Novelis
Aluminium in Molding and Tooling

Excellent machinability and
outstanding thermal conductivity

Novelis

Customized Aluminium Solutions

At Novelis we believe that it's a win-win situation for all parties when we bring our customers further. Innovation, Commitment, Forward-Thinking. These values are non-negotiable. When we partner and collaborate with our customers to find solutions, we're contributing to their success and shaping a more sustainable world together.

The information contained in this brochure have been compiled with great care in close cooperation with the Steinbeis-Transferzentrum „Produktionstechnik & Werkzeugmaschinen" based in Horgau.

All tool images have been kindly provided by Walter Deutschland GmbH.

About us

Not just aluminium, Novelis Aluminium.™ This is the basis of our success. We offer customers innovative, tailor-made solutions and develop long-term partnerships in the manufacturing industry.

Our aluminium alloys WELDURAL® and HOKOTOL® shorten significantly machining times in mold and die production. With our expertise and resources and solution-oriented commitment, we help users capture the potential of aluminium to meet their specific needs.

CUSTOMER-SPECIFIC SOLUTIONS continue to gain in significance. Novelis customers develop their products and applications in an ongoing dialogue with our technical support. The quick and easy handling of the two light metals WELDURAL® and HOKOTOL® opens up new opportunities and solutions in mold and tool making without compromising product quality. This is a true advantage for every stage along the manufacturing chain.

PRODUCT SUSTAINABILITY is important to us. We have been certified according to ISO 14001 and ISO 50001 and have committed ourselves to achieving sustainability goals. With our strong expertise in aluminium recycling we make sure that resources and operations are managed in a responsible manner.

For a number of years in a row we have been certified according to (amongst others):

- DIN EN ISO 9001
- DIN EN ISO 50001
- DIN EN 14001
- EN 9100
- IATF 16949
- ASI member

Innovator in Sustainable Aluminum Solutions

OPERATIONAL EXCELLENCE is what drives our people. We're not satisfied with today's solutions. Instead we continue to look for ongoing improvement for our products and production processes. Our high-strength alloys have proven to be successful even under the most demanding customer requirements and Novelis relies on strong partnerships with end users for the development of new, innovative aluminium products. Keeping abreast of technological advancements, we ensure that we're offering our customers the best materials based on leading-edge technology to meet tomorrow's challenges today.

COMMITMENT is part of our identity. Our facility in Koblenz is a globally leading production site that produces plate, sheet and coil material in more than 130 alloys. These are used in a variety of key sectors like engineering and transportation, aerospace, and further advanced industry applications.

Advantages of Aluminium

Aluminium vs. steel

LINK BETWEEN MATERIAL REMOVAL RATE AND SPEED
Machining is indispensable for the production of molds. For this cutting rates, tool speed and feed rates are necessary.

Definition of material removal rate [Q]
The material removal rate Q, is the volume of material removed from the workpiece by machining, in the form of chips, in a fixed period of time. This is an important measure in manufacturing, as the productivity of tools and machines can be measured and compared by this method.

Material removal rate:
$Q = v_f \cdot a_p \cdot a_e / 1{,}000$ [cm³/min]
v_f = feed rate [mm/min]
a_p = axial feed [mm]
a_e = radial feed [mm]

Example:

ALUMINIUM → SOFT → HIGH teeth feed

STEEL → HARD → LOW teeth feed

Definition of speed [n]
Speed is the number of revolutions of the aluminium tool per minute (rpm).

Spindle speed:
$n = v_c \cdot 1{,}000 / (\pi \cdot D_c)$ [1/min]
v_c = cutting speed [m/min]
D_c = tool diameter [mm]

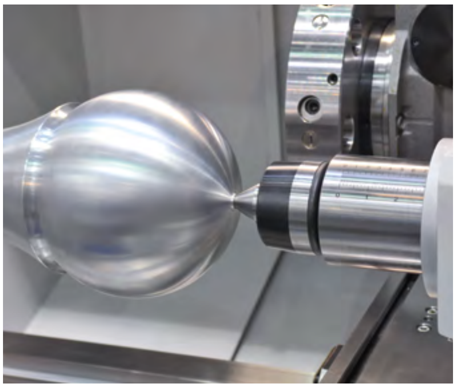
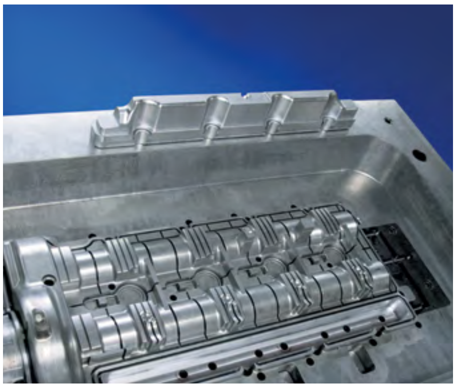
Definition of teeth feed [f_z]
The teeth feed is the direction of the tool relative to the cutting edge and is selected based on the load capacity of the tool cutting edge, and the material to be machined.

Teeth feed:
$f_z = v_f / (z \cdot n)$ [mm]
v_f = feed rate [mm/min]
z = number of cutting edges
n = spindle feed [1/min]

Aluminium offers a number of benefits

- **Low tooling mass**
  The density of aluminium is three times lower than that of steel, which results in lower stress on the molding machine, which in return can extend your machine service life
- **Excellent machinability**
  Molds can be made in one-tenth of the time required by steel
- **Outstanding thermal conductivity**
  Considerably shorter cooling times; consequently speeding up processing time
- **Very good electrical conductivity**
  Higher speeds can be achieved in the electrical discharge machining (spark eroding) process

Saving your time and costs

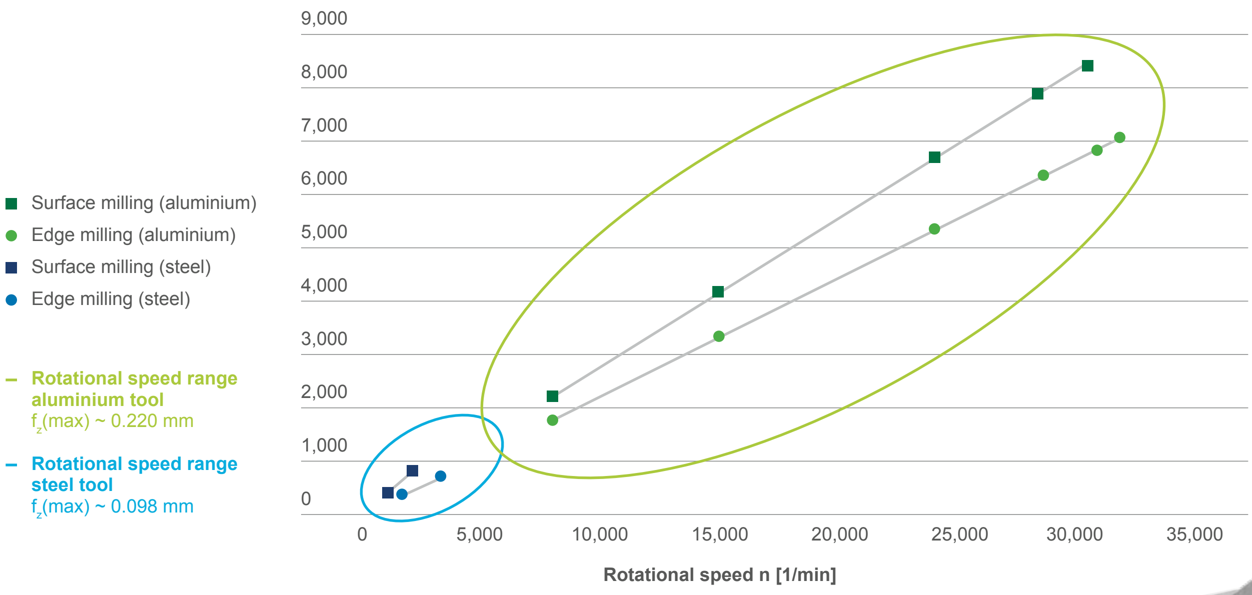
Our aluminium materials allow for high tooling speed and feed rates. Metal removal rates can be up to 10 times compared to steel.

