

# RIGOR

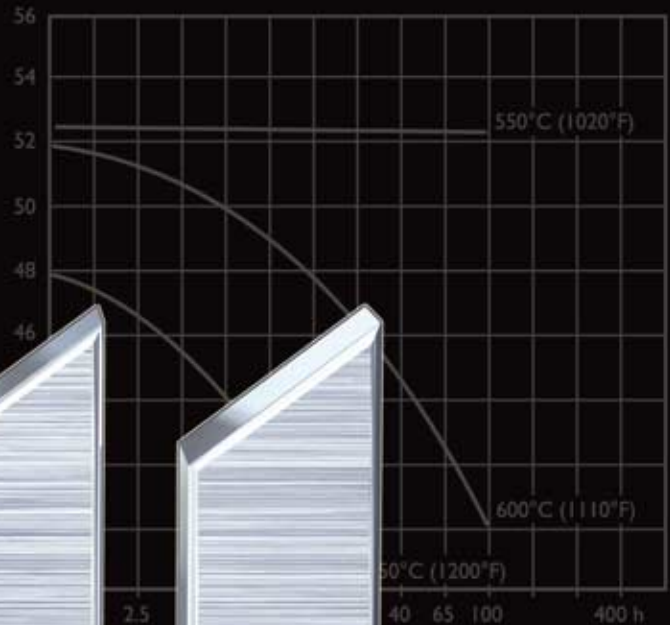
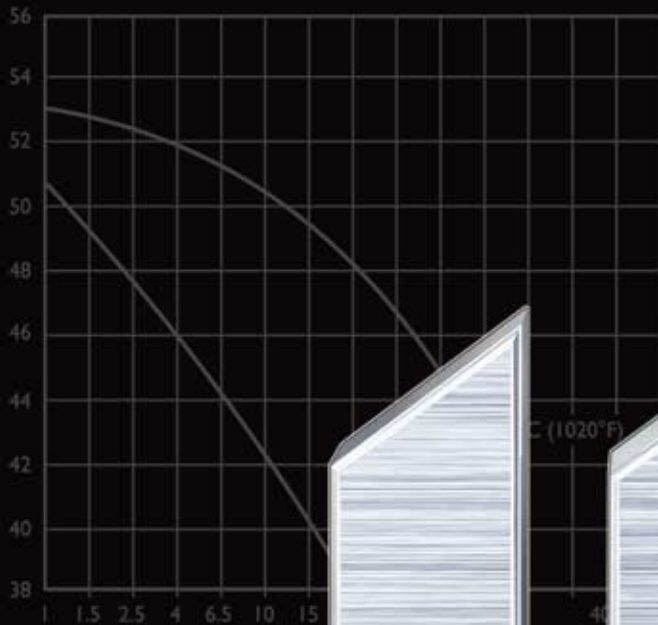
## Cold work tool steel

COLD WORK

PLASTIC MOULDING

HOT WORK

HIGH PERFORMANCE STEEL



Typical analysis %	C 2,05
Standard specification	AISI D6, ( )
Delivery condition	Soft annealed
Colour code	Red

Typical analysis %	Mn 0,8	Cr 4,5	W 0,2
Standard specification	D3 (W.Nr. 1.2796)		
Delivery condition	to approx. 200 HB		
Colour code			

Temperature	20°C (68°F)	200°C (390°F)	400°C (750°F)
Density kg/m <sup>3</sup> lbs/m <sup>3</sup>	7 770 0,281	7 670 0,277	7 650 0,275
Modulus of elasticity N/mm <sup>2</sup> psi	194 000 28,1 × 10 <sup>6</sup>	188 000 27,3 × 10 <sup>6</sup>	178 000 25,8 × 10 <sup>6</sup>
Coefficient of thermal expansion per °C from 20°C per °F from 68°F	to 100°C 11,7 × 10 <sup>-6</sup> to 212°F 6,5 × 10 <sup>-6</sup>	to 200°C 12 × 10 <sup>-6</sup> to 400°F 6,7 × 10 <sup>-6</sup>	to 400°C 13,0 × 10 <sup>-6</sup> to 750°F 7,3 × 10 <sup>-6</sup>
Thermal conductivity W/m °C Btu in (ft <sup>2</sup> h°F)	-	27 187	32 221
Specific heat K/kg °C Btu/lbs °F	455 0,109	525 0,126	608 0,145

