Welding of Tools & Dies

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INTRODUCTION

Tools, dies & molds are used in Industrial metal forming and cutting applications, viz; casting , forging, stamping, extrusion, trimming, coining etc. Tool, die & mould steels are special grade of materials, with unique mechanical properties to suit a specific application. Tool & Die steels are characterized by a combination of properties, such as :

1) Hot Hardness
2) Edge retention
3) Mechanical strength & toughness
4) Red Hardness

Tool & Die steels are highly alloyed materials, containing 0.30 to 2.00% Carbon and other alloying elements like, Manganese, Silicon, Nickel, Chromium, Molybdenum, Vanadium, Tungsten, Cobalt, Niobium.

Carbon & alloy content of Tool & die steels, promotes :

a] High hardenability (depth of hardening),
b] High hardness
c] Wear Resistance
d] Red Hardnes

Selection of tool & die steels is based on a trade-off between various properties, described above, to suit a particular application. These properties are dependent on

a] Alloy content
b] Subsequent Heat Treatment

Tool & die steels are classified by the American Iron & Steel Institute [AISI] and the Society of Automotive Engineers [SAE] into 7 major groups, given in Table. 1 below.

TABLE.1 - MAJOR TOOL STEEL GROUPS, PROPERTIES & USES

AISI/SAE Steel Specification	Group	Type of Steel	Properties	Uses
W1, W2	Water Hardening	Plain carbon	Tough core, hard wear resistant	Trim dies, Cold header dies, punches
S1, S5, S7	Shock Resisting	Med-carbon, Low-alloy	Excellent toughness & strength	Blanking dies , forming rolls, slitting cutters
O1, O6	Oil Hardening	Medium alloy	Wear resistant at moderate temperature	Dies and punches
A2, A4	Air Hardening	Medium alloy	Dimensionally stable	Dies, punches, forming rolls
D2	Air Hardening	High carbon, High chromium	Hardness & wear resistance	Shear blades, stamping dies
H11, H12, H13	Hot Work	Chromium Tungsten Molybdenum	Toughness & Red hardness	Hot extrusion dies
M1, M2, M10, T1, T2, T4	High speed	Molybdenum Tungsten	High hardenability	Drills reamers, broaches
P20, P21	Mold	Low-carbon	Low hardness & resistance to work hardening	Die casting dies, Injuction molding dies
L2, L6	Special Purpose	Low-alloy	High toughness & strength	Arbors, chucks, Spindles

Weldability of Tool & Die steels

High alloy content and heat treatment of tool & die steels increases their hardness, wear resistance, hardenability and dimensional stability.

Tool & die steels, therefore, possess better mechanical properties and have superior performance in forming & cutting of other materials like Carbon & Low alloys steel.

However, increased alloy content and hardness of tool & die steels, reduces lowers their weldability considerably. Tool & Die steels, are therefore,more difficult to weld than low alloy steels . For example, Air-hardenable tool & dies steels like, high carbon high chrome, require greater care to be exercised during welding due to their higher alloy content and hardenability.

The cooling curve in the Isothermal transformation (T-T-T)diagram, Fig.1, shows the control of cooling rate to avoid martensitic transformation in the tool & die steel.

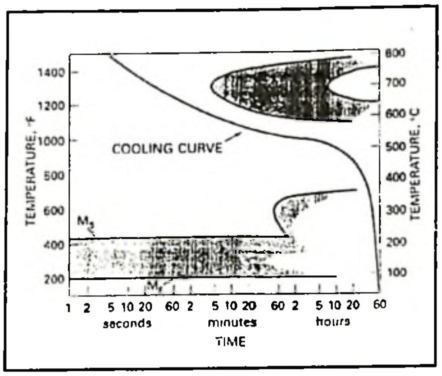

Fig. 1 Cooling Curve Avoiding Martensitic Transformatin Plotted Isothermal Transformation Diagram

Scope of Welding of tool & die steels :

Welding of tool & die steels is grouped in to following five areas.

1] Weld assembly of components into single tool or die.

2] Composite fabrication of tool or die.

3] Modification of tool or die for engineering changes.

4] Repair of cracks, damaged areas

5] Rebuilding of worn surfaces and cutting edges.

Most of the scope for welding of tool & die steels is for:

a] Rebuilding of worn surfaces and cutting edges.

b] Composite fabrication of Tools .

