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Evaluation of Mechanical Properties of AISI 5140 steel using a Blend of Biodegradable Oils with Quench Accelerators

Rajkumar Shinde[1],
[1](Research Scholar, Assistant Professor, Mechanical, Dr. D Y Patil institute of TechnologySant Tukaram Nagar, Pimpri, Pune-411 018)

Abstract: *Steels having favorable properties are used in many industrial applications because of their low cost and ease of fabrication. The mechanical properties desired can be achieved by either alloying suitable elements or by various heat treatment processes. Heat treatment process is a combination of heating and cooling operations applied to metals and alloys to obtain desired properties. Hardening is a heat treatment process carried to increase hardness of steel by heating it above critical point and then allowing it to cool down by immersing in a quenching medium such as water or oil. By quenching in appropriate medium the mechanical properties of steel can be improved. Biodegradable oils are gaining popularity as quenching media because these are renewable, ecofriendly and are of low cost. In the present work, it is proposed to study mechanical properties of steel 5140 (EN-18) quenched in a blend of biodegradable oils. The specimen is heated to austenizing temperature of 820ºC-890ºC and held at that temperature for an appropriate soaking time and quenched in quenching media to cool down. Quenching media used is a blend of groundnut oil and neem oil in varying proportions. To this blend of quenchants metal salts in varying concentrations are added as quench accelerator. Specimens are then subjected to tempering at 540ºC - 680ºC to remove the brittleness and internal stresses. These specimens are then subjected wear, hardness and impact tests to evaluate its mechanical properties. By the process of quenching in biodegradable oil and tempering process it is expected to have improved mechanical properties as by conventional quenching and also show the effectiveness of biodegradable oils as quenchants with quench accelerators.*

Keywords: *Steel AISI 5140, Quenching Process, Groundnut oil, Neem oil, Quench Accelerators*

I. Introduction

The microstructure of a metal and its properties can be altered by heating the metal to a definite temperature and then allowing it to cool at suitable rate. This process is called heat treatment and can be performed on all types of metal including ceramics and composite material. During heat treatment process, the selected material undergoes phase, microstructural and crystallographic changes.