Temperature	20°C (68°F)	200°C (390°F)	400°C (750°F)
Density kg/m <sup>3</sup> lbs/m <sup>3</sup>	7 770 0,281	7 670 0,277	7 650 0,275
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Thermal conductivity W/m °C Btu in (ft <sup>2</sup> h°F)	-	20,5 142	21,5 149
Specific heat K/kg °C Btu/lbs °F	460 0,110	-	-

## General

*RIGOR* is an air- or oil hardening chromium-molybdenum-vanadium alloyed tool steel characterized by:

- Good machinability
- High stability after hardening
- High compressive strength
- Good hardenability
- Good wear resistance.

Typical analysis %	C 1,0	Si 0,3	Mn 0,6	Cr 5,3	Mo 1,1	V 0,2
Standard specification	AISI A2, BA2, W.-Nr. 1.2363, Euro X 100 CrMoV 5					
Delivery condition	Soft annealed to approx. 215 HB					
Colour code	Red/green					

## Applications

*RIGOR* takes a place in the Uddeholm tool steel range between *ARNE* and *SVERKER 21*, offering an excellent combination of good wear resistance and toughness. It may be regarded, therefore, as a "universal" cold work steel.

For cutting operations the good toughness of *RIGOR* gives excellent resistance to chipping of the cutting edge. In many cases tools made from this steel have given better tooling economy than high-carbon, high-chromium steels of the BD3/W.-Nr. 2080 type. *RIGOR* has much better machining and grinding properties.

## CUTTING

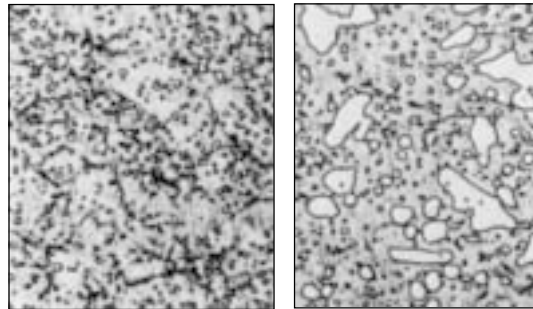
	Material thickness mm	Hardness HRC
<i>Tools for:</i> Blanking, punching, piercing, cropping, shearing, trimming, clipping	up to 3 mm (1/8")	60–62
	3–6 mm (1/8–1/4")	56–60
	6–10 mm (1/4–13/32")	54–56
Short cold shears Rotary shear blades for plastic waste		56–60
Clipping, trimming tools for forgings	Hot	58–60
	Cold	56–58

## FORMING

	Hardness HRC
<i>Tools for:</i> Bending, raising, deep-drawing, rim-rolling, spinning and flow-turning	56–62
Coining dies	56–60
Tube- and section forming rolls	58–62
Master hobs for cold hobbing	58–60
Swaging blocks	56–60
Gauges, measuring tools, guide rails bushes, sleeves	58–62
Dies and inserts for moulding tablets, abrasive plastics	58–62

## Availability

*RIGOR* can be supplied in various finishes, including the hot-rolled, pre-machined and fine-machined condition. It is also available in the form of hollow bar and rings.



Comparison of fine-grained *RIGOR* with high-carbon, high-chromium steel of the D3/W.-Nr. 2080 type.

This information is based on our present state of knowledge and is intended to provide general notes on our products and their uses. It should not therefore be construed as a warranty of specific properties of the products described or a warranty for fitness for a particular purpose.

## Properties

### PHYSICAL DATA

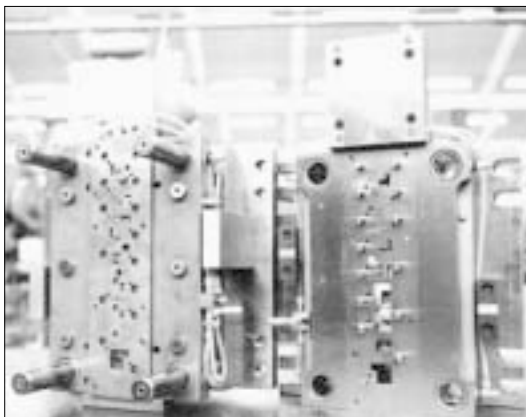
Hardened and tempered to 62 HRC. Data at room temperature and elevated temperatures.

