WELDING IN TOOL MAKING

A guideline for welding of cold work steels, hot work steels, high speed steels, plastic mould steels including PM steels

MATERIALS IN TOOL MAKING

Contents

Introduction

Tools often need to be welded. This is especially true for expensive tools such as die-casting dies, large forging dies, plastic moulds, car body dies and cutting and forming tools where repair and adjustment via welding is a highly cost-attractive and economic alternative to the expense of producing new tools. Welding of tools may be required for the following reasons:

- Refurbishment and repair of cracked or worn tools
- Renovation of worn or chipped cutting edges, e.g. on cutting tools
- Adjustment of machining errors
- Design changes.

The weldability of steels with high carbon content is usually considered to be poor. Tool steels with 0.3 – 2.5% carbon are difficult to weld due, for instance, to their alloying elements. The main problem in welding tool steel stems from its high hardenability. Thermal stresses concurrent with microstructure transformation occur during the cooling of the weld. This transformation may generate cracks in the welded area. Such reductions in the weld's properties should be avoided if welds are to comply with quality requirements.

This brochure mainly gives technological directions on welding equipment, welding consumables, welding technique, heat treatment and subsequent thermal treatments that are required in order to weld tool steels and plastic mould steels successfully. We also give welding recommendations concerning materials in connection with UTP weld consumables for the performance of repair welds and adjustments in tool making.

This brochure was written in cooperation with UTP Schweißmaterial GmbH.

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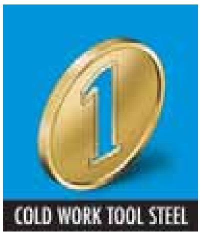
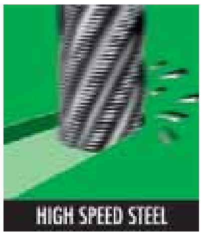
Tool making mainly uses tool steels which can be divided into cold work steels, hot work steels, high speed steels and plastic mould steels according to DIN EN ISO 4957:1999.

Tool steels





Tool steels are ferrous materials which are suitable for hardening. Hardening mechanisms generally stem from transformation hardening i.e. martensite formation and partly from precipitation hardening by the formation of carbides and nitrides. Cooling rate required to achieve a specific hardness is shown in time-temperature-transformation graphs. Tool steels have high hardness, high wear resistance and toughness which all comply with their specific application.

Cold work steels are unalloyed or alloyed steels used in applications with a general surface temperature below approximately 200 °C.

Hot work steels are alloyed steels for applications with a general tool surface temperature above 200 °C when in service.

High speed steels have the highest hot hardness and tempering resistance due to their chemical composition and are, therefore, used at temperatures up to 600 °C (they are mainly used in machining and forming).

Plastic mould steels are used in the manufacturing of forming and shaping tools in plastic processing. The preferred steels here are unalloyed steels, case-hardened steels or tool steels. Plastic mould steels excel in two categories: They ensure the highest steel quality and their steel properties can be adjusted individually and ideally to the different requirements of the tool and the plastic product in question. Plastic mould steels satisfy the highest requirements as regards degree of purity, polishability, uniform hardness and microstructure, wear resistance, temperature resistance, machinability, toughness and hardness and not to forget thermal conductivity and corrosion resistance.

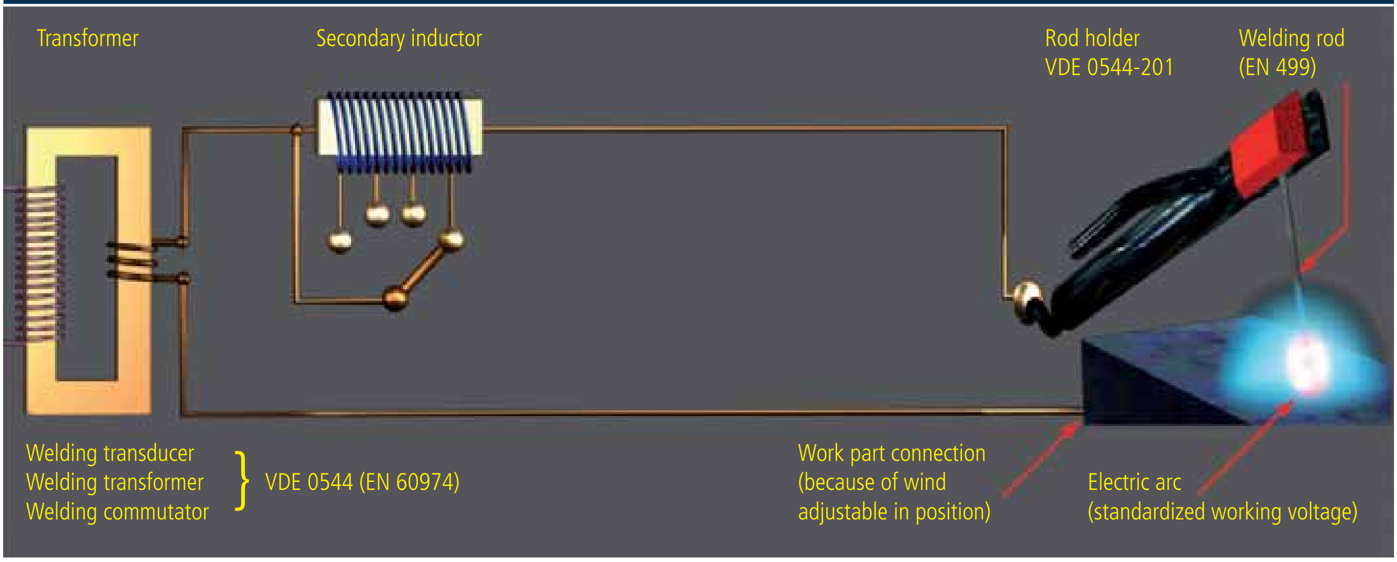
Welding methods used

Manual arc welding

An electric arc is struck between a coated electrode and the workpiece. Contamination by air during the transfer of molten drops from electrode to workpiece in the weld pool, and during solidification of the weld pool, is inhibited by slag and by inert gas created during melting of the electrode. The composition of the weld metal deposit is controlled via the composition of the consumables in the bead wire and in the electrode coating.

For manual electric arc welding, it is possible to use either an AC or a DC generator. However, which ever is used, the generator must provide a voltage and current which is compatible with the chosen electrode.

Procedure of manual arc welding



More then 50 different electrodes are available for the repair of tools. Rutile (Ti-oxide) electrodes or basic coated electrodes are made use of depending on the requirements.

Rutile coated electrodes have a stable and soft spray arc and enable welding with low amperage. The resulting even welding bead is ideal for the welding of cutting edges. The slag comes off on its own. Mechanical weld quality ranges from good to very good. But note that the mechanical weld quality will not reach that of a basic coated electrode.

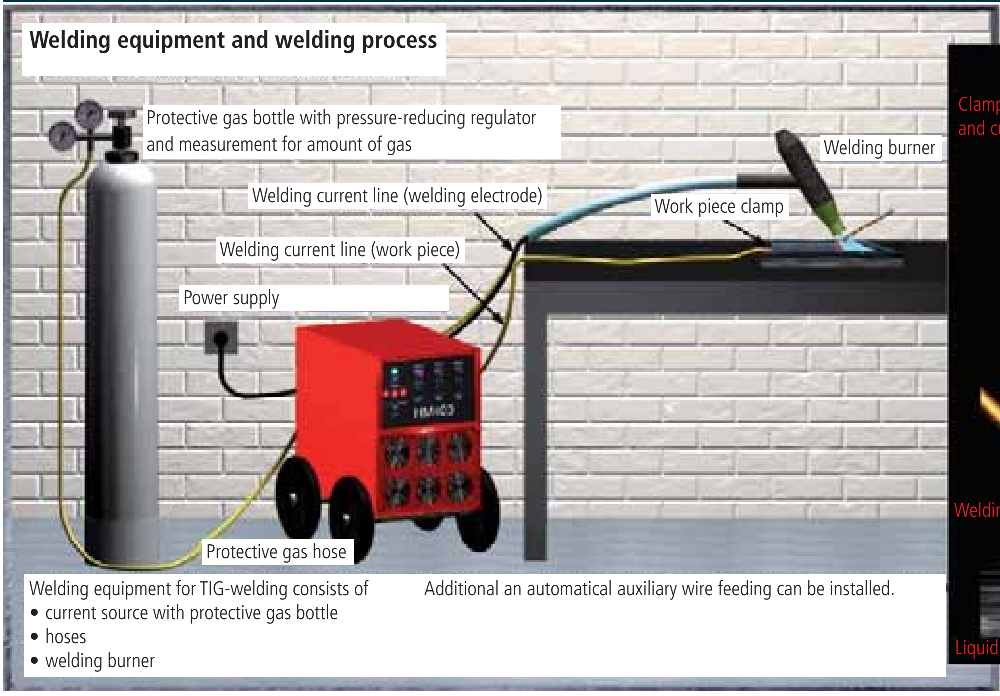
Basic coated electrodes have a more intense arc, stronger arcing and higher coating. Welds do not appear as finely flaked as with rutile coated electrodes. The slag needs not be removed at multi-run welding, which is an advantage when larger welding jobs are performed. Weld metal deposit having superior toughness can achieve hydrogen contents of < 5 ppm.

TIG welding

In TIG welding, the arc is initially struck by subjecting the tungsten electrode and the workpiece under an inert-gas coating (argon) to a high-frequency voltage. The resulting ionization of the gas between electrode and workpiece means contact is unnecessary between electrode and workpiece.

