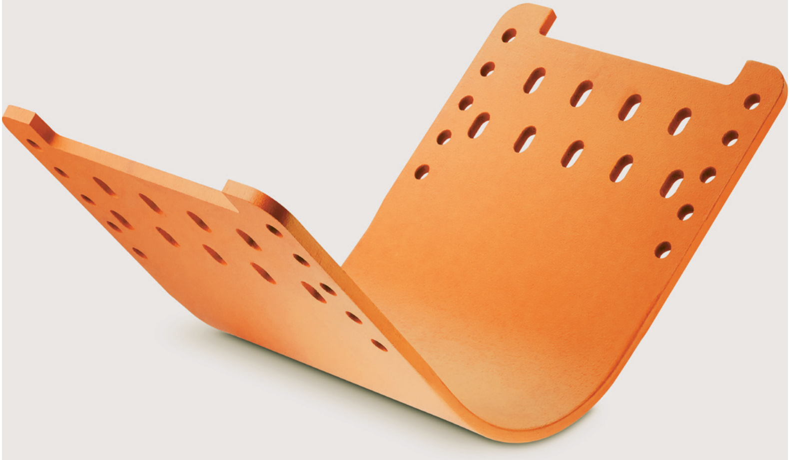
Industeel

ArcelorMittal

# User guide for Mars® protection steels



Industeel

ArcelorMittal

# User guide for Mars® protection steels

The information presented in this guide were the most up-dated at time of printing. Variations are always possible depending on advancement in our Research programs on protection steels.
We advise you to get in touch with us to verify them before placing order. In addition, the field conditions for each application are specific. The information presented here are only indicative and cannot be considered as a guarantee unless there is explicit confirmation in the form of a warranty contract written by our specialised departments.

Publisher: Industeel ArcelorMittal - 56 rue Clémenceau - 71200 LE CREUSOT

Writers: Yves ROYAL, Antoine PROUST, Jean-Pierre LAURENT, Frédéric BOUCHAUD, Anne HIGELIN, Damien DELORME
Layout: Clarisse TOURNEAU
Printing: NECC - 26 place de Beaune - 71100 Chalon s/ Saone

English Edition 2019

## Introduction



## Mechanical operations

## Thermal operations



## Forming

# Welding

## A. General and basic precautions of welding



## B. Consumables



## C. Assembly with high density energy process

## Safety

**Mars® protection steels must be used with caution. The stored elastic energy during forming may lead to rupture or shifting. It is essential to maintain a safe distance and not situate oneself in front of the plate while it is being formed.** As a general rule, when using Mars® protection steel, the increased mechanical characteristics of this material must be taken into account.

It is crucial to wear appropriate individual safety equipment and to equip machines with collective protection.

## General points

Mars® steels are high hardness (up to 650 HBW in the case of Mars® 650) protection steels offering the optimal combination of ballistic resistance and fabricability properties for their various uses.

If a specific technique - furthermore, one used on more classical construction steels - must be used, probative tests must be carried out and validated prior to manufacture.

**Mars® 280** (MIL-DTL-12560 class 2) is a less hardness (280 HBW), high toughness protection steel offering maximum resistance to shock and blast waves for all vehicle structures (main battle tanks, armoured personal carriers ...).

**Mars® 380** (NF A36-800 CLA / MIL-DTL-12560 class 1 & 3 / DEF STAN 95-13) is a protection steel (380 HBW) designed for all vehicle structures (main battle tanks, armoured personal carriers ...) and for ammunition testing targets.

Mars® 380 steel is highly versatile, combining ease of use even in important thicknesses, with good ballistic properties against all ammunitions.

**Mars® 440** (NF A36-800 THD1 / MIL-DTL-12560 class 4)is a protection steel intended to be used as vehicle structures for protection against mines and IED. It offers optimal compromise in terms of hardness (440 HBW), toughness, and ductility for resistance against blast loads and fragments, while keeping an excellent workability, especially bending and welding, for building specific vehicle profiles used for blast protection (example: V-shaped floor).

**Mars® 500** (NF A36-800 THD2 / MIL-DTL-46100) is a high-hardness (500 HBW) protection steel offering the optimal combination of ballistic resistance and workability for the following applications:

- Very light to medium-weight vehicles structures
- Add-on armour of any thickness for usage up to heavy tanks.
- Boxes, containers, shelters, reservoirs, door frames, etc.

**Mars® 600** (NF A36-800 THD4 / MIL-DTL-32332) is a multipurpose ultra-high-hard (600 HBW) protection steel with an impressive ballistic behavior in terms of deformation capacity and resistance to multi-impacts together with an excellent toughness and a workability (mainly bending) close to a 500HB steel.

Its great properties suggest unlimited possibilities, as add-on armor but also as structural material

**Mars® 650** (NF A36-800 THD5) is a ultra-high-hard (650 HBW) protection steel offering uncompromising ballistic resistance performance, for use as add-on armor when weight reduction is essential.

**In the Mars® 650 perforated version**, holes are evenly distributed within the surface to interact with the diameter of the incoming threat. The use of specific perforation process leads to very good flatness, absence of HAZ and low residual stress.

