ENDURA

The Premium Grade of Wear Steel

TITUS STEEL

The Premium Grade of Wear Steel

7 Years in Development

So Unique it has been Patented

TABLE of CONTENTS

1. General Information

This unique steel features the best wear resistance of any homogeneous anti-abrasive plate:

- an average wear resistance 8 times greater than mild steels
- 4-5 times greater than AR 400
- 2-3 times greater than AR 500
- significantly easier processing.

1.1 APPLICATION VALUE: A few words about the exceptional high level of wear resistance of ENDURA.

As-delivered hardness is only one consideration regarding the level of wear resistance of steels.

The ability of steel to increase its own hardness during service is of great importance on the wear resistance level.

Despite "as-delivered hardness" of only 470 BHN (which optimizes ease of processing, see below), ENDURA WORK HARDENS to 540-570 BHN,

This high "in-service" hardness is independent of the level of wear on the steel because the outer layer is continuously hardened proportional to the degree of wear (strain hardening depth is determined proportionally to impact intensity).

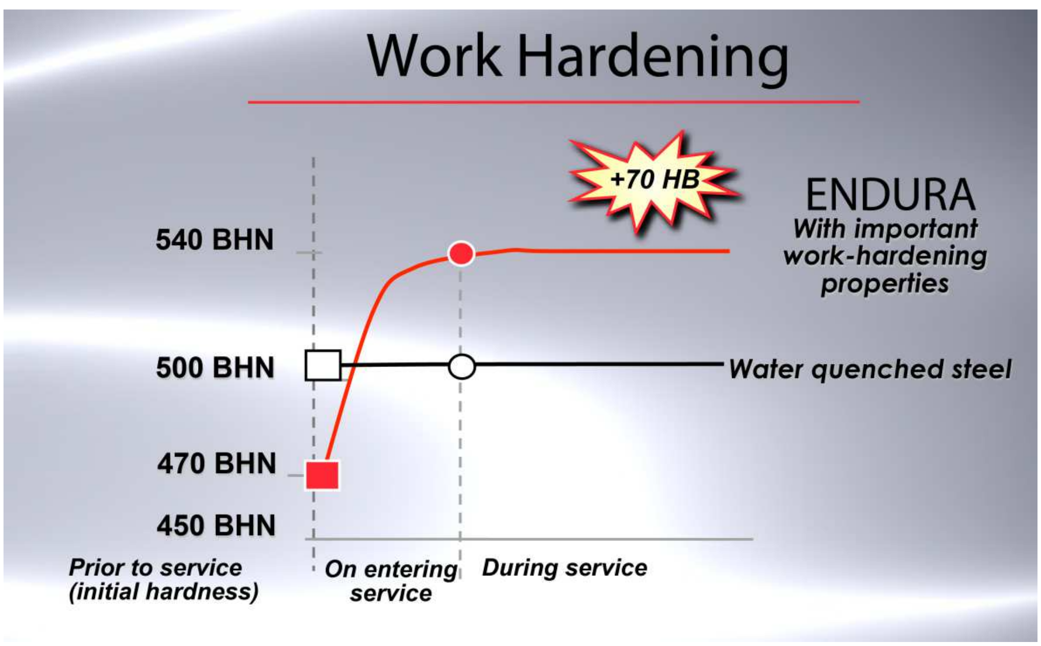


Figure 1: Work Hardening

Moreover, a controlled dispersion of fine hard Chromium and Molybdenum carbides adds to the resistance of the steel at the time of ultimate micro deformation preceding the shearing of steel particles.

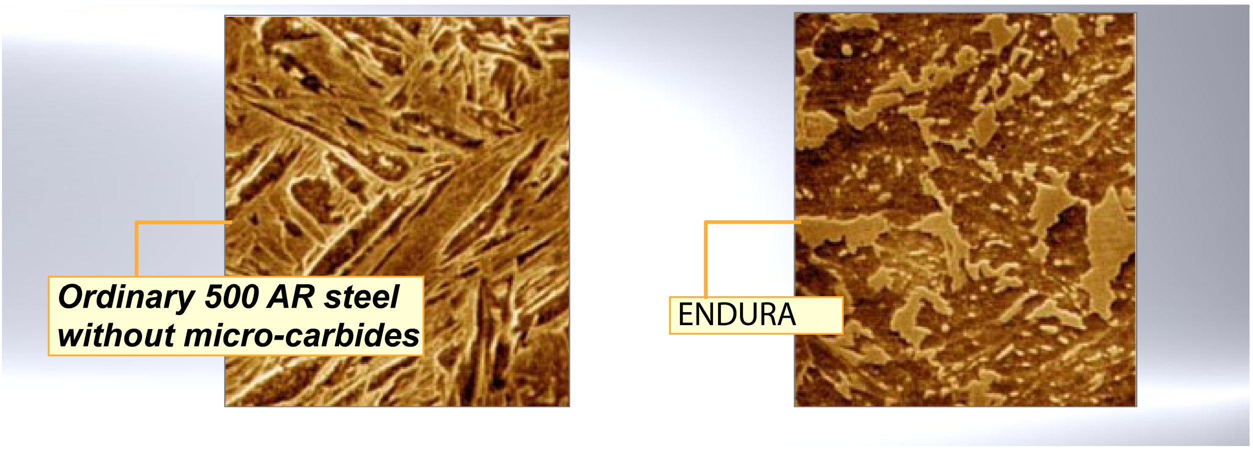


Figure 2: Microstructure Comparison

Conventional 500 BHN quenched steel Microstructure without carbide

ENDURA
Microstructure enriched with micro-carbides

Finally, a significant increase in ductility allows larger micro shearing and thus retards the ultimate shearing of steel particles.

This is obtained by a new and revolutionary metallurgical phenomenon known as the **TRIP** effect (**Transformation Induced by Plasticity**), which is achieved by the spontaneous rearrangement of metallic atoms under the stress and strains resulting from impact abrasion.

The cumulative extra-contributions of….

- strong strain hardening during service
- hard Cr – and Mo- microcarbides
- delayed tearing of metal particles thanks to the TRIP effect

Result in….

- Exceptionally high level of wear resistance along with
- Easy processing (cutting, forming, machining, welding) thanks to a limited as-delivered hardness.

1.2 FIELDS OF APPLICATION

ENDURA is ideal for applications in cases of extreme wear and from impact and sliding abrasion.

Quarries, Construction – Earth Moving

- Blades, outside stiffeners, underteeth pad of loaders, of shovel dippers.
- Crushers and mills lateral liner plates.
- Spurs of shield-blades of bulldozers.
- Screens.
- Feed crown-wheel, sprocket wheel.

Mines, Coal-Mines

- Extracting and loading equipment.
- Shovel-wheel buckets.
- Hopper lateral liner plates.
- Blades if grab buckets
- Helical gravity conveyors.
- Mixer bottoms and paddles.
- Parts if chain – conveyors

Cement Plants

- Liners for drier-tubes.
- Hoppers.
- Clinker cooler outlet shields.
- Separating plates of compound grinding mills.
- Parts of separators.

Iron and Steel Industry

- Inside plates of skips.
- Grit dividers.
- Blades of grab buckets.
- Guilding and shifting plates.
- Vibrating plates.
- Liners of shotblasting chambers.

