Investigation of effect of mechanical properties and Influence of Heat treatment on AISI 4140 steel

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Abstract: - The optimization methods in metal heating processes, considered to be a vital tool for continual improvement of output quality in products. In order to optimize the gains from the raw material of AISI 4140 alloy steel, an accurate process must be constructed. The carbon content in AISI4140 steel ranges from 0.38 to 0.43%. In this approach the mechanical properties mainly like Hardness, Yield Strength, Wear Resistance are amenable to modification via heat treatment. In the present work the objective is to test the chosen steel with various heat treatment processes and also analyze their microstructure. A comparative study made across the properties vs. heat treat processes. Finally, to choose the best heat treatment process and optimal properties that can be achieved.

Keywords: heat treatment, hardness, alloy steel; microstructure; optimization; properties;

1. Introduction
In this study, heat insulation tests of AISI 4140 steel are carried out under different temperatures and holding times, and the grains sizes are measured. However, when the components made of this alloy steel are exposed to harsh operating conditions, such as surface rolling and sliding contact, during their service life, they are susceptible to serious surface damage, such as micro pitting, abrasive wear, and corrosion, which could accelerate premature failure and shorten the life cycle of these critical and expensive components. Thus, it is essential to restore the worn-out or damaged components so as to lengthen their service life.

2. Literature review
Literature survey is required to understand the specific objective of the research work. The previous research which gives clear contain and clear ideas about the work. Jon L.Dossett, P.E [1] et al, maximum hardness is a function of the carbon content of the steel being used and hardenability of steel and Determining the expected core hardness range can be determined by using the Jominy equivalent cooling rate (JEC) chart. Hamad K.Al-Khalid [2] et al, demonstrated that for a given microstructure, the apparent hardness of a ferrous P/M material is related to the density of the material, apparent hardness increases as density increases. A. Calika [3] et al, The hardness of borides, boride layer thickness and room temperature tensile properties were measured and it was observed that hardness and tensile properties strongly depend on chemical composition of steels.

3. Experimental details
3.1 Heat Treatment Process
The mechanical properties can be improved by heat treatment. These are stronger compared to low
carbon steels. Medium carbon steels have low hardenability. Addition of Cr, Ni, Mo, improves the
heat treating capacity [1]. Eutectoid steel is the stage in the iron carbide diagram, in which the steel
contains completely pearlite in its microstructure. This forms at 727°C contains 0.76% carbon. At this
temperature, ferrite and cementite is formed in combination called pearlite. Pearlite is a mixture of
ferrite (0.022% C) and cementite (6.7% of C). Pearlite microstructure consists of alternate layers of α-
ferrite and cementite. Hypo eutectoid steels contain less than 0.76% carbon where ferrite is in
combination with cementite having thin lamellar called coarse pearlite. In which percentage of ferrite
is decreasing. Eutectoid steel having 0.83% carbon where complete pearlite is formed. Hyper eutectoid
steels having more than 0.83% percent carbon in which ferrite are completely decreased and cementite
is increased in percentage where the cementite lamellar becomes thick called fine pearlite.

3.2 Experimental Procedure
Tensile test according to ASTM Standard’s, Test Method: ASTM E8-15a:[15] These test methods
cover the tension testing of metallic materials in any form at room temperature, specifically, the
methods of determination of yield strength, yield point elongation, tensile strength, elongation, and
reduction of area. In this, we made an attempt of testing 7 specimens. Which are, one specimen for
Normal untreated, 3 specimens for Normalizing at 1100 °C under holding time 30, 45 and 60 minutes.
Three specimens are used for Annealing at 1000 °C under holding time 30, 45 and 60 minutes.