Temperature	20°C (68°F)	200°C (375°F)	400°C (750°F)
Density kg/m <sup>3</sup> lbs/in <sup>3</sup>	7 750 0,279	7 700 0,277	7 650 0,275
Modulus of elasticity N/mm <sup>2</sup> psi	190 000 27,5 x 10 <sup>6</sup>	185 000 26,9 x 10 <sup>6</sup>	170 000 24,6 x 10 <sup>6</sup>
Coefficient of thermal expansion per °C from 20°C per °F from 68°F	— —	11,6 x 10 <sup>-6</sup> 6,5 x 10 <sup>-6</sup>	11,3 x 10 <sup>-6</sup> 6,3 x 10 <sup>-6</sup>
Thermal conductivity W/m °C Btu in/(ft <sup>2</sup> h°F)	26,0 181	27,0 188	28,5 199
Specific heat J/kg °C Btu/lb °F	460 0,11	— —	— —

### COMPRESSIVE STRENGTH

Approximate values.

Hardness	Rc0,2	
	Nmm <sup>2</sup>	ksi
62 HRC	2200	319
60 HRC	2150	312
55 HRC	1800	261
50 HRC	1350	196



## Heat treatment

### SOFT ANNEALING

Protect the steel and heat through to 850°C (1560°F). Then cool in the furnace at 10°C (20°F) per hour to 650°C (1200°F), then freely in air.

### STRESS RELIEVING

After rough machining the tool should be heated through to 650°C (1200°F), holding time 2 hours. Cool slowly to 500°C (930°F), then freely in air.

### HARDENING

*Preheating temperature:* 650–750°C (1200–1300°F)

*Austenitizing temperature:* 925–970°C (1690–1780°F) but usually 940–960°C (1720–1760°F).

Temperature °C      °F		Soaking* time min.	Hardness before tempering
925	1700	40	approx. 63 HRC
950	1740	30	approx. 64 HRC
970	1780	20	approx. 64 HRC

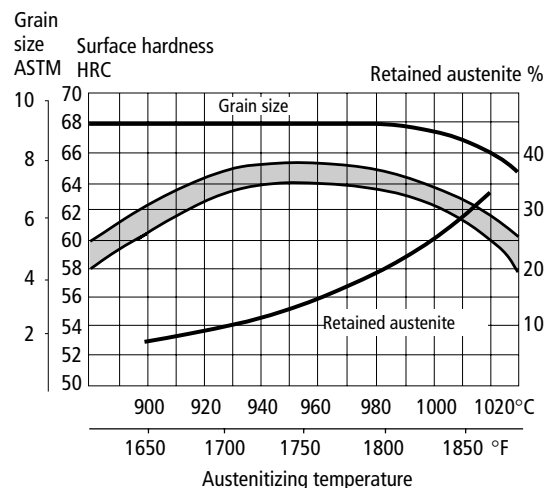
\* Soaking time = time at hardening temperature after the tool is fully heated through.

