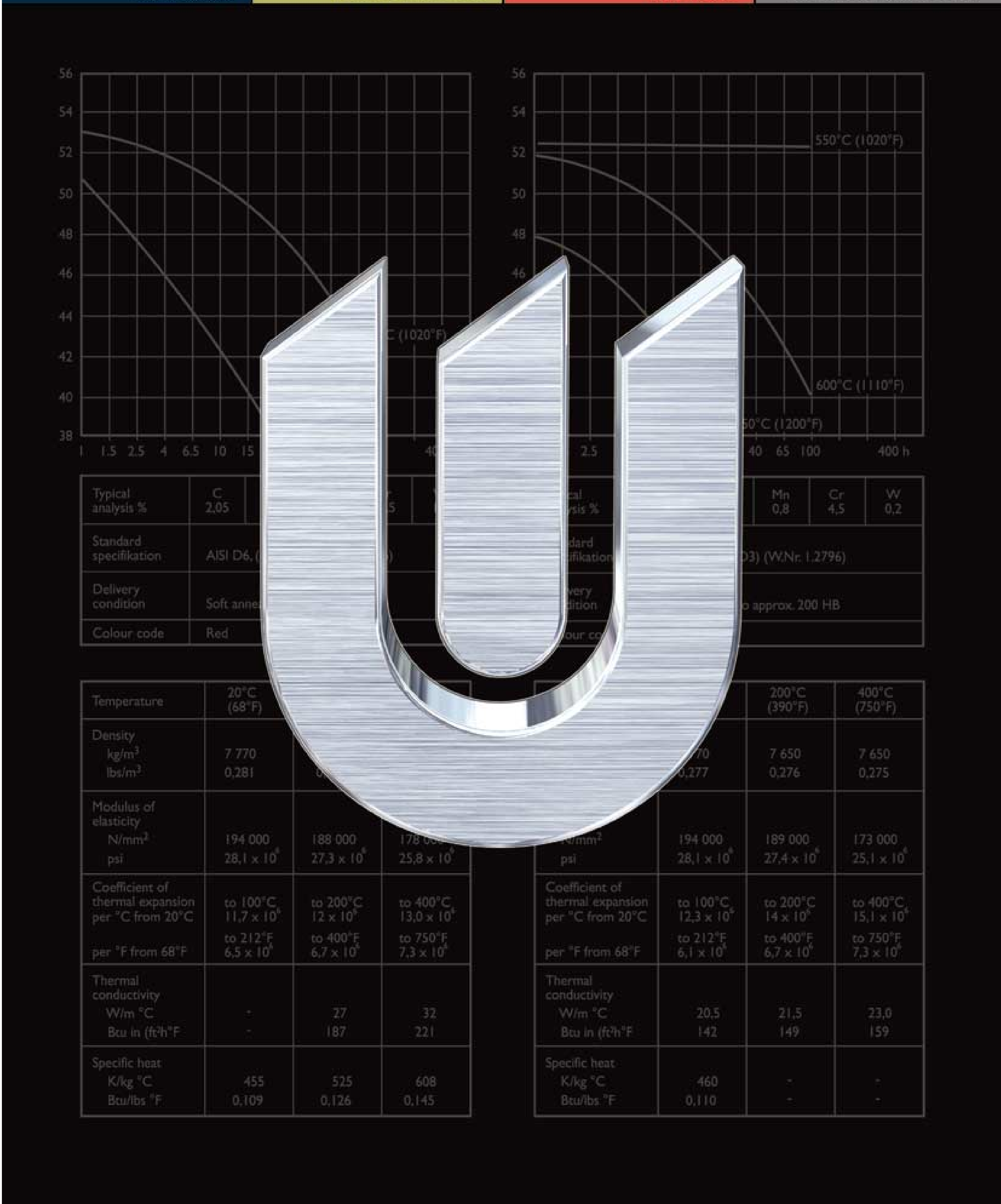
Welding of tool steel

COLD WORK | PLASTIC MOULDING | HOT WORK | HIGH PERFORMANCE STEEL



Content

Introduction

The weldability of steels with more than 0,2% carbon is usually considered to be poor. Hence, tool steels with 0,3–2,5% carbon are difficult to weld and many steel suppliers will actually recommend against welding. However, improved quality of consumables, refined welding equipment, developments in welding technique and, not least, improvements in tool steel quality have combined to render tool welding as a realistic possibility, which can have considerable economic consequences.

Hence, Uddeholm recognizes that tool steels often need to be welded; this is especially true for expensive tooling like die-casting dies, large forging dies, plastic moulds, carbody dies and blanking tools where repair and adjustment via welding is highly cost-attractive in comparison with the expense of producing new tooling.

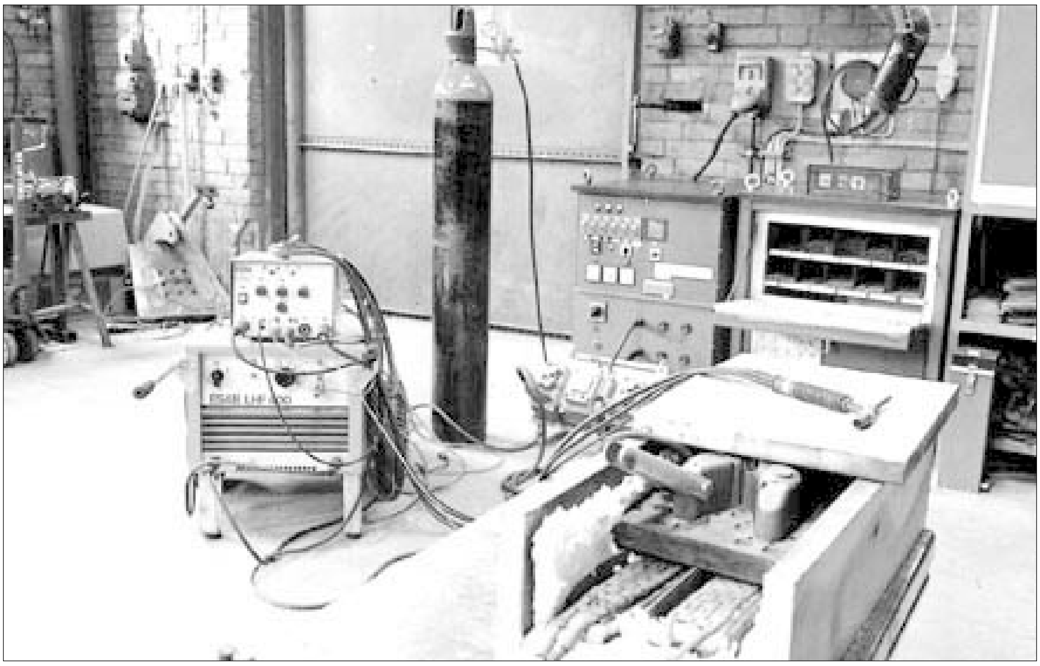
General information on welding of tool steel

Tool steels contain 0,3–2,5% carbon as well as alloying elements such as manganese, chromium, molybdenum, tungsten, vanadium and nickel. The main problem in welding tool steel stems from its high hardenability. Welds cool quickly once the heat source is removed and the weld metal and part of the heat-affected zone will harden. This transformation generates stresses because the weld is normally highly constrained, with a concomitant risk for cracking unless great care is exercised.

