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A Study On Microstructural And Mechanical Properties Effected By Different Heat Treated Of Aisi 1055 Steel

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ABSTRACT: Heat treatment plays a vital role in modifying material properties by manipulating the phase transformation and grain size. In this regard, the present study was conducted on AISI 1055 steel. The annealing, normalizing, quenching, and tempering heat treatment process was performed on AISI 1055 steel to modify its microstructural characteristics. The microstructural characteristics were examined under optical microscopy and scanning electron microscopy. The effect of phase transformation on the hardness was studded, and there is more than 70% increment was observed by quenching and tempering the heat-treatment process. In contrast, the tensile properties are significantly affected. It was observed that the yield strength was increased from 380 to 433, 425 and 735 MPa ,the ultimate tensile strength was increased from 581 to 716, 709 and 980 MPa, the% strain was reduced from 21.06 to 17, 18.5, and 16 by the heat treatment process name as normalizing, annealing and tempering, respectively.
Keywords: AISI 1055, Heat Treatment, Microstructure, Tensile Strength, Hardness

I. INTRODUCTION

In the last few decades, there have been some significant advances in the metal industry. Iron is a very important compound used as a structural material because it is easily available and having a low cost, which makes the steel as more appropriate and application in the industries for a different type of component. Based on its application, lots of research work is going on to improve and manipulate its physical, chemical, mechanical, and electrical properties to make it more useful in the industry [1-3]. Many processes are used in industry for different-different steels

Heat treatment processes are used to modify the property of the material in terms of physical, chemical, electronic, and mechanical properties. For these properties, many technics are widely used in the industry, such as Induction hardening, Flame hardening, Annealing, Quenching, Normalizing, Chemical Vapour deposition, Physical Vapour deposition, Carburizing, Nitriding, boronising, Shot pinning, Burnishing, etc. The heat treatment process was considered according to the type of properties which require to improve. Chemical Vapour Deposition, Physical Vapour deposition, Carburizing, Nitriding, Boronising process were used to improve surface properties up to a depth of few microns. Similarly, other processes are considered [4-6].

An alloying element thatis added in the iron gives some modification in the properties of the material. Depending upon the quantity of alloying elements, create a different type of grade. The elements which are primarily added in iron discussed below [7-12]. **Carbon-** Carbon is the main element that is added in steel up to 2%. Carbon is either dissolve or in a combined form (Fe3C). It was observed that the hardness and tensile properties is increased but the weldability and ductility is reduced as an increase in carbon content.**Manganese-** In general, 0.3% manganese is found in steel, and the content may increase up to 1.5%. It helps to reduce the formation of iron sulfate in the matrix. In consideration of mechanical properties, strength and hardenability were increase. **Silicon-** the silicon is used in the rolling process as an amount of 0.2 % to act as deoxidizer. Similarly, for casting 0.35 to 1.0% silicon is used to introduce strength in the casted material. Welding process, the base material having 0.5 % silicon more suitable and the 1.0 % silicon in the electrode improves the cleaning effect in the welded part. **Sulfur-** sulfur hasa tendency to

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increase the brittleness in the steel so that it will be avoided for steel making. If the sulfur increases more than 0.05 %, the weldability if steel reduce. Whereas steel having sulfur in the range of 0.1 to 0.3 %, machinability improves, but weldability reduces.**Phosphorus-** It is an undesirable element in steel. In general, it will found a maximum of 0.04 % in carbon steel. If the phosphorus is added up to 0.1 % in the steel, it may be favorable as an increase in strength and corrosion resistance, but It is generally not used in steel. **Chromium-** It is an important element for the iron-carbon matrix because it is an austenite stabilizer which increases the hardenability of the material. Chromium will increase the corrosion resistance of steel, so it improves the life of a component. If stainless steel, chromium is added more than 12% to prevent corrosion.**Molybdenum-** It is used in steel to improve the properties at an elevated temperature. It is used up to the range of 0.1 % in steel also a strong carbide former.**Nickel-** It will increase the hardenability of steel, also improves toughness and ductility. Generally, it is used in the steel, which is used at cold placed because it improves the toughness of the material at low temperature.**Niobium-** it is also known as Columbium. In general it improves the hardenability of steel, but it has strong affinity to carbon so that it may reduce the overall hardenability of steel.

The thermal and thermochemical processes have been successfully used for surface treatment of steels, but it gives shallow case depth, which is impractical and uneconomical, especially when the large parts are to be treated locally. Such as the surface of large gears, large rolls and dies, large bearing cages as well as the ends of the valve stem and pushrods and wearing surfaces of cams and levers etc.

The thermal hardening by morphological modification is used successfully for the modification of steel, but it also has certain disadvantages. The use of flame hardening may cause zonal variation of heating and it is difficult to control the temperature of heating of the component. The explosive fuel gases have to be used cautiously in the flame hardening process. The induction hardening process is more complicated with relatively poor adaptability, where it is difficult to guarantee the quality of some complex shaped workpiece. The induction heater is quite complex and costly. The input itemsare relatively high due to poor interchangeability and adaptability of the induction coil (inductor). Often it cannot be used for the complex shape of the workpiece.

The study was carried out on AISI 1055 steel by applying various heat treatment processes such as annealing, normalizing and quenching with the tempering process. For the tempering process, three different temperatures and three different holding time were taken for the batter understanding of microstructure. The microstructure was studied under optical as well as scanning electron microscopy. The hardness properties were studied by Rockwell hardness tester and correlated with the microstructure. The mechanical properties such as the behaviour of stress-strain curve, yield strength, ultimate tensile strength, and % elongation were studied. Fracture image after the tensile test has been studied for different heat treatment conditions.

II. EXPERIMENTATION

The heat treatment was carried out on AISI 1055 steel. This steel is also known as AISI 1055 and CK55 steel. The chemical composition of AISI 1055 steel has been shown in table 1. The material supplier gives the chemical composition result as a test certificate of the material. In AISI 1055 steel carbon contents are 0.55% Mn- 0.75, Si-0.20, S- 0.035, Mo-0.05, P-0.02 and remaining are Fe. The experimental specimen such that tensile and other test samples are easily fabricated from that. The sample cleaning was done before heat treatment by 100 grit paper after that acetone cleaning so that the outer surface of the sample is clean and rust-free.