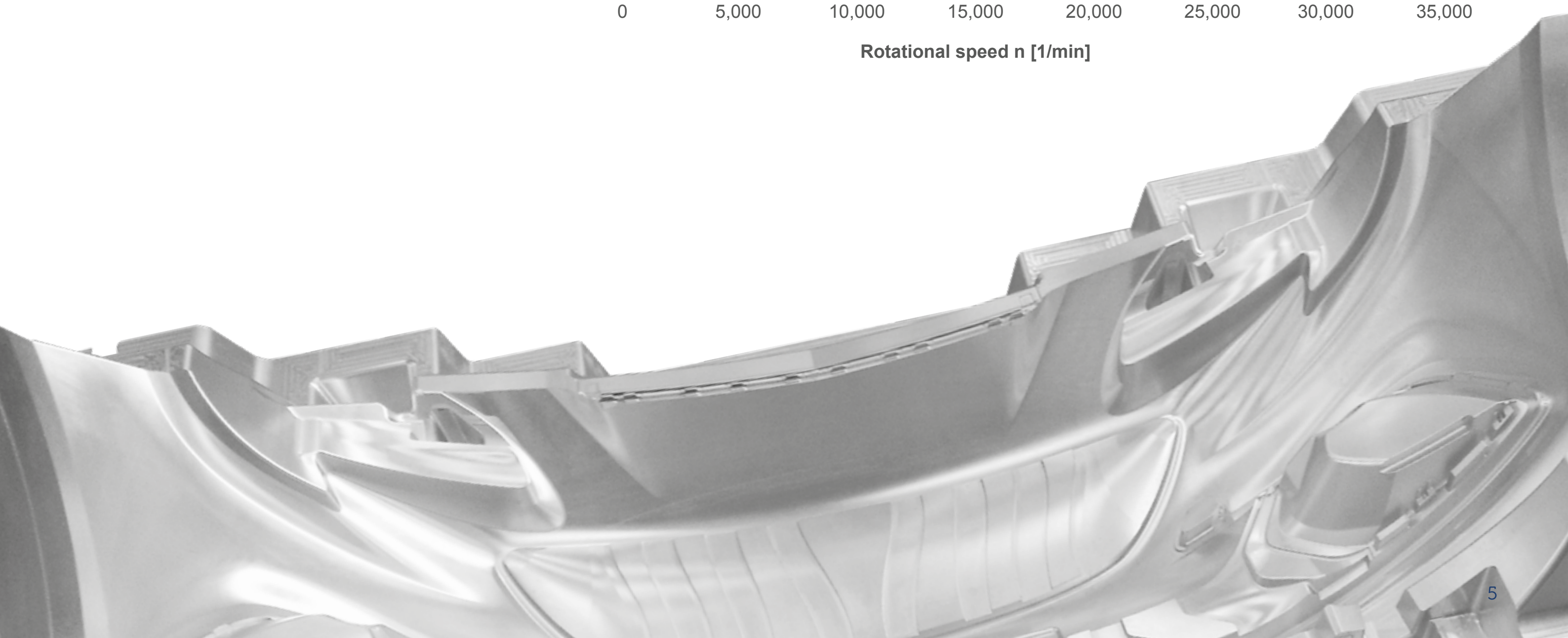
The high hardness of these aluminiums allows for comparative high tooling rotational speed range and cutting rates, giving excellent material removal rates.

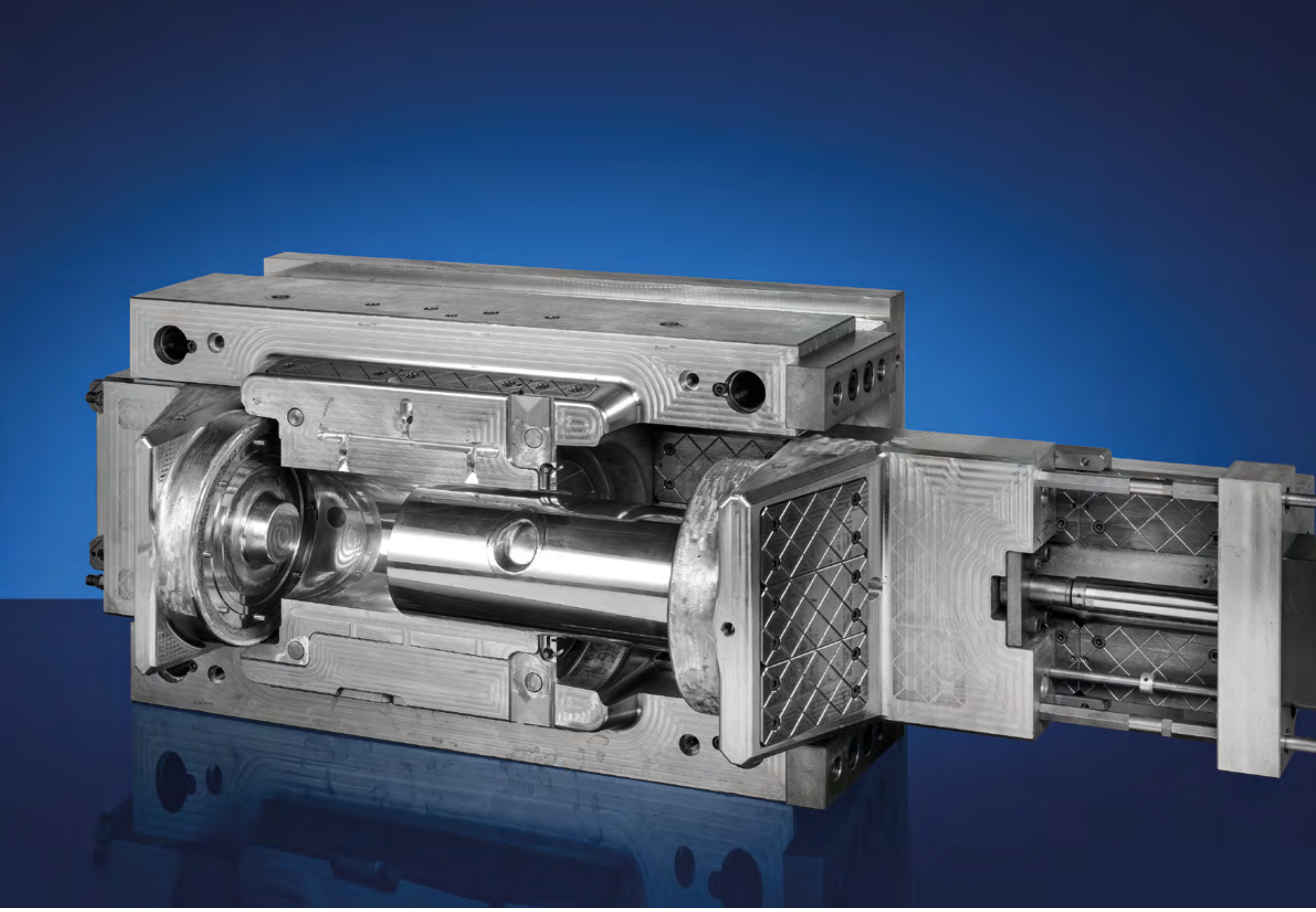
Material removal rate aluminium vs. steel

	Rotational speed n [1/min]	Material removal rate Q [cm³/min]
Aluminium	Factor 10	Factor 10
Steel	1	1

Material removal rate aluminium vs. steel







WELDURAL®

Advantages of WELDURAL®

- High-temperature resistance to long-term heating
- Ideally suited for welding
- Superior thermal conductivity
- High uniform mechanical properties across the entire thickness
- High dimensional stability due to low residual stress
- Excellent machinability

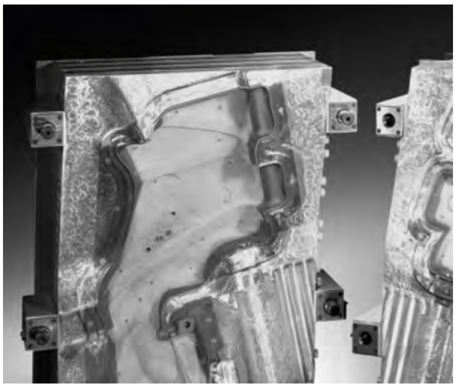
HIGH-TEMPERATURE RESISTANCE

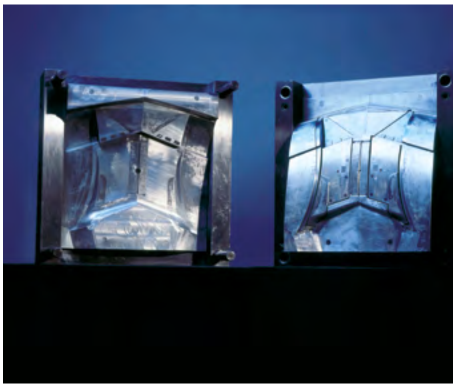
WELDURAL® has been developed to provide the best possible mechanical stability in a temperature range of up to 250 °C. Even when exposed to heat for more than 1,000 hours the strength is significantly higher than that of alloy 7075.

Typical strength properties under long-term temperature influence[1]

Temperature [°C]	Tensile strength R_m [MPa]	Yield strength $R_{p0.2}$ [MPa]	Elongation A [%]
24	449	335	9
100	414	324	15
150	338	276	17
200	248	200	20

[1]Measured at S/4 after 1,000 h under test temperature;
S/4 corresponds to 25 % of thickness depth.
Further information upon request via molding@novelis.adityabirla.com.