In what follows, a description is given of the welding equipment, welding technique and weld consumables that are required in order to weld tool steel successfully. Of course, the skill and experience of the welder is also a vital ingredient in obtaining satisfactory results. With sufficient care, it is possible to achieve weld repairs or adjustments which, in terms of tooling performance, are hardly inferior to that of the base steel.

Welding of tooling may be required for anyone of the following reasons:

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



The welding bay.

Welding methods for tool steel

SHIELDED METAL-ARC WELDING (SMAW OR MMA)

Principle

An electric arc generated by a DC or AC power source is struck between a coated, rod-like electrode and the workpiece (Fig. 1).

The electrodes consist of a central wire core, which is usually low-carbon steel, covered with a coating of pressed powder (flux). The constitution of this coating is complex and consists of iron powder, powdered ferro-alloys, slag formers and a suitable binder. The electrode is consumed under the action of the arc during welding and drops of molten metal are transferred to the workpiece. Contamination by air during the transfer of molten drops from electrode to workpiece and during solidification and cooling of the weld deposit is inhibited partly by slag formed from constituents in the electrode coating and partly by gases created during melting of the electrode.

The composition of the deposited weld metal is controlled via the constitution of the electrode coating.

Power source

For MMA welding, it is possible to use either an AC or DC power source. However, whichever is used, the source must provide a voltage and current which is compatible with the electrode. Normal arc voltages are:

- Normal recovery electrodes: 20–30 V
- High recovery electrodes: 30–50 V

Uddeholm welding consumables are of normal-recovery type. A suitable power source for these is a DC unit with an open voltage of 70 V and which is capable of delivering 250A/30 V at 35% intermittence.

GAS TUNGSTEN-ARC WELDING (GTAW OR TIG)

Principle

In MMA welding, the electrode rod from which the arc is struck is consumed during welding.

The electrode in TIG welding is made of tungsten or tungsten alloy which has a very high melting point (about 3300°C/6000°F) and is therefore not consumed during the process (Fig. 2). The arc is initially struck by subjecting the electrode-workpiece gas to a high-frequency voltage. The resulting ionization permits striking without the necessity for contact between electrode and workpiece. The tungsten electrode is always connected to the negative terminal of a DC power source because this minimizes heat generation and thereby any risk of melting the electrode. Current is conducted to the electrode via a contact inside the TIG-gun. Any consumables which are required during TIG-welding are fed obliquely into the arc in the form of rod or wire. Oxidation of the weld pool is prevented by an inert-gas shroud which streams from the TIG tun over the electrode and weld.

Power source

TIG welding can be performed with a regular MMA power source provided this is complemented with a TIG control unit. The gun should be water cooled and be capable of handling a minimum current of 250 A at 100% intermittence. A gas lens is also a desirable feature in order that the inert gas protection is as efficient as possible. Welding is facilitated if the current can be increased steplessly from zero to the optimum level.

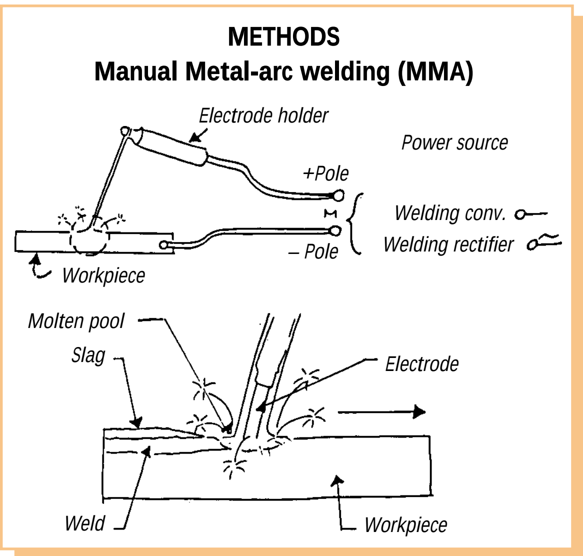


Fig. 1

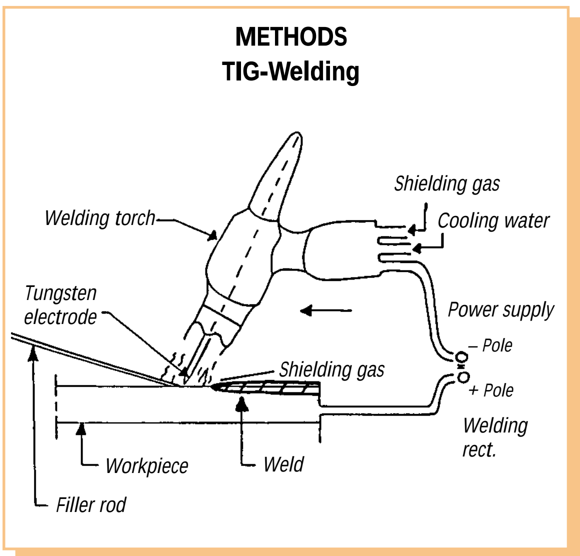


Fig. 2

The welding bay

In order to be able to effect satisfactory welding work on tool steel, the following items of equipment are to be regarded as minimum requirements (over and above the welding equipment).

DRY CABINET

The coated electrodes used for MMA welding are strongly hygroscopic and should not be allowed to come into contact with anything other than dry air. Otherwise, the weld will be contaminated with hydrogen (see later). Hence, the welding bay should be equipped with a dry cabinet for storage of electrodes. This should be thermostatically controlled in the range 50–150°C (120–300°F). The electrodes should be removed from their containers and lie loose on racks.

For welding of tooling outside the welding bay, it will also be found useful to have a portable heated container in which the electrodes can be carried.

