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Effect of Tempering Behavior on Heat Treated Medium Carbon (C 35 Mn 75) Steel

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Abstract: Investigations were carried out to study the effects of heat treatment on the mechanical properties of medium carbon steel. Samples of medium carbon steel were examined after heating at 900^0C and soaked for 60 minutes in a muffle furnace and quenched in oil. The mechanical behavior of the samples was investigated using universal tensile testing machine for tensile test and Rockwell hardness method for hardness testing. The hardness values and tensile strength of the quenched samples were relatively higher than those of the as-received samples, suggesting improved mechanical properties. The mechanical properties such as ductility, toughness, strength, hardness and tensile strength can easily be modified by heat treating the medium carbon steel to suit a particular design purpose. Tensile test specimens were produced from medium carbon steel and were subjected to various forms of heat treatment processes like annealing, normalizing, hardening and tempering. Results showed that the mechanical properties of medium carbon steel can be changed and improved by various heat treatments for a particular application.

Keywords: Tensile strength, hardness, Rockwell method, Medium carbon steel, Heat treatment

1. INTRODUCTION

Steel is an alloy of iron with definite percentage of carbon ranges from 0.15-1.5%, [1]. These plain carbon steels are changed on the basis of their carbon content as their major alloying element is carbon. [2] Steels with carbon content varying from 0.25% to 0.65% are classified as medium carbon, while those with carbon content less than 0.25% are termed as low carbon. The carbon content of high carbon steels usually ranges within 0.65% – 1.5%.Steel is mainly an alloy of iron and carbon, where other elements are present in quantities too small to affect [3] the properties. The other alloying elements allowed in plain-carbon steel are manganese and silicon. Steel with low carbon content has the same properties as iron, soft but easily formed. As carbon content rises, the metal becomes harder [4] and stronger but less ductile and more difficult to weld. Medium carbon steels are used in mining equipment, and tractors. In addition, machined parts such as bolts, and concrete reinforcing bars are made of this class of carbon steel. Gears, wire rods, seamless tubing, hot-rolled/cold-finished bars and forging products are more objects constructed from medium carbon steel [5]. Also medium carbon steel is made up of between 0.3% to 0.6% carbons. Increasing the carbon concentration to 0.55% in TRIP-type steels [6] makes possible to obtain very high strength properties without a deterioration of the ductility, compared to most often used steels containing about 0.2%. Although the number of steel specifications runs into thousand, plain carbon steel accounts for more than 90% of the total steel output. The reason for its importance is that it is a tough ,ductile and cheap material with reasonable [7] casting, working and machining properties ,which is also amenable to simple heat treatments to produce a wide range of properties.

The material modification process modifies the behavior [8] of the steels in a beneficial manner to maximize service life i.e. stress relieving or strength properties e.g. cryogenic treatment or some other desirable properties. Heat treatment is a combination of timed heating and cooling applied to a particular metal or alloy in the solid state in such ways as to produce certain microstructure and desired mechanical properties (hardness, toughness, yield strength, ultimate tensile strength, young’s modulus, percentage of elongation and percentage of reduction).Annealing ,normalizing, hardening and tempering are the most important heat treatments often used to modify the microstructure [9]and mechanical properties of engineering materials steels. Heat treatment involves the application of heat, to a material to obtain desired material properties [10]. During the heat treatment process, the material usually undergoes phase micro structural and cryptographic changes. The purpose of heat treating carbon steel is to change the mechanical properties of steel, usually ductility, hardness, Yield strength, tensile strength and impact resistance. The standard strengths of steels used in the structural design [11] are prescribed from their yield strength. Most engineering calculations for structure are based on yield strength. The heat treatment develops hardness, softness, and improves the mechanical properties (such as tensile strength, yield strength, ductility, corrosion resistance and creep rupture. These processes also help to improve [12] machining effect, and make them versatile. Heat treatment operation is a means of controlled heating and cooling of materials in order to effect changes [13] in their mechanical properties. Heat treatment is also used to increase the strength of materials by altering

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some certain manufacturability objectives especially after the materials might have undergone major stresses like forging and welding. Hardened sample had the highest tensile strength and hardness with lowest ductility and impact strength when compared to other heat treated samples. Hardening is strongly recommended when the strength and hardness [14] are the prime desired properties in design. Quenching in water resulted in higher tensile strength and hardness possibly due to the formation of martensite structure [15] after quenching.