Agricultural Equipment-Brickworks-Foundries-Scrap Recovery…

N.B. This list of applications is not exhaustive

2. General Characteristics

2.1 CHEMICAL COMPOSITIONS

C	Mn	Ni	Cr	Mo	S	P
≤0.280	≤1.600	about 0.400	≤1.600	≥0.200	<0.005	<0.015

2.2 DIMENSIONAL PROGRAM

<table>
<tr><th></th><th>Small Sizes</th><th colspan="2">Large Sizes</th></tr>
<tr><td>Thickness
mm
(inches)</td><td>1500 x 3000
(60” x 120”)</td><td>2000 x 6000
(72” x 240”)</td><td>2500 x 8000
(96” x 280”)</td></tr>
<tr><td>4
(0.18”)</td><td>XX</td><td colspan="2"></td></tr>
<tr><td>5 to 45
(0.2” to 1.75”)</td><td>X</td><td>X</td><td>XX</td></tr>
<tr><td>46 to 50
(1.75” to 2”)</td><td>X</td><td>XX</td><td rowspan="2"></td></tr>
<tr><td>51 to 120
(2” to 5”)</td><td colspan="2">Please Contact Us</td></tr>
</table>

XX Recommended sizes X Possible sizes

2.3 GENERAL DELIVERY CONDITIONS

DIN	AFNOR	ASTM	OTHER STANDARDS
1543	NFA 46503	A 20	Please consult us

Guaranteed flatness tolerance: ≤ 5mm/m

Thickness tolerance up to 1" thick - 0.22 mm

2.4 MECHANICAL CHARACTERISTICS

2.4.1 Delivered Hardness:

470 BHN typical value, 430 BHN minimum
540-560 work hardening with impact

2.4.2 Toughness

High toughness for so hard a steel

- Guarantee: K_{CVL} -20°C (-4°F): ≥ 40 J/cm² (≥ 23.6 ft. lbs)
- Typical value at -20°C (-4°F): 55 J/cm² (32 ft. lbs)

2.4.3 Tensile strength at 20°C (68°F)

Indicative values:
UTS : 1630 MPa (235 KSI)
Y.S : 1250 MPa (180 KSI)
EI. (5d): 12%

2.5 ELEVATED TEMPERATURES BEHAVIOUR

2.5.1 Hot tensile strength (indicative values)

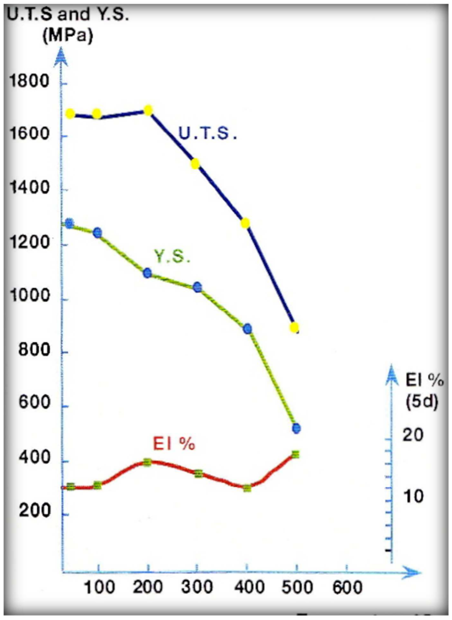


Figure 3: Tensile Strength v Temperature

2.5.2 Softening behaviour

Typical tempering curve:

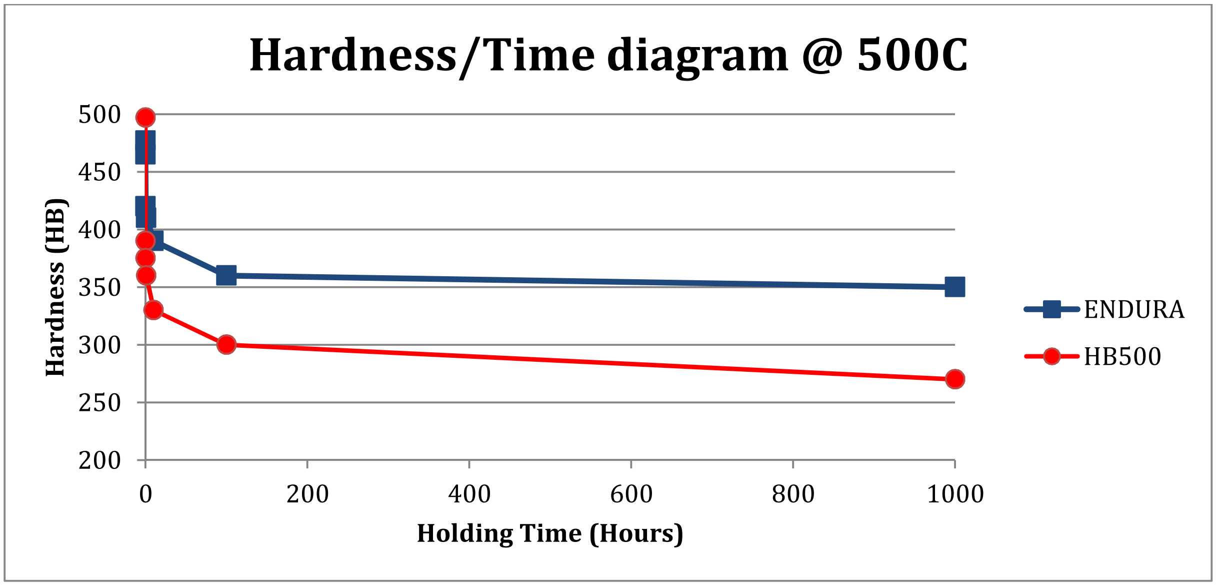


Figure 4: Tempering Curve

2.5.3 Coefficients of expansion: Average coefficients to 600°C

20°C to 100°C = 11.2 x 10^{-6}°C^{-1}
100°C to 200°C = 12.7 x 10^{-6}°C^{-1}
200°C to 300°C = 13.4 x 10^{-6}°C^{-1}
300°C to 400°C = 15.0 x 10 $^{-6}$°C^{-1}
400°C to 500°C = 16.0 x 10^{-6}°C^{-1}
500°C to 600°C = 16.3 x 10^{-6}°C^{-1}

20°C to 100°C = 11.2 x 10^{-6}°C^{-1}
20°C to 200°C = 12.0 x 10^{-6}°C^{-1}
20°C to 300°C = 12.5 x 10^{-6}°C^{-1}
20° to 400°C = 13.2 x 10^{-6}°C^{-1}
20°C to 500°C = 13.8 x 10^{-6}°C^{-1}
20°C t0 600°C = 14.2 x 10^{-6}°C^{-1}