Table 1 AISI 1055 steel Chemical Composition.

C	Mn	Si	Mo	S	P	Fe
0.55	0.75	0.2	0.05	0.035	0.02	Balance

2.1 Annealing

The annealing process was carried out such that the material is heated to more than AC3 temperature followed by the holding for some time and cooled in the furnace. In this regard, AISI 1055 steel sample was heated to 810^{o}C and hold it for one hour to ensure the homogenizing of the specimen. After that, the furnace was switched off such that sample was kept inside for 24 hours to ensure furnace temperature reaches room temperature.

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2.2 Normalizing

The normalizing process was carried out such that the material is heated to the more than AC3 temperature followed by the holding at same temperature for some time and cooled in the open environment. In this regard, AISI 1055 steel sample was heated to 810^{o}C and hold it for one hour to ensure the homogenizing of the specimen. After that, the furnace was switch off,and the sample was kept outside and naturally cooled tillit reaches room temperature.

2.3 Quenching andTempering

Quenching process- The quenching process was carried out such that the material is heated to the more than AC3 temperature followed by the holding at the same temperature for some time and sudden cool to room temperature using the different cooling medium. In this regard, AISI 1055 steel sample was heated to 810^{o}C and hold it for one hour to ensure the homogenizing of the specimen. After that,the specimen was quenched in water to room temperature.

Tempering process- The tempering process was carried out such that the material is heated to the below AC3 temperature followed by the holding at the same temperature for some time followed by cooling in still air. In this regard, two different conditions by varying temperature and time period was considered such as sample was heated to 250 and 550 ^{o}C and hold it for one, two and three hour after that the specimen was cooled in still air.

2.4 Hardness Testing-

Hardness testing was carried out on Rockwell hardness tester at room temperature. A standard procedure was used for this test with a minor load of 10 kg and a major load of 150 kg with a dwell time of 30 seconds. Depth was measured by the machine and converted into hardness as per the ASTM standard supplied by the tester manufacturing company.

2.5 Tensile test

Tensile samples are fabricated after the heat treatment of steel. The sample size is taken according to the ASTM standard E8 and follows a standard procedure with a strain rate of 0.5mm/min at room temperature. Three samples are tested for each condition and the average of that was shown in the result and discussion. The gauge length of the tensile sample was polished with 1000 grit paper to ensure that there is no stress concentration in the gauge length. The size of the tensile sample has been shown in fig. 1.

The test was carried out on a UTM machine. The machine hasthe capability to apply load up to 50 kN. The machine was calibrated before performing the tensile test. The calculation of stress, strain and other properties was done as per ASTM standard. The fractured sample was kept safely in a vacuum vessel for fracture analysis in scanning electron microscopy.

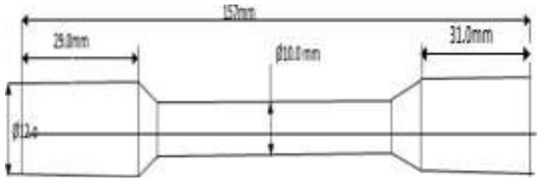

Fig. 1 Standard size of tensile test sample

2.5Microstructural Analysis

The heat-treated samples are examined under an optical microscope to understand microstructural modification such as phase transformation like ferrite, pearlite, martensite etc.in the matrix and size of grains in the matrix. For the examination of such properties on a sample, the sample was polished by up to 2000 grid paper followed cloth polish. Finally, the sample was etched by using 4% nital for 22 seconds.

III. RESULT AND DISCUSSION

3.1Microstructural Analysis

The heat treatment process is primarily adopted to modify the microstructural properties such as phase transformation and grain refinement. Such a change in the microstructure plays an essential role in modifying the mechanical and physical properties where the chemical composition was the same.

The optical microstructural study of normalized AISI 1055 steel material has been shown in fig. 2. It depicts that the equiaxed grain structure in the matrix in which the light area shows ferrite in the matrix, and the dark area shows parealite [13]. It is also observed that the grain boundary is not clearly visible. The microstructure under scanning electron microscopy has been shown fig. 3 (a and b). the fig. 3 confirms that the ferrite and pearlite in the matrix and carbide were absent in the matrix [14].

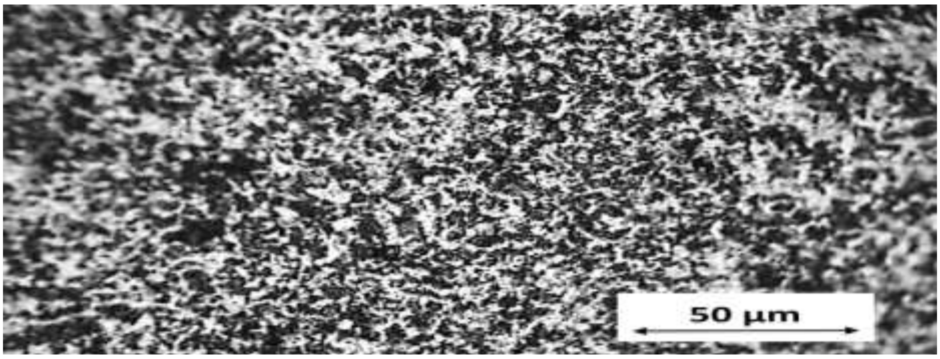

Fig. 2 Microstructure of normalized sample under an optical microscope.

