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Hot rolled Steel Plates, Sheets and Coils

Steels resistant to wear and surface pressure

Raex

Hardened steel resistant to abrasive wear caused by rolling contact and high surface pressure can be used to significantly lower the costs generated by wear and break -down of stuctural components. Despite its strength and hardness, weldability and formability of the steel grade are good.

Applications

- bodies, buckets and cutting edges of earth moving machines
- wearing parts of mining machines
- wearing parts of concrete mixing plants and wood processing machines
- platform structures
- feeders, funnels

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HR 2.1.46 07.2007

- **Designation**
Raex 400, Raex 450 and Raex 500 are hardened wear-resistant steel grades. The number of the designation indicates the average Brinell hardness value: 400 HBW, 450 HBW and 500 HBW, respectively.

- **Product shapes and dimensions**
Cut lengths and heavy plates. Dimensional ranges are in table 3.

- **Supply condition**
Hardened.

- **Tolerances on dimensions and shapes**
Plate products: Thickness EN 10029 Class A. Width and length EN 10029. Flatness EN 10029, Class N normal tolerances of flatness, steel type H.

Cut lengths: Thickness, width and length EN 10051. Flatness EN 10029 Class N, steel type H.

- **Chemical composition**
The chemical composition is shown in Table 1.

- **Mechanical properties**
The mechanical properties are shown in Table 2.

- **Surface finish**
EN 10163-2 Class A3. Repair welding of plates is not permitted in plate production of Raex steels.

- **Abrasion resistance and hardness**
The microstructure of abrasion resistant steel is martensitic, which guarantees high hardness and tensile strength. The hardness of Raex 500 is over three times that of S355 structural steel, Raex 450 is nearly three times and Raex 400 is two and a half times as hard as S355 structural steels. High hardness and tensile strength give steel high resistance to abrasion in rolling contact. Good abrasion resistance is the most important basis for choosing these steels.

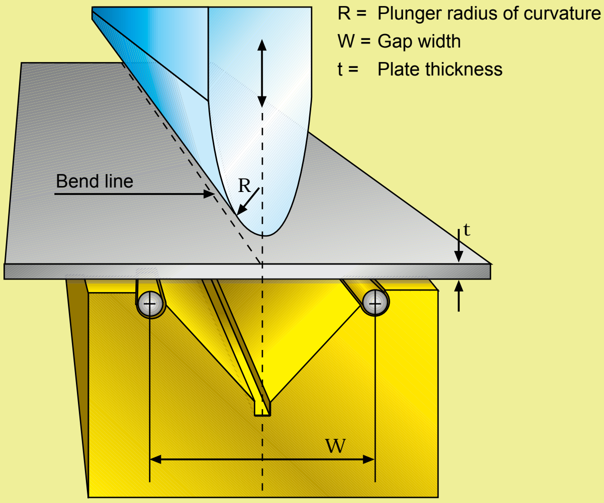
- **Testing**
Brinell hardness HBW is measured in accordance with EN ISO 6506-1.

- **Inspection document**
A test report in accordance with standard EN 10 204-2.2 is issued. The test report verifies the chemical composition of the product but not the result of mechanical tests. However, the hardness of the hardened plate is given.

- **Flanging and free bending**
Despite of their high strength Raex 400 and Raex 450 steel grades can be formed by free bending or flanging. However, the bending force, springback effect and the bending radius are greater than those for softer structural steels. When bending or flanging, workshop practices, condition of the tools and careful planning must be taken in to consideration. General recommendations for the bending of abrasion resistant steels:
  - Use the widest possible bending radii, the values are presented in table 4.
  - Grind away any scratches and other surface defects from the tension side plate surface – otherwise they may function as initial cracks.
  - Grind away any rough edges on thermally or mechanically cut plate, at least on the tension side of the plate.
  - Carry out the bending in a single pass to the ultimate curvature; springback must not occur during the work.
  - The die and plunger surfaces of the edging press must be smooth.
  - Lubrication of bending surfaces reduces friction.
  - Preheating to 100 – 200°C reduces the bending force required and the risk of cracking.
  - A die of the type shown in figure 1 improves the quality of bending.

- **Work safety**
Hardened Raex wear-resistant steels have to be handled with special care during workshop processing, such as bending and flanging. The instructions given by the steel supplier and good quality of the engineering workshop practice form an essential part of work safety.

