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Effect of Cryogenic Treatment on the Impact Strength of AISI D2 Steel

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ABSTRACT: The influence of incorporating different cryogenic phases in the heat treatment sequence of D series cold working tool steels is reviewed. The micro structural changes taken place for different grades of cold working steels under this series, by incorporating a cryogenic treatment process within the conventional heat treatment cycle is focused for this review analysis. Also, the changes in mechanical as well as tribological properties of these steels due to this additional treatment are discussed with emphasis on the factors contributing to the enhancement of these properties. AISI D series represents tool steels with high carbon and high chromium contents which exhibit good post treatment hardness and are having good machinability in the pre-treated conditions. Hence, they are widely used for making press tools, plastic moulds, knifes, blades, etc which need good wear characteristics. D2, D3, D5, D6, and D7 are the grades of tool steel selected for this review. The improvements obtained by the deep as well as shallow sub-zero treatments conducted in various sequences of operations are noted. Comparisons within the material and within the series are reviewed for different cases. The advantages and disadvantages of having cryogenic treatment as a secondary heat treatment for D series tool steels are highlighted.

KEYWORDS: Cryogenic Treatment, AISI D2 Steel, Strength, Toughness.

I. INTRODUCTION

Cutting and forming tools are often subjected to extreme wear while working. Prevention of wear is an important step to be taken for larger life of the tools. Wear is often a result of degradation of mechanical properties of tool materials. Impact strength is one of the important properties that need to be analysed. Cryogenic treatment is a technology that is being researched to improve the wear resistance of the tool materials. The hardened and tempered AISI D2 die steel has poor impact strength. Impact strength is one of the important properties responsible for failure of die. Hence the project was taken up to study whether cryogenic treatment of D2 Die steel improves the impact strength or not.

1) AISI D2 Tool Steel
2) Impact Strength
3) Cryogenic Treatment
4) Methodology

Steel is the most significant material used in manufacturing industry in various forms. Tool steels are high-quality steels made to close compositional and physical tolerances. These are used to make tools for cutting, forming, or shaping a material into a desired part or component for a specific use. In service, most tool steels are subjected to extremely high and fluctuating loads. The material must withstand those loads for long times without breaking and without undergoing excessive wear or deformation. For a tool steel at a given hardness, wear resistance may vary widely depending on the heat treatment used and wear mechanism involved in the process. Among tool steels with widely differing compositions but identical hardness, wear resistance may vary under identical wear conditions. There are many components in the manufacturing process, but from a cost benefit approach to productivity, tooling technology is going to yield the biggest return. Facing the international competition and the rapid evolution of the technological progress, enterprises must continually improve their productivity as well as the quality of their products. Typically, AISI D2 steel is from group D of tool steel that is High-carbon, high- chromium, cold-work steels. Typical application of group D steels include long-run dies for blanking, forming, thread rolling, and deep drawing; does for cutting laminations; brick mold; gages; burnishing tools; rolls; and shear and slitter knives.

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II. LITERATURE REVIEW

A. Review

Fracture toughness is the resistance of a material to propagate a pre-existing flaw. This is a very important property as flaws cannot be avoided completely in the processing of the material. Flaws may appear as cracks, voids, metallurgical inclusions, or combinations of the same. Together with fatigue behavior, fracture toughness is one of the main parameters for designing tools. Outcomes from tests conducted on AISI H13 steel by Molinari et al. have shown that even if DCT does not influence the hardness of the steel, it improves both toughness and wear resistance. This is an important factor in performance of steel, where the wear resistance and toughness are the key properties in use. This is also supported by Kollmer. It is also concluded in case of ARK diamond that increases in cohesive forces between crystallites and phase would only be the reason for strengthening the diamond. Precipitation of fine carbides during the CT cycle to improve the toughness is also supported by Collins.

III. DISCUSSION

A. Effect on Cryogenic Treatment

Cryogenic treatment is carried out as a process within the heat treatment cycle by cooling below atmospheric temperatures with liquid nitrogen. It is classified as shallow cryogenic treatment and deep cryogenic treatment. Though initiated in the beginning of 20th century, real importance of the cryo-treatments has been noticed only during the last years of the century. The basic cryogenic treatment process is cooling down slowly to sub-zero temperature and holding there for certain duration, freezing time and then gradually bring back to room temperature. This is done to achieve enhancement in mechanical properties and tribological properties especially to optimize hardness and toughness.

