The Effects of Heat Treatment on The Microstructure and Mechanical Properties of EN19 Steel Alloy

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Manuscript submitted November 10, 2017; accepted January 30, 2018
doi: 10.17706/ijmse.2018.6.2.56-66

Abstract: The EN19 steel alloy finds its application in the automotive industry like manufacturing gears, spindles, and shafts. In this paper, we aim to improve the strength and ductility of the EN19 steel alloy by tempering process. Generally, heat treatment is the method of exposing the specimen to high temperatures and cooling it, to bring a change in its physical and chemical properties. In this experiment, the process of annealing, normalizing and quenching followed by tempering were performed on the steel specimens. On heating the specimens to 900^0C, and cooling it from slower to a faster rate, we were able to observe and compare the changes in the microstructure, hardness, tensile strength and impact strength of the specimens before and after the heat treatment. On studying the microstructures and grain analysis of the specimens after each heat treatment process, we were able to observe the difference in the composition of the constituents and understand how this affects the mechanical properties of the material. The quenchants used are oil, water and brine solution for quenching. Since the specimens become brittle on quenching, tempering is performed on the specimens to improve the toughness of the material. It is found that the strength of the specimen is improved by quenching and toughness is improved by tempering it. On comparing the values of toughness of the tempered specimens with that of the quenched specimens, it is found that the oil tempered specimen increases by 25%, water tempered specimen by 80% and brine tempered specimen by 75% from the oil quenched, water quenched and the brine quenched specimens respectively.

Keywords: EN19 steel alloy, heat treating, tensile strength, microstructure, hardness.

1. Introduction

The material used is EN19 steel alloy[1], [2]. Heat treatment is used to improve the mechanical properties of the given specimen. The different heat treatment techniques include normalizing, annealing, quenching and tempering. On performing these tests, we aim to improve the strength and hardness of the specimens. Heat treatment also results in a change in the microstructure of the specimen. This change in microstructure can be observed under a microscope. The specimen for the tensile test is in the form of a bone structure with dimensions of 75X12.5mm. The impact test specimen has dimensions of 50X10X10mm with a groove of depth 5mm in the center. In this paper, we have used the Motic Plus software to observe the grain sizes which was not used in the earlier papers. Also, the tensometer enables us to perform the tensile test on specimens of smaller dimensions unlike, the previous papers.

The main objective is to simultaneously enhance the strength and ductility of the steel alloy by heat treatment. Therefore to improve the strength and ductility, the specimen is quenched. Although this increases the hardness, the specimen becomes very brittle on quenching. In order to reduce the brittleness and improve toughness, tempering is done on the quenched specimens

2. Material Selection

EN19 Steel alloy is a medium carbon steel with around 0.36–0.44% of carbon content. It is a good quality steel alloy with high strength. Medium carbon steel exhibits good ductility properties. Steel has good wear resistance and shock resistance. It is high tensile steel with 850-1000 N/mm^2 tensile strength. It finds applications in machine tools and motor industries. The composition of EN19 steel alloy is given in Table 1 [1].

Table 1. Composition of EN19 Steel Alloy

Chemical composition	Weight
Carbon	0.36-0.44
Silicon	0.10-0.40
Manganese	0.70-1.00
Sulphur	0.040 Max
Phosphorous	0.035 Max
Chromium	0.90-1.20
Molybdenum	0.25-0.35
Nickel	0.23

3. Heat Treatment Methods

3.1. Normalizing

Normalizing is a heat treatment technique in which the specimen is heated up to its re-crystallization temperature and is kept at that temperature for the required soaking time. It is then cooled in air. [2-4] In the case of EN19 Steel alloy, it was heated up to a temperature of 900^0C and is soaked at that temperature for about 60 minutes. It is then removed from the furnace and is allowed to cool in air.

3.2. Annealed

In the annealing process, the specimen is heated up to its recrystallization temperature, and soaked for the required amount of time. It is then allowed to cool inside the furnace itself. In the case of EN19 Steel alloy [2]-[4], it is heated up to 900^0C and soaked for about 60 minutes. It is then allowed to cool inside the furnace itself.

3.3. Quenching

Quenching is a heat treatment process in which the specimen is heated up to its recrystallization temperature, and soaked for the given period of time. The specimen is then taken and immersed in a quenchant immediately. The quenchants used were water, brine, and oil (SAE 40). In the case of EN19 Steel alloy [2]-[4], 3 specimens are taken. They are heated up to 900^0C and soaked for 60 minutes. After the soaking time, one specimen is immersed in water, another in brine and the third specimen is immersed in quenchant oil. Brine solution has the fastest cooling rate. Whereas, water and oil quenchants are slower, with oil being the slowest.