PREHEATING EQUIPMENT

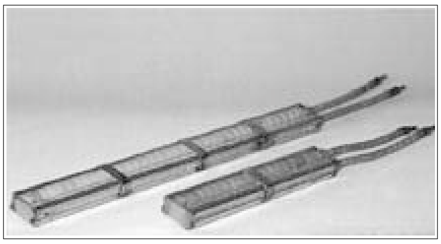
Tool steels cannot be welded at room temperature without considerable risk for cracking and it is generally necessary to pre-heat the mould or die before any welding can be attempted (see later). While it is certainly possible to weld tools successfully by preheating in a furnace, the chances are that the temperature will fall excessively prior to completion of the work. Hence, it is recommended that the tool be maintained at the correct temperature using an electrical heating box supplied from a current-regulated DC source. This equipment also enables the tool to be heated at a uniform and controlled rate.

For minor repairs and adjustments, it is acceptable that the tool be preheated using a propane torch. Hence, liquid propane cylinders should be available in the welding bay.

GRINDING MACHINES

The following should be available:

- Disc grinder with minimum 180 Ø x 6 mm wheel (7 Ø x 0,25 inch) for preparing the joint and grinding out of any defects which may occur during welding.
- Flat grinder capable of ≥25 000 rpm for grinding of minor defects and of the finished weld.
- If a welded mould is subsequently to be polished or photo-etched, it may be necessary to have a grinder capable of giving a sufficiently fine finish.



Electrical elements for an insulated preheating box.

WORKBENCH

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 a sufficiently level that the work can be positioned securely and accurately. It is advantageous if the workbench is rotatable and adjustable vertically, since both these features facilitate the welding operation.

Dry cabinet for storage of electrodes.

Filler-metal characteristics

The chemical composition of a weld deposit is determined by the composition of the consumable (filler metal), the base steel composition and the extent to which the base material is melted during welding. The consumable electrode or wire should mix easily with the molten base steel giving a deposit with:

- Uniform composition, hardness and response to heat-treatment
- Freedom from non-metallic inclusions, porosity or cracks
- Suitable properties for the tooling application in question.

Since tool steel welds have high hardness, they are particularly susceptible to cracking which may originate at slag particles or pores. Hence, the consumable used should be capable of producing a high-quality weld. In a similar vein, it is necessary that the consumables be produced with very tight analysis control in order that the hardness as welded and the response to heat treatment is reproducible from batch to batch. High-quality filler metals are also essential if a mould is to be polished or photo-etched after welding. Uddeholm welding consumables meet these requirements.

TIG filler rod is normally produced from electro-slag remelted stock while coated electrodes are of basic type, which are far superior to rutile electrodes as regards weld cleanliness. Another advantage with basis coated electrodes over those of rutile type is that the former give a much lower hydrogen content in the weld metal.

In general, the consumable used for welding tool steel 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 filler metal 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.

Uddeholm welding consumable are designed to be compatible with the corresponding tool steel grades (QRO 90 WELD and QRO 90 TIG-WELD are recommended for all Uddeholm hot work steels) irrespective of whether welding is carried out on annealed or hardened-and-tempered base material.

Obviously, the weld metal of welded tools will require different properties for different applications.

For the three main application segments for tool steels (cold work, hot work and plastic moulding), the important weld-metal properties are:

Cold Work
- Hardness
- Toughness
- Wear resistance

Hot Work
- Hardness
- Temper resistance
- Toughness
- Wear resistance
- Heat checking resistance

Plastic Moulding
- Hardness
- Wear resistance
- Polishability
- Photoetchability

These properties are discussed briefly on following pages.

MMA welding consumables from Uddeholm.

HARDNESS

If the mould or die is welded in the hardened and tempered condition, then it is important that the weld exhibits the same hardness as the base steel in the as-welded condition. Such being the case, small welds can be effected without the necessity of subsequently tempering the tool. All Uddeholm welding consumables fulfil this requirement (Fig. 3).

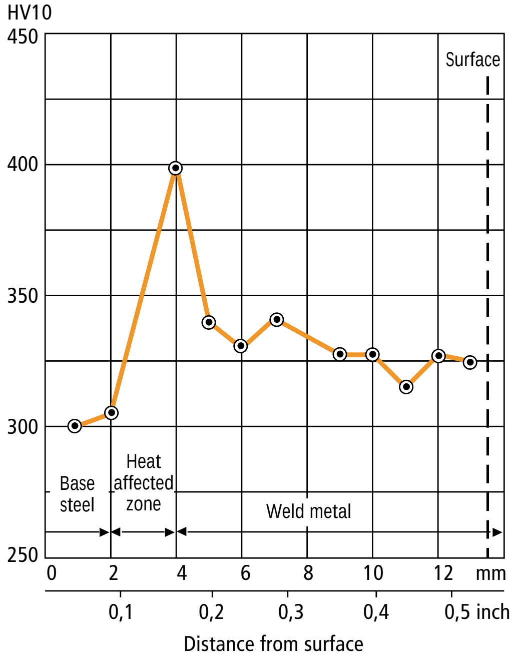


Fig. 3. Hardness profile across a weld in IMPAX SUPREME (MMA welding using IMPAX WELD electrodes).

Note the uniform hardness distribution, only marginally higher than the base hardness, and the very narrow heat-affected zone with only a modest hardness increase at the fusion line.

TEMPER RESISTANCE

If the mould or die is to be heat treated after welding (base steel in annealed condition), then the hardening and tempering characteristics of the weld metal should be similar to those of the base steel so that the same hardness is obtained in both (Fig. 4).

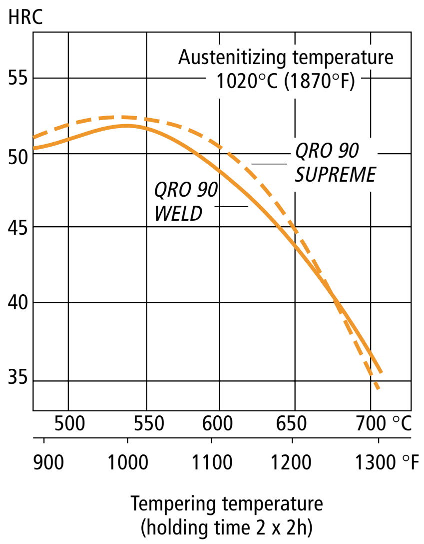


Fig. 4. Comparison of tempering curves for QRO 90 SUPREME and weld metal produced by MMA welding with QRO 90 WELD electrodes.

