Condition test of H11 Alloy Steel for application as FIR in CRM

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Abstract **-** Specifically for hot work applications, the current study sought to develop an optimal heat treatment strategy for H11. AISI H11 is chromium tool steels, which means they have excellent toughness and hardness, making them ideal for high-load metalforming operations. When it comes to hot-work forging and extrusion, the H11 grade of steel is excellent option. The die and tooling can be made to last longer and be more precise by heat treating this alloy steel. In spite of its suitability for both hot and cold work, the use of H11 steel for metalworking dies and tools is surprising. Die designers and hot-work practitioners can benefit from the findings presented here by exploring the tool steel's versatility and implementing appropriate heat treatment strategies for various applications such as Cold Rolling Cluster Rolling Mill (CRM) tool named as First Intermediate Roll (FIR) which supports Work Roll for efficient rolling.

Index Terms – Cold Rolling Mill, Cluster, First Intermediate Roll, Tool Steel, Work Roll.

INTRODUCTION & LITERATURE REVIEW

When it comes to steel, the greatest items are those that have excellent properties and are therefore the best. Depending on the carbon percentage, steel can be classified as low carbon (0.0 to 0.3%), medium carbon (0.3 to 0.6%), or high carbon (0.6 to 0.9%. Low carbon steel has a carbon concentration upto 0.3 percent, which suggests that it isn't extremely hard. Low carbon steel has a wide range of applications, which is one of its many advantages. On the outside, it's not brittle or ductile due to the lower carbon content. Bendable metal and plastic are weaker than unbending metal and plastic. Steel that isn't particularly dense has iron-like properties. Adding carbon to a metal makes it stronger and more durable, but it also makes it more difficult to weld. [1]. In steel, a specific quantity of carbon is included, ranging from 0.15 to 1.5%. Steels having a carbon content of 0.1-0.25% are considered plain carbon steels. Steel is widely employed for two primary reasons: In the Earth's crust, it is found in the form of Fe_2O_3, and it requires very little energy to transform it into Fe. The variety of microstructures and mechanical strengths that may be achieved with this material is astounding. Plain carbon steel accounts for more than 90% of all steel manufacturing, despite the fact that there are hundreds of distinct varieties of steel. Strong, flexible, and relatively low-cost are just a few of the advantages of this versatile metal. A wide variety of qualities can be achieved by heating and cooling the metal. They can be found in a wide range of products, including train tracks, building support beams, concrete reinforcing rods, ships, boiler tubes, oil and gas pipelines, automobile radiators, and cutting tools, among others [2].

An alloy of steel that is used to manufacture cutting, forming, and shaping tools is referred to as a tool steel. For tool steels to be able to tolerate greater wear and tear while remaining more precise and resistant to cracking, they must include significantly higher levels of tungsten, molybdenum, manganese, and chromium than standard tool steels. [3].

Chromium-molybdenum steels have a very high hardenability because of their molybdenum content. This feature is mostly due to the presence of molybdenum, which is present in concentrations of 1 percent or more. Tungsten may be present, but its presence has no effect on hardenability, whereas vanadium, which forms stable vanadium carbides, has the opposite effect by reducing it. High silicon content in these steels makes them more oxidation resistant and easier to clean because it changes the type of scale that forms during air cooling, resulting in improved performance. In these steels, the effects of carburization and decarburization both increase the likelihood of heat checking. The temperature ranges across the various carbide coexist with crystal structure for Fe-Cr C alloys containing 5 weight % chrome may be seen in the vertical section of the specimen, which is also visible in the horizontal section (Figure 1) In order to plan annealing and hardening regimens as well as heat treatments, this information can be utilised. [4].

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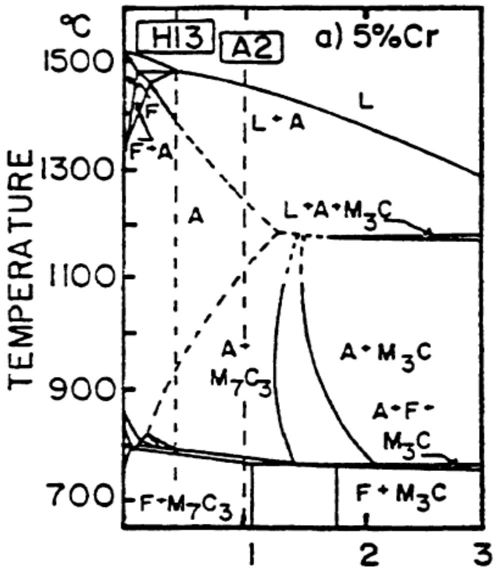

Figure 1 : Equilibrium diagram of Fe-C-Cr system.[5]