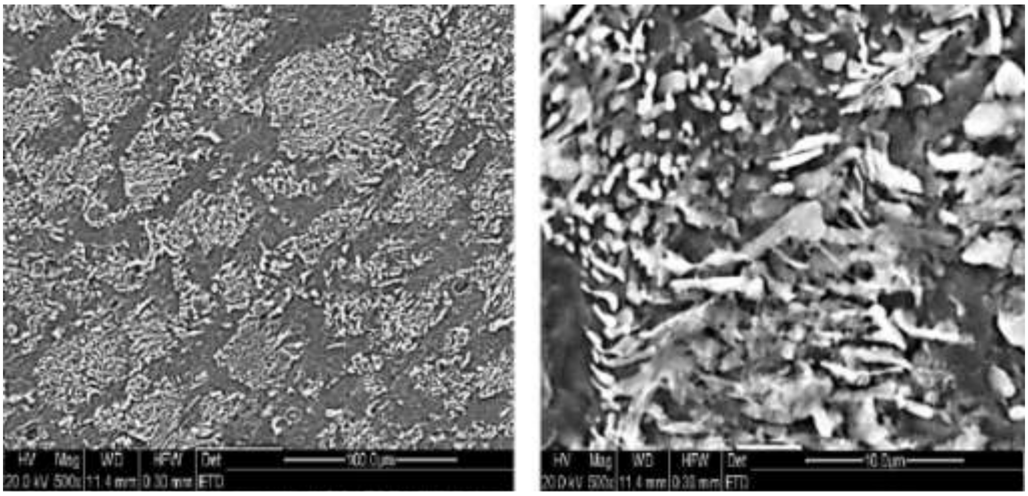

Fig. 3 Microstructure of normalized sample under scanning electronmicroscopy at (a) lower magnification, (b) Higher magnification.

The effect of annealing heat treatment on the microstructure has been shown in fig. 4 and 5. The fig. 4 shows that the ferrite and pearlite in the matrix with an equal ratio. It is also observed that the grain boundary are little visible as compare to normalizing. The same sample was examined in scanning electron microscopy. It was observed that the thickness of the grain boundary was an increase. This phenomenon may be happened due to a reduction in cooling rate as compare to normalizing [15].

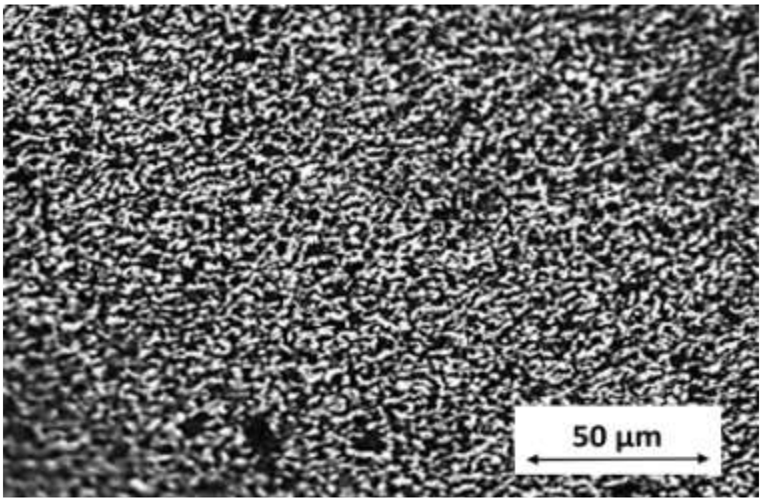

Fig. 4 Microstructure of Annealed Steel under optical microscope.

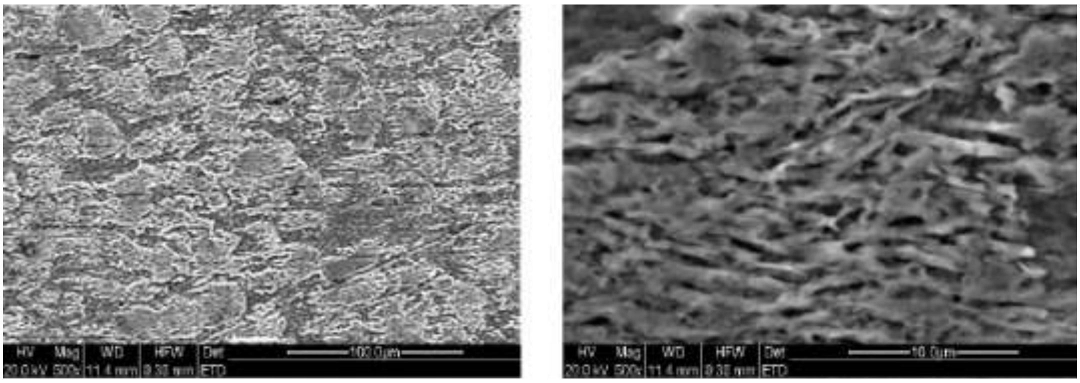

Fig. 5 Microstructure of Annealed Steel under scanning electron microscopy at (a) lower magnification, (b) Higher magnification

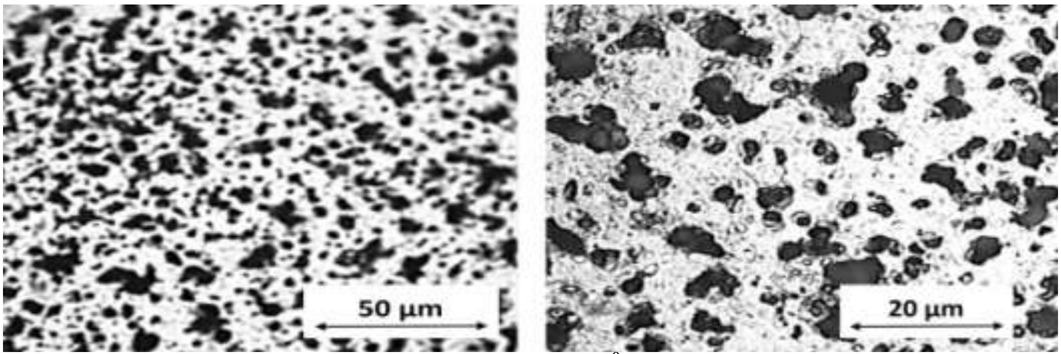

Fig. 6 Microstructure of Quench and Tempered steel at 240^{0}C under an optical microscope at (a) lower magnification, (b) Higher magnification