TOUGHNESS

In spite of the fact that we are dealing with that is essentially a casting, weld metal in tool steel can be surprisingly tough as a result of the rather fine microstructure derived from a high rate of solidification. In general, however, the toughness will be improved by subsequent heat treatment. Hence, larger weld repairs on a fully-hardened tool should always be tempered after welding, even though the hardness of the weld metal and base steel may be compatible in the as-welded condition.

For cold work steels, where very high hardness is required, it will be advisable to use a softer filler metal for the initial layers and finish with a hard electrode on the working surface of the tool. This procedure will produce a tougher repair than if the hard electrode had been used throughout.

WEAR RESISTANCE

Just as with tool steel, the wear resistance of a weld metal increases with its hardness and alloy content. Uddeholm welding consumables are designed to give weld metals with the same wear resistance as the compatible base steel.

HEAT-CHECKING RESISTANCE

Welds in hot work tools will normally heat-check faster than the base steel because of poorer hot strength, temper resistance or toughness (ductility). However, if a consumable is used which gives a weld metal with superior hot strength and hot hardness, then the heat-checking resistance can be equal to or even better than the base steel.

QRO 90 WELD and TIG-WELD produce welds which exhibit excellent resistance to heat checking (Fig. 5).

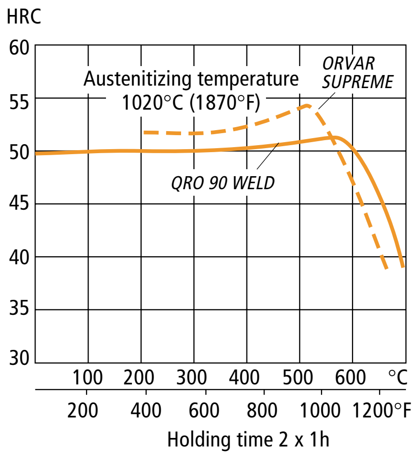


Fig. 5. QRO 90 WELD exhibits superior temper resistance to premium H13 base steel (ORVAR SUPREME).

POLISHABILITY

For plastic mould which need to be polished after welding, it is essential that the weld metal does not differ greatly in composition or hardness from the base steel. Otherwise, an outline of the weld is visible after polishing which will leave a witness mark on the plastic part.

IMPAX SUPREME and *STAVAX ESR* welded with IMPAX and STAVAX WELD (or TIG-WELD) consumables, will in conjunction with correct welding procedure, normally give welds which are to all intents and purposes invisible after polishing.

PHOTOETCHABILITY (TEXTURABILITY)

The weld metal and the base steel must also be similar in composition of a welded surface of a plastic mould is to be textured via photoetching. If not, the response to etching will vary between the weld and the base metal and this will result in a witness mark on the plastic component. Welds in *IMPAX SUPREME* and *STAVAX ESR* with IMPAX or STAVAX WELD (or TIG-WELD) will normally not be discernible after photoetching, provided that the proper welding procedure is used.

Be careful as regards hydrogen!

Weld in tool steel have high hardness and are, therefore, especially susceptible to cold cracking derived from hydrogen ingress during welding. In many cases, hydrogen is generated as a result of water vapour being adsorbed in the hygro-scopic coating of MMA electrodes.

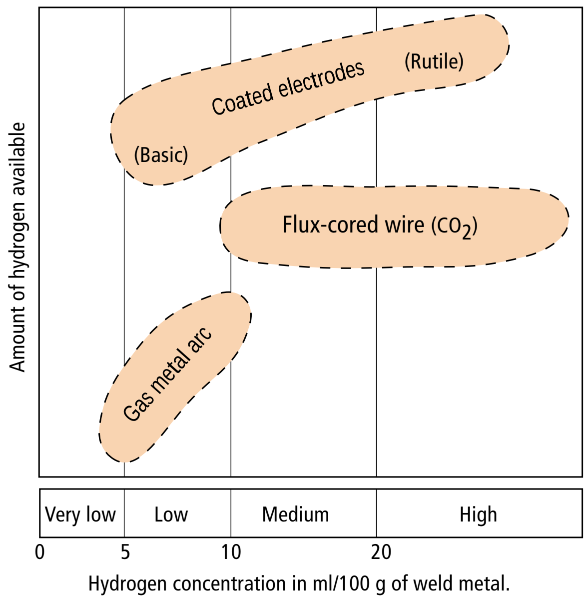
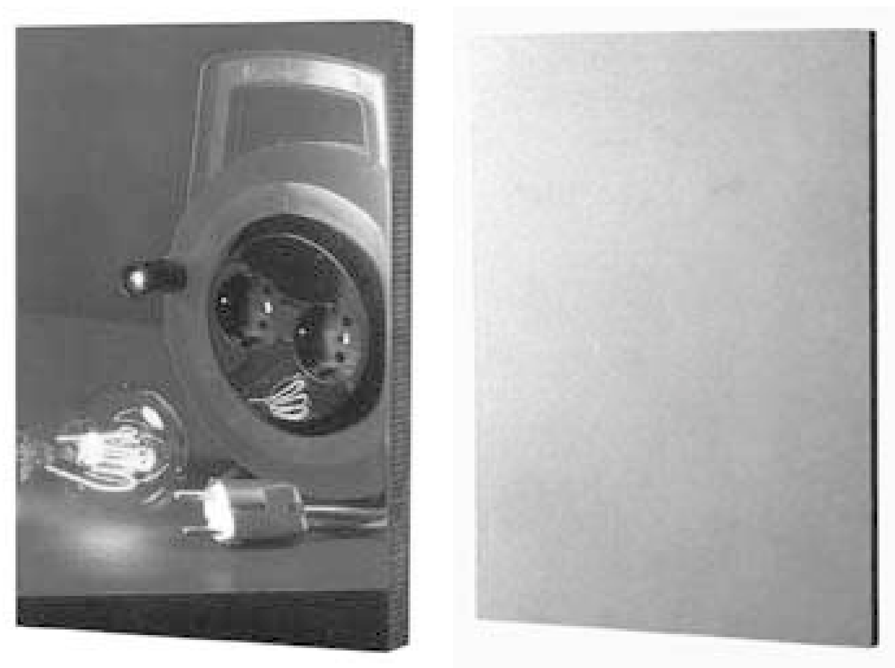


Fig. 6. Typical quantities of hydrogen available and weld metal hydrogen contents for different welding processes and electrode types.



STAVAX WELD/TIG WELD and IMPAX WELD/ TIG WELD match their corresponding tool steel grades exactly and give perfect results after polishing or texturing of a welded mould.

The susceptibility of a weld to hydrogen cracking depends on:

- The microstructure of the weld metal (different microstructures have different hydrogen sensitivities)
- The hardness of the steel (the greater the hardness, the higher the susceptibility)
- The stress level
- The amount of diffusible hydrogen introduced in welding.