The welding rod, a necessary weld consumable, is moved in the arc at an angle and is consumed during welding without any flow of current. Oxidation of the weld metal deposit is prevented by an inert-gas coating.

Procedure of TIG welding



TIG welding can be performed with a regular electric arc welding power generator provided it is complemented with a TIG control unit. The tungsten electrode is always connected to the negative terminal of a DC generator in order to minimize heat generation and thereby any risk of melting the electrode. Welding is facilitated if the current can be increased progressively from zero to the optimum level. The unit should have a foot switch with which current can be reduced and controlled exactly. The inert-gas should be argon with a purity of 99.996 vol%.

TIG welding is particularly applied in repairs of small tools. It is advantageous when complicated cutting edges and dies are to be repaired. If small tungsten electrodes are used, heat can accumulate better. And weld metal can be deposited better without influencing the basic steel too much as regards heat and minimizing distortion.

MIG/MAG welding and flux cored arc welding

An endless and mostly positive wire electrode is fed via a wire feeder to the arc and melted under inert-gas (MIG) or active gas (MAG). The power source has a flat load curve and specific welding properties. Different arcs ban be formed by changing the amperage of the power source. The table below gives an overview of properties and informs on applications of different arcs. In general, wires of 1.2 mm or 1.6 mm are used.

Procedure of MIG/MAG welding

The MIG/MAG welding equipment consists of:

1. Welding current source with power supply welding line
2. Wire electrode feeding with wire coil and wire feeding equipment
3. Protective gas feeding with measurement for ammount of protective gas
4. Control unit
5. Hoses with welding burner

Electric arcs in conventional MIG/MAG welding

Electric arc	Application	Material transition	Spattering	Remarks
MIG/MAG dip-transfer arc	thin sheets, out-of-position welds, root welding	in short circuit, with thick droplets	low, with appropriate power source	low heat input, low melting deposition rate
MIG/MAG intermediate arc	medium sheet thickness, out-of-position welds	material transition partly in short circuit	partly spatter-prone on workpiece	medium rate
MIG/MAG spray arc	medium and high sheet thickness in position PA, PB	material transition with thin droplets and without any short circuits	low	high melting deposition rate
MAG long arc	medium and high sheet thickness in position PA, PB	material transition partly in short circuit	partly spatter-prone on workpiece	high melting deposition rate
MIG/MAG impulse arc	large working area	without shortening, 1 droplet per impulse	very low	higher heat input than in dip-transfer arc

MIG/MAG welding is widely used in economic welding of large volumes of weld metal in the metal processing industry. Typical applications in tool making are the following: armoring of large shearing knives made of unalloyed steels, flux cored welding of forging dies or shaping thereof and build-up welding of rolls.

Flux cored electrodes are simple a metal tube with welding powder. Following their fillers, flux cored electrodes are divided into rutile, basic and metal powder electrodes. Gas-shielded flux cored wires need an inert-gas shielding having the same quality than solid core electrodes. Self-protective flux cored electrodes have a core with a high content of gas-forming substances (MF procedure). A free wiretail of at least 20 mm is necessary so that a sufficient amount of shielding gas can generate. This MF procedure is a big advantage at construction sites because no special shielding is needed in welding. Such wires are more frequently made use of in build-up welding.

A selection of weld consumables

High-quality weld consumables are vital in tool making, since welds in tool applications need to have different properties such as hardness, toughness, wear resistance, temper resistance, heat-checking resistance and oxidation.

The chemical composition of a weld deposit is determined by the composition of the weld consumable, the base steel composition and the extent to which the base material is melted during welding. Since tool steel welds have high hardness, they are particularly susceptible to cracking which may originate as slag particles or pores. Hence, the consumable used should be capable of producing a high-quality weld free from any non-metallic inclusions, porosity and cracks.

In general, the welding consumable used for tool steels should be similar in composition to the base material. When welding in the annealed condition, e.g. if a mould or die has to be adjusted while in the process of manufacture, it is vital that the consumable has the same heat treatment characteristics as the base steel, otherwise the welded area in the finished tool will have different hardness. Large compositional differences are also associated with an increased cracking risk in connection with hardening. TIG welding rods and MIG/MAG filler rods which are normally produced from electro-slag remelted stock will comply with the corresponding tool steel grades. For manual welding, basic electrodes are used, which are superior to rutile electrodes as regards weld cleanliness. Another advantage with basic electrodes is that they give a much lower hydrogen content in the weld metal.

Preparation prior to welding

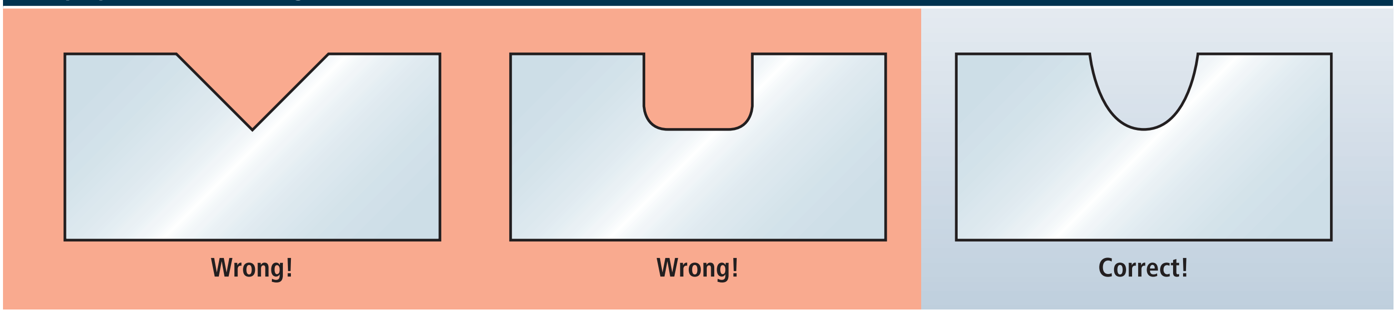
The importance of careful preparation prior to welding of tools can not be over-emphasized. First of all determine whether a workpiece is suitable for welding. It is necessary to know whether the workpiece is in a soft annealed or heat-treated (hardened and then tempered) condition. Note that tools which are hardened by quenching and did not have any further thermal treatment after that (i.e. no tempering) cannot be welded at all.

Furthermore, tools should not have any cracks. Non-destructive dye penetrant tests are often performed in this case. Cracks should be ground out properly so that the joint bottom is rounded off and the joint slope is at an angle of at least 30° to the vertical. The width of the joint bottom should be at least 1 mm greater than the maximum electrode diameter which will be used.

Erosion or heat-checking damage on hot work tools should be ground down to steel free from any defects. Prior to starting welding, the ground areas should be checked with fluorescent penetrant to make sure all defects have been removed.

Then properly clean the area to be welded and its surrounding surface. Make sure that there are no penetrant, oil or fatty residues left. If the workpiece is not properly cleaned it may be susceptible to cracking during or after welding due to hydrogen embrittlement. Hydrogen embrittlement is caused by the ingress of hydrogen during welding and by solidification of a typical high hardened martensitic and bainitic microstructure in the heat-affected zone and in the weld metal deposit.

Joint preparation for welding of tools



The tool should be welded immediately after joint preparation and cleaning are finished, because otherwise there is a risk of contamination of the joint surfaces with dust, dirt or moisture. Besides the proper cleaning of the welding area make sure the hydrogen ingress is reduced during welding and hence hydrogen embrittlement by always storing coated electrodes in a heated dry cabinet or heated container once the pack has been opened. For welding outside the welding bay, it will also be found useful to have a portable heated container in which the electrodes can be carried. It is recommended to re-dry moistened electrodes (Ask for more information at UTP in Bad Krozingen, Germany.).

Working temperature before and during welding

Additional measures need to be taken at room temperatures below + 5 °C:
Cover all components, heat areas extensively, preheat particularly when welding at relatively low heat input (energy input per unit length) such as with thin fillet welds or else at rapid heat removal such as with thick-walled components. It is generally necessary to preheat the steels before any welding can be attempted. This necessity and the preheating temperature depend on several factors (complexity of components, welding method used, room temperature). Such factors are given in the table below.

Influences on preheating temperature

Preheating temperature is being decreased	Influences on preheating	Preheating temperature is being increased
small	workpiece or component thickness, heat removal, stiffness, internal stress condition	big
butt joints, thick (multi-run) welds	joint type, weld shape and size	T-joints, thin (one layer) welds
high	room or workpiece temperature	low
high	heat input (energy input per unit length) during welding	low
low	hydrogen content of weld metal (type and re-drying of weld consumables)	high

Please note preheating and filler recommended by tool manufacturers when you perform tool repairs. Materials having a high chromium and tungsten content should be preheated slowly in order to avoid cracks derived from stresses caused by low heat conductivity.

The basic reason for welding tool steels at elevated temperature derives from the high hardenability and, therefore, crack sensitivity of weld deposits and heat-affected zones. Welding of a cold tool will cause rapid cooling of the weld metal and heat-affected zone. The resulting transformation to brittle martensite leads to a higher risk for cracking. Cracks formed in the weld could well propagate through the entire tool if this is cold. During multi-run welding of a properly preheated tool at the correct temperature, most of the weld will remain austenitic under the entire welding operation and will transform slowly as the tool cools down. This ensures a uniform hardness and microstructure over the whole weld.