Welding Process

Electric arc welding processes, like SMAW, GTAW, GMAW, FCAW, can be used for welding of tool & die steels . Selection of a process depends on the :

a) size of the tool or die & its complexity of design

b) amount of weld metal to be deposited

c) preheat, interpass temperature control

d) post weld cooling

e) availability of suitable filler alloy.

SMAW process is most widely used for tool & die welding as it offers great flexibility in terms of electrodes and ease of deposition.

Advantages of SMAW process are :

a) Flexibility

b) Accessibility

c) Positional welding

d) Simple power source AC/DC

e) Electrodes as welding consumables with range of composition and properties.

Filler Alloy :

Selection of a suitable filler alloy for tool & die welding depends on the following factors :

a) Composition and heat treatment tool & die material

b) Location of welding functional / non-functional area

c) Amount of buildup or overlay

d) Properties required in "as welded " or heat treated condition.

For many tool & die welding applications, the filler alloy weld deposit and the base metal are required with similar response to the heat treatment. Generally, filler alloys are made with slightly lower carbon and increased alloy content for greater toughness and to minimize weld deposit cracking.

While selecting a filler alloy for welding tool & die steels in hardened & tempered condition, a filler alloy depositing a weld metal with red hardness, strength, edge retention properties in "as welded "or stress relieved / tempered condition, is preferred for rebuilding the cutting edges or impression in the die.

However, if scope of weld deposition is in the non functional area of the tool or die, a filler alloy depositing a weld metal with maximum resistance to cracking, higher toughness and ductility, may be selected to achieve satisfactory welding of Tools & Dies.

Welding Procedures & Practices

Tool & die welding should, preferably be done in Annealed condition, whenever feasible. Tool & die materials when welded in hardened & tempered condition, exhibit higher susceptitalbility to cracking.

Welding procedure for tool & die welding must be planned well and developed on the basis of factors which produce a desired performance in service. Procedure for welding of tool & die is listed below :

1) Assessment of the scope of welding

2) Identification of the type of tool or die material to be welded

3) Grinding / Polishing of surface defects

4) Dye-penetrant checks.

5) Selection of suitable welding process and filler alloy.

6) Preheat & Interpass temperature depending on the type of tool & die material, as given in Table 2

7) Slow cooling to room temperatures, especially large tools & dies, to prevent cracking in the heat affected zone.

8) Short, stringer weld bead sequence to minimize heat input.

9) Skip welding, Back-step welding technique to maintain interpass temperature.

10) Hot peening of weld deposits to prevent weld cracking.

Welding applications of Tools & Dies

Some of the key applications in Rolling Mills, Tube Mills, Hot Forging of automotive components, tool & dies lose material from their functional areas due to repeated contact with hot metal, impact loads and abrasion by hot metal scale. This results in wear out of impression areas cutting edges, cavity and die opening.

Automotive forming & stamping dies, Drop and Press Forging dies, hot and cold shear blades in steel rolling mils, piercing punches and hot upsetting / heading dies, plastic injection molds are typical examples of high welding potential in the scope of tool & die welding.

		Preheat & Interpass Temperature ^{0}C	
AISI/SAE Steel Specification	Type of Steels	Annaled Base Metal	Hardened Base Metal
W1, W2	Water Hardening	120-230	120-230
S1, S5, S7	Sock Resisting	150-260	120-260
O1, O6	Oil Hardening	150-205	150-205
A2, A4	Air Hardening	150-260	150-205
D2	Air Hardening	370-480	370-480
H11, H12, H13	Hot Work	480-650	370-540
M1, M2, M10, T1, T2, T4	High speed	510-595	510-565

Table .2 - Typical preheat & interpass temperatures for welding types of tool steels.

Welding of Automotive stamping dies.

Automotive stamping dies are massive in size, made form either gray or ductile (nodular) irons. Due to repeated stamping operations, these dies undergo loss of profile, change of dimensions due to

a) constant metal to metal contact

b) relative movement between steel sheet & cast iron surface.

Cast Iron surfaces of the stamping die show metal removal, scoring and some times minor cracks, which affects the quality of the stampings.

These defects on stamping die working area, can be corrected by a weld deposition procedure described below :

1) Identification of cast Iron Gray cast iron, ferritic or pearlitic nodular Iron.

2) Grinding of cracks and other defects.