MICROSTRUCTURE/HARDNESS

The characteristic microstructures giving high hardness in the heat-affected zone and weld metal, i.e. martensite and bainite, are particularly sensitive to embrittlement by hydrogen. This susceptibility is, albeit only marginally, alleviated by tempering.

STRESS LEVEL

Stresses in welds arise from three sources:

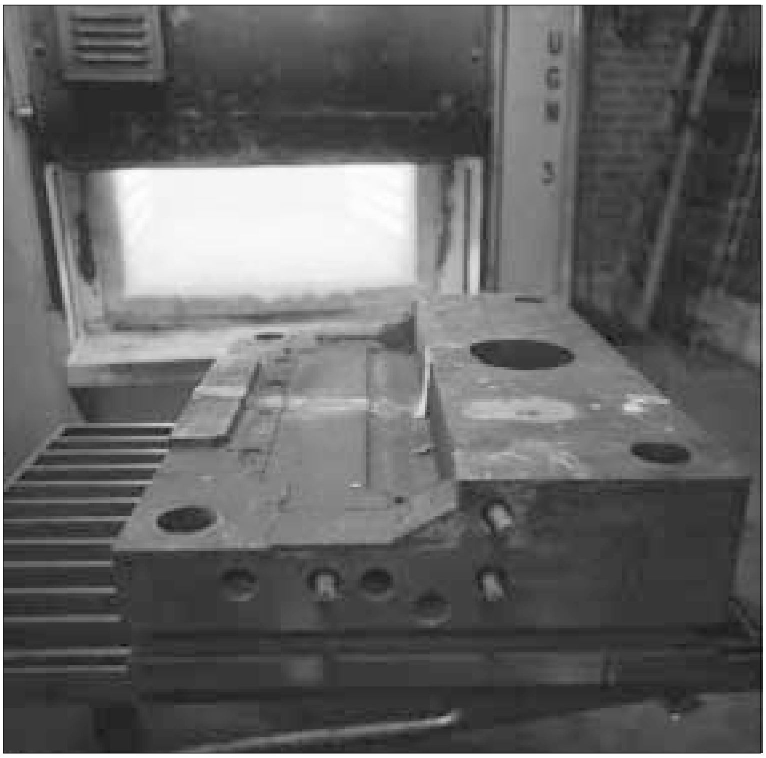
- Contraction during solidification of the molten pool
- Temperature differences between weld, heat-affected zone and base steel
- Transformation stresses when the weld and heat-affected zone harden during cooling.

In general, the stress level in the vicinity of the weld will reach the magnitude of the yield stress, which for hardened tool steel is very high indeed. It is very difficult to do anything about this but the situation can be improved somewhat via proper weld design, (bead location and sequence of runs). However, no measures to reduce stress will help if the weld is seriously contaminated by hydrogen.

CONTENT OF DIFFUSIBLE HYDROGEN

As regards the susceptibility of welds to cold cracking, this is the factor that it is easiest to do something about. By adhering to a number of simple precautions, the amount of hydrogen introduced during welding can be reduced appreciably.

- Always store coated electrodes in a heated storage cabinet or heated container once the pack has been opened (see earlier).
- Contamination on the surfaces of the joint of the surrounding tool surface, e.g. oil, rust or paint, is a source of hydrogen. Hence, the surfaces of the joint and of the tool in the vicinity of the joint should be ground to bare metal immediately prior to starting to weld.
- If preheating is performed with a propane burner, it should be remembered that this can cause moisture to form on the tool surfaces not directly impinged by the flame.

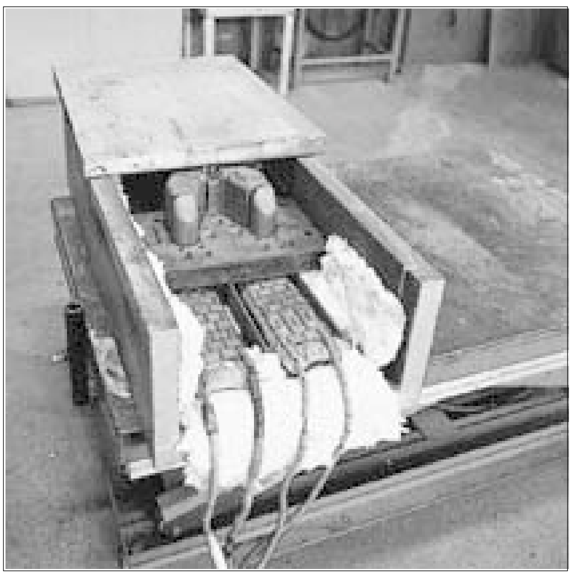


Heat treatment of a die-casting die after welding.

Elevated working temperature

The basic reason for welding tool steel at elevated temperature derives from the high hardenability and therefore crack sensitivity of tool steel welds and heat-affected zones. Welding of a cold tool will cause rapid cooling of the weld metal and heat-affected zone between passes with resulting trans-formation to brittle martensite and risk for cracking. Cracks formed in the weld could well propagate through the entire tool if this is cold. Hence, the mould or die should during welding be maintained at 50–100°C (90–180°F) above the M_S-temperature (martensite-start temperature) for the steel in question; note that, strictly speaking, the critical temperature is the M_S 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 M_S-temperature. Hence, pre-heating the tool for welding will cause a drop in hardness. For example, most low-temperature tempered cold-work steels will have to be pre-heated to a temperature in excess of the tempering temperature, which is usually ca. 200°C (400°F). The hardness drop must be accepted in order to perform a proper preheating and mitigate the risk for cracking during welding.



Preheating in an insulated box.

During multi-run welding of a properly pre-heated tool, 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 in comparison with the situation where each run transforms to martensite in between passes (quite apart from the risk for cracking in the latter instance).

It will be clear from this discussion that 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.

While it is feasible to pre-heat tools in a furnace, there is the possibility that the temperature is uneven (creates stresses) and that it will drop excessively before welding is completed (especially if the tool is small).

The best method of preheating and maintaining the tool at the requisite temperature during welding is to use an insulated box with electrical elements in the walls (see earlier).

Fig. 7 shows the differences in hardness distribution across welds which were made on tools preheated in a furnace and in an insulated box. It is clear that the tool preheated in a furnace shows a considerably greater scatter in hardness than that preheated in an insulated box.