## Heat chemical composition (weight %)*

| Grade | Thickness (mm-*inch*) | C | S | P | Si | Mn | Ni | Cr | Mo | V | B | CE** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mars® 280 | 5 to 50.8<br>0.20 to 2 | 0,27 | 0,002 | 0,012 | 0,4 | 1,2 | 1,8 | 1,5 | 0,6 | 0,1 | 0,003 | 0,80 |
| Mars® 380 | *5 to 304.8*<br>*0.20 to 12* | 0,30 | 0,002 | 0,012 | 0,4 | 1,2 | 1,8 | 1,5 | 0,6 | 0,1 | 0,003 | 0,85 |
| Mars® 440 | 4 to 50<br>*0.16 to 2* | 0,22 | 0,002 | 0,015 | 0,5 | 1,5 | 2,0 | 1,0 | 0,6 | - | 0,003 | 0,70 |
| Mars® 440 | >20 to 80*<br>*0.79 to 3.15* | 0,24 | 0,002 | 0,015 | 0,5 | 1,5 | 5,0 | 2,0 | 0,6 | - | 0,003 | - |
| Mars® 500 | 2.5 to 50.8<br>*0.09 to 2* | 0,31 | 0,002 | 0,010 | 0,5 | 1,0 | 1,8 | 1,6 | 0,6 | - | 0,003 | 0,80 |
| Mars® 600 | 2.8 to 20<br>*0.11 to 0.79* | 0,45 | 0,002 | 0,010 | 1,0 | 1,0 | 2,4 | 0,5 | 0,5 | - | 0,003 | 0,77 |
| Mars® 600 | > 20<br>*0.79* | 0,55 | 0,002 | 0,010 | 1,0 | 0,7 | 4,5 | 0,4 | 0,5 | - | 0,003 | - |
| Mars® 650 and perfo | 2.8 to 16<br>*.11 to 0.63* | 0,55 | 0,002 | 0,010 | 1,0 | 0,7 | 2,4 | 0,4 | 0,5 | - | 0,003 | 0,83 |

**Carbon equivalence per ASTM A6/A6M, i.e. :*
*CE = C + [Mn/6] + [(Cr + Mo + V)/5] + [(Ni + Cu)/15]*

*** Air hardened, auto-tempering version, specially suitable for the hot forming of heavy vehicles underbellies*

# Mechanical properties

| Grade | Thickness mm-*(inch)* | Delivery condition | Usual range of hardness (HB) | YS Rp 0.2 MPa (ksi) | UTS Rm MPa (ksi) | Elongation 5d (%) | KV Transverse Direction -40° J (*ft.lbs*)* |
|---|---|---|---|---|---|---|---|
| Mars® 280 | | Guarantees | 260 - 310 | | | | ≥ 43 (≥ 32) |
| Mars® 380 | ≤ 13 (t ≤ *0.51"*) | Guarantees | 352 - 388 | | | | ≥ 20 (≥ *15*) |
| Mars® 380 | 13 < t ≤ 35 *(0.51"<t≤1.38")* | Guarantees | 331 - 375 | | | | ≥ 24 (≥ *18*) |
| Mars® 380 | 35 < t ≤ 60 *(1.38"<t≤2.36")* | Guarantees | 302 - 341 | | | | ≥ 32 (≥ *24*) |
| Mars® 380 | 60 < t ≤ 80 *(2.36"<t≤3.14")* | Guarantees | 262 - 331 | | | | ≥ 36 (≥ *26*) |
| Mars® 380 | 80 < t ≤ 120 *(3.14"<t≤4.72")* | Guarantees | 248 - 285 | | | | ≥ 56 (≥ *41*) |
| Mars® 380 | 120 < t ≤ 150 *(4.72" < t ≤ 6")* | Guarantees | 241 - 277 | | | | ≥ 64 (≥ *47*) |
| Mars® 440 | 4 < t ≤ 50 *(0.16 "< t ≤ 2")* | Guarantees | 420 - 470 | ≥ 1100 (*160*) | ≥ 1250 (*181*) | ≥ 10 | ≥ 27 (≥ *20*) |
| Mars® 440 | | Typical values | 440 | 1150 (*167*) | 1450 (*210*) | 13 | 48 (*35*) |
| Mars® 440 | 50 < t ≤ 70 *(2 "< t ≤ 2.75")* | Guarantees | ≥ 390 | ≥ 800 (*116*) | ≥ 1200 (*189*) | ≥ 10 | ≥ 20 (≥ *15*) |
| Mars® 500 | | Guarantees | 477 - 534 | ≥ 1150 (*167*) | ≥ 1500 (*218*) | ≥ 8 | ≥ 24 (≥ *18*) |
| Mars® 500 | | Typical values | 500 | 1250 (*181*) | 1700 (*247*) | 12 | 28 (21) |
| Mars® 600 | | Guarantees | 577 - 655 | ≥ 1300 (*189*) | ≥ 2000 (*290*) | ≥ 7 | ≥ 16 (≥ *12*) |
| Mars® 600 | | Typical values | 601 | 1450 (*210*) | 2150 (*312*) | 10 | 23 (*17*) |
| Mars® 650 | | Guarantees | ≥ 577 | | | | ≥ 8 (≥ *6*) |
| Mars® 650 | | Typical values | 650 | | | | 9 (7) |
| Mars® 650 perforated | | Typical values | 650 | | | | |
| Mars® 650 perforated | | Guarantees | ≥ 577 | | | | |

**The classical operations using mechanical process (drilling, milling, sawing) may be done on protection steels, but due to their increased hardness, require the use of special tools, for example, carbide tools. It is possible to perform drilling using thermal operations, please see the "Thermal Operations" chapter.**

## General recommendations for machining Mars® steels

1 – It is very important to strongly fasten the steel part to the support in order to avoid vibrations that will cause splintering and tool breakage.