3) Cleaning & degreasing

4) Dye-penetrant check

5) Searing the weld area with a flame.

6) Preheating to 250-300 C

7) Short, skip & back-step welding, staggered welding

8) Hot peening of weld deposits

9) Slow cooling to ambient temperature.

Selection of Filler Alloy

For successful welding of automotive stamping dies, the selection of an appropriate filler alloy is critical. The automotive stamping dies, are very old, contaminated and used for a long time.

The filler alloy has to be designed with operating characteristics like, penetrating arc force, scavenging action, and a quick freezing alloy having excellent compatibility with cast Iron. Weld deposit in single and multi-pass should have high mechanical strength and hardness of 42-44 HRC.

Welding of Forging Dies

In the recent years, the Forging Industry has shown excellent growth due to growing demand of the automotive sector. The wide range of forged automotive components, shown in Fig.2, forms the basis of large tonnage of forging used in the automotive Industry.

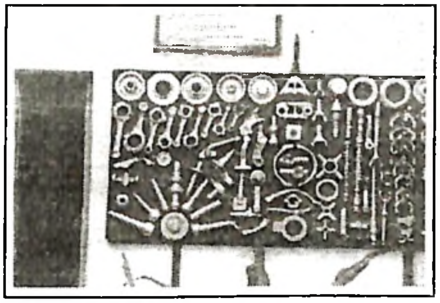

Fig.2 - Automotive Forgings

Automotive forgings are produced by hammering or pressing a hot billet / blank in an open or closed die cavity. Forging quality steel, heated billet / blank, is forged in three sets of dies called Buster, Blocker & Finisher, as shown in Fig.3

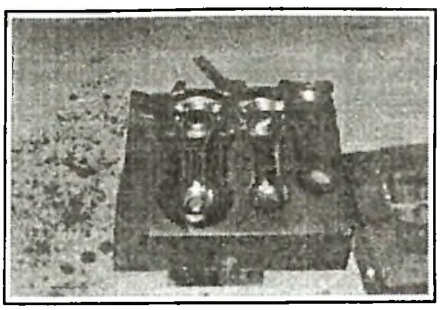

Fig.3 - Connecting Rod Forging Die

Two major types of forging processes are used in manufacturing of automotive components, viz, Drop or Hammer Forging and Press forging.

During the forging operations, the forging die impressions are subjected to high mechanical and impulsive loads, abrasion by hot metal scale, and thermal fatigue. Die Impressions undergo change in profile, dimensions and tolerance.

Forging dies therefore, undergo excessive wear, thermal checking, cracking in the die impression and the die cavity.

With rising cost of die blocks, forging industry relies greatly on the weld repair & rebuilding of the damaged die blocks, shown in Fig. 4

Fig.4 - Damaged Forging Die Blocks

Three major areas of welding of forging dies are :

1) Rebuilding of worn out lower & upper die impressions

2) Repair of cracks in the die cavity or die block.

3) Complete fill-up of die cavity and re-sinking " Flood welding "

The first two areas of welding of forging dies, viz, rebuilding of worn out impressions and repair of cracks in the die block, is very widely used in the forging industry for smaller sizes of die blocks, as shown in Fig. 5

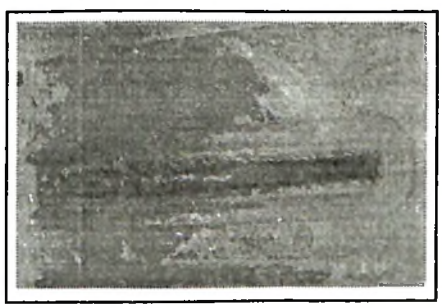

Fig.5 - Rebuilding of small Axle Forging die block

"Flood Welding"- a modified SMAW process using a specially manufactured power source of 1000 Amps output, large electrode diameters upto 19mm and electrode manipulators, oxy-fuel heating torch to preheat and maintain interpass temperatures through out the weld deposition process. Deposition rates up to 14Kg./ hr are obtained. Flood-welding " of forging dies is done after the die impressions have been completely machined out and the die cavity so formed, is completely filled up with the weld metal.