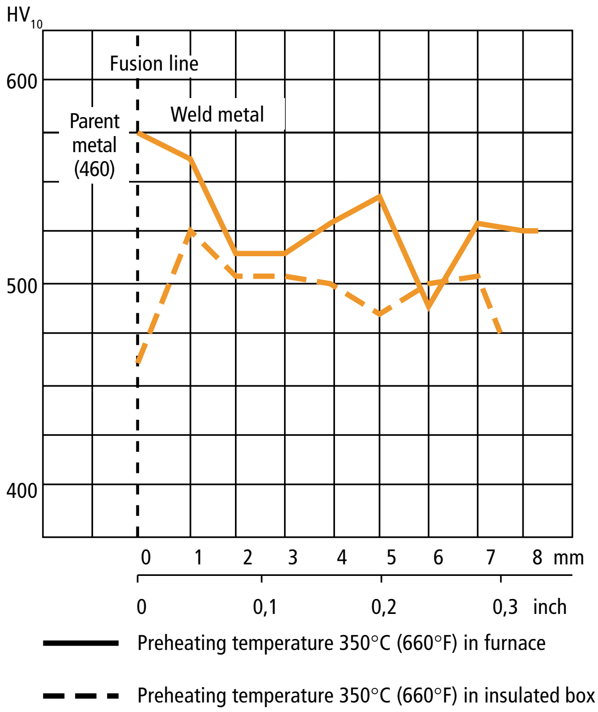


Fig. 7. Hardness distribution across welds using QRO 90 WELD where preheating has been performed in a furnace and in an insulated box.

Welding procedure

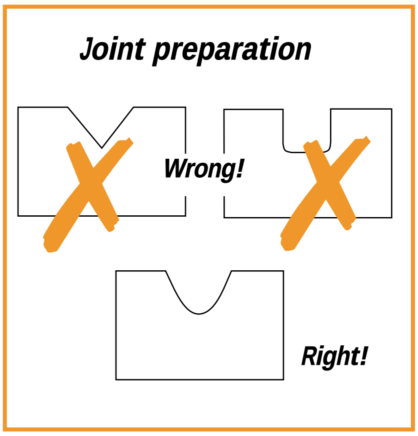
Even with the very best of equipment and properly designed consumables, tool steel can not be welded successfully unless considerable care is exercised in **joint preparation**, in the actual **welding operation**, and i performing proper **heat treatment after welding**.

JOINT PREPARATION

The importance of careful joint preparation can not be over-emphasized. Cracks should be ground out so that the joint slope at an angle of at least 30° to the vertical. The width of the joint bottom should be at least 1 mm (0.04 inch) greater than the maximum electrode diameter which will be used.

Erosion or heat-checking damage on hot work tools should be ground down to sound steel.

The tool surfaces in the immediate vicinity of the intended weld and the surfaces of the joint itself must all be ground down to clean metal. Prior to starting welding, the ground areas should be checked with penetrant to make sure all defects have been removed. The tool should be welded immediately joint preparation is finished, because otherwise there is risk for contamination of the joint surfaces with dust, dirt or moisture.



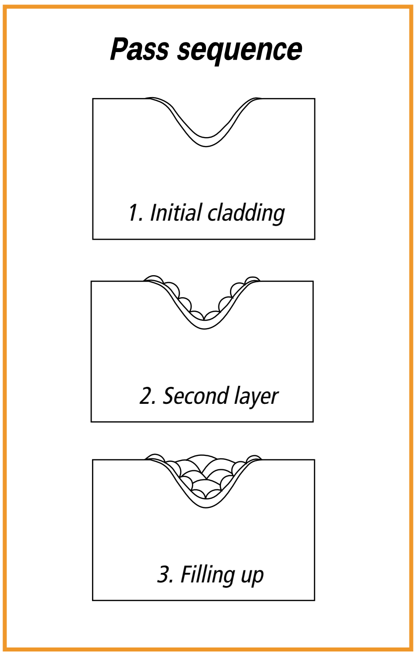
BUILDING UP THE WELD

First of all, the joint surfaces are clad in using an appropriate number of runs. This initial layer should be made with a small diameter MMA electrode (3,25 mm – 1/8 inch – Ø max.) or via TIG welding (max. current 120 A).

The second layer is made with the same electrode diameter and current as the first 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. The remainder of the joint bode can be welded with a higher current and larger-diameter electrodes.

The final runs should be built up well above the surface of the tool. Even small welds should comprise a minimum of two runs. Grind off the last runs.

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°C to the direction of forward movement.



The arc should be struck in the joint and not on any tool surfaces which are not being welded. The sore form striking the arc is 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 a partly-used MMA electrode, the tip should be cleaned free from slag; this assists striking the arc at the same time as a potential source of porosity is eliminated.

In building up edges or corners, both time and consumables can be saved by using a piece of copper plate or graphite as support for the weld metal (Fig. 8). Using such support also means that the molten pool i hotter which reduces the risk for pore formation (low currents need to be used when building up sharp edges or corners).

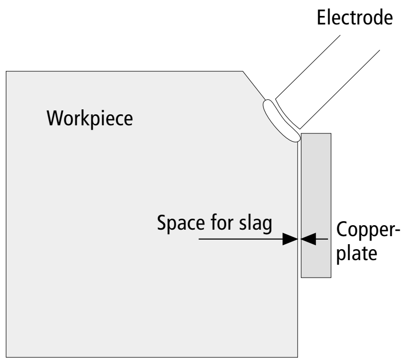


Fig. 8. A copper plate as support for the weld when building up corners.

If copper or graphite support is used, an extra 1,5 mm (0,06 inch) must be allowed between the support and the required weld surface because the slag takes up a certain amount of space (MMA welding).

For repair or adjustment of expensive tooling, e.g. plastic mould with a polished or textured cavity, 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(s) should be 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. Before 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.

HEAT TREATMENT AFTER WELDING

Depending on the initial condition of the tool, the following heat treatments may be performed following welding:

- Tempering
- Soft annealing, then hardening + tempering as usual
- Stress relieving.

Tempering

Fully-hardened tools which are repair welded should if possible be tempered after welding.

Tempering improves the toughness of the weld metal and is particularly important when the welded area is highly stressed in service (e.g. cold work and hot work tooling).

The tempering temperature should be chosen that the hardness of weld metal and base steel are compatible. An exception to this rule is when the weld metal exhibits appreciably improved temper resistance over the base material (e.g. *ORVAR SUPREME* welded with QRO 90 WELD); in this case, the weld should be tempered at the highest possible temperature concomitant with the base steel retaining its hardness (typically 20°C/40°F under the previous tempering temperature).

Product brochures for Uddeholm welding consumables and tool steels give tempering curves from which the tempering conditions for welded tools can be ascertained.