Hence, the mould or tool should during welding be maintained at 50 – 100 °C above the MS-temperature (austenite-martensite-start temperature) for the steel in question; note that, strictly speaking, the critical temperature is the MS of the weld metal, which may not be the same as that of the base metal. In some instances, it may be that the base steel is fully hardened and has been tempered at a temperature below the MS-temperature. Hence, preheating the tool for welding will cause a drop in hardness. For example, this is true for most low-temperature tempered cold work steels (ca. 200 °C). The hardness drop must be accepted in order to perform a proper preheating and mitigate the risk for cracking during welding.

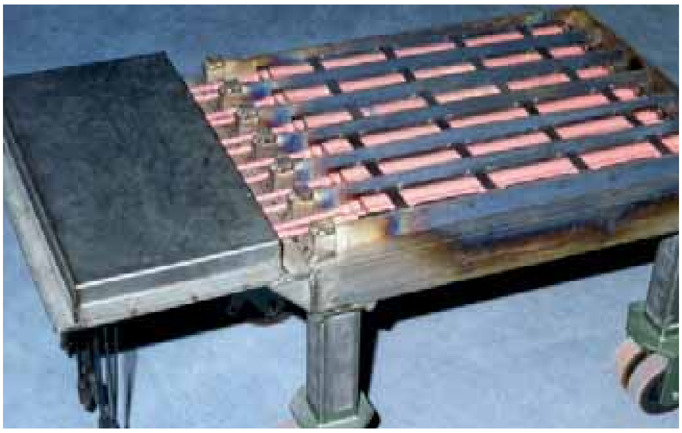
The entire welding operation should be completed while the tool is hot. Partially welding, letting the tool cool down and then preheating later on to finish the job is not to be recommended because there is considerable risk that the tool will crack. Minimum preheating temperature corresponds with filler runs temperature and it must not drop below it during the entire welding job. It must be higher than the temperature of martensite forming (see martensite line in time-temperature-transformation graph).

In the event that cutting tools are being repaired note that damaged areas need to be cleaned first. Then they need to be preheated to approximately 150 °C. Such preheating is sufficant for small defects or cracks which do not affect the base steel. If larger defects need to be repaired a preheating temperature of about 450 – 600 °C is required. Chromium-molybdenum steels should be preheated to 400 °C when build-up welding is performed, NiCrMo steels require preheating to 300 °C.

Preheating can be done in annealing units and also via mobile heaters such as gas burners or electrical induction or resistance heaters. It is a prerequisite that all prescribed or desired preheating and filler runs temperatures shall be maintained at a constant level and be controlled during the entire welding job. This can be done by means of appropriate devices or aids such as mounted thermometers, temperature sensors or color changing pens. A preheating and heat retaining table supplied from a current-regulated DC source also enables the tool to be heated at a uniform and controlled rate. In order to possibly minimize the cooling rate of preheated components, it is absolutely necessary to cover all components during the welding job. For minor repairs and adjustments, it is acceptable that the tool be preheated using a propane torch. In this case use a torch which produces a soft but not smoking flame avoiding the risk of contamination in the welding area. Avoid local over-heating.

While it is feasible to preheat tools in a furnace, there is the possibility that the following four problems arise:

- The temperature in the furnace is not necessarily even (this may create stresses);
- Slow preheating in the furnace can heat the entire tool (up to its core) to the prescribed preheating temperature.
- After removing of the workpiece from the furnace protect it from cooling down by taking appropriate measures.
- The temperature may drop excessively before welding is completed (especially if the tool is small). The tool needs to be preheated again.



Preheating and heat retaining table for welding of tools

Manual arc welding and covering of components

How to perform the welding

It is particularly important during critical welding operations, of the type performed with tool steel, that the welder enjoys a comfortable working position. Hence, the workbench should be stable, of the correct height and sufficiently level that the work to be welded can be positioned securely and accurately. It is advantageous if the workbench is rotatable and vertically adjustable.

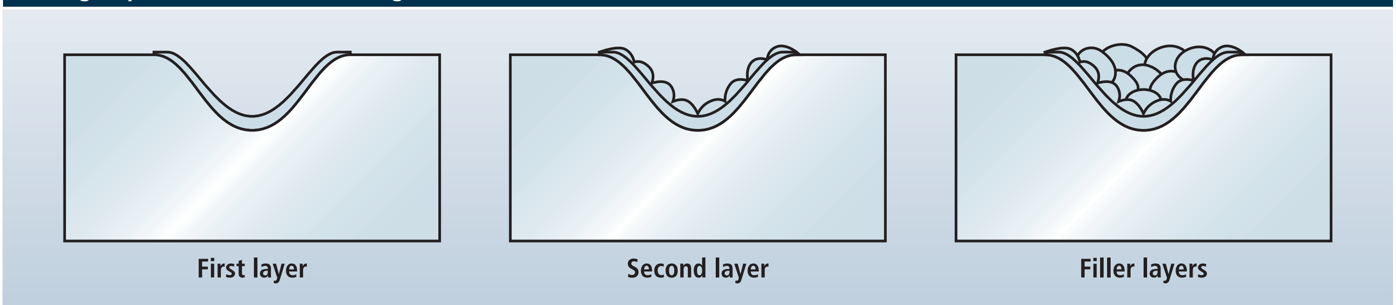
In welding of tool steels it is equally necessary to preheat, and to provide for filler runs, temperature as well as to control heat input or energy input per unit length. Too high a heat input results in a possible deformation and higher internal stresses after welding is completed and also in a too low cooling rate, hence risk of undesired grain growth or grain coarsening in the weld metal deposit.

In general, welding is performed under minimum energy input per unit length. Be aware of the correct setting of all welding parameters to ensure appropriate heat input and of using multi-run welding with components of higher thickness. It is advantageous to make use of a smaller electrode diameter which reduces the overall heat input. In manual arc welding, the first layer should be made with smaller diameter electrodes (max. 3.25 mm Ø). In TIG welding, do not use amperage exceeding 120 A. All subsequent layers are made upon already existing weld metal. The second layer is made with the same electrode diameter and current as the first layer in order that the heat-affected zone is not too extensive. The idea here is that any hard, brittle microstructures, which may form in the base-material heat-affected zone of the first layer, will be tempered by the heat from the second layer and the propensity to cracking will thereby be reduced. Filler layers can be welded with a higher current and larger-diameter electrodes. The final runs should be built up at least 1.5 to 2 mm above the surface of the tool in order to be able to treat them mechanically and grind them. Even small welds should comprise a minimum of two runs.

Generally tool steels are used at high hardness, so it is advisable to use a soft electrode for the initial layers and finish with a hard electrode. This procedure will produce a tougher weld than if the harder electrode had been used throughout. Tool steels which are sensitive to cracking are welded with short stringer beads. Electrodes with smaller diameters are used in order to prevent stress cracking caused by contraction. During welding, the arc should be short and the beads deposited in distinct runs. The electrode should be angled at 90° to the joint sides so as to minimize undercut. In addition, the electrode should be held at an angle of 75 – 80° to the direction of forward movement.

The arc should always be struck in the joint and not on any tool surfaces. The position of the first strike of the arc (sore) is a likely location for crack initiation. In order to avoid pores, the starting sore should be melted up completely at the beginning of welding. If a restart is made with manual arc welding, the tip of a partly used electrode should be cleaned free from slag; this assists striking the arc and at the same time a potential source of porosity is eliminated.

Welding sequence at multi-run welding

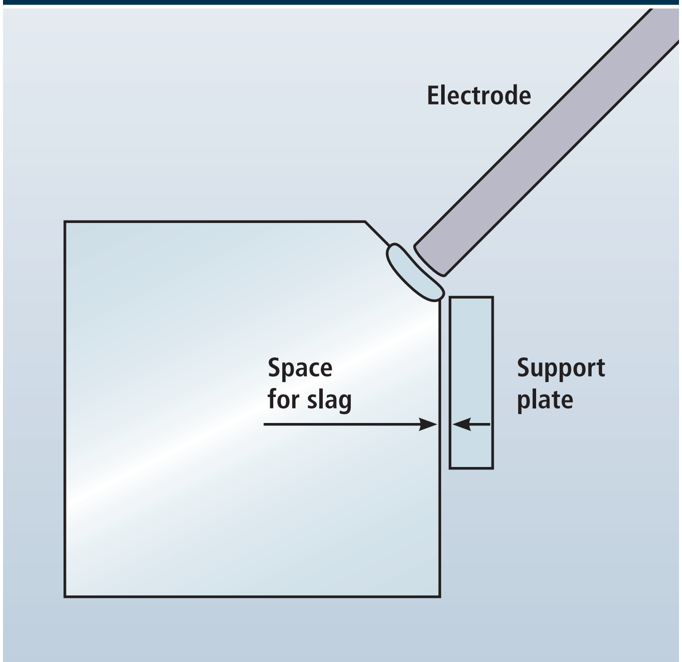


In building up edges or corners, both time and welding consumables can be saved by using a piece of copper plate or graphite as support for the weld metal. Using such support also means that the molten weld deposit is hotter which reduces the risk for pore formation. Low currents need to be used when building up sharp edges or corners. If copper or graphite support is used in manual arc welding, an extra 1.5 mm space must be allowed between the support and the required weld surface because the slag takes up a certain amount of space. The diagram below shows the typical build-up of cutting edges under low and high cutting pressure when weld repairs are performed on cutting tools.