The Steel developed by quenching followed by tempering process at a desired temperature [16] has the highest ultimate tensile strength with excellent combination of impact strength, ductility and hardness which is very attractive for structural use. This brittleness is therefore removed by tempering. Tempering results in a desired combination of hardness, ductility, toughness, strength and structural stability. The strength of the steel may be improved by quenching followed by tempering [17] with some compromise on toughness. The heat treatment processes are to modify the microstructure and consequently change the properties (18) of the work piece throughout. The ultimate tensile strengths steadily decrease by increasing tempering time and temperature. The ductility of the samples is measured by the tensile test. The percent of elongation is upward trend in the increment of tempering time and [19] temperature. Hardness and other mechanical properties of plain carbon steels increase with the rise in concentration [20] of carbon dissolved in austenite prior to quenching during hardening heat treatment which may be due to transformation [21] of austenite in to martensite. The transformation of austenite to martensite by diffusion less shear type transformation in quenching is also responsible for higher hardness obtained and this property is attributed [22] to the effectiveness of the interstitial carbon in hindering the dislocation motion. Martenitic structure, which has an experimental effect on toughness, is also produced during continuous [23] water quenching. The hardness of the steel increases [24] with cooling rate and also with increasing pearlite percentage which increases as the percentage martensite increases. The reason being that martensite is one of the strengthening phases in steel. In the present study, medium carbon steel samples are heat-treated at different temperature above the austenitic region and quenched followed by tempering in order to investigate the effect of different tempering temperature on the mechanical properties of the steel. The changes in mechanical behavior as compared with unquenched samples are explained in terms of changes in tensile strength.

II. MATERIALS AND METHODS

A. Chemical Composition

The chemical composition of medium carbon steel samples used for this investigation is given in the following Table.

Table No. 1: **Chemical composition of the specimen.**

%of C	% of Si	% of Mn	% of P	% of S
0.35	0.15	0.75	0.035	0.035

B. Test specimen preparation

The material used for this study is a medium carbon steel with carbon content of 0.30% carbon. The specimens were then prepared for a tensile test using a standard format of ASTM. Tensile tests were carried out by a Universal testing machine using prepared specimens.

C. Heat treating the medium carbon steel

Standard heat treatment procedures were adapted to heat treat the medium carbon steel. Five different samples were prepared for each of the operation and the average values were calculated based on the analysis was made.

1) Hardening Process

The specimens to be hardened were placed inside the furnace and heated to a temperature of 900^0C. The samples were retained at this temperature for a period of one hour (because of its mass) during which the transformation must have been completed. The hardening operation was carried out on five medium carbon steel samples having the same dimensions.

2) Tempering Process

Tempering, consists of reheating quenched steel to a suitable temperature below the transformation temperature for an appropriate time and cooling back to room temperature. This process allows microstructure modifications to reduce the hardness to the desired level while increasing the ductility. Tempering results in a

desired combination of hardness, ductility, toughness, strength and structural stability. The desired properties and structures depend on tempering temperature and time .The tempering of the quenched specimens was also carried out in a muffle furnace for one hour. Experimental heat treatment cycles for selective alloy is hardening and followed by tempering are done at 250^0C increased by 100^0C to 550^0C for each tempering time interval.

D. Mechanical test

After these treatments, mechanical properties specimens were examined of the i.e. hardness, tensile strength, yield strength, elongation and percentage of elongation.

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1) Hardness test

The hardness of specimens was measured with the aid of Rockwell method. The specimens were brought in contact with the indenter .The hardness of a specimen is indicated by the penetration of the indenter on the said specimen and displayed in dial of the machine. Indents were made on the polished surfaces using a 150kg load for HRC scale.

2) Tensile test

The heat-treated specimens were tested in the universal testing machine. The initial gauge length and diameter were measured before subjecting them to tension. The yield and maximum loads were recorded, the broken ends of each of the specimens were fitted and final gauge length and also the smallest diameter of the specimen's neck were measured. The reading thus obtained was used in the determination of the yield strength, tensile strength, elongation and toughness.

III.RESULTS AND DISCUSSIONS

The heat treated specimens were now subjected to hardness test, using standard Rockwell testing machine and tensile test using universal testing machine. The resulting values are obtained from the hardness test and tensile test and plotted in the Figures 1 to 5 showing the range of tempering temperature and the variation of mechanical properties such as hardness and tensile behavior etc. The data generated from these graphs for each of the heat treated specimens processes output result values were analyzed. The data generated from these graphs for each of the heat treated specimens i.e., Hardening at 900^0C and tempered at different tempering temperature 250^0C to 550^0C. The processes output were analyzed. The data clearly show an improvement in hardness after hardening; whereas a decrease in hardness is observed with increase in tempering temperature.