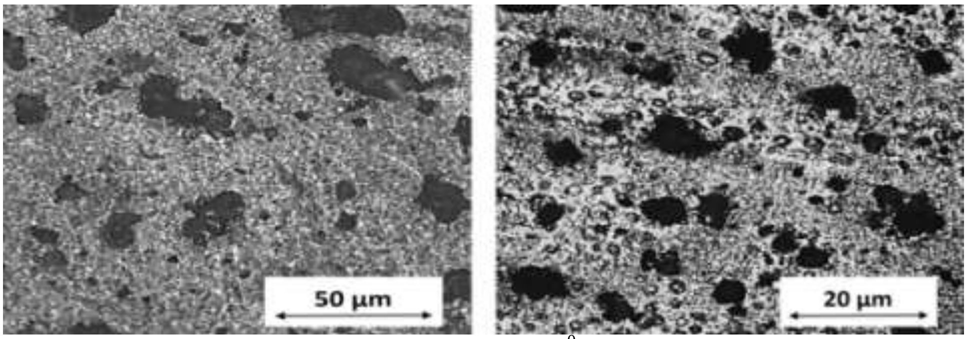

Fig. 7 Microstructure of Quench and Tempered steel at 420^{0}C under an optical microscope at (a) lower magnification, (b) Higher magnification

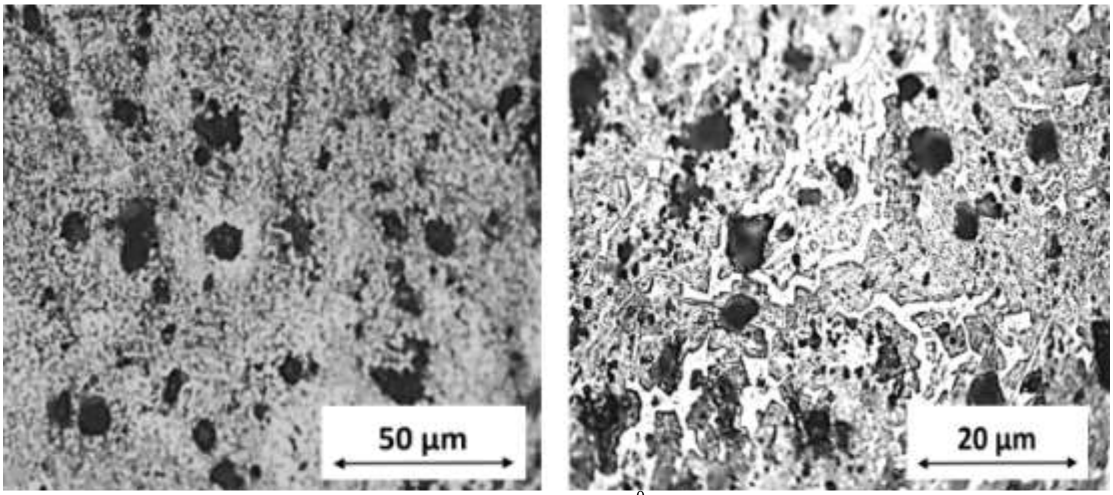

Fig. 8 Microstructure of Quench and Tempered steel at 600^{0}C under an optical microscope at (a) lower magnification, (b) Higher magnification

The effect of Quenching and tempering at a different temperature on the microstructure of AISI 1055 has been shown in fig. 6, 7, and 8. The fig. 6 shows that the concentration ferrite in the matrix was increased in fig. 4.6 and 4.7, which conclude that the ferrite contains are increased as tempering temperature increase from 240 to 600 ^{o}C. It is also observed that the spherodized carbide [16] wasraised. These phenomena were happened due to an increase in tempering temperature. The tempered martensite was observed in the matrix of the sample prepared by tempering at 200 ^{o}C, and also a small amount of cementite was observed as the tempering temperature was increased from 240 to 420, tempered martensite and globular cementite observed in the matrix as shown in fig 7. Similarly, martensite content in the matrix was reduced and an enhanced amount of ferrite and more globular cementite was shown in the matrix by an increase in tempering temperature to 600 ^{o}C [16].

3.2 Mechanical Properties

3.2.1 HardnessMeasurement

The hardness of the received material and after the different heat treatment is shown in table2.The hardness of the as-received material was found as 34 RC. After heat treatment, the hardness was increased from 34 to 63, 53 and 68 RC by normalizing, annealing and tempering, respectively, as shown in fig 9 (a). Here the improvement was considered due to two reasons, first is phase transformation from ferrite to martensite or bainite in the matrix and second is grain refinement. The annealing process shows the hardness as 50 RC, which is approximately 40 % more as compared to the received material. In the case of normalizing heat treatment, the hardness was increased to 63 RC, which is 70 % more as compare to the as-received and 26 % as compare to annealing. The hardness is further increased to 68 RC if quenching and tempering were done at 240 ^{o}C @ 1 Hr. this is happened due to an increase in the cooling rate.

The hardness of AISI 1055 steel was changed as the heat treatment parameter, such as temperature and time of quenching and tempering process. The maximum hardness was observed as 68RC in the case of quenching and tempering at 200 ^{o}C with a time period of one hour. This has happened because the martensite and bainite transformation was observed after the quenching process and this martensite is very less tempered at the process parameter of 200 ^{o}C with a time period of one hour for the tempering process. As the tempering process time period increase, the hardness is reduced from 68 to 57 RC, as shown in fig 9 (b). It is also observed that the increase in the temperature of the tempering process leads to the reduction of hardness. The minimum hardness was observed at the quenching and tempering process parameter of 600 ^{o}C temperature and 3 hour holding time. The formation of ferrite in the microstructure confirms such reduction of the hardness, as discussed previously.

Table 2 Hardness of different processes Specimen

Specimen Specification	Hardness in RC					Average hardness in RC
As received	33	34	34	35	34	34
Normalized at 810^{0}C	62	62	64	64	63	63
Annealed at 810^{0}C	50	49	51	50	50	50
Tempered at 200^{0}C, 1 Hr	69	68	68	67	68	68
Tempered at 200^{0}C, 2 Hr	63	62	64	62	62	62
Tempered at 200^{0}C, 3 Hr	56	58	57	57	57	57
Tempered at 400^{0}C, 1 Hr	62	60	62	60	61	61
Tempered at 400^{0}C, 2 Hr	55	56	56	57	56	56
Tempered at 400^{0}C, 3 Hr	51	51	51	51	51	51
Tempered at 600^{0}C, 1 Hr	54	56	54	54	54	54
Tempered at 600^{0}C, 2 Hr	51	50	50	50	49	50
Tempered at 600^{0}C, 3 Hr	47	46	46	47	46	46