Chemical composition [all data wt.-%]

Alloy		Chemical elements Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr	Other individual	Other total
WELDURAL®	min.	-	-	5.8	0.2	-	-	-	0.02	0.10	-	-
	max.	0.3	0.4	6.8	0.4	0.10	0.05	0.10	0.10	0.25	0.05	0.15

Physical properties in comparison to steel

Property	Hardness [HB]	Density [g/cm³]	E-Modulus [MPa]	Coefficient of thermal expansion 20 - 100 °C [10⁻⁶/K]	Thermal conductivity at room temperature [W/(m·K)]	Electrical conductivity at room temperature [MS/m]
WELDURAL®	130	2.84	73,800	22.5	130	17.4
Steel 1.2312 (40CrMnMoS8-6)	300	7.85	215,000	12.5	35	10.3
Comparison Al : St	**1 : 2.3**	**1 : 2.8**	**1 : 2.9**	**1.8 : 1**	**3.7 : 1**	**1.7 : 1**

Minimum strength properties for various thicknesses[1]

Thickness [mm]	Tensile strength R_m [MPa]	Yield strength $R_{p0.2}$ [MPa]	Elongation A [%]
8 - 100	415	305	5
>100 - 150	395	290	4
>150 - 180	370	270	3
>180 - 200	370	270	3
>200 - 220	370	270	3
>220 - 254	340	240	2
>254	data on request		

[1]Measured at room temperature, test direction LT

Typical strength properties for various thicknesses[1]

Thickness [mm]	Tensile strength R_m [MPa]	Yield strength $R_{p0.2}$ [MPa]	Elongation A [%]
8 - 100	460	350	8
>100 - 150	455	350	7
>150 - 180	445	340	6
>180 - 200	440	335	6
>200 - 220	435	330	6
>220 - 254	425	325	5
>254	data on request		

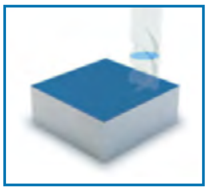
[1]Measured at room temperature, test direction LT

Delivery program

Thickness [mm]	Width [mm]	Length [mm]
8 - 100	2,900	4,000
>100 - 115	2,900	4,000
>115 - 130	2,700	4,000
>130 - 150	2,400	4,000
>150 - 180	2,050	4,000
>180 - 200	1,850	4,000
>200 - 254	1,500	4,000

Further dimensions upon request via molding@novelis.adityabirla.com.

Machinability of WELDURAL®



Surface Milling

Surface milling is one of the most commonly used milling techniques and a variety of different tool types can be used. It is mostly used to prepare and create the main profile of the mold or die. Surface quality is not critical for initial rouging stages but can be critical for finishing steps.

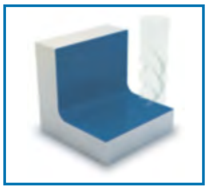
Surface milling of WELDURAL®

Tool [ø 25 mm]		Rotational speed n [1/min]	Material removal rate Q [cm^3/min]
VHM[1] 	Roughing [a_p = 24.5 mm]	30,500	8,428
		24,000	6,631
		15,000	4,144
	Finishing [a_p = 0.5 mm]	36,000	219
		24,000	146
		15,000	91

Tool [ø 200 mm]		Rotational speed n [1/min]	Material removal rate Q [cm^3/min]
WSP[2] 	Roughing [a_p = 4.5 mm]	3,198	6,039
	Finishing [a_p = 0.5 mm]	3,357	570

Tool [ø 10 mm]		Rotational speed n [1/min]	Material removal rate Q [cm^3/min]
VHM[1] 	Roughing [a_p = 9.8 mm]	68,100	8,428
		24,000	2,970
		15,000	1,856
	Finishing [a_p = 0.2 mm]	80,000	219
		24,000	66
		15,000	41

Tool [ø 50 mm]		Rotational speed n [1/min]	Material removal rate Q [cm^3/min]
WSP[2] 	Roughing [a_p = 4.5 mm]	11,498	2,839
		8,000	1,975
	Finishing [a_p = 0.5 mm]	13,357	324
		8,000	194



Edge Milling

Edge milling is used to produce two or more surfaces simultaneously in one tooling pass. This technique requires peripheral milling of an external contour, in conjunction with a planar milling operation.
The production of a shoulder with a 90° angle is one of the most important applications in mold making. Because of the large number of possibilities, it is important to consider the application's specific requirements in order to make the best choice.

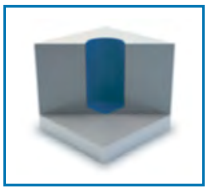
Edge milling of WELDURAL®

Tool [ø 25 mm]		Rotational speed n [1/min]	Material removal rate Q [cm^3/min]
VHM[1] 	Roughing [a_p = 24.5 mm]	31,831	7,019
		24,000	5,292
		15,000	3,307
	Finishing [a_p = 0.5 mm]	38,579	111
		24,000	69
		15,000	43.1

Tool [ø 50 mm]		Rotational speed n [1/min]	Material removal rate Q [cm^3/min]
WSP[2] 	Roughing [a_p = 15 mm]	10,361	3,840
		8,000	2,964

Tool [ø 10 mm]		Rotational speed n [1/min]	Material removal rate Q [cm^3/min]
VHM[1] 	Roughing [a_p = 24.5 mm]	78,941	1,560
		24,000	474.2
		15,000	285
	Finishing [a_p = 0.5 mm]	78,304	36
		24,000	11
		15,000	7

Tool [ø 32 mm]		Rotational speed n [1/min]	Material removal rate Q [cm^3/min]
WSP[2] 	Roughing [a_p = 10 mm]	21,685	2,320
		15,000	1,604
		8,000	855



Drilling

Drill feeds can be affected by the movement of the drill or the work piece. Drilling is often used in mold making, for example, for pilot hole, tooling connections or assemblies and to introduce deep cooling channels into the work piece geometry.

Drilling of WELDURAL®

Tool [Drilling depth 6 x D]	Diameter D [mm]	Rotational speed n [1/min]	Material removal rate Q [cm^3/min]
VHM[1]	12	9,629	436
	6	19,947	159
		15,000	120
[Drilling depth 5 x D]	**[mm]**	**[1/min]**	**[cm^3/min]**
WSP[2] 	30	1,942	784
	16	4,377	367

[1] VHM = Solid carbide tool, [2] WSP = Indexable tool

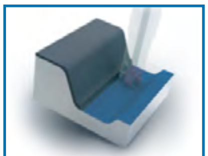
Slot Milling

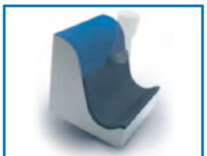
Tooling cut-outs are often made as short or flat grooves and pockets. These contours can be straight, oblique or curved. Deep slotting operations are often carried out with roller-end milling cutters.

Slot milling of WELDURAL®

Tool [ø 25 mm]		Rotational speed n [1/min]	Material removal rate Q [cm³/min]
VHM[1] 	Roughing [a_p = 25 mm]	23,800	11,063
		15,000	6,973
		8,000	3,718
Tool [ø 80 mm]		**Rotational speed n [1/min]**	**Material removal rate Q [cm³/min]**
WSP[2] 	Roughing [a_p = 40 mm]	6,167	14,801

Tool [ø 10 mm]		Rotational speed n [1/min]	Material removal rate Q [cm³/min]
VHM[1] 	Roughing [a_p = 10 mm]	59,100	2,120
		15,000	538
		8,000	286
Tool [ø 25 mm]		**Rotational speed n [1/min]**	**Material removal rate Q [cm³/min]**
WSP[2] 	Roughing [a_p = 8.3 mm]	27,502	2,720
		15,000	1,481
		8,000	789


FLAT CONTOUR


STEEP CONTOUR

3D Contouring

This refers to the multi-axis milling of convex and concave shapes in two or three directions. Special contours for design and aesthetics requirements can be taken into account. The larger the work piece size is, the more complicated the contour machining process becomes, and so the more important the planning processes. All preliminary work such as surface or edge milling have to be complete with several roughing and finishing operations.