For both hot and cold work, H11 is an excellent steel. carbon and high-chromium steel (H10 to H19). Sheer tensile and flexural strength. Rotor blades and helicopter landing gear, for example, benefit greatly from its properties. Despite its high shear strength, hot metal forging is rarely used. H11 steel is well suited to the processes of die casting and hot forging. Surface wear, micro-chipping or cracking, and heat-checking can affect the die geometry and integrity. Materials need to be tougher and harder. To prevent tool geometry from being altered by local plastic deformation, toughness and hardness can be used [6]. **V. Leskovsek et al.** Optimized vacuum-heat treatment processes for traditional hot-work AISI H11 tool steel. It was shown that the fracture testing method was highly sensitive to variations in microstructure and material homogeneity. The combined tempering diagram was utilised to identify the optimal vacuum-heat treatment settings. The study of the tempering patterns revealed a maximum fracture toughness at 620°C and a minimum hardness at 540°C. Due to the peak in secondary hardening, there is a drop in ductility. [7]. **B. Skela et al.** tested the anti-wear performance of hot work tool steels using modified 1.2367 hot work tool steel. They did this by comparing the hardness and anti-wear qualities of hot work tool steel with varied microstructures (obtained through various heat treatments). Temperatures of 1030 °C and 1150 °C were employed for austenitizing. Differences in the volume proportion of undissolved carbides (carbo-nitrides) are apparent at both austenitizing temperatures, with vanadium-rich MC type carbides dominating. In order to evaluate wear performance for various austenitizing and tempering temperature combinations, they performed reciprocating sliding wear tests at room temperature and pin-on-disc contact setup. 100Cr6 and Al2O3 balls were utilized as counter-bodies to model the wear components of adhesive and abrasive wear. Comparing 100Cr6 counter-body data to 1150 °C austenitized specimens, where adhesive and abrasive wear components occurred, a lower wear rate exceeding 50 HRc was noted. The ceramic counter body had a higher or equal wear rate when abrasive wear was predominant [8]. **F. Deirmina et al.** Some parameters of H13 hot work tool steel after direct tempering and after quenching and tempering were studied using selective laser melting (SLM). Heterogeneous dendritic microstructures can be seen at the melt pool boundaries of H13 tool steel after the SLM technique is used, as well as micro-segregation at the cell boundaries. Due to the larger percentage of retained austenite (RA) in the as-built microstructure compared to quenched steel (RA2% vol.) and the therefore stronger secondary hardening after tempering, the as-built microstructure exhibits higher secondary hardening. In addition, quenching removes the cellular/dendritic SLM structure as well as the uneven local hardness, resulting in a partial recovery of the solidification structure. Fracture toughness values that seemed very promising were obtained when the materials were evaluated using a notch plane parallel to the construction plane (XY plane). The fracture toughness of tempered samples was equivalent to that of quenched and tempered ones, despite the greater hardness of tempered samples [9]. **N. Mebarki et al.** investigated the microstructure of a tempered martensitic steel containing 5% Cr using transmission electron microscopy, energy-dispersive X-ray analysis, X-ray diffraction, and carbide extraction (AISI H11). Tempering and cyclic loading soften the material, according to the X-ray peak profile study, and this softening is related with a large drop in the dislocation density. The yield stress reduced as dislocation density dropped and secondary carbides formed during tempering and fatigue. Tempering the precipitation between 550 and 600 °C softens it, but the carbon distribution among the numerous precipitates is not stable, and the transition from iron carbides to specific carbides is still occurring. Although there is no evidence of coalescence, a rise in the overall weight fraction of carbides may result in an increase in yield stress. Coalescence of carbides and a decrease in dislocation density are two phenomena that lead to material softening over 600 °C. [10]. Five percent chromium steel X38CrMoV5 was examined by **I.Souki et al.** for fracture toughness and fatigue crack propagation (AISI H11). It was possible to observe and quantify the different cracking zones. A more ductile fracture occurs in the ultimate rupture zone of 42HRC steel compared to the 50 HRC grade. The findings of the experiments showed that the fracture propagation rate increases and the toughness reduces as the hardness increases, and that increasing the austenitizing temperature from 990°C to 1050°C had no effect on either the crack propagation rate or the toughness. Changing the austenitizing temperature, i.e., the grain size and morphology of primary carbides, has no effect on the fracture properties of the material. Fracture toughness and crack propagation rates are drastically altered by tempering adjustments that directly affect the alloy hardness [11]. **D. Delagnes et al.** using transmission electron microscopy and small-angle neutron scattering, researchers found that silicon influenced secondary carbide stability and fatigue characteristics. Researchers employed TEM and SANS observations and experiments to investigate the effects of twofold tempering and a fatigue test on average carbide size and volume percentage. The largest differences between AISI H11 steel (1% silicon) and low-silicon steel (0.35% silicon) were compared. Better tensile and fatigue properties at 550°C (predicted tool surface temperature during high pressure injection of aluminum alloys) were achieved by low silicon alloys with higher secondary carbide volume percentage (mainly vanadium carbides). Because silicon shifts the secondary hardening peak toward lower tempering temperatures, it is assumed to be harmful. Steels tempered above the secondary hardening peak can be used between 20 and 30 °C [12]. **Mesquita et al.** studied that less silicon concentration and higher tempering temperature increased fracture toughness in H11 Charpy impact samples. Because Si prevents cementite production during low temperature tempering, higher Si hot work steels are less robust. Toughness is increased in low-Si hot work steels due to early production of tiny cementite particles, which results in more uniform dispersion of alloy carbides. High-temperature tempering increased the distribution of secondary alloy carbides in low-Si steels [13]. **S. QAMAR** investigated the mechanical characteristics of AISI H11 hot work tool steel after various heat treatments (annealing, austenitizing, air cooling or oil quenching, single and double tempering). It was also used to evaluate heat treatment's effect on mechanical properties. Hardness rises initially, then falls; impact strength rises, then falls; and yield strength rises, then falls. At 600oC, ductility dramatically increases. Double-tempering at 550°C rather than 600°C is found to be optimal for oil-quenched samples (greatest combination of hardness and toughness) [14].