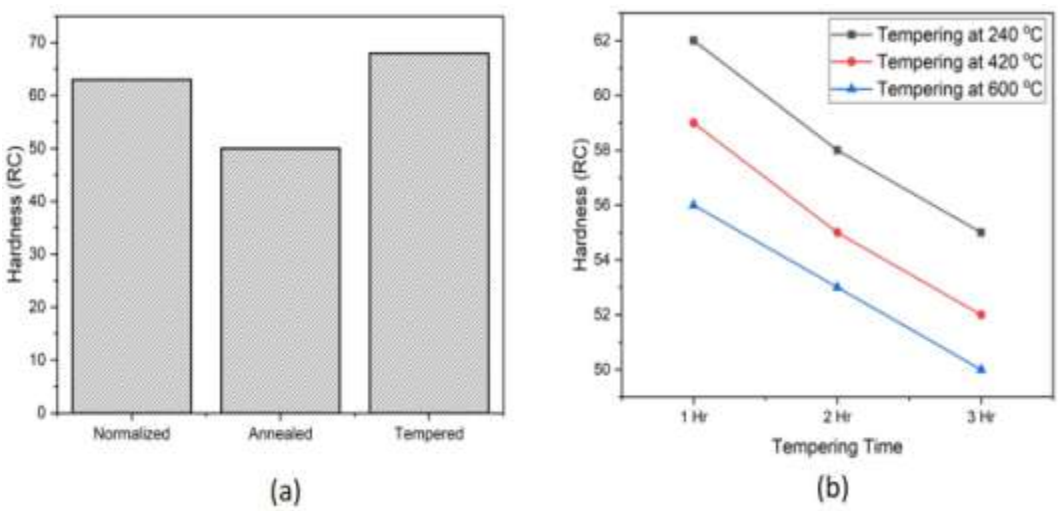

Fig. 9a) Hardness at the different heat treatment process, b) Hardness at the different parameter of quenching and tempering process

3.3.2 Tensile properties

The engineering stress-strain curve has been shown in fig. 10, 11,12 and 13. The fig. 10 shows the stress-strain curve after the normalizing and annealing process. The curve depicts that the yielding characteristics are very less in the normalizing process as compare to the annealing process. Fig. 11 (a, b and c) shows the stress-strain curve for the quenching and tempering at 240 ^oC with a variation of holding time of 1, 2 and 3 hr, respectively. Fig. 12 (a, b and c) shows the stress-strain curve for the quenching and tempering at 420 ^oC with a variation of holding time of 1, 2 and 3 hr, respectively.Fig. 13 (a, b and c) shows the stress-strain curve for the quenching and tempering at 600 ^oC with a variation of holding time of 1, 2 and 3 hr, respectively. A discussion of tensile properties is discussed below for all process parameter.

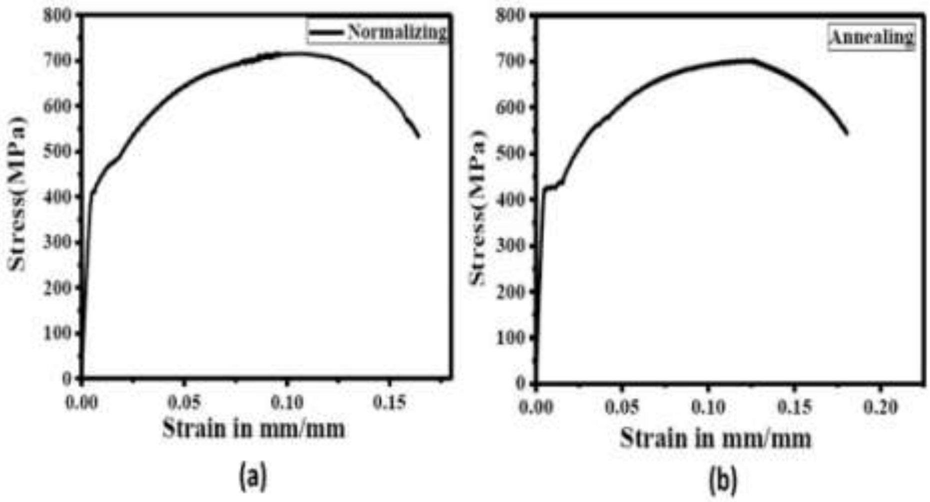

Fig. 10 Stress-strain curve after a) normalizing b) annealing process

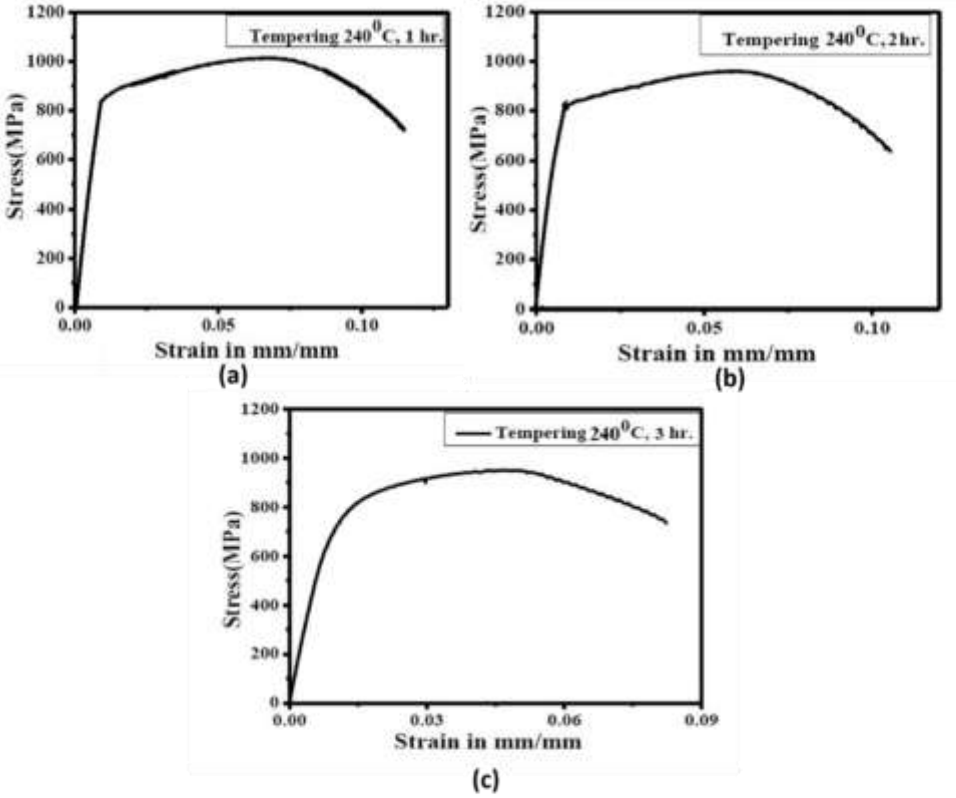

Fig. 11 Stress-strain curve for the quenching and tempering at 240 ^{o}C with a variation of holding time of a) 1, b) 2 and c) 3 hr