The maximum hardness of 58HRC has been obtained at 900^0C hardening. The untreated samples value of mechanical behavior was noted as follows: tensile strength 325.42N/mm^2, yield strength 209.47N/mm^2, hardness 42 HRC, toughness 61.10J, and percentage of elongation 23.24. The hardened samples values of mechanical behavior were noted as follows: tensile strength 469.01N/mm^2, yield strength 412.10N/mm^2, hardness 58 HRC, toughness 41.00J, and percentage of elongation 23.00.The mechanical properties of hardening samples tempered at 250^0C showed that the tensile strength, yield strength, hardness, toughness and percentage of elongation were 378.23N/mm^2, 290.00N/mm^2, 53 HRC, 60.78J, 39.96respectively. The mechanical properties of hardening samples tempered at 250^0C, 350^0C, 450^0C and 550^0C showed that the tensile strength, yield strength, hardness, toughness and percentage of elongation were 355.17N/mm^2, 355.17N/mm^2, 49 HRC, 58.53J, 35.50 respectively. The mechanical properties of hardening samples tempered at 450^0C showed that the tensile strength, yield strength, hardness, toughness and percentage of elongation were 343.80N/mm^2, 217.31N/mm^2, hardness 44 HRC, 58.88J, 21.16respectively. The mechanical properties of hardening samples tempered at 550^0C showed that the tensile strength, yield strength, hardness, toughness and percentage of elongation were 336.37N/mm^2, 265.74N/mm^2, 39HRC, 70.29J, 47.01respectively. The results of the specimens which were hardened with oil quenched and then tempered at 250^0C, 350^0C, 450^0C and 550^0C are expressed graphically in Figure.1.

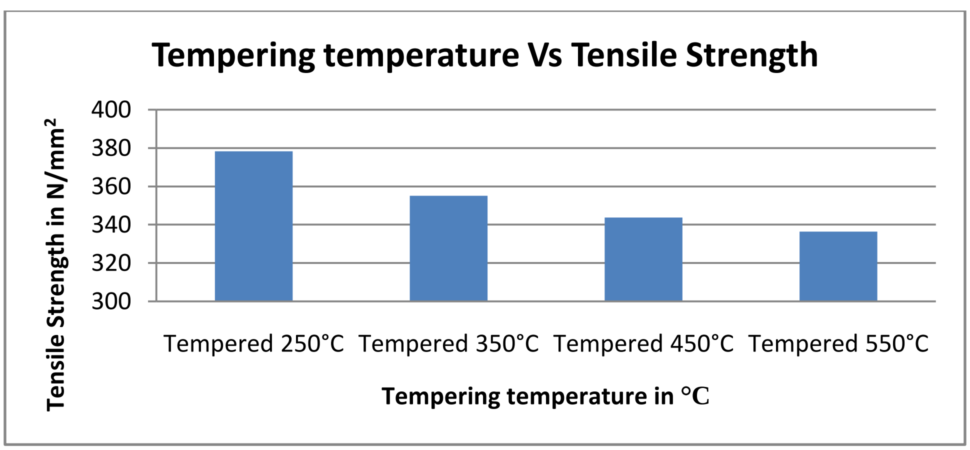

Figure: 1. Tensile strength Vs Tempering temperatures of 250^0C to 550^0C

The mechanical properties of tempering samples were tempered at 250^0C, 350^0C, 450^0C and 550^0C showed that the tensile strength, 378.23N/mm^2, 355.17 N/mm^2, 343.80 N/mm^2 and 336.37 N/mm^2 respectively. The results of the

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specimens which were hardened with oil quenched and then tempered at 250^0C, 350^0C, 450^0C and 550^0C are expressed graphically in Figure.2.