CHEMICAL COMPOSITION AND PROPERTIES OF H11

TABLE I

CHEMICAL COMPOSITION

Element	Content (%)
Carbon, C	0.33-0.43
Manganese, Mn	0.20-0.50
Silicon, Si	0.80-1.20
Chromium, Cr	4.75-5.50
Nickel, Ni	0.3
Molybdenum, Mo	1.10-1.60
Vanadium, V	0.30-0.60
Copper, Cu	0.25

TABLE II

PHYSICAL AND MECHANICAL PROPERTIES

Properties	Metric
Density	7.81 G/CM^3
Melting point	1427°C
Modulus of Elasticity	207 GPa
Hardness, Rockwell C (1038°C, 45 mins)	57
Charpy impact (V-notch)	33.9J
Machinability (1% carbon steel)	75-80%
Poisson's ratio	0.27-0.30
Thermal conductivity (@100ºC/212ºF)	42.2 W/mK

(COURTESY TABLE 1 AND TABLE 2 HTTPS://WWW.AZOM.COM/ARTICLE.ASPX?ARTICLEID=6209)

METHODOLOGY AND RESULTS

Specimen Preparation : An appropriate specimen size must match the machine's requirements. The cylindrical sample of H11 is shown. Surface quality was not good on the sample. So the procedure of turning and facing was completed. SEM and EDS testing necessitated chips, which could only be obtained by performing the following procedure. For the hardness test, a minimum material size of 15cm was required, as well as a level surface. Cylindrical grinders were used for surface machining after the facing operation A water quenching specimen and an air quenching specimen were both manufactured from H11 material.

Figure 2 : H11 Samples for Testing

Heat Treatment and Quenching : Heat treatment was performed on two samples of each of H11. For 40 minutes, they were roasted to 816°C in an automated oven. It was at this time that the open hearth furnace was started, allowing it to achieve a temperature of between 1100 and 1200 degrees Celsius. In an open hearth furnace, the samples were heated to 1100° to 1200°C for 20 to 40 minutes after which they were removed. One set was placed in water, while the other was exposed to dry air during the cooling process.

Testing for Mechanical Properties:

TABLE III

HARDNESS TESTING

Sample	Hardness Before Heat Treatment	Hardness After Heat Treatment
Sample 1 H11 Water Quenching	25 HrC	65 HrC
Sample 2 H11 Air Quenching	22 HrC	53 HrC

Charpy V- Notch Impact Testing:

To test for charpy impact, we used the Hounsfield Balanced Impact Machine, which has a maximum weight capacity of 48 pounds and an accuracy of 1 foot pounds or less.

Result of Charpy Impact Testing Sample 1 = 40.8 J

Result of Charpy Impact Testing Sample 2 = 47.4 J

Tensile Testing:

TABLE III

TENSILE TESTING

Sample	Applied Load (GPa)	Tension (MPa)
Sample 1	498±8	2392±67
	527±31	2773±145
	542±27	1476±127
	552±19	2007±112
Sample 2	492±14	2912±472
	527±10	2754±217
	515±16	2531±414
	598±23	1502±8

