

Strength Behaviour of Hot Die Steel with Respect to its Heat Treatment



Md Gulam Sarvar, Vishal Jagota

Abstract: The surface temperature of hot die steel reaches typically up to 550°C or above during processes like hot extrusion and casting non-ferrous material. The present paper explores the impact of austenitizing temperature as well as tempering temperature on the tensile strength of hot die steel. Heat treatment is done at three different austenitizing temperatures of 1010°C, 1030°C, and 1050°C, followed by tempering done at two different temperatures of 540°C and 580°C. Tempering is done twice for two hours. Metallographic grinding, polishing, and then etching using 2% Nital is done to investigate the microstructure of hot die steel with respect to its heat treatment. It is found that the grain size of hot die steel increases with an increase in austenitizing temperature. The impact on tensile strength of hot die steel for its heat treatment is examined by conducting the uniaxial tensile test to fracture. And investigation of the morphology of the fracture surface produced after the tensile test is done. It was found that hot die steel with large grain size exhibits lesser tensile strength. Whereas, the one having smaller grain has higher tensile strength that is found to be in accordance with the Hall-Patch equation.

Keywords: Grain size, Heat treatment, Hot die steel, Tensile strength.

I. INTRODUCTION

H13 tool steel has good strength, wear-resistance, and impact toughness. Its major alloying elements along with Carbon are Chromium, Molybdenum, Vanadium, and Silicon [1]. H13 steel has good strength properties by virtue of alloy carbides like Mo₂C and VC. Steel with finer grain usually has better mechanical properties (i.e., toughness and strength) in comparison to the one having coarse size grain. The mechanical properties of steel, particularly strength, increases with a reduction in grain size. The relationship between grain size and mechanical properties of steel can be explained by the Hall-Petch equation that states smaller the grain size higher the strength [2]. Similar to all hot die steel, H13 is also heat-treated to attain the properties like resistance to wear and getting softer at the elevated temperature. Commonly H13 steel is used in the martensitic phase as this phase provides the increased high-temperature strength [3]. The martensitic

phase is achieved by quenching H13 steel at a temperature of around 990 to 1050°C. Quenching causes an increase in the hardness at high-temperature values [4]. The formation of martensite is a process in which steel at the austenitic phase is heated and then rapidly cooled enough to avoid the formation of the pearlite [5]. For achieving the desired martensite structure, the steel has to undergo the structural rearrangement in which the atoms are changed from the face-centered cubic to the body-centered tetragonal structure. This process causes an increase in the volume of the steel, thus making it at a highly stressed condition, which makes martensite harder than the austenite, although they have the same chemistry [6]. Tempering temperature when raised causes precipitation of alloy carbides initially and then decreases the martensite tetragonality and finally produces the BCC ferritic matrix of tempered martensite [7, 8].

II. MATERIALS AND TEST

The sample material used for experimentation is a hot rolled and annealed round bar of diameter 10.6 mm. H13 tool steel when tested for chemical composition by spectroscopy is found to have 0.38 wt.% of C, 4.89 wt.% of Cr, 1.11 wt.% of V, 1.32 wt.% of Mo, 0.99 wt.% Si, 0.36 wt.% of Ni and 0.35 wt.% of Mn. H13 tool steel is austenitized at different temperatures to explore the impact of austenitizing temperature on its strength behavior. The austenitizing of H13 steel samples is done at different austenitizing temperatures at 1010°C, 1030°C, and 1050°C in a vacuum furnace. Half of the samples were tempered twice at temperature 540°C, and another half was tempered twice at 580°C.



Figure 1: Universal Testing Machine for measuring tensile strength.

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Microscopic investigation for micro-structure is done after grinding and polishing and then etching with 2% Nital. Polishing machine is used with emery paper of various grade from rough 400, 600, 800 and then fine grain 1200, 2000, 2500, 3000. The H13 tool steel rods were machined into dumbbell shaped samples after performing the heat treatment process. Samples for tensile testing are prepared of dumbbell shape having 150 mm length and neck dia 7.2 mm. Tensile strength is tested with the help of an universal testing machine (make: FIE). For each experiment condition, three tests are performed, and the mean is taken. Fracture surface post tensile testing is analysed to check the behaviour of H13 die steel corresponding to different austenitizing temperatures. The fracture surface is investigated using scanning electron microscope (SEM) to find the difference in fracture behaviour. The UTM used for the uniaxial tensile testing to fracture is shown in figure 1 (make FIE). Its maximum load capacity was 200kN with an accuracy of 0.1kN.