*Protect the part against decarburization and oxidation during hardening.*

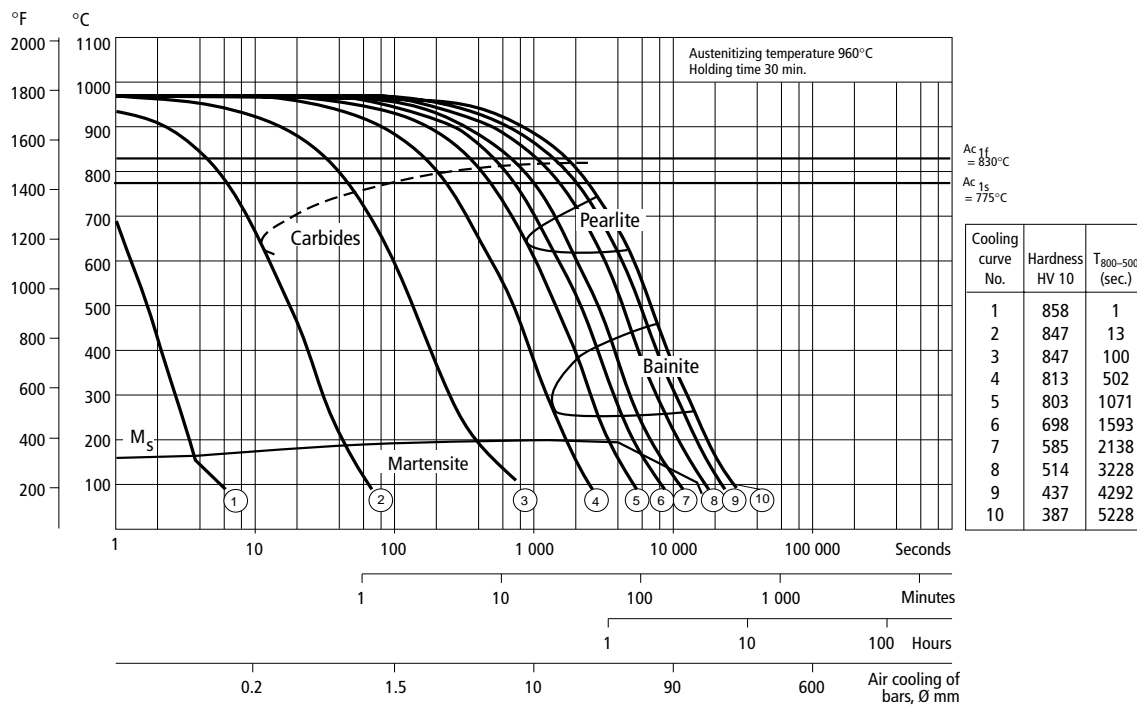
### QUENCHING MEDIA

- Martempering bath or fluidized bed at 180–220°C (360–430°F) or 450–550°C (840–1020°F) then cool in air
- Circulating air or atmosphere
- Vacuum furnace with overpressure of gas at cooling
- Oil (only for small and uncomplicated tools).

*Hardness as a function of hardening temperature.*



## CCT graph



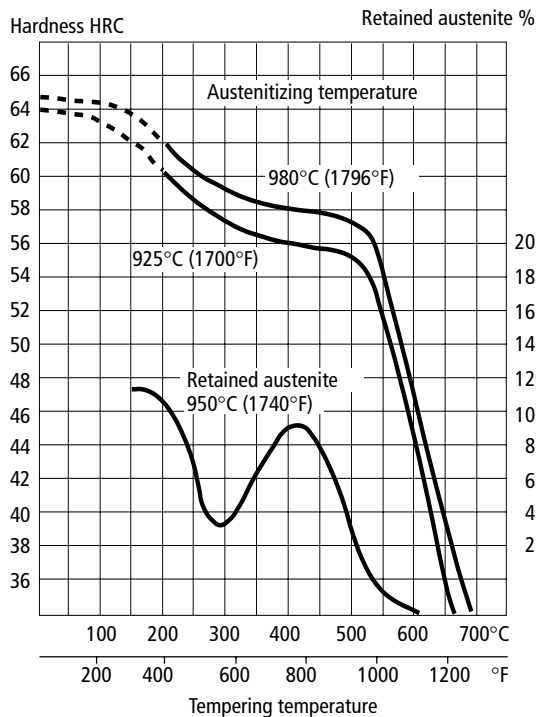
## TEMPERING

Choose the tempering temperature according to the hardness required by reference to the tempering graph. Temper twice with intermediate cooling to room temperature. Lowest tempering temperature 180°C (360°F). Holding time at temperature minimum 2 hours.



Transfer mould with RIGOR inserts to produce encapsulated electronic components.

The tempering graphs are valid for small samples.  
The hardness received is also dependent on the tool size.



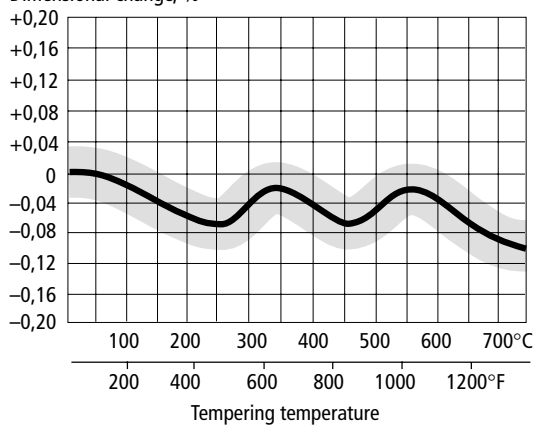
## DIMENSIONAL CHANGES DURING HARDENING

Sample plate, 100 x 100 x 25 mm, 4" x 4" x 1".