Very small repairs need not be tempered after welding; however, this should be done if at all possible.

Soft annealing

Tools which are welded to accommodate design changes or machining errors during toolmaking, 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 weld 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 the tool may be finished 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.

Stress relieving

Stress relieving is sometimes carried out after welding in order to reduce residual stresses. For very large or highly-constrained welds, this is an important precaution. If the weld is to be tempered or soft annealed, then stress relieving is not normally necessary. However, prehardened tool steel, e.g. *IMPAX SUPREME* welded with IMPAX WELD or IMPAX TIG-WELD, should be stress relieved after welding since no other heat treatment is normally performed.

The stress relieving temperature must be chosen such that neither the base steel nor the welded area soften extensively during the operation. If *IMPAX SUPREME* is to be machined after welding, it is absolutely essential that the mould is stress relieved in order that adequate dimensional stability is achieved.

Very small weld repairs or adjustments will normally not require a stress relieving treatment.

Further information

Information concerning heat treatment of the tool subsequent to welding can be obtained from the brochures for the welding consumable and/or the tool steel in question.

The following tables give details concerning weld repair or adjustment of tooling made from Uddeholm tool steel grades for hot work, plastic moulding and cold work applications.

WELD REPAIR OF HOT WORK TOOL STEEL

Uddeholm tool steel	Condition	Welding method	Consumables	Preheating temperature	Hardness as welded	Heat treatment	Remarks
VIDAR SUPREME	Soft annealed	MMA (SMAW)	QRO 90 WELD	Min. 325°C (620°F)	50–55 HRC	Soft annealing	Heat treatment See product information brochure for parent steel.
ORVAR SUPREME/ ORVAR 2 Microdized	Soft annealed	MMA (SMAW)	QRO 90 WELD	Min. 325°C (620°F)	50–55 HRC	Soft annealing	
QRO 90 SUPREME	Soft annealed	MMA (SMAW)	QRO 90 WELD	Min. 325°C (620°F)	50–55 HRC	Soft annealing	
DIEVAR	Soft annealed	MMA (SMAW)	QRO 90 WELD	Min 325°C (620°F)	50–55 HRC	Soft annealing	
ALVAR 14	Prehardened	MMA (SMAW)	UTP 73G4 ESAB OK 83.28	225–275°C (430–520°F)	340–390 HB 340–390 HB	None	Stress relieve large repairs.
VIDAR SUPREME	Hardened	MMA (SMAW)	QRO 90 WELD	Min. 325°C (620°F)	50–55 HRC	Tempering	10–20°C (20–40°F) below the original tempering temperature.
ORVAR SUPREME/ ORVAR 2 Microdized	Hardened	MMA (SMAW)	QRO 90 WELD	Min. 325°C (620°F)	50–55 HRC	Tempering	
QRO 90 SUPREME	Hardened	MMA (SMAW)	QRO 90 WELD	Min. 325°C (620°F)	50–55 HRC	Tempering	
DIEVAR	Hardened	MMA (SMAW)	QRO 90 WELD	Min 325°C (620°F)	50–55 HRC	Tempering	

Uddeholm tool steel	Condition	Welding method	Consumables	Preheating temperature	Hardness as welded	Heat treatment	Remarks
VIDAR SUPREME	Soft annealed	TIG (GTAW)	QRO 90 TIG-WELD	Min. 325°C (620°F)	50–55 HRC	Soft annealing	Heat treatment See product information brochure for parent steel.
ORVAR SUPREME/ ORVAR 2 Microdized	Soft annealed	TIG (GTAW)	QRO 90 TIG-WELD	Min. 325°C (620°F)	50–55 HRC	Soft annealing	
QRO 90 SUPREME	Soft annealed	TIG (GTAW)	QRO 90 TIG-WELD	Min. 325°C (620°F)	50–55 HRC	Soft annealing	
DIEVAR	Soft annealed	TIG (GTAW)	QRO 90 TIG-WELD DIEVAR TIG-WELD	Min 325°C (620°F)	50–55 HRC	Soft annealing	
ALVAR 14	Prehardened	TIG (GTAW)	UTPA 73G4 ESAB OK Tigrod 13.22	225–275°C (430–520°F)	340–390 HB 340–390 HB	None	Stress relieve large repairs.
VIDAR SUPREME	Hardened	TIG (GTAW)	QRO 90 TIG-WELD	Min. 325°C (620°F)	50–55 HRC	Tempering	10–20°C (20–40°F) below the original tempering temperature.
ORVAR SUPREME/ ORVAR 2 Microdized	Hardened	TIG (GTAW)	QRO 90 TIG-WELD	Min. 325°C (620°F)	50–55 HRC	Tempering	
QRO 90 SUPREME	Hardened	TIG (GTAW)	QRO 90 TIG-WELD	Min. 325°C (620°F)	50–55 HRC	Tempering	
DIEVAR	Hardened	TIG (GTAW)	QRO 90 TIG-WELD DIEVAR TIG-WELD	Min 325°C (620°F)	50–55 HRC	Tempering	

WELD REPAIR OF PLASTIC MOULD STEEL

Uddeholm tool steel	Condition	Welding method	Consumables	Preheating temperature	Hardness as welded	Heat treatment	Remarks
STAVAX ESR	Soft annealed	MMA (SMAW)	STAVAX WELD	200–250°C (390–480°F)	54–56 HRC	Soft annealing	Heat treatment See product brochure for parent steel.
STAVAX ESR	Hardened	MMA (SMAW)	STAVAX WELD	200–250°C (390–480°F)	54–56 HRC	Tempering	Tempering temp. 200–250°C (390–480°F)
IMPAX SUPREME	Prehardened	MMA (SMAW)	IMPAX WELD	200–250°C (390–480°F)	320–350 HB	None	Stress relieve large repairs.
GRANE	Hardened	MMA (SMAW)	UTP 73G2 UTP 67S	225–275°C (430–520°F)	55–58 HRC	Tempering	Tempering temp. 200–250°C (390–480°F)
RAMAX S	Prehardened	MMA (SMAW)	STAVAX WELD	200–250°C (390–480°F)	54–56 HRC	Tempering	Tempering temp. 590–630°C (1090–1170°F)
HOLDAX	Prehardened	MMA (SMAW)	IMPAX WELD	150–200°C (300–390°F)	320–350 HB	None	Stress relieve large repairs.
ELMAX	Hardened	MMA (SMAW)	Inconel 625 type UTP 701	250–300°C (480–570°F)	280 HB approx. 56 HRC (initial plus finishing layers respectively)	Tempering at 200°C (390°F)	Welding of ELMAX should generally be avoided, due to the risk for cracking.
CALMAX	Soft annealed	MMA (SMAW)	CALMAX/CARMO WELD	200–250°C (390–480°F)	59–62 HRC	Soft annealing	See product brochure
CALMAX	Hardened	MMA (SMAW)	CALMAX/CARMO WELD	180–250°C (360–480°F)	59–62 HRC	Tempering	Contact your local Uddeholm office.

