Hot-Work Tool Steel

Deutsche Edelstahlwerke

Member of Swiss Steel Group

Tools from hot-work tool steel

The significance of tool steel goes far beyond what is generally perceived as commonplace. Nearly all of the objects we are surrounded by and encounter on a daily basis are manufactured with the help of tool steels.

The spectrum of applications for hot-work steel is broad and the tools manufactured with them are used in a variety of fields. Hot-work tool steel is used for the non-cutting forming of workpieces made of iron and non-ferrous metals as well as alloy derivatives at high temperatures. They are applied in processes such as pressure die casting, extrusion, and drop forging as well as in tube and glass product manufacturing.

During processing, hot-work tool steel is generally exposed to high temperatures exceeding 200 °C. The microstructure of this steel should be sufficiently stable and resistant to tempering because microstructural changes must be prevented at all costs.

Tools made from hot-work steel are not only subject to consistently high temperatures when employed but also to fluctuating thermal stresses occurring where the tool surfaces come into contact with the materials to be processed. Combined with the wear caused by abrasion or impact, these thermal stresses constitute very specific requirements of the hot-work tool steels. The key demands are high tempering resistance, thermal shock resistance, high-temperature strength, hightemperature toughness, and wear resistance.

These properties, however, are impossible to realize in only one type of steel at the same time and in the same manner. The requirements often vary significantly from one tool to the next and are therefore impossible to fulfill with steels from a very limited alloy range. Steel grades thus have to be selected based on the primary demands of the tool to be employed.

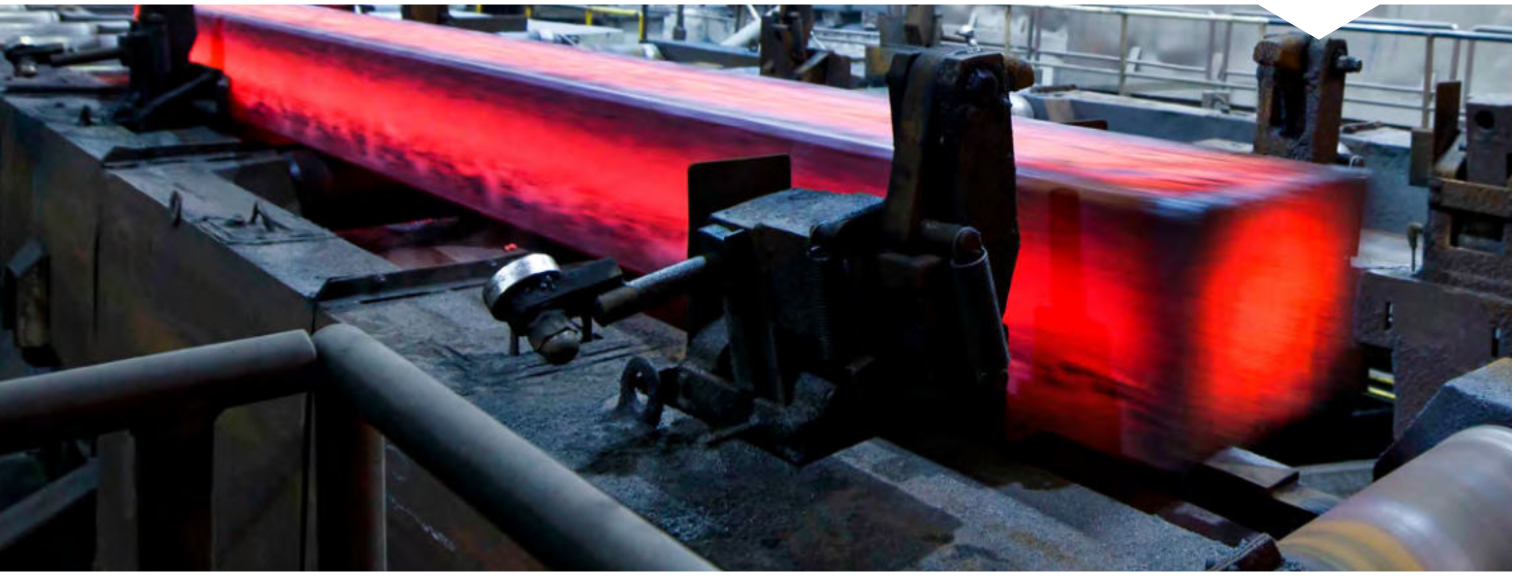
Using high-quality hot-work tool steel is imperative in order to ensure a high degree of operating efficiency and productivity during manufacturing.

Deutsche Edelstahlwerke – the hot-work tool steel experts

Deutsche Edelstahlwerke hot-work tool steel feature high durability and can be individually matched to a variety of properties required of a tool or processing method. By applying cutting-edge technology, the hot-work tool steel produced at Deutsche Edelstahlwerke is able to meet the highest standards regarding:

» Tempering resistance
» Thermal shock resistance
» High-temperature strength and toughness
» High-temperature wear resistance
» Resistance to erosion, high-temperature corrosion, and oxidation
» Machinability
» Low adhesion tendency

In order to offer tool manufacturers, the processing and manufacturing industries as well as other industrial users the best conditions necessary for their specific demands, Deutsche Edelstahlwerke has expanded their range of services to include customer and application-specific consulting and product development.



Process reliability from consultation to the final product

Depending on their intended purpose, hot-work tool steel must meet a number of different requirements. In ensuring that these requirements are met, the proper selection and treatment of a steel grade play an important role in the resulting manufacturing quality and profitability.

Technical consulting

We offer competent consultation for anything from the selection of the most suitable steel to heat treatment solutions to the custom development of a specific tool steel grade. For you, our know-how and technical consulting means maximum production assurance right from the start. Any factors relevant for production can be coordinated in advance, which in turn minimizes production costs. Our technicians and material specialists are also glad to offer advice and support in the case of tools encountering service life problems. They perform failure analyses and material tests to determine the cause and to rectify the issue in a speedy and sustainable manner.

Processing and service

Our highly efficient team and ultra-modern machine tools guarantee the flexibility and speed necessary to meet practically any customer demand. This may include the peeling, turning, pressure-polishing, and chamfering of rolled or forged bar steel after straightening. Square and rectangle shapes may be milled or ground. Rotation-symmetric parts with unit weights of up to 22 tons are manufactured in modern rolling and forging plants and then machined on turning, grinding, and milling equipment. In our Witten facility, we employ computercontrolled state-of-the-art equipment to manufacture products for the toolmaking and mould construction sector. The broad range of products and production services offered by Deutsche Edelstahlwerke extends from pre-milled billets to precision flats and squares to ready-made molded parts with unit weights of up to 40 tons. Upon request, molded parts may be pre-machined up to 0.3 mm on the finished contour. Sophisticated custom products, such as premachined and chromium-plated mandrel bars for the production of seamless tubes, are part of our versatile range of services as well.

Quality

In order to guarantee consistent and reproducible quality, we take advantage of our active and certified management system in accordance with ISO 9001, ISO/TS 16949, ISO 14001, AS 9100KTA 1401, and our accredited test laboratories according to ISO/IEC 17025. All of our manufacturing processes – from melting to casting, from testing for internal or surface flaws and identity checks of products machined in our rolling mill and forging finishing lines to the mechanical and technological testing of samples – are monitored, controlled, and supervised. Our customers can rely on this quality, which is proven by the fact that we have been granted all essential licenses from the automobile industry (CNOMO, GM, and Ford) as well as those from other significant institutions such as VDG, DGM, and NADCA.

Resistance to thermal shock

The ability of a steel to cope with recurring temperature fluctuations without sustaining surface damage, is of particular importance for hot-work tool steel. An optimum of resistance to thermal shock and toughness is achieved by adding a higher percentage of alloys. In order to ensure these properties and to balance them, we employ the services of our testing laboratory, where we simulate the thermal stresses in a thermal shock system developed specifically for that purpose. In this machine, the steels undergo temperature fluctuations of over 500 °C within seconds. The knowledge gained from these tests is valuable in developing and producing even better hot-work tool steel.

Extensive range of products and stock

Deutsche Edelstahlwerke delivers customized dimensions from stock within very favorable delivery times. Our broad range of tool steels allows us to meet any quality requirement. Furthermore, we have a constant stock of approximately 10,000 tons of tool steels in several thousand different dimensions at our disposal. It goes without saying that we also manufacture custom products needed as feedstock in tool production.

Steel production all from one source

We guarantee our customers precision work from once source – from consulting and steel manufacturing to finishing by means of heat treatment and individual steel prefabrication to world-wide delivery.
They can rely on receiving the same level of precision in every too and with any processing method.

World-wide availability

No matter where on earth a selected steel is needed, with the distribution network of Swiss Steel Group Deutsche Edelstahlwerke ensures dependable delivery, speed, and consistently high quality.

Our technology and experience – your guarantee for premium quality

Steel production in our modern steelworks is the basis for the purity and homogeneity of our tool steels.
We achieve very clearly defined properties as a result of precise specifications regarding alloys and procedures for melting, shaping, and heat treatment.

Tool steel produced by Deutsche Edelstahlwerke is melted in 130 ton electric arc furnaces. Analytical fine-tuning is then performed in a ladle furnace and the steel is degassed just before casting.

At Deutsche Edelstahlwerke, two casting processes are used to cast the metallurgically treated melts depending on the required size of the final product:
the arc casting method and optimized vertical continuous casting method or – for large forging dimensions – ingot casting.

Custom remelting

For tool steels requiring particularly high levels of homogeneity, toughness, and purity, Deutsche Edelstahlwerke uses several electroslag remelting furnaces (ESRs) and vacuum arc remelting furnaces (VARs). The quality desired for the remelted steel determines which procedure is the most suitable. Electroslag remelting achieves significantly better sulfidic purity levels than non-remelted steel. Vacuum arc remelting, on the other hand, improves the oxidic level of purity.

Custom heat treatment

Deutsche Edelstahlwerke looks back on decades of tradition and expert knowledge in all ranges of heat treatment.
We are now able to offer the entire production chain – from steel production to prefabrication to finishing by means of heat treatment – from one source and in all of the important markets of the world. These are the prerequisites for outstanding tool quality.

In our hardening facilities around the world, we have vacuum tempering furnaces, inert gas plants, and plasma nitriding plants for thermo-chemical treatments at our disposal. Computer-controlled process flows of all steps from incoming goods inspection to the final heat-treated product are what makes our heat treatment procedures reproducible at any time.

Benefits for our customers

Due to an inert chamber precision-hardening process developed by Deutsche Edelstahlwerke, we are able to reduce the deformation of narrow components, such as rails, to a minimum.

Hot-work tool steel for various manufacturing processes

A hot-work tool steel's functionality is defined by its chemical composition, the technology applied for production, and the ensuing heat treatment. Selecting the right steel grade and means of employment leads to considerable cost savings and increased production reliability for the user.

Deutsche Edelstahlwerke supplies excellent hot-work tool steel for every type of manufacturing process. The steel require special heat treatment in order to meet the high demands. Deutsche Edelstahlwerke delivers these steels marked with "EFS" (extra-fine structure). For the absolutely highest standards, these steels are re-melted in addition and then carry the label Superclean or Ultraclean.

On the following pages, you will find lists of processing methods and fields of application for the most important steel grades offered by Deutsche Edelstahlwerke. The following processing methods - and the steel grades most recommended for them – will be covered:

» Pressure die casting
» Extrusion
» Forging
» Glass product manufacturing
» Tube manufacturing

Overview of hot-work tool steel

Brand	Pressure die casting	Extrusion	Forging	Glass product manufacturing	Tube manu-facturing
Formadur® 2083 Superclean				●	
Thermodur® 2329		●			
Thermodur® 2342 EFS					●
Thermodur® 2343 EFS	●	●	●		●
Thermodur® 2343 EFS Superclean	●	●	●		
Thermodur® 2344 EFS	●	●	●	●	●
Thermodur® 2344 EFS Superclean	●	●	●	●	
Thermodur® 2365 EFS	●	●	●		
Thermodur® 2367 EFS	●	●	●		
Thermodur® 2367 EFS Superclean	●	●	●		
Cryodur® 2709	●				
Thermodur® 2714		●	●		
Thermodur® 2740					●
Thermodur® 2782 Superclean				●	
Thermodur® 2787				●	
Thermodur® 2787 Superclean				●	
Thermodur® 2999 EFS Superclean	●		●		
Thermodur® E 38 K Superclean	●	●	●		

Steels for pilot and supporting tools

Formadur® 2312	●	●	●		
Cryodur® 2379	●		●		
Formadur® 2738	●				
Cryodur® 2842	●				

Pressure die casting

Pressure die casting is one of the most cost-effective manufacturing processes used in the foundry industry and is renowned for its high dimensional accuracy and homogeneity during series production.

This method entails injecting molten metal into a die cavity at a very high speed. The pressure applied to transport the molten metal stream into even the narrowest of cross-sections is imperative for precise shape reproduction, which is one of the special benefits of pressure die casting.

Pressure die cast parts are predominantly designed to be thin-walled in order to allow for shorter cycle times and to minimize the thermal stresses on the die.
Nevertheless, the moulds are exposed to considerable mechanical and thermal loads during die casting, which is why the durability of a die is of particular importance.

The die‘s service life depends largely on the quality of the hot-work tool steel as well as its means of production and heat treatment. The effects that choosing suitable steels and the purposeful adjustment of individual alloys can have on the die’s quality, reliability, and service life should therefore not be underestimated.

During pressure die casting, temperatures fluctuate immensely and the fluctuation intervals are extremely short and vary from metal to metal. This makes the thermal shock resistance of the hot-work tool steel a top priority for the die caster.

The steel should display the following properties:
» High thermal shock resistance
» Excellent high-temperature strength
» Outstanding high-temperature toughness
» High thermal conductivity
» Good high-temperature wear resistance
» High compression strength

Regardless of the type of machine used to process a specific material - at Deutsche Edelstahlwerke you will receive highperformance steel, which set global standards for hot-work tool steel.

Benefits for the tool manufacturer

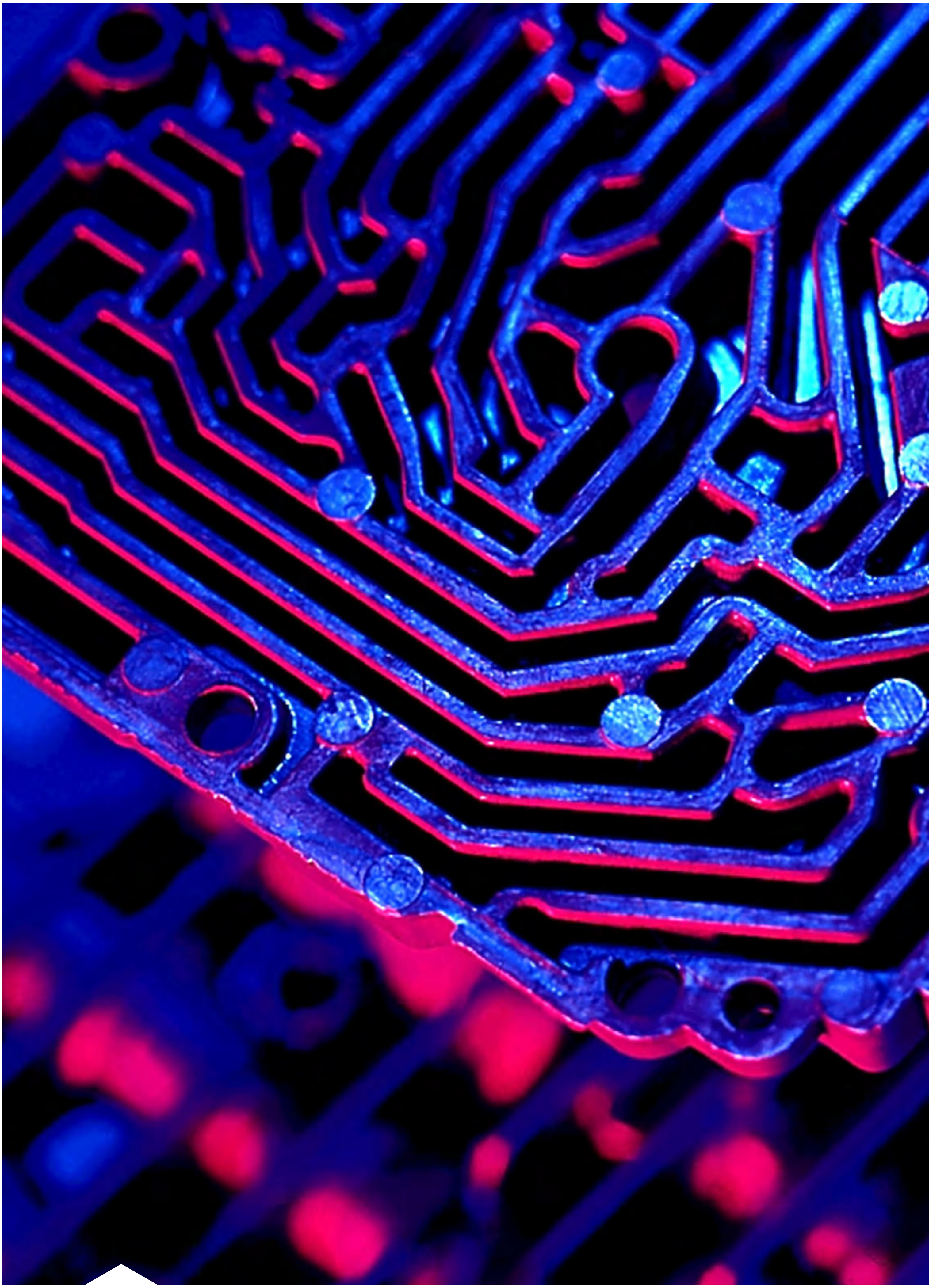
» Adherence to delivery dates
» Consistent quality
» Cost-effective machinability
» Uncomplicated heat treatment
» Good repair weldability
» Competent consulting
» Short delivery times

Benefits for the die caster

» Long service life
» Low die costs and low costs per unit
» Low susceptibility to hot cracking
» Negligible repair efforts
» Good repair weldability
» Low tool turnover
» Technical consulting
» Good dimensional stability

Benefits for the user

» Long service life
» Low component costs
» Reproducible die casting quality
» Technical consulting



Properties and applications of pressure die casting steel

Group-specific property comparison

Grade	Wear resistance	Toughness	Insusceptibility to hot cracking	Thermal conductivity
Thermodur® 2343 EFS Superclean	●	● ●	●	●
Thermodur® 2344 EFS Superclean	● ●	●	●	●
Thermodur® 2365 EFS Superclean	● ●	●	● ●	● ● ●
Thermodur® 2367 EFS Superclean	● ●	● ●	● ●	● ●
Thermodur® 2885 EFS	● ●	●	● ●	● ● ●
Thermodur® 2999 EFS Superclean	● ● ● ●	●	● ● ●	● ● ●
Thermodur® E 38 K Superclean	●	● ● ●	●	●

Grades for holding blocks and for die cast parts subject to contact with metal

Tools for Al/Al, Zn/Sn, and Pb alloys	Grade	Working hardness in HRC (typical values)
Holding blocks	Cryodur® 1730 Formadur® 2312	(approx. 650 N/mm²) (approx. 1000 N/mm²)
Cavity inserts, core-slides, cores	Thermodur® 2343 EFS Superclean Thermodur® 2344 EFS Superclean Thermodur® 2367 EFS Superclean Thermodur® E 38 K Superclean	44 – 48 44 – 46 44 – 46 44 – 48
Orifices, shot sleeves	Thermodur® 2343 EFS Superclean Thermodur® 2344 EFS Superclean Thermodur® 2367 EFS Superclean	44 – 48 44 – 46 44 – 46
Ejectors	Thermodur® 2344 EFS Superclean	44 – 48

Grades for holding blocks and for die cast parts subject to contact with metal

Tools for Cu/Cu alloys	Grade	Working hardness in HRC (typical values)
Holding blocks	Formadur® 2312	(approx. 1000 N/mm²)
Cavity inserts, core-slides, cores	Thermodur® 2365 EFS Superclean Thermodur® 2367 EFS Superclean Thermodur® 2885 EFS Thermodur® 2999 EFS Superclean	38 – 43 38 – 43 38 – 43 38 – 43
Orifices, shot sleeves	Thermodur® 2365 EFS Superclean Thermodur® 2367 EFS Superclean Thermodur® 2999 EFS Superclean	38 – 43 38 – 43 38 – 43
Ejectors	Thermodur® 2344 EFS Superclean	44 – 48

Steel for pressure die casting

Deutsche Edelstahlwerke offers a broad selection of homogenous steels for pressure casting dies.

We recommend the high-performance steels from our Thermodur® Superclean range for more durable, reliable, and cost-effective dies. We have highlighted the following steel grades as the most representative of our complete range:

Thermodur® E 38 K Superclean is a hot-work tool steel, which can be applied universally. Compared to 2343 EFS, it displays better toughness and can be utilized for largedimension pressure casting dies.

Thermodur® 2343 EFS is a hot-work tool steel, which can be applied universally. It shows a high toughness potential and is thus particularly successful with large dies for the processing of light metal alloys. It is also used for forging dies, shrink rings, and hot-shear blades. The most notable properties of Thermodur® 2343 EFS are its high-temperature strength and toughness as well as the outstanding thermal conductivity and insusceptibility to hot cracking.

Thermodur® 2344 EFS is a versatile hot-work tool steel, which can be used in a broad range of applications. Compared to Thermodur® 2343 EFS, it features increased high-temperature resistance and wear resistance. This makes it especially suitable for small to medium-sized dies in the production of light metal die castings.

Thermodur® 2367 EFS combines the positive qualities of Thermodur® 2343 EFS and 2344 EFS, while also displaying improved high-temperature strength and temperature stability. Its excellent resistance to tempering and thermal shock make Thermodur® 2367 EFS perfect for the production of light metal die castings frequently subjected to high temperatures.

Extrusion

Extrusion is a hot-forming process used to manufacture wire, pipes, and especially intricately shaped full or hollow profiles.
In this process, a billet pre-heated to deformation temperature is forced through an extrusion die under high hydraulic pressure. This method is used most often for aluminum alloys, brass, and other copper alloys as well as steel.