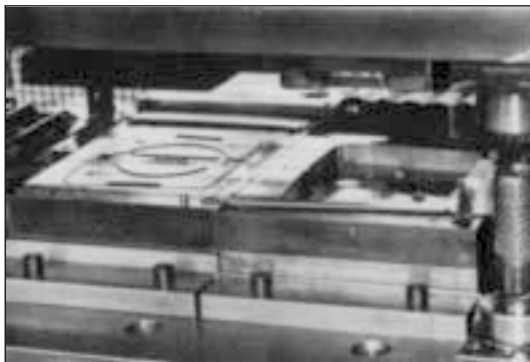
		Width %	Length %	Thickness %
Oil hardening from 960°C (1760°F)	min. max.	-0,10 -0,05	-0,02 +0,06	-0,05
Martempering from 960°C (1760°F)	min. max.	+0,04 +0,05	+0,06 +0,08	+0,04
Air hardening from 960°C (1760°F)	min. max.	+0,08 +0,14	+0,13 +0,15	+0,04

## DIMENSIONAL CHANGES DURING TEMPERING

Dimensional change, %



*Note: The dimensional changes on hardening and tempering should be added together.*



*This tool was made from RIGOR. 3 million parts were manufactured before the tool was reground.*

## SUB-ZERO TREATMENT AND AGING

Pieces requiring maximum dimensional stability should be sub-zero and/or artificially aged as volume changes may arise in the course of time. This applies, for example, to measuring tools like gauges and certain structural components.

### Sub-zero treatment

Immediately after quenching, the piece should be sub-zero refrigerated to between -40 and -80°C (between -40 and -110°F) followed by tempering or aging. Sub-zero refrigeration for 2–3 hours will give a hardness increase of 1–3 HRC. Avoid intricate shapes as there is a risk of cracking.

### Aging

Tempering after quenching is replaced by aging at 110–140°C (230–285°F). Holding time 25–100 hours.

## NITRIDING

Nitriding will give a hard diffused surface layer which is very resistant to wear and erosion, and also increases corrosion resistance. Nitriding in ammonia gas at a temperature of 525°C (975°F) gives a surface hardness of approx. 1000 HV<sub>1</sub>.

Nitriding temperature		Nitriding time hours	Depth of case, approx.	
°C	°F		mm	in.
525	980	20	0,2	0,008
525	980	30	0,3	0,012
525	980	60	0,4	0,016

2 hours nitrocarburizing treatment at 570°C (1060°F) gives a surface hardness of approx. 900 HV<sub>1</sub>. The case depth having this hardness will be 10–20 µm (0,0004–0,0008").

# Machining recommendations

The cutting data below, valid for *RIGOR* in soft annealed condition, are to be considered as guiding values which must be adapted to existing local conditions.

## TURNING

Cutting data parameters	Turning with carbide		Turning with high speed steel Fine turning
	Rough turning	Fine turning	
Cutting speed ( $v_c$ ) m/min f.p.m.	100–160 335–525	160–210 525–690	18–23 60–75
Feed (f) mm/r i.p.r.	0,2–0,4 0,008–0,016	0,05–0,2 0,002–0,008	0,05–0,3 0,002–0,012
Depth of cut ( $a_p$ ) mm inch	2–4 0,08–0,16	0,5–2 0,02–0,08	0,5–2 0,02–0,08
Carbide designation ISO US	P20–P30 C6–C5 Coated carbide	P10 C7 Coated carbide or cermet	– –

## MILLING

### Face and square shoulder milling

Cutting data parameters	Milling with carbide	
	Rough milling	Fine milling
Cutting speed ( $v_c$ ) m/min f.p.m.	130–200 425–655	200–240 655–785
Feed ( $f_z$ ) mm/tooth inch/tooth	0,2–0,4 0,008–0,016	0,1–0,2 0,004–0,008
Depth of cut ( $a_p$ ) mm inch	2–4 0,08–0,16	–2 –0,08
Carbide designation ISO US	P20–P40 C6–C5 Coated carbide	P10–P20 C7–C6 Coated carbide or cermet

## End milling

Cutting data parameters	Type of milling		
	Solide carbide	Carbide indexable insert	High speed steel
Cutting speed ( $v_c$ ) m/min f.p.m.	80–120 260–395	120–170 395–560	15–20 <sup>1)</sup> 50–65 <sup>1)</sup>
Feed ( $f_z$ ) mm/tooth inch/tooth	0,03–0,20 <sup>2)</sup> 0,001–0,008 <sup>2)</sup>	0,08–0,20 <sup>2)</sup> 0,003–0,008 <sup>2)</sup>	0,05–0,35 <sup>2)</sup> 0,002–0,014 <sup>2)</sup>
Carbide designation ISO US	K20 C2	P20–P40 C6–C5	– –

<sup>1)</sup> For coated HSS end mill

$v_c = 30–35$  m/min. (100–115 f.p.m./min.)