3.4. Tempering

Since quenching can lead to undesirable mechanical properties such as higher hardness, brittleness etc. due to the formation of martensite and fine grains. Another heat treatment technique is performed on the quenched specimens to restore its ductility. This heat treatment technique is known as tempering. In the case of EN19 steel, the oil quenched and water quenched specimens are heated up to 550^{0}C. It is then soaked for 60 minutes and then allowed to cool in air.

4. Results and Discussions

4.1. Microstructural Analysis

The microstructure and grain analysis of a specimen gives us an idea about the grain size and the composition of microstructure. [3] The grains are made up of two different layers. The light layer is ferrite and the dark layer is pearlite. Ferrite gives steel the properties of ductility, whereas cementite gives the properties of hardness and strength. The microstructure of a specimen gives us information about how different heat treatment techniques results in a change in microstructure which in result gives us an idea about the change in mechanical properties at a microscopic level. Motic Images Plus software was used for grain analysis and to find the grain size. The microstructure and grain analysis of untreated EN19 steel alloy is shown below.

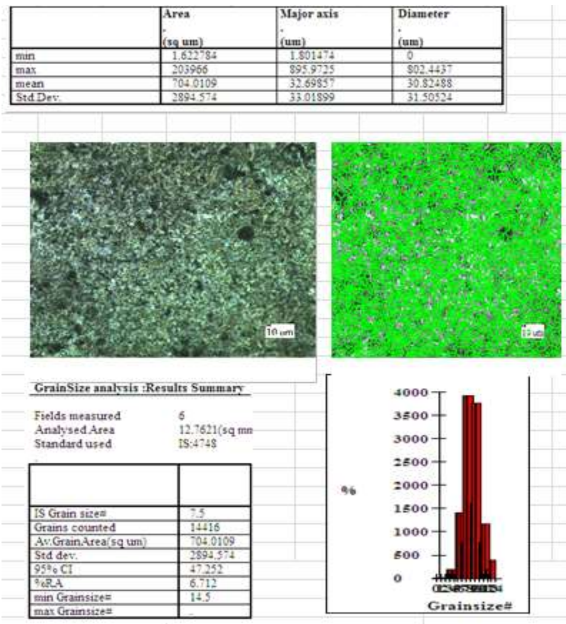

Fig. 1. Grain analysis of untreated EN19 Steel Alloy (100x).

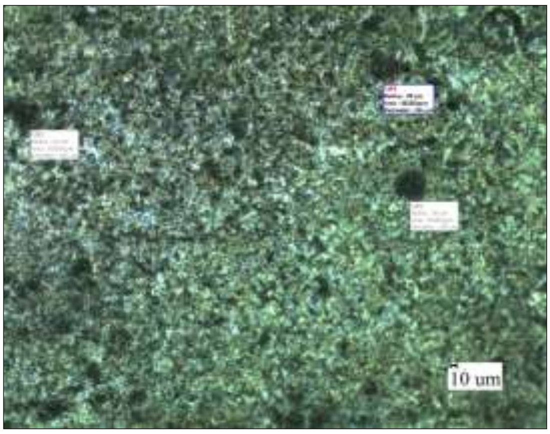

Fig. 2. Microstructure of untreated EN19 Steel Alloy (100x).

The microstructure of EN19 steel alloy after normalizing is shown below. In normalizing, after cooling in air, fine grains are formed. This results in the normalized EN19 specimen to be stronger than the untreated specimen.

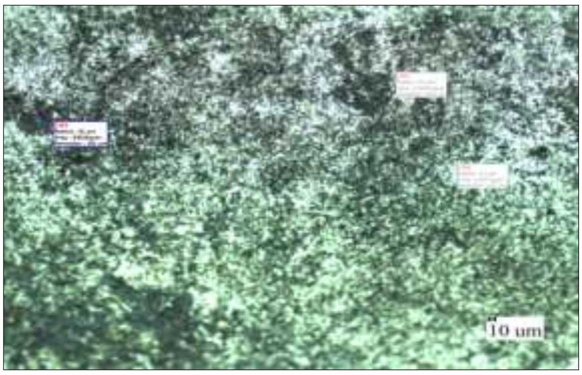

Fig. 3. Microstructure of normalized EN19 Steel Alloy (100x).