Any tool directly touching the materials to be extruded, meaning the pressure pad, inner liner and die, is subject to extremely high pressures, temperatures, and friction.

During extrusion, the die's dimensional stability and shape retention are essential for the production of precision profiles of consistently high quality.
Excellent high-temperature wear resistance and strength are therefore the most important properties the tool steels have to fulfill.

The hot-work tool steels from the Thermodur® EFS and Superclean range offered by Deutsche Edelstahlwerke meet all of those demands, thus ensuring significantly increased service lives and dimensional stability.

Benefits for the tool manufacturer

» Adherence to delivery dates
» Consistent quality
» Cost-effective machinability
» Uncomplicated heat treatment
» Good repair weldability
» Competent consulting
» Short delivery times
» Joint material development

Benefits for the extruder

» Long service life
» Outstanding dimensional stability
» Minimal unit costs per die
» Less repair efforts
» Good repair weldability
» Low tool change
» Technical consulting

Properties and applications of extrusion steel

Group-specific property comparison

Grade	Hardness	Wear resistance	Toughness	Dimensional stability	Weldability
Thermodur® 2343 EFS	●	●	●	●	●
Thermodur® 2344 EFS	●	● ●	●	●	●
Thermodur® 2365 EFS	●	● ● ●	●	● ●	●
Thermodur® 2367 EFS	●	● ● ●	● ●	● ●	●
Thermodur® 2885 EFS	●	● ● ●	●	● ●	●
Thermodur® 2999 EFS Superclean	●	● ● ● ●	●	● ●	●
Thermodur® E 38 K Superclean	●	●	● ● ●	● ●	●

Grades for wearing tools

Tool	Alloy	Uses	Grade	Working hardness in HRC (typical values)
Dies, bridge tools, chamber and spider tools (as well as webs and inserts for the above mentioned tools)	zinc and lead alloys	pipes, bars and sections	Thermodur® 2343 EFS Thermodur® 2344 EFS	44 – 48 44 – 48
	light metal alloys	bars, sections and pipes under normal stress	Thermodur® 2343 EFS Thermodur® 2344 EFS	44 – 48 44 – 48
		special sections and pipes under high stress	Thermodur® 2367 EFS Thermodur® E 38 K Superclean	44 – 48 44 – 48
	heavy metal alloys	bars, sections and pipes	Thermodur® 2365 EFS Thermodur® 2367 EFS Thermodur® 2885 EFS	44 – 48 44 – 48 44 – 48
	steel	sections and pipes	Thermodur® 2343 EFS Thermodur® 2344 EFS Thermodur® 2999 EFS Superclean	44 – 48 44 – 48 44 – 48

Grades for pilot tools

Tool	Grade	Working hardness in HRC (typical values)
Die holders	Thermodur® 2714 Thermodur® 2329 Thermodur® 2343 EFS	41 – 46 41 – 46 41 – 46
Backup tools	Thermodur® 2714 Thermodur® 2329 Thermodur® 2343 EFS	35 – 44 35 – 44 35 – 44
Pressure rings and disks, pressure pots, and mandrel holders	Thermodur® 2714 Thermodur® 2329	38 – 46 38 – 46
Tool holders and mounts	Thermodur® 2714 Thermodur® 2329	35 – 44 35 – 44
Upsetting punches, shearing punches and mandrels	Thermodur® 2344 EFS	41 – 48

Steel for extrusion

Deutsche Edelstahlwerke offers a broad selection of homogenous steels for extrusion.

We have highlighted the following steel grades as the most representative of our complete range. All of the steels may be tempered to the desirable working hardness.
We recommend these steels for bridge tools, which are used to manufacture light metal pipes and pipe profiles as well as inner liner, pressure dies, pressure pads and mandrels.

Thermodur® 2343 EFS is a hot-work tool steel, which can be applied universally. It shows a high toughness potential and is thus particularly successful with large extrusion dies. The most notable properties of Thermodur® 2343 EFS are its high-temperature strength and toughness as well as the outstanding thermal conductivity and insusceptibility to hot cracking.

For larger dimensions and increased toughness requirements, we recommend Thermodur® 2343 EFS Superclean (ESR).

Thermodur® E 38 K Superclean is used for profiles with particularly complex geometries.

Thermodur® 2344 EFS is a versatile hot-work tool steel, which can be used in a broad range of applications.
Compared to Thermodur® 2343 EFS, it features increased high-temperature resistance and wear resistance. This makes it especially suitable for medium-sized extrusion dies. For larger dimensions and increased toughness requirements, we recommend Thermodur® 2344 EFS Superclean (ESR).

Thermodur® 2329 is an even more refined steel for pressure disks and other backup tools. It features improved workability, especially by means of torch cutting.

Drop forging

Drop forging is a forming process commonly used in the industry to produce large quantities of forgings.

The key requirements for the various forging tools are:

» High resistance to tempering
» Excellent high-temperature strength
» Outstanding high-temperature toughness
» Low susceptibility to hot cracking
» Very good high-temperature wear resistance

Depending on the forging process employed, the forging dies are subjected to varying degrees of thermal, mechanical, chemical, and tribological stress. Selecting the appropriate tool steel therefore largely depends on the forging method involved.

Hammer dies

When forging with the use of a hammer, the mechanical stress is extremely high, while the warming effects remain relatively low. Drop forging dies – characterized by a very short contact time between tool and forging – must therefore exhibit excellent toughness.

Press dies

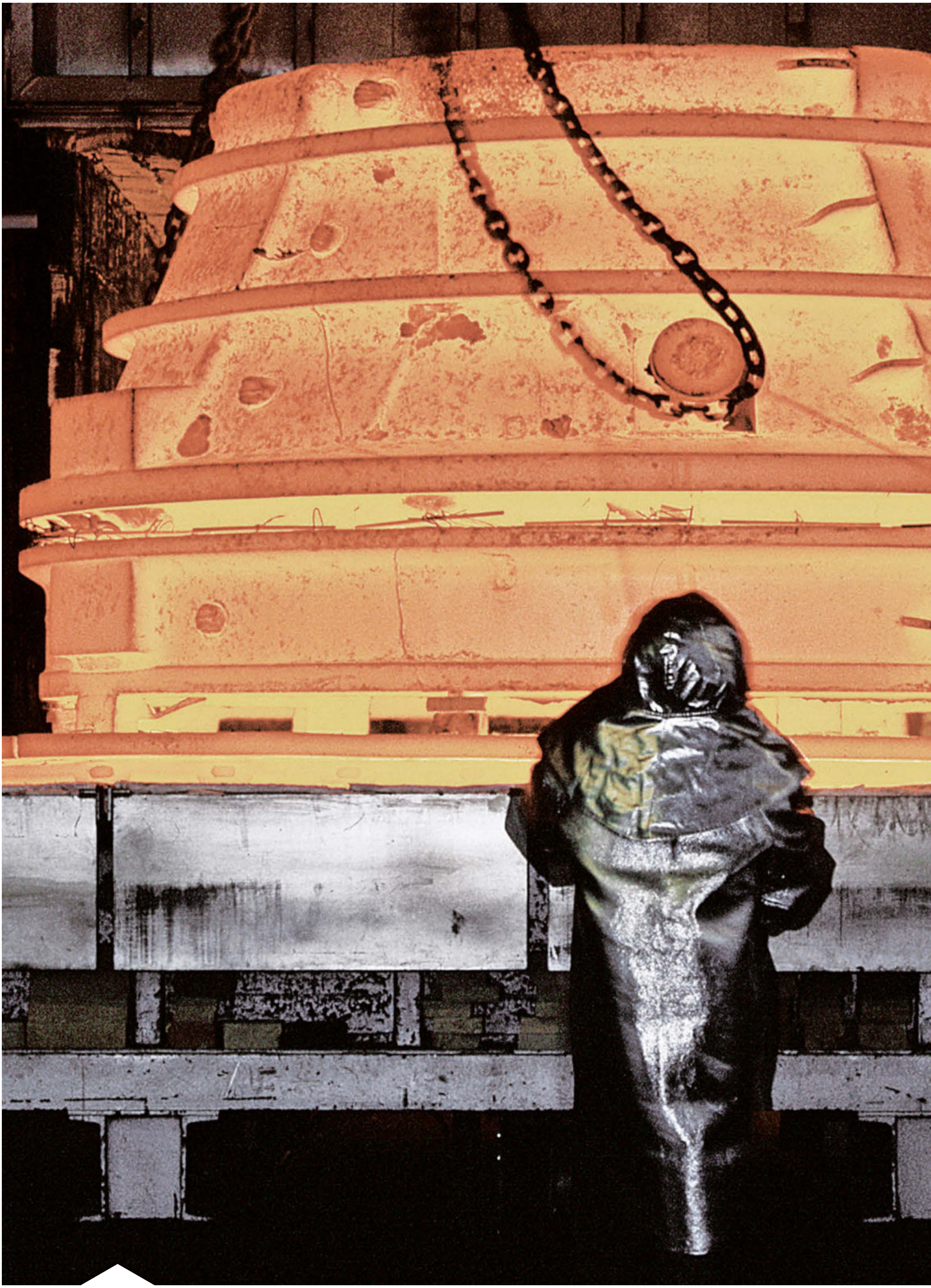
During press forging, on the other hand, the mechanical stress is rather low, while the temperature stresses are very high. As a result, the die inserts for press dies require higher alloyed steel grades. Deutsche Edelstahlwerke developed the Cr-Mo-V alloyed steel family to meet this specific need.

High-speed forging machines

Forging on high-speed machines operating at frequencies of 80 or more parts per minute, creates a very specific set of requirements the steel must meet. Only highly alloyed steels featuring good high-temperature wear resistance and thermal conductivity may be used in those machines due to the high processing speeds and intense water cooling involved.

Benefits for the forger

» Outstanding dimensional stability
» Long service life
» Good cooling capacity
» Rapid cycle times
» Low tool turnover
» Low unit costs
» Good repair weldability
» Less repair efforts
» Technical consulting



Properties and applications of forging steel

Group-specific property comparison

Grade	Hardness	Toughness	High-temperature wear	Thermal conductivity
Thermodur® 2714	○	● ● ●	○	● ●
Thermodur® 2343 EFS	●	●	●	●
Thermodur® 2344 EFS	●	●	●	●
Thermodur® E 38 K Superclean	●	● ●	●	●
Thermodur® 2365 EFS	●	●	●	● ●
Thermodur® 2367 EFS	●	●	● ●	● ●
Thermodur® 2999 EFS Superclean	● ●	●	● ● ●	● ● ●

Grades for holding blocks and for die cast parts subject to contact with metal

Forging type	Tool	Grade	Working hardness in HRC (typical values)
Hammer	Bottom dies, drop forging dies	Thermodur® 2714	38 – 52
	Die inserts	Thermodur® 2343 EFS Thermodur® 2344 EFS Thermodur® 2999 EFS Superclean	41 – 52 41 – 52 41 – 52
	Impact rims	Thermodur® 2714	49 – 52
Press	Drop forging dies	Thermodur® 2714 Thermodur® 2343 EFS Thermodur® 2344 EFS Thermodur® 2365 EFS Thermodur® 2367 EFS Thermodur® 2999 EFS Superclean	38 – 52 41 – 50 41 – 50 41 – 50 41 – 50 41 – 50
	Bottom dies	Thermodur® 2714	30 – 43
	Die inserts	Thermodur® 2344 EFS Thermodur® 2365 EFS Thermodur® 2367 EFS Thermodur® 2999 EFS Superclean	41 – 50 41 – 50 41 – 50 41 – 50
High-speed forging machine (horizontal)	Dies, mandrels	Thermodur® 2344 EFS Thermodur® 2365 EFS Thermodur® 2999 EFS Superclean	41 – 50 41 – 50 41 – 50

Grades for trim dies

Tool	Grade	Working hardness in HRC (typical values)
Unarmored trim dies	Thermodur® 2714 Thermodur® 2343 EFS Thermodur® 2344 EFS	44 – 50 44 – 54 44 – 54
Armored trim dies	Cryodur® 1730 Thermodur® 2714	(approx.650 N/mm^2) 44 – 50

Steel for forging

Deutsche Edelstahlwerke offers a select range of tempered and annealed steels for forging tools.

The steels exhibit good toughness and hardness as well as the hightemperature wear resistance and thermal conductivity required for each of the applications and forging methods.
In addition to our standard steels Thermodur® 2343 EFS and Thermodur® 2344 EFS, we have highlighted the following high-performance steel grades as the most representative of our range of products:

Thermodur® 2365 EFS is the most sought after tool steel for high-speed forging tools worldwide. This is due to the steel's insusceptibility to hot cracking and its excellent thermal conductivity, which allows it to withstand excessive water cooling.

It also achieves a very good level of high-temperature strength and is thus often used for tools subject to extremely high temperatures.

Thermodur® 2714 is a tough die steel with an outstanding resistance to tempering, which is fully quenched and tempered.
It is generally supplied in an annealed state or tempered to 1300 N/mm². Thermodur® 2714 is a standard steel for all types of forging dies. Its nickel content makes it exceptionally impact-resistant and therefore highly suitable for large hammer and press dies.

Thermodur® 2999 EFS is a new highperformance steel exclusively developed for the demands of the forging industry. It was designed especially for the hot forming of heavy metals. Its characteristic high-temperature strength and wear resistance are attributed to the 5% molybdenum content, which results in a long tool service life. The outstanding thermal conductivity over the entire range of service temperatures makes Thermodur® 2999 EFS particularly appealing for employment in high-speed forging machines.

Glass product manufacturing

Only top-quality tool steel is able to meet the high requirements for appearance demanded of glass products.

Different processing methods, temperatures, and chemical compositions require different tool steels. They cannot be realized by a single “all-round steel”.

The following properties are required of glass product manufacturing steel:
» Resistance to scaling
» Good high-temperature strength
» Dimensional stability during thermal stress
» Thermal conductivity
» Thermal shock resistance
» Chemical consistency
» Polishability
» Resistance to high-temperature corrosion

Hot-work tool steel developed by Deutsche Edelstahlwerke achieves the optimal quality for each requirement thanks to various alloy additives such as chromium, silicon, or aluminum, which is necessary to make the steel resistant to scaling. Steel for glass product manufacturing also shows high levels of purity and very homogenous microstructures.

Benefits for the tool manufacturer
» Adherence to delivery dates
» Consistent quality
» Cost-effective machinability
» Joint material development
» Competent consulting
» Short delivery times

Benefits for the glass manufacturer
» Long service life
» Good dimensional stability
» Higher production output
» Low tool turnover
» Technical consulting
» Low unit costs

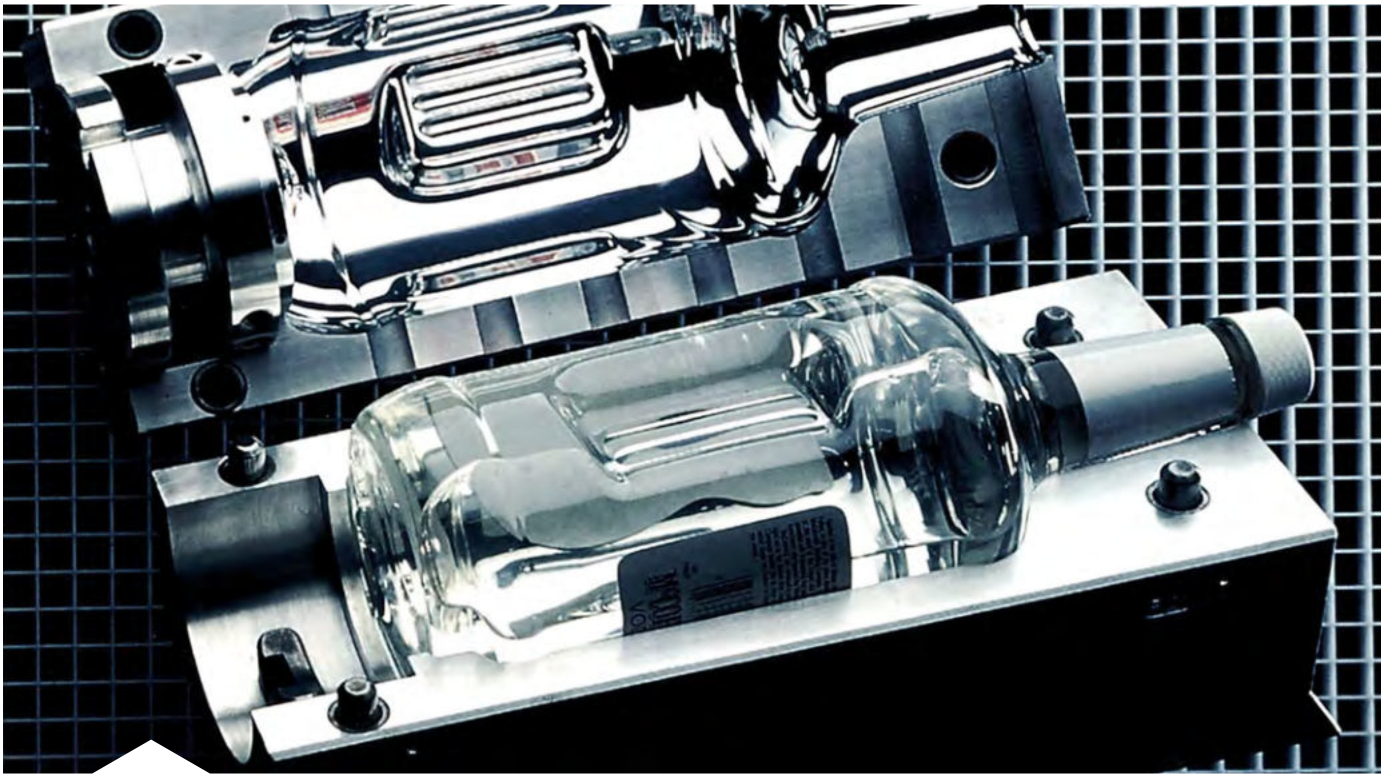
Properties and applications of glass product manufacturing steel

Group-specific property comparison

Grade	Hardness	Resistance to scaling	Thermal conductivity	Polishability	Weldability
Thermodur® 2343 EFS	● ●	●	● ●	● ●	●
Thermodur® 2344 EFS	● ●	●	● ●	● ●	●
Formadur® 2083	● ●	●	● ●	● ● ●	●
Thermodur® 2782 Superclean	○	● ● ●	●	● ●	● ● ●
Thermodur® 2787 Superclean	●	● ●	● ●	● ●	● ●

Steel grades for glass product manufacturing

Tool	Grade	Working hardness in HB (typical values)	Working tensile strength in N/mm² (typical values)
Moulds	Formadur® 2083 Thermodur® 2343 EFS Thermodur® 2344 EFS Thermodur® 2782 Superclean Thermodur® 2787 Superclean	180 – 230 180 – 230 180 – 230 180 – 230 225 – 275	650 – 800 650 – 800 650 – 800 650 – 800 800 – 950
Punches	Thermodur® 2782 Superclean Thermodur® 2787 Superclean	180 – 230 225 – 275	650 – 800 800 – 950
Couplers, orifices, blowpipes, gathering irons	Thermodur® 2782 Superclean	180 – 230	650 – 800
Blowing iron heads and mandrels, ladles, paddles, orifice mandrels	Thermodur® 2782 Superclean	180 – 230	650 – 800
Nozzles	Thermodur® 2782 Superclean	180 – 230	650 – 800



Steel for glass product manufacturing

Deutsche Edelstahlwerke offers a select range of tempered steel with excellent scaling resistance and weldability for glass product manufacturing.

We have highlighted the following steel grades as the most representative of our complete range:

Thermodur® 2782 is a non-scaling, austenitic hot-work tool steel, which is resistant to oxidizing environments and displays good cold workability. It is used to manufacture a broad spectrum of general high-performance tools. This steel is delivered in remelted form exclusively as it must meet high surface quality requirements. Thermodur® 2782 is mainly used in tools for glass product manufacturing, such as punches, couplers, blowing iron heads and mandrels, orifices, blowpipes, and gathering irons.

Thermodur® 2787 is a hot-work tool steel, which is resistant to corrosion and scaling and may be tempered. Under normal stresses, this steel can be used in a broad range of applications, for example tools such as dies and punches for glass product manufacturing. For your most challenging requirements, we recommend Thermodur® 2787 Superclean.

Tube manufacturing

Industrial tube manufacturing began around 1890, when the Mannesmann brothers invented the cross rolling method.

It was this process that allowed a solid steel billet to be pierced into a hollow block.

In the second manufacturing stage, the hollow block is rolled into a loop on a mandrel bar employing various rolling methods. These methods include the continuous tube, push bench, MPM (Multistand Pipe Mill), FQM (Fine Quality Mill), and ASSEL rolling processes.
In a third and last production stage, the loop is rolled in a stretch reduction mill, where the diameter and wall thickness are reduced down to the pipe's final dimensions.

Depending on the process, the tools, such as pilger mandrels, mandrel bars, rolls, etc., are exposed to a range of different stresses, which result from the varying periods of contact between the tools and the material at rolling temperature.

Steel must contain a balanced mix of alloys in order to achieve the longest possible service life and thus high tonnage per tool insert.

Steel used for tube manufacturing must meet the following demands:
» Good high-temperature strength
» Low susceptibility to hot cracking and resistance to high-temperature wear
» Excellent high-temperature toughness

Deutsche Edelstahlwerke supplies mandrels either in fully machined chromium-plated or scaled condition or in rough-machined (tempered and peeled) condition.

In addition to universally applicable standards steels, we offer specialty steels specifically tailored to different manufacturing processes and individual customer requirements.

Deutsche Edelstahlwerke also delivers high-performance bar steels for tube round.