Flanging and free bending *Figure 1*



- *The surface hardness of the upper edges of the die groove must be greater than the hardness of the plate that is to be bent. In the structure shown in the figure, the upper edge of the die groove is equipped with 20 mm iron rods with the hardness of approximately 53 HRC.*
- *The grooves in which the iron rods are located must be kept clean.*
- *Widening the die groove decreases the need for bending force but increases springback.*
- *Springback:*
  Raex 400 9° – 13°
  Raex 500 10° – 15°

Welding

All the normal welding procedures can be used for hardened abrasion resistant steel grades, provided that a professional welder pays special attention to the following factors:
- Use of correct working temperature.
- Correct choice of welding consumables.
- Suitable arc energy.

A reserved attitude to post-weld heat treatments should be taken, because they have a tendency to weaken the most important property of these steels i.e. wear resistance.

Carbon equivalent value (CEV)

The carbon equivalent values are shown in Table 9.

Working temperature

Increasing the working temperature slows the cooling of welded joints, which decreases the generation of a microstructure that is too hard and brittle and vulnerable to cracking in the heat affected zone (HAZ). It is advisable to increase the working temperature of Raex 400 steels, when the combined plate thickness exceeds about 40 mm. The respective thickness is about 30 mm for Raex 450 and about 20 mm for Raex 500. Generally a working temperature of 100°C is high enough to ensure a good result.

However, when heavy and complicated structures are welded and when welding takes place under difficult circumstances, a higher, 150 – 200°C, working temperature is recommended, see table 5. A higher working temperature than this may weaken the mechanical properties.

Welding consumables

Either conventional, so-called non-alloyed filler materials or so-called alloyed materials that produce high-strength weld metals can be used as filler material. Generally non-alloyed filler materials are silicon and manganese alloyed, and the strength of the weld metal they produce remains lower than the strength of the hardened base material. In this case we talk about "undermatching" filler materials, such as E 7018, AWS A5.17, AWS A5.18, AWS A5.20. Correspondingly, we use the word "matching" when we talk about alloyed filler material, such as E 11018, E 9018, AWS A5.28, AWS A5.29. An important advantage of non-alloyed filler material is that the softer weld metal they produce responds better to welding stresses. This is due to the better elongation and deformation ability of the soft weld metal in comparison with high-strength weld metal. It is highly advisable to use low-hydrogen (hydrogen content of the weld HD ≤ 5 ml/100 g), basic filler materials so that the amount of hydrogen will remain on a safely low level.

Non-alloyed filler materials are used if the welded joints in the structures are not exposed during use to hard wear and loads. Correspondingly, the use of alloyed filler materials is necessary, if a welded joint is exposed to hard wear or the filler material is supposed to have the high strength level of the base material. When alloyed filler materials are used, the need for increasing the working temperature is higher than welding with non-alloyed filler materials. Generally, when moderately thick plates are welded, it is enough that 1 – 3 final runs are welded with matching filler material and the fill up runs with undermatching filler material. Recommended welding consumables are listed in table 6.

Arc energy

The maximum value of arc energy for Raex steels has to be limited so that, on the one hand, we can limit the growth of austenite grain and, on the other hand, we can limit the tempering of martensite in the heat affected zone. Excessive growth of the grain size lowers toughness properties of a joint whereas a proportional increase of tempered martensite lowers hardness and strength. The minimum value of arc energy also has to be considered. It has to be high enough so that we can avoid excessive hardening of the HAZ. In this way we can achieve a parallel effect as by increasing the working temperature.

Achieving the optimal properties in welded structures requires the choosing of arc energy so that the cooling time $t_{8/5}$ for a welded joint is 10 s minimum but maximum of 20 s. For instance, for MAG welding a plate of thickness 10 mm this requirement corresponds to 1.2 – 1.7 kJ/mm arc energy. The dimension $t_{8/5}$ means the cooling time for a joint over the temperature range of 800 – 500°C, which is crucial from the point of view of the microstructure of HAZ.

Practical tips for welding

- Any distortion expected can be avoided by proper selection of welding parameters.
- Prehating is important, especially when tack welding.
- A strong tack welds should be made in the middle of the plate to be welded.
- The supplier's instructions for the storage, handling and drying of welding consumables should be followed carefully.
- It is recommended that welding is commnenced in the middle of the plate and proceeds towards the edges.
- The joint area should be kept at the correct temperature e.g. by welding without interruption.
- When welding thick plates, full penetration preparation should be used on both sides.
- Protect large surfaces and thick joints from excessively rapid cooling with for example mineral wool.
- Separate run off plates should be used on plate edges.