In Annealing, due to slow cooling of the specimen in the furnace, the austenite completely transforms into pearlite and ferrite [5]. Therefore, the annealed specimen is very ductile and has very little hardness. The microstructure of annealed EN19 steel alloy is shown below.

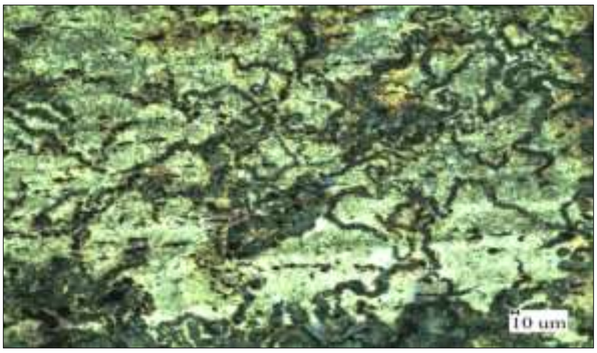

Fig. 4. Microstructure of annealed EN19 Steel Alloy (100x)

The microstructures and grain analysis of water quenched, brine quenched and oil quenched EN19 steel alloy are shown below.

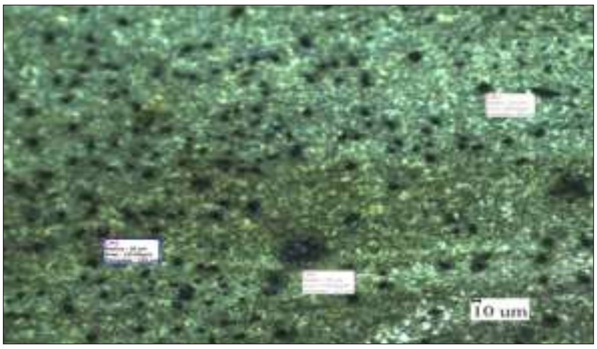

Fig. 5. Microstructure of water quenched EN19 Steel Alloy (100x).

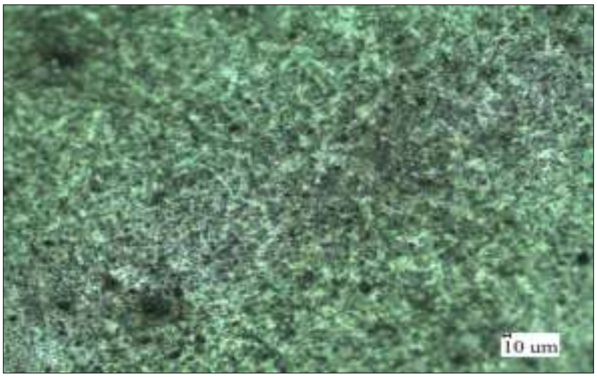

Fig. 6. Microstructure of brine quenched EN19 Steel Alloy (100x).

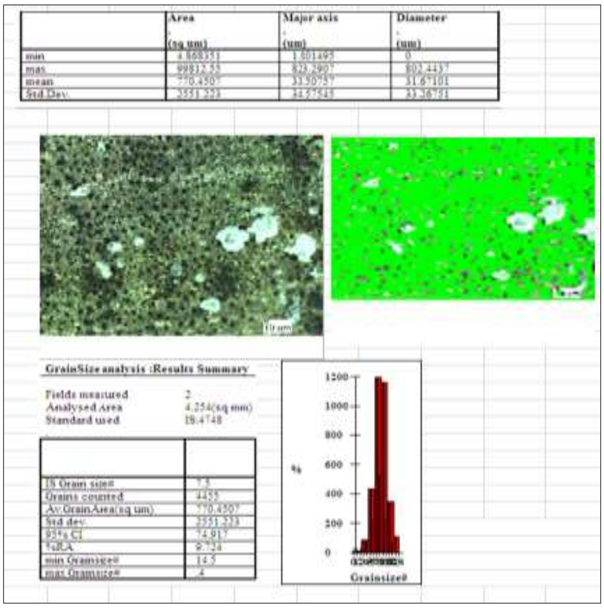

Fig. 7. Grain analysis of brine quenched EN19 Steel Alloy (100x).