2 – For these same reasons, the machine tools used must be as rigid as possible.

3 – Drilling is done with the shortest drill possible.

4 – The drill deterioration (beyond normal use) is accelerated by punchings at the end of drilling (flaking). To remedy this, guide bushings may be used; drilling in "bundles" is strongly discouraged.

5 – Generally speaking, we advise using carbide tools (tungsten, for example). It is possible to use high-speed steels, but only for Mars® 280 and 380.

6 – "Soluble oil" type lubricants are advised for operations. Lime-sulphur additives may be used to enable better lubrication. The lubrication pressure must be at least 10 bar in order to be effective.

7 – Cutting parameters (speed, feed, depth of cut for milling) must be reduced by at least half compared to that used for a classical steel of average hardness (type XC38 - SAE- J403-1038).

8 – Particular attention should be paid to the problems of condensation on plates (when the plates temperature is less than the ambient temperature),

9 – For other questions on this matter, contact us at:
contact.industeel@arcelormittal.com

## A. Drilling

**Examples of parameters for drilling with a diameter of 10 mm (*0.39″*)(depth: maximum 5 times the drill diameter).**

*Monobloc carbide bit, Seco Feedmax SD1103:*

| Grade | Cutting speed Vc m/min (*ft/min*) | Feed f mm/tr (*inch/rev*) |
|---|---|---|
| 42CrMo4 * (Rm = 700 N/mm²) | 75 (*246*) | 0.24 (*0.01*) |
| Mars® 280 | *45 (148)* | *0.17 (0.0067)* |
| Mars® 380 | 45 (*148*) | 0.17 (*0.0067*) |
| Mars® 440 | 45 (*148*) | 0.16 (*0.0063*) |
| Mars® 500 | 45 (*148*) | 0.16 (*0.0063*) |
| Mars® 600 | 35 (*115*) | 0.09 (*0.0035*) |
| Mars® 650 | 33 (*108*) | 0.10 (*0.0039*) |

*Interchangeable bit crown, Seco Crownloc SD103:*

| Grade | Cutting speed Vc m/min (*ft/min*) | Feed f mm/tr(*inch/rev*) |
|---|---|---|
| 42CrMo4 * (Rm = 700 N/mm²) | 85 (*219*) | 0.19 (*0.0075*) |
| Mars® 280 | *45 (148)* | *0.14 (0.0055)* |
| Mars® 380 | 45 (*148*) | 0.14 (*0.0055*) |
| Mars® 440 | 45 (*148*) | 0.13 (*0.0051*) |
| Mars® 500 | 45 (*148*) | 0.13 (*0.0051*) |
| Mars® 600 | 30 (98) | 0.088 (*0.0035*) |
| Mars® 650 | 25 (*82*) | 0.085 (*0.0033*) |

*As reference

It is possible to use an indexable insert tool, but its use will be advised for diameters greater than 15 mm (*0.59″*), of the higher hardness grades of the Mars® range.

## B. Milling

**Example of milling conditions** (during finishing) with a Walter brand mill, ref. F4033.B.050.Z06.06 Xtra.Tec. Chip ref. SNGX1205ANN-F57, grade WSP 45 Tiger.tec

| | Mars® | XC38 hardened (SAE 1038) |
|---|---|---|
| Cutting speed (rev/min) | 200 | 500 |
| Feed per round mm/min (*inch/min*) | 180 (*7.08″*) | 310 (*12.20″*) |
| Depth of cut mm (inch) | 0.1 (*0.0039″*) | 0.2 (*0.0078″*) |

## C. Sawing

In the same manner as for milling, a carbide coated blade will be the best solution. It is crucial to reduce the cutting speed by at least 50% compared to that used for a classical steel of the XC38 hardened type - SAE- J403-1038.

## D. Water jet cutting

This method is ideal for producing small parts from plates, but can also be used for parts with larger dimensions.

The main interest in water jet lies in **the absence of a Heat Affected Zone (HAZ)** and thus by the absence of a modification in structure. This process enables processing products with greater thicknesses than thermal cutting methods, with better tolerances, but generally lower productivity.

Various methods of cutting and machining using thermal processes are quite interesting for Mars® steels. In fact, the very high hardness of Mars® steels (specifically Mars® 600 and 650) does not affect the cutting speed. However, laser processes, oxygen cutting and plasma cutting create a heat affected zone (HAZ) that must be taken into account for the future steps of product processing and for its use.

**During cold periods** or in workshops that are inadequately heated, **it is advised to pre-heat** the plates whose temperature is less than **15°C-60°F.**

Particular attention should be paid to the problems of condensation on plate (when the plate temperature is less than the ambient temperature).

Significant condensation may lead to the introduction of hydrogen in the plate during cutting.
In fact, trapped hydrogen can be harmful for the steel's structure.

Monitor the inward angles, the windows or shapes cut inside parts and in general, all areas that may be prone to stress concentrations.

## A. Laser procedure

This process is very interesting for Mars® steels, in particular for Mars® 600, 650 and 650 perforated steels that offer increased hardnesses.