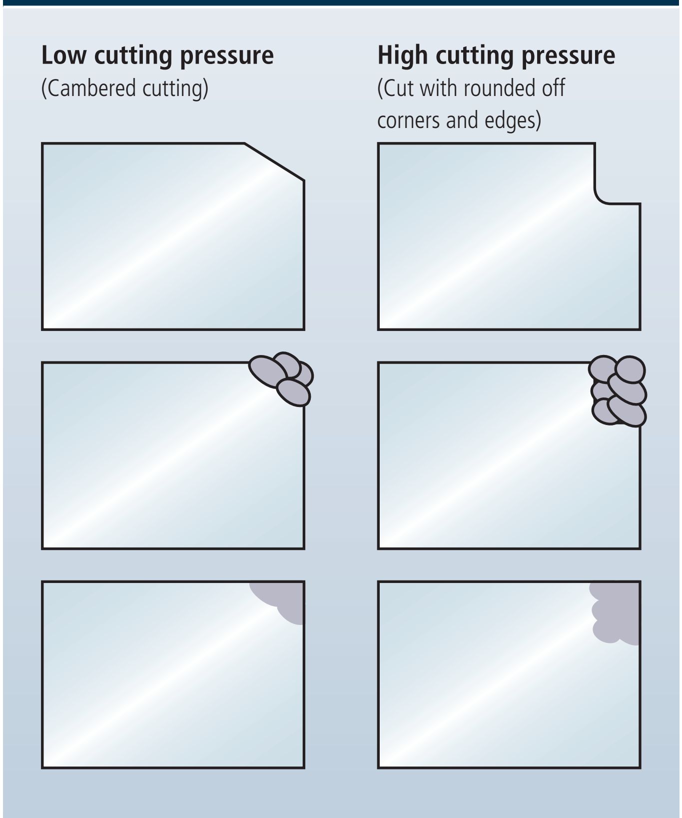
For repair or adjustment of expensive tools, it is essential that there is good contact between the return cable and the tool. Poor contact gives problems with secondary arcing and the expensive surface can be damaged by arcing sores. Such tools should be placed on a copper plate which provides for the best possible contact. The copper plate must be preheated along with the tool. The completed weld should immediately be hammered and carefully cleaned and inspected prior to allowing the tool to cool down. Any defect, such as arcing sores or undercut, should be dealt with immediately prior to cooling down. After the tool has cooled, the surface of the weld should be ground down almost to the level of the surrounding tool before any further processing.

Moulds where welded areas have to be polished or photo-etched should have the final runs made using TIG welding, which is less likely to give pores or inclusions in the weld metal.

Support plate when building up corners and edges



Building up cutting edges with low and high cutting pressure



Heat treatment after welding

Tool steels and plastic mould steels are frequently heat treated after welding is completed in order to modify certain properties. This is particularly true for large welding jobs such as adjustments in shape. Depending on the initial condition of the tool, heat treatments such as soft annealing, tempering and stress relief annealing may be performed. In order to be able to affect satisfactory welding work after the heat treatment, the following directions are given for a functional heat treatment.

Soft annealing

In most cases the soft annealed condition is most functional for machining and cold forming. The soft annealed microstructure is the most beneficial microstructure for hardening. Hence, it is advantageous to soft anneal steels, which were heat-treated before, prior to hardening if they should be heat treated to achieve higher strength. Tools which are welded to accommodate design changes or machining errors during tool making, and which are in soft annealed condition, will need to be heat treated after welding. Since the weld metal will have hardened during cooling following welding, it is highly desirable to soft anneal the tool prior to hardening and tempering of the tool. The soft annealing cycle used is that recommended for the base steel. The welded area can then be machined and heat treated as usual. However, even if the tool can be finished by merely grinding the weld, soft annealing is first recommended in order to mitigate cracking during heat treatment.

Tempering

Tempering gives higher toughness of the hardened component. Fully-hardened tools which are repair welded should if possible be tempered after welding. Tempering improves the toughness of the weld metal. Very small welds can be applied without tempering the tool. The tempering temperature should be chosen specifically that the hardness of weld metal and base steel are compatible. Only when the weld metal exhibits appreciably improved temper resistance over the base material should the weld be tempered at the highest possible temperature. In this case a typical tempering temperature is to be determined which is 20°C under the previous tempering temperature of the base steel.

Heat slowly to achieve tempering temperature. Holding time in the tempering furnace should, all in all, be 1 hour per each 20 mm wall thickness and 2 hours at a minimum. Then let the tool cool down exposed to the air. It is advisable to temper twice in order to equally temper martensite which was formed from remaining austenite after it had first cooled from tempering temperature.

Stress relief annealing

Stress relief annealing is sometimes carried out after welding in order to reduce internal stresses. There are three causes of stressed welds:

- Contraction during solidification of the molten weld metal;
- Temperature differences between weld, heat-affected zone and base steel;
- Transformation stresses when the weld and heat-affected zone harden during cooling.

In general, the stress level in the vicinity of the weld will reach the magnitude of the yield stress of the base steel. Bigger, irregular adjustments in shape after welding may be caused by the stresses altogether. It is very difficult to do anything about these high stresses but the situation can be improved somewhat via proper weld design, welding with minimum energy input per unit length, consistently using stringer bead method, avoidance of excessive welds and sequence of welds.

Very large welds or those which are extremely out of position definitely need to be stress relief annealed. Tool steels which are heat-treated before should be annealed prior to their final mechanical treatment at 550 – 650 °C for 1 to 2 hours since no other heat treatment is performed after welding. Stresses will be alleviated, hence limiting expensive treatment after that on the finished tool. Stress relief annealing shall be performed in the following way: Heat the component slowly and uniformly to the prescribed temperature. Holding time for these areas should, all in all, be 2 minutes per each mm wall thickness and 30 minutes at a minimum. Then let the tool cool down exposed to inactive air. It is advisable not to exceed holding time above 150 minutes with thick-walled components.

If welds are tempered or soft annealed, then stress relief annealing is not normally necessary. Very small weld repairs or adjustments will normally not require a stress relief annealing either.

Examination if BÖHLER K340 ISODUR produced from electro-slag remelted stock and BÖHLER K390 MICROCLEAN produced from powder metallurgy are suitable for welding.

In a practical test, build-up welding was performed on the BÖHLER grade K340 ISODUR (electro-slag remelted 8% Cr cold work steel with optimum toughness) and the BÖHLER K390 MICROCLEAN cutting edges produced from powder metallurgy. The steels in question were hardened and tempered to achieve a hardness of 61 HRC which is typical of their application. The edges of the test plates were chamfered over a width of 5 mm at an angle of 45° for a multi-run building up of edges.

Two sides were built up on each plate by manual arc welding using a UTP rod-like electrode. Rod-like electrodes of the type UTP 73 G2 and UTP 690 were used. Welding was performed with rod-like electrodes with a diameter of 2.5 mm with 50A. The plates were preheated in the furnace to 600 °C. During welding, the temperature was maintained at a temperature of 550 to 600 °C on a heat retaining table. In addition, the test plates were covered with aluminum foil to avoid heat loss.

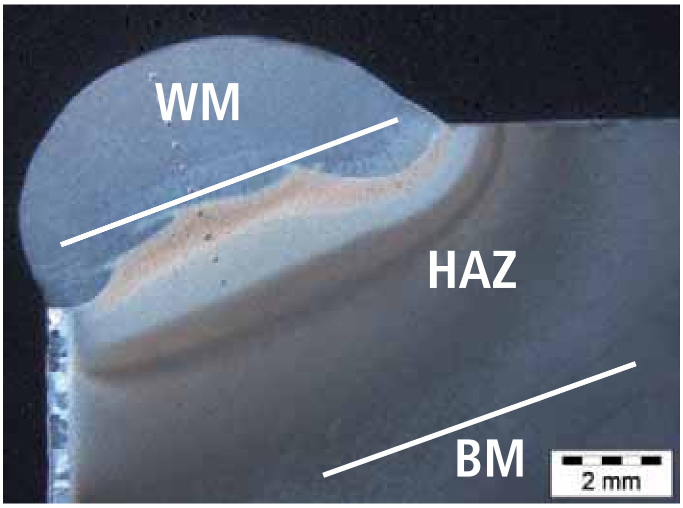
After the welding was completed, the weld was hammered, producing compressive stresses which counteract sensitivity to cracking. Then the furnace was cooled slowly in order to keep internal stresses at a low level. Subsequently, the cutting edge was abraded manually on one side, followed by a surface crack test (dye penetrant test). This test did not come up with any cracks in both materials and both welding electrodes used.

Finally the hardness profile was determined in the weld metal (named “SG” in the pictures), in the transition zone or heat-affected zone (“WEZ”) and in the base material (“GM”). The following diagram shows how UTP electrodes are applied; you will see multi-run welding with the UTP electrode 690 for the BÖHLER grades K340 ISODUR and K390 MICROCLEAN.

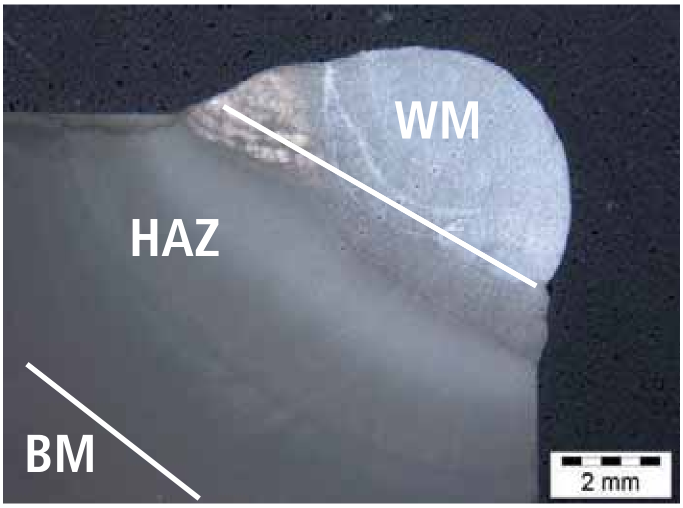
Hardness in the welding zone will reach the magnitude of the hardness of the base steel. In the heat-affected zone, the tempering effect will cause a drop in hardness due to the fact that the weld deposits highly affect temperature.