3. Processing Ability of Endura Compared with Conventional 500 BHN Steels

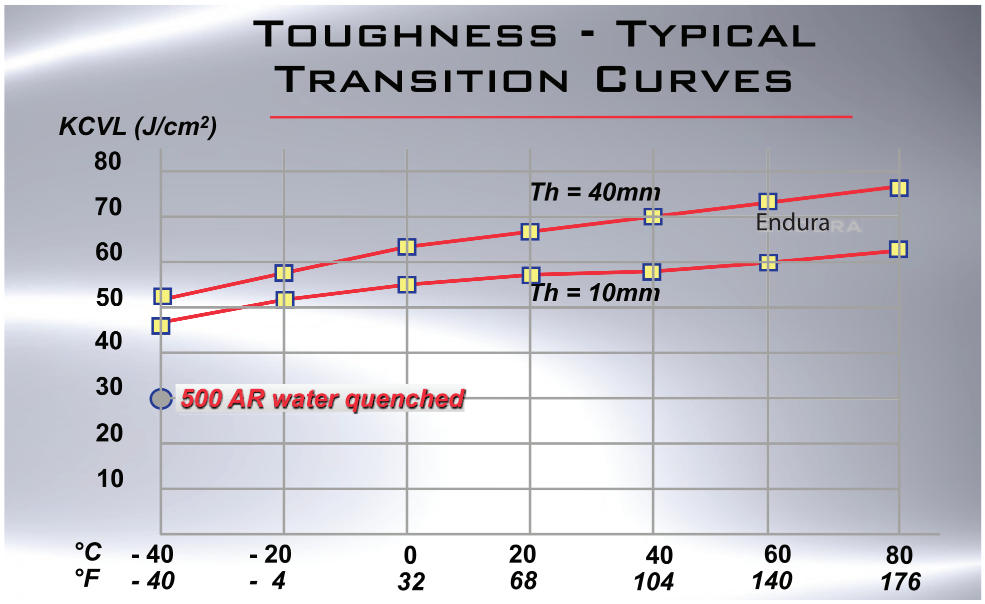


Figure 5: Toughness

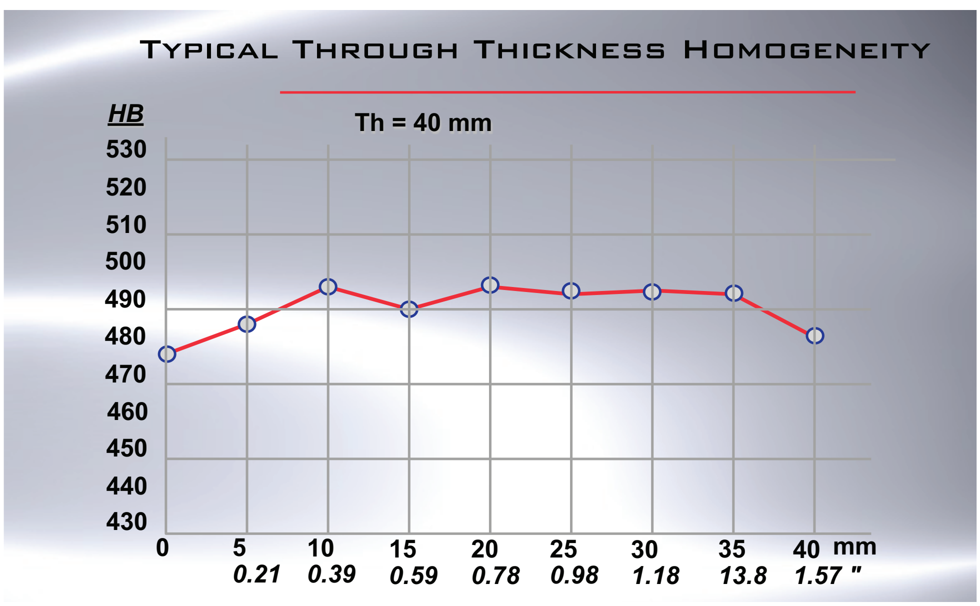


Figure 6: Homogeneity

3.1 Benefits of Endura

- Tough
- Ductile (***TRIP*** – Transformation Induced by Plasticity)
- Superior Thru-Hardness
- Homogeneous Microstructure makes Endura much more resistant to chipping, cracking, tearing, etc.
- Significantly easier to process, weld, and cut.

3.2 Performance of Endura

Endura offers maximum performance with minimal gauge.

These unique characteristics allow for a REDUCTION in Gauge while realizing the same or improved wear of thicker AR 500 steel.

- Reduce Thckness
- Reduce Weigth
- Increase Wear
- Increase Pay-Load

Example – 3/8" ENDURA will out perform ½" AR 500.

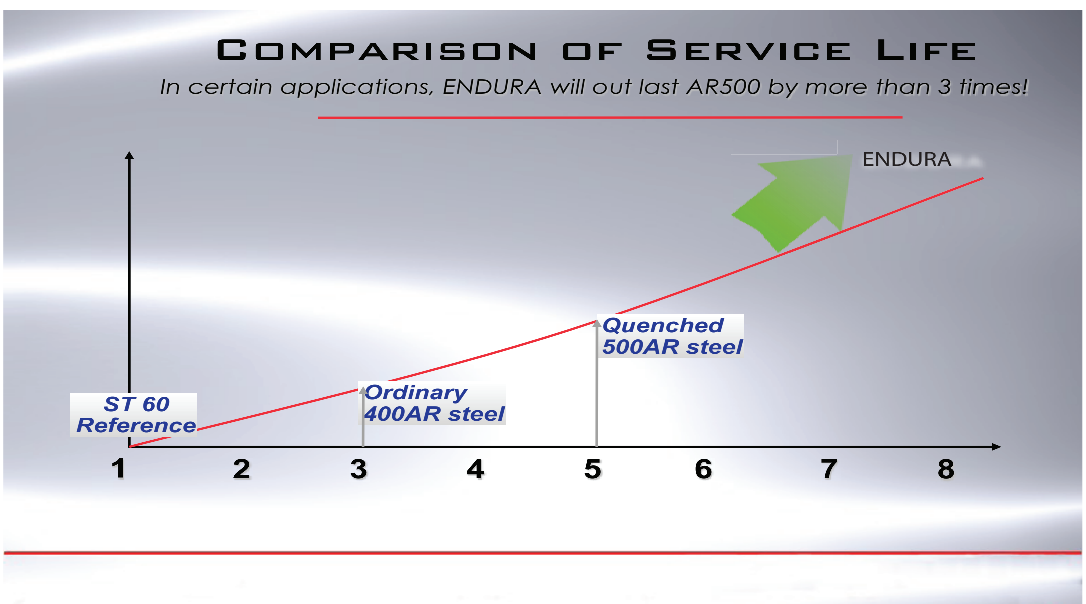


Figure 7: Service Life

Processing Endura

Operation	ENDURA	Ordinary 500 AR Steel
Bending Minimum bending radius	Ri ≥ 5 thickness	Ri ≥ 5 thickness
Rolling Minimum diameter	Int Ø ≥ 40 thickness	-
Welding Ct= combined thickness (welding energy ≈ 15 J/cm)	No preheating up to Ct = 50mm (2")	Preheating for all thicknesses
Flame cutting (Oxygen cutting, plasma…)	No preheating up to 40mm thickness (1.6")	Up to th 20 or 30 mm (0.78 or 1.18")
Machining (drilling, milling)	Possible with high speed tool HSSCO or tools with tip in tungsten carbine	Tungsten carbide tools or High speed steel with tip in tungsten carbide
Charpy V (-20°C)	≥ 40 J/cm^2	≥ 31 J/cm^2
Yield Tensile	1370 MPA (197KSI) 1640 (236KSI)	1300 MPA (187KSI) 1550 (223KSI)
Elongation	12 %	8 %
Service life	1,5	1

Figure 8: Processing Description

4. Cutting

ENDURA plates can be cut using any thermal techniques i.e. oxygen, plasma and laser cutting. Plates thicker than 40 mm must be preheated to about 150°C (302°F) in order to avoid cracking.

4.1 OXYGEN CUTTING

4.1.1 Fuel gases

Any fuel gases usually available are suitable: acetylene, propane, natural gas, tetrene etc.