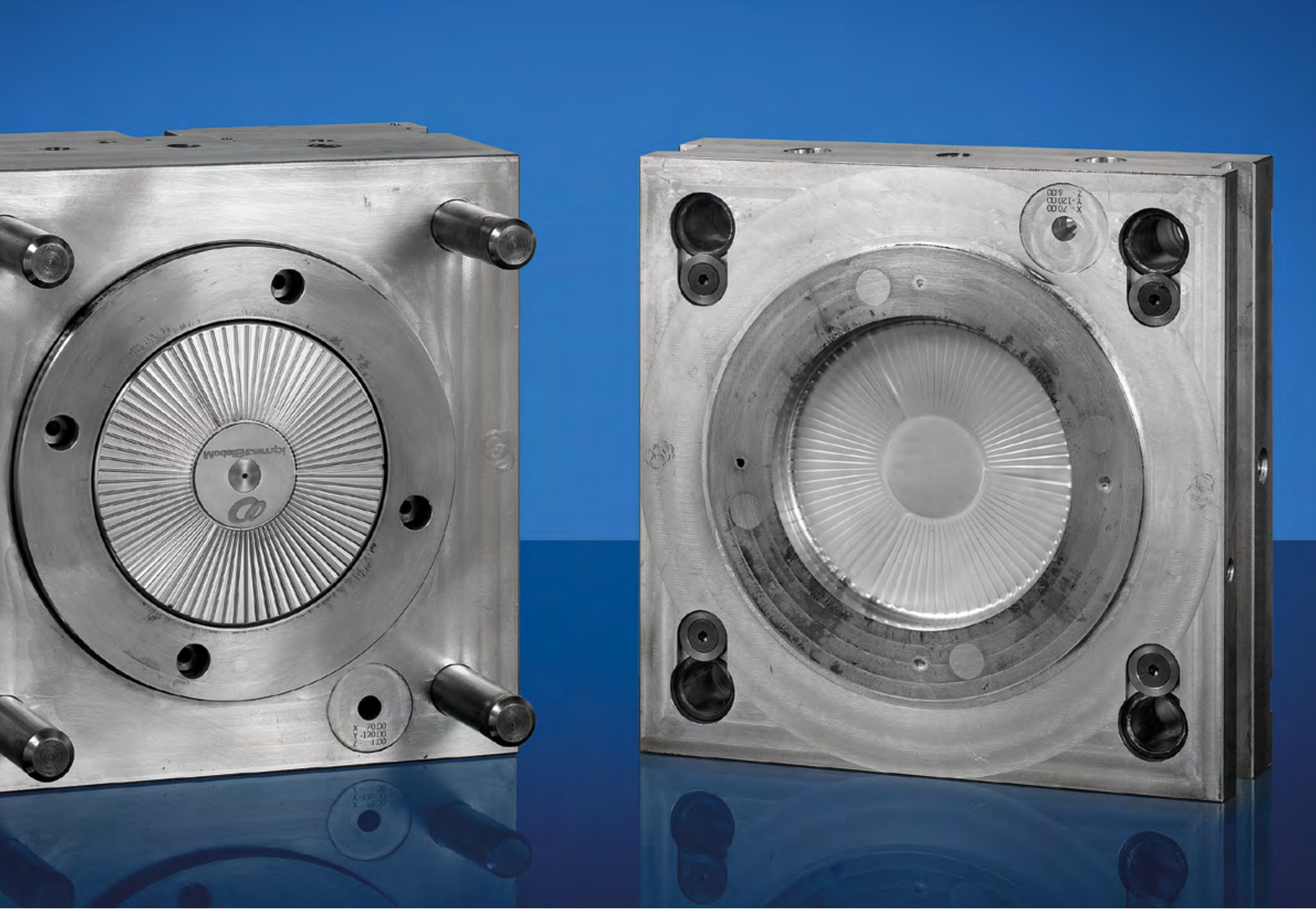
3D contouring of WELDURAL®

Tool [ø 25 mm]		Rotational speed n [1/min]	Material removal rate Q [cm³/min]
VHM[1] 	Roughing flat [a_p = 5.1 mm]	20,000	200
		15,000	150
	Finishing [a_p = 1.0 mm]	15,000	54
		3,183	12
Tool [ø 2 mm]		**Rotational speed n [1/min]**	**Material removal rate Q [cm³/min]**
VHM[1] 	Roughing flat [a_p = 0.41 mm]	51,900	0.44
		24,000	0.20
		15,000	0.13
	Finishing [a_p = 0.28 mm]	51,885	0.35
		24,000	0.16
		15,000	0.10
Tool [ø 25 mm]		**Rotational speed n [1/min]**	**Material removal rate Q [cm³/min]**
WSP[2] 	Roughing [a_p = 1.25 mm]	38,400	198
		24,000	123
		15,000	077

Tool [ø 10 mm]		Rotational speed n [1/min]	Material removal rate Q [cm³/min]
VHM[1] 	Roughing flat [a_p = 2.0 mm]	63,300	51
		24,000	19
		15,000	12
	Finishing [a_p = 1.0 mm]	73,500	34
		24,000	11
		15,000	7
Tool [ø 1 mm]		**Rotational speed n [1/min]**	**Material removal rate Q [cm³/min]**
VHM[1] 	Roughing flat [a_p = 0.20 mm]	40,000	0.04
		24,000	0.03
		15,000	0.02
	Finishing [a_p = 0.02 mm]	40,000	0.04
		24,000	0.03
		15,000	0.02
Tool [ø 10 mm]		**Rotational speed n [1/min]**	**Material removal rate Q [cm³/min]**
WSP[2] 	Roughing [a_p = 0.67 mm]	64,700	47
		24,000	18
		15,000	11

Please note the additional instructions and precautions on milling on page 16 and 17.

All values are approximate.



HOKOTOL®

Advantages of HOKOTOL®

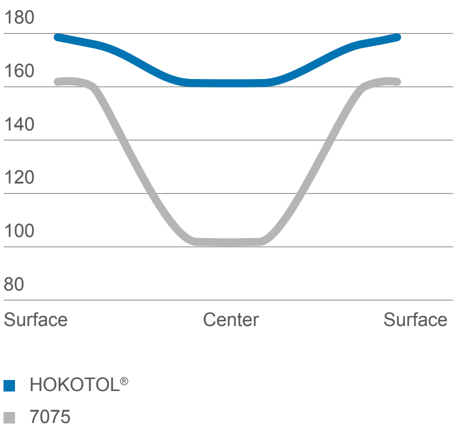
- Consistent hardness across the entire thickness
- Good grinding & polishability for surface critical components / optical surfaces
- Very good thermal conductivity
- Extremely uniform mechanical properties across the entire thickness
- High dimensional stability due to low residual stress
- Excellent machinability

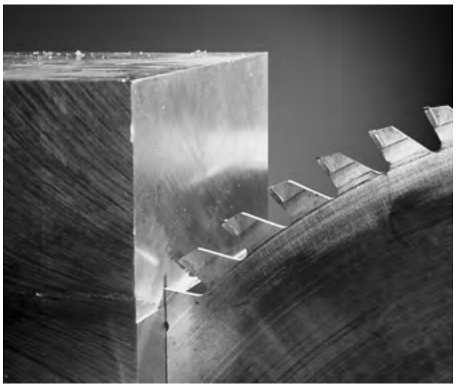
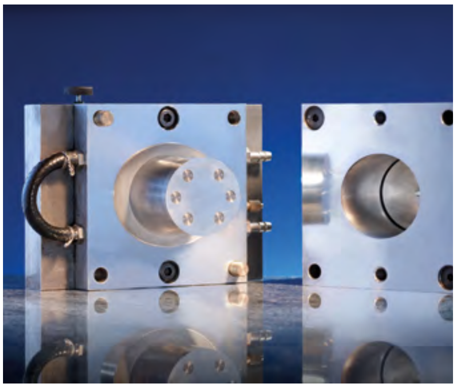
HARDNESS

HOKOTOL® has been developed to ensure a high grade of hardness across the entire plate thickness. This in an advantage when surfaces have to be polished or machined away. Polished surfaces are often used in translucent elements like headlamps, spotlights or lamp housings.

Hardness across plate thickness

Hardness HB [2.5/187.5]



Chemical composition [all data wt.-%]

Alloy		Chemical elements Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr	Other individual	Other total
HOKOTOL®	min.	-	-	1.5	-	1.8	-	5.7	-	0.08	-	-
	max.	0.3	0.35	2.6	0.1	2.6	0.05	7.6	0.06	0.25	0.05	0.15

Physical properties in comparison to steel

Property	Hardness [HB]	Density [g/cm³]	E-Modulus [MPa]	Coefficient of thermal expansion 20 - 100 °C [10^{-6}/K]	Thermal conductivity at room temperature [W/(m·K)]	Electrical conductivity at room temperature [MS/m]
HOKOTOL®	180	2.83	73,800	23.5	154	23
Steel 1.2312 (40CrMnMoS8-6)	300	7.85	215,000	12.5	35	10.3
Comparison Al : St	**1 : 1.7**	**1 : 2.8**	**1 : 2.9**	**1.9 : 1**	**4.4 : 1**	**2.2 : 1**

Minimum strength properties for various thicknesses[1]

Thickness [mm]	Tensile strength R_m [MPa]	Yield strength $R_{p0.2}$ [MPa]	Elongation A [%]
8 - 100	550	495	4
>100 - 140	530	475	2
>140 - 180	500	430	1
>180 - 220	490	420	1

[1]Measured at room temperature, test direction LT

Typical strength properties for various thicknesses[1]