### 1. Laser cutting

**Laser cutting has the following benefits:**

- Dimensional precision and regularity of cut.
- The heat affected zone is not as large as that resulting from a plasma cut (total zone ≤ 1 mm (*0.039"*) for thicknesses of ≤ 15 mm (*0.59"*)),
- Little deformation due to the cut because of the very limited heating of the metal in the area where the cut is made,
- Few or no burrs requiring immediate post-cut trimming,
- Reduced draft area compared to plasma or oxycutting techniques that leaves dross of 1.5mm (*0.059"*) to 7mm (*0.28"*) on the surface

These benefits make laser cutting the best current method for thermal cutting Mars® steels for thin thicknesses.

**To make the most of the process, it is necessary to:**

- Eliminate all foreign bodies present on the surfaces to be cut (water, grease, oil, paint, chloride products, etc.). Shot blasted plates are perfectly suitable,
- Adjust the cutting parameters (power, speed, beam diameter, protection gas, focusing distance, etc.) based on the thicknesses and the quality criteria imposed (roughness), as well as the productivity and type of laser.

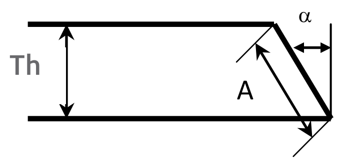
## 2. Laser beveling

Beveling is similar to a cutting operation. The thickness to be taken into account for cutting the thickness of the plate should be multiplied by : $\frac{1}{\cos\alpha}$

where α is the targeted bevel angle:

Thickness to be cut =

$$A = \frac{Th}{\cos \alpha}$$




The maximum thickness is thus based on the thickness of the plate and the bevel.

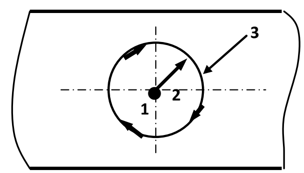
*Some cut thickness values based on the plate thickness:*

| | Angle of targeted bevel (°) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Thickness t mm (*inch*)** | 15 mm | 15 inch | 30 mm | 30 inch | 45 mm | 45 inch | 60 mm | 60 inch |
| **3 (*0.12"*)** | 3.1 | 0.122 | 3.5 | 0.136 | 4.2 | 0.167 | 6.0 | 0.236 |
| **5 (*0.2"*)** | 5.2 | 0.204 | 5.8 | 0.227 | 7.1 | 0.278 | 10.0 | 0.394 |
| **7 (*0.28"*)** | 7.2 | 0.285 | 8.1 | 0.318 | 9.9 | 0.390 | 14.0 | 0.551 |
| **8 (*0.315"*)** | 8.3 | 0.326 | 9.2 | 0.364 | 11.3 | 0.445 | 16.0 | 0.630 |
| **10 (*0.39"*)** | 10.4 | 0.408 | 11.5 | 0.455 | 14.1 | 0.557 | 20.0 | 0.787 |
| **13 (*0.52"*)** | 13.5 | 0.530 | 15.0 | 0.591 | 18.4 | 0.724 | 26.0 | 1.024 |
| **15 (*0.59"*)** | 15.5 | 0.611 | 17.3 | 0.682 | 21.2 | 0.835 | 30.0 | 1.181 |

## 3. Laser drilling

The laser may be used advantageously for drilling Mars® grade plates.
As an example, and for sufficient diameters in relation to the thickness, proceed as follows:

- Pierce to the centre of the circle to be drilled, then move towards the periphery and cut the hole:




- **Phase 1: drilling,**
- **Phase 2: cutting a radius,**
- **Phase 3: cutting a hole.**

This technique should be refined when the hole's diameter is less than the plate thickness.

<u>Procedure limitation:</u>

- The maximum drillable thickness: approximately 15 mm (*0.59"*), according to the capacities of the equipment used.
- The laser's post-drilling reaming is not industrially feasible; the thermally affected zones created by the laser drilling lead to hardnesses that are too great.

## B. Oxygen cutting

The usual precautions for cutting speed, gas flow, nozzle sizes, etc. must be adhered to.

*Speed values usable for oxygen cutting of Mars® steels: (Of course these values vary based upon the material used)*

| Thickness mm (*inch*) | Movement speed m/min *(ft/min)* | Gas consumption L/hour *(gallon/hour)* | | Bleed width mm *(inch)* |
|---|---|---|---|---|
| | | Oxygen | Acetylene | |
| 4 *(0.16")* | 0.6 to 1 *(2-3.3)* | 800 to 1200 *(210 - 315)* | | 2 *(0.08")* |
| 5 *(0.2")* | 0.6 to 0.9 *(2-3)* | 800 to 1200 *(210 - 315)* | | 2 *(0.08")* |
| 8 *(0.315")* | 0.5 to 0.7 *(1.6-2.3)* | 1000 to 1400 *(265 - 310)* | 200 to 300 *(55 - 80)* | 2 *(0.08")* |
| 10 *(0.39")* | 0.4 to 0.65 *(1.3-2.1)* | 1000 to 1600 *(265 - 425)* | | 2.5 *(0.1")* |
| 12 *(0.47")* | 0.4 to 0.6 *(1.3-2)* | 1200 to 1800 *(315 - 475)* | | 2.5 *(0.1")* |

## C. Plasma torch cutting

**Plasma torch cutting is strongly discouraged under water.**

Dry plasma torch cutting is appropriate if cutting gas contains minimal hydrogen. Plasma cutting is used for the most common thickness range. Its benefits in terms of speed, fewer deformations, smaller HAZ, makes it preferable to classical oxygen cutting.