Note:

- Acetylene and tetrene provide a higher thermal value, which enables an increase in cutting speeds
- Tetrene cutting results in reduced adhesion of oxides to the oxygen cut edges

4.1.2 Recommendations

Standard

- Cut plates at a temperature ≥ 10°C (≥ 50°F)
- Select gas nozzle according to the thickness of the sheet to be cut.
- Observe cutting parameters: gas output and pressure cutting speed etc. specified in operating instructions.

Additional recommendations

- Reduce cutting speed at rounded corners;
- Profile inner holes before cutting off the external edges of the part
- Sequence cutting to reduced distortion of the component and limit the possibility of crack formation during straightening operations.

4.2 PLASMA CUTTING

Plasma cutting offers more advantages than oxygen cutting:

- For 20 mm thick plates and less, cutting speed is doubled;
- Reduced deformation after cutting;
- In thin plates, no slag sticking to cut edges;
- Heat Affected Zone (HAZ) is reduced by half, enabling arc welding to be carried out directly on the edges after simple brushing

NOTE:

- Underwater Plasma is preferred to eliminate HAZ
- Use of nitrogen as plasma carrier gas is preferable to argon + hydrogen mixture, not only because of the lower cost of nitrogen itself, but also because of the reduced risk of cracks in heating affected zones of the edges (the presence of hydrogen could possibly sensitize this zone).

4.3 LASER CUTTING

Laser cutting offers a number of advantages but cannot be used for thicker sizes over 15 mm

- High precision and regularity of cutting
- No deformation of the part after cutting
- Insignificantly altered heat affected zone
- No excess material at root or metal drops underneath
- Direct welding without preparation of edges
- Reduced warming in the case of small parts

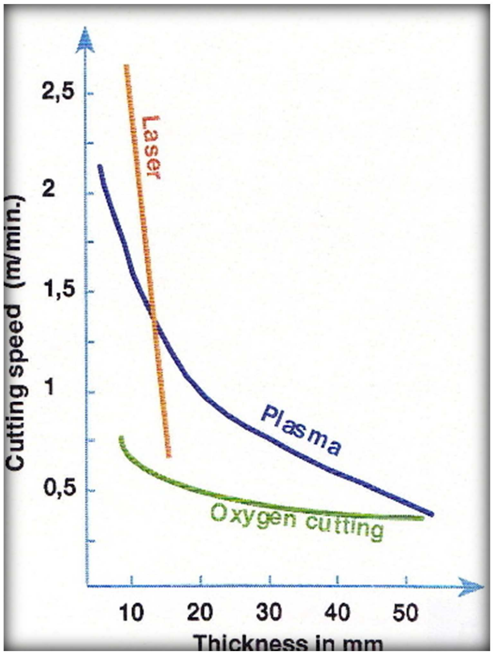


Figure 9: Comparison of Cutting Speed Between Oxygen / Laser / Plasma Cutting

5. WELDING

ENDURA plates can be joined using any conventional welding technology: manual welding with coated electrode, gas metal arc welding with flux cored wire, submerged arc welding.

ENDURA plates can also be welding without preheating for thickness up to 50mm (2”).

There is a wide range of welding electrodes and ancillary products available for ENDURA welding.

5.1 PREPARATION

5.1.1 Surface Preparation

Surfaces must be clean to avoid deterioration of weld quality due to oxides, oil, grease or other contamination.

5.1.2 Raw edges after oxygen cutting

These should be ground to remove any residual oxides, dross or slag.

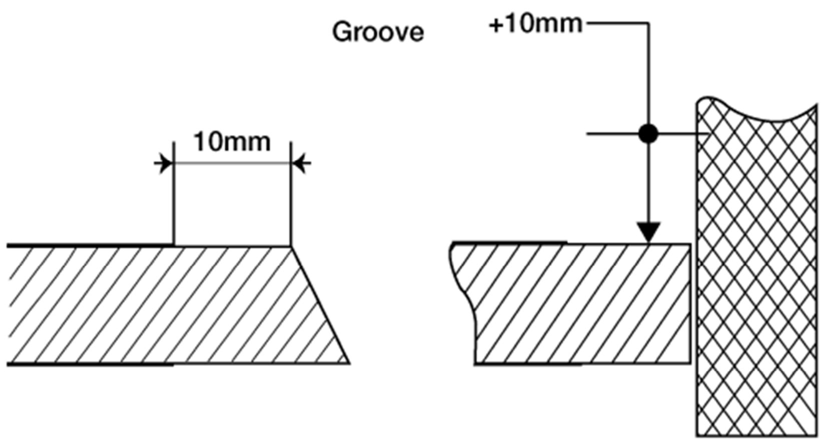


Figure 10: Weld Preparation

5.1.3 Edges before welding

These should be clamped in position, preferably with mechanical devices.

5.1.4 Weld points

These should be made by skilled welders under conditions required for welding:

- Electrodes dry and stored according to the recommendations of producers
- Possible pre and post-heating if the weld length is more than 30mm.

The parent metal dilution should be limited to avoid risk of weld metal deposited cracks.

Backward welding at the end of each bead to properly fill the craters of the weld pass and thus avoid incipient cracks.

Any cracked tack welds must be removed before the welding operation.

5.1.5 Alignment tolerances

Fastening of welded edges to ensure compliance with alignment tolerances during all the welding operations.

5.1.6 Wettability and shape of the beads

Good wettability and appropriate shape of the beads are suggested. Continuous welds are preferred . Geometrical stress concentrations must be avoided.

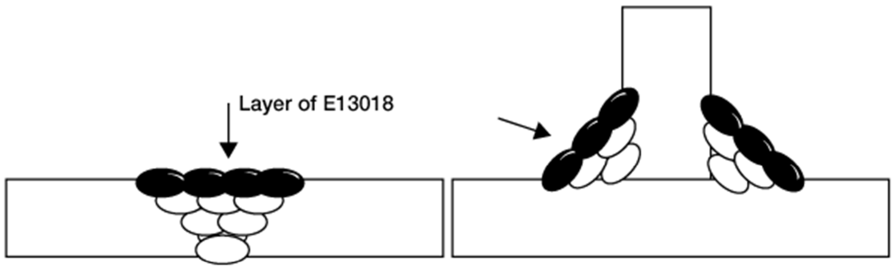
5.2 FILLER MATERIALS

5.2.1 General information

Electrodes (low hydrogen) currently used in welding of E 255 (A 350 LF1 and LF2) steel grades are suitable for joining abrasion resistant plates.

These products provide much softer weld beads than the plate itself. We suggest in cases where designs of the fabrication lead to wear exposure of weld joints, to carry out protective passes using harder metals such as:

- Electrode E 13018 according to AWS A 5 – 5
- Hardfacing materials ensuring 350 to 450 BHN.



In MAG and Gas protected cored wire electrode welding processes we suggest to use preferably an Argon/18-20% CO_2 gas mixture (M21 mixture according to DIN).

5.2.2 Ferritic welding materials for joints not exposed to wear

Coated Electrodes

AFNOR Specification	DIN Specification	AWS Specification
A 81309 E 514/3B	DIN 1913 E 5143 B 10 class	AWS A5-1 E 7016 class Or E 7018 class

Welding materials with very low hydrogen content are recommended.

Some examples:

- Boehler→ Fox EV 50
- ESAB→ OK 48-04
- Klockner→ Firma 5520 R
- Oerlikon→ Tenacito 38 R
- SAF→ SAFNER NF 58 – SAFDRY NF 58
- UTP→ 613 Kb
- Smitweld→ Conarc 49 C – EMR Sahara
- And any other equivalent product.