- The root must be opened carefully.
- The use of carbon arc gouging should be avoided.
- In the case that carbon arc gouging is used the carbonised layer should be ground off thoroughly.
- Welding should be finished off by grinding all edges and corners smooth.

Heat treatment

The steels are not intended to be heat treated during or after fabrication. Tempering at moderate temperatures, 150 – 200°C, is the only heat treatment which will without fail allow the steel to retain its original wearing properties.

Thermal cutting

A heat affected zone (HAZ) will build up on a thermally cut surface which is similar to the HAZ on a fusion welded steel surface. The surface hardens to a depth of 1 – 2 mm during thermal cutting and post heat results in a soft tempered layer below this.

General recommendations for the gas cutting of abrasion resistant steels:
- Plates must not be taken to gas cutting directly from the cold storage.
- Thick plates should be preheated before cutting; the recommended working temperatures are shown in table 7.
- The cutting of over 45° bevels on thick plates in some cases needs to be followed by controlled cooling, for example, under mineral wool cover.
- For workshop engineering, any flame cut surfaces should be ground clean of hardened material and sharp edges.
- The cutting speeds depend on the method and equipment used.
- The thermal cutting properties of abrasion resistant steels are usually somewhat better than for structural steels.

In practice, it is beneficial to preheat the plate to be cut when the thickness of the plate exceeds 10 mm.

Take note that the maximum allowable working temperature must be kept below 200°C to ensure that the wear resistance will meet requirements throughout the plate. The cooling of a cut surface must not be accelerated under any circumstances, on the contrary, the cooling of the plate surface can be slowed down if necessary e.g. by covering with mineral wool. A basic requirement for succesful cutting is that, prior to commencing work, a workpiece that has been stored in a cold atmosphere is allowed to warm up thoroughly to room temperature (+20°C).

Flame straightening

Any flame straightening should be carried out under consideration of their mechanical properties, which have been achieved by heat treatment. In flame straightening, the hot spot temperature must not exceed 450°C, because this could lead to local strain relief and reduction of hardness. Special caution in flame straightening is required, when the structure is exposed to fatigue loading. For example, fan blades are typical structures exposed to such loads.

Straightening with jack

Hydraulic and mechanical presses can be used for straightening abrasion resistant steel plate to correct minor waviness. The forces applied in straightening with jack are heavy and so is the springback effect on steel. The straightening of thin-gauge structures can also be carried out by combined working with hammer and jack, while a combination of flame straightening and straightening with a jack in most cases is not recommended.

Mechanical cutting

The high strength and great hardness of abrasion resistant steels have a great effect on mechanical cutting. As the material to be cut is almost as hard as the cutting blade, the blade's service life is shortened because of the damage caused by great surface pressures during cutting, such as cracking, stickiness and blunting of the blade.

However, mechanical cutting of abrasion resistant steels is possible if the characteristics of this material are taken into account. Raex 400 steel can be cut with heavy-duty cutting machines. The hardness of the cutting blade must exceed 53 HRC. The mechanical cutting of Raex 500 steel can be recommended only with certain reservations, and then only at thicknesses of less than 10 mm. See figure 2 and table 8.

General recommendations for the mechanical cutting of abrasion resistant steels:
- A heavy-duty cutting machine that is free from backlash must be used.
- The hardness of the cutting blade must be over 53 HRC when Raex 400 and Raex 450 steels are to be cut, and over 57 HRC for Raex 500.
- The life of the cutter blades can be increased by rounding the cutting edge with an oil whetstone.
- The pieces that are separated from the material during cutting must be supported from below so that they cannot rip down and discontinuously tear the material that is being cut. Tearing distorts the cutting line, and the risk of damaging the cutting blade increases.
- The plate that is being cut must be securely attached to the bench during cutting.

- Jamming of the cutter blade can be prevented by using dry coolants on the cutting edges.
- Blade damage can be detected by listening to the cutting sound.
- A cutter-specific cutting data chart is helpful for determining the correct parameters.

Machining

Raex steels can be machined using heavy-duty machines and hard metal tools. It is even possible to drill holes using tools made of high-speed steel, given proper tool geometry and using suitable cutting fluids.