Currently, cryogenic processing is widely used in aerospace industry and various other manufacturing industries. A wide range of research and analyse are carried out by using cryogenic treatment in the field of tooling industry to improve the wear performances of the steel. Though a clear mechanism for this improvement being not defined, various hypothesis with changes in micro-structural behaviour are discussed in literature and analysis of experimental studies conducted in this direction. Before cryogenic treatment, carbon in austenite structure having poor bonding and bond strength while after the process the carbon atoms are very closer to iron atoms and thus they give strong bonding characteristics to the microstructure. In majority of the studies, two mechanisms are identified as the reason for the increased mechanical properties when it undergoes cryogenic treatment. One is conversion of retained austenite left during hardening to martensite and the other one is the precipitation of carbides and its nucleation within the lattice. Martensite which is hard in nature because of the orientation of carbon atoms in the lattice offer better resistance to plastic deformation than austenite structure. Additionally, the precipitation of nano-carbides during tempering will also lead to better mechanical properties.

B. Treatment on D2 Tool

D2 steel from AISI D2 series is hardened by the process of vacuum hardening and then tempered in the conventional method. But it is recommendable to add an additional operation of sub zero treatment in between the hardening and tempering cycle which could improve the final properties of the product and assure reduction in dimensional distortion. The tempering can be of single or multiple steps in a temperature range from 520 °C to 540 °C. The deep treatment at a temperature of -150 °C gives better dimensional stability and the duration of cycle or freezing time is not very influential.

While hardening D2 tool steel, increase in autenizing temperature increases the hardness to a certain extent and then drops down due to the presence of retained austenite formed at elevated temperatures. With cryogenic treatment, peak hardness becomes more and can be obtained at a higher austenizing temperature. After cryogenic treatment, the toughness of the steel shows improvement which is due to the micro-structural changes taking place within the martensite itself and this improvement in toughness will be more for samples with lower austenizing temperatures. By cooling, martensite forms continually below the normal transition temperature and holding further in the same temperature range, promotes the precipitation of fine carbides in large amount in tempering.

Fracture toughness is an equally important property when it comes to the tool or die steel. Wear resistance depends upon hardness as well as toughness and optimizing these two parameters can give economical tool life. The most common failure mechanisms in tools which include cracking, chipping, galling etc can be reduced by controlling the fracture toughness of the steel used for making punches and dies. A study conducted on the fracture toughness of D2 tool steel revealed the amount of dissolved carbon and other alloying elements play a vital role in achieving proper

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toughness. In the case of D2 fracture toughness can be improved by refining the carbides present in the matrix by heat treatment conditions and controlling the elements for alloying. Presence of fine carbides and its distribution pattern. Cryogenic treatments help to modify the precipitation of metallic carbides, obtaining a finer and even distribution. Farina et al. (2011) in their study, indicated the presence of homogeneous distribution of nano-carbides after the cryogenic treatment.Depending upon the type of composition of metals in the tool steel it is considered.

IV. CONCLUSION

The major valid findings that can be concluded from the above discussions are the formation of martensite from the retained austenite by cryogenic treatment and carbide formations. The lattice structure of the martensite obtained from the cryogenic treatment is different from one obtained by conventional heat treatment. The matrix obtained with conventional heat treatment is composed of martensite, retained austenite and eutectic carbides and the subzero treatment reduces retained austenite and refines the martensite. In case of D3 retained austenite reduction is more than D2 and D6. However, all the materials of this category of cold working tool steels exhibit a good reduction in retained austenite. Another aspect is the precipitation of carbide particles depending upon the duration of the process and this time dependent formation of nano carbide particles are contributing to improve the mechanical properties of the cold working tool steels after cryogenic treatment. As the percentage of metals and carbon in the composition increases the hardness and wear resistance improves because of more fine carbide formation. Deep cryogenic treatment is the reason for the nucleation of the carbides and with this the fine carbide formation temperature is also coming down. As the tempering temperature is increased, the hardness decreases but the wear resistance and impact energy improved and are more prevailed in deep treated samples. The structure revealed that the post cryogenic tempering gives better results than tempering done before cryogenic treatment. Depending upon the type of composition of metals in the tool steel, multiple tempering may be considered.

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