ENDURA – Example of a SMAW weld joint
Plate thickness 40 mm, stick SAFDRY Ø 4 mm butt weld
Combines thickness = 80 mm, preheating at 150°C

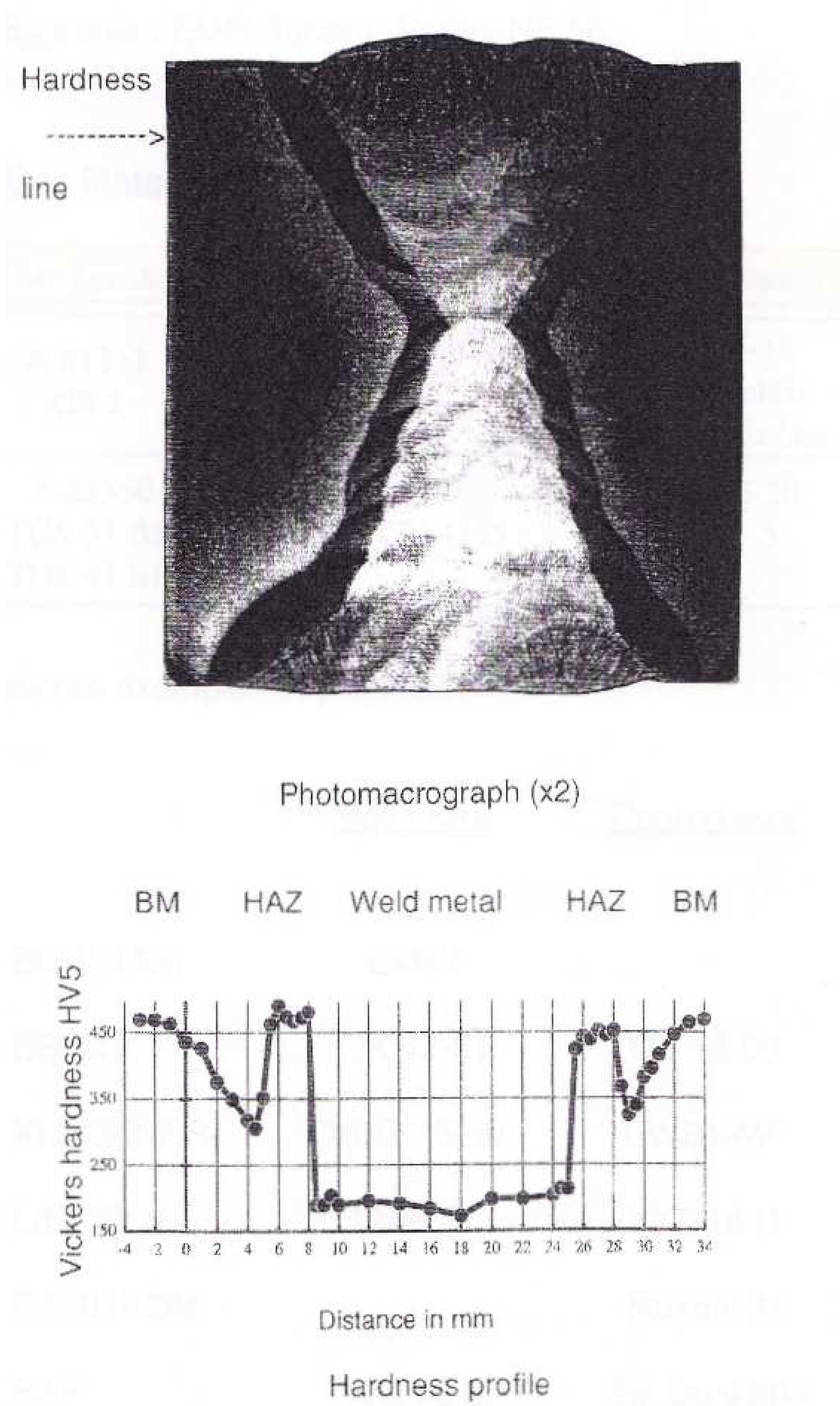


Figure 11: SMAW Cross Section (photo macrograph)

In case of on-site welding, we recommend the use of coated electrodes with vacuum packing to consumed in the same day after opening of the pack.

Example: EMR Sahara, SAFDRY NF 58.

Gas Metal Arc Welding (GMAW)

AFNOR Specification	DIN Specification	AWS Specification
A 81311 GS 2	DIN 8559 SG 2	AWS A5-18 ER 70S4 class Or ER 70S6 class
A 81350 TGS 51 BH TGS 47 BH	DIN 8559 SGB 1 CY 4255	AWS A-5-20 ER 71 T 5

Some examples of products:

	Solid Wire	Coated Wire
BOEHLER	EMK7	--
ESAB	OK 12-51	OK 15.00
KLOCKNER	VDG 15/60	EWB1-MF
LINCOLN	LNM 27	MC710 H
OERLIKON	--	Fluxofil 31
SAF	NiC 70 S	Saf Dual 200

Submerged Arc Welding

AFNOR Specification	DIN Specification	AWS Specification
NFA 81316 FP/F or B…IFB SA2.47.0302	DIN 8557 UP-Y 35 or Y 31 – 43 S [1 to 3] F AB Or – or 1…. B FB	AWS A5-17 wire EM 12 K flux F6.A4.EL 12 or flux F7.A4.EM 12

Examples of products:

- ESAB→ OK Autrod 12-10 + Flux 10-71
- SAF→ Wire AS 26 + Flux AS 72
  Wire AS 35 + Flux AS 72
- LINCOLN→ Wire Lincolnweld 860 + Flux L-61
  Wire Lincolnweld 882 + Flux L-60

- And other equivalent products.

5.2.3 Ferritic welding materials for joints exposed to wear

These materials can be used in surface-protective runs.

Manual welding with coated electrode

AFNOR Specification	DIN Specification	AWS Specification
A 81340 EY 89	DIN 8529 EY 89	AWS A5-5 E 12018 class

Examples of products:

- BOEHLER→ Fox EV 85
- ESAB→ OK 78-05
- OERLIKON→ Tenacito 100
- SAF→ SAFER ND100 – SAFDRY ND100
- Smitweld→ Conarc 85 EMR Sahara
- And any other equivalent product

GMAW

AFNOR Specification	AWS Specification
A 81352 TG5 Y89	AWS A5-28 ER 120 S1 class

Examples of products:

- Solid Wire
  - BOEHLER→ Ni Cr Mo 90 IG
  - KLOCKNER → EW – X 90
  - SAF→ NIC 88
- Coated Wire
  - OERLIKON→ Fluxofil 45
- And any other equivalent materials

5.2.4 Hardfacing – Welding Material

In this case the preheating conditions will be defined by the welding material being more alloyed than the parent metal.

Examples:

- Manual welding with coated electrodes:
  - BOEHLER→ Fox dur 350
  - COMMERCY→ Cydur 2

- SOUDOMETAL→ Soudodur 400
- KLOCKNER→ Dura EA 350

- GMAW:
    - BOEHLER→ Dur 350 IG
    - ESAB→ OK Tubrod 1403
    - KLOCKNER→ Dura EA 300SG

5.3 AUSTENITIC OR AUSTENO-FERRITIC MATERIAL

In case of on-site repairs when it is difficult to maintain the necessary conditions (for lack of electrodes under vacuum packing, electrode drying, pre-heating of thick plates, very restrained assembly) austenitic welding material can be used.