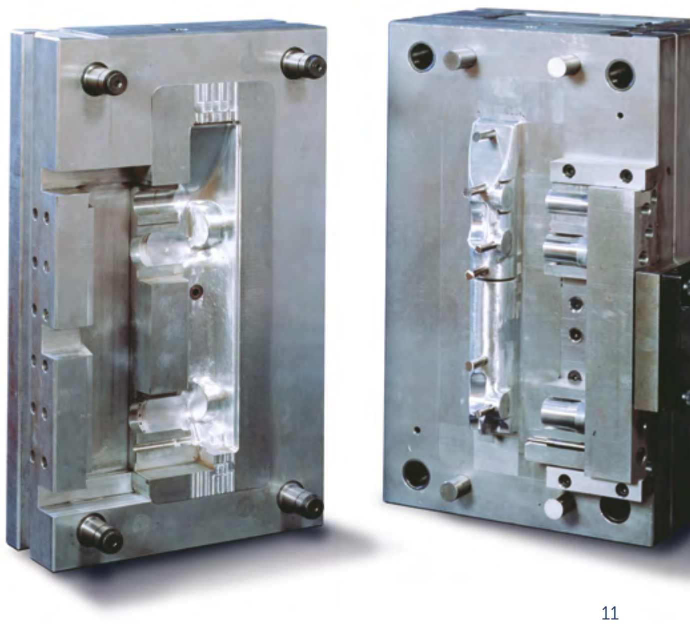
Thickness [mm]	Tensile strength R_m [MPa]	Yield strength $R_{p0.2}$ [MPa]	Elongation A [%]
8 - 100	590	545	10
>100 - 140	575	525	7
>140 - 180	565	505	6
>180 - 220	550	495	4

[1]Measured at room temperature, test direction LT

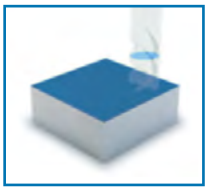
Delivery program

Thickness [mm]	Width [mm]	Length [mm]
8 - 100	2,000	10,000
>100 - 140	1,550	7,500
>140 - 180	1,225	7,500
>180 - 190	1,150	7,200
>190 - 200	1,100	6,800
>200 - 210	1,050	6,500
>210 - 220	1,000	6,000

Further dimensions upon request via molding@novelis.adityabirla.com.



Machinability of HOKOTOL®



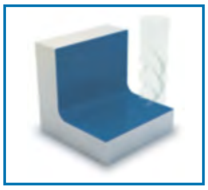
Surface Milling

Surface milling is one of the most commonly used milling techniques and a variety of different tool types can be used. It is mostly used to prepare and create the main profile of the mold or die. Surface quality is not critical for initial rouging stages but can be critical for finishing steps.

Surface milling of HOKOTOL®

Tool [ø 25 mm]		Rotational speed n [1/min]	Material removal rate Q [cm^3/min]
VHM[1] 	Roughing [a_p = 24.5 mm]	27,120	7,323
		24,000	6,481
		15,000	4,051
	Finishing [a_p = 0.5 mm]	30,303	182
		24,000	144
		15,000	90
Tool [ø 200 mm]		**Rotational speed n [1/min]**	**Material removal rate Q [cm^3/min]**
WSP[2] 	Roughing [a_p = 4.5 mm]	2,894	5,464
	Finishing [a_p = 0.5 mm]	3,041	516

Tool [ø 10 mm]		Rotational speed n [1/min]	Material removal rate Q [cm^3/min]
VHM[1] 	Roughing [a_p = 9.8 mm]	61,434	1,799
		24,000	703
		15,000	439
	Finishing [a_p = 0.2 mm]	73,848	55
		24,000	18
		15,000	11
Tool [ø 50 mm]		**Rotational speed n [1/min]**	**Material removal rate Q [cm^3/min]**
WSP[2] 	Roughing [a_p = 4.5 mm]	10,359	2,555
	Finishing [a_p = 0.5 mm]	12,046	275



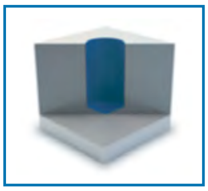
Edge Milling

Edge milling is used to produce two or more surfaces simultaneously in one tooling pass. This technique requires peripheral milling of an external contour, in conjunction with a planar milling operation.
The production of a shoulder with a 90° angle is one of the most important applications in mold making. Because of the large number of possibilities, it is important to consider the application's specific requirements in order to make the best choice.

Edge milling of HOKOTOL®

Tool [ø 25 mm]		Rotational speed n [1/min]	Material removal rate Q [cm^3/min]
VHM[1] 	Roughing [a_p = 24.5 mm]	28,775	6,345
		24,000	5,292
		15,000	3,308
	Finishing [a_p = 0.5 mm]	34,887	100
		24,000	69
		15,000	43
Tool [ø 100 mm]		**Rotational speed n [1/min]**	**Material removal rate Q [cm^3/min]**
WSP[2] 	Roughing [a_p = 15 mm]	6,175	5,420

Tool [ø 10 mm]		Rotational speed n [1/min]	Material removal rate Q [cm^3/min]
VHM[1] 	Roughing [a_p = 9.8 mm]	71,301	1,409
		24,000	474
		15,000	296
	Finishing [a_p = 0.2 mm]	78,304	36
		24,000	11
		15,000	7
Tool [ø 50 mm]		**Rotational speed n [1/min]**	**Material removal rate Q [cm^3/min]**
WSP[2] 	Roughing [a_p = 15 mm]	12,478	3,509



Drilling

Drill feeds can be affected by the movement of the drill or the work piece. Drilling is often used in mold making, for example, for pilot hole, tooling connections or assemblies and to introduce deep cooling channels into the work piece geometry.

Drilling of HOKOTOL®

Tool [Drilling depth 6 x D]	Diameter D [mm]	Rotational speed n [1/min]	Material removal rate Q [cm^3/min]
VHM[1] 	12	8,700	374
	6	18,038	474
		15,000	115
[Drilling depth 5 x D]	**[mm]**	**[1/min]**	**[cm^3/min]**
WSP[2] 	30	1,761	7,880
	16	3,959	315

[1] VHM = Solid carbide tool, [2] WSP = Indexable tool

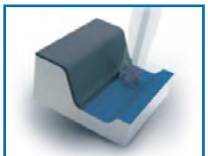
Slot Milling

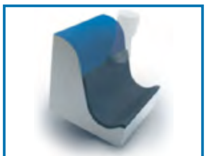
Tooling cut-outs are often made as short or flat grooves and pockets. These contours can be straight, oblique or curved. Deep slotting operations are often carried out with roller-end milling cutters.

Slot milling of HOKOTOL®

Tool [ø 25 mm]		Operation	Rotational speed n [1/min]	Material removal rate Q [cm³/min]
VHM[1]		Roughing [a_p = 25 mm]	21,518	10,086
			15,000	7,031
			8,000	3,750
Tool [ø 80 mm]			**Rotational speed n [1/min]**	**Material removal rate Q [cm³/min]**
WSP[2]		Roughing [a_p = 40 mm]	5,769	13,500

Tool [ø 10 mm]		Operation	Rotational speed n [1/min]	Material removal rate Q [cm³/min]
VHM[1]		Roughing [a_p = 10 mm]	53,476	1,925
			15,000	540
			8,000	288
Tool [ø 25 mm]			**Rotational speed n [1/min]**	**Material removal rate Q [cm³/min]**
WSP[2]		Roughing [a_p = 8.3 mm]	24,828	2,430
			15,000	1,468
			8,000	783


FLAT CONTOUR


STEEP CONTOUR

3D Contouring

This refers to the multi-axis milling of convex and concave shapes in two or three directions. Special contours for design and aesthetics requirements can be taken into account. The larger the work piece size is, the more complicated the contour machining process becomes, and so the more important the planning processes. All preliminary work such as surface or edge milling have to be complete with several roughing and finishing operations.

3D contouring of HOKOTOL®

Tool [ø 25 mm]		Operation	Rotational speed n [1/min]	Material removal rate Q [cm³/min]
VHM[1]		Roughing flat [a_p = 5.1 mm]	20,000	200
			15,000	150
		Finishing [a_p = 1.0 mm]	15,000	54
			2,878	10
Tool [ø 2 mm]			**Rotational speed n [1/min]**	**Material removal rate Q [cm³/min]**
VHM[1]		Roughing flat [a_p = 0.41 mm]	51,900	0.44
			24,000	0.20
			15,000	0.13
		Finishing [a_p = 0.28 mm]	51,900	0.35
			24,000	0.16
			15,000	0.10
Tool [ø 25 mm]			**Rotational speed n [1/min]**	**Material removal rate Q [cm³/min]**
WSP[2]		Roughing [a_p = 1.25 mm]	34,700	179
			24,000	124
			15,000	77

Tool [ø 10 mm]		Operation	Rotational speed n [1/min]	Material removal rate Q [cm³/min]
VHM[1]		Roughing flat [a_p = 2.0 mm]	63,300	51.0
			24,000	19.33
			15,000	12.08
		Finishing [a_p = 0.6 mm]	66,400	30.6
			24,000	11.06
			15,000	6.91
Tool [ø 1 mm]			**Rotational speed n [1/min]**	**Material removal rate Q [cm³/min]**
VHM[1]		Roughing flat [a_p = 0.20 mm]	40,000	0.05
			24,000	0.03
			15,000	0.02
		Finishing [a_p = 0.20 mm]	40,000	0.04
			24,000	0.03
			15,000	0.02
Tool [ø 10 mm]			**Rotational speed n [1/min]**	**Material removal rate Q [cm³/min]**
WSP[2]		Roughing [a_p = 0.67 mm]	58,400	43
			24,000	18
			15,000	11

Please note the additional instructions and precautions on milling on page 16 and 17.