4. Results and Discussions
Tensile test provides information on the strength and ductility of materials under uniaxial tension
stresses. This evidence may be useful in comparisons of materials, alloy development, quality control,
and design under certain conditions.

| Table 1. Strength In Untreated V/S ASTM Standard |
|  Sl No | Particular | ASTM Standard’s | Untreated specimen |
|-------|-----------|-----------------|-------------------|
| 1     | Tensile strength | 655 MPa | 997.87 |
| 2     | Yield strength | 415 MPa | 827.47 |

| Table 2. Obtained Young’s Modulus results |
|  Sl No | Particular | Holding Time (Min) | Young’s Modulus(Mpa) |
|-------|------------|--------------------|----------------------|
| 1     | Normalizing at 1100 °C | 30 | 958.32 |
|       |           | 45 | 1077.03 |
|       |           | 60 | 1082.53 |
| 2     | Annealing at 1000 °C | 30 | 761.90 |
|       |           | 45 | 758 |
|       |           | 60 | 774.48 |
Table 3. Obtained Yield Strength results

| SI No | Particular                | Holding Time (Min) | Yield Strength (Mpa) |
|-------|---------------------------|--------------------|----------------------|
| 1     | Normalizing at 1100 °C    | 30                 | 1017.54              |
|       |                            | 45                 | 1127.86              |
|       |                            | 60                 | 1176.87              |
| 2     | Annealing at 1000 °C      | 30                 | 787.58               |
|       |                            | 45                 | 767.54               |
|       |                            | 60                 | 740.17               |

Table 4. Obtained Ultimate Strength results

| SI No | Particular                | Holding Time (Min) | Ultimate Tensile Strength (Mpa) |
|-------|---------------------------|--------------------|---------------------------------|
| 1     | Normalizing at 1100 °C    | 30                 | 1147.54                         |
|       |                            | 45                 | 1274.58                         |
|       |                            | 60                 | 1276.57                         |
| 2     | Annealing at 1000 °C      | 30                 | 917.57                          |
|       |                            | 45                 | 917.57                          |
|       |                            | 60                 | 931.57                          |

As compared to the untreated specimen, in Normalizing process as the holding time increases the Young’s modulus, Yield strength, and Ultimate strength are gradually increasing, whereas in case of Annealing process for different holding time the properties are varied which results annealing soften the specimen.

4.1 Brinell Hardness Test

Test Method: IS1500-2010, Ball: 5mm, Load: 3000Kg

Figure 1. BHN v/s Holding time
4.2 Wear Test
Specimen Diameter = 7 mm, length = 30 mm.

![Graph showing wear rate vs holding time](image)

**Figure 2.** Wear rate vs Holding time

4.3 Scanning Electron Microscopic (SEM)

![SEM image of fractured specimen](image)

**Figure 3.** SEM on fractured specimen
Figure 4. SEM on fractured specimen

![SEM on fractured specimen](image)

Figure 5. SEM on fractured specimen

From above Figure 3. magnification of untreated specimen there is Ridges and Dimples with a Interstitial free due to its carbon contain These steels have been designed to provide an excellent combination of drawability and mechanical strength based on their specific interstitial-free (IF) metallurgy. In Figure 4. microstructure there is a Tyretracks and Microvoid where this tyretracks which are perpendicular to crack propagation or crack growth. In Figure 5. the magnification image, there is a Dimples and river pattern with Quasi cleavage fracture, which is a fracture mode that combines the characteristics of cleavage fracture and dimpled rupture fracture. Cleavage is tendency of material to break along smooth plane parallel to the zones of weak bonding[14].

5. Conclusions

The AISI4140 material has undergone with different heat treatment process. The tensile test, hardness test and wear rate test were conducted for both treated and untreated specimens, from the results following points were noted.

- By comparing the values of yield strength for normalizing and annealing process, normalizing gives optimized results at 60 minutes of holding time during process.
- It has been observed that yield strength increased gradually in normalizing process.
- Microstructure reveals globular structure with coarse carbides at grain boundaries in a matrix of ferrite.
- The optimized values of hardness and the wear rate is obtained for Two hours of holding time at 950°c during heat treatment process.

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