### Precautions for oxygen and plasma cutting :

- Follow the preheating temperature; see table below
- Minimize heat affected zone (by configuring the cut parameters) in order to avoid soft spots that are too large and that may cause the rejection of certain parts.
- Avoid repeat cutting,
- Finish the post-cutting operations without delay,
- Inspect, at least visually, but preferably using dye penetrant, the absence of cracks on the plasma cut edges.

### Preheating table

| | Plate thickness mm (*inch*) | | | | |
|---|---|---|---|---|---|
| | 12 *(0.47")* | 15 *(0.59")* | 20 *(0.78")* | 50 *(2")* | 75 *(3")* |
| Mars® 280 | No preheating | | | | 150°C |
| Mars® 380 | No preheating | | | | 150°C |
| Mars® 440 | No preheating | | | 100 °C - 200 °C | |
| Mars® 500 | No preheating | | 150 °C | | |
| Mars® 600 | No preheating | | 100 °C - 130 °C | | |
| Mars® 650 | No preheating | | | | |

## A. Cold forming - Bending

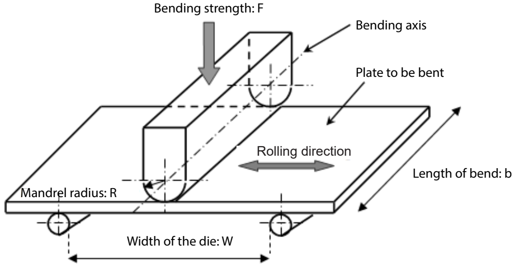
### Safety

Taking into account the yield strength of Mars® steels, the roll forming and bending operations must be carried out with caution.
It is essential to provide for a safety distance and the appropriate individual and collective safety equipment.
Furthermore, these operations require powerful machines equipped with tooling (rollers, mandrels, dies, etc.) with mechanical characteristics that are capable of enduring the hardness level of the metal plates.

*Example of part obtained after cold bending.*
*Mars® 500 steel Th 4.75 mm (0.18”)*

## 1. Recommendations and precautions for cold forming Mars® steels

**- Direction of the bending axis:**
As much as possible, the bending will be directed perpendicularly to the plate rolling direction :




**- Condition of the edges:**
The edges must be free from cracking initiation defect (blow-cuts or burrs from oxygen cutting) and will also be ground in order to remove the rough edges. Ideally, the edges of the plate lower surface should be rounded by grinding at the point where the die will exert pressure.

**- Condition of the plate surface:**
The metal plates must not have marks in the bending zone (steel stamping marks, for example) or other surface defects capable of producing a crack starter during operation.

**- Temperature:**
For a plate temperature less than 15 °C *(60°F)*, preheating will preceed the processing of the plates.

**- Tooling condition:**
Keep the tooling clean by eliminating the scale deposited at each operation. Proper lubrication of the mandrel and the die helps a good sliding of the metal between them and thus good stress distribution. For the same reasons, it is advised to round out the female die's edges. The bending force and the springback can thus also be slightly reduced.

**- Bending speed:**
In extreme cases, a slow bending speed enables carrying out the operation with greater safety.

**- Bending parameters:**
The mandrel bending radius is the most influential parameter over the risk of cracking.
It must be as large as possible and must not be less than the values indicated in the table below.

*Minimum bending conditions:*

| Grade | Thickness t mm (inch) | Mandrel R // | Mandrel R ⊥ | Width of the die (W) |
|---|---|---|---|---|
| Mars® 380 | | 5t | | R x 2 + 3t |
| Mars® 440 | < 8 (*0.315"*) | 5t | 4t | |
| | 8 to 16(*0.315 to 0.63"*) | 6t | 5t | |
| | > 16 (*0.63"*) | Contact us | | |
| Mars® 500 | < 8 (*0.315"*) | 8t | 5t | |
| | 8 to 16 (*0.315 to 0.63"*) | 9t | 7t | |
| | > 16 (*0.63"*) | Contact us | | |
| Mars® 600 | < 4 (*0.16"*) | 10t | 8t | |
| | 4 to 6 (*0.16 to 0.24"*) | 12t | 10t | |
| | 6 to 9 (*0.24 to 0.35"*) | 14t | 12t | |
| | > 9 : contact us | | | |
| Mars® 650 | | Contact us | | |

**t is the thickness of the plate.**
**R is the minimum radius of the mandrel.**
**// or ⊥ => Bending line parallel or perpendicular in the rolling direction.**
**Industeel may deliver formed parts upon request.**
****For multi-steps bending, contact us at contact.industeel@arcelormittal.com**

## 2. Bending force

The bending force depends on four main parameters:

- The thickness
- The yield strength
- The length of the bend
- The width of the female die

It can be estimated based on the following formula:

$$F = \frac{b.\ t^2 \,.R_m}{W - R - ep}$$

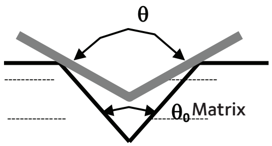
Where:

- F is the bending force (in N)
- *b* is the length of the bend (in mm)
- $R_m$ (UTS) is the maximum resistance of the material (MPa)
- *W* is the width of the die (in mm)
- *t* is the plate thickness (in mm)
- *R* is the mandrel radius (in mm)

Friction mitigation will also reduce the bending force.