III. RESULTS AND DISCUSSION

Austenitizing is done with three different austenitizing temperatures i.e., 1010°C, 1030°C and 1050°C. After that as per design of experiment (DOE) H13 tool steel is tempered twice at different tempering temperature of 540°C and 580°C. Also, few samples are kept without doing tempering to test them later for impact of austenitizing temperature on their strength and microstructure. Post heat treatment universal testing machine (UTM) is used for tensile strength test and scanning electron microscope (SEM) is used for measuring grain size. Table 1 shows the experimental data acquired during tensile testing and grain size measurement of H13 tool steel after different heat treatment combinations.

Table 1 Grain size and tensile strength w.r.t. heat treatment parameters.

Sr. No.	Austenitizing Temperature (°C)	Tempering Temperature (°C)	Tensile Strength (kN/mm ²)	Grain size (µm)
1	1010	As quench	1.248	7.1
2	1010	540	1.927	6.6
3	1010	580	2.158	5.9
4	1030	As quench	1.129	9.0
5	1030	540	1.881	8.8
6	1030	580	2.083	8.2
7	1050	As quench	1.028	9.9
8	1050	540	1.795	9.4
9	1050	580	1.937	8.8

Figure 2 shows the decrease in tensile strength in H13 steel with an increase in austenitizing temperature. The decrease in UTS is due to an increase in grain size at higher austenitizing temperature, which is in accordance with the Hall-patch equation.

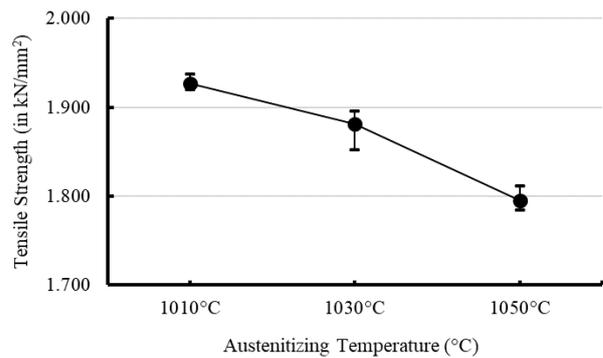


Figure 2: Tensile strength at different austenitizing temperature.

The fractography of fracture surfaces of H13 steel samples is investigated using SEM. H13 steel austenitized at 1010°C and tempered twice at 580°C has a rupture structure of fracture surface different from the one tempered at 540°C. Lips formation on the rupture surface are visible in figure 3(a), 4(a), and 5(a) for surface fractured during testing of sample austenitized at 1010°C, 1030°C, and 1050°C with tempering done at 580°C. It has a high value of UTS, and transgranular quasi-cleavage fracture has occurred in these samples. The fractography of the sample tempered at 540°C exhibits a mesh-like rough fracture surface. Whereas sample tempered at 580°C some cleavage facets, as shown in figures 3(b), 4(b), and 5(b). It also shows raising lips and rough structure of the rupture surface that indicates enhanced tensile strength.

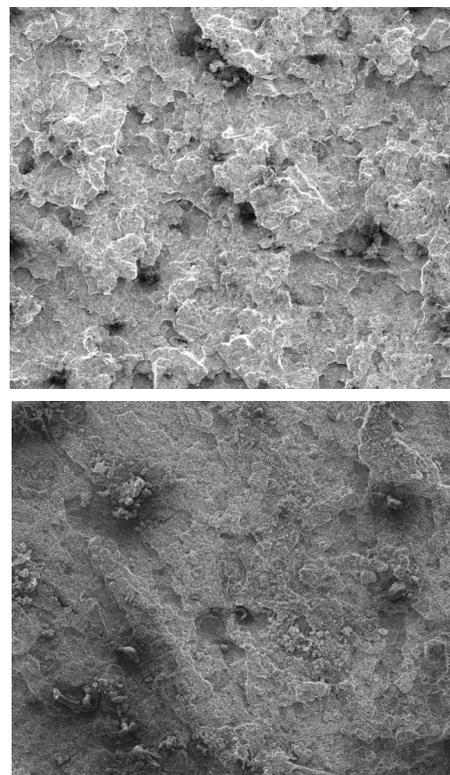


Figure 3 Fracture surface of H13 steel austenitized at 1010°C and (a) Tempered at 580°C, (b) Tempered at 540°C.