Benefits for the pipe manufacturer

» Steel and heat treatment all from one source
» Short delivery times through direct delivery
» Long service lives through consistent quality (ISO 9002)
» Competent consulting

Properties and applications of tube manufacturing steel

Group-specific property comparison

Grade	Primary use	Insusceptibility to hot cracking	High-temperature wear resistance	Toughness	Scale adhesion
Thermodur® 2740	push benches	●	● ●	● ● ●	● ●
Thermodur® 2342 EFS	MPM mills and large continuous trains	● ●	● ● ●	● ●	● ● ●
Thermodur® 2343 EFS	continuous trains	● ●	● ● ●	●	● ● ●
Thermodur® 2344 EFS	small continuous trains	● ●	● ● ● ●	●	● ● ●

Steel grades for different tube manufacturing processes

Manufacturing process	Tool	Grade	Working hardness in HB (typical values)	Working tensile strength in N/mm² (typical values)
PQF, FQM and MPM mills	mandrel bars	Thermodur® 2342 EFS Thermodur® 2344 EFS	300 – 375 300 – 375	1000 – 1275 1000 – 1275
Continuous tube mill	mandrel bars	Thermodur® 2342 EFS Thermodur® 2343 EFS	265 – 375 265 – 375	900 – 1275 1000 – 1275
	piercing mandrels	Thermodur® 2790	customer-specified	customer-specified
Push bench plants	mandrel bars	Thermodur® 2740	300 – 355	1000 – 1200
	rolls	Thermodur® 2365 EFS	470 – 510	1600 – 1750
ASSEL mill and shoulder piercing mill	mandrel bars	Thermodur® 2740	300 – 355	1000 – 1200
	piercing mandrels vent caps	Thermodur® 2344 EFS Thermodur® 2365 EFS	265 – 355 265 – 355	900 – 1200 900 – 1200
Hot pilger mill	pilger mandrels	Thermodur® 2740	300 – 355	1000 – 1200
Cross rolling mill	piercing mandrels	Thermodur® 2344 EFS	265 – 355	900 – 1200
Extrusion	extrusion rams	Thermodur® 2367 EFS Thermodur® 2365 EFS	50 – 52 HRC 50 – 52 HRC	
Cold pilger mill	pilger mandrels	Cryodur® 2379 Cryodur® 2709 Thermodur® 2344 EFS	50 – 56 HRC approx. 56 HRC approx. 56 HRC	
	pilger rolls	Cryodur® 2327 Cryodur® 2362 Thermodur® 2344 EFS	customer-specified customer-specified approx. 54 HRC	
Welded pipes	forming rolls	Cryodur® 2379	58 – 60 HRC	
	welding rolls	Thermodur® 2344 EFS	customer-specified	

Steel for pipe manufacturing

Deutsche Edelstahlwerke offers a broad selection of homogenous steels for tube manufacturing.

Two steel groups are highly recommended for mandrels: nickel-alloyed hot-work tool steel displaying good toughness and chromiummolybdenum-alloyed hot-work tool steel with exceptional high-temperature wear resistance. We have highlighted the following steel grades as the most representative of our complete range:

Thermodur® 2342 EFS is a versatile Cr-Mo-V-alloyed hot-work tool steel, which can be used in a broad range of applications. The key features of this high-alloyed steel are its excellent high-temperature toughness and wear resistance.
Thermodur® 2342 EFS is most often used for mandrel bars in MPM (Multistand Pipe Mill), PQF (Premium Quality Finishing) and FQM (Fine Quality Mill) rolling mill, for which it is delivered in tempered, fully machined, and chromium-plated condition.

Thermodur® 2343 EFS is a versatile hot-work tool steel with excellent high-temperature toughness and wear resistance, which can be used in a broad range of applications. This Cr-Mo-V-alloyed steel is most often used for mandrel bars in continuous trains. Thermodur® 2343 EFS is always delivered in tempered condition.

Thermodur® 2740 is a specialty hot-work tool steel with excellent high-temperature toughness and thermal shock resistance.
It is a nickel-alloyed and air-hardening steel, which is especially suitable for mandrel bars in push bench rolling mills.
We supply the fully machined tools in tempered and scaled condition.

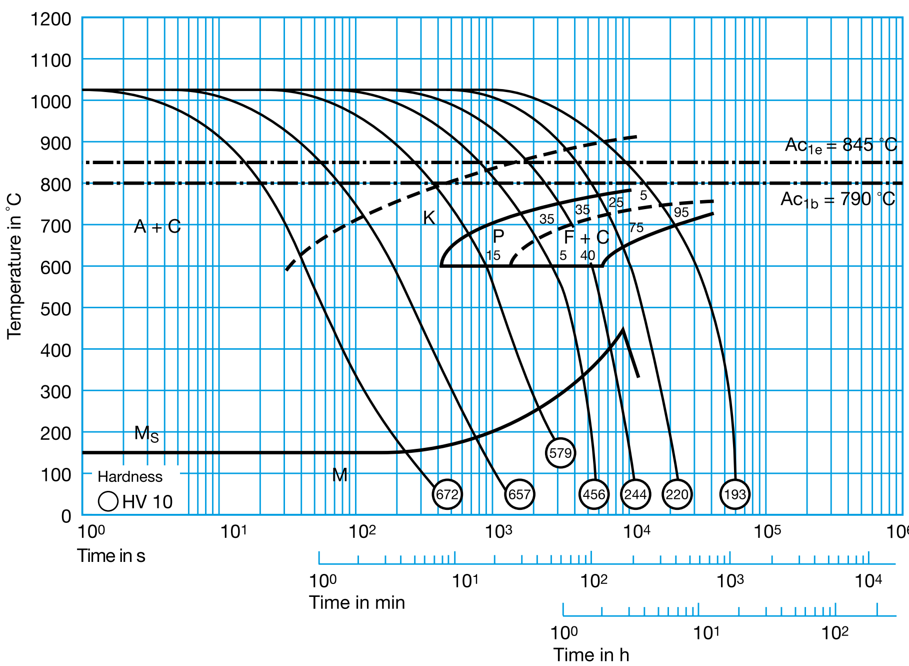
Material Data Sheets

Consecutively the most important materials in the area of hot-work tool steel with its steel properties, standards, physical properties, applications and heat treatment.

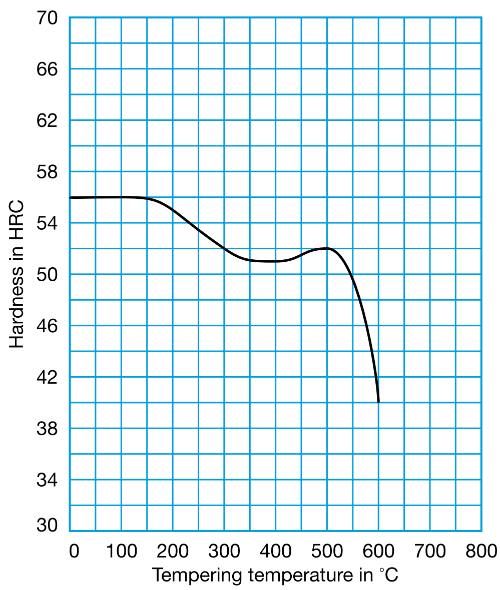
Formadur® 2083/2083 Superclean

X40Cr14	C 0.40 Cr 13.0						
Steel properties	Corrosion-resistant, good polishability. For the best polishability, we recommend Thermodur® 2083 Superclean.						
Standards	**AISI** 420	**AFNOR** Z40C14					
Physical properties	**Coefficient of thermal expansion**						
	at °C	20 – 100		20 – 200		20 – 300	
	10^{-6} m/(m • K) Annealed	11.1		11.4		11.8	
	10^{-6} m/(m • K) Quenched and tempered	11.1		11.5		11.6	
	Thermal conductivity at °C	100	150	200	250	300	
	W/(m • K) Annealed	28.4	28.6	28.8	29.2	29.6	
	W/(m • K) Quenched and tempered	22.5	23.1	23.5	24.4	25.7	
Applications	Moulds for glass product manufacturing and moulds for processing corrosive plastics.						
Heat treatment	**Soft annealing °C**	**Cooling**			**Hardness HB**		
	760 – 800	Furnace			max. 230		
	Hardening °C	**Quenching**			**Hardness after quenching HRC**		
	1000 – 1050	Oil or hot bath, 500 – 550 °C			56		
	Tempering °C	100	200	300	400	500	600
	HRC	56	55	52	51	52	40

Time-temperature-transformation diagram



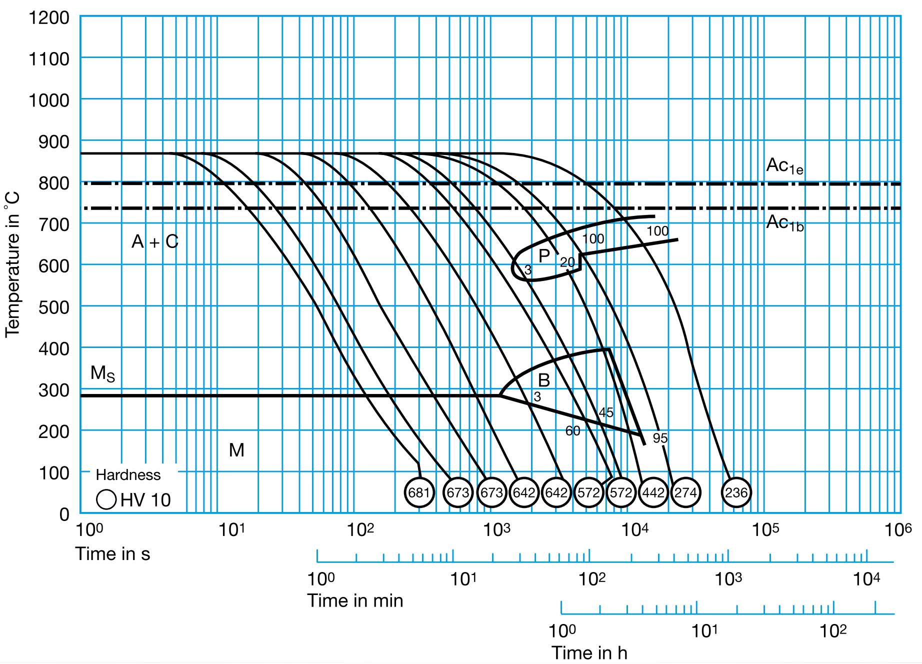
Tempering diagram



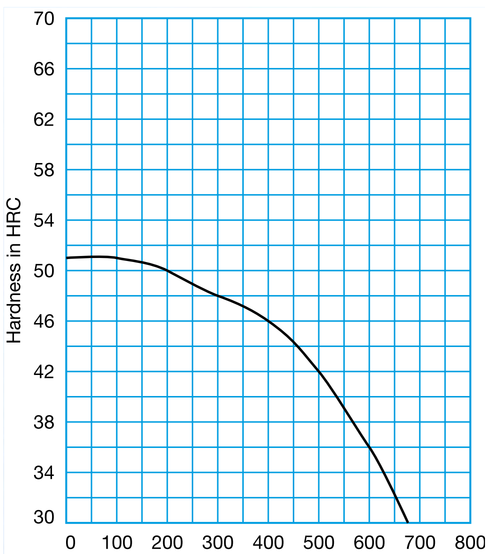
Formadur® 2312

40CrMnNiMo8-6-4	C 0.40 Mn 1.50 Cr 1.90 Mo 0.20 S 0.05							
Steel properties	Tempered plastic mould steel, as-supplied hardness 280 to 325 HB. Better machinability than Formadur® 2311.							
Standards	**AISI** P20+S							
Physical properties	**Coefficient of thermal expansion**							
	at °C	20 – 100		20 – 200		20 – 300		
	10^{-6} m/(m • K) Annealed	12.5		13.4		13.9		
	10^{-6} m/(m • K) Quenched and tempered	12.3		13.0		13.7		
	Thermal conductivity at °C	100	150	200	250	300		
	W/(m • K) Annealed	40.2	40.9	40.3	40.0	39.0		
	W/(m • K) Quenched and tempered	39.8	40.4	40.4	39.9	39.0		
Applications	Mould frames for pressure casting dies.							
Heat treatment	**Soft annealing °C**	**Cooling**			**Hardness HB**			
	710 – 740	Furnace			max. 230			
	Hardening °C	**Quenching**			**Hardness after quenching HRC**			
	840 – 870	Oil or hot bath, 180 – 220 °C			51			
	Tempering °C	100	200	300	400	500	600	700
	HRC	51	50	48	46	42	36	28

Time-temperature-transformation diagram



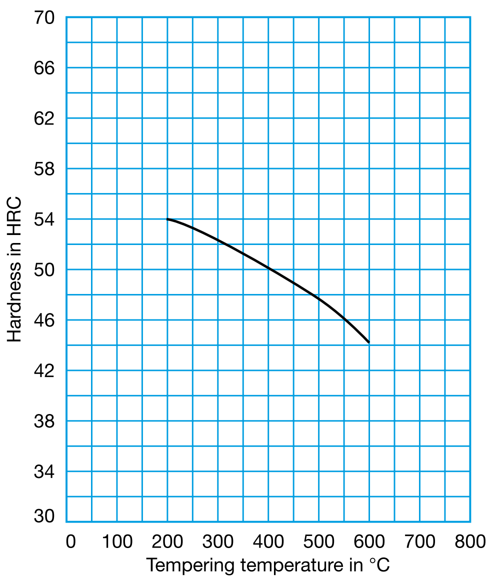
Tempering diagram



Thermodur® 2329

46CrSiMoV7	C 0.45 Si 0.70 Mn 0.80 Cr 1.80 Mo 0.30 Ni 0.60 V 0.20		
Steel properties	Excellent tempering resistance, high-temperature strength, full quenching and tempering properties, outstanding weldability, nitridable, PVD and CVD coatable, good machinability.		
Applications	Hot-work tool steel for forging dies, pressure disks for extrusion, mould press dies, and many other applications.		
Heat treatment	**Soft annealing °C**	**Cooling**	**Hardness HB**
	780 – 800	Furnace or air	max. 230
	Hardening °C	**Quenching**	**Hardness after quenching HRC**
	880 – 920	Air, oil or hot bath, 200 – 250 °C	53 – 55

Tempering diagram



Thermodur® 2342 EFS

X35CrMoV5-1-1	C 0.35 Si 0.80 Cr 5.00 Mo 1.00 V 0.85
Steel properties	Excellent high-temperature toughness, thermal conductivity, low susceptibility to hot cracking, may be water-cooled to a limited extent.
Physical properties	(see below)
Applications	Mandrel bars, pressure casting dies, and extrusion tools.
Heat treatment	(see below)

Physical properties

Coefficient of thermal expansion

at °C	20 – 100	20 – 200	20 – 300	20 – 400	20 – 500	20 – 600	20 – 700
10^{-6} m/(m • K)	10.9	11.9	12.3	12.7	13.0	13.3	13.5

Thermal conductivity

at °C	20	350	700
W/(m • K)	24.5	26.8	28.8

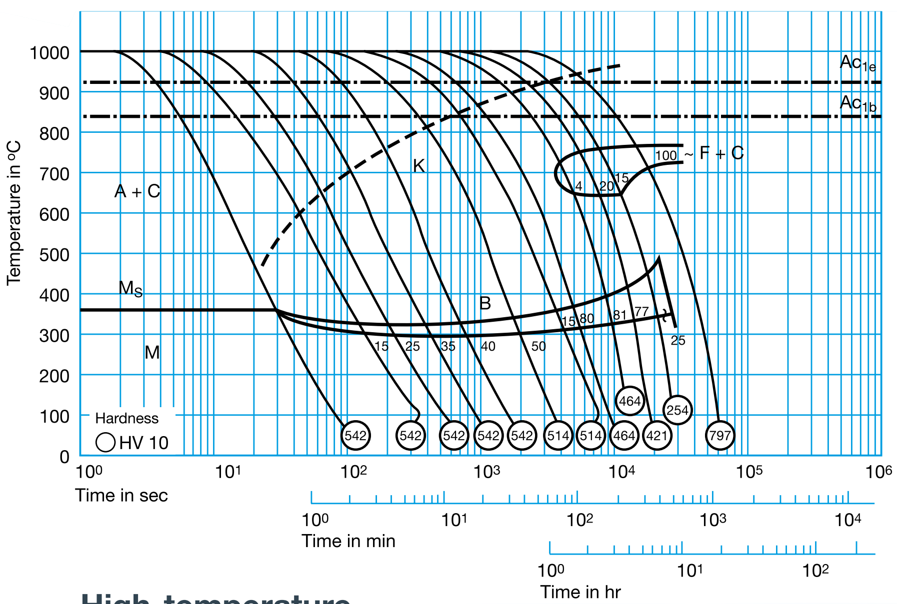
Heat treatment

Soft annealing °C	Cooling	Hardness HB
750 – 800	Furnace	max. 230

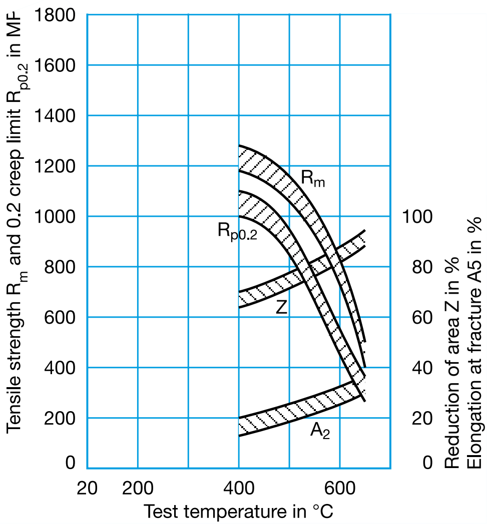
Hardening °C	Quenching	Hardness after quenching HRC
1000 – 1040	Air, oil or hot bath, 500 – 550 °C	53

Tempering °C	100	200	300	400	500	550	600	650	700
HRC	52	50	49	49	50	49	46	36	26

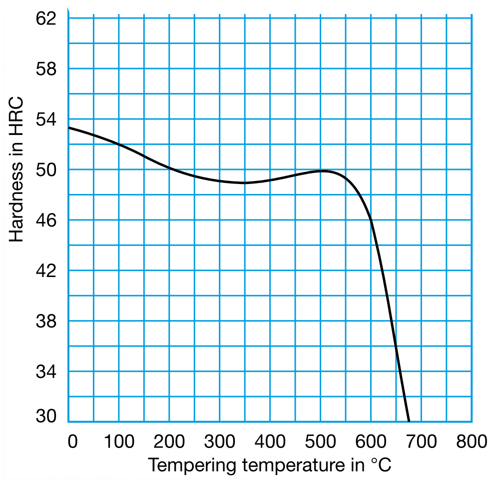
Time-temperature-transformation diagram



High-temperature strength diagram



Tempering diagram



Thermodur® 2343 EFS/2343 EFS Superclean

X37CrMoV5-1	C 0.38 Si 1.00 Cr 5.30 Mo 1.30 V 0.40
Steel properties	Outstanding high-temperature strength and toughness. Excellent thermal conductivity and low susceptibility to hot cracking. May be water-cooled to a limited extent.
Standards	**AISI** H11 **AFNOR** Z38CDV5

Physical properties

Coefficient of thermal expansion0

at °C	20 – 100	20 – 200	20 – 300	20 – 400	20 – 500	20 – 600	20 – 700
10^{-6} m/(m • K)	11.8	12.4	12.6	12.7	12.8	12.9	12.9

Thermal conductivity at °C	20	350	700
W/(m • K) Annealed	29.8	30.0	33.4
W/(m • K) Quenched and tempered	26.8	27.3	30.3

Applications

Hot-work tool steel for universal use. Mandrel bars, pressure casting dies, and extrusion tools. Pressure casting dies and extrusion tools for light metal processing, forging dies, mandrels, shrink rings, hot-shear blades.
For your most challenging requirements, we recommend Thermodur® 2343 EFS Superclean (ESR).