Welding Process	Manual welding with coated electrode	GMAW Solid Wire
Chemical Composition	20 Cr – 10 Ni – 3 Mo*	18 Cr – 8 Ni – 6Mn
AWS Specification	E 308 Mo (AWS A5.4)	ER 307 Si (AWS A5.9)
DIN Specification	E 19123 B (DIN 8556)	SG X 15 Cr Ni Mn 18.8 (DIN 8556)

* Coated electrode used for armored welding.

Despite the obvious security provided by such filler materials, it is strongly recommended to dry the electrodes or fluxes according to supplier requirements

5.4 WELDING CONDITIONS

5.4.1 General environment conditions

To avoid risk of cracks:

- For high production processes, limit dilution of the parent metal
- All welded joints should be protected from wind and rain until complete cooling of weld has been obtained
- Vibration inducing operations carried out in the vicinity of welded plates (for example chipping) have an adverse effect on the soundness of welded joints and should be prohibited during welding operations

5.4.2 Welding with ferritic welding material

ENDURA can be welded without preheating, if combined thickness does not exceed 50 mm. Above this combined thickness, it is recommended to apply the preheating parameters shown in the following table.

<u>Table of welding temperatures</u>

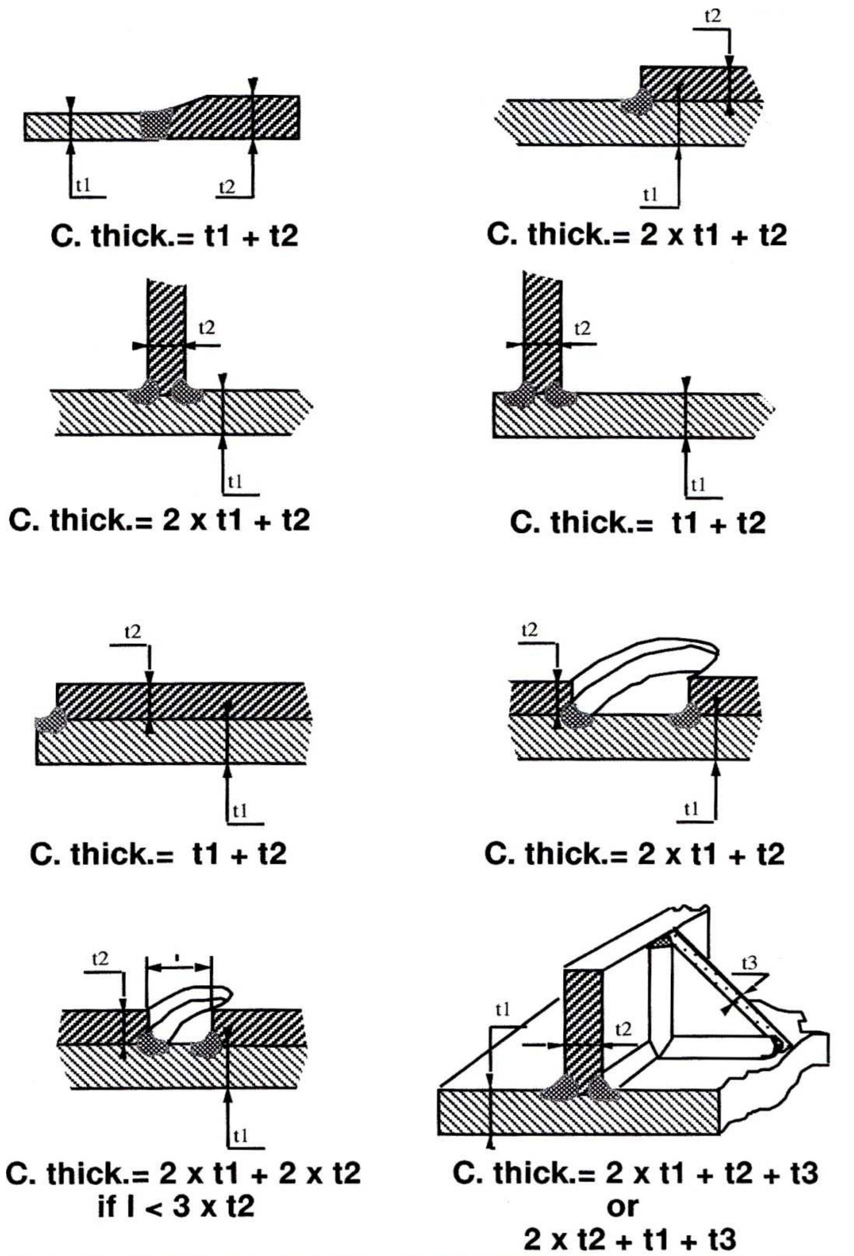
Welding Process	Welding Energy (kJ/cm)	Pre and post-heating conditions Combined thickness (mm) 10 20 30 40 50 60 70 80 90
1) Manual welding coated electrode	15/20	
2) Semi-automatic MIG	15	
	30	
3) Submerged Arc Welding	20	
	30	

- Stick or fluxes must be dried and stored according to the supplier requirements. To avoid any drying of filler materials, we suggest using under-vacuum packed sticks.
- Only welding gas free of hydrogen uses preferably mixture of Argon, CO_2, O_2, He (Atal 5, Arcal 14, Arcal 21, Migaz 18, Argon Mix 1 etc.)
- In the case of welding with high tensile filler materials, a preheating can be necessary even for low combined thickness, because of cracking in weld metal

If necessary, ask the filler material supplier for more details.

For the same reasons, we suggest to avoid too much dilution with base material. For high deposition rate processes (SAW), high travel speeds are suggested.

Determination of combined thickness (Ct)



NB: Combined thickness is only a way to assess clamping in weldments. When several plates are welded together a weldment is highly clamped, one might over evaluate combined thickness to guarantee sufficient security.

5.4.3 Welding with austenitic welding material

In this case ENDURA plates are welded without preheating,

Nevertheless, for sufficient security, and for highly clamped structures (combined thickness > 100 mm) or repairs, it is recommended to use a preheating and an interpass temperature higher than 75/100°C.

5.4.4 Limitation of welding stresses

A proper sequence of welding operation should be followed in order to limit welding stresses.

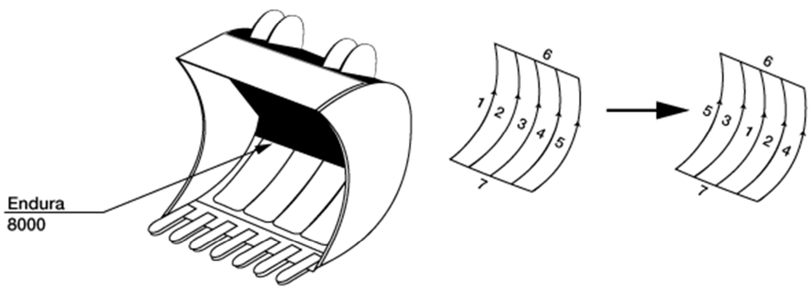
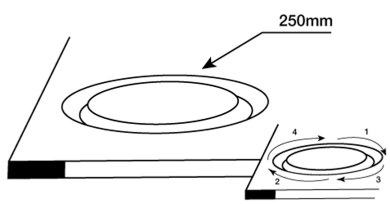
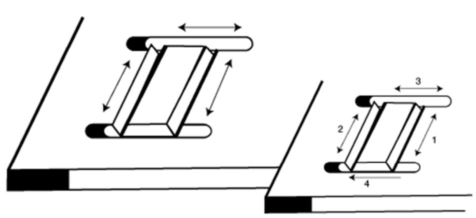


Figure 12: Welding Sequence

Prefer the internal welding to the external welding

<u>Surface repair in thick plates:</u>





As with all high abrasion resistance steels, post-welding heat treatment is not recommended. Any softening of the ENDURA base material would affect its excellent anti-abrasive properties (for your guidance, refer to the softening resistance curve: 5-2 paragraph, part 2).