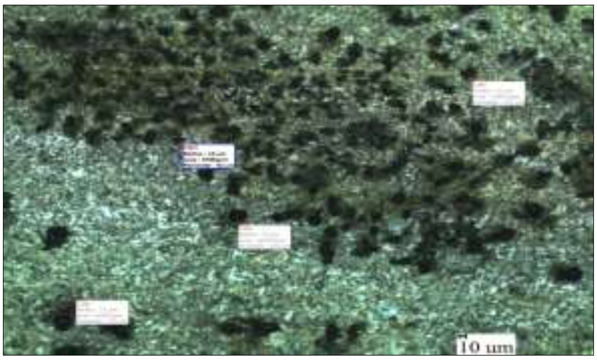

Fig. 8. Microstructure of oil quenched EN19 Steel Alloy (100x).

The quenched specimens have finer grain size than the normalized specimens. Out of the three quenchants used, EN19 steel alloy quenched in brine showed the highest hardness. This is because the rate of cooling in brine is much faster than water and oil, with oil being the slowest. If the time taken to transfer the specimens from the furnace to the quenching medium is less than two seconds, the composition is going to be completely martensite with no traces of pearlite. If the time taken is between two to six seconds, the composition will be 95% pearlite and 5% martensite. And if the time taken is more than six seconds, the composition will consist of pearlite alone.

The microstructure of oil-tempered and brine tempered EN19 Steel alloys are shown below. On tempering, the martensite formed quenching is transformed into tempered martensite. Therefore, the tempered specimen will have an increase in ductility and decrease in hardness. On tempering, the grain size of the specimens is altered.

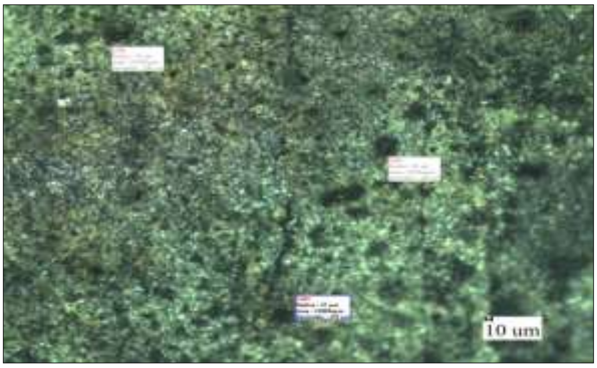

Fig. 9. Microstructure of brine tempered EN19 Steel Alloy (100x).

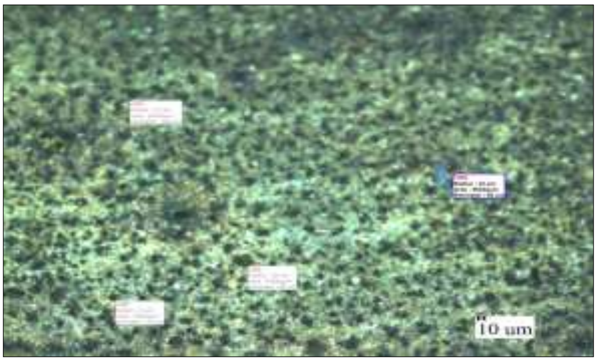

Fig. 10. Microstructure of oil tempered EN19 Steel Alloy (100x).

Using the Motic Image Plus software we were able to find the grain size of each specimen. An average was taken and, the calculated grain size was tabulated below.

Table 2. Grain Size

Specimen	Grain Size(μm)
Annealed	42
Untreated	37
Normalized	31
Oil tempered	25
Water Tempered	23
Brine Tempered	20
Oil quenched	18
Water quenched	14
Brine quenched	12

4.2. Tensile Strength

To find the ultimate tensile strength, peak load, break load, and other factors, a tensometer was used.The tensometer used was of Kudale make. It uses a load cell of 20 kN. The least count of the tensometer is

0.1mm. The elongation ranges between 0–500mm. The minimum load permissible in the tensometer is 10N. The accuracy of the tensometer is ±1%. The tensometer used had an ASTM standard of A370-E8.

The specimen whose tensile strength is to be found is clamped between the two jaws of the tensometer. The tensometer is then switched on and the movable jaw moves till the specimen breaks into two. The information from the tensometer is then transferred to a computer.