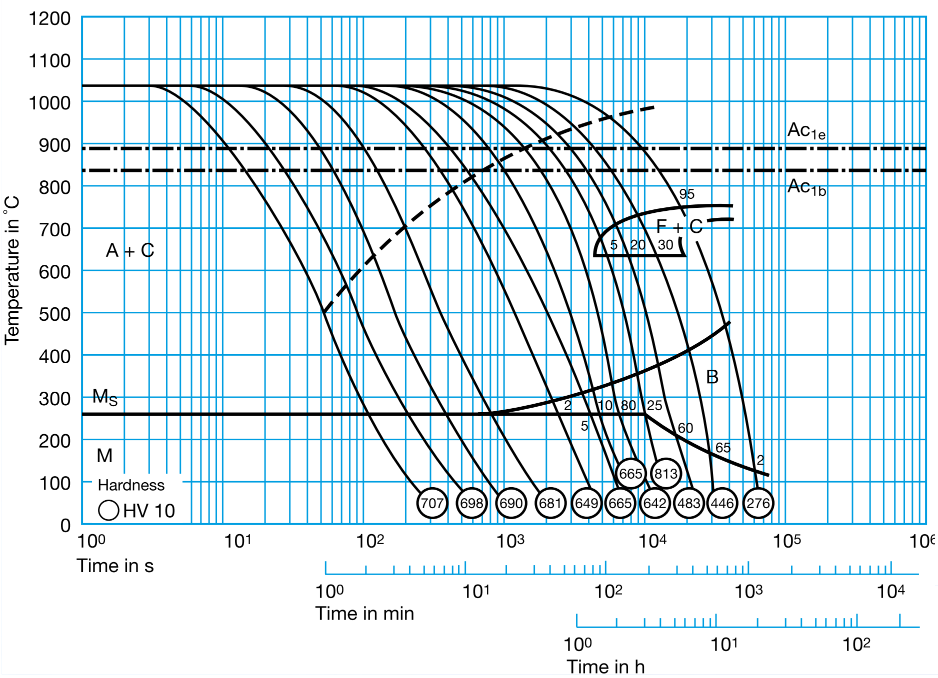
Heat treatment

Soft annealing °C	**Cooling**	**Hardness HB**
750 – 800	Furnace	max. 230

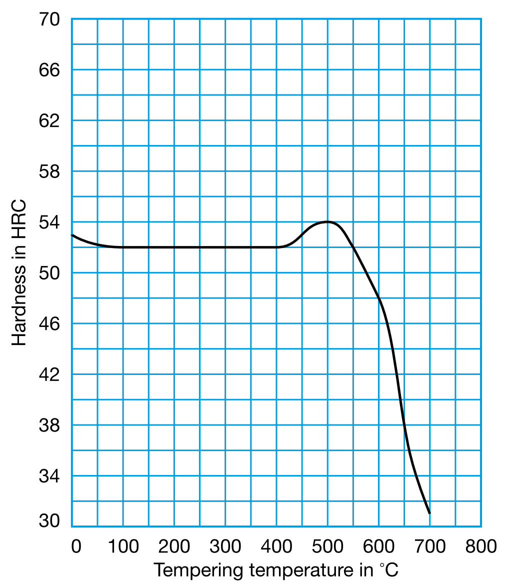
Hardening °C	**Quenching**	**Hardness after quenching HRC**
1000 – 1030	Air, oil or hot bath, 500 – 550 °C	54

Tempering °C	100	200	300	400	500	550	600	650	700
HRC	52	52	52	52	54	52	48	38	31

Time-temperature-transformation diagram

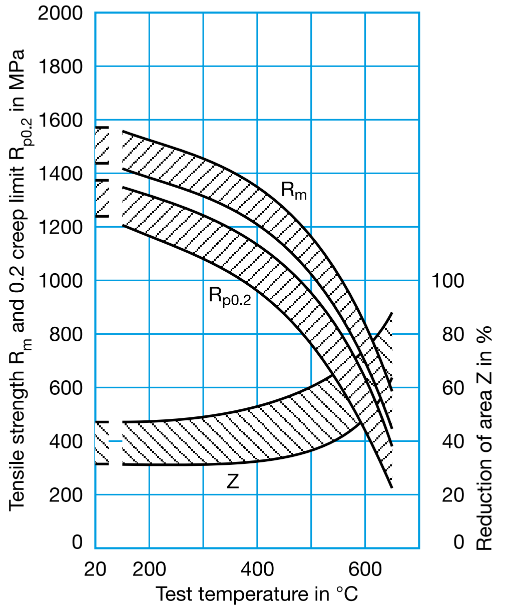


Tempering diagram

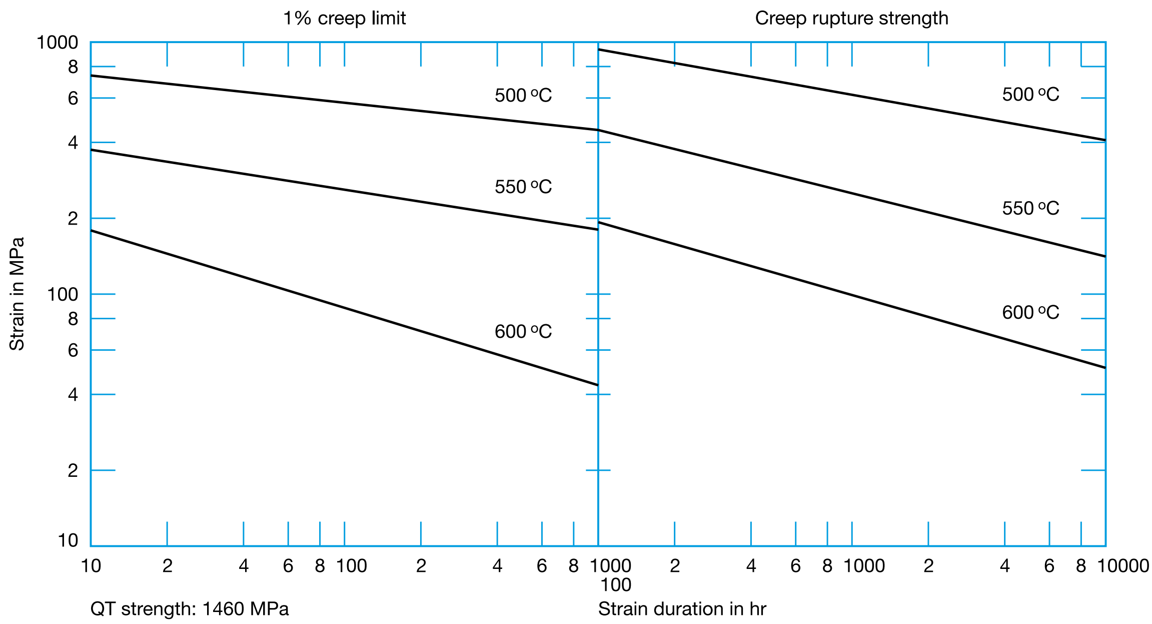


Thermodur® 2343 EFS/2343 EFS Superclean

High-temperature strength diagram



Creep behavior



Thermodur® 2344 EFS/2344 EFS Superclean

X40CrMoV5-1	**C 0.40 Si 1.00 Cr 5.30 Mo 1.40 V 1.00**
Steel properties	Outstanding high-temperature wear resistance, strength, and toughness. Excellent thermal conductivity and low susceptibility to hot cracking. May be water-cooled to a limited extent.
Standards	**AISI** H13 **AFNOR** Z40CDV5
Physical properties	**Coefficient of thermal expansion**
Applications	Hot-work tool steel for universal use. Mandrel bars, pressure casting dies, and extrusion tools. Pressure casting dies and extrusion tools for light metal processing, forging dies, mandrels, nitrided ejectors, hot-shear blades. **For your most challenging requirements, we recommend Thermodur® 2344 EFS Superclean (ESR).**
Heat treatment	

Coefficient of thermal expansion

at °C	20 – 100	20 – 200	20 – 300	20 – 400	20 – 500	20 – 600	20 – 700
10⁻⁶ m/(m • K) Annealed	10.9	11.9	12.3	12.7	13.0	13.3	13.5

Thermal conductivity at °C	20	350	700
W/(m • K) Annealed	27.2	30.5	33.4
W/(m • K) Quenched and tempered	25.5	27.6	30.3

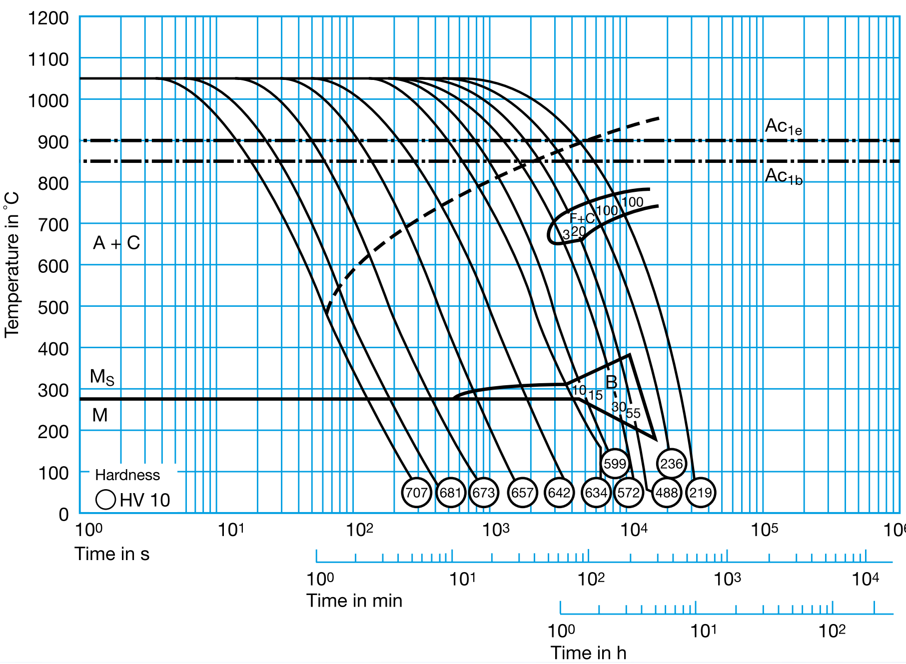
Heat treatment

Soft annealing °C	**Cooling**	**Hardness HB**
750 – 800	Furnace	max. 230

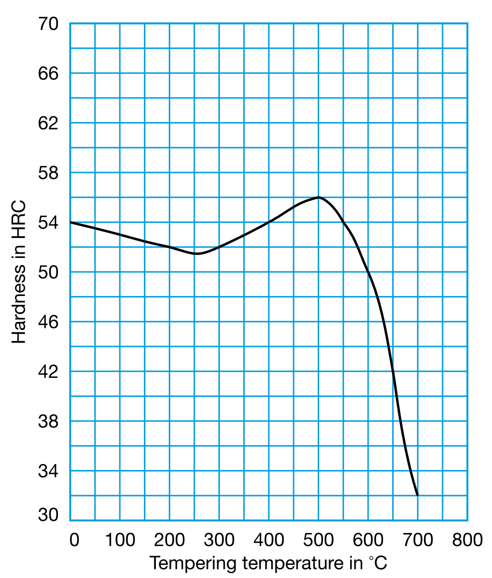
Hardening °C	**Quenching**	**Hardness after quenching HRC**
1010 – 1030	Air, oil or hot bath, 500 – 550 °C	54

Tempering °C	100	200	300	400	500	550	600	650	700
HRC	53	52	52	54	56	54	50	42	32

Time-temperature-transformation diagram

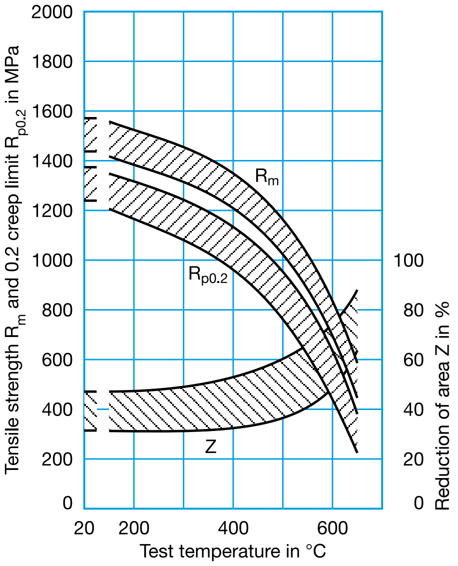


Tempering diagram

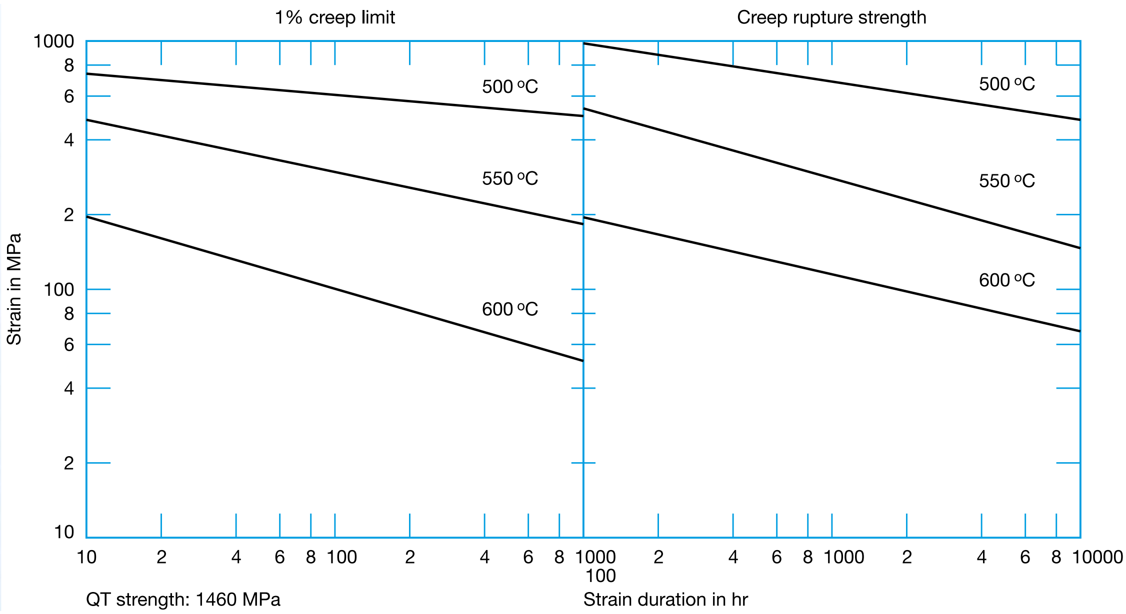


Thermodur® 2344 EFS/2344 EFS Superclean

High-temperature strength diagram



Creep behavior



Thermodur® 2365 EFS/2365 EFS Superclean

32CrMoV12-28	C 0.32 Cr 3.00 Mo 2.80 V 0.50
Steel properties	Excellent high-temperature strength and tempering resistance, thermal conductivity, low susceptibility to hot cracking. May be water-cooled to a limited extent. Suitable for cold hobbing.
Standards	**AISI** H10 **AFNOR** 32CDV12-28

Physical properties

Coefficient of thermal expansion

at °C	20 – 100	20 – 200	20 – 300	20 – 400	20 – 500	20 – 600	20 – 700
10^{-6} m/(m • K) Annealed	11.8	12.5	12.7	13.1	13.5	13.6	13.8

Thermal conductivity at °C	20	350	700
W/(m • K) Annealed	32.8	34.5	32.2
W/(m • K) Quenched and tempered	31.4	32.0	29.3

Applications

Press and piercing mandrels, die inserts, heavy metal die casting tools.
For your most challenging requirements, we recommend Thermodur® 2365 EFS Superclean (ESR).

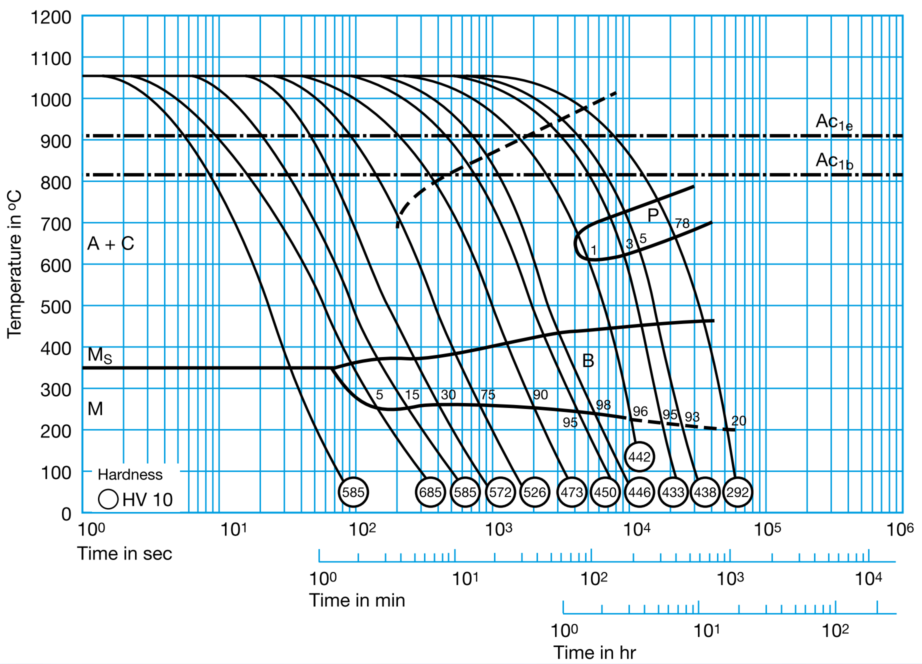
Heat treatment

Soft annealing °C	**Cooling**	**Hardness HB**
750 – 800	Furnace	max. 185

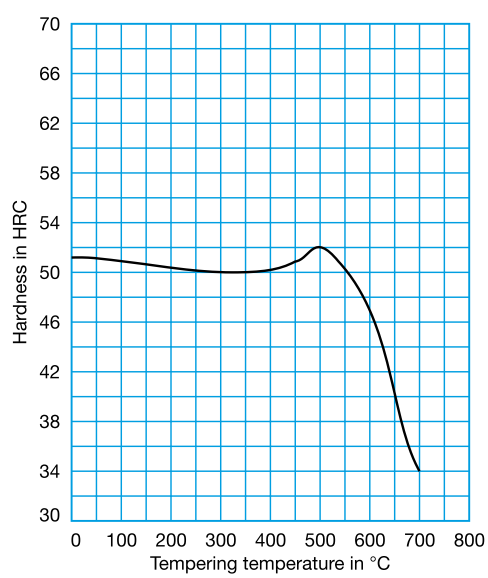
Hardening °C	**Quenching**	**Hardness after quenching HRC**
1030 – 1050	Oil or hot bath, 500 – 550 °C	52

Tempering °C	100	200	300	400	500	550	600	650	700
HRC	51	50	50	50	52	50	47	40	34

Time-temperature-transformation diagram

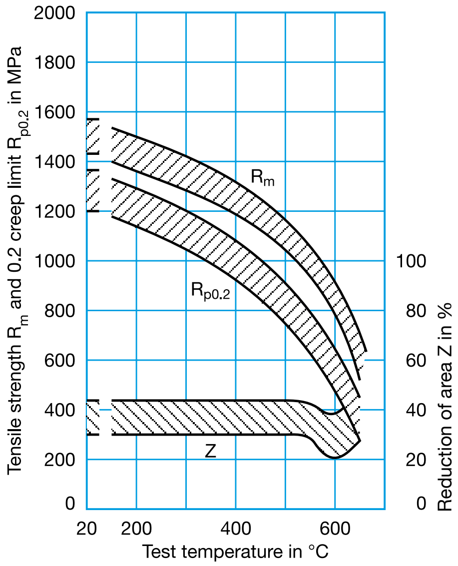


Tempering diagram

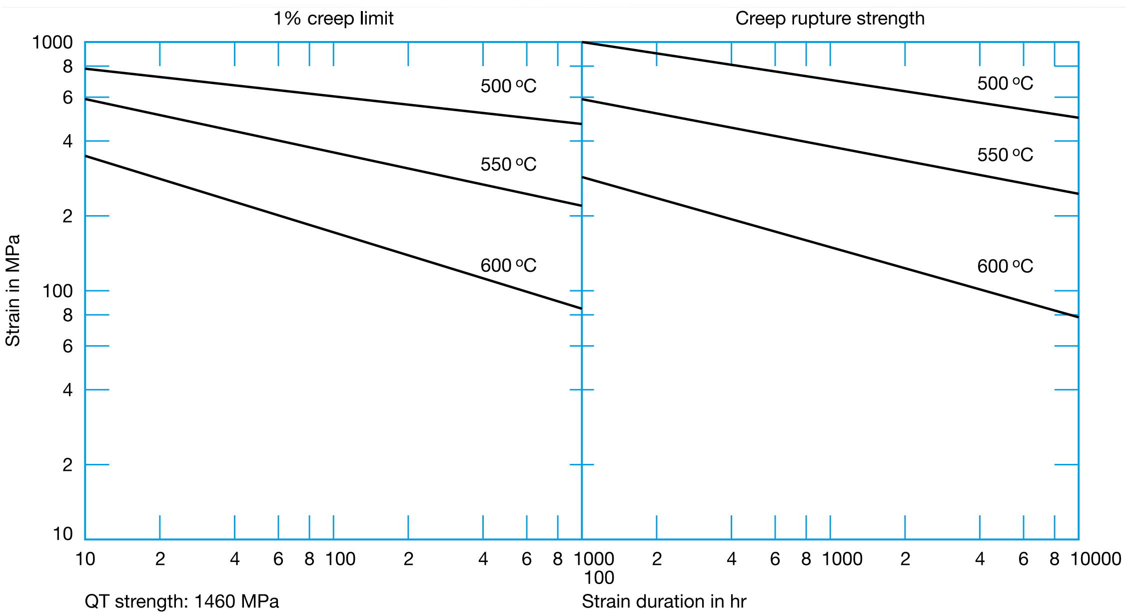


Thermodur® 2365 EFS/2365 EFS Superclean

High-temperature strength diagram



Creep behavior



Thermodur® 2367 EFS/2367 EFS Superclean

~X38CrMoV5-3	C 0.37 Cr 5.00 Mo 3.00 V 0.60
Steel properties	Excellent high-temperature strength and tempering resistance, good hardenability, minimal warpage.