### 3. Springback after bending

During the bending operation, under the action of the mandrel, the metal sheet is bent at an angle of $\Theta_0$ .




When the mandrel raises, the bend opens to an angle $\Theta$.

The phenomenon, due to the relaxation of elastic stress, is called springback.

At the time of the tooling design, it will therefore be necessary to take this phenomenon into account.

The springback increases when the elastic limit of the material increases.
The ratio between bend radius and plate thickness also influence the springback.

The springback is also very sensitive to the clearance between the sheet and the tooling, in other words, to the gap between the die, the plate, and the mandrel.

Friction between the metal plate and the tools may aggravate this phenomenon.

Springback angles of several tens of degrees are possible for harder steels.

Preliminary trials are essential for accurately assessing this elastic springback.

## B. Hot forming

Hot forming of Mars® grades is theoretically possible.

Nevertheless, the cooling speeds obtained after forming has to be consistent with the hardenability of the grade considered.

The hot forming temperatures are generally located between 900 °C (*1650°F)* and 950 °C (*1740°F)* based on the grade considered. After die quenching, a proper tempering treatment followed by air cooling has to be done → in this case contact us at contact.industeel@arcelormittal.com in order to determine the conditions.

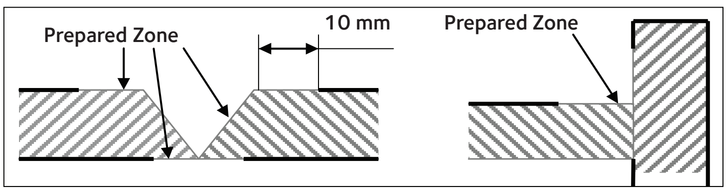
When hot forming is planned on a Mars® steel, it must be specified in the order so as to be able to potentially adjust the grade to the required thickness and the capacities for cooling tools.

## A. General and basic welding precautions:

### 1. Assembly cleanliness

The condition of the plate cleanliness for the elements to be assembled may be an important factor in avoiding defects such as inclusions or cracks.

Therefore it is essential to:
- Grind the surfaces before welding. In fact, after a thermal cutting operation or even at the stage of delivery, a superficial layer of oxide exists. Mechanical grinding is the most effective method for eliminating these traces. Brushing, shot-blasting, and sand-blasting may also be suitable in the case of a slightly oxidised surface.




The following technique is recommended:
- Clean, de-grease, and dry surfaces using a solvent and a clean cloth before welding.
- Visually inspect the appearance of the edges to be welded and if possible, use dye penetration inspection. A thermal cutting defect may cause the crack initiation during welding.

### 2. Fitting

- It is preferable to position and hold the plates using mechanical means (bridges, clamps, *bolts, Chicago bridges*, etc.).
- Avoid beveling angles that are too sharp.
- Avoid gaps that are too big to mitigate shrinkage stress.
- Position the welds at a distance from the bend of at least equal to five times the plates thickness.

### 3. Plate temperature

Other than specific recommendation (p44, B. Consumables) about the welding conditions, Mars® steel may be welded without preheating if austenitic consumables are used.

However, in order to eliminate the risk of cracking, it is imperative that the temperature of the plates is at least 15 °C (*60°F)* before any operation.

Particular attention should be paid to the problems of condensation on plate (when the plate temperature is less than the ambient temperature).

### 4. Tack welding

Tack welding must be done by a qualified welder (NF A80 200-1) and with as much consideration as for a normal welding operation.

- The advised length of a tack weld is at least 50 mm (*2")*.
- The welding parameters used for tack welding must be reduced so as to limit dilution which decreases the risk of cracking in melted metal.
- Any cracked point must be ground and done again.
- The process of tack welding influences the appearance of the weld bead. MIG/MAG tack welding is preferable using a coated EE electrode (greater risks of bonding).

## 5 Making seams

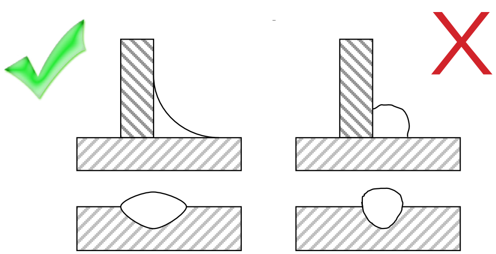
The welding must be done by a qualified welder (NF A 80 200-1).

1. Priming
In the case of a shaft weld, it is recommended to use the run out tabs at the start and end of the seam. They enable the absorption of priming defects in the arc and craters at the end. These are then eliminated by grinding.

2. Length of the arc
When the length of the arc is too long, it may cause deterioration of the gas protection or by slag that may result in the introduction of ambient hydrogen and increase the risk of cold cracking.

