ6148 - Fluxofil 42	OK Autrod 13.13 OK Autrod 13.29 OK Autrod 13.31 - Elgamatic 135 Carbofil NiMoCr Spoolcord TD-T90	OK 13.43/ OK Flux 10.62 - - Fluxocord 42/ Powder OP 121TT	ESAB Filarc ELGA Oerlikon
Domex 700 MC	OK 75.75 Filarc 118 P 110 MR; Maxeta 110 Tenacito 75 Tenacito 80	OK Tubrod 15.27 PZ6148; PZ 6149 - Fluxofil 42 SAF Dual 270	OK Autrod 13.13 OK 13.29; OK 13.31 - - Carbofil NiMoCr Spoolcord TD-T90	OK 13.43/ OK Flux 10.62 - - Fluxocord 70/ Powder OP 121TT	ESAB Filarc ELGA Oerlikon

Table 5: Standardized welding consumables.

Steel grade	Manual metal arc welding, coated electrode	Gas-shielded metal arc welding Tubular electrode	 Wire electrode	Submerged arc welding Wire
Domex 315 MC Domex 355 MC Domex 420 MC	AWS: A5. 1 E7018 DIN1913: E5153B10 EN499: E42X-xx	AWS: A5. 20 E71T-X DIN8558: T521 EN758: T42X-xx	AWS: A5. 18 ER70S-X DIN8559: SG 2 EN440: G42X-xx	AWS: A5. 23-F7AX-EM12K -
Domex 460 MC Domex 500 MC	AWS: A5. 5 E9018 DIN8529: EY5543MnMoB EN499: E50X-xx	AWS: A5. 29 E81T-X DIN7084: T541 EN758: T50X-xx	AWS : A5. 18 ER80S-X DIN8559: SG 2 EN440: G50X-xx	AWS: A5. 23-F7AX-EX -
Domex 550 MC Domex 600 MC	AWS: A5. 5 E11018 DIN8529: EY6965 Mn2NiCrMoB EN757: E62X-xx	AWS: A5. 29 E100T-X	AWS: A5. 28 ER100S-X	AWS: A5. 23-F10A4-EX
Domex 650 MC	AWS: A5. 5 E11018 DIN8529: EY6965 Mn2NiCrMoB EN757: E69X-xx	AWS: A5. 29 E110T-X	AWS : A5. 28 ER100S-X AWS : A5. 28 ER110C-X DIN SGNiMoCr2	AWS: A5. 23-F11AX-EX
Domex 700 MC	AWS: A5.5 E11018 DIN8529: EY6965 Mn2NiCrMoB EN757: E79X-xx	AWS: A5. 29 E110T-X	AWS: A5. 28 ER100S-X AWS: A5. 28 ER110C-X DIN SGNiMoCr2	AWS: A5. 23-F114X-EX

X= required impact toughness to be selected

Stress relief annealing against residual stresses

Stress relief annealing

Stress relief annealing is often used on heavy plate in order to reduce the residual stresses in welded structures. Stress relief annealing is also used on ordinary structural steels in order to reduce the hardness and improve the toughness in the HAZ. No stress relief annealing for this purpose is necessary on Domex cold-forming steels. The hardness need not be reduced and the impact toughness of Domex cold-forming steels in the welded condition is good. The only occasion when stress relief annealing of cold-forming steels is justified is if the residual welding stresses need to be lowered or if a cold-forming steel has been welded to some other steel that requires stress relief annealing. Stress relief annealing may also be specified by the manufacturing standard.

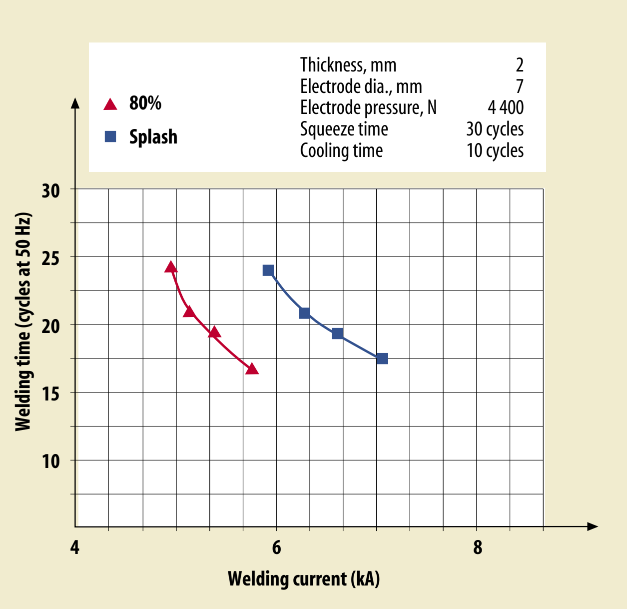
The recommended temperature ranges for stress relief annealing of welded cold-forming steels are 550 - 650°C for Domex HS steels (Domex 315 MC - 420 MC) and 530 - 580°C for Domex EHS steels (Domex 460 MC - 700 MC).

Resistance welding

Resistance welding can be used also for joining thin Domex cold-forming steel sheet. The methods included in the resistance welding group are spot welding, seam welding and projection welding. All steels included in the cold-forming range are easy to weld using these methods, since the steels have lean compositions. It is particularly important to maintain the contents of carbon, phosphorus and sulphur at a low level to ensure good welding results. As an example, Domex 650 MC and Domex 700 MC steels, which have the highest alloying element contents in the cold-forming series, have compositions that are substantially within the limits known by experience to produce good spot welding results. Best results are achieved if the surface is pickled or blast-cleaned.

Typical spot-welding trials on hot rolled, coldforming steels have been run on 2 mm thick Domex 650 MC. Spot welding was done on ordinary overlap joints (2+2 mm). The results of the trials are shown in Figure 4 in which the weld lobe is plotted. This type of graph is often used in spot welding and describes the variation in current which is acceptable without impairing the nugget diameter. In this case, the acceptable nugget diameter requirement has been set at 80 percent of the electrode tip diameter, which is a common requirement. The width of the weld lobe – in this case for Domex 650 MC – is 1.2 kA, which may be regarded as satisfactory.

Figure 4. Weld lobe for Domex 650 MC.



Laser welding

Laser welding is a relatively new method. A typical application of laser welding of thin sheet is in the automotive industry. In recent years, interest has also increased in using laser welding for thicker hot rolled sheet. Compared to MAG welding, the benefits of laser welding include higher productivity due to higher welding speed and fewer runs. Laser welding also produces less distortion and a reduced heat-affected zone in the parent material.

Since the heat input in laser welding is lower than that in ordinary fusion welding, the cooling rate in the material will be higher. This causes increased risk of hard zones in the welded joint if the steel is highly alloyed. Since Domex cold-forming steels have very low contents of alloying elements, no hard zones will occur in the weld. In tensile testing across the weld, the test piece will fail outside the weld, in the parent material itself. The results of tensile testing of laserwelded joints are given in Table 3.

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

SSAB Tunnplåt is a member of the SSAB Swedish Steel Group, has a turnover of SEK 10 billion, and has around 4000 employees in Sweden. The company produces about 2.5 million tonnes of sheet steel annually.

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

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

DOMEX®
hot-rolled steel sheet

DOCOL®
cold-reduced steel sheet

DOGAL®
metal-coated steel sheet

PRELAQ®
prepainted steel sheet

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We assist our customers in selecting the steels that are best suited for improving their competitiveness. Our strength lies in the quality of our products, our reliability of supply, and our flexible technical customer service.

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