Uddeholm tool steel	Condition	Welding method	Consumables	Preheating temperature	Hardness as welded	Heat treatment	Remarks
STAVAX ESR	Soft annealed	TIG (GTAW)	STAVAX TIG-WELD	200–250°C (390–480°F)	54–56 HRC	Soft annealing	Heat treatment See product brochure for parent steel.
STAVAX ESR	Hardened	TIG (GTAW)	STAVAX TIG-WELD	200–250°C (390–480°F)	54–56 HRC	Tempering	Tempering temp. 200–250°C (390–480°F)
IMPAX SUPREME	Prehardened	TIG (GTAW)	IMPAX TIG-WELD	200–250°C (390–480°F)	320–350 HB	None	Stress relieve large repairs.
GRANE	Hardened	TIG (GTAW)	UTPA 73G2 UTPA 67S	225–275°C (430–520°F)	55–58 HRC	Tempering	Tempering temp. 200–250°C (390–480°F)
RAMAX S	Prehardened	TIG (GTAW)	STAVAX TIG-WELD	200–250°C (390–480°F)	54–56 HRC	Tempering	Tempering temp. 590–630°C (1090–1170°F)
HOLDAX	Prehardened	TIG (GTAW)	IMPAX TIG-WELD	150–200°C (300–390°F)	320–350 HB	None	Stress relieve large repairs.
ELMAX	Hardened	TIG (GTAW)	UTPA 701	250–300°C (480–570°F)	~56 HRC	Tempering at 200°C (390°F)	Welding of ELMAX should generally be avoided, due to the risk for cracking.
CALMAX	Soft annealed	TIG (GTAW)	CALMAX/ CARMO TIG-WELD	200–250°C (390–480°F)	58–61 HRC	Soft annealing	See product brochure
CALMAX	Hardened	TIG (GTAW)	CALMAX/ CARMO TIG-WELD	180–250°C (360–480°F)	58–61 HRC	Tempering	Contact your local Uddeholm office.
CORRAX	Solution treated	TIG (GTAW)	CORRAX TIG-WELD	None	30–35 HRC	Ageing	See produc brochure CORRAX TIG-WELD
CORRAX	Aged	TIG (GTAW)	CORRAX TIG-WELD	None	30–35 HRC	Depending on hardness	

WELD REPAIR OF COLD WORK TOOL STEEL

Uddeholm tool steel	Condition	Welding method	Consumables	Preheating temperature	Hardness as welded	Heat treatment	Remarks
ARNE	Hardened	MMA (SMAW)	AWS E312 ESAB OK 84.52 UTP 67S Castolin 2 Castolin N 102	200–250°C (390–480°F)	300 HB 53–54 HRC 55–58 HRC 54–60 HRC 54–60 HRC	Tempering	Initial layers welded with soft weld metal. Choose consumable for finishing layers which gives suitable hardness. For FERMO and CARMO, small repairs can be made with tool at ambient temperature.
FERMO	Prehardened	MMA (SMAW)		200–250°C (390–480°F)			
RIGOR	Hardened	MMA (SMAW)		200–250°C (390–480°F)			
VIKING	Hardened	MMA (SMAW)		200–250°C (390–480°F)			
SVERKER 21	Hardened	MMA (SMAW)	Inconel 625 type UTP 67S Castolin 2 Castolin 6	200–250°C (390–480°F)	280 HB 55–58 HRC 56–60 HRC 59–61 HRC	Tempering	
SVERKER 3	Hardened	MMA (SMAW)		200–250°C (390–480°F)			
VANADIS 4	Hardened	MMA (SMAW)	Inconel 625 type Castolin 6	200–250°C (390–480°F)	280 HB 59–61 HRC	Tempering	
SLEIPNER	Hardened	MMA (SMAW)	AWS E312 UTP 69 Castolin 6	250°C (480°F)	300 HB 60–64 HRC 59–61 HRC	Tempering	
CARMO	Prehardened	MMA (SMAW)	CALMAX/CARMO WELD	200–250°C (390–480°F)	59–62 HRC	Tempering	
CALMAX		MMA (SMAW)	See "Weld repair of plastic mould steel"				

Note: Consumables with high carbon content are generally not recommended for MMA welding because of the cracking risk

Uddeholm tool steel	Condition	Welding method	Consumables	Preheating temperature	Hardness as welded	Heat treatment	Remarks
ARNE	Hardened	TIG (GTAW)	AWS ER 312 UTPA 67S UTPA 73G2 Castotig 5	200–250°C (390–480°F)	300 HB 55–58 HRC 53–56 HRC 60–64 HRC	Tempering	Initial layers welded with soft weld metal. Choose consumable for finishing layers which gives suitable hardness. For FERMO and CARMO, small repairs can be made with tool at ambient temperature. Castotig 5 should not be used for more than 4 layers (cracking risk).
FERMO	Prehardened	TIG (GTAW)		200–250°C (390–480°F)			
RIGOR	Hardened	TIG (GTAW)		200–250°C (390–480°F)			
VIKING	Hardened	TIG (GTAW)		200–250°C (390–480°F)			
SVERKER 21	Hardened	TIG (GTAW)	Inconel 625 type UTPA 73G2 UTPA 67S UTPA 696 Castotig 5	200–250°C (390–480°F)	280 HB 53–56 HRC 55–58 HRC 60–64 HRC 60–64 HRC	Tempering	
SVERKER 3	Hardened	TIG (GTAW)		200–250°C (390–480°F)			
VANADIS 4	Hardened	TIG (GTAW)	Inconel 625 type UTPA 73G2 UTPA 696 Castotig 5	200–250°C (390–480°F)	280 HB 53–56 HRC 60–64 HRC 60–64 HRC	Tempering	
SLEIPNER	Hardened	TIG (GTAW)	AWS ER 312 UTPA 696 Castotig 5	250°C (480°F)	300 HB 60–64 HRC 60–64 HRC	Tempering	
CARMO	Prehardened	TIG (GTAW)	CALMAX/CARMO TIG-WELD	200–250°C (390–480°F)	58–61 HRC	Tempering	
CALMAX		TIG (GTAW	See "Weld repair of plastic mould steel"				