3. Additional passes
When a weld is resumed, it is necessary to grind the end of the previous pass before remelting.

4. Bead shape and types of assembly
Defects in bead shape may cause cracks during use. To avoid these, some rules should be followed:

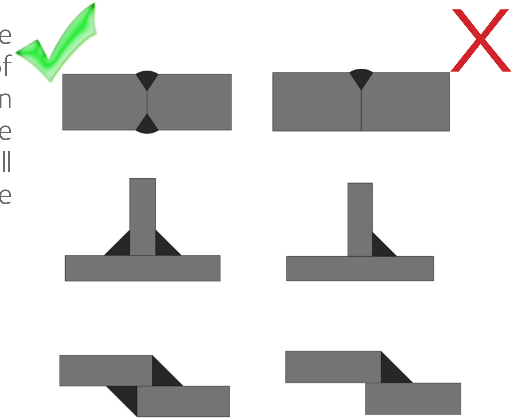


Particular case: At the ends of seams, crater cracks may occur. Thus it may be necessary to modify the parameters for arc fading in order to feed the crater at the end of the seam (here a convex form is preferred).





Also, during the conception of the design, when possible, the double seams will be preferred to the sngle seams:



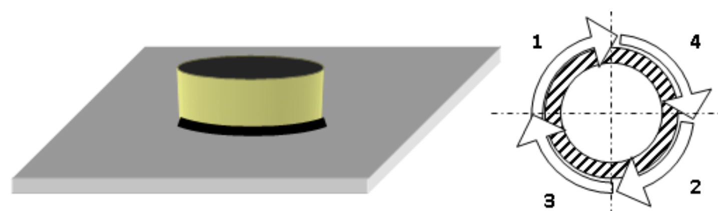
## 6 Welding sequences

The optimisation of welding sequences helps reducing residual stress and thus the risk of cracking and deformation.

The creation of residual stress is due essentially to the phenomenon of shrinkage of the heated parts. Indeed, a welding operation will cause localised heating, generating differences in dilatation and metallurgical transformations.

By allowing the possibility of deformation at assembly (thus by decreasing the level of clamping), we decrease the residual stress.

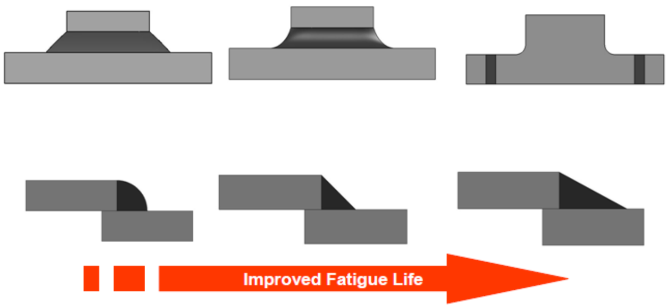
Example sequence:



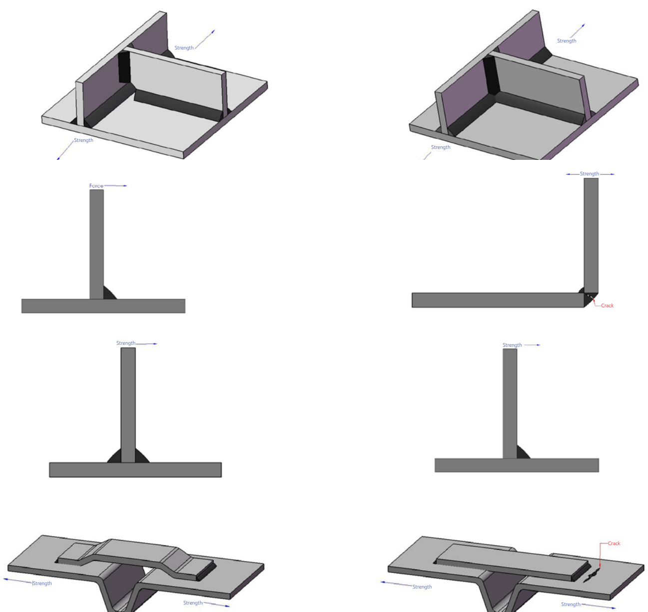

Sequence referred to as "pilger milling"

## 7. Assembly fatigue

Some simple rules in design or finishing allow improvement of the resistance to fatigue of welded assemblies.




**Recommended** **To be avoided**



## 8. Handling of plate and parts before welding

The Mars® steels must not be handled with magnets or electromagnets. This equipment generates significant remanent magnetisation that may cause arc blowing.

## 9. Finishing

- Trimming seams by grinding allows improvement in the resistance to fatigue and removing the effects of notching.
- Hammering after welding has to be well managed to avoid development of micro-cracks.
- Welds cleaning may be done using a shot peening, brushing, shot-blasting or sand-blasting.
- Hot flame straightening or straightening by hammering has to be avoided.

# B. Consumables

## 1. General information on consumables

The welding process for protection steels requires the use of :
- austenitic or austenitic-ferritic consumable products
- or ferritic consumable products.

The products proposed in this guide serve as examples and are suitable for working with Mars® protection steels.

However, based on the configuration of assembly and the dilution rate, the sensitivity to hot cracking may increase. Other austenitic or austenitic-ferritic consumables, for example, those enriched in manganese and molybdenum, may also be more appropriate. For more information, contact us at: contact.industeel@arcelormittal.com

For high thicknesses or high stresses level, preheating is recommended according to below table :

### Preheat temperature and consumables

| Grades | Thick (mm) | Temp. max (°C) | Plate thickness (mm) |
|---|---|---|---|
| | | | 3 15 25 40 50 70 80 400 |
| | | | *Low stresses* … *High stresses* |
| Mars® 280 & 380 | 4-400 | 250 | F 125, F 175, F 200 / A 15, A 100 |
| Mars® 440 | 3-70 | 180 | F 100, F 150 / A 15 |
| Mars® 500 | 2.5-50 | 160 | F 150 / A 15, A 100 |
| Mars® 600 | 3-80 | 130 | A 15, A 100 |
| Mars® 650 | 3-16 | 130 | A 100 |

Non applicable
Ferritic F (ER70), 100°C
Ferritic F (ER70), 125°C
Ferritic F (ER70), 150°C
Ferritic F (ER70), 175°C
Ferritic F (ER70), 200°C

Austenitic A (307), 15°C
Austenitic A (307), 100°C

T max : Maximal temperature acceptable by plate to preserve mechanical properties.