The purpose of heat treating is to improve the mechanical properties of steel, usually ductility, hardness, yield strength, tensile and impact resistance. The electrical conductivity, corrosion and thermal conductivity are also altered during the process of heat treatment. Hardening is a type of heat treatment process carried in order to increase hardness of steel by heating it above critical point and then allowed to cool down by immersing in quenching medium such as water or oil. Hardening by quenching is carried out to prevent the formation of ferrite or pearlite and allow bainite or martensite to be formed. The beneficial changes that occur in microstructure do not take place during the heating process, but during the cooling or quenching from the high temperature to room temperature. Quenching media is important since it is the effective way of hardening the material. The selection of quenching medium depends on the hardenability of a particular alloy, the section thickness and shape, and the cooling rate needed to achieve desired microstructure [5]. The commonly used quenchants are water, brine, oil and synthetic solution. Water even though abundant and low cost has a drawback of forming crack or effecting dimensional changes due to high cooling rate and oil does not induce enough hardness. Polymer quenchant can provide severity between water and oil but has a problem of varying concentration. This creates a need of a suitable quenching medium with good economics and producing appreciable hardening. [6] Thus conventional oil is slowly being replaced by biodegradable oil because they are non toxic, environmental friendly and less expensive. Groundnut oil and neem oil are biodegradable oils that are easily available. Metal salts are added in quenching media as quench accelerator. The metal salts should have high rate of heat transfer, should remain stable at operating temperature, produce no smoke during operation and should be easily recovered. The present work involves heat treating steel AISI 5140 (EN-18) in a blend of groundnut oil and neem oil. These oils are mixed in varying proportions to which metal salts are added. The mechanical properties of the heat treated specimen are evaluated and are compared with untreated specimen. By the process of quenching in biodegradable oil, specimens have improved mechanical properties and also it shows the effectiveness of biodegradable oil as quenchants and use of quench accelerators. Joshua T O, et.al. [3]: studied the effects of various quenching media on the mechanical properties of inter-critically annealed 0.267%C – 0.83%Mn steel. The samples were quenched in water, distilled water and palm kernel oil respectively after been allowed to attain the inter-critical temperature of 760ºC, 770ºC, 780ºC, 790ºC and 800ºC. The specimens were held in each of these inter-critical temperatures for 1 hour and then quenched for hardening heat treatment in each quenchants mentioned. After cooling the samples were removed and cleaned, after which it was subjected to evaluation of microstructure and mechanical properties. Samples quenched in water and distilled water was observed to produce martensitic structures in ferrite matrix, and it was observed that the grains of distilled water quenched samples were fine and hence responsible for higher strength and hardness values. While the samples quenched in palm kernel oil were observed to produce higher level of bainite in ferrite at the grain boundaries. These results therefore imply that for higher strength and hardness value it is recommended that quenching be done in distilled water, while for increase of strength and toughness palm kernel oil can be used. Hassan S B, et.al. [4]: have made their study on hardening characteristics of plain carbon steel and ductile cast iron using neem oil as quenchant. The samples were also quenched in water and SAE engine oil to compare the effectiveness of neem oil as quenchant. The hardness test and impact test samples were initially normalized, followed by austenizing at 860ºC for 15 mins and then quenched in three different quenchants such as neem oil, water and SAE engine oil respectively. Mechanical property tests and metallographic analysis were carried out for each as quenched sample in the selected media. From the result it is noted that the hardness value of the medium carbon steel increased from 18.30 HVN in the as-cast condition to 21.60, 20.30 and 20.70 HVN while that of ductile cast iron samples increased from 18.90 HVN in the as-cast condition to 22.65, 20.30 and 21.30 HVN for water, neem oil and SAE engine oil respectively. The impact strength of medium carbon steel samples were 50.84, 41.35, 30.50 and 45.15 Joule and that of ductile iron is 2.71, 1.02, 0.68 and 1.70 Joule for as-cast condition, neem oil, water and SAE engine oil quenched respectively. The microstructure of the samples quenched in neem oil revealed the formation of martensite. Hence it can be concluded that neem oil can be used where cooling severity is less than that of water but greater than SAE 40 engine oil is required for hardening of plain carbon steels and ductile cast iron. J K Odusote, et.al. [7]: studied the evaluation of mechanical properties of medium carbon steel quenched in water and oil. Samples of medium carbon steel were heated to 900C, 940C and 980C and soaked in these temperatures for 45 minutes using a muffle furnace. Test samples were quickly taken out of the furnace after each of the heat treatment temperatures, and quenched in water and palm oil separately. Surface morphologies of the quenched samples were examined using optical microscope and hardness by Vickers pyramid method and tensile test by using universal tensile testing machine were also carried out on each of the samples. The tensile strength and hardness values of the quenched samples were relatively higher than those of as cast samples, suggesting improved mechanical properties. The samples quenched in palm oil displayed better properties compared with that of water quenched samples. This behavior was traced to the fact that the carbon particles in palm oil quenched samples were more uniform and evenly distributed, indicating the formation of more pearlite structure, than those quenched in water and the as received samples. Therefore it can be noted that palm oil cooling improves the ductility of the steel because of its lower cooling rate compared with water. Thus, palm oil will be a viable quenching medium, where improve elongation of the sample is critical. The study conducted by these authors gives a strong reason to attempt using blend of biodegradable oils as quench ants and also see the influence of metal salts as quench accelerators.

II. Quenching Media

A. Chemical Composition

Details of steel, oil and metal salts. Steel AISI 5140, blends of groundnut oil and neem oil in varying proportions, potassium nitrate and sodium nitrate as quench accelerators have been chosen for this study. The chemical composition of the selected steel sample is given in table 1.

Table 1: Chemical Composition

Chemical composition of Steel AISI 5140 (%)							
C	Si	Mn	P	S	Cr	Mo	Ni
0.385	0.221	0.696	0.014	0.006	0.900	0.005	0.018

B. Preparation of Oil Blend

The two biodegradable oils, groundnut oil and neem oil were taken in a known proportion and blended using a magnetic stirrer. The blend was allowed to stay and settle to check if they were separated and seen distinctly.

This method was followed for three combinations of blend of groundnut oil and neem oil with ratio 80:20, 50:50 and 20:80 respectively. The different quenching media and their blend details are shown in the table 2.