Physical properties

Coefficient of thermal expansion

at °C	20 – 100	20 – 200	20 – 300	20 – 400	20 – 500	20 – 600	20 – 700
10^{-6} m/(m • K)	11.9	12.5	12.6	12.8	13.1	13.3	13.5

Thermal conductivity at °C	20	350	700
W/(m • K) Annealed	30.8	33.5	35.1
W/(m • K) Quenched and tempered	29.8	33.9	35.3

Applications

Forging dies, die casting dies, die holders, extrusion dies for heavy metals, inner liner for light metals, profiling dies, and mandrels. **For your most challenging requirements, we recommend Thermodur® 2367 EFS Superclean (ESR).**

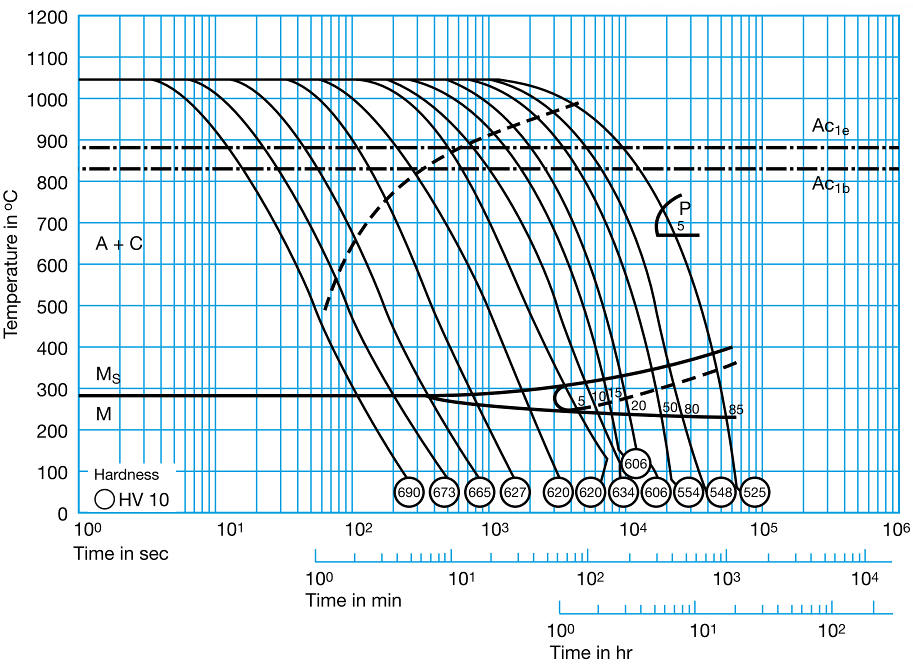
Heat treatment

Soft annealing °C	**Cooling**	**Hardness HB**
730 – 780	Furnace	max. 235

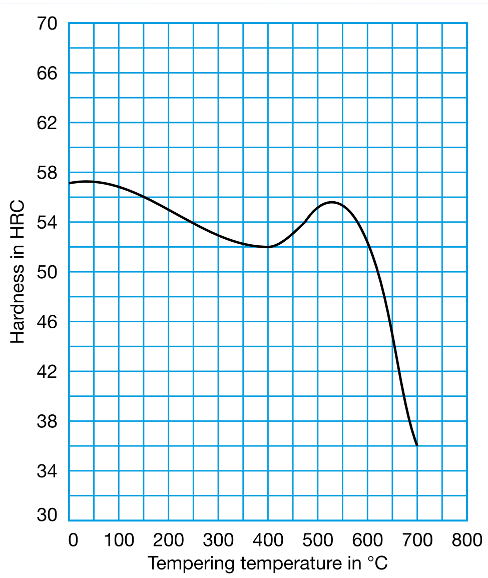
Hardening °C	**Quenching**	**Hardness after quenching HRC**
1020 – 1050	Air, oil or hot bath, 500 – 550 °C	57

Tempering °C	100	200	300	400	500	550	600	650	700
HRC	57	55	53	52	55	55	52	45	36

Time-temperature-transformation diagram

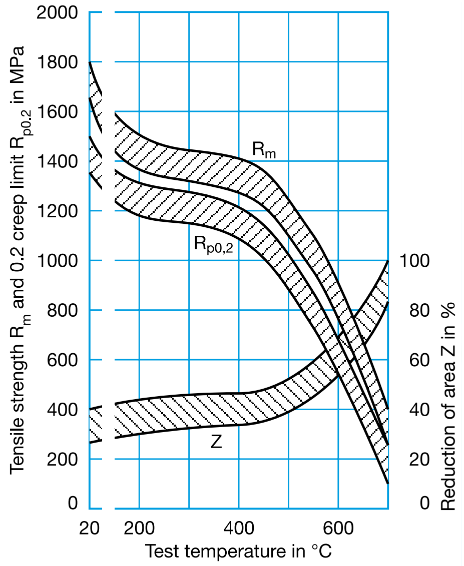


Tempering diagram

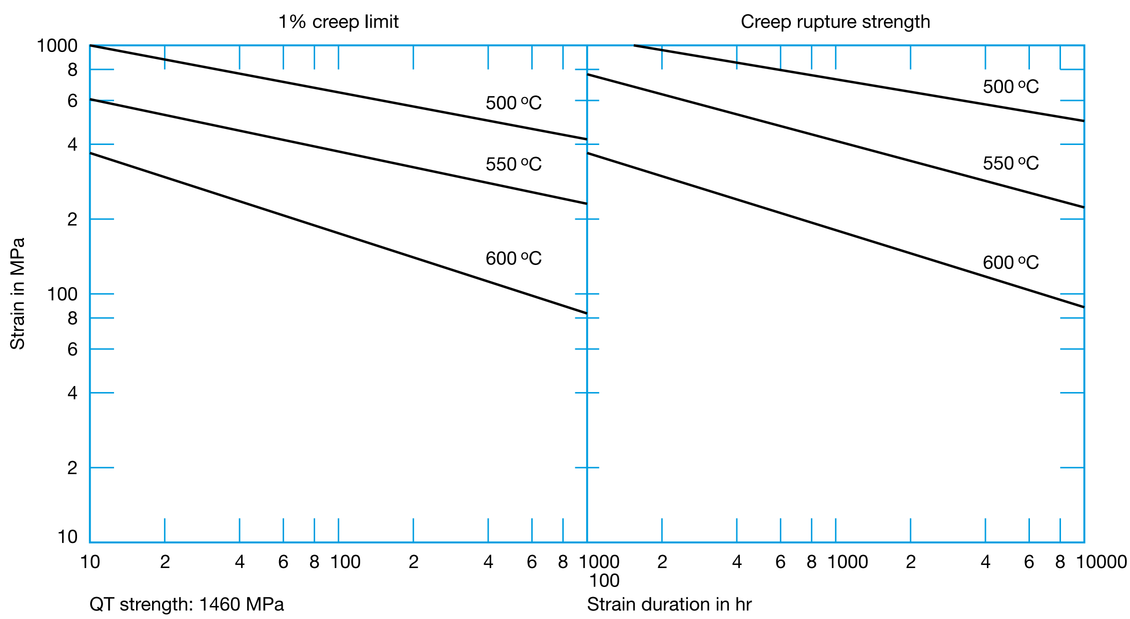


Thermodur® 2367 EFS/2367 EFS Superclean

High-temperature strength diagram



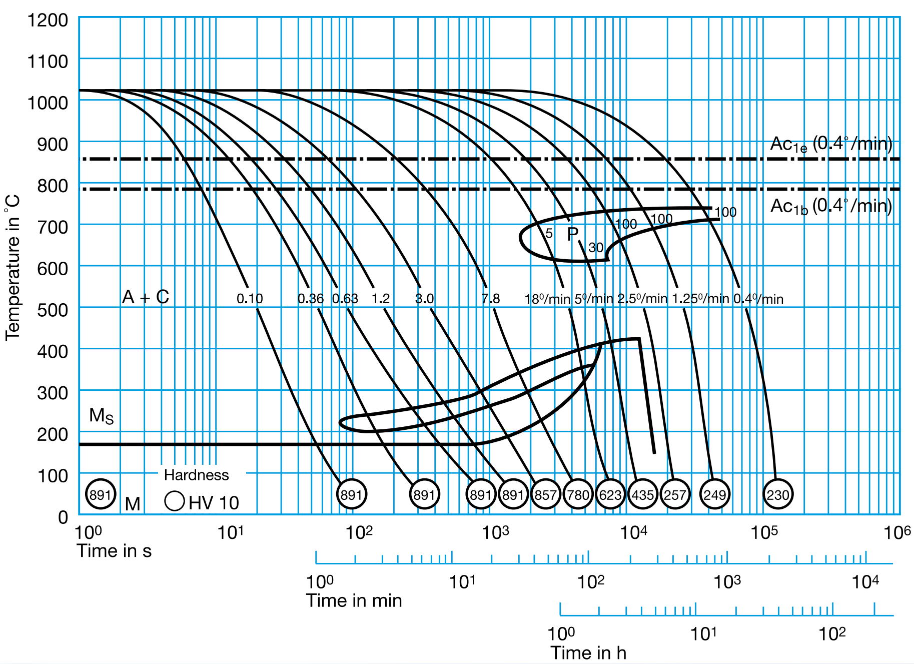
Creep behavior



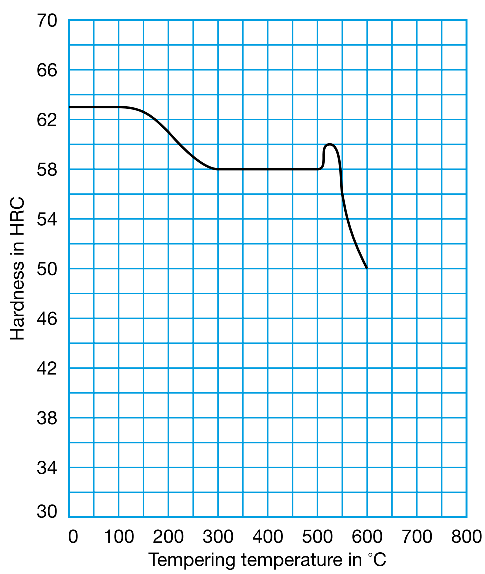
Cryodur® 2379

X153CrMoV12	C 1.55 Si 0.30 Mn 0.35 Cr 12.00 Mo 0.75 V 0.90
Steel properties	12% ledeburitic chromium steel. Combines maximum wear resistance, good high-temperature toughness, outstanding cutting edge retention, and tempering resistance. Nitridable after special heat treatment.
Standards	**AISI** D2 **AFNOR** Z160CDV12
Physical properties	**Coefficient of thermal expansion** **at °C** 20 – 100 20 – 200 20 – 300 20 – 400 **10^{-6} m/(m • K)** 10.5 11.5 11.9 12.2 **Thermal conductivity at °C** 20 350 700 **W/(m • K)** 16.7 20.5 24.2
Applications	Deburring tools, thread-rolling tools and dies, cold extrusion tools, cutting and punching tools for sheet thicknesses up to 6 mm, precision cutting tools up to 12 mm. Cold pilger mandrels, circular-shear blades, deep-drawing tools, pressure pads, and plastic moulds with high wear resistance.
Heat treatment	**Soft annealing °C** 830 – 860; **Cooling** Furnace; **Hardness HB** max. 250 **Stress-relief annealing °C** 650 – 700; **Cooling** Furnace **Hardening °C** 1000 – 1050; **Quenching** Air, oil or hot bath, 500 – 550 °C; **Hardness after quenching HRC** 63 **Tempering °C** 100 200 300 400 500 525 550 600 **HRC** 63 61 58 58 58 60 56 50

Time-temperature-transformation diagram
Hardening temperature: 1030 °C



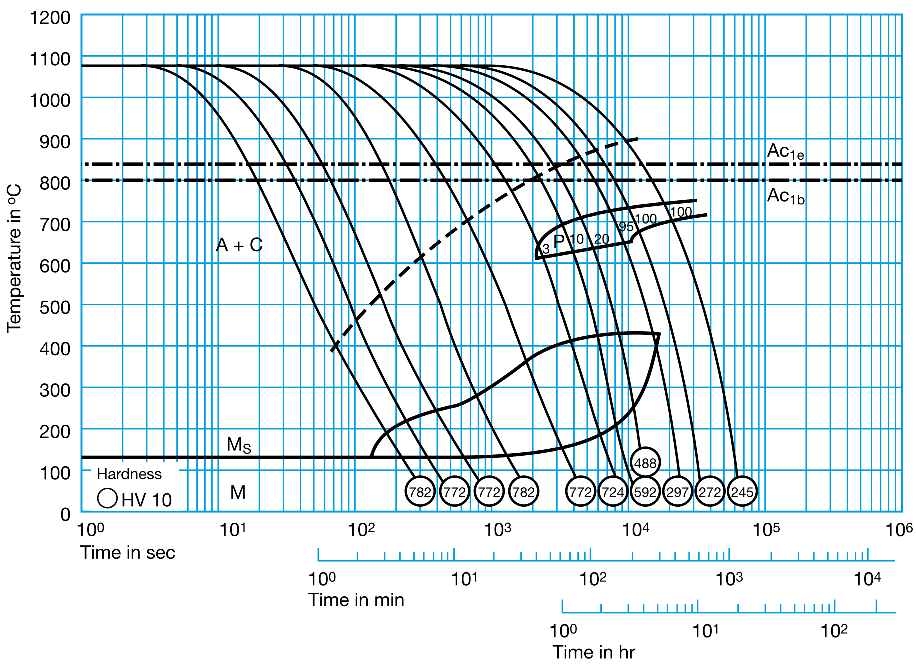
Tempering diagram



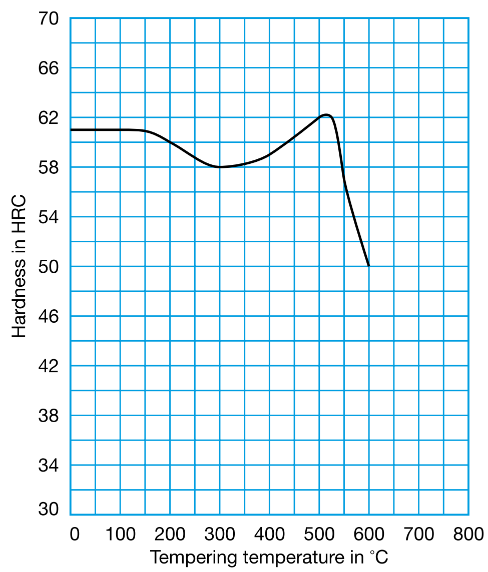
Cryodur® 2379

Special heat treatment	Hardening °C	Quenching			Hardness after quenching HRC				
	1050 – 1080	Air, oil or hot bath, 500 – 550 °C		61					
	Tempering °C: (three times)	100	200	300	400	500	525	550	600
	HRC	61	60	58	59	62	62	57	50

Time-temperature-transformation diagram
Hardening temperature: 1080 °C



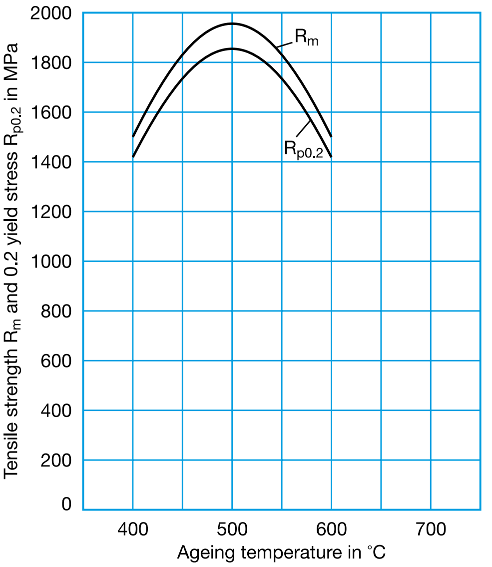
Tempering diagram



Cryodur® 2709

(X3NiCoMoTi18-9-5)	C < 0.02 Mo 5.00 Ni 18.00 Co 10.00 Ti 1.00					
Steel properties	Distortion low, precipitation-hardening, high yield point and tensile strength combined with a good level of toughness.					
Standards	**AISI** 18MAR300					
Physical properties	**Coefficient of thermal expansion**					
	at °C	20 – 100	20 – 200	20 – 300	20 – 400	20 – 500	20 – 600
	10^{-6} m/(m • K)	10.3	11.0	11.2	11.5	11.8	11.6
	Thermal conductivity at °C	20	350	700			
	W/(m • K)	14.2	18.5	22.5			
Applications	Pressure casting dies for light metals with particularly complex geometries as well as cold pilger mandrels.					
Heat treatment	**Solution annealing °C**	**Cooling**	**Hardness HB**			
	820 – 850	Water	max. 340			
	Precipitation hardening °C		**Attainable hardness HRC**			
	490 / 6 hours (air)		approx. 55			

Precipitation diagram



Reference numbers in parentheses are not standardized in EN ISO 4957.

Thermodur® 2714

55NiCrMoV7	C 0.56 Cr 1.10 Mo 0.50 Ni 1.70 V 0.10
Steel properties	Tough die steel with an outstanding resistance to tempering and through-hardenability. This steel grade is commonly delivered in annealed condition or tempered to a working hardness of 370 to 410 HB (round) or 355 to 400 HB (square, flat).
Standards	**AISI** ~L6 **AFNOR** 55NCDV7
Physical properties	see below
Applications	Standard steel for forging dies of all kinds, press dies, extrusion stems, die holders, armored trim dies, and hot-shear blades.
Heat treatment	see below

Physical properties

Coefficient of thermal expansion

at °C	20 – 100	20 – 200	20 – 300	20 – 400	20 – 500	20 – 600
10^{-6} m/(m • K)	12.2	13.0	13.3	13.7	14.2	14.4

Thermal conductivity at °C	20	350	700
W/(m • K)	36.0	38.0	35.0

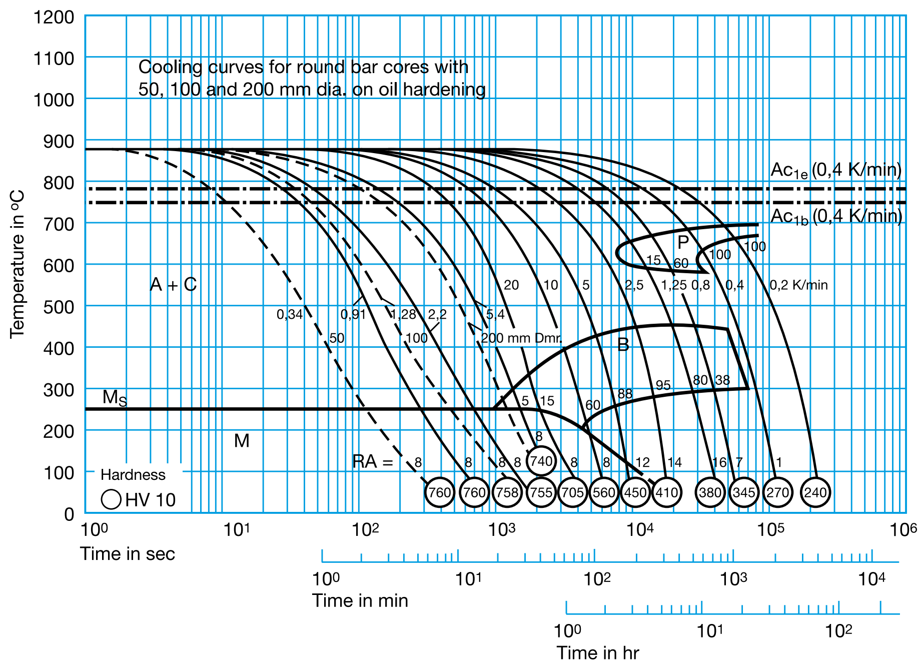
Heat treatment

Soft annealing °C	**Cooling**	**Hardness HB**
650 – 700	Furnace	max. 250

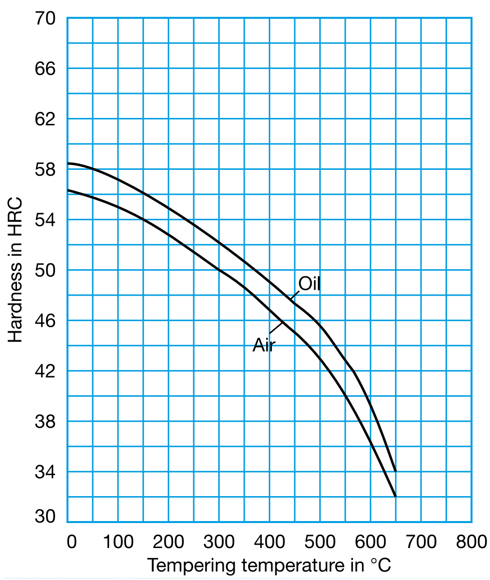
Hardening °C	**Quenching**	**Hardness after quenching HRC**
830 – 870	Oil	58
860 – 900	Air	56

Tempering °C	100	200	300	400	450	500	550	600	650
after quenching									
in oil – HRC	57	54	52	49	47	46	43	38	34
in air – HRC	55	52	50	47	45	43	40	36	32

Time-temperature-transformation diagram

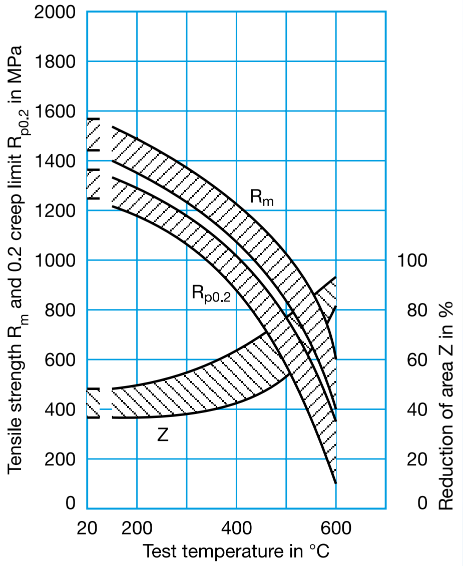


Tempering diagram

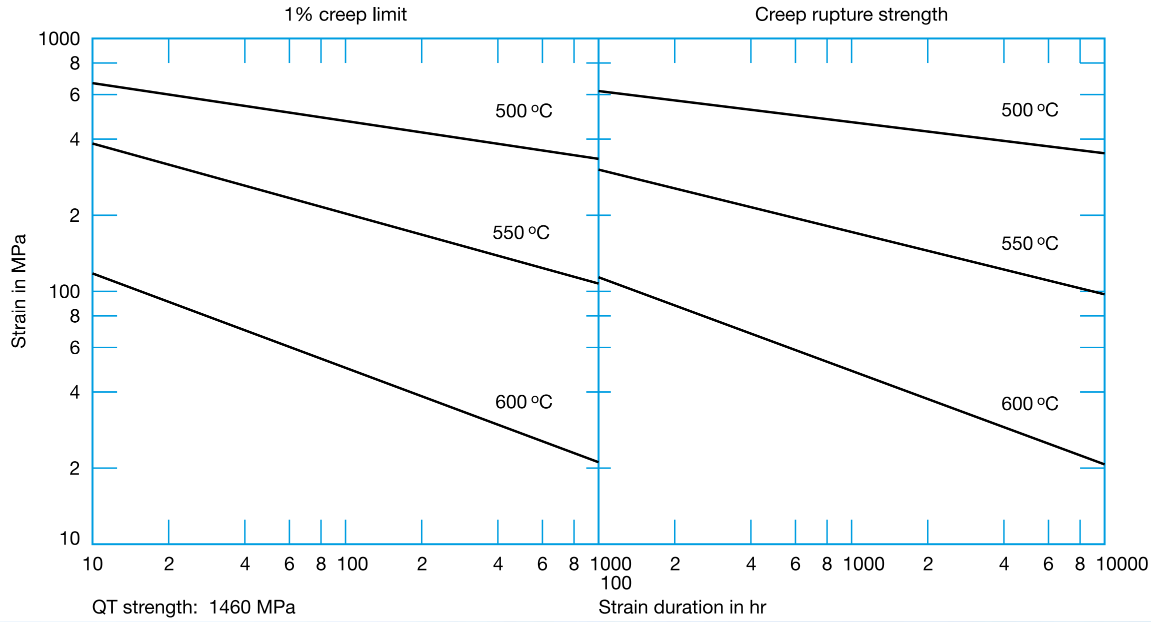


Thermodur® 2714

High-temperature strength diagram



Creep behavior



Formadur® 2738

40CrMnNiMo8-6-4	C 0.40 Mn 1.50 Cr 1.90 Ni 1.00 Mo 0.20
Steel properties	Tempered plastic mould steel, as-supplied hardness of 280 to 325 HB. Good machinability, suitable for texturing. Full quenching and tempering properties improved compared to Formadur® 2311. Good polishability.
Standards	**AISI** P20+Ni

Physical properties

Coefficient of thermal expansion

at °C	20 – 100	20 – 200	20 – 300	20 – 400	20 – 500	20 – 600	20 – 700
10^{-6} m/(m • K)	11.1	12.9	13.4	13.8	14.2	14.6	14.9

Thermal conductivity

at °C	20	350	700
W/(m • K)	34.5	33.5	32.0

Applications	Mould frames for pressure casting dies and large plastic moulds.