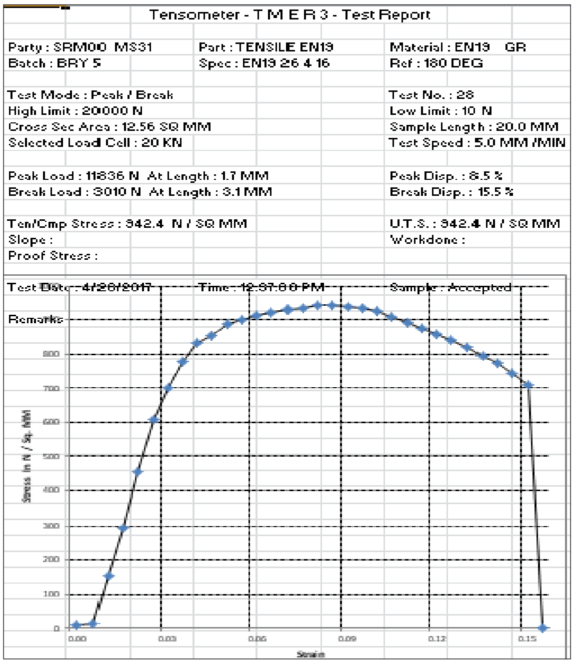

Fig. 11. Stress vs. strain graph for oil tempered specimen.

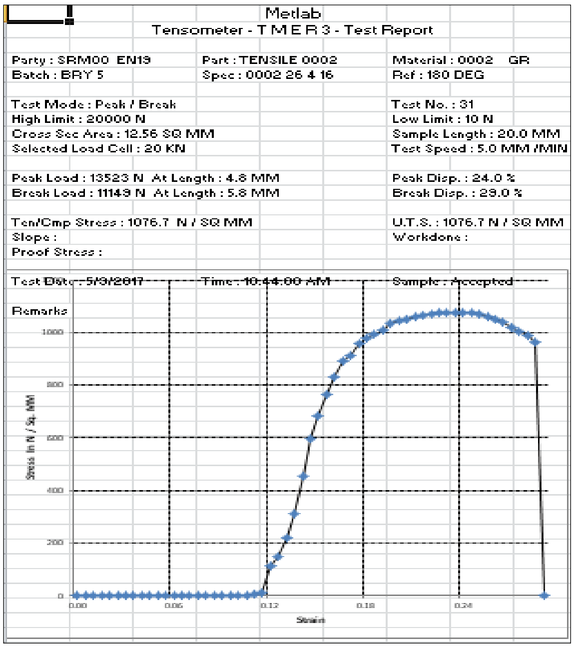

Fig. 12. Stress vs. strain graph for brine tempered specimen.

Comparing the tensile strength of the heat treated specimens with the untreated specimen from Table 3 [3], it is seen that the brine quenched specimen has the highest strength as it increased by 157%.The normalized specimen increased in strength by 39.8%. The annealed specimen decreased by 7%. The oil quenched, water tempered and the oil tempered specimens increased by 145%, 104%, and 78.5%

respectively. It is thus observed that the rate of cooling has an effect on the tensile strength of EN19 steel alloy. Rapid cooling results in the formation of martensite which cause the specimen to have a higher tensile strength. More rapid the cooling, finer grains are formed which results in a specimen to have higher tensile strength.

Table 3. Break Load, Peak Load and Ultimate Tensile Strength of EN19 Steel Alloy

Specimen	Break Load (N)	Peak Load(N)	Ultimate Tensile Strength (N/mm^2)
Untreated	6628	6628	527.7
Annealed	6158	6158	490.3
Normalized	7138	9276	737.8
Oil Quenched	16259	16259	1294.5
Water Quenched	10218	17034	1356.2
Brine quenched	18147	18147	1422.6
Oil Tempered	3010	11836	942.4
Water tempered	12464	12464	989.7
Brine tempered	11149	13523	1076.7

4.3. Hardness

To find the hardness of the specimen Rockwell hardness test is used. In Rockwell hardness test, the specimen is kept in place on the holder. A load of 150kgf is loaded. The indenter used for steel specimen is a diamond cone indenter. The indenter is lowered onto the specimen. The Rockwell hardness machine is then switched on. Then it goes through a period of dwell for 10 seconds and the indenter comes back up again. The reading is displayed on the display unit of the machine. This procedure is then repeated 3 times and the average is taken. This is done so as to get an accurate reading. The average of the three readings is taken and the value is noted.

Table 4. Rockwell Hardness Value

Specimen	Rockwell Hardness Value
Untreated	31.4 HRC
Annealed	15.6 HRC
Normalized	41.8 HRC
Oil Quenched	68.6 HRC
Water Quenched	71.6 HRC
Brine Quenched	72.4 HRC
Oil Tempered	44.4 HRC
Water Tempered	46.3 HRC
Brine tempered	56.5 HRC

Comparing the hardness values of heat treated specimens with the untreated specimen from Table 4 [1]-[4], it is seen that the brine quenched specimen has the highest hardness which increased by 130%. The normalized specimen increased by 33%. The annealed specimen decreased in hardness by 50.4%. The water quenched and oil quenched specimens increased in hardness by 128% and 118% respectively. The oil tempered and water tempered specimens increased by a margin of 41.4% and 79.9% respectively.