Hydrogen : 5mL/100g - Heat Input : 1 kJ/mm

## 2. Coated electrode welding


*Assembly with a coated electrode performed at the Centre de Recherche Industeel, Mars® grade 500*

- Electrodes must have basic coating
- Electrodes must be preliminarily heated in a heat chamber and stored at high temperature
  + Baking 350°C (*662°F*) for 2 hours
  + Storage 150°C (*302°F*)
- Some electrodes are vacuum-packed and do not require baking. They must however be used within 8 hours after package opening. Please follow consumable supplier recommendations.

Among the various electrodes that can be used, we list:

| | SMAW Austenitic | SMAW Ferritic |
|---|---|---|
| | **EN ISO 3581-A :** E 18 8 Mn or E 20 10 3 **AWS A5.4 :** E307-15, E307-16 or E308Mo-17 | **EN ISO 2560-A :** E4x 5 Bxx H5 **AWS A5.18 :** E70xx H4 |
| ESAB | OK 67.45 or OK 67.43 | OK 55.00, FILARC 56S |
| LINCOLN | Jungo 307 | Basic 7018 |
| OERLIKON | SUPRANOX RS 307 | SUPERCITO |
| SELECTRAC | 307B, 307R, INOX 308Mo | B56S |
| vaBW | BOHLER FOX A 7-4, THERMANIT X, THERMANIT XW Or BOHLER FOX CN 19/9 M THERMANIT 20/10 W | FOX EV 50, PHOENIX 120 K |

## 3. Semi-automatic gas-shielded welding

- In the case of MIG (Metal Inert Gas) welding, only use wire.

- You can perform MIG (Metal Insert Gas) welds with greater bevel gaps. Sweeping the torch is therefore necessary and limits the energies introduced.

- The use of high silicon (0.7%) wire promotes wettability and provides good handling during welding.

Among the various wires that can be used, we list:

| | GMAW Austenitic | GMAW Ferritic |
|---|---|---|
| | **EN ISO 14343-A / 17633-A :** T-G 18 8 Mn or G 20 10 3 **AWS A5.9 :** ER307 or ER308Mo | **EN ISO 14341-A :** G3Si1 **AWS A5.18** ER70S-6 |
| CASTOLIN | EGAP 5216 | - |
| ESAB | OK Autrod 16.95 OK Tubrod 15.34 | OK Autrod 12.51 |
| LINCOLN | LNM 307 | SUPRAMIG |
| OERLIKON | FILINOX 307 | CARBOFIL1 |
| SELECTRAC | 18/8 Mn | F57 |
| vaBW | THERMANIT X AVESTA 307-Si Or BOHLER CN 19/9 M-IG THERMANIT 20/10 | UNION K 52 BOHLER SG 2 |

*Shielding gas : Ar + 2% $CO_2$ (EN ISO 14175 M12) or Ar + 18% $CO_2$ (EN ISO 14175 M21)*

**Note:** The properties of the austenitic structure wires are different from those of Mars® steels. The builders of armoured vehicles must take these differences into account and provide for lap joints rather than butt welded joints.

*T (MIG) Assembly: test performed at the Centre de Recherche Industeel, Mars® 600, thickness 8.4 mm (0.33")*

## C. Assembly with high density energy process

### 1. Electron-beam welding (EB)

EB welding of Mars® grade steels with low thickness is industrially used:

- The quality of the welds obtained (good soundness, no cracks) is completely satisfactory.

- The yield strength of the weld is comparable to that of the base material (weld without filler metal), on the other hand, its toughness is lower than that of a joint made with austenitic or austenitic-ferritic filler metal (cases of MIG welds and coated electrodes).

In fact, EB welding is still little used for carrying out large mechanical welded assemblies (e.g. armoured vehicle hulls).

There is a major reason for this: this process requires a substantial investment due in large part to the necessity of welding in a vacuum (→ large capacity vacuum chamber, pumping unit, etc).

### 2. Laser welding

*Part obtained by laser welding. Mars® 500 steel*

Laser welding of Mars® grade steels with low thickness where t. < 10 / 12 mm (*0.39"/0.47"*) is possible.

The characteristics of welded joints are similar to those of joints done by electron beam.

The main advantage of the laser beam compared to the electron beam is that there is no need for a vacuum in order to perform it. Welding is done under a gas shielding (like MIG) and without filler metal, the risks of introducing hydrogen during welding are limited, therefore the risk of cracking is also limited.

It is possible to use the hybrid laser / MAG welding process with gas: nitrogen, argon, helium.

For any other information, contact us at:
contact.industeel@arcelormittal.com

Notes :

Notes :

**Notes :**

**Notes :**

Notes :

Notes :