Further information

The following data sheets are related to the subject: Boron steel, Welding, Thermal cutting and flame straightening, Flanging and forming, Mechanical cutting, Machining.

Chemical composition

Table 1

	Thickness mm		Content %, maximum (ladle analysis)									
	Cut lengths	Heavy plates	C	Si	Mn	P	S	Al	Cr	Ni	Mo	B
Raex 400	2.5 – 12	5 – 30	0.20	0.70	1.70	0.030	0.015	0.060	1.50	0.40	0.50	0.004
	–	(30) – 60	0.24	0.70	1.70	0.030	0.015	0.060	1.00	0.70	0.50	0.004
Raex 450	3 – 12	5 – 60	0.26	0.70	1.70	0.030	0.015	0.060	1.00	0.70	0.50	0.004
Raex 500	3 – 12	5 – 60	0.30	0.70	1.70	0.030	0.015	0.060	1.00	0.80	0.50	0.004

Aluminium (Al) and/or titanium (Ti) is used for binding nitrogen (N).

Mechanical properties

Table 2

	Thickness mm		Yield strength	Tensile strength	Elongation	Hardness range	Impact strength	
	Cut lengths	Heavy plates	$R_{p0,2}$ N/mm²	R_m N/mm²	A_5 %	HBW	t °C	KV J
Raex 400	2.5 – 12	5 – 15	1000	1250	10	360 – 420	-40	30
	–	(15) – 30	1000	1250	10	380 – 450	-40	20
	–	(30) – 60	1100	1400	8	380 – 480	-40	20
Raex 450	3 – 12	5 – 60	1200	1450	8	425 – 475	-40	20
Raex 500	3 – 12	5 – 60	1250	1600	8	450 – 530	-30	20

Values are directive.

Dimensional ranges

Table 3

Cut lengths

	Thickness mm	Width range mm [1]	Max length mm
Raex 400	2.5 – 6.4	1200 – 1560	12 000
Raex 400	(6) – 12	1200 – 1524	6 000
Raex 450	3 – 6	1200 – 1560	12 000
Raex 450	(6) – 12	1200 – 1524	6 000
Raex 500	3 – (4)	1200 – 1295	6 000
Raex 500	4 – 12	1200 – 1524	6 000

[1] The exact values depend on thickness.

Heavy plates

	Thickness mm [1]	Width range mm [2]	Max length mm
Raex 400/450/500	5 – 60	1750 – 2500	6 000

[1] Plates thicker than 60 mm by special agreement only.
[2] The exact values depend on thickness.

Free bending

Table 4

	Thickness mm	Free bending < 90° Plunger radius of curvature / plate thickness R/t Bend line position vs. rolling direction: Transversal	Longitudinal	Gap width / plate thickness W/t: Transversal	Longitudinal	Bending to 90° V-channel W/t
Raex 400	2.5 – 6	3.0	3.0	9	9	≈ 15
Raex 400	(6) – 20	3.0	4.0	9	11	≈ 15
Raex 450	3 – 20	4.0	5.0	11	13	≈ 15
Raex 500	5 – 20	≈ 10.0	≈ 12.0	23	27	–

Directive values for bending.
It is recommended to consult our Customer Service in questions related to bending of plates thicker than 20 mm.