<sup>2)</sup> Depending on radial depth of cut and cutter diameter.

## DRILLING

### High speed steel twist drill

Drill diameter		Cutting speed ( $v_c$ )		Feed (f)	
mm	inch	m/min	f.p.m.	mm/r	i.p.r.
– 5	–3/16	14–16*	45–50*	0,05–0,15	0,002–0,006
5–10	3/16–3/8	14–16*	45–50*	0,15–0,20	0,006–0,008
10–15	3/8–5/8	14–16*	45–50*	0,20–0,25	0,008–0,010
15–20	5/8–3/4	14–16*	45–50*	0,25–0,35	0,010–0,014

<sup>1)</sup> For coated HSS drill  $v_c = 24–26$  m/min. (80–85 f.p.m./min.)

## Carbide drill

Cutting data parameters	Type of drill		
	Indexable insert	Solide carbide	Brazed carbide <sup>1)</sup>
Cutting speed ( $v_c$ ) m/min f.p.m.	150–170 490–560	80–100 260–330	50–60 165–195
Feed (f) mm/r i.p.r.	0,05–0,25 <sup>2)</sup> 0,002–0,01 <sup>2)</sup>	0,10–0,25 <sup>2)</sup> 0,004–0,01 <sup>2)</sup>	0,15–0,25 <sup>2)</sup> 0,006–0,01 <sup>2)</sup>

<sup>1)</sup> Drill with internal cooling channels and brazed carbide tip.

<sup>2)</sup> Depending on drill diameter.

## GRINDING

General grinding wheel recommendation for *RIGOR* is given below. More information can be found in the Uddeholm brochure "Grinding of Tool Steel".

### Wheel selection

Type of grinding	Wheel recommendation	
	Soft annealed condition	Hardened condition
Face grinding straight wheel	A 46 HV	A 46 HV
Face grinding segments	A 24 GV	A 36 GV
Cylindrical grinding	A 46 LV	A 60 KV
Internal grinding	A 46 JV	A 60 IV
Profile grinding	A 100 LV	A 120 JV

## Electrical-discharge machining–EDM

If EDM is performed in the hardened and tempered condition, the tool should then be given an additional temper at about 25°C (50°F) below the previous tempering temperature.

## Welding

Good results when welding tool steel can be achieved if proper precautions are taken during welding (elevated working temperature, joint preparation, choice of consumables and welding procedure). If the tool is to be polished or photo-etched, it is necessary to work with an electrode type of matching composition.

Welding method	Working temperature	Consumables	Hardness after welding
MMA (SMAW)	200–250°C (390–480°F)	AWS E312 ESAB OK 84.52 UTP 67S Castolin 2 Castolin N 102	300 HB 53–54 HRC 55–58 HRC 54–60 HRC 54–60 HRC
TIG	200–250°C (390–480°F)	AWS ER312 UTPA 67S UTPA 73G2 Castotig 5	300 HB 55–58 HRC 53–56 HRC 60–64 HRC

## Further information

Please contact your local Uddeholm office for further information on the selection, heat treatment, application and availability of Uddeholm tool steels, including the publications "Steels for Presswork Tooling".

## Relative comparison of Uddeholm cold work tool steel

### MATERIAL PROPERTIES AND RESISTANCE TO FAILURE MECHANISMS

Uddeholm grade	Hardness/ Resistance to plastic deformation	Machinability	Grindability	Dimension stability	Resistance to		Fatigue cracking resistance	
					Abrasive wear	Adhesive wear	Ductility/ resistance to chipping	Toughness/ gross cracking
ARNE	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■
CALMAX	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■
RIGOR	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■
SLEIPNER	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■
SVERKER 21	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■
SVERKER 3	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■
VANADIS 4	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■
VANADIS 6	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■
VANADIS 10	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■
VANADIS 23	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■	■■■■■