The base material will show no reduction in hardness after the welding. Furthermore, the fine carbides of the PM steel are not coarsened, either. The second rod-like electrode UTP 73G2 used had the same hardness profile for both materials in question than that of electrode UTP 690.

PRACTICE ORIENTED WELDING TEST WITH VARIOUS DIFFERENT BÖHLER HIGH PERFORMANCE STEELS

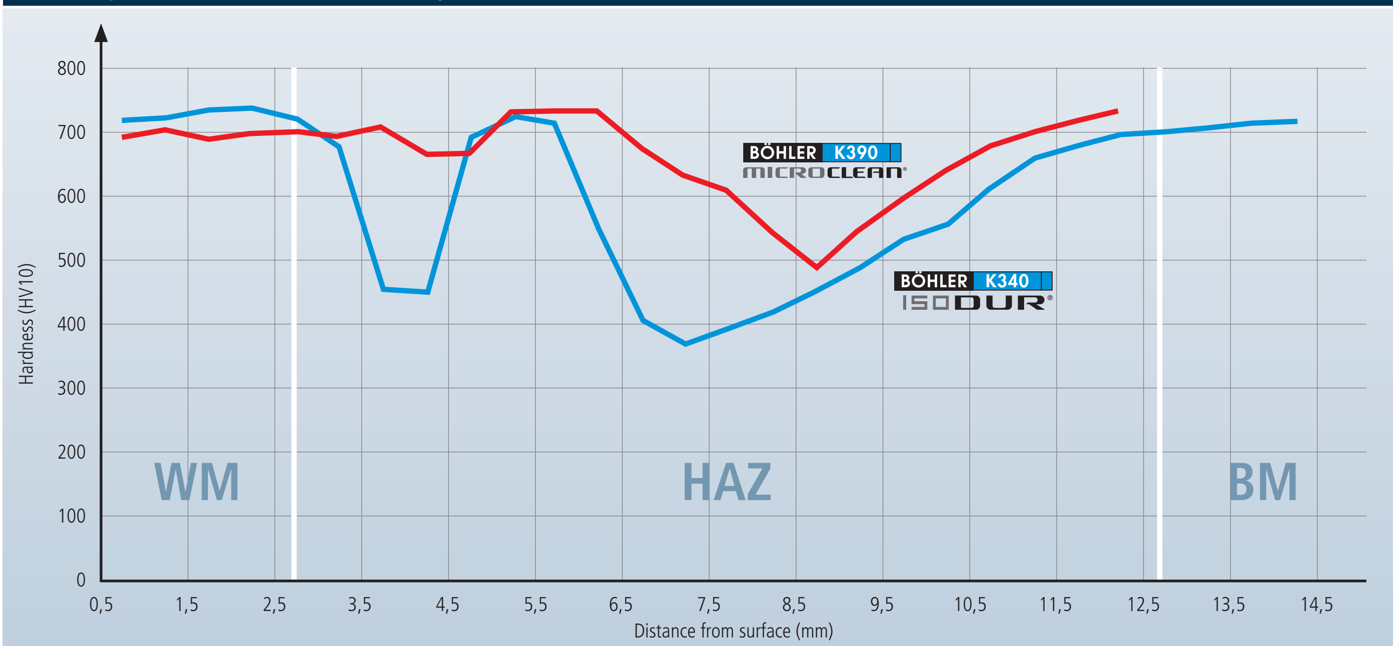


BÖHLER K340 ISODUR, multi-layer, UTP 690



BÖHLER K390 MICROCLEAN, multi-layer, UTP 690

Hardness profile (HV) across weld, multi-layer, UTP 690



WM = weld metal deposit
HAZ = transition zone or heat-affected zone
BM = base material

WELDING RECOMMENDATIONS CONCERNING MATERIALS

The following tables give details concerning weld repair or adjustments of tools or dies made from BÖHLER hot work steels, plastic mould steels, cold work steels and high speed steels. Recommendations were made in cooperation with BÖHLER Edelstahl GmbH & Co KG and UTP Schweiß-material GmbH.

Welding of powder metallurgical materials

BÖHLER has advanced the manufacturing process of powder metallurgical high speed steels and tool steels. The state-of-the-art plant in Kapfenberg, the most modern in the world, produces MICROCLEAN materials in the third generation with ever increased performance features.

High performance steels called BÖHLER MICROCLEAN re-define high performance as regards **toughness, wear resistance, compressive strength** and **corrosion resistance** in a convincing way.

A comprehensive range of cold work, plastic mould and high speed steels provides our customers with a clear competitive edge.

Information concerning welding recommendations for BÖHLER steels produced by powder metallurgy and which are difficult to weld due to their high C content can be obtained from this brochure for the first time.

BÖHLER grade	Standard designation	Tool condition	Welding method	Weld consumables	Hardness as welded	Preheating temperature	Cool-ing	Heat treatment	Remarks
BÖHLER K460 BÖHLER K720	1.2510 100MnCrW4 1.2842 90MnCrV8	heat-treated[5]	LHS[1]	UTP 65 D UTP 67S UTP 73 G2 UTP 673	ca. 220 HB[4] 55 – 58 HRc ca. 58 HRc ca. 58 HRc	200 – 250 °C	[2]	Slow cooling in the furnace or under a blanket.	Initial layers to be welded with soft electrodes for a thick build up. Choose electrodes for finishing layers which give suitable hardness. Weld short stringer beads (ca. 50 – 60 mm) and hammer immediately after.
BÖHLER K455	1.2550 60WCrV7	heat-treated[5]	LHS[1]	UTP 65 D UTP 665 UTP 67S UTP 73 G2	ca. 220 HB[4] 55 – 58 HRc 55 – 58 HRc ca. 58 HRc (for 1-2 layers)	200 – 250 °C	[2]		
BÖHLER K600 BÖHLER K605	1.2767 X45NiCrMo4 ~1.2721 ~50NiCr13	heat-treated[5]	LHS[1]	UTP A 651 UTP A 73 G2 UTP A 73 G3 UTP A 73 G4 UTP A 702	ca. 220 HB[4] 55 – 58 HRc 45 – 48 HRc 38 – 42 HRc ca. 37 HRc	300 – 400 °C	[2]	Very slow cooling.	UTP A 702: 3 – 4h/480 °C cured 50 – 54 HRc
BÖHLER K305	1.2363 X100CrMoV5-1	heat-treated[5]	LHS[1]	UTP 665 – UTP 65 D UTP 67S UTP 73 G2 UTP 673	ca. 55 HRc (for 1-2 layers) ca. 220 HB[4] 55 – 58 HRc 55 – 58 HRc ca. 58 HRc	150 °C (Fast repair) 200 – 250 °C	[2]	Very slow cooling, tempering for 4 h at 500 °C and cooling in the furnace.	Initial layers to be welded with soft electrodes for a thick build up. Choose electrodes for finishing layers which give suitable hardness. Weld short stringer beads (ca. 50 – 60 mm) and hammer immediately after.
BÖHLER K329	– X50CrMoV8-2	heat-treated[5]	LHS[1]	UTP 65 D UTP 67S UTP 73 G2 UTP 673	ca. 220 HB[4] 55 – 58 HRc 55 – 58 HRc ca. 58 HRc	400 °C	[2]		
BÖHLER K110	1.2379 X153CrMoV12	heat-treated[5]	LHS[1]	UTP 665 UTP 65 D UTP 67S UTP 73 G2 UTP 673	ca. 55 HRc (for 1-2 layers) ca. 220 HB[4] 55 – 58 HRc 55 – 58 HRc ca. 58 HRc	150 °C (Fast repair) 450 – 500 °C	[2]		
BÖHLER K340 ISODUR BÖHLER K360 ISODUR	Patent: X110CrMoV8-2 X125CrMoV9-3-1	heat-treated[5]	LHS[1]	UTP 665 – UTP 65 D UTP 67S UTP 73 G2 UTP 690 UTP 702	ca. 55 HRc (for 1-2 layers) ca. 220 HB[4] 55 – 58 HRc 55 – 58 HRc 62 HRc 34 – 37 HRc	150 °C (Fast repair) 450 – 500 °C	[3]	Very slow cooling, if required tempering for 4 h at 500 °C and cooling in the furnace.	Weld short welds, hammer the welds, allow to cool down slowly. UTP A 702: 3 – 4h/480 °C cured 50 – 54 HRc
BÖHLER K390 MICROCLEAN	Patent: X250VCrMo9-4-4	heat-treated[5]	LHS[1]	UTP 690	ca. 62 HRc	500 °C	[2]	Very slow cooling, if required tempering for 4 h at 500 °C and cooling in the furnace.	Initial layers to be welded with soft electrodes for a thick build up. Choose electrodes for finishing layers which give suitable hardness. Weld short stringer beads (ca. 50 – 60 mm) and hammer immediately after.
BÖHLER K490 MICROCLEAN	Patent: X140CrWVMo6-4-4-2	heat-treated[5]	LHS[1]	UTP 690	ca. 62 HRc	500 °C	[2]	Very slow cooling.	Weld short welds, hammer the welds, allow to cool down slowly.
BÖHLER K890 MICROCLEAN	Patent: X85CrWMoV4-3-3	heat-treated[5]	LHS[1]	UTP 690	ca. 62 HRc	500 °C	[2]		
BÖHLER S600 BÖHLER S705 BÖHLER S500	1.3343 (HS6-5-2C) 1.3243 (HS6-5-2-5) 1.3247 (HS2-9-1-8)	heat-treated[5]	LHS[1]	UTP 65 D UTP 653 UTP 690	ca. 220 HB[4] ca. 220 HB[4] ca. 62 HRc	500 – 600 °C	[2]		
BÖHLER S790 MICROCLEAN	1.3345 (HS6-5-3C)	heat-treated[5]	LHS[1]	UTP 65 D UTP 653 UTP 690	ca. 220 HB[4] ca. 220 HB[4] ca. 62 HRc	500 – 600 °C	[2]		
BÖHLER S690 MICROCLEAN	~1.3351 (~HS6-5-4)	heat-treated[5]	LHS[1]	UTP 65 D UTP 653 UTP 690	ca. 220 HB[4] ca. 220 HB[4] ca. 62 HRc	500 – 600 °C	[2]		
BÖHLER S590 MICROCLEAN	1.3244 (HS6-5-3-8)	heat-treated[5]	LHS[1]	UTP 65 D UTP 653 UTP 690	ca. 220 HB[4] ca. 220 HB[4] ca. 62 HRc	500 – 600 °C	[2]		
BÖHLER S390 MICROCLEAN	Patent: HS11-2-5-8	heat-treated[5]	LHS[1]	UTP 65 D UTP 653 UTP 690	ca. 220 HB[4] ca. 220 HB[4] ca. 62 HRc	500 – 600 °C	[2]		
BÖHLER S290 MICROCLEAN	Patent: HS14-2-5-11	heat-treated[5]	LHS[1]	UTP 65 D UTP 653 UTP 690	ca. 220 HB[4] ca. 220 HB[4] ca. 62 HRc	500 – 600 °C	[2]		