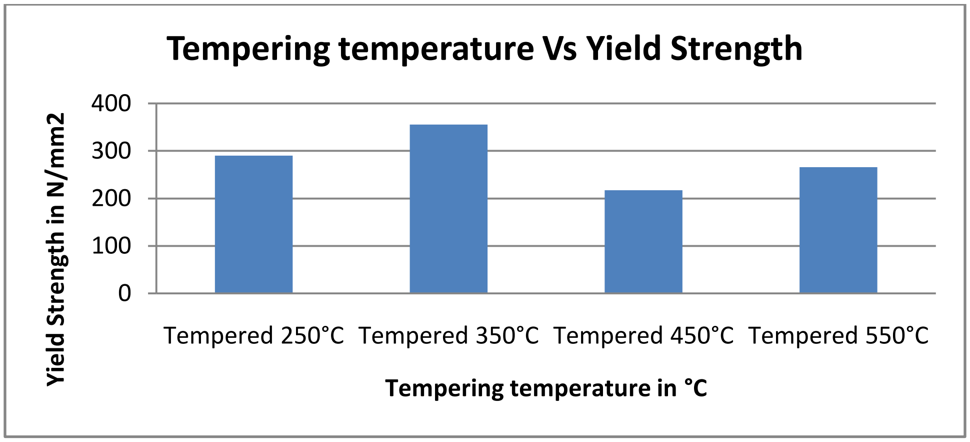

Figure: 2. Yield strength Vs Tempering temperatures of 250^0C to 550^0C

The mechanical properties of tempering samples (tempered at 250^0C, 350^0C, 450^0C and 550^0C) showed that the yield strength, 290.00 N /mm^2, 355.17 N/mm^2, 217.31 N/mm^2 and 217.31 N/mm^2 respectively. The results of the specimens which were hardened with oil quenched and then tempered at 250^0C, 350^0C, 450^0C and 550^0C are expressed graphically in Figure.3.

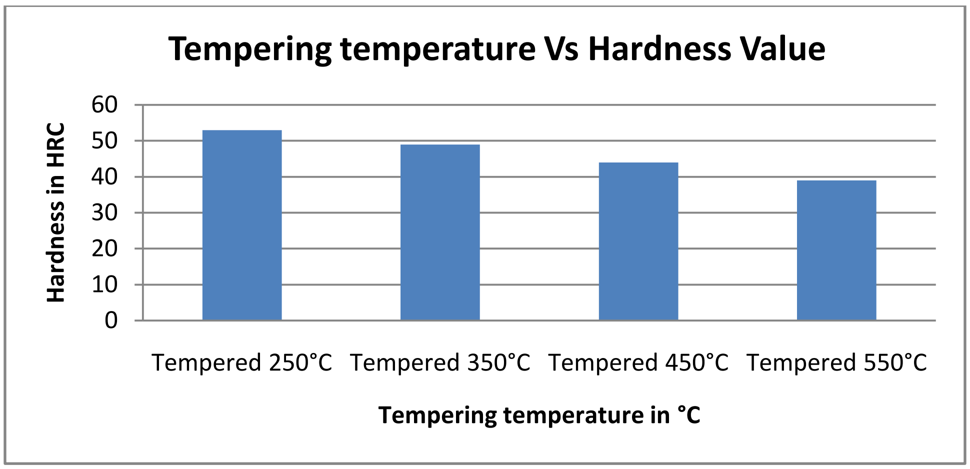

Figure: 3 Hardness Vs Tempering temperatures of 250^0C to 550^0C

The mechanical properties of tempering samples (tempered at 250^0C, 350^0C, 450^0C and 550^0C) showed that the hardness value in HRC is noted as 53, 49, 44, and 39 respectively. The results of the specimens which were hardened with oil quenched and then tempered at 250^0C, 350^0C, 450^0C and 550^0C are expressed graphically in Figure.4.

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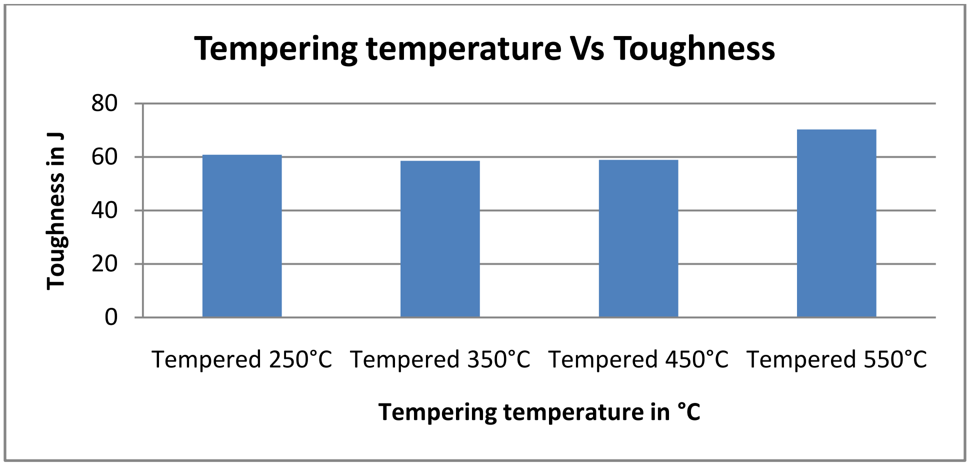