All values are approximate.

Coating

COATING OPTIONS

Many aluminium alloys, including WELDURAL® and HOKOTOL® can be coated to enhance their specific surface characteristics. The type of coating material depends on the alloy used. WELDURAL® achieves good results in hard anodizing.

Below you will find two coating examples for our products WELDURAL® and HOKOTOL®.

Advantages

- Improving mold service time
- Increasing the number of process cycles
- Improved corrosion protection
- Enhancing surface quality

HARD CHEMICAL NICKEL PLATING

Elemental Nickel is used for wear or corrosion protection. A prerequisite for this process is a very clean surface finish.

The corrosion protection is achieved by a high content of phosphorus.

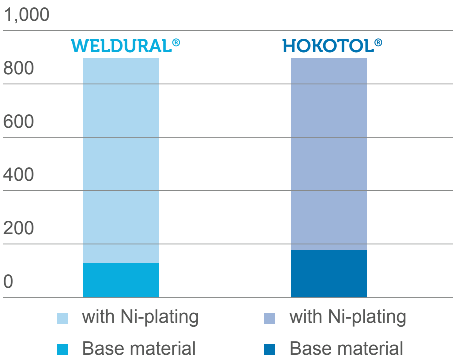
Visual appearance:

Blast surface
matt

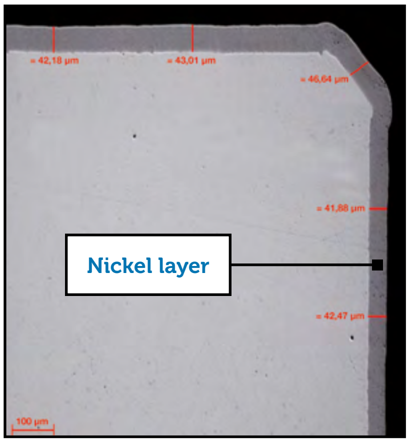
Polished surface
bright

Surface treatment with hard chemical nickel plating

Hardness Vickers [HV 0.05]



WELDURAL®: 900 HV
HOKOTOL®: 900 HV

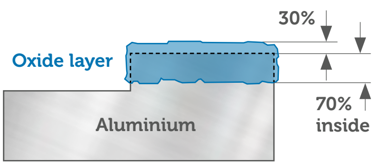


Alloy: WELDURAL®
Plated by Novoplan, Aalen, Germany

HARD / INDUSTRIAL ANODIZING

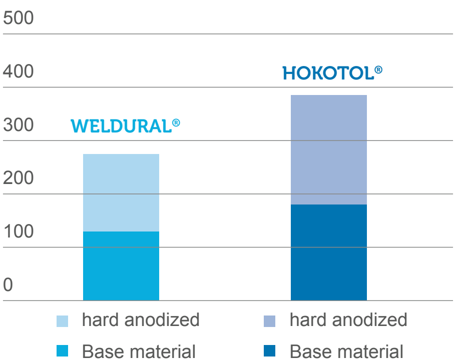
The aluminium oxide layer is increased by the anodization process to serve as a protective layer for the base metal against corrosion and abrasion. Oxide layers are produced between 0.5 and 150 µm thick.

During hard anodizing, the oxide layer can grow on all exposed component surfaces, as shown in the figure below.

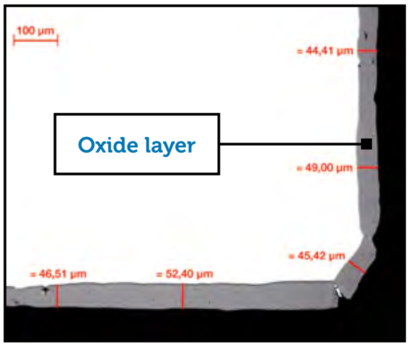


Surface hard anodized

Hardness Vickers [HV 0.05]



WELDURAL®: 270 HV
HOKOTOL®: 385 HV



Alloy: WELDURAL®
Anodized by AHC Oberflächentechnik, Kerpen, Germany

Polishing

Both molding alloys WELDURAL® and HOKOTOL® have a good polishability.
Below you can find typical roughness data for WELDURAL® and HOKOTOL®.

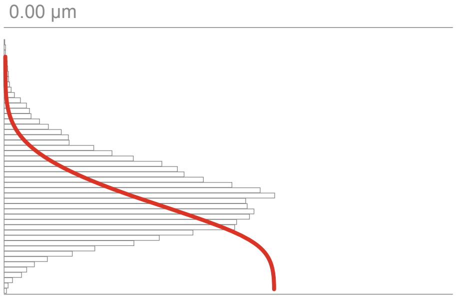
WELDURAL® and HOKOTOL® have excellent mechanical properties for a wide range of applications. A further important factor in the production of molds is excellent surface quality for components with aesthetic requirements. This can only be achieved if the surface of the molding material has a correspondingly good polished quality. Our materials are also suitable for these applications.

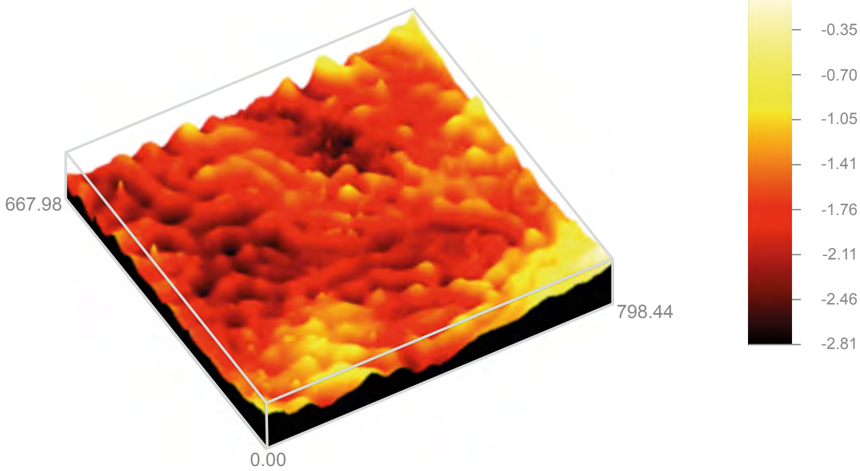
With standard polishing procedures we are able to demonstrate very satisfactory roughness values. As a result, both alloys can also be used for other different surface requirements, such as high gloss surfaces (e.g., headlamp tools), textured surfaces (e.g. automotive interiors), painted surfaces and sheet molded compounds (e.g., exterior skin tools).

WELDURAL®

shows good polishability next to the surface.

Profil depth = 2.74 µm
Arithmetical mean deviation of the roughness profile [S_a] = 0.21 µm
Quadratic mean deviation of the roughness profile [S_q] = 0.26 µm

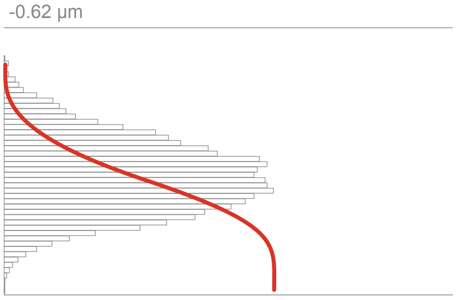


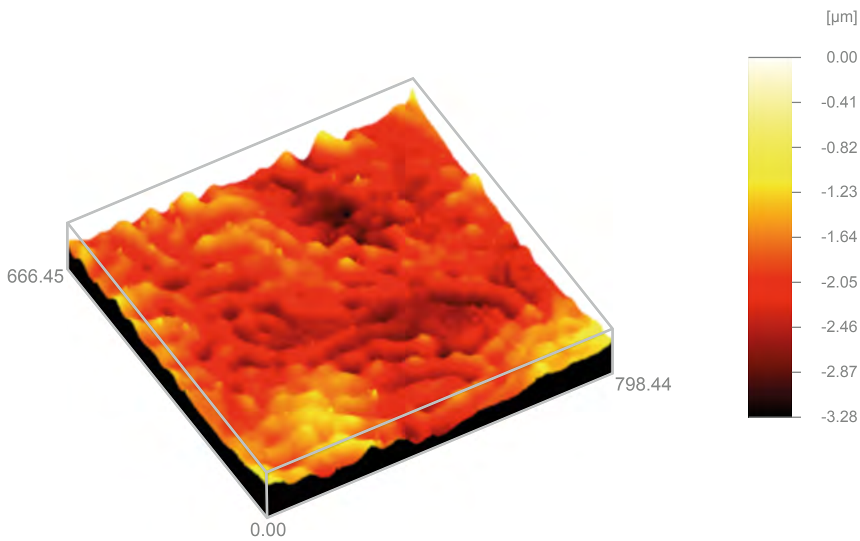


HOKOTOL®

can be polished through the entire plate thickness.