Weldability of Forging die block materials

Forging dies are manufactured from either low-alloy steel similar to AISI 4350, a Ni-Cr-Mo- alloy steel, or AISI H-12 or AISI-13, Hot work Tool steel , forged & heat treated to a hardness range of 37-40 HRC. The die block materials with multiple alloying elements,exhibit a high hardenability characteristics as shown in Fig. 6

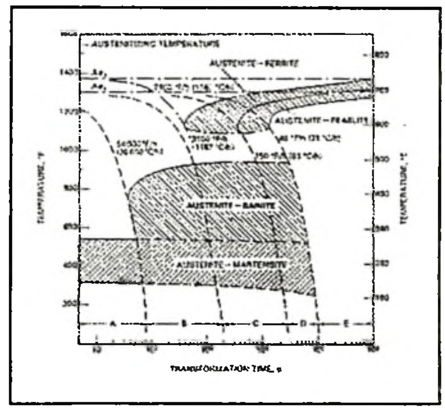

Fig.6 T-T-T- Diagram for AISI 4350 Steel

Even with lower cooling rates, the cooling curve shows the formation of hard martensitic phases at lower temperatures due to higher hardenabiltiy of die block materials.

This is of great importance in the Heat Affected zone in the base metal during weld deposition in the die impression areas.

Filler Alloy :

Selection of filler alloy for rebuilding of worn out lower and upper die impression and repair of cracks in forging dies, depends on the specific properties of the weld metal required in the operating environment.

Table 3. - Typical mechanical properties of filler alloys for forging dies

Area	Tensile Strength MPa	Yield Strength	% Elongation	% Reduction in area MPa	CVN Impact strength - J
Lower Impression	1150	900	10	30	28
Upper Impression	1300	1100	2	5	-----

For rebuilding of the lower & upper impressions in the forging dies, the weld metal should have higher mechanical properties, higher hardness in " as welded ' condition, compared to the original die block material.

Filler alloys, generally , have a composition different from that of the die block material. Filler alloys are manufactured with lower carbon & higher alloy content , to obtain desired mechanical properties like high tensile & yield strength, high CVN impact strength.

Typical mechanical properties of the filler alloys used for rebuilding of lower & upper impressions in the forging dies are given below in Table.3

The operating characteristics of welding consumable as filler alloy are also important factor in rebuilding of forging dies. The depth of lower impression is more. Accessibility & manouvering of the welding electrode is limited. Therefore, the welding electrode should have ;

a) Excellent arc stability ,
b) Ease of arc strike, / re-strike
c) Multipass weld deposition with quick-freezing alloy characteristics,
d) Non-conducting covering to prevent accidental arcing
e) Low density slag with good cleansing action.
f) Highly moisture resistant coating of low diffusible hydrogen, less than 5ml. / 100 gms. of weld metal, to prevent Hydrogen Induced cracking.

Rebuilding of Hot Shear Blades

Hot shear blades are used for cropping of Billets & Merchant Mill products to required lengths. Due to repetitive contact with hot metal, thermal checking, intermittent cooling and shearing action of the blade for parting the products, the blade edges undergo loss of shape and sharpness. The size of hot shear blades, varies depending or the location in the rolling mills. Rebuilding of the worn shearing edges of the Hot shear blades is regularly done by weld alloy deposition. The weld alloy is a specially developed Iron-base alloy with Nickel & Molybdenum as alloying additions. The microstructure of the alloy consists of finely dispersed carbides in a tough bainitic matrix.

Rebuilding procedure for hot shear blades :

1) Grind /gouge worn-out, chipped edges.
2) Dye penetrant check
3) Preheat to temperature of 200-250 ^{o}C
4) Maintain interpass temperature of 250-300 ^{o}C
5) Short, stringer weld bead
6) Hot peen weld deposit.
7) Slow cool to ambient temperature

& life prolonging solutions for rebuilding and repair of tools & dies in the industry.

CONCLUSION

With the present day requirements of global markets for high quality and competitively priced products, there is greater need for high productivity manufacturing processes. To match the high volume output of new generation machines, higher performance of tools & dies assumes greater importance. This offers an ever growing potential for new types of welding filler alloys, welding processes and procedures to rebuild the die impressions and cutting edge with longer service life, thereby reducing the number of regrinds, tool & die replacements, and machine downtime.

While tool & die materials are more difficult to weld compared to the carbon & low alloy steels, innovative approach based on the metallurgy of tool & die steels, composition & operating characteristics of welding filler alloys, heat treatment and a carefully developed welding procedure, provides, cost effective.