[1] Manual arc welding, [2] Let cool down slowly after the welding is completed: 10 – 20 °C/h for 2 h, then 50 °C/h, [3] 20 – 40 °C/h the first 2 h, then 5 °C/h, [4] Joint welding,
[5] heat-treated = hardened and tempered

WELDING RECOMMENDATIONS CONCERNING MATERIALS COLD WORK TOOL STEELS AND HIGH SPEED STEELS

BÖHLER grade	Standard designation	Tool condition	Welding method	Weld consumables	Hardness as welded	Preheating temperature	Cool-ing	Heat treatment	Remarks
BÖHLER K460 BÖHLER K720	1.2510 100MnCrW4 1.2842 90MnCrV8	heat-treated[5]	TIG MAG	UTP A 651 UTP A DUR 600 UTP A 73 G2 UTP A 673	ca. 220 HB[4] 55 – 58 HRc ca. 58 HRc ca. 58 HRc	200 – 250 °C	[2]	Slow cooling in the furnace or under a blanket.	Initial layers to be welded with soft electrodes for a thick build up. Choose electrodes for finishing layers which give suitable hardness. Weld short stringer beads (ca. 50 – 60 mm) and hammer immediately after.
BÖHLER K455	1.2550 60WCrV7	heat-treated[5]	TIG MAG	UTP A 651 UTP A DUR 600 UTP A 73 G2	ca. 220 HB[4] 55 – 58 HRc ca. 58 HRc	200 °C 250 °C	[2]		
BÖHLER K600 BÖHLER K605	1.2767 X45NiCrMo4 ~1.2721 ~50NiCr13	heat-treated[5]	TIG MAG	UTP A 651 UTP A 73 G2 UTP A 73 G3 UTP A 73 G4 UTP A 702	ca. 220 HB[4] 55 – 58 HRc 45 – 48 HRc 38 – 42 HRc ca. 37 HRc	300 – 400 °C	[2]	Very slow cooling.	UTP A 702: 3 – 4h/480 °C cured 50 – 54 HRc
BÖHLER K305	1.2363 X100CrMoV5-1	heat-treated[5]	TIG MAG	UTP A 660 – UTP A 651 UTP A 068 HH UTP A DUR 600 UTP A 73 G2 UTP A 673	ca. 55 HRc (for 1-2 layers) ca. 220 HB[4] ca. 180 HB[4] 55 – 58 HRc 55 – 58 HRc ca. 58 HRc	150 °C (Fast repair) 200 – 250 °C	[2]	Very slow cooling, if required tempering for 4 h at 500 °C and cooling in the furnace.	Initial layers to be welded with soft electrodes for a thick build up. Choose electrodes for finishing layers which give suitable hardness. Weld short stringer beads (ca. 50 – 60 mm) and hammer immediately after.
BÖHLER K329	– X50CrMoV8-2	heat-treated[5]	TIG MAG	UTP A 651 UTP A 068 HH UTP A DUR 600 UTP A 73 G2 UTP A 673	ca. 220 HB[4] ca. 180 HB[4] 55 – 58 HRc 55 – 58 HRc ca. 58 HRc	400 °C	[2]		
BÖHLER K110	1.2379 X153CrMoV12	heat-treated[5]	TIG MAG	UTP A 660 – UTP A 651 UTP A 068 HH UTP A DUR 600 UTP A 73 G2 UTP A 673	ca. 55 HRc (for 1-2 layers) ca. 220 HB[4] ca. 180 HB[4] 55 – 58 HRc 55 – 58 HRc ca. 58 HRc	150 °C (Fast repair) 450 – 500 °C	[2]		
BÖHLER K340 ISODUR BÖHLER K360 ISODUR	Patent: X110CrMoV8-2 X125CrMoV9-3-1	heat-treated[5]	TIG MAG	UTP A 660 – UTP A 651 UTP A DUR 600 UTP A 73 G2 UTP A 696 UTP A 702	ca. 55 HRc (for 1-2 layers) ca. 220 HB[4] 55 – 58 HRc 55 – 58 HRc 62 HRc 32 – 35 HRc	150 °C (Fast repair) 450 – 500 °C	[3]	Very slow cooling, if required tempering for 4 h at 500 °C and cooling in the furnace.	Weld short welds, hammer the welds, allow to cool down slowly. UTP A 702: 3 – 4h/480 °C cured 50 – 54 HRc
BÖHLER K390 MICROCLEAN	Patent: X250VCrMo9-4-4	heat-treated[5]	TIG	UTP A 696	ca. 62 HRc	500 °C	[2]	Very slow cooling, if required tempering for 4 h at 500 °C and cooling in the furnace.	Initial layers to be welded with soft electrodes for a thick build up. Choose electrodes for finishing layers which give suitable hardness. Weld short stringer beads (ca. 50 – 60 mm) and hammer immediately after.
BÖHLER K490 MICROCLEAN	Patent: X140CrWVMo6-4-4-2	heat-treated[5]	TIG	UTP A 696	ca. 62 HRc	500 °C	[2]	Very slow cooling.	Weld short welds, hammer the welds, allow to cool down slowly.
BÖHLER K890 MICROCLEAN	Patent: X85CrWMoV4-3-3	heat-treated[5]	TIG	UTP A 696	ca. 62 HRc	500 °C	[2]		
BÖHLER S600 BÖHLER S705 BÖHLER S500	1.3343 (HS6-5-2C) 1.3243 (HS6-5-2-5) 1.3247 (HS2-9-1-8)	heat-treated[5]	TIG	UTP A 651 UTP A 696	ca. 220 HB[4] ca. 62 HRc	500 – 600 °C	[2]		
BÖHLER S790 MICROCLEAN	1.3345 (HS6-5-3C)	heat-treated[5]	TIG	UTP A 651 UTP A 696	ca. 220 HB[4] ca. 62 HRc	500 – 600 °C	[2]		
BÖHLER S690 MICROCLEAN	~1.3351 (~HS6-5-4)	heat-treated[5]	TIG	UTP A 651 UTP A 696	ca. 220 HB[4] ca. 62 HRc	500 – 600 °C	[2]		
BÖHLER S590 MICROCLEAN	1.3244 (HS6-5-3-8)	heat-treated[5]	TIG	UTP A 651 UTP A 696	ca. 220 HB[4] ca. 62 HRc	500 – 600 °C	[2]		
BÖHLER S390 MICROCLEAN	Patent: HS11-2-5-8	heat-treated[5]	TIG	UTP A 651 UTP A 696	ca. 220 HB[4] ca. 62 HRc	500 – 600 °C	[2]		
BÖHLER S290 MICROCLEAN	Patent: HS14-2-5-11	heat-treated[5]	TIG	UTP A 651 UTP A 696	ca. 220 HB[4] ca. 62 HRc	500 – 600 °C	[2]		

[2] Let cool down slowly after the welding is completed: 10 – 20°C/h for 2 h, then 50°C/h, [3] 20 – 40°C/h the first 2 h, then 50°C/h, [4] Joint welding or buffer layer,
[5] heat-treated = hardened and tempered