Recommended working temperatures in welding °C

Table 5

<table>
<tr><th rowspan="2"></th><th rowspan="2">Welding method
Hydrogen content
of the weld HD</th><th rowspan="2">Minimum
arc energy
E kJ/mm</th><th colspan="11">Combined plate thickness t mm</th></tr>
<tr><th colspan="11">10 20 30 40 50 60 70 80 90 100 110 120</th></tr>
<tr><td rowspan="9">Raex 400</td><td rowspan="3">MAG solid wire
Flux cored welding,
electrode HD ≤ 5 ml/100 g</td><td>1.5</td><td colspan="3">20</td><td>50</td><td>75</td><td>125</td><td colspan="5">150</td></tr>
<tr><td>2</td><td colspan="5">20</td><td colspan="3">125</td><td colspan="3">150</td></tr>
<tr><td>2.5</td><td colspan="5">20</td><td colspan="2">100</td><td colspan="4">125</td></tr>
<tr><td rowspan="3">Flux cored welding,
electrode
HD = 5 – 10 ml / 100 g</td><td>1.5</td><td colspan="2">20</td><td>100</td><td colspan="2">125</td><td colspan="4">175</td><td colspan="2">200</td></tr>
<tr><td>2</td><td colspan="3">20</td><td>100</td><td>125</td><td colspan="2">150</td><td colspan="4">175</td></tr>
<tr><td>2.5</td><td colspan="4">20</td><td>75</td><td>125</td><td colspan="3">150</td><td colspan="2">175</td></tr>
<tr><td rowspan="3">Submerged arc welding
HD = 5 – 10 ml / 100 g</td><td>1.5</td><td colspan="2">20</td><td>50</td><td>100</td><td>125</td><td>150</td><td colspan="5">175</td></tr>
<tr><td>2</td><td colspan="4">20</td><td>75</td><td>125</td><td colspan="3">150</td><td colspan="2">175</td></tr>
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<tr><td rowspan="3">Flux cored welding,
electrode
HD = 5 – 10 ml / 100 g</td><td>1.5</td><td>20</td><td>150</td><td>175</td><td colspan="8">200 1)</td></tr>
<tr><td>2</td><td>20</td><td>100</td><td>150</td><td>175</td><td colspan="7">200 1)</td></tr>
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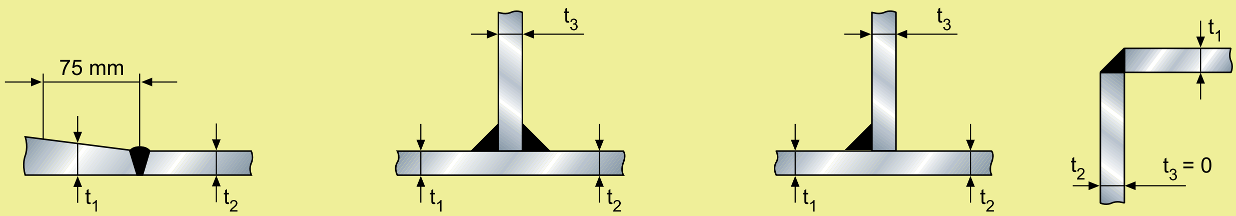
HD = 5 – 10 ml / 100 g</td><td>1.5</td><td>20</td><td>100</td><td>150</td><td>175</td><td colspan="7">200 1)</td></tr>
<tr><td>2</td><td>20</td><td>50</td><td>100</td><td>150</td><td colspan="7">200 1)</td></tr>
<tr><td>2.5</td><td colspan="2">20</td><td>50</td><td>100</td><td colspan="7">200 1)</td></tr>
</table>

1) *Working temperatures over 200° may impair the mechanical propertiees of the weld. Please contact our Customer Service, if necessary.*

$$E = \frac{60 \cdot U \cdot I}{100 \cdot v}$$

where E = arc energy (kJ/mm) I = welding current (A)
U = arc voltage (V) v = welding speed (mm/min)



t_1 = average thickness over a distance of 75 mm.
Combined plate thickness
$t = t_1 + t_2$

Both sides are welded at the same time.
Combined plate thickness
$t = ½ \cdot (t_1 + t_2 + t_3)$