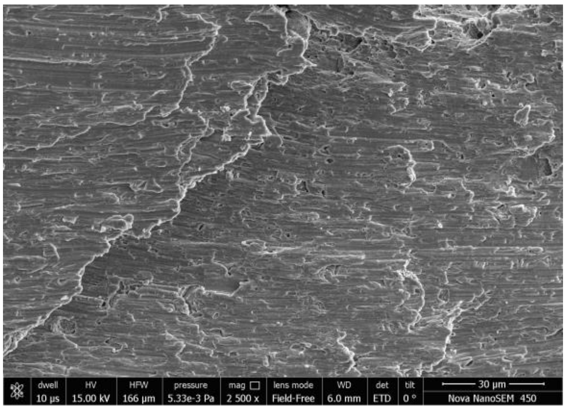

Figure 3 : High hardened SEM image of H11 sample 1 Water Quenched

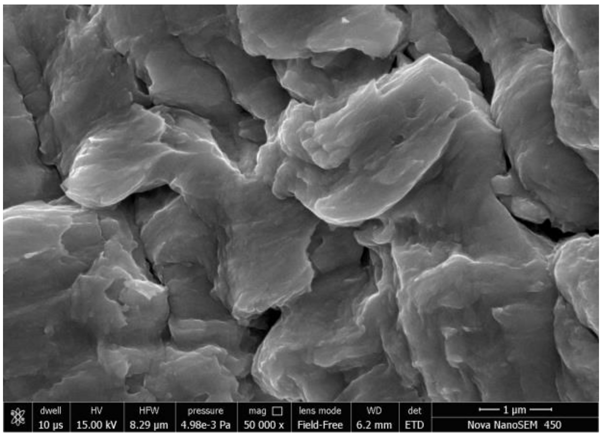

Figure 4 : High hardened image showing Dendritic structure of Sample 1 H11 Water Quenched

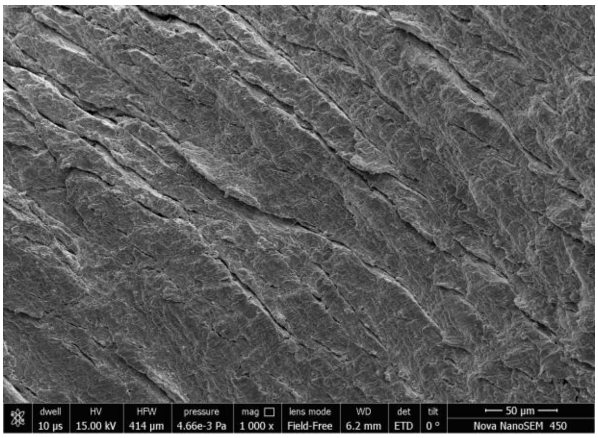

Figure 5 : Image of Sample 2 of H11 heat treated and Air Quenched

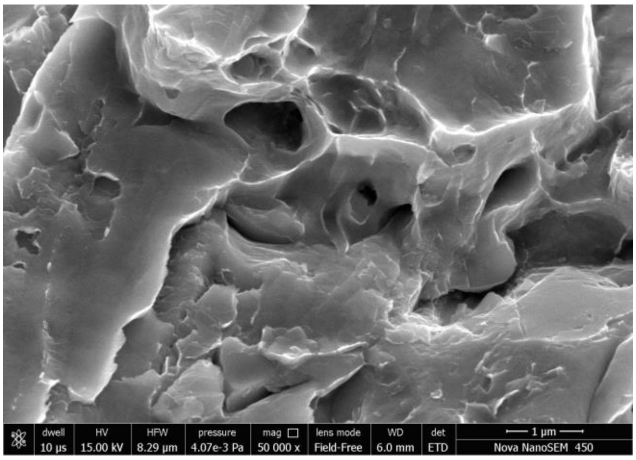

Figure 6 : SEM Image of Sample 2 showing less tight crystal structure then water quenched

CONCLUSION

The H11 Tool Steel is being used in many engineering applications. The condition test of H11 sample with adequate heat treatment operation is done with varying quenching methods and It has been found during experimentation and during testing that fseveral mechanical properties are held responsible on heat treatment procedure. Following are the findings of the experimental work.

1. The Hardness of Plain H11 is 20-25 Hrc where as during heat treatment operation the soaking period was around 4 to 5 hrs the hardness increased in both the samples to 50 to 60 Hrc, which shows better stability of H11 as FIR in CRM operation.
2. The impact test done on Charpy Izode impact testing machine, the test result shows around 40 and 48 J in comparison with the base metal which was around 33 J. This may be done possibly by the virtue of Quenching medium, In water quenched samples the impact loading is slightly less then air quenched sample of H11. This will create a difference of the sample if used as FIR in CRM.
3. The ultimate tensile strength test conducted in basic UTM shows tensile strength on various loads. The result shows the adequate ductility of H11 tool steel.
4. After having a detailed study of SEM images its found that after heat treatment the crystal structure of H11 samples which were water quenched and air quenched have changed. The water quenched structure is more compact and less gap between crystals then the sample of air quenched. The resultant is increase in hardness of the material which is more differ in nature if comparison made from forged steel H11 bar.

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