BÖHLER grade	Standard designation	Tool condition	Welding method	Weld consumables	Hardness as welded	Preheating temperature	Cool-ing	Heat treatment	Remarks
BÖHLER W300 BÖHLER W302	1.2343 X38CrMoV5-1 1.2344 X40CrMoV5-1	Soft annealed	LHS[1]	UTP 73 G2 UTP 73 G3 UTP 73 G4	55 HRc 45 HRc 40 HRc	350 – 400 °C	[2]	Soft annealing	Immediately after the welding is com-pleted, perform soft annealing at 850 °C in a protected atmosphere. Then let cool down in the furnace and 10 °C/h up to 650 °C, expose to the air.
BÖHLER W303	1.2367 X38CrMoV5-3	Soft annealed	LHS[1]	UTP 73 G2 UTP 73 G3 UTP 73 G4	55 HRc 45 HRc 40 HRc	350 – 400 °C	[2]	Soft annealing	Weld short stringer beads (ca. 50 – 60 mm), followed by immediate hammering.
BÖHLER W320	1.2365 X32CrMoV3-3	Soft annealed	LHS[1]	UTP 73 G2 UTP 73 G3 UTP 73 G4	55 HRc 45 HRc 40 HRc	350 – 400 °C	[2]	Soft annealing	Immediately after the welding is com-pleted, perform soft annealing at 850 °C in a protected atmosphere. Then let cool down in the furnace and 10 °C/h up to 650 °C, expose to the air. UTP 702: 3–4h/480 °C cured 50 – 54 HRc.
BÖHLER W321	~1.2885 ~X32CrMoCoV3-3-3	Soft annealed	LHS[1]	UTP 702 UTP 750	37 – 40 HRc 48 – 52 HRc	350 – 400 °C	[2]	Soft annealing	
BÖHLER W350 ISOBLOC	Patent	Soft annealed	LHS[1]	UTP 73 G2 UTP 73 G3 UTP 73 G4	55 HRc 45 HRc 40 HRc	350 – 400 °C	[2]	Soft annealing	Weld short stringer beads (ca. 50 – 60 mm), followed by immediate hammering.
BÖHLER W360 ISOBLOC	Patent	Soft annealed	LHS[1]	UTP 702 UTP 73 G2 UTP 67S	37 – 40 HRc 55 – 58 HRc 55 – 58 HRc	350 – 400 °C	[3]	Soft annealing	Immediately after the welding is com-pleted, perform soft annealing at 850 °C in a protected atmosphere. Then let cool down in the furnace and 10 °C/h up to 600 °C, expose to the air. UTP 702: 3–4h/480 °C cured 50 – 54 HRc.
BÖHLER W400 VMR BÖHLER W403 VMR	~1.2343 ~X37CrMoV5-1 ~1.2367 ~X38CrMoV5-3	Soft annealed	LHS[1]	UTP 73 G2 UTP 73 G3 UTP 73 G4	55 HRc 45 HRc 40 HRc	350 – 400 °C	[2]	Soft annealing	Weld short stringer beads (ca. 50 – 60 mm), followed by immediate hammering.

[1] Manual arc welding, [2] Let cool down slowly after the welding is completed: 10 – 20 °C/h for 2 h, then 50°C/h, [3] 20 – 40 °C/h the first 2 h, then 50 °C/h

BÖHLER grade	Standard designation	Tool condition	Welding method	Weld consumables	Hardness as welded	Preheating temperature	Cool-ing	Heat treatment	Remarks
BÖHLER W300 BÖHLER W302	1.2343 X38CrMoV5-1 1.2344 X40CrMoV5-1	heat-treated[4]	LHS[1]	UTP 73 G2 UTP 73 G3 UTP 73 G4	55 HRc 45 HRc 40 HRc	400 – 450 °C	[2]	Stress relief annealing: 25 °C below the previous tempering tem-perature, 2 h	Weld short stringer beads (ca. 50 – 60 mm), followed by immediate hammering.
BÖHLER W303	1.2367 X38CrMoV5-3	heat-treated[4]	LHS[1]	UTP 73 G2 UTP 73 G3 UTP 73 G4	55 HRc 45 HRc 40 HRc	400 – 450 °C	[2]		
BÖHLER W320	1.2365 X32CrMoV3-3	heat-treated[4]	LHS[1]	UTP 73 G2 UTP 73 G3 UTP 73 G4	55 HRc 45 HRc 40 HRc	400 – 450 °C	[2]		
BÖHLER W321	~1.2885 ~X32CrMoCoV3-3-3	heat-treated[4]	LHS[1]	UTP 702 UTP 750	37 – 40 HRc 48 – 52 HRc	400 – 450 °C	[2]		Weld short stringer beads (ca. 50 – 60 mm), followed by immediate hammering. UTP 702: 3–4h/480 °C cured 50 – 54 HRc.
BÖHLER W350 ISOBLOC	Patent	heat-treated[4]	LHS[1]	UTP 73 G2 UTP 73 G3 UTP 73 G4	55 HRc 45 HRc 40 HRc	400 – 450 °C	[2]		Weld short stringer beads (ca. 50 – 60 mm), followed by immediate hammering.
BÖHLER W360 ISOBLOC	Patent	heat-treated[4]	LHS[1]	UTP 702 UTP 73 G2 UTP 67S	37 – 40 HRc 55 – 58 HRc 55 – 58 HRc	400 – 450 °C	[3]		Weld short stringer beads (ca. 50 – 60 mm), followed by immediate hammering. UTP 702: 3–4h/480 °C cured 50 – 54 HRc.
BÖHLER W400 VMR BÖHLER W403 VMR	~1.2343 ~X37CrMoV5-1 ~1.2367 ~X38CrMoV5-3	heat-treated[4]	LHS[1]	UTP 73 G2 UTP 73 G3 UTP 73 G4	55 HRc 45 HRc 40 HRc	400 – 450 °C	[2]		Weld short stringer beads (ca. 50 – 60 mm), followed by immediate hammering.

[1] Manual arc welding, [2] Let cool down slowly after the welding is completed: 10 – 20 °C/h for 2 h, then 50 °C/h, [3] 20 – 40 °C/h the first 2 h, then 50 °C/h,
[4] heat-treated = hardened and tempered

WELDING RECOMMENDATIONS CONCERNING MATERIALS
HOT WORK TOOL STEELS

BÖHLER grade	Standard designation	Tool condition	Welding method	Weld consumables	Hardness as welded	Preheating temperature	Cool-ing	Heat treatment	Remarks
BÖHLER W300 BÖHLER W302	1.2343 X38CrMoV5-1 1.2344 X40CrMoV5-1	Soft annealed	WIG MAG	UTP A 73 G2 UTP A 73 G3 UTP A 73 G4	55 HRc 45 HRc 40 HRc	350 – 400 °C	[2]	Soft annealing	Immediately after the welding is com-pleted, perform soft annealing at 850 °C in a protected atmosphere. Then let cool down in the furnace and 10 °C/h up to 650 °C, expose to the air.
BÖHLER W303	1.2367 X38CrMoV5-3	Soft annealed	WIG MAG	UTP A 73 G2 UTP A 73 G3 UTP A 73 G4	55 HRc 45 HRc 40 HRc	350 – 400 °C	[2]	Soft annealing	Weld short stringer beads (ca. 50 – 60 mm), followed by immediate hammering.
BÖHLER W320	1.2365 X32CrMoV3-3	Soft annealed	WIG MAG	UTP A 73 G2 UTP A 73 G3 UTP A 73 G4	55 HRc 45 HRc 40 HRc	350 – 400 °C	[2]	Soft annealing	Immediately after the welding is com-pleted, perform soft annealing at 850 °C in a protected atmosphere. Then let cool down in the furnace and 10 °C/h up to 650 °C, expose to the air. UTP 702: 3–4h/480 °C cured 50 – 54 HRc.
BÖHLER W321	~1.2885 ~X32CrMoCoV3-3-3	Soft annealed	WIG MAG	UTP A 702	37 – 40 HRc	350 – 400 °C	[2]	Soft annealing	
BÖHLER W350 ISOBLOC	Patent	Soft annealed	WIG MAG	UTP A 73 G2 UTP A 73 G3 UTP A 73 G4	55 HRc 45 HRc 40 HRc	350 – 400 °C	[2]	Soft annealing	Weld short stringer beads (ca. 50 – 60 mm), followed by immediate hammering.
BÖHLER W360 ISOBLOC	Patent	Soft annealed	WIG MAG	UTP 702 UTP A 73 G2 UTP A DUR 600	37 – 40 HRc 55 – 58 HRc 55 – 58 HRc	350 – 400 °C	[3]	Soft annealing	Immediately after the welding is com-pleted, perform soft annealing at 850 °C in a protected atmosphere. Then let cool down in the furnace and 10 °C/h up to 600 °C, expose to the air. UTP 702: 3–4h/480 °C cured 50 – 54 HRc.
BÖHLER W400 VMR BÖHLER W403 VMR	~1.2343 ~X37CrMoV5-1 ~1.2367 ~X38CrMoV5-3	Soft annealed	WIG MAG	UTP A 73 G2 UTP A 73 G3 UTP A 73 G4	55 HRc 45 HRc 40 HRc	350 – 400 °C	[2]	Soft annealing	Weld short stringer beads (ca. 50 – 60 mm), followed by immediate hammering.