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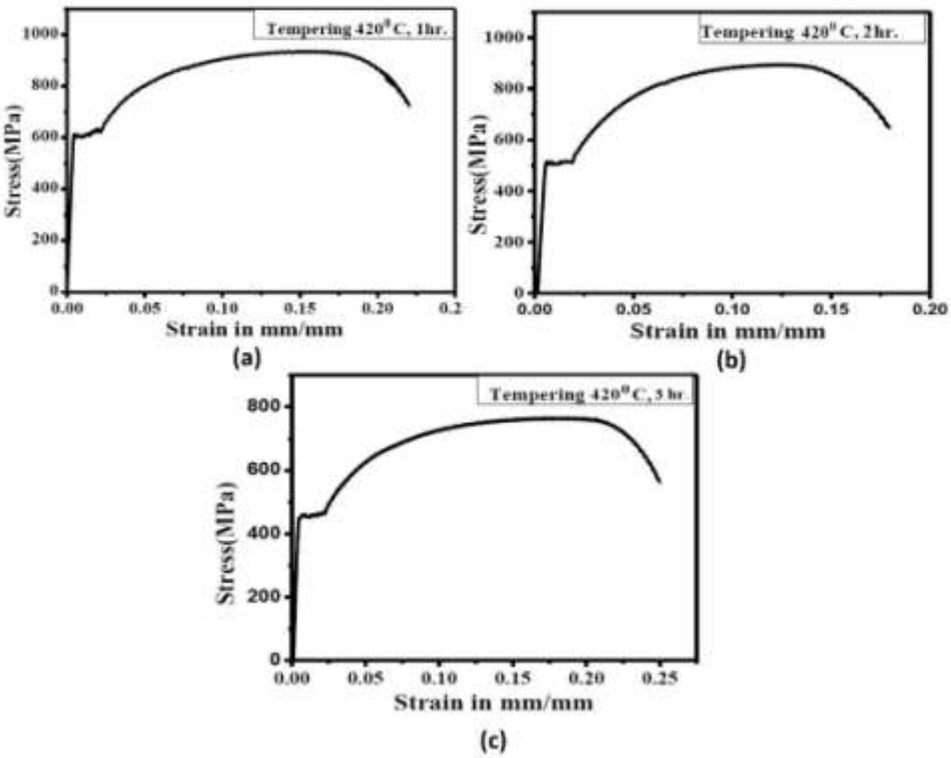

Fig. 12 Stress-strain curve for the quenching and tempering at 420 ^{o}C with a variation of holding time of a) 1, b) 2 and c) 3 hr

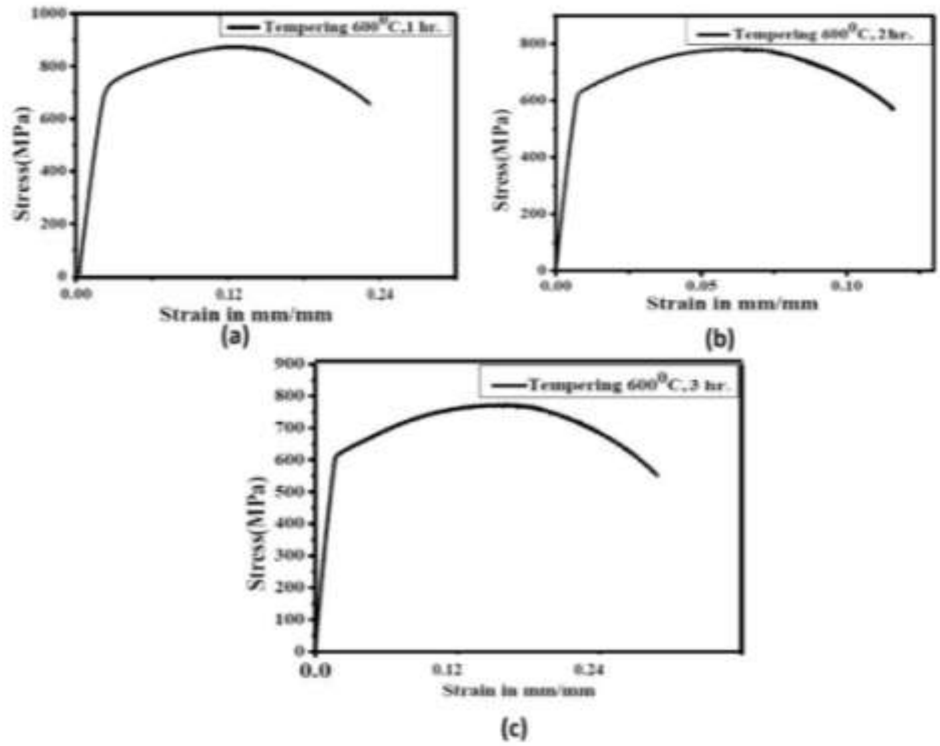

Fig. 13 Stress-strain curve for the quenching and tempering at 600 ^{o}C with a variation of holding time of a) 1, b) 2 and c) 3 hr

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The Tensile properties of the received material and after the different heat treatment is shown in fig. 14. The tensile properties such as yield strength, ultimate tensile strength and % strain of the as-received material were found as 380 MPa, 581 MPa and 21.60%, respectively. After heat treatment, the yield strength was increased from 380 to 433, 425 and 735 MPa by normalizing, annealing and tempering, respectively, as shown in fig 14 (a). Here the improvement was considered due to two reasons; first is phase transformation from ferrite to martensite or bainite in the matrix and second is grain refinement [17-19]. The ultimate tensile strength was increased from 581 to 716, 709 and 980 MPa by normalizing, annealing and tempering, respectively, as shown in fig 14 (b). The % strain was reduced from 21.06 to 17, 18.5 and 16 by normalizing, annealing and tempering, respectively, as shown in fig 14 (c).