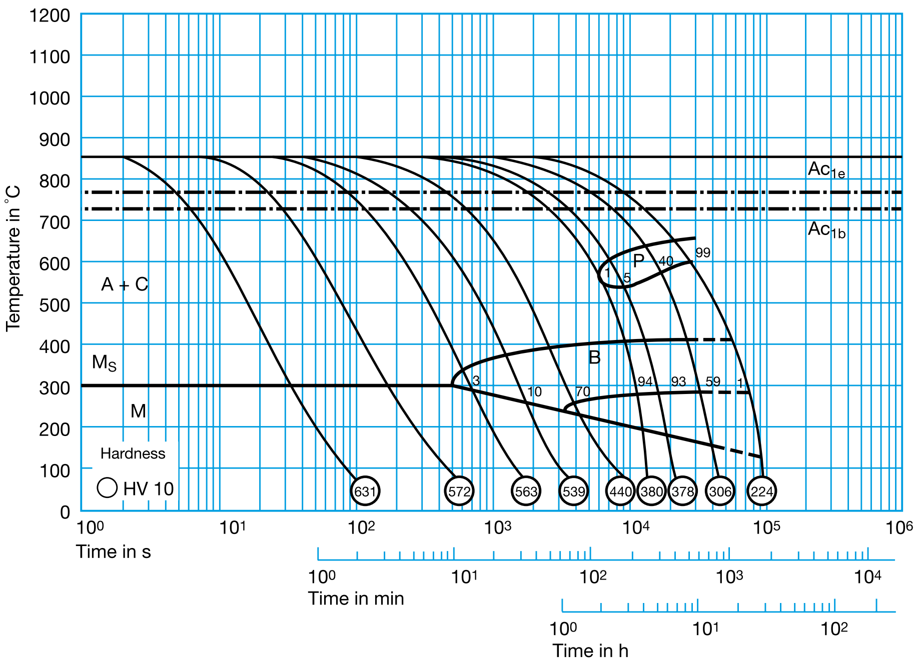
Heat treatment

Soft annealing °C	**Cooling**	**Hardness HB**
710 – 740	Furnace	max. 235

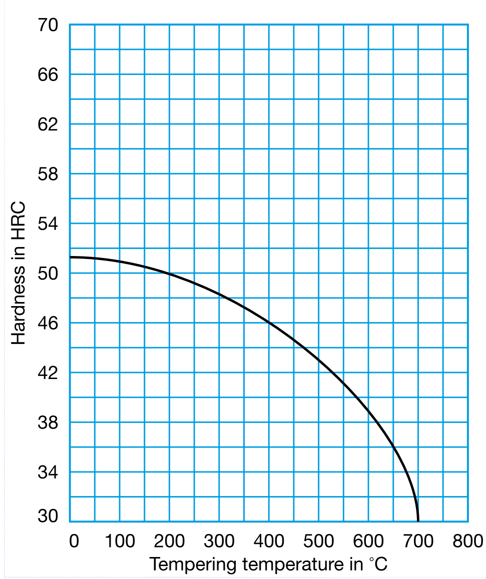
Hardening °C	**Quenching**	**Hardness after quenching HRC**
840 – 870	Polymer or oil	51

Tempering °C	100	200	300	400	500	600	700
HRC	51	50	48	46	42	39	28

Time-temperature-transformation diagram
Härtetemperatur: 1030 °C



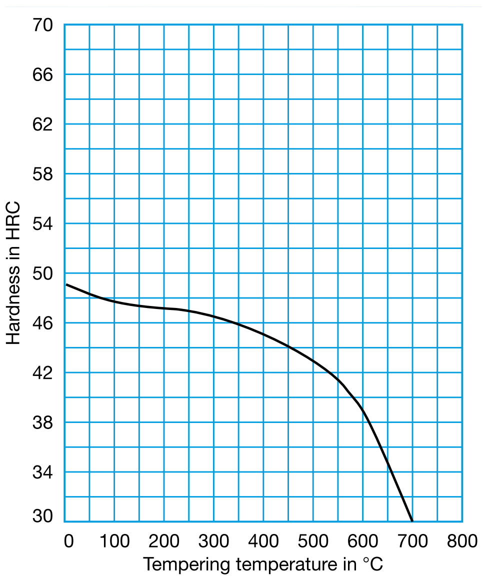
Tempering diagram



Thermodur® 2740

28NiCrMoV10	C 0.28 Cr 0.70 Mo 0.60 Ni 2.50 V 0.30		
Steel properties	Air-hardening special steel for hot working. Outstanding high-temperature toughness and thermal shock resistance.		
Applications	Special steel for mandrels and pilger mandrels. We generally supply the rough-machined or fully machined tools in tempered condition.		
Heat treatment	**Soft annealing °C**	**Cooling**	**Hardness HB**
	670 – 700	Furnace	max. 240
	Hardening °C	**Quenching**	**Hardness after quenching HRC**
	840 – 870	Air or oil	49

Tempering diagram



Thermodur® 2782 Superclean

X16CrNiSi25-20	C 0.15 Si 2.00 Mn 0.80 Cr 25.00 Ni 20.00			
Steel properties	Non-scaling, austenitic hot-work tool steel, which is resistant to oxidizing environments and displays good cold workability. Resistant to scaling in air up to approx. 1150 °C. Delivered in precipitation hardened condition 650 – 800 MPa.			
Physical properties	**Coefficient of thermal expansion**			
	at °C	20 – 200	20 – 400	20 – 600
	10^{-6} m/(m • K)	16.5	17.0	17.5
	Thermal conductivity at °C	20		500
	W/(m • K)	13.0		19.0
Applications	Tools for glass product manufacturing, such as punches, couplers, blowing iron heads and mandrels, orifices, blowpipes, and gathering irons.			
Heat treatment	**Soft annealing °C**	**Quenching**	**Hardness after quenching MPa**	
	1000 – 1100	Air or water	495 – 705	

Thermodur® 2787/2787 Superclean

X23CrNi17	C 0.22 Si 0.40 Mn 0.50 Cr 16.50 Ni 1.70
Steel properties	Corrosion and scaling resistant hot-work tool steel, which can easily be tempered.
Physical properties	**Coefficient of thermal expansion**

at °C	20 – 100	20 – 200	20 – 300	20 – 400	20 – 500
10^{-6} m/(m • K)	10.0	10.5	11.0	11.0	11.0

Thermal conductivity

at °C	20
W/(m • K)	25.0

Applications

Tools for glass product manufacturing

For your most challenging requirements, we recommend Thermodur® 2787 Superclean.

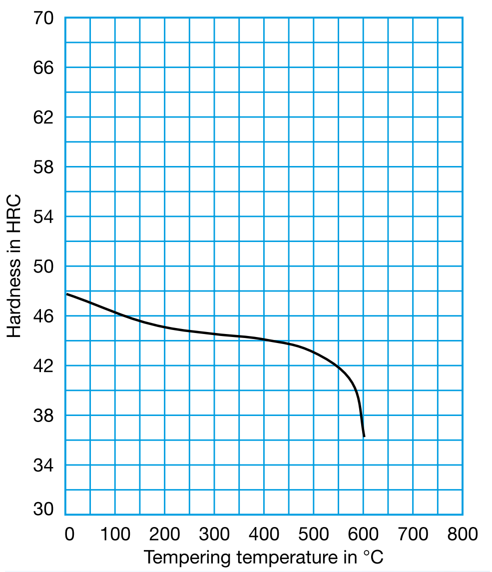
Heat treatment

Soft annealing °C	**Cooling**	**Hardness HB**
710 – 750	Furnace	max. 245

Hardening °C	**Quenching**	**Hardness after quenching HRC**
990 – 1020	Oil or hot bath, 200 °C	47

Tempering °C after quenching	100	200	300	400	500	600
in oil – HRC	46	45	45	44	43	36

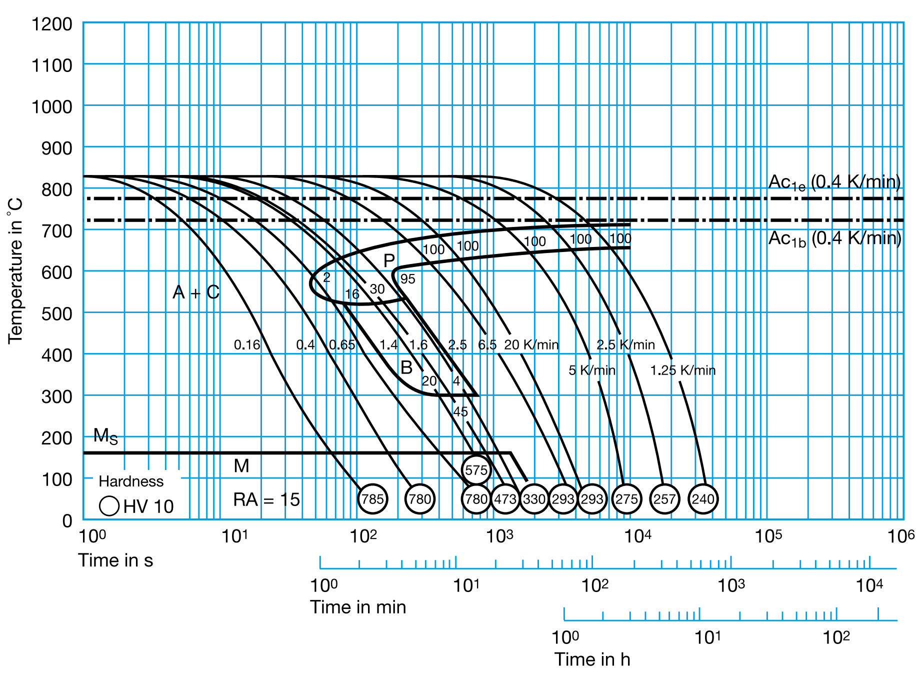
Tempering diagram



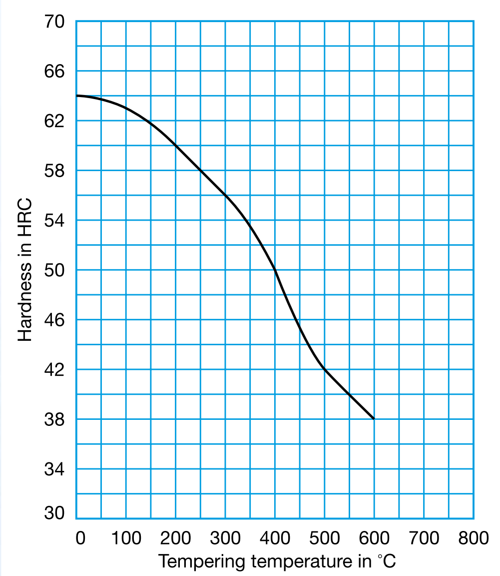
Cryodur® 2842

90MnCrV8	C 0.90 Mn 2.00 Cr 0.40 V 0.10						
Steel properties	Good cutting edge retention, good hardenability, dimensionally stable during heat treatment.						
Standards	**AISI** O2	**AFNOR** 90MV8					
Physical properties	**Coefficient of thermal expansion**						
	at °C	20 – 100	20 – 200	20 – 300	20 – 400	20 – 500	20 – 600	20 – 700
	10^{-6} m/(m • K)	12.2	13.2	13.8	14.3	14.7	15.0	15.3
	Thermal conductivity at °C	20	350	700				
	W/(m • K)	33.0	32.0	31.3				
Applications	Tool steel for universal use. Deburring tools, trimming and punching tools for sheet thicknesses up to 6 mm, thread-cutting tools, reamers, gauges, measuring tools, plastic moulds, shear blades, and guide strips.						
Heat treatment	**Soft annealing °C**	**Cooling**	**Hardness HB**				
	680 – 720	Furnace	max. 220				
	Hardening °C	**Quenching**	**Hardness after quenching HRC**				
	790 – 820	Oil or hot bath, 180 – 220 °C	64				
	Tempering °C	100	200	300	400	500	600
	HRC	63	60	56	50	42	38

Time-temperature-transformation diagram



Tempering diagram

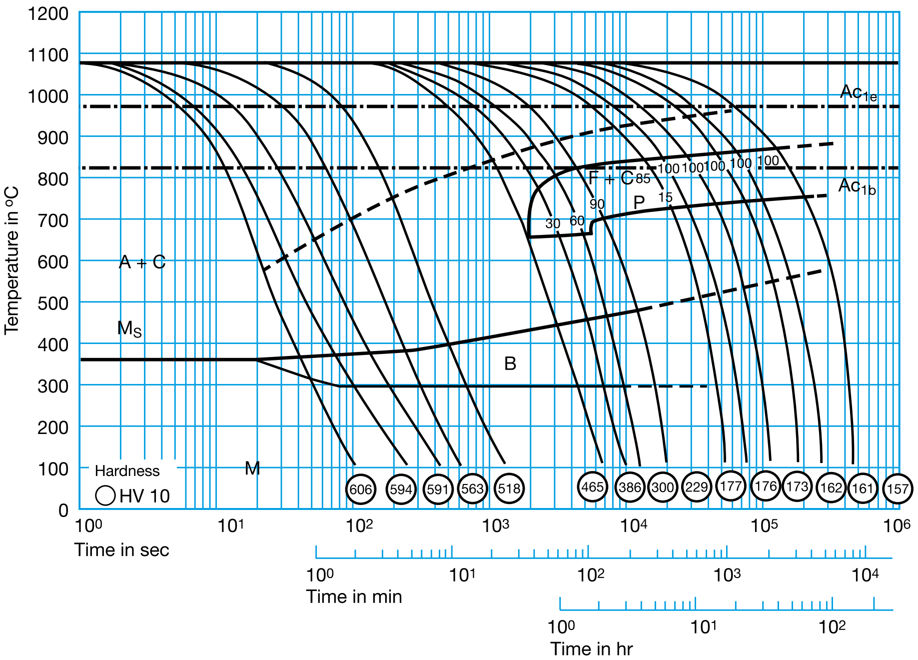


Thermodur® 2999 EFS Superclean

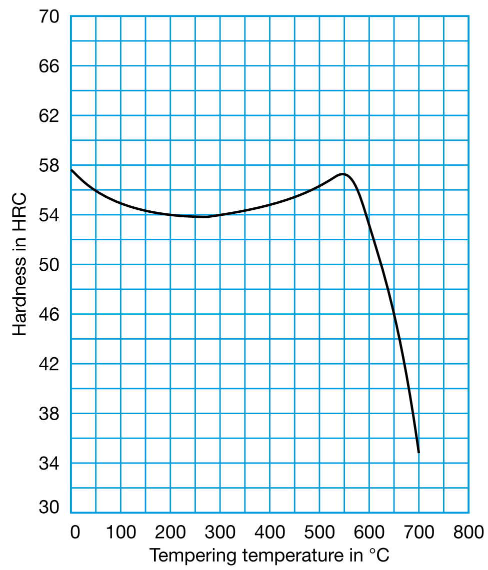
X45MoCrV5-3-1	C 0.45 Si 0.30 Mn 0.30 Cr 3.00 Mo 5.00 V 1.00							
Steel properties	Maximum high-temperature strength, good high-temperature wear resistance, excellent thermal shock resistance and thermal conductivity across the entire range of service temperatures.							
Physical properties	**Coefficient of thermal expansion**							
	at °C	20 – 100	20 – 200	20 – 300	20 – 400	20 – 500	20 – 600	20 – 700
	10^{-6} m/(m • K)	11.3	11.9	12.2	12.6	13.0	13.3	13.5
	Thermal conductivity at °C		20	350	700			
	W/(m • K) Annealed		37.8	39.5	39.5			
	W/(m • K) Quenched and tempered		31.4	35.2	36.2			
Applications	Die inserts and high-speed forging tools exposed to severe wear stresses, heavy metal die casting, hot-work tool steels for use at highest temperatures.							

Heat treatment								
Soft annealing °C	750 – 800							
Cooling	Furnace							
Hardness HB	max. 230							
Hardening °C	1070 – 1100							
Quenching	Oil or hot bath, 500 – 550 °C							
Hardness after quenching HRC	57							
Tempering °C	100	200	300	400	500	550	600	650
HRC	55	54	54	55	56	57	53	46

Time-temperature-transformation diagram



Tempering diagram



Thermodur® E 38 K Superclean

approx. X35CrMoV5-1	C 0.35	Si 0.30	Mn 0.30	S < 0.003	Cr 5.00	Mo 1.35	V 0.45

Steel properties

Outstanding high-temperature strength and improved toughness. Excellent thermal conductivity and low susceptibility to hot cracking. May be water-cooled to a limited extent.

Physical properties

Coefficient of thermal expansion

at °C	20 – 100	20 – 200	20 – 300	20 – 400	20 – 500	20 – 600	20 – 700
10^{-6} m/(m • K)	11.8	12.4	12.6	12.7	12.8	12.9	12.9

Thermal conductivity at °C	20	350	700
W/(m • K) Annealed	29.8	30.0	33.4
W/(m • K) Quenched and tempered	26.8	27.3	30.3

Applications

Hot-work tool steel for universal use, which is particularly suitable for applications involving high flexural stresses due to its outstanding toughness.

» Extrusion tools for light metal processing

» Die casting tools for light metal processing

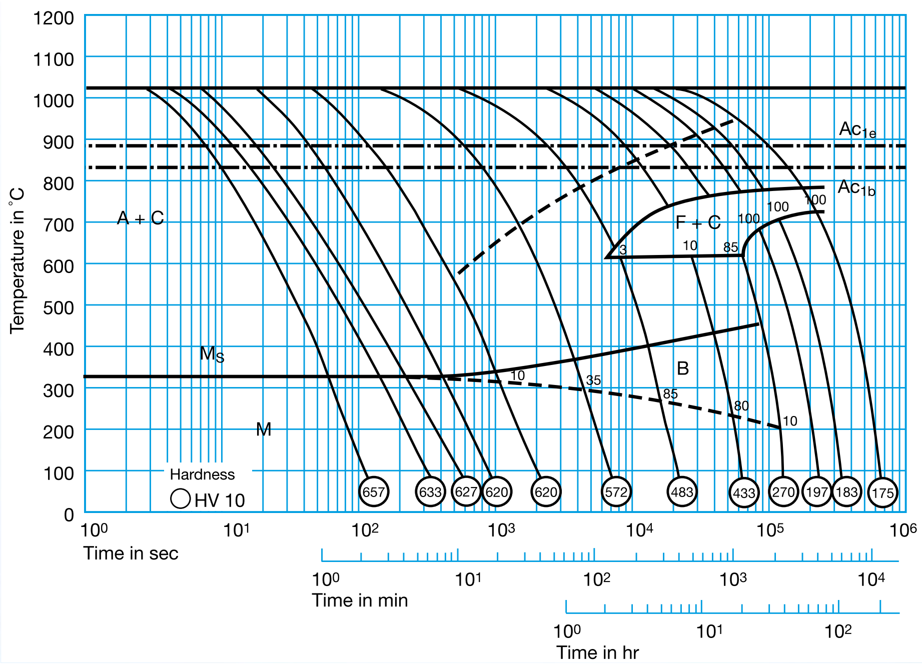
Heat treatment

Soft annealing °C	**Cooling**	**Hardness HB**
740 – 780	Furnace	max. 200

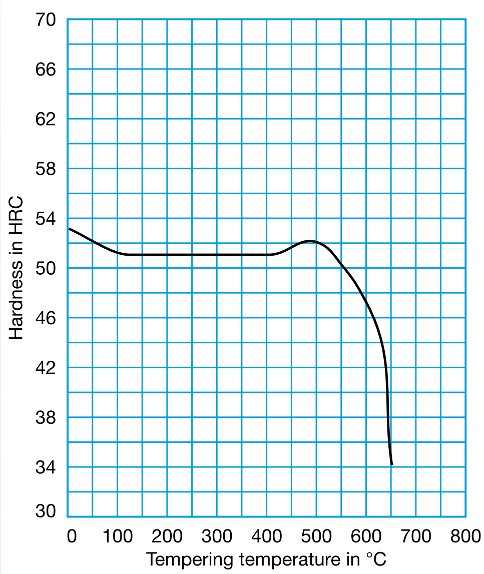
Hardening °C	**Quenching**	**Hardness after quenching HRC**
1000 – 1030	Oil or hot bath, 500 – 550 °C	53

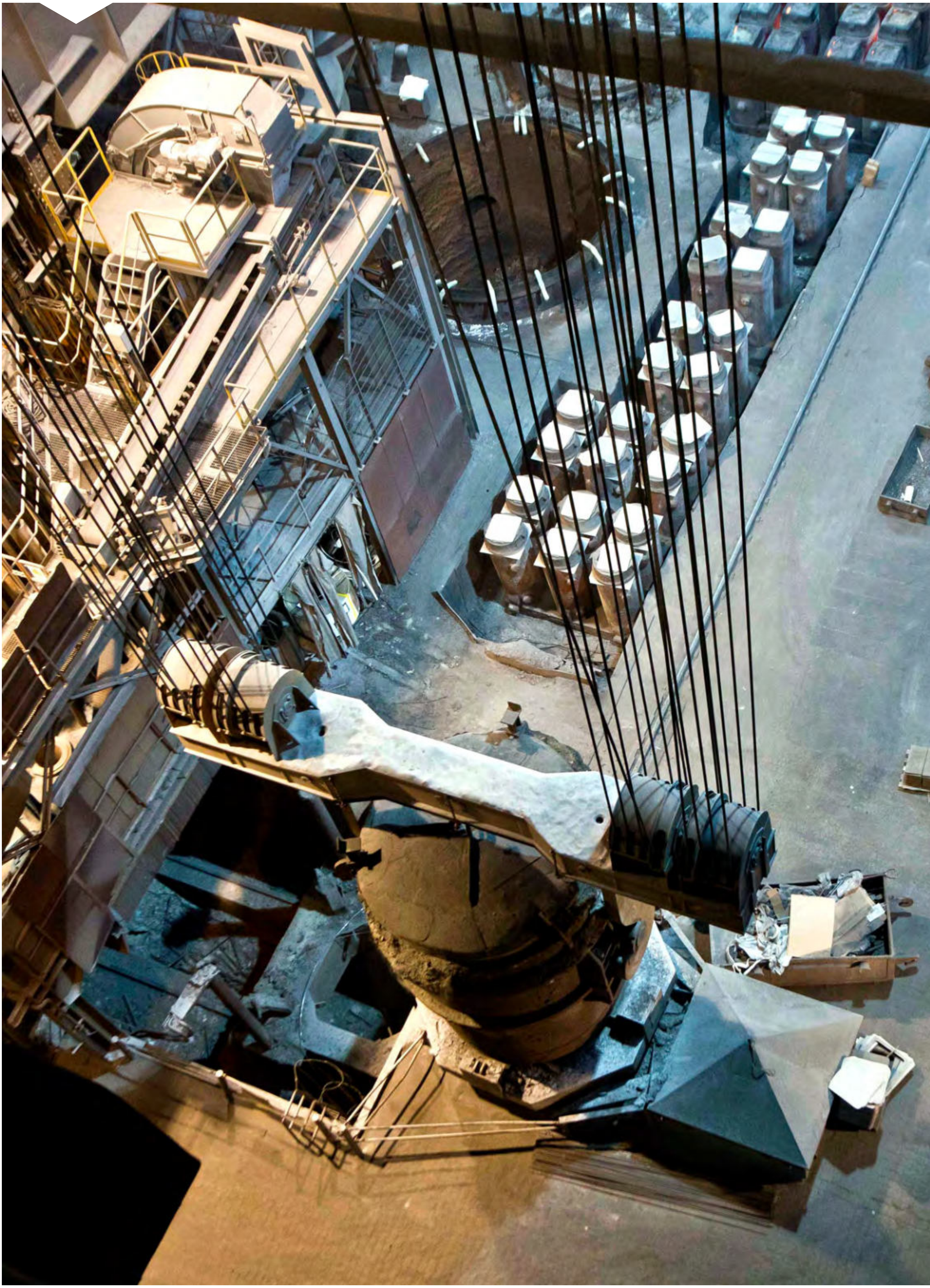
Tempering °C	100	200	300	400	500	550	600	700
HRC	51	51	51	51	52	50	47	34

Time-temperature-transformation diagram



Tempering diagram





Processing guidelines

Design

The design of a tool is essential for its costeffective application later. A precisely machined tool, which has undergone the proper heat treatment and is made of the best possible steel, may still break prematurely if its design is faulty. The right design and proper heat treatment are essential prerequisites for preventing negative effects in regards to time and costs. The following factors can promote susceptibility to cracking or breaking:

» Incorrect dimensioning
» Abrupt cross-section transitions
» Sharp notches (e.g. tool marks and grinding marks, scriber marks, punched numbers, etc.)