Table 2: Different Quenching Media

Groundnut oil (%)	Neem oil (%)	Metal salts	Blend Details and Designation
100	0	-	B1
80	20	-	B2
50	50	-	B3
20	80	-	B4
0	100	-	B5
100	0	5% of (NaNO3 and KNO3)	B6
80	20	5% of (NaNO3 and KNO3)	B7
50	50	5% of (NaNO3 and KNO3)	B8
20	80	5% of (NaNO3 and KNO3)	B9
0	100	5% of (NaNO3 and KNO3)	B10

C. Test Specimen Preparation

Specimens were prepared for hardness test, wear test, impact test and for microstructural analysis. The specimens are 6mm diameter and 30 mm long for wear test, 60 mm diameter and 10 mm thick for hardness test, and standard charpy specimens for impact test. All these dimensions follow the ASTM standards. Figure1 to 3 give the details of the specimens.

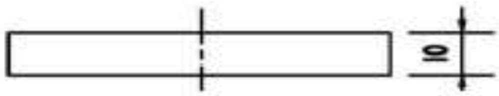

Figure 1: Hardness Test Specimen

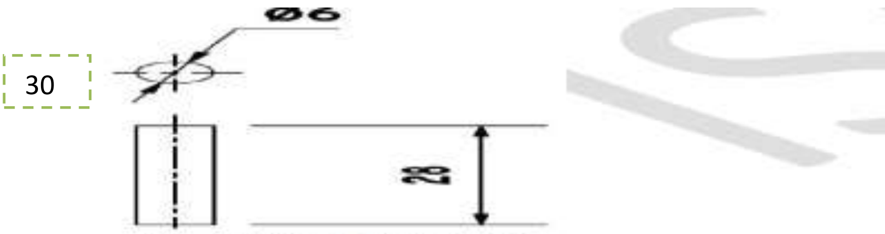

Figure 2: Wear test Specimen

Figure 3: Impact Test Specimen

D. Heat Treatment of the Specimen

The specimens were heated to a temperature of 870°C in an electric furnace with a soaking time of 90 minutes as shown in figure 4. The specimens were then quenched in different blends of oil given above firstly without any metal salts and then blends with 5% of potassium nitrate and sodium nitrate. The specimens were allowed to cool down to room temperature in the quenching medium and then the specimens were removed and cleaned for tempering process. Tempering process involved heating the specimen to a temperature of 530°C with a soaking time of 90 minutes. The specimens were then allowed to cool to room temperature then subjected to mechanical testing.

E. Mechanical Testing

The heat treated specimens were subjected to hardness test, impact test and wear test. 11 hardness test specimens and impact test specimens were prepared and 22 wear test specimens were prepared and their average values were considered. Brinell hardness test was carried out for determining the hardness of the specimen using Brinell hardness tester as shown in figure 5. Charpy test was conducted for impact test as in figure 6 and pin on disc test was conducted to determine the wear resistance of the material as in figure 7.

Figure 4: Electric Furnace

Figure 5: Brinell Hardness Test

Figure 6: Impact Test

Figure 7: Pin on Disc Wear Test.

Table 3 shows the result obtained from the tests conducted.

Blend details	Hardness BHN	Impact energy Joules	Weight Loss gm
B0 (untreated)	277.66	65.31	0.0122
B1	357.19	106.91	0.0118
B2	389.75	110.5	0.0105
B3	389.75	117.02	0.0094
B4	428.24	119.74	0.0087
B5	428.24	125.72	0.0080
B6	389.75	120.65	0.0080
B7	428.24	121.19	0.0084
B8	428.24	125.72	0.0075
B9	472.64	127.69	0.0066
B10	472.64	131.07	0.0064

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III. Conclusion

From the above results, the following conclusion can be made:

- The hardness value and impact resistance value of the heat treated specimens were greater than that of untreated specimens and the weight loss due to wear was less for heat treated specimens.
- Groundnut oil and neem oil can be used as a quenching medium to obtain better mechanical properties.
- Pure Neem oil is better than groundnut oil and also the blend of these two oils. This may be because neem oil is less viscous and thus viscosity is an important factor to be considered in selecting quenching media.
- Metal salts such as potassium nitrate and sodium nitrate can be used as accelerators to improve the rate of quenching.

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