4.4. Impact Strength

Here we have conducted the Charpy test to determine the impact strength and the toughness of the heat treated specimens. To do so, we have used the AIT 300N model made by FASNE Pvt Ltd. The maximum impact energy of the pendulum is 300J and the machine weighs 250kgf. [1]Also, the specimens were machined to a dimension of 50x10x10 with a groove in the center. In the Charpy test, the pendulum with a heavyweight at the end is lifted to its maximum height. Once this is done, the specimen is placed in the provided space and the pendulum is dropped on the specimen, placing a high impact load on the specimen. This load causes the specimen to fracture and gives us the value of the energy absorbed by the specimen from the dial indicator. To calculate the impact value of the specimen, we have divided the energy absorbed by the specimen by the cross-sectional area of the specimen. The test was conducted three times and the average of the values obtained have been tabulated.

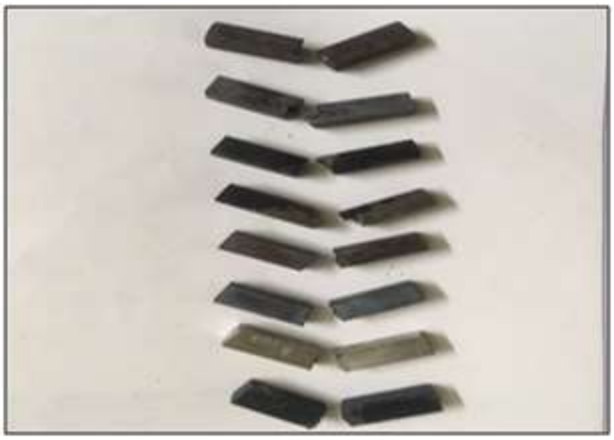

Fig. 13. Specimen after impact test.

Table 5. Impact Strength Values

Specimen	Impact strength (J)
Untreated	20
Annealed	40
Normalized	15
Oil Quenched	8
Water Quenched	5
Brine Quenched	4
Oil Tempered	10
Water Tempered	9
Brine Tempered	7

From Table 5 [3] it is clear that the annealed specimen is the most ductile with an increase of 200% in toughness and brine quenched specimen the least ductile, decreasing by 80%. The normalized specimen decreased by 25%. The water and oil quenched specimens decreased in toughness by 75% and 60% respectively. The oil, water, and brine tempered specimens decreased by 50%, 60%, and 65% respectively. For the more ductile materials, the ability to absorb energy is more, thereby increasing the impact strength of the material. Therefore, it is noticed that the rate of cooling has an impact on the impact strength of EN19 steel alloy. The slower the cooling, the higher the impact strength. From Table 2, it is observed that annealed specimen has the largest grain size. This also causes the specimen to have higher impact strength. Therefore, the annealed specimen has the highest impact strength.

5. Conclusion

In this paper, the heat treatment processes annealing, normalizing and quenching followed by tempering are done to compare the tensile strength, hardness, microstructure and impact strength of EN19 steel.

We observe that the brine quenched specimen has the highest tensile strength and the annealed specimen the lowest. On comparing the tensile strength of the tempered specimens with the quenched specimens, we find that oil tempered specimen decreases by 27.19%, water tempered decreases by 27.02% and brine tempered decreases by 24.31% from the oil quenched, water quenched and brine quenched respectively.

It was found that the brine quenched specimen had the highest hardness and the annealed specimen the lowest. On comparing the values of the tempered specimens with that of the quenched specimens we find that the oil tempered specimen decreases in hardness by 35.27%, the water tempered specimen decreases by 35.33 and the brine tempered specimen decreases by 21.96% from the oil quenched, water quenched and brine quenched specimens respectively.

We also found that the annealed specimen had the highest impact strength and the brine quenched specimen the lowest. On comparing the values of the impact strength of the tempered specimens with that of the quenched specimens, we noted that the oil tempered specimen increases by 20%, water tempered specimen by 44.4% and brine tempered specimen by 42.85% from the oil quenched, water quenched and the brine quenched specimens respectively.

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