5.4.5 Welding of thin plates (thickness < 6 mm)

- As detailed earlier, take care in the preparation of plates. (Grinding or sand blasting)
- When thin plates are welded together, it is better to control the use of heat input (1.3kJ/mm). Large beads are deleterious because they cause distortions and heat affectation through the thickness of plates
- Some care must be applied to use appropriate welding sequences. A shrinkage direction must be kept free to avoid too high stresses and distortions

Welding sequences must be optimized to weld without too many residual stresses.

- Welding consumables must have medium mechanical properties and GMAW should be used preferably.

5.4.6 Recommendations

- When welding with GMAW a wire speed lower than 4.5 m/min can guarantee a heat input lower than 1.3 kJ/mm.
- When pulsed GMAW is used, we suggest to use 10/10mm instead of 12/10mm diameter wires.
- Equivalent carbon formulas are not applicable to ENDURA, which is a high hardness steel grade with alloy additions
- Equivalent carbon formulas or HAZ hardness criteria's have been defined for carbon manganese steels. Therefore they are inoperative on high wear resistance steels. One might, for instance, wonder of the validity of criteria's such as hardness in HAZ lower than 350 HV when the base material itself has a hardness of 460 HV.
- Recommendations for ENDURA welding have been determined on a welding test basis. They have been confirmed by industrial experiments.

5.4.7 FLASH STUD WELDING

It is recommended to use mild steel studs S 235 J2 or St 37 (A 350 LF1) grade.

Recommendation:

In order to guarantee good quality of welds, it is necessary:

- To grind and to centre punch the position where the stud must be welded
- To keep welding gun perpendicularly to the surface on which the stud has to be welded
- Check welding parameters by carrying out five preliminary flash welds followed by a pull-off test according to NF A 89020 part 2 specification (+ XPA 89022, performance classes).
- To check periodically for current operational parameters at manufacturing

6. MACHINING

Machining operations which are commonly performed on components made of wear resistant plates are:

- Drilling
- Milling
- Counter sinking, spotfacing
- Tapping

In spite of higher mechanical characteristics and owing to its microstructure ENDURA has excellent machinability. However, some caution is necessary to obtain good results.

6.1 DRILLING

Use radical type machine-tools in good condition with automatic advance and sufficient power. Machined parts should be rigidly secured to the working table.

6.1.1 Tool geometry

Twist drill with a long helical pitch (class H according to DIN 1836).

6.1.2 Selection of drills

Taper shank if diameter allows or with dive tenon

Short flutes (called short type) if thickness allows.

6.1.3 Quality of tool

Three possibilities:

1. Drill made of super-carburized high-speed cobalt steel of HSSCO type (for small and medium hole series).

Example:

AFNOR Specification	DIN Specification	AISI Specification
AR. 2. 9. 1. 8.	S. 2. 9. 1. 8. (Wekstoff 1.3247)	M 42

Trademarked examples: Guhring, Vadium

2. Drill made of high-speed steel with tip in tungsten carbide or solid carbide drill (used for smaller diameters) with straight flutes.

3. Carbide quality: K 10 – K 20 according to ISO Standards. Trademarked examples: Diager, Westa, Coromant

6.1.4 Cutting parameter (for information)

*HSSCO Drill

Drill	Ø (mm)	Cutting Speed (m/min)	Rotation Speed (RPM)	Feed (mm/rev.)
	10		125 – 190	0.07
AR.2.9.1.8	20	4 – 6	65 – 95	0.10
(M 42)	30		40 – 65	0.12

*Drill with tip in tungsten

Drill	Ø (mm)	Cutting Speed (m/min)	Rotation Speed (RPM)	Feed (mm/rev.)
	10		575 – 700	0.07
Carbide tip	20	18 – 22	285 – 350	0.10
K 20	30		190 – 235	0.12

Use drills equipped with carbide tip and TiN overlay. These drills (ex. Diager) used with the recommended cutting parameters allow a life span twice as long as compared to the standard carbide tip drill.

6.1.5 Lubrication

20% soluble oil, abundant flow (10 l/min flow rate) under low pressure.

Soluble oil ISO – L – MAD 6743/7 Class

6.2 MILLING

To be carried out with powerful machine tools, the parts must be securely fastened.

6.2.1 Preparation

Before surfacing or grooving the parts produced by oxygen cutting, it is recommended to remove the top surface of hardened part by grinding to a depth corresponding to pass depth. This will reduce premature wear of milling cutters.

6.2.2 Tool geometry

Milling cutter with a geometry suitable for the operation to be carried out.

6.2.3 Quality of tool

There are two possibilities:

Surfacing or roughing out can be executed with HSSCO mills (super-carburized cobalt alloyed high steels).

AFNOR Specification	DIN Specification	AISI Specification
AR.6.5.2.5.	S.6.5.2.5 (Werkstoff n° 1.3243)	M 35
AR.12.0.5.5.	S.12.0.5.5. (Werkstoff n° 1.3202)	T 15

Trademarked examples: Fraisa, Astra, Couurcelle-Gavelle

Tools equipped with inserted or detachable carbide tips are particularly suitable for the milling of ENDURA. For large series, these tools widely supersede the HSSCO tools for grooving and finishing operations.

Quality of carbide tips in terms of the machining operations (for your guidance)

- Removing and roughing: P 10 or P 20 carbide according to ISO
- Small surfacing: K 10 or K 20 carbide
- Grooving: P 25 carbide

Trademarked examples: Sandvik, Saferty, Stellram

NB- In grooving-operation-P 25 carbide-the use of beveled tips type SMA gives an improvement in the service life of tools.

6.2.4 Cutting parameters (for information)

Tool	Depth pass (mm)	Cutting Speed (m/min)	Feed per tooth (mm/tooth)
HSSCO Steel T15	1 4 8	10 – 12 8 – 11 5 – 8	0.08 0.12 0.12

In slab milling, feed per tooth will be smaller, however it will not result in oversized chips provoking refusal of cutting.

Cutting parameters in surfacing

- Roughing (depth pass: 2 mm)
- Carbide tips: P 10 to P 30
- Cutting speed: 70 m/min

Feed per tooth: 0.20 mm/tooth

End operations (depth pass: 0.2 mm)

- Carbide tips: K 10 / K20
- Cutting speed: 70 m/min
- Feed per tooth: 0.10 mm/tooth

Cutting parameters in grooving

Roughing

- Carbide tips: P 25 (with strengthening edge at 20°)
- Cutting speed: 45 m/min
- Feed per tooth: 0.15mm/tooth

End operations (depth pass: 0.2 mm)

- Carbide tips: (see above)
- Cutting speed: 50 m/min
- Feed per tooth: 0.08 mm/tooth

6.2.5 Lubrication

- 10% soluble oil or cooling by blown air for end passes.