Profil depth = 2.54 µm
Arithmetical mean deviation of the roughness profile [S_a] = 0.21 µm
Quadratic mean deviation of the roughness profile [S_q] = 0.26 µm





Tips and Techniques

Practical procedures when milling

1. Max. number of teeth [z]
   Depending on the diameter and tool size

2. Sensible teeth feed [f_z]
   Depending on the size of the tool, tool flute and teeth feed. This aspect has to be managed, if too low, the tool grinds more than cuts (note minimum thickness and spindle torque)

3. Max. possible feed speed [v_f] of the machine
   The speed at which acceptable surface tolerance accuracy is achievable – note: this strongly depends on the contours to be machined (lengths and directional), and can differ for roughing and finishing operations. It is often useful to conduct a simple corner contour test to confirm

4. From z, f_z, v_f the resulting speed:
   $n = v_f / (f_z \cdot z)$

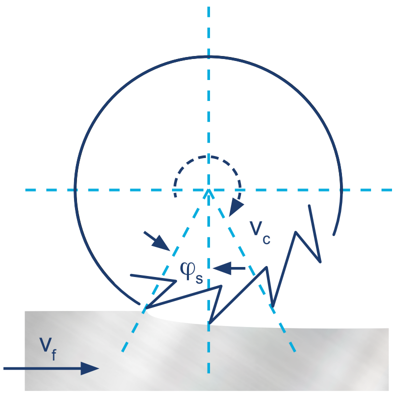
5. From speed [n] the cutting speed:
   $v_c = \varpi \cdot D_c \cdot n / 1{,}000$

6. Select a suitable material for a given cutting speed so that project tool life or tool costs are acceptable

7. Always consider total machine and tool costs (or piece time and throughput / time) – it is necessary to find an optimum with the minimum number of changes in tool feed and torque.

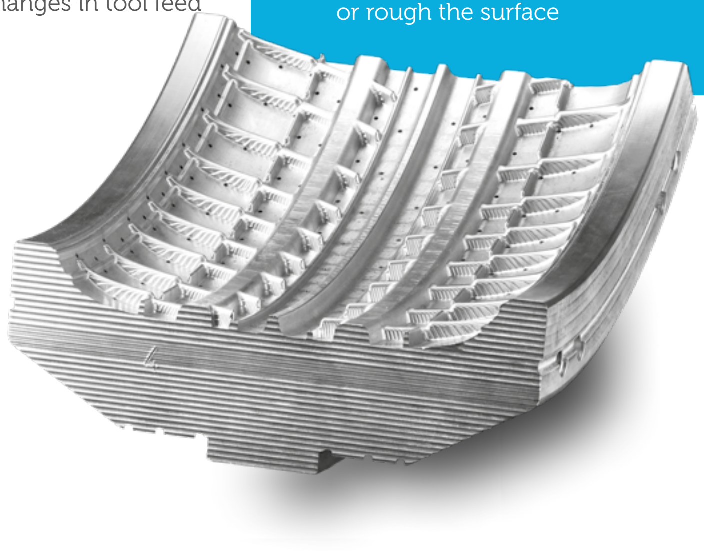
Important relationships when milling

- Cutting force:
  $F_c \sim k_c \cdot a_p \cdot h$ [N]
- Cutting capacity:
  $P_c = F_c \cdot v_c$ [W]
- Torque:
  $M_c = F_c \cdot D_c / 2$ [Nm]
- Teeth feed:
  (at $a_e/D_c = 0.5 = h_{max}$):
  $f_z = v_f / (z \cdot n)$ [mm]
- Cutting angle:
  $\phi_s = \arccos [1- (2 \cdot a_e / D_c)]$ [°]
- Chip thickness:
  $h \sim f_z \cdot a_e / (\phi_s \cdot D_c)$ [mm]
- Feed rate:
  $v_f = f_z \cdot z \cdot n$ [mm/min]
- Main time:
  $t_H \sim 1 / v_f$ [min]
- Cutting speed:
  $v_c = \varpi \cdot D_c \cdot n / 1{,}000$ [m/min]
- Spindle speed:
  $n = v_c \cdot 1{,}000 / (\varpi \cdot D_c)$ [1/min]
  At a given cutting speed for a certain tool life
- Surface finish:
  $R_{kin} \sim h \cdot D_c / z$ [µm]
  The larger R_{kin}, the more wavy or rough the surface



v_c = cutting speed [m/min]
v_f = feed rate [mm/min]
φ_s = cutting angle [°]

k_c = material constant
a_p = axial feed [mm]
a_e = radial feed [mm]
D_c = tool diameter [mm]
φ_s = cutting angle [°]
z = cutting speed of the tool



Additional Advice

It should be noted that the cutting data given here are to be considered as guidelines only. All results based on stable processing of designs without complexity geometries, e.g. without long cantilever lengths, and the use of standard industrial tools, incl. coated tools.

Additional clarification of the above, technical advice and support can be provided on request. Please contact molding@novelis.adityabirla.com.

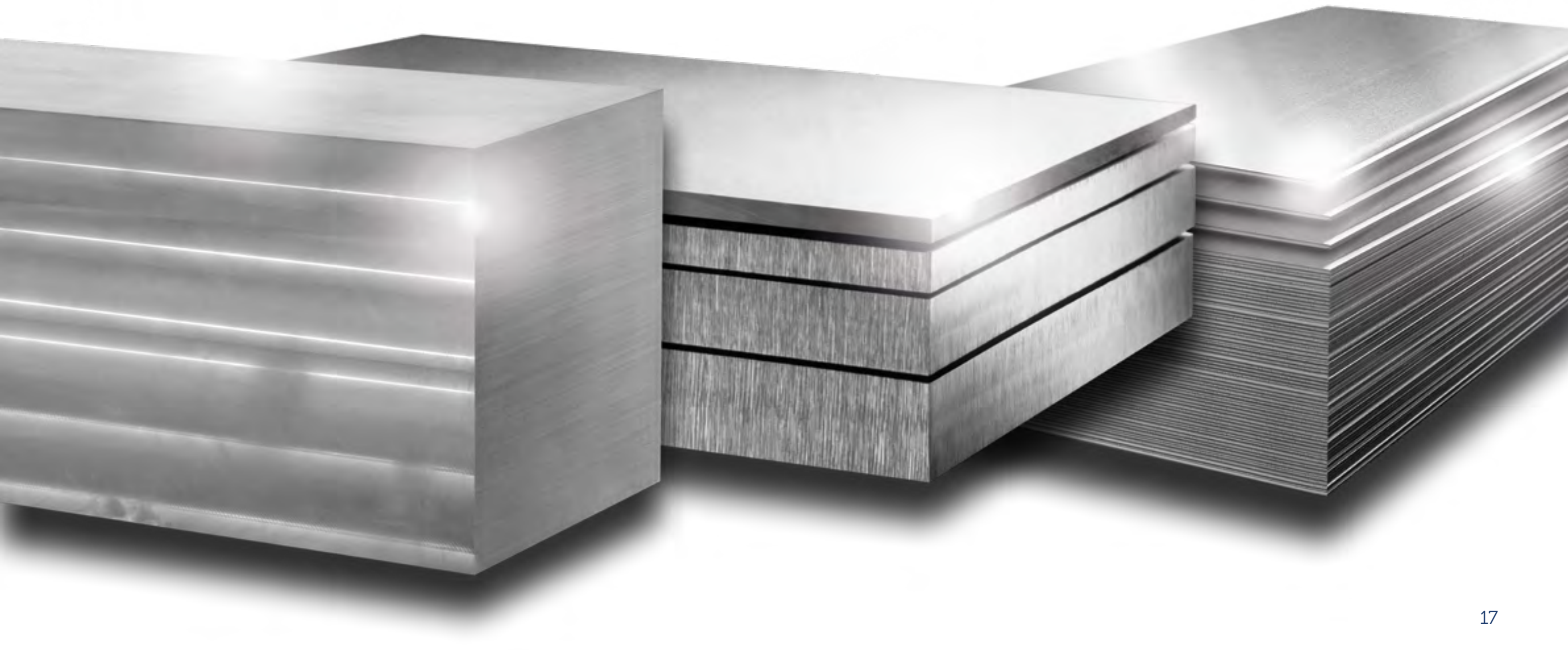
Their accuracy and applicability are subject to the following influencing factors:

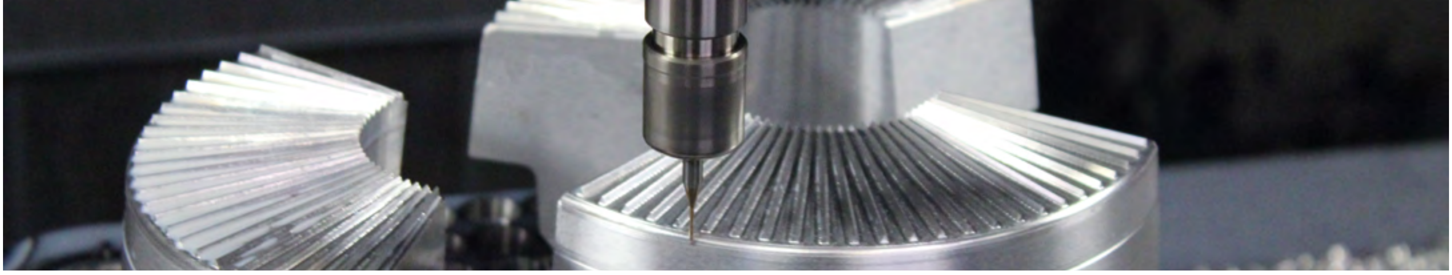
- **Current state** of tool wear
- **Surface condition** of workspace (e.g. pre-machining, mill scale etc.)
- **Actual hardness** of work piece (average hardness has been assumed here)
- **Cooling lubrication** (proper mill emulsions have been used for conducting of machining data in this brochure)
- **Robustness** of the entire system (work piece, clamping device, tool, diameter, projection length, carbide grade with tool holder, main spindle and machine components)
- **Machine design** (e.g. horizontal or vertical processing)
- **Performance characteristics** of main spindle (reachable torque limit)
- **Cutting strategy** (number of cutting passes – the default values specified have been considered here, which means that an increased performance can be achieved by means of the so-called trochoidal milling)

Should the machine not be able to run the speeds indicated, the maximum available speed should be engaged without altering the tool feed, whilst the torque remains unchanged.

Increasing the hardness of the work piece as well as cutting speed leads to increased tool wear and reduced tool life. Although higher cutting speeds enhance metal removal rate, these can also lead to excessive tool wear. A medium degree of hardness has been assumed for the aluminium alloys. As a general rule, assuming greater hardness in the reference values results in lower cutting speeds (increased tool wear).

Due to the chip volume and the required size of chip space of the tool, the tooth feed should in general not be increased. If long tools are used, vibration may be induced. Here too, the cutting data (primarily the axial feed and possibly the radial feed) need to be adjusted. Selecting the right rotation speed in combination with the axial feed plays a significant role here (so-called chip / scrap handling). However, this strongly depends on system characteristics. Here too, the tooth feed or the feed rate per rotation should not be lowered to guarantee adequate machining processes.





Reduction of Mold Costs

The mold costs can be obtained by the sum of the following items:

- materials
- mold components (fittings, columns, heaters, hot chambers, ...)
- working capital
- machining (tools and lubricants/setup of machinery and mold, ...)

COST OF MATERIALS

Although the density ratio of aluminium to steel is 1:3, it is necessary to use a greater thickness for aluminium alloys. Thus in reality the expected weight saving is approximately half of the weight of the original steel part.

In cases where aluminium alone is not able to fulfil the required mechanical properties, it is possible to use a composite mold made from aluminium and steel.

COST OF MOLD COMPONENTS

- standard steel components can be used in conjunction with aluminium without problems
- most aluminium molds have steel parts

Thus the cost of the components for both, aluminium and steel molds, are equal.

WORKING CAPITAL

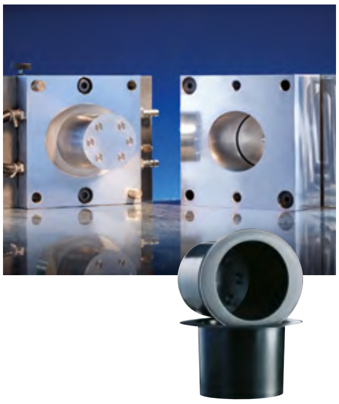
Aluminium molds are manufactured in less time therefore substantial financial advantages can be obtained.

Reduction of mold costs – aluminium vs. steel

	Front dial Washing machine	Underseat component Motorcycle	Door panel component Motorcar
Alloy	HOKOTOL®	WELDURAL®	HOKOTOL®
Surface	Mirror finish	Mill finish	Photo-engraved finish
Type of plastic	ABS	PP + 20 % Talc	PP
Foreseen closures	300,000	40,000	100,000
Advantage compared to steel 1.2311			
Cost	33 %	25 %	24 %
Manufacturing time	3 weeks	2 weeks	2 weeks

Examples of molds and their manufacturing process

	Flower stand	Swing arm
Weight / piece	0.022 kg	0.055 kg
Until now produced	700,000 pieces	1,000 pieces
Type of plastic	PP	PA6 + 30 % GF
Method of production	Injection molding	Injection molding
Temperature of plastic injection	225 °C	235 °C
Mold temperature	25 - 30 °C	80 °C
Injection pressure	600 bar	800 bar
Mold material	Aluminium 7075 and steel 37	Aluminium 7075 and steel 37



Savings / benefits of the use of an aluminium / steel composite mold in comparison to a steel mold

	Flower stand	Swing arm
Mold weight	– 42 %	– 54 %
Price of material	– 47 %	– 50 %
Mold machining costs	– 33 %	– 24 %
Production / min	+ 35 %	+ 10 %
Price / piece	– 33 %	– 9 %

Your Reliable Partner

Not just aluminium, Novelis Aluminium.™

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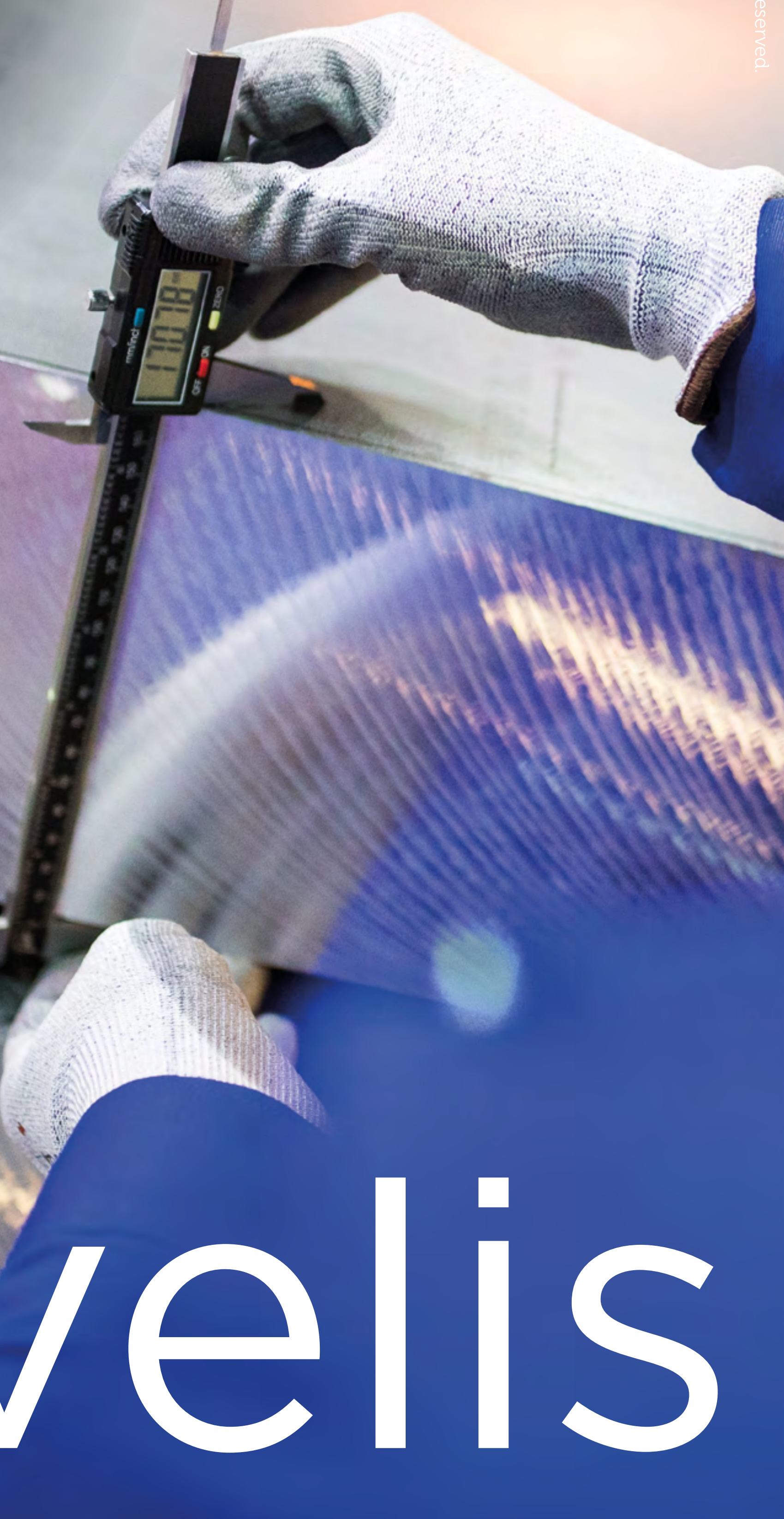

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