A tool's susceptibility to notching increases with its strength: The higher the hardness selected, the more carefully the surfaces and cross-section transitions must be machined. The radii should therefore be designed to be as large as possible, and they should be polished as well.
In general, the reduced toughness at high hardness levels as well as the different toughness properties of the various grades must be taken into account.

Design and heat treatment

The microstructural transformations occurring during heat treatment and the temperature differences, which inevitably occur between the surface and the core, cause stresses resulting in dimensional changes. The range of temperature differences is dependent on the size and shape of the tool. A symmetric design of the tool is recommended. As the temperature differences increase at larger tool volumes, it might be effective in some cases to divide the tool into individual sections. That type of design would also offer the advantage that individual worn or damaged parts could be replaced more efficiently.

Thin webs within the mould are a frequent cause of problems during heat treatment. These thin webs cool more quickly than the rest of the tool, which results in a faster transformation from austenite to martensite than that would be the case with larger cross-sections. In such cases, dividing the mould into smaller sections should always be given some consideration.

Machining

Tools made of hot-work tool steel are manufactured in metal-cutting and non-cutting shaping processes. During metal-cutting, surface tension is generated and the tension of the workpiece is altered to varying degrees depending on the depth of machining. In the event of extensive metal-cutting, it is recommended to perform thermal relief for annealed and tempered parts in order to reduce the risk of distortion or stress cracking during finish machining.
Critical machining processes are processes, in which the structure of the steel is altered as a result of thermal influences.

Electrical discharge machining

In this process, the surface is eroded by a park discharging between an electrode and the tool to be manufactured.
Electrical discharge machining (EDM) is especially suitable for machining hardened tools. The extreme temperatures in the working gap (approx. 10,000 °C) cause the eroded material to evaporate before being carried off by the dielectric fluid. A melted zone is left with heat effects reaching deep into the material. Fine incipient cracks form in that area, which may result in premature failure of the mould.
The depth of this brittle new hardening zone and the magnitude of those stresses are determined by the extent of the impulse energy and the washing away by the dielectric fluid. Only careful mechanical reworking (removal of damaged edge zones) can sufficiently prevent these cracks from progressing. During structure erosion, washing must occur evenly from all sides in order to avoid the structure being shaped in the direction of washing.

Milling

Our tool steel can be cut to suit their intended area of application. For economical reasons, machining should be performed with modern metal-cutting tools (carbide cutting tools). Setting the metal-cutting parameters properly (cutting speed and feed rate) and in accordance with the following table and the tool manufacturer guidelines is essential for a successful machining process. Milling with carbide cutting tools must be performed “dry” (without lubricoolants). If increased wear occurs at the reversible tip during milling, the type of wear should be examined and assessed. Based on the outcome of the assessment, the cutting speed and feed rate may have to be checked and readjusted. Experience shows that these are often set too low at the start. The size of cutting depth ap is of little significance in terms of wear when setting the feed rate and cutting speed. Stable machines and clamping conditions should always be aimed for.

» Always use reversible carbide cutting tips without lubricoolants
» Rough-machine at an angle of 0° and with negative chamfer
» Set the cutting speed at the high end of the range

When using HSS tools, the lubricoolants must be mixed in the upper range according to the manufacturer’s instructions.

Grinding

Perfect grinding of the hardened tools is of particular importance. When selecting the grinding wheel, it is essential that particle size, hardness, and bond are properly matched to the steel to be ground. The harder the steel, the softer the wheel and the lower the contact pressure must be. If the wrong grinding wheels are selected or the contact pressure is too high, local overheating might occur despite sufficient water cooling, which would then lead to negative thermal effects and grinding cracks. Tempering discoloration or so called „burnt“ areas must be prevented. The following guidelines always apply to grinding:

» Use a suitable grinding wheel
» Apply an appropriate amount of contact pressure (the higher the hardness, the lower the contact pressure)
» Use open grinding wheels
» Provide a generous, well-controlled supply of coolant

Polishing

Polishing is often the last machining step when manufacturing a mould. The quality of the polished surface is the deciding factor in the acceptance of a mould. The polishing outcome is further determined by:

» Steel quality
» Heat treatment condition
» Polishing method

Steel quality
The polishability of a mould is not only affected by its chemical composition but also the manufacturing process used.
The polishing results are also influenced by non-metallic inclusions (purity) or hard structural components such as primary carbides, which can stipple the polished surface. In order to improve purity levels hot-work-steel manufactured by Deutsche Edelstahlwerke undergoes secondary metallurgical treatment in ladle furnaces and vacuum-degassing plants.
The electroslag remelted version (ESR) or vacuum arc remelted version (VAR) provide further refinement, e.g. Thermodur® 2343/44 EFS Superclean or Formadur® 2083 Superclean.

Heat treatment condition
It is fundamentally true that the harder a mould is, the better it can be polished. Hardness values > 50 HRC are recommended for mirrorfinish polishing. There is a chance that rippling (the so-called orange peel) may occur with low or uneven hardnesses.

Polishing method
In addition to selecting the right steel grade and heat treatment, the polishing method is very important as well. The polishing result largely depends on the experience and skill of the polisher. The finer the graduation of the grinding and polishing processes, the better the surface quality.

Machining values for drilling tool steels

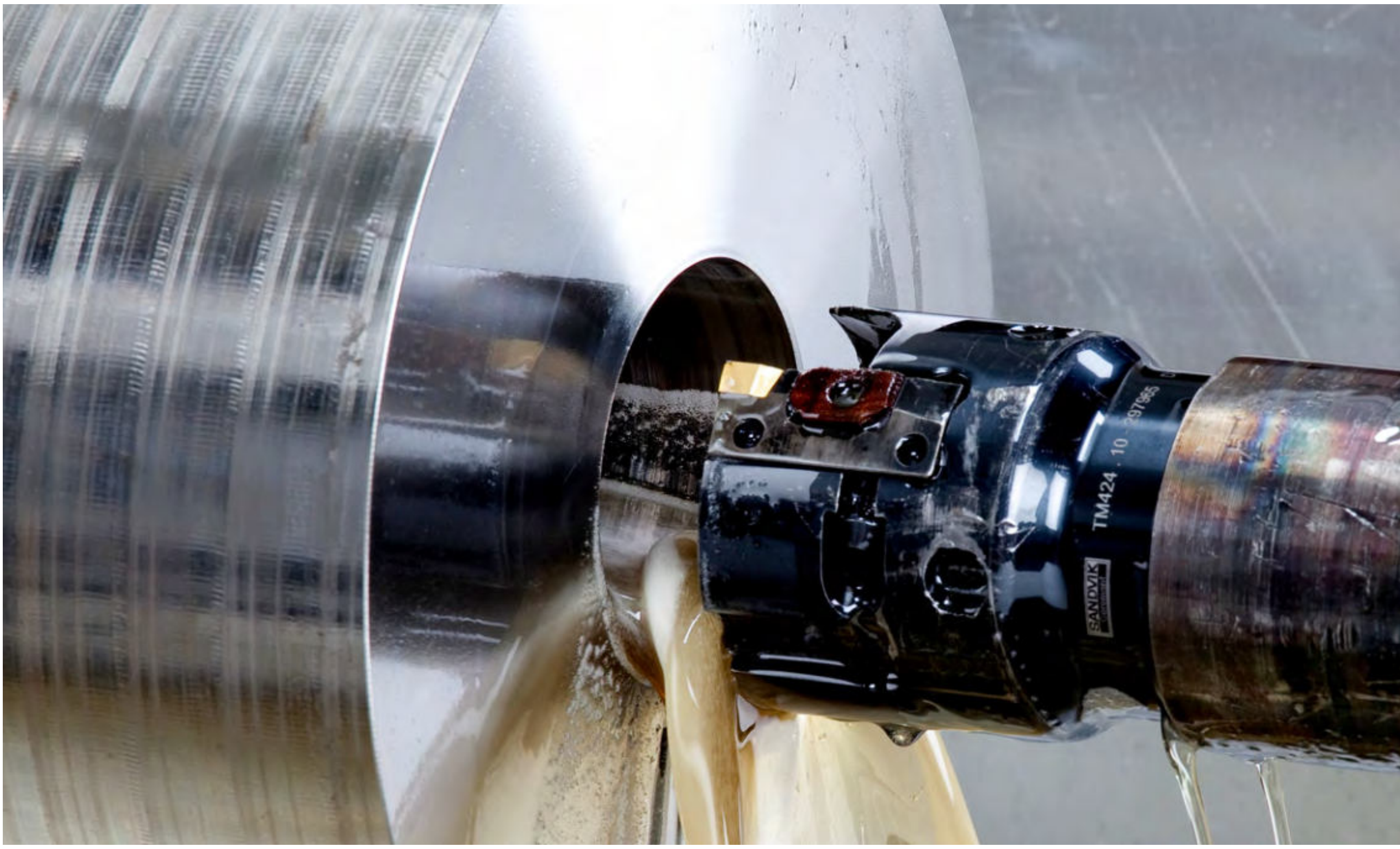
Grade	Treatment condition	Cutting speed v = m/min			Feed rate s = mm/rev.			Drill diameter mm		
		3343/ 3243	3343/ 3243 + TiN	HM K 10	3343/ 3243	3343/ 3243 + TiN	HM K 10	3343/ 3243	3343/ 3243 + TiN	HM K 10
Cryodur® 1730	Annealed	14 – 20	25 – 30	60 – 100	0.04 – 0.20	0.16 – 0.25	0.06 – 0.30	8 – 16	8 – 16	20 – 47
Formadur® 2083	Annealed	8 – 14	18 – 23	40 – 60	0.04 – 0.14	0.12 – 0.20	0.06 – 0.20	8 – 16	8 – 16	20 – 47
Formadur® 2312	QT	10 – 16	20 – 25	50 – 80	0.04 – 0.20	0.16 – 0.25	0.06 – 0.30	8 – 16	8 – 16	20 – 47
Thermodur® 2329	QT	6 – 10	15 – 20	30 – 50	0.04 – 0.16	0.12 – 0.20	0.06 – 0.20	8 – 16	8 – 16	20 – 47
Thermodur® 2342 EFS	Annealed	8 – 14	18 – 23	40 – 60	0.04 – 0.14	0.12 – 0.20	0.06 – 0.20	8 – 16	8 – 16	20 – 47
Thermodur® 2343 EFS	Annealed	8 – 14	18 – 23	40 – 60	0.04 – 0.14	0.12 – 0.20	0.06 – 0.20	8 – 16	8 – 16	20 – 47
Thermodur® 2344 EFS	Annealed	8 – 14	18 – 23	40 – 60	0.04 – 0.14	0.12 – 0.20	0.06 – 0.20	8 – 16	8 – 16	20 – 47
Thermodur® 2365 EFS	Annealed	8 – 14	18 – 23	40 – 60	0.04 – 0.14	0.12 – 0.20	0.06 – 0.20	8 – 16	8 – 16	20 – 47
Thermodur® 2367 EFS	Annealed	8 – 14	18 – 23	40 – 60	0.04 – 0.14	0.12 – 0.20	0.06 – 0.20	8 – 16	8 – 16	20 – 47
Cryodur® 2379	Annealed	6 – 10	15 – 20	30 – 50	0.04 – 0.16	0.12 – 0.20	0.06 – 0.20	8 – 16	8 – 16	20 – 47
Cryodur® 2709	Sol.-annealed	8 – 14	18 – 23	40 – 60	0.04 – 0.14	0.12 – 0.20	0.06 – 0.20	8 – 16	8 – 16	20 – 47
Thermodur® 2714	QT	6 – 10	15 – 20	30 – 50	0.04 – 0.16	0.12 – 0.20	0.06 – 0.20	8 – 16	8 – 16	20 – 47
Formadur® 2738	QT	6 – 10	15 – 20	30 – 50	0.04 – 0.16	0.12 – 0.20	0.06 – 0.20	8 – 16	8 – 16	20 – 47
Thermodur® 2740	Annealed	8 – 14	18 – 23	40 – 60	0.04 – 0.14	0.12 – 0.20	0.06 – 0.20	8 – 16	8 – 16	20 – 47
Thermodur® 2782	Sol.-annealed	8 – 14	18 – 23	40 – 60	0.04 – 0.14	0.12 – 0.20	0.06 – 0.20	8 – 16	8 – 16	20 – 47
Thermodur® 2787	QT	6 – 10	15 – 20	30 – 50	0.04 – 0.16	0.12 – 0.20	0.06 – 0.20	8 – 16	8 – 16	20 – 47
Cryodur® 2842	Annealed	10 – 18	20 – 25	50 – 80	0.04 – 0.20	0.16 – 0.25	0.06 – 0.30	8 – 16	8 – 16	20 – 47
Thermodur® 2999 EFS	Annealed	8 – 14	18 – 23	40 – 60	0.04 – 0.14	0.12 – 0.20	0.06 – 0.20	8 – 16	8 – 16	20 – 47
Thermodur® E 38 K Superclean	Annealed	8 – 14	18 – 23	40 – 60	0.04 – 0.14	0.12 – 0.20	0.06 – 0.20	8 – 16	8 – 16	20 – 47

Machining values for turning tools using HSS and carbide cutting tools

Grade	Treatment condition	HSS tool THYRAPID® 3207		THYRAPID® 3207		Carbide cutting tool Coated with P25/P25 TIALAN		P10/P15	
		Rough-machining		Finish-machining		Rough-machining		Finish-machining	
		Cutting speed Vc (m/min)	Feed rate s = mm/U	Cutting speed Vc (m/min)	Feed rate s = mm/U	Cutting speed Vc (m/min)	Feed rate s = mm/U	Cutting speed Vc (m/min)	Feed rate s = mm/U
Cryodur® 1730	Annealed	20 – 40	0.2 – 0.4	40 – 70	0.1 – 0.2	150 – 230	0.4 – 1.0	300 – 420	0.1 – 0.4
Formadur® 2083	Annealed	15 – 25	0.2 – 0.4	25 – 50	0.1 – 0.2	125 – 195	0.4 – 1.0	250 – 370	0.1 – 0.4
Formadur® 2312	QT	15 – 30	0.2 – 0.4	35 – 60	0.1 – 0.2	130 – 200	0.4 – 1.0	270 – 390	0.1 – 0.4
Thermodur® 2329	QT	10 – 20	0.2 – 0.4	20 – 30	0.1 – 0.2	115 – 175	0.4 – 1.0	235 – 350	0.1 – 0.4
Thermodur® 2342 EFS	Annealed	15 – 25	0.2 – 0.4	25 – 50	0.1 – 0.2	125 – 195	0.4 – 1.0	250 – 370	0.1 – 0.4
Thermodur® 2343 EFS	Annealed	15 – 25	0.2 – 0.4	25 – 50	0.1 – 0.2	125 – 195	0.4 – 1.0	250 – 370	0.1 – 0.4
Thermodur® 2344 EFS	Annealed	15 – 25	0.2 – 0.4	25 – 50	0.1 – 0.2	125 – 195	0.4 – 1.0	250 – 370	0.1 – 0.4
Thermodur® 2365 EFS	Annealed	15 – 25	0.2 – 0.4	25 – 50	0.1 – 0.2	125 – 195	0.4 – 1.0	250 – 370	0.1 – 0.4
Thermodur® 2367 EFS	Annealed	15 – 25	0.2 – 0.4	25 – 50	0.1 – 0.2	125 – 195	0.4 – 1.0	250 – 370	0.1 – 0.4
Cryodur® 2379	Annealed	10 – 20	0.2 – 0.4	20 – 30	0.1 – 0.2	115 – 175	0.4 – 1.0	235 – 350	0.1 – 0.4
Cryodur® 2709	Sol.-annealed	15 – 25	0.2 – 0.4	25 – 50	0.1 – 0.2	125 – 195	0.4 – 1.0	250 – 370	0.1 – 0.4
Thermodur® 2714	QT	10 – 20	0.2 – 0.4	20 – 30	0.1 – 0.2	115 – 175	0.4 – 1.0	235 – 350	0.1 – 0.4
Formadur® 2738	QT	10 – 20	0.2 – 0.4	20 – 30	0.1 – 0.2	125 – 175	0.4 – 1.0	235 – 350	0.1 – 0.4
Thermodur® 2740	Annealed	15 – 25	0.2 – 0.4	25 – 50	0.1 – 0.2	125 – 195	0.4 – 1.0	250 – 370	0.1 – 0.4
Thermodur® 2782	Sol.-annealed	15 – 25	0.2 – 0.4	25 – 50	0.1 – 0.2	125 – 195	0.4 – 1.0	250 – 370	0.1 – 0.4
Thermodur® 2787	QT	10 – 20	0.2 – 0.4	20 – 30	0.1 – 0.2	115 – 175	0.4 – 1.0	235 – 350	0.1 – 0.4
Cryodur® 2842	Annealed	15 – 30	0.2 – 0.4	35 – 60	0.1 – 0.2	130 – 200	0.4 – 1.0	270 – 390	0.1 – 0.4
Thermodur® 2999 EFS	Annealed	10 – 20	0.2 – 0.4	20 – 30	0.1 – 0.2	115 – 175	0.4 – 1.0	235 – 350	0.1 – 0.4
Thermodur® E 38 K Superclean	Annealed	15 – 25	0.2 – 0.4	25 – 50	0.1 – 0.2	125 – 195	0.4 – 1.0	250 – 370	0.1 – 0.4