The annealing process shows the Yield strength as 433 MPa, which is approximately 14 % more as compared to the received material. In the case of normalizing heat treatment, the hardness was an increase to 425 RC, which is 12 % more as compared to the as-received and 2 % less as compared to annealing. The Yield strength is further increased to 735 MPa if quenching and tempering were done at 240 oC @ 1 hr, which is 93 % more as compare to the as-received material and 70 % less as compare to annealing. This is happened due to an increase in the cooling rate.

The tensile properties of AISI 1055 steel were changed as the heat treatment parameter such as temperature and time of quenching and tempering process. The maximum yield and ultimate tensile strength were observed as 810 and 978 MPa, respectively, in the case of quenching and tempering at 240 ^{o}C with a time period of one hour. As yield and ultimate tensile strength were increased, there is a reduction in the % strain from 21.6 to 11.5 %. This happens because the martensite and bainite transformation was observed after the quenching process and this martensite is very less tempered at the process parameter of 240 ^{o}C with a time period of one hour for the tempering process.

As the tempering process time period increase, the yield and ultimate tensile strength are reduced from 810 to 718 MPa and 978 to 905 MPa, respectively, as shown in fig 15. It is also observed that the increase in the temperature of the tempering process leads to the reduction of yield and ultimate tensile strength but an increase in %strain. The minimum tensile properties were observed at the quenching and tempering process parameter of 600 oC temperature and 3-hour holding time, as shown in fig. 15. The formation of ferrite in the microstructure confirms such reduction of the yield and ultimate tensile strength, as discussed previously in the microstructure section.

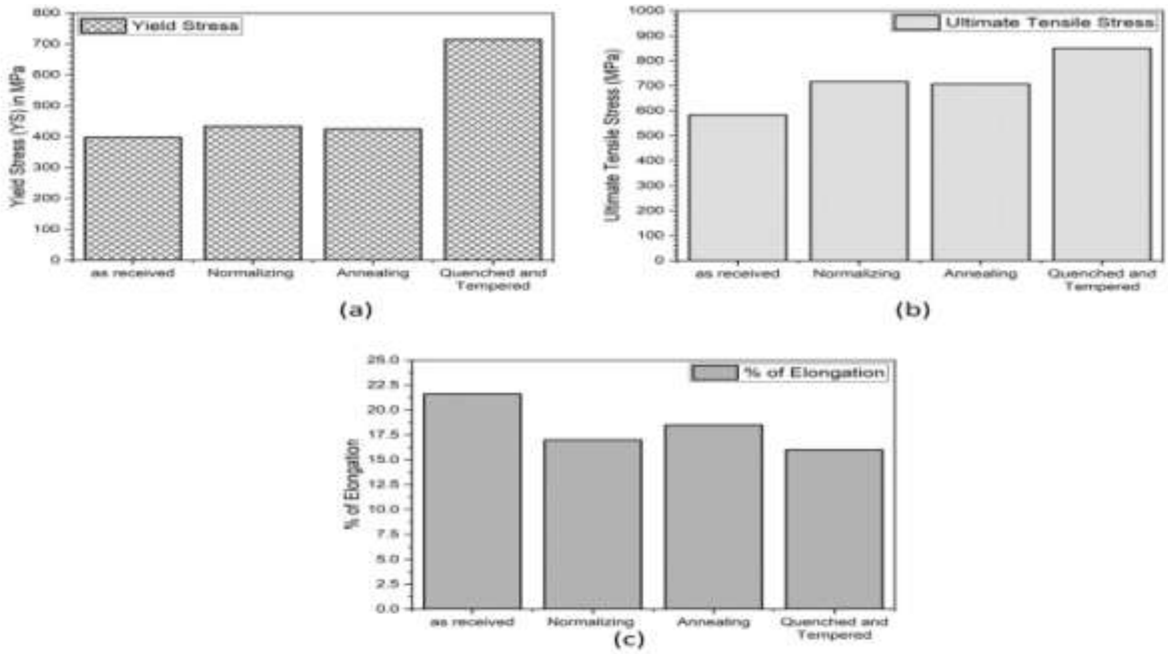

Fig. 14a) Yield strength **b)** Ultimate tensile strength **and c)** % strain at the different heat treatment process