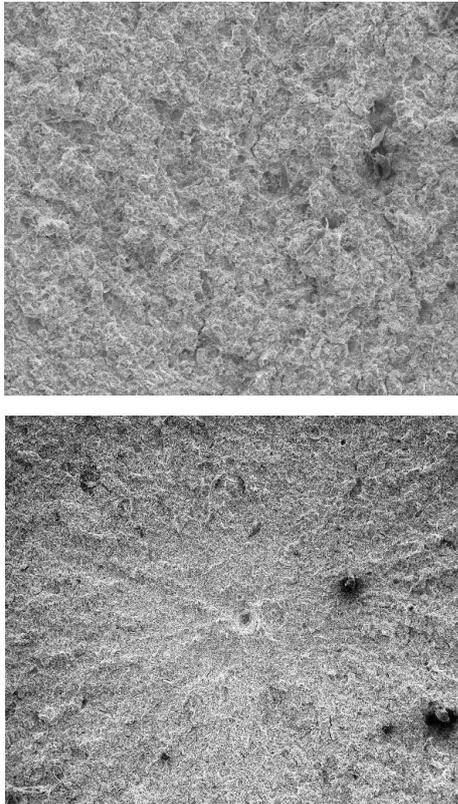


Figure 4: Fracture surface of H13 steel austenitized at 1030°C and (a) Tempered at 580°C, (b) Tempered at 540°C.

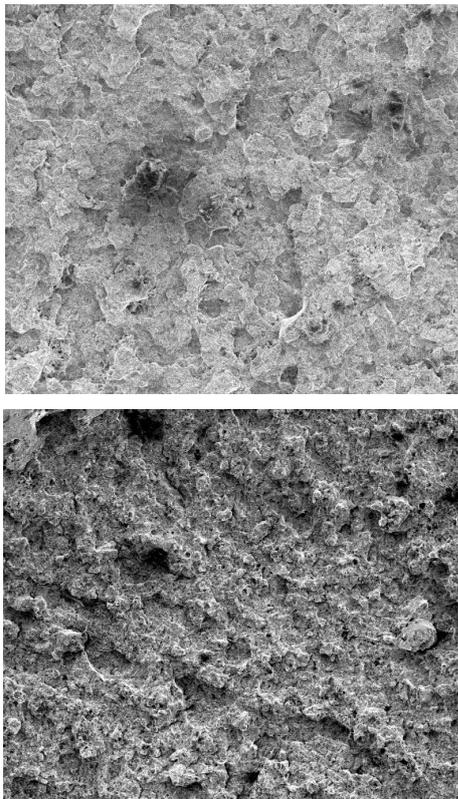


Figure 5: Fracture surface of H13 steel austenitized at 1050°C and (a) Tempered at 580°C, (b) Tempered at 540°C.

IV. CONCLUSION

The heat treatment process parameters like austenitizing temperature and tempering temperature influence the mechanical properties and grain size of H13 steel. Based on these experimental results, it is found that the ultimate tensile strength (UTS) of H13 steel diminishes with the rise in austenitizing temperature from 1010°C to 1050°C when tempering is not done. However, tensile strength increases as the tempering temperature increases from 540°C to 580°C. The austenitizing temperature influences the grain size, and grain size increases from 5.9µm to 9.9 µm with an increase in austenitizing temperature. H13 steel with the largest grain size gives the lowest tensile strength as compared to the H13 tool steel having smaller grain size. The UTS increases as the grain size decreases, and it became a minimum of 1.795 kN/mm² at 1050°C as compared to 1.927 kN/mm² at 1010°C. The grain size decreases as tempering temperature increases. In tempered H13 steel samples, the maximum value of grain size is nine µm, which is observed at 540°C tempering temperature after austenitizing at 1050°C.

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