Machining values for milling tools using HSS and carbide cutting tools

Grade	Treatment condition	HSS tool THYRAPID® 3207		THYRAPID® 3207		Carbide cutting tool P40, TIALAN-beschichtet		P25	
		Rough-machining		Finish-machining		Rough-machining		Finish-machining	
		Cutting speed Vc (m/min)	Feed rate fz (mm)	Cutting speed Vc (m/min)	Feed rate fz (mm)	Cutting speed Vc (m/min)	Feed rate fz (mm)	Cutting speed Vc (m/min)	Feed rate fz (mm)
Cryodur® 1730	Annealed	15 – 25	0.10 – 0.20	20 – 40	0.05 – 0.10	150 – 210	0.30 – 0.60	120– 200	0.10 – 0.20
Formadur® 2083	Annealed	10 – 18	0.10 – 0.20	15 – 30	0.05 – 0.10	110 – 170	0.30 – 0.60	110 – 170	0.10 – 0.20
Formadur® 2312	QT	12 – 20	0.10 – 0.20	20 – 35	0.05 – 0.10	140 – 190	0.30 – 0.60	120 – 180	0.10 – 0.20
Thermodur® 2329	QT	8 – 10	0.18 – 0.25	10 – 15	0.20 – 0.40	80 – 160	0.20 – 0.40	90 – 180	0.15 – 0.25
Thermodur® 2342 EFS	Annealed	10 – 18	0.20 – 0.40	15 – 25	0.30 – 0.60	100 – 160	0.20 – 0.40	110 – 190	0.15 – 0.25
Thermodur® 2343 EFS	Annealed	10 – 18	0.10 – 0.20	15 – 30	0.05 – 0.10	110 – 170	0.30 – 0.60	110 – 170	0.10 – 0.20
Thermodur® 2344 EFS	Annealed	10 – 18	0.10 – 0.20	15 – 30	0.05 – 0.10	110 – 170	0.30 – 0.60	110 – 170	0.10 – 0.20
Thermodur® 2365 EFS	Annealed	10 – 18	0.10 – 0.20	15 – 30	0.05 – 0.10	110 – 170	0.30 – 0.60	110 – 170	0.10 – 0.20
Thermodur® 2367 EFS	Annealed	10 – 18	0.10 – 0.20	15 – 30	0.05 – 0.10	110 – 170	0.30 – 0.60	110 – 170	0.10 – 0.20
Cryodur® 2379	Annealed	8 – 15	0.10 – 0.20	12 – 20	0.05 – 0.10	90 – 160	0.30 – 0.60	100 – 160	0.10 – 0.20
Cryodur® 2709	Sol.-annealed	10 – 18	0.20 – 0.40	15 – 25	0.30 – 0.60	100 – 160	0.20 – 0.40	110 – 190	0.15 – 0.25
Thermodur® 2714	QT	8 – 10	0.18 – 0.25	10 – 15	0.20 – 0.40	80 – 160	0.20 – 0.40	90 – 180	0.15 – 0.25
Formadur® 2738	QT	8 – 15	0.10 – 0.20	12 – 20	0.05 – 0.10	90 – 160	0.30 – 0.60	100 – 160	0.10 – 0.20
Thermodur® 2740	Annealed	10 – 18	0.20 – 0.40	15 – 25	0.30 – 0.60	100 – 160	0.20 – 0.40	110 – 190	0.15 – 0.25
Thermodur® 2782	Sol.-annealed	10 – 18	0.20 – 0.40	15 – 25	0.30 – 0.60	100– 160	0.20 – 0.40	110 – 190	0.15 – 0.25
Thermodur® 2787	QT	8 – 10	0.18 – 0.25	10 – 15	0.20 – 0.40	80 – 160	0.20 – 0.40	90 – 180	0.15 – 0.25
Cryodur® 2842	Annealed	12 – 20	0.10 – 0.20	20 – 35	0.05 – 0.10	140 – 190	0.30 – 0.60	120 – 180	0.10 – 0.20
Thermodur® 2999 EFS	Annealed	8 – 10	0.18 – 0.25	10 – 15	0.20 – 0.40	80 – 160	0.20 – 0.40	90 – 180	0.15 – 0.25
Thermodur® E 38 K Superclean	Annealed	10 – 18	0.10 – 0.20	15 – 30	0.05 – 0.10	110 – 170	0.30 – 0.60	110 – 170	0.10 – 0.20



Repair welding

Because of the alloy structure of tool steel welding does bear a certain risk factor. While the weld seam cools, thermal and microstructural transformations occur, which may lead to cracking. However, design modifi cations, natural wear and cracking, or tool failure due to breakage or cracking often mean that a repair by means of electric welding is inevitable. The following basic rules should be followed during repair welding:

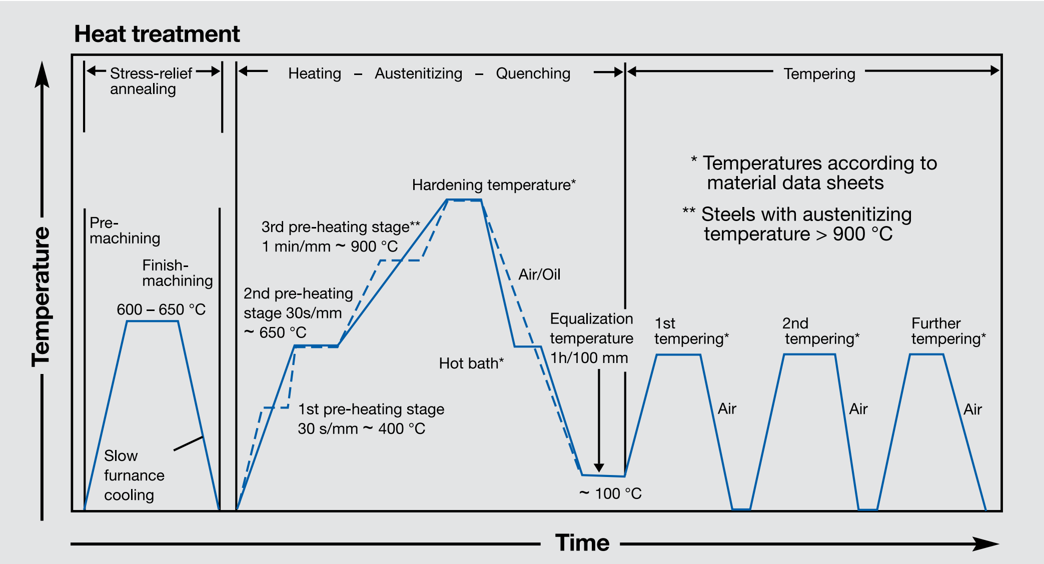
» Clean surfaces thoroughly, grind out cracks in U-shaped fashion
» Thorough pre-heating; pre-heating temperature above martensite formation temperature (see Ms line for time-temperature transformation diagram in the material sheet) in order to avoid microstructural transformations during welding
» High-alloy steel: pre-heat to 350 to 450 °C
» Weld (with intermediate heating if necessary)
» Use electrodes corresponding to the main material
» The TIG welding method has the advantage of a fi ner microstructure as it involves less heating and a higher cooling rate than covered welding electrodes.
» In order to minimize deformation, relatively large areas should be welded in fields during deposition and then joined together later. The welding bead should be hammered to reduce shrinkage.
» Cool the tools to approx. 80 to 100 °C after the welding process.
» Heat to annealing temperature immediately afterwards and soft-anneal (annealed tools) or heat to approx. 50 °C below the original tempering temperature and then temper (tempered steel grades).

Heat treatment

The potential of a steel is only fully exploited by means of heat treatment adapted to the steel composition, the intended use and the component size. Incorrect heat treatment may impair the functionality and the properties of a tool. Toughness may be considerably reduced by a coarse hardening microstructure despite achieving the required hardness. Extensive research and practical studies have helped further develop and improve heat treatment processes. The furnace units used for heat treatment today are primarily inert gas, chamber, fluidized bed, and vacuum furnaces. Despite their excellent flexibility, salt bath systems are no longer common due to stricter environmental protection regulations. The material data sheets contain time-temperature transformation diagrams (TTT diagrams) for continuous cooling to allow for a better understanding of the transformation processes occurring during hardening.

Advantages and disadvantages of various heat treatment systems

Properties System	Salt bath	Chamber furnace	Fluidized bed furnace	Inert gas furnace	Vacuum furnace
Heat transfer	● ● ●	● ●	● ● ●	● ●	●
Flexibility	● ● ●	● ●	● ● ●	● ●	●
Deformation problems	● ●	● ● ●	● ●	●	●
Surface treatment	●	●	●	●	○
Partial hardening/tempering	●	●	○	○	○
Environmental pollution	● ● ●	●	● ●	● ●	●
Prevention of undesirable surface effects	● ●	○	● ●	● ●	● ● ●
Cleaning of tools	○	○	●	● ●	● ● ●



Stress-relief annealing

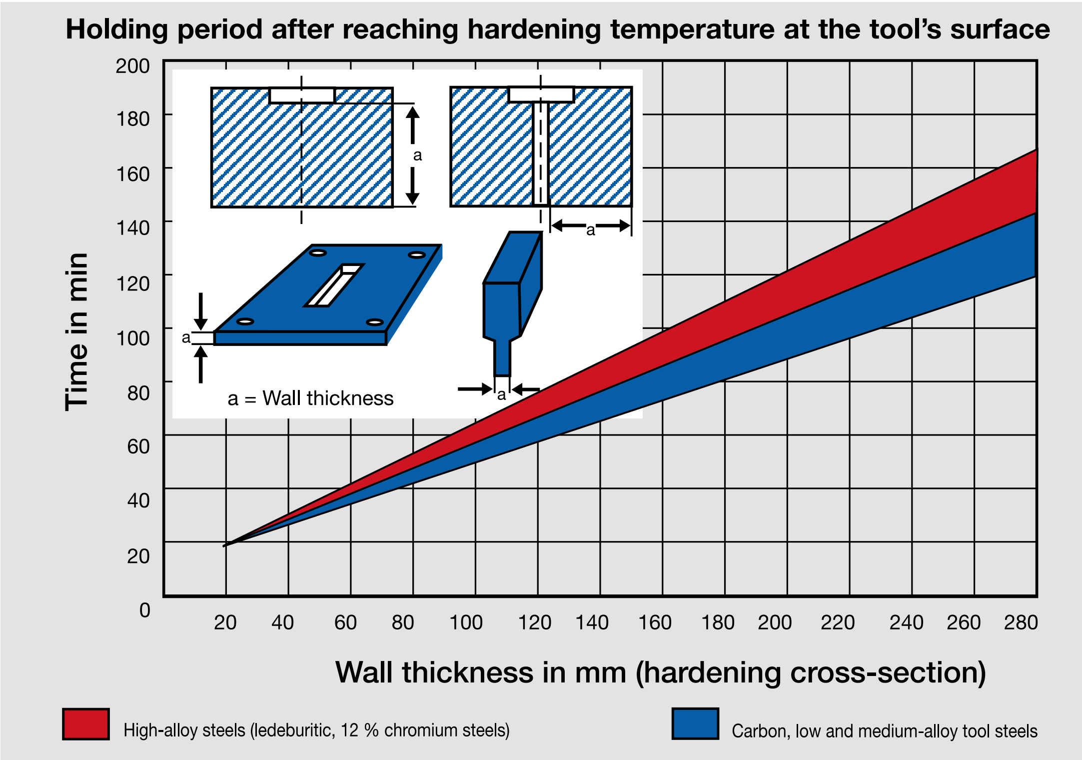
Machining stresses occur during metal cutting and non-cutting shaping. These stresses may result in deformation and possibly expensive reworking in the course of subsequent heat treatment. Stress-relief annealing should be performed at a temperature of 600 to 650 °C after initial machining, especially for tools with a complex geometry. The holding time at this temperature should be at least two hours or at least one hour per 50 mm wall thickness for larger tools. The tool must then slowly cool down in the furnace. This stress-relief annealing should also be performed on heattreated steels, in which case the temperature must be 50 °C below the last tempering temperature in order to avoid a drop in hardness.

Hardening

Heating

As a result of low thermal conductivity and different tool cross-sections, considerable thermal stresses occur in the event of rapid heating to hardening temperature. These stresses may cause the tools to deform or even crack. Certain pre-heating stages indicated in the time-temperature sequences in the material data sheets must be observed. The holding time at the temperature is 30 seconds per mm wall thickness for the first and the second pre-heating stage.
For high-alloy steel with a hardening temperature of more than approx. 900°C, the third pre-heating stage at around 850 °C also serves the purpose of dissolving part of the carbides in addition to the reasons already mentioned.

The holding time at this temperature is thus one minute per mm wall thickness – twice as long as the second pre-heating stage.



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EL379500/1
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61363/1
9480,-kg
2343/856900
970x310x4030
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Schmolz+Bickenbach Malaysia
SSS, EWK, HBW, C, 6034
Malaysia
VPE:469022
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61972/1
4850,-kg
2344 Chg.856820
42460/1
7180 Kg
2085
EL-375661 1/1

Austenitizing

After the last pre-heating stage, the tools are brought up to hardening temperature listed in the material data sheets. After thorough heating (temperature equalization), they must be kept at this temperature to ensure complete transformation. The diagram provides reference values, which help in selecting the time after reaching the hardening temperature on the tool surface in relation to the wall thickness. The immersion times in the salt bath may be determined from the diagram as well.

Quenching

Quenching the tools is the most critical phase of the heat treatment process. There is a risk of hardness tension cracks developing as a result of thermal and microstructural transformation stress. Design-related factors promoting cracking are abrupt material transitions, different wall thicknesses (webs), and large hardening cross-sections. For the material, it would be ideal to aim for cooling to be as quick as possible in order to achieve a purely martensitic transformation. However, compromises are necessary due to the risk of cracking addressed earlier. Those compromises must be coordinated between the steel manufacturer, the heat treatment company, and the toolmaker for each individual case. The quenching medium for each steel grade is indicated in the respective material data sheets. In hot bath hardening, the workpieces remain in the hot bath until the temperature has adjusted and are then cooled further in the air. Quenching to room temperature should always be avoided due to the risk of stress cracking. It is more advisable to cool the tools to approx. 80 °C, possibly hot wash them, and then transfer them into an equalization furnace.

Equalization

Once the tools have been quenched to 80 °C, they are transferred directly to a furnace with a temperature of 100 to 150 °C. Especially the large tools are held at this temperature in order to equalize the temperature across the entire cross-section and achieve optimum transformation in the core as well.

Tempering

Tempering is necessary in order to achieve an appropriate hardness and toughness necessary for the intended service requirement. Tempering must be performed immediately after quenching and equalizing to prevent tension cracks. The tools are slowly heated to the required tempering temperature. These temperatures depend on the desired working hardness and may be found in the tempering diagram of the material data sheet. The holding time at tempering temperature is 1 hour per 20 mm wall thickness, the minimum being two hours. The tools are then cooled in air and their hardness is tested.

Surface treatment

Processes

With the help of surface treatment processes, the tool steel properties in surface areas may be modified and the tool service lives thus be extended. The processes may be divided into coating and diffusion processes.

Nitriding

Nitriding has become the most important of all known surface treatment processes for tools. Before nitriding, the tools must be heat-treated and tempered at a temperature above the subsequent nitriding temperature. Steel grades delivered in tempered condition must be stress-relief annealed at 600 to 650 °C after initial machining in order to prevent deformation during the subsequent nitriding process. Due to the thinness of the nitrided layer, the tools can generally not be reground.

Before nitriding, the tools must be cleaned and degreased. Nitriding may be performed in a salt bath, gas, or plasma. Layer thicknesses of up to 0.5 mm are achieved, and the hardness of nitrided surfaces is up to 1100 HV (approx. 70 HRC) depending on the steel composition.

Bath nitriding

For bath nitriding or the Tenifer treatment, it is essential to observe the following: Tools must first be pre-heated to 400 °C. Bath nitriding is performed at a temperature between 520 and 570 °C. The holding time depends on the desired depth of nitriding but is generally two hours.

Gas nitriding

Gas nitriding is performed at 480 to 540 °C. The nitriding time required for tools in this process is generally between 15 and 30 hours. By partially covering certain areas with a coating of copper, nickel, or pastes, these areas can be excluded from the nitriding treatment, thus achieving partial nitriding.

Plasma nitriding

Plasma nitriding is a thermo-chemical process. Treatment is carried out in vacuum plants, into which treatment gases containing nitrogen are fed. A plasma state is created by an electrical field. This generates electrically charged nitrogen ions. These ions are then accelerated towards the workpiece and can then diffuse into the surface. Treatment temperatures range from 400 to 600 °C in this process.

Processes	Treatment temperatures in °C	Prerequisites and properties required of the tool steel	Layer thickness	Surface hardness in HV
Nitriding	470 – 570	tempering resistance, hardened or tempered state, depassivated surface	up to 0.5 mm	max. 1100
Boriding	800 – 1050	sensitivity to overheating, lowest possible Si content	up to 0.4 mm	max. 2000
Oxidizing	300 – 550	tempering resistance, degreased surfaces	up to 0.01 mm	–
Spark deposition	several 1000	none	up to 0.1 mm	approx. 950
Hard material coating (e.g. TiN, TiCN, CrN etc.)	> 900	sensitivity to overheating, shiny metallic surfaces	6 – 9 µm	approx. 4800
Hard material coating (e.g. TiN, TiCN, CrN etc.)	approx. 500	tempering resistance, high basic hardness	2 – 5 µm	2000 – 2500
Hard nickel plating Hard chromium plating	50 – 70	owest possible C content, de-passivated surface, heat treatment in neutral environment	up to 1 mm	1000 – 1200

Hardness comparison table

Tensile strength	Brinell hardness		Vickers hardness	Rockwell hardness		
R_m MPa	Ball indentation mm Ø	HB	HV	HRB	HRC	HR 30 N
255	6.63	76.0	80	–	–	–
270	6.45	80.7	85	41.0	–	–
285	6.30	85.5	90	48.0	–	–
305	6.16	90.2	95	52.0	–	–
320	6.01	95.0	100	56.2	–	–
335	5.90	99.8	105	–	–	–
350	5.75	105	110	62.3	–	–
370	5.65	109	115	–	–	–
385	5.54	114	120	66.7	–	–
400	5.43	119	125	–	–	–
415	5.33	124	130	71.2	–	–
430	5.26	128	135	–	–	–
450	5.16	133	140	75.0	–	–
465	5.08	138	145	–	–	–
480	4.99	143	150	78.7	–	–
495	4.93	147	155	–	–	–
510	4.85	152	160	81.7	–	–
530	4.79	156	165	–	–	–
545	4.71	162	170	85.0	–	–
560	4.66	166	175	–	–	–
575	4.59	171	180	87.1	–	–
595	4.53	176	185	–	–	–
610	4.47	181	190	89.5	–	–
625	4.43	185	195	–	–	–
640	4.37	190	200	91.5	–	–
660	4.32	195	205	92.5	–	–
675	4.27	199	210	93.5	–	–
690	4.22	204	215	94.0	–	–
705	4.18	209	220	95.0	–	–
720	4.13	214	225	96.0	–	–
740	4.08	219	230	96.7	–	–
755	4.05	223	235	–	–	–
770	4.01	228	240	98.1	20.3	41.7
785	3.97	233	245	–	21.3	42.5
800	3.92	238	250	99.5	22.2	43.4
820	3.89	242	255	–	23.1	44.2
835	3.86	247	260	(101)	24.0	45.0
850	3.82	252	265	–	24.8	45.7
865	3.78	257	270	(102)	25.6	46.4
880	3.75	261	275	–	26.4	47.2
900	3.72	266	280	(104)	27.1	47.8
915	3.69	271	285	–	27.8	48.4
930	3.66	276	290	(105)	28.5	49.0
950	3.63	280	295	–	29.2	49.7
965	3.60	285	300	–	29.8	50.2
995	3.54	295	310	–	31.0	51.3
1030	3.49	304	320	–	32.2	52.3
1060	3.43	314	330	–	33.3	53.6
1095	3.39	323	340	–	34.4	54.4

Conversion of hardness values using this table is only approximate. See DIN 50150, December 1976.

Tensile strength	Brinell hardness		Vickers hardness	Rockwell hardness		
R_m MPa	Ball indentation mm Ø	HB	HV	HRB	HRC	HR 30 N
1125	3.34	333	350	–	35.5	55.4
1155	3.29	342	360	–	36.6	56.4
1190	3.25	352	370	–	37.7	57.4
1220	3.21	361	380	–	38.8	58.4
1255	3.17	371	390	–	39.8	59.3
1290	3.13	380	400	–	40.8	60.2
1320	3.09	390	410	–	41.8	61.1
1350	3.06	399	420	–	42.7	61.9
1385	3.02	409	430	–	43.6	62.7
1420	2.99	418	440	–	44.5	63.5
1455	2.95	428	450	–	45.3	64.3
1485	2.92	437	460	–	46.1	64.9
1520	2.89	447	470	–	46.9	65.7
1555	2.86	(456)	480	–	47.7	66.4
1595	2.83	(466)	490	–	48.4	67.1
1630	2.81	(475)	500	–	49.1	67.7
1665	2.78	(485)	510	–	49.8	68.3
1700	2.75	(494)	520	–	50.5	69.0
1740	2.73	(504)	530	–	51.1	69.5
1775	2.70	(513)	540	–	51.7	70.0
1810	2.68	(523)	550	–	52.3	70.5
1845	2.66	(532)	560	–	53.0	71.2
1880	2.63	(542)	570	–	53.6	71.7
1920	2.60	(551)	580	–	54.1	72.1
1955	2.59	(561)	590	–	54.7	72.7
1995	2.57	(570)	600	–	55.2	73.2
2030	2.54	(580)	610	–	55.7	73.7
2070	2.52	(589)	620	–	56.3	74.2
2105	2.51	(599)	630	–	56.8	74.6
2145	2.49	(608)	640	–	57.3	75.1
2180	2.47	(618)	650	–	57.8	75.5
–	–	–	660	–	58.3	75.9
–	–	–	670	–	58.8	76.4
–	–	–	680	–	59.2	76.8
–	–	–	690	–	59.7	77.2
–	–	–	700	–	60.1	77.6
–	–	–	720	–	61.0	78.4
–	–	–	740	–	61.8	79.1
–	–	–	760	–	62.5	79.7
–	–	–	780	–	63.3	80.4
–	–	–	800	–	64.0	81.1
–	–	–	820	–	64.7	81.7
–	–	–	840	–	65.3	82.2
–	–	–	860	–	65.9	82.7
–	–	–	880	–	66.4	83.1
–	–	–	900	–	67.0	83.6
–	–	–	920	–	67.5	84.0
–	–	–	940	–	68.0	84.4

Processes and process parameters		
Brinell hardness[1] ([1] calculated from: HB = 0.95 · HV) (0.102 F/D^2 = 30) D = 10	Diameter of ball indentation in mm Hardness value = $\frac{0.102 \cdot 2F}{\varpi D(D - \sqrt{D^2 - d^2})}$	d HB
Vickers hardness	Diamond pyramid Test forces ≥ 50 N	HV
Rockwell hardness	Kugel 1.588 mm (1/16") Total test force = 98 N Diamond cone Total test force = 1471 N Diamond cone Total test force = 294 N	HRB HRC HR 30 N

General note (liability)

All statements regarding the properties or utilization of materials or products mentioned are solely for the purpose of description. Guarantees regarding the existence of certain properties or a certain application require a special agreement in writing. Misprints, errors, or modifi cations are expected.

Swiss Steel Group
www.swisssteel-group.com

Deutsche Edelstahlwerke
Specialty Steel GmbH & Co. KG

Auestr. 4
58452 Witten
GERMANY

Phone: +49 (0)2302 29 - 0
Fax: +49 (0)2302 29 - 4000

info@dew-stahl.com
www.dew-stahl.com

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