[2] Let cool down slowly after the welding is completed: 10 – 20 °C/h for 2 h, then 50 °C/h, [3] 20 – 40 °C/h the first 2 h, then 50 °C/h

BÖHLER grade	Standard designation	Tool condition	Welding method	Weld consumables	Hardness as welded	Preheating temperature	Cool-ing	Heat treatment	Remarks
BÖHLER W300 BÖHLER W302	1.2343 X38CrMoV5-1 1.2344 X40CrMoV5-1	heat-treated[4]	WIG MAG	UTP A 73 G2 UTP A 73 G3 UTP A 73 G4	55 HRc 45 HRc 40 HRc	400 – 450 °C	[2]	Stress relief annealing: 25 °C below the previous tempering tem-perature, 2 h	Weld short stringer beads (ca. 50 – 60 mm), followed by immediate hammering.
BÖHLER W303	1.2367 X38CrMoV5-3	heat-treated[4]	WIG MAG	UTP A 73 G2 UTP A 73 G3 UTP A 73 G4	55 HRc 45 HRc 40 HRc	400 – 450 °C	[2]		
BÖHLER W320	1.2365 X32CrMoV3-3	heat-treated[4]	WIG MAG	UTP A 73 G2 UTP A 73 G3 UTP A 73 G4	55 HRc 45 HRc 40 HRc	400 – 450 °C	[2]		
BÖHLER W321	~1.2885 ~X32CrMoCoV3-3-3	heat-treated[4]	WIG MAG	UTP A 702	37 – 40 HRc	400 – 450 °C	[2]		Weld short stringer beads (ca. 50 – 60 mm), followed by immediate hammering. UTP 702: 3–4h/480 °C cured 50 – 54 HRc.
BÖHLER W350 ISOBLOC	Patent	heat-treated[4]	WIG MAG	UTP A 73 G2 UTP A 73 G3 UTP A 73 G4	55 HRc 45 HRc 40 HRc	400 – 450 °C	[2]		Weld short stringer beads (ca. 50 – 60 mm), followed by immediate hammering.
BÖHLER W360 ISOBLOC	Patent	heat-treated[4]	WIG MAG	UTP A 702 UTP A 73 G2 UTP A DUR 600	37 – 40 HRc 55 – 58 HRc 55 – 58 HRc	400 – 450 °C	[3]		Weld short stringer beads (ca. 50 – 60 mm), followed by immediate hammering. UTP 702: 3–4h/480 °C cured 50 – 54 HRc.
BÖHLER W400 VMR BÖHLER W403 VMR	~1.2343 ~X37CrMoV5-1 ~1.2367 ~X38CrMoV5-3	heat-treated[4]	WIG MAG	UTP A 73 G2 UTP A 73 G3 UTP A 73 G4	55 HRc 45 HRc 40 HRc	400 – 450 °C	[2]		Weld short stringer beads (ca. 50 – 60 mm), followed by immediate hammering.

[2] Let cool down slowly after the welding is completed: 10 – 20 °C/h for 2 h, then 50 °C/h, [3] 20 – 40 °C/h the first 2 h, then 50 °C/h, [4] heat-treated = hardened and tempered

BÖHLER grade	Standard designation	Tool condition	Welding method	Weld consumables	Hardness as welded	Preheating temperature	Cool-ing	Heat treatment	Remarks
BÖHLER M200	1.2312 40CrMnMoS8-6	heat-treated before	LHS[1]	UTP 641 Kb UTP 73 G4	200 HB[4] 38 – 42 HRc	300 – 400 °C	[2]	Slow cooling down, if required tempering for 2h at 590 °C and cooling in the furnace	Stress relief annealing after larger repairs at ca. 550 °C.
BÖHLER M238 BÖHLER M268 VMR	1.2738 40CrMnMo7 1.2738 VMR 40CrMnMo7	heat-treated before	LHS[1]	UTP 65 D UTP 73 G2 UTP 73 G3 UTP 73 G4	ca. 220 HB[4] 55 – 58 HRc 45 – 48 HRc 38 – 42 HRc	300 – 400 °C	[2]	Slow cooling in the furnace or under a blanket.	
BÖHLER M261 EXTRA BÖHLER M461 EXTRA	X13NiCuAlS4-1-1 X13NiCuAl4-1-1	heat-treated before	LHS[1]	UTP 73 G4 UTP 702	38 – 42 HRc ca. 37 HRc	100 – 150 °C	[2]	Slow cooling in the furnace or under a blanket.	Weld short stringer beads (ca. 50 – 60 mm), followed by immediate hammering. UTP A 702: 3 – 4h/ 480 °C cured 50 – 54 HRc
BÖHLER M314 EXTRA BÖHLER M315 EXTRA	~1.2085 X33CrS16 M315: Patent (X5CrCuS13)	heat-treated before	LHS[1]	UTP 65 D UTP 665 UTP 750	ca. 220 HB[4] ca. 350 HB 42 – 52 HRc	400 – 450 °C	[2]	Tempering	Tempering temperature: M314: ca. 550 °C; M315: ca. 480 °C;
BÖHLER M303 EXTRA	Patent: ~1.2316 X38CrMo16	heat-treated before	LHS[1]	UTP 65 D UTP 665 UTP 750	ca. 220 HB[4] ca. 350 HB 42 – 52 HRc	300 – 400 °C	[2]	Slow cooling down, if required tempering for 2h at 580 °C and cooling in the furnace	Stress relief annealing after larger repairs at ca. 550 °C.
BÖHLER M310 ISOPLAST® BÖHLER M333 ISOPLAST®	~1.2083 X40Cr14 M333: Patent (X30CrN14)	Soft annealed	LHS[1]	UTP 65 D UTP 665 UTP 750	ca. 220 HB[4] ca. 350 HB 42 – 52 HRc	200 – 250 °C	[2]	Soft annealing	Heat treatment see brochure for parent steel.
BÖHLER M310 ISOPLAST® BÖHLER M333 ISOPLAST® BÖHLER M340 ISOPLAST®	~1.2083 X40Cr14 M333: Patent (X30CrN14) M340: Patent (X55CrMoN17-1)	heat-treated[5]	LHS[1]	UTP 65 D UTP 665 UTP 750	ca. 220 HB[4] ca. 350 HB 42 – 52 HRc	200 – 250 °C	[2]	Tempering	Tempering temperature: 200 – 250 °C
BÖHLER M390 MICROCLEAN®	Patent: X190CrVMo20-4	heat-treated[5]	LHS[1]	UTP 73 G2 UTP 690	55 – 58 HRc 62 HRc	500 – 600 °C	[2]	Tempering to 500 °C/1h	Weld short welds, hammer the welds, allow to cool down slowly.

[1] Manual arc welding, [2] Let cool down slowly after the welding is completed: 10 – 20 °C/h for 2 h, then 50 °C/h, [3] 20 – 40 °C/h the first 2 h, then 50 °C/h, [4] Joint welding or buffer layer, [5] heat-treated = hardened and tempered

WELDING RECOMMENDATIONS CONCERNING MATERIALS
PLASTIC MOULD STEELS

BÖHLER grade	Standard designation	Tool condition	Welding method	Weld consumables	Hardness as welded	Preheating temperature	Cool-ing	Heat treatment	Remarks
BÖHLER M200	1.2312 40CrMnMoS8-6	heat-treated before	TIG MAG	UTP A 641 UTP A 73 G4	200 HB[4] 38 – 42 HRc	300 – 400 °C	[2]	Slow cooling down, if required tempering for 2h at 590 °C and cooling in the furnace	Stress relief annealing after larger repairs at ca. 550 °C.
BÖHLER M238 BÖHLER M268 VMR®	1.2738 40CrMnMo7 1.2738 VMR 40CrMnMo7	heat-treated before	TIG MAG	UTP A 651 UTP A 73 G2 UTP A 73 G3 UTP A 73 G4	ca. 220 HB[4] 55 – 58 HRc 45 – 48 HRc 38 – 42 HRc	300 – 400 °C	[2]	Slow cooling in the furnace or under a blanket.	
BÖHLER M261 EXTRA BÖHLER M461 EXTRA	X13NiCuAlS4-1-1 X13NiCuAl4-1-1	heat-treated before	TIG MAG	UTP A 73 G4 UTP A 702	38 – 42 HRc ca. 37 HRc	100 – 150 °C	[2]	Slow cooling in the furnace or under a blanket.	UTP A 702: 3 – 4h/480 °C cured 50 – 54 HRc
BÖHLER M314 EXTRA BÖHLER M315 EXTRA	~1.2085 X33CrS16 M315: Patent (X5CrCuS13)	heat-treated before	TIG MAG	UTP A 651 UTP A 661	ca. 220 HB[4] ca. 40 HRc	400 – 450 °C	[2]	Tempering	Tempering temperature: M314: ca. 550 °C; M315: ca. 480 °C;
BÖHLER M303 EXTRA	Patent: ~1.2316 X38CrMo16	heat-treated before	TIG MAG	UTP A 651 UTP A 661	ca. 220 HB[4] ca. 40 HRc	300 – 400 °C	[2]	Slow cooling down, if required tempering for 2h at 580 °C and cooling in the furnace	Stress relief annealing after larger repairs at ca. 550 °C.
BÖHLER M310 ISOPLAST® BÖHLER M333 ISOPLAST®	~1.2083 X40Cr14 M333: Patent (X30CrN14)	Soft annealed	TIG MAG	UTP A 651 UTP A 661	ca. 220 HB[4] ca. 40 HRc	200 – 250 °C	[2]	Soft annealing	Heat treatment see brochure for parent steel.
BÖHLER M310 ISOPLAST® BÖHLER M333 ISOPLAST® BÖHLER M340 ISOPLAST®	~1.2083 X40Cr14 M333: Patent (X30CrN14) M340: Patent (X55CrMoN17-1)	heat-treated[5]	TIG MAG	UTP A 651 UTP A 661	ca. 220 HB[4] ca. 40 HRc	200 – 250 °C	[2]	Tempering	Tempering temperature: 200 – 250 °C
BÖHLER M390 MICROCLEAN®	Patent: X190CrVMo20-4	heat-treated[5]	TIG MAG	UTP A 73 G2 UTP A 696	55 – 58 HRc 62 HRc	500 – 600 °C	[2]	Tempering to 500 °C/1h	Weld short welds, hammer the welds, allow to cool down slowly.

[2] Let cool down slowly after the welding is completed: 10 – 20 °C/h for 2 h, then 50 °C/h, [4] Joint welding or buffer layer, [5] heat-treated = hardened and tempered

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