6.3 COUNTERBORING AND COUNTERSINKING OF SCREW HEAD SEAT

Use cutting mills with 3 or 4 teeth and carbide tips – Type P 25 according to ISO Standard – with axial pilot the diameter of which corresponds to that of the hole.

Example of adjustment for a counterbore at 90° in a 10 mm hole:

- spindle speed: 1500 RPM
- advance: 0.12 mm/rev
- lubrication: 10% soluble oil – flow at about 10 l/min

6.4 TAPPING

This operation can be performed only by a tapping machine

6.4.1 Example of tapped holes with small diameters maximum M 15

It is necessary to use special taps (example: TARAUD ALLIGATOR)

a) Tapping geometry

- Reinforced tool (thickset)
- Straight flutes (3 flutes)
- Recessed threads

b) Preparation

- Tapping drill holes should be drilled in diameter within upper limits of tolerance with allowance 0.1 to 0.2 depending on thread pitch.
- Execute small countersinking of predrilled holes.

c) Quality of that kind of tap

High speed steel HSSE Trademark ALLIGATOR

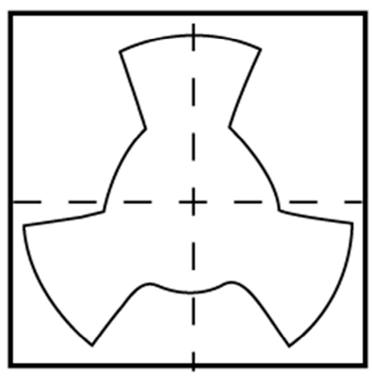


Figure 13: Alligator Tap Profile

d) Cutting Speed

2 m/min gives the best results

e) Lubrication

- Continuously sprayed oil under very high pressure
- Example: special oil ALLIGATOR Filoil 2

6.4.2 Example of tapped holes with large diameters up to M 60

- It is necessary to is threading countersinkers (example: Dixi from Vadium)
- Use of a machine with numerical control is necessary.
- Solid carbide threading countersinker – K 10 or P 25 according to ISO standard (micro-granular carbide).

a) *Cutting parameters*

- Cutting speed: about 80 m/min
- Feed per tooth: can be quite correctly assessed by following formula: fz= 0.01 x D1(D1 is the diameter of the tool)

b) *Lubrication:*

- 20% soluble oil

7. BENDING – ROLLING

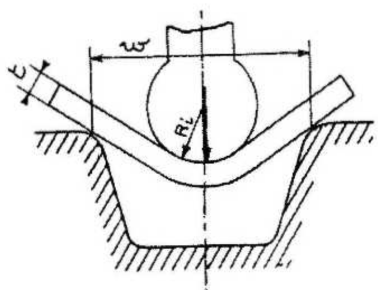
Due to treatment under a high vacuum at the steel plant, ENDURA has excellent flatness. This also enables cold bending and rolling in spite of high tensile values (U.T.S and Y.S)

However, these high mechanical characteristics require some operator caution when bending or rolling the plates.

7.1 BENDING

7.1.1 Type of Press

The operation should be carried out on a conventional hydraulic bending or brake press. Use of presses with a fabricated bending beam is not recommended for ENDURA.



7.1.2 Capacity of Press (P)

The capacity of the machine used should be compatible with the work to be carried out. Bending loads depend of the steel tensile strength, the thickness of the plate, the radius of the mandrel and the V-blocking opening.

In the case of ENDURA, U.T.S. = about 1600 MPa.

For information:

- P = 200 t/m for 10 mm sheet
- P = 430 t/m for 20 mm sheet

Therefore, bending ENDURA, implies bending presses with greater capacity than used on AR steels.

7.1.3 Spring-back

Because of the relatively high elastic limit of this steel grade, the operator must allow for spring-back (opening of angle after releasing load).

Design of tools, and especially, angle of V-block and its depth should be properly chosen (i.e. smaller V-block angle, deeper V-black).

7.1.4 Inside minimum bending radius RI for 90° bending

$r_i \geq 5$ t (t = plate thickness)
($r_i \geq 6$ t, with the axis parallel to the rolling direction of the plate)
V-block width: ≥ 14 t

According to the equipment available, bending can be performed.

- with mandrel with a radius matching the bending radius,
- or, in the case of larger radius, in several consecutive bending operations with progressive steps. Here, a thrust block will allow regular folding to be obtained.

7.1.5 Recommendations for bending operation

- Bending must be carried out with direction of the bending line perpendicular to direction of plate rolling to avoid cracking.
- Bend plates at a temperature ≥ 10°C (≥ 50°F)
- Remove all gouges or scratches on the surfaces to be worked, namely on outside surface, submitted to tensile strength
- Grind a chamfer on the edges outside and grind away the dross left oxygen cutting in order to avoid incipient fractures
- Do not carry out bending in one stroke but in several consecutive “bumps” at regular and limited increments
- Lubricate the mandrel and support edges with graphite; this will facilitate of the metal
- Avoid excessively long outside storage of plates intended to be bent. Rust can considerably alter bending capability in the smaller radius range.
- **Safety of personnel: as the elastic energy accumulation in the plate is high, one should consider the possibility of sudden cracking. Therefore, the operator should stand at the side of the machine, not in front of it to avoid injury.**

7.2 ROLLING

Rolling of ENDURA can be performed on all types of roll bending machines.

7.2.1 Types of rolling presses

Rolling press, pyramid type, with 3 rolls

Preliminary bending of extremities of the plate is necessary before rolling; it can be performed on a pending press or on an open-front forging press.

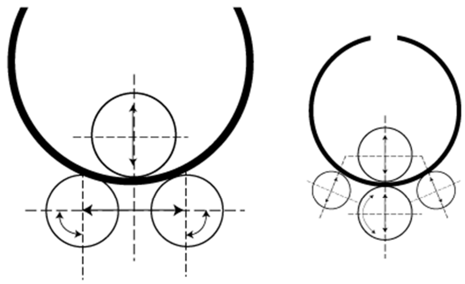


Figure 14: Rolling Press with 3 and 4 rolls

7.2.2 Capacity of rolling

With ENDURA plates the maximum thickness that can be cold rolled is about the one third thickness allowed by the rolling machine used for mild steel, E 24 (A 350 LF 1) grade.

7.2.3 Spring back

As in the case of bending, the relatively high elastic limit results in a high spring-back trend.

In rolling, this phenomenon becomes critical, namely thin or medium-thickness plates (t < 20 mm) have to be rolled around a large diameter (Ø > 1m), i.e. if the Ø/t ratio is high.

In such cases, in order to obtain the expected diameter of the finished product, one has to process the plate in forming rolls of a considerably smaller bending radius. Here, the skills of the operator are decisive.

7.2.4 Quality of rolls

Considering the mechanical properties of ENDURA, we recommend using rolls made of a high quality grade, forged and thermally treated in order to avoid any flow marks.

Examples of steel grade:

AFNOR Specification	DIN Specification
35 NCD 16	Werkstoff n° 1 6757

In order not to damage rolls made of standard quality grade, we recommend the ENDURA plate be placed between two thin plates of extra mild steel.

7.2.5 Minimum inside rolling diameter $Ø_i$

Conventional workshop methods

$\mathbf{Ø_i \geq 40\ t}$ (t = plate thickness)

7.2.6 Recommendations for rolling

The above-mentioned recommendations for bending apply. More over we recommend:

- rolling must be carried out with a sufficient number of return passes
- gradual tightening
- suitably chosen rolling speed