Figure: 4 Toughness Vs Tempering temperatures of 250^{0}C to 550^{0}C

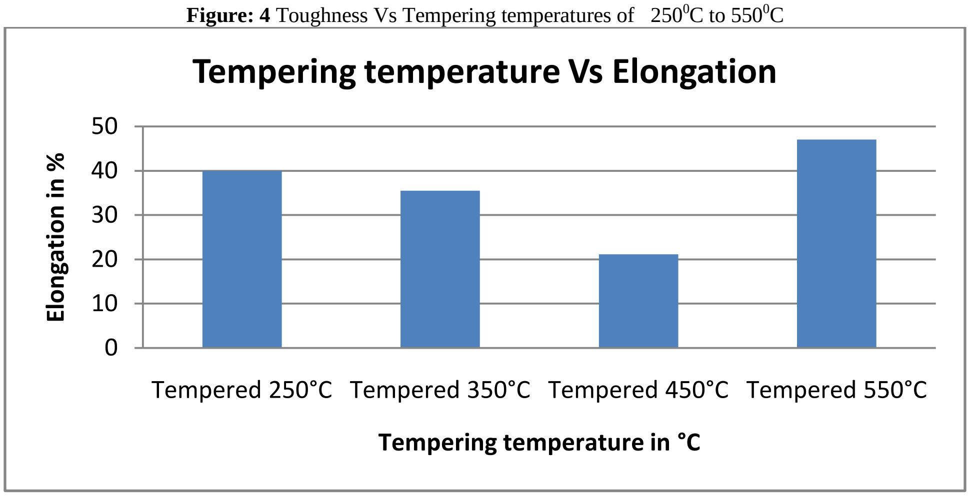

Figure: 5 Elongation Vs Tempering temperatures of 250^{0}C to 550^{0}C

The mechanical properties of tempering samples (tempered at 250^{0}C, 350^{0}C, 450^{0}C and 550^{0}C) showed that the Toughness in J is noted as 60.78, 58.53, 58.88 and 70.29 respectively. The results of the specimens which were hardened with oil quenched and then tempered at 250^{0}C, 350^{0}C, 450^{0}C and 550^{0}C are expressed graphically in Figure.5. The mechanical properties of tempering samples (tempered at 250^{0}C, 350^{0}C, 450^{0}C and 550^{0}C) showed that the % of elongation is noted as39.96, 35.50, 21.16, and 47.01 respectively.

IV.CONCLUSION

The tempered samples gave an increase in tensile strength and hardness than untreated samples. Comparing the mechanical properties of tempering sample with hardened sample, it was found that there was decrease in toughness and percentage of elongation. The quench and subsequent tempering of the steel in the temperature range 250^{0}C to 550^{0}C resulted in a corresponding decrease in tensile strength. In the above tempering temperature range, toughness of the steel gradually increased with increase in temperature. The result for yield strength receives more value at 350^{0}C compared to the corresponding tempering temperature. The percentage of elongation is received at lower value in 450^{0}C compared to the other tempering temperature.

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BIOGRAPHY

Mr.V.K.Murugan received his both Master and Bachelor degree in Mechanical /Industrial Engineering from Thiagarajar College of Engineering, Madurai Kamarajar University. He has over 20 years experience in the Industry line working on heat treatment and general insurance. Also he has teaching experience of over 8 years. He has specialized in "Heat Treatment Processes". He is a Life Member- Indian Society for Technical Education. He has good administrative skills as; he has completed MBA, Mphil (Labour Studies), MPhil (Management): also published six research papers on International Journals in the field of heat treatment. Presented papers in over ten international conferences. He has also been reviewing papers in the international journals. At present he holds the position of Associate Professor in Mechanical Engineering, Kalaivani College of Technology, Coimbatore. India.

Dr. P. Koshy Mathews has received his M.E, PhD degree from Bharathiar University – Coimbatore, India. He is a life member of Indian Welding society and presently vice-chairman of Coimbatore local centre. He has specialized in the fields of Welding, I.C.Engine, Refrigeration and Air-Conditioning. He has presented 100 research papers and guiding 12 PhD. Also he has conducted 11 National & International Conferences. He is currently working as a Principal in Kalaivani College of Technology, Coimbatore. India.