Combined plate thickness
$t = t_1 + t_2 + t_3$

Recommended welding consumables for the welding of Raex wear resistant steels

Table 6

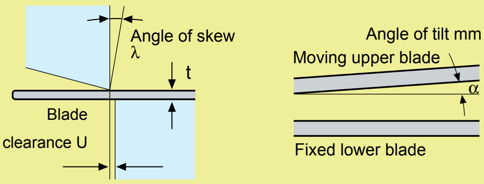
Welding method	Manufacturer / representative	Welding consumable: Low alloy, 'undermatching' filler material (the yeld strength of the filler material is lower than that of the parent material)	High alloy, 'matching' filler material (the filler and the parent materials' yield strengths are equal)
Manual metal arc welding Universal electrode	ELGA	P62 MR	P110
	ESAB	OK 48.00	OK 78.16
	FILARC	Filarc 35	Filarc 118
	IMPOMET OY	Oerlikon Supercito	Oerlikon Cromocord Kb
	LINCOLN ELECTRIC	CONARC 48	CONARC 85
	RETCO OY	COMET J 50+	MOLYCROM 15
	OY UDDEHOLM AB	Fox EV 50	SH Schwartz 3 K Ni
Manual metal arc welding High efficiency electrode	ELGA	MAXETA 24	MAXETA 110
	ESAB	OK 38.65	OK 38.65
	FILARC	Filarc C6HH	
	IMPOMET OY	Oerlikon Febacito 160S	Oerlikon Febacito 160S
	LINCOLN ELECTRIC	CONARC V 180	
	RETCO OY	COMET J 160	
MAG welding Solid wire	ELGA	Elgamatic 100	Elgamatic 135
	ESAB	OK Autrod 12.51	OK Autrod 13.12
	IMPOMET OY	Oerlikon Carbofil 1	Oerlikon Carbofil CrMo 1
	LINCOLN ELECTRIC	LNM 26	LNM MONIVA
	RETCO OY	IS-10 BRONZE	
	OY UDDEHOLM AB	EMK6	Union NiMoCr
Filler wire welding Metal-cored wire	ESAB	OK Tubrod 14.12	OK Tubrod 14.03
	FILARC	Filarc PZ 6102	Filarc PZ 6102
	IMPOMET OY	Oerlikon Fluxofil M8	Oerlikon Fluxofil 36
	LINCOLN ELECTRIC	OS MC 710-H	OS MC 1100
	RETCO OY	Trimark METALLOY-76	
	OY UDDEHOLM AB	MV 70	
Filler wire welding Flux-cored wire	ELGA	DWA 50	110B
	ESAB	OK Tubrod 15.14	OK Tubrod 15.09
	FILARC	Filarc PZ 6113	Filarc PZ 6148
	IMPOMET OY	Oerlikon Fluxofil 14HD	Oerlikon Fluxofil 14HD
	LINCOLN ELECTRIC	OS 71 E-H	
	RETCO OY	Trimark TM-770	
	OY UDDEHOLM AB	RV 71	
Submerged arc welding Wire / flux	ELGA	Elfasaw 102 / Elgaflux 251 B	
	ESAB	OK Autrod 12.22 / OK Flux 10.71	OK Autrod 13.43 / OK Flux 10.62
	IMPOMET OY	Oerlikon OE-S2 / Oerlikon OP 122	Oerlikon OE-S3NiMo1/ Oerlikon OP 121TT
	LINCOLN ELECTRIC	L-61 / FX P 230	LNS168 / FX P230

Recommended working temperatures for thermal cutting °C

Table 7

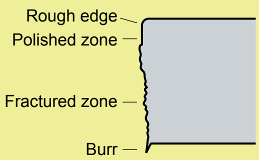
	Thickness mm	Working temperature °C
Raex 400	15 – 30 (30) – 60	50 – 75 75 – 125
Raex 450	15 – 60	75 – 125
Raex 500	10 – 60	125 – 175

Cutting geometry and terms



Sections of the cut surface

Figure 2



Mechanical cutting of Raex 400 steels

Table 8

	Tensile strength	Elongation	Mechanical cutting, guideline values				
			Plate thickness	Blade clearance	Angle of tilt	Angle of skew	Shearing force
	R_m N/mm²	A_5 %	mm t	mm U	α °	λ °	x 10^3 N
Raex 400	1200	10	6	0.60 – 0.72	3 – 4	0 – 3	150 – 200
			8	0.80 – 1.28	3 – 5	0 – 5	250 – 350
			10	1.00 – 1.80	4 – 6	0 – 5	300 – 450
			12	1.20 – 2.16	4 – 6	0 – 5	400 – 600

Carbon equivalent (CEV)

Table 9

	Thickness mm	CEV	Product shape
Raex 400	2.5 – 12	0.49	Cut lengths
Raex 400	5 – 12	0.45	Heavy plates
Raex 400	(12) – 30	0.50	Heavy plates
Raex 400	(30) – 60	0.56	Heavy plates
Raex 450	3 – 12	0.49	Cut lengths
Raex 450	5 – 30	0.50	Heavy plates
Raex 450	(30) – 60	0.58	Heavy plates
Raex 500	3 – 12	0.54	Cut lengths
Raex 500	5 – 60	0.64	Heavy plates

Typical values.

CEV = C + Mn / 6 + (Cr + Mo + V) / 5 + (Ni + Cu) / 15

Our Customer Service is happy to give you further information

Sales, technical support info.metals@ruukki.com

Rautaruukki Corporation, P.O. Box 138, FI-00811 Helsinki, Finland. tel. +358 20 5911 www.ruukki.com