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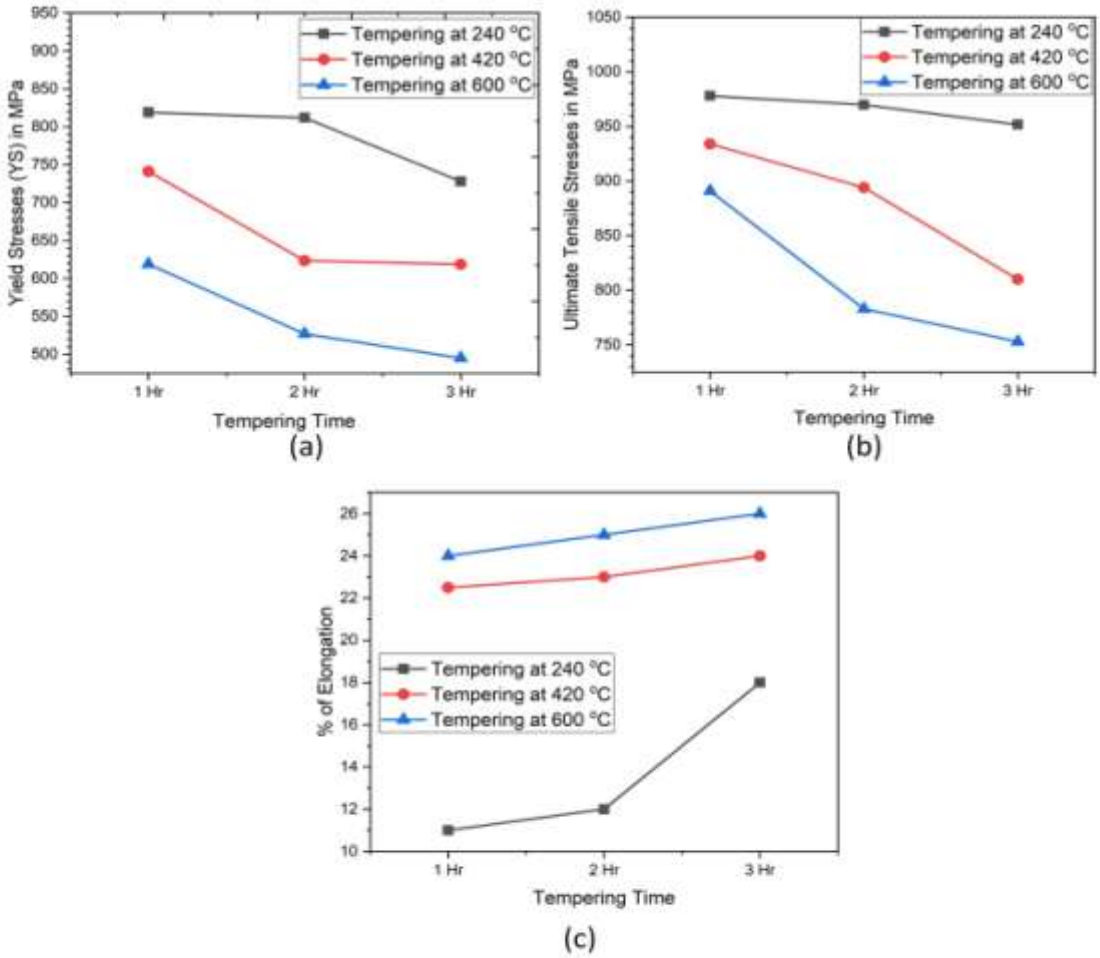

Fig. 15a) Yield strength **b)** Ultimate tensile strength **and c)** % strain at the different parameter of quenching and tempering process

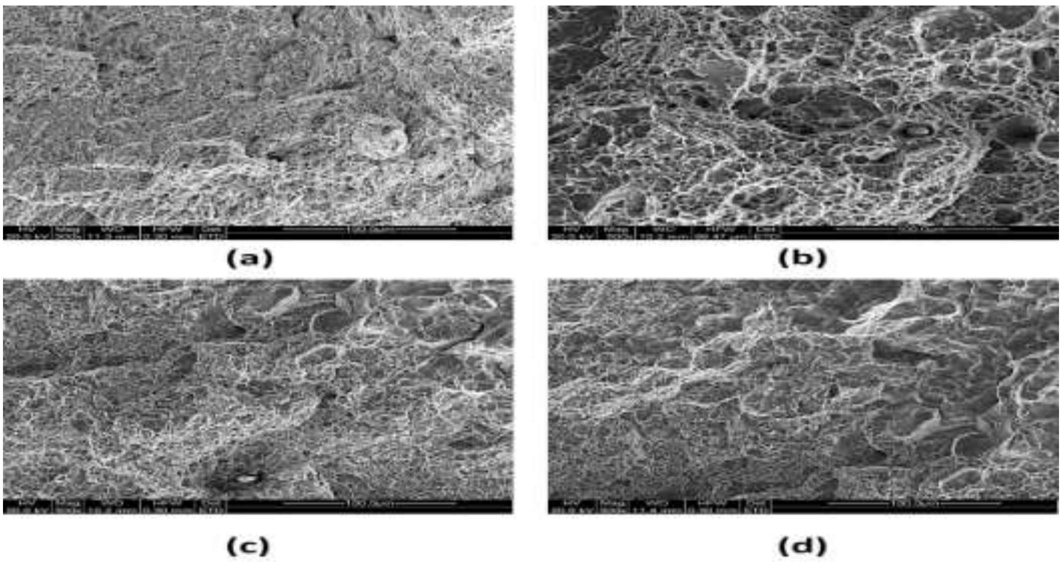

Fig. 16 Fracture micro graphical view of a tensile sample of a) As received b) Normalizing, c) Annealing d) Quenching and tempering.

Fracture image after the tensile test has been shown in fig. 16 under different heat treatment conditions. Fig. 4.20 (a) shows the dimple like structure and it is finest as compared to the other fracture image, which causesan increase in ductility in the material. Whereas, the coarse grain was observed in fig. 4.20 (d) [31]. Fig. 4.20 d also depicts that the intergranular brittle fracture at many places shows the more hard phase transformation as compare to the normalizing and annealing process. The fracture gives clear information on the formation of hard phase transformation and grain refinement and makes an agreement with the microstructure and the tensile properties of AISI 1055 steel.

IV. CONCLUSIONS

The following conclusion has been made on the heat treatment process and the parameters.

- The microstructure modification, such as phase change and grain refinement, was achieved by controlling process and process parameters. A martensitic phase transformation was observed in quenching and tempering at 200 ^{o}C with a time period of one hour.
- As the Tempering temperature increase, martensite content in the matrix was reduced, and an enhanced amount of ferrite and more globular cementite was shown in the matrix by an increase in tempering temperature to 600 ^{o}C
- The maximum hardness is observed as 68 RC if quenching and tempering were done at 240 ^{o}C @ 1 Hr. The annealing process shows the hardness as 50 RC, which is approximately 40 % more as compared to the received material. In the case of normalizing heat treatment, the hardness was an increase to 63 RC, which is 70 % more as compare to the as-received and 26 % as compare to annealing.
- As the tempering process time period increase, the hardness is reduced and if the temperature of the tempering process leads to the reduction of hardness.
- The yield strength was increased from 380 to 433, 425 and 735 MPa, and the ultimate tensile strength was increased from 581 to 716, 709 and 980 MPa, the% strain was reduced from 21.06 to 17, 18.5 and 16 by the heat treatment process name as normalizing, annealing and tempering, respectively.
- As the tempering process time period increases, the yield and ultimate tensile strength are reduce and as an increase in the temperature of the tempering process leads to the reduction of yield and ultimate tensile strength but increase in %strain.

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