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Effect of Heat Treatment on Microstructure and Mechanical Properties of Medium Carbon Steel

B.S. Motagi, Ramesh Bhosle
Department of Mechanical Engineering, P.D.A. Engineering College, Gulbarga India

Abstract**—*In the present work conventional heat treatment proceeds like annealing, normalizing and tempering of the material has been performed. The material used in this study is medium carbon steel. Two different grades of Steel (one with copper and another without copper) have been used.cureent work reports and analyze result of mechanical testing performed on various heat treated samples of two grades of steel. The samples are tempered at 200°C, 400°C and 600°C for 1 hr.Heat treated samples were then mechanically tested for hardness (Rockwell) ,tensile properties (ultimate strength, ductility) and the microstructure, The comparison of mechanical properties and microstructure of two grades of steel has also been studied. The results revealed that steel with copper has high hardness, ultimate tensile strength and low ductility.*****

Keywords**—*Annealing, Normalizing, Quenching, Tempering, Hardness*****

I. INTRODUCTION

Today heat treatment process is widely used to achieve high mechanical properties. Major requirements of medium carbon steel are high yield strength, high proportional limit, and high fatigue strength. These desirable properties of medium carbon steel can be achieved by adding suitable alloying elements and secondly by heat treatment. 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 elongation and percentage reduction). Annealing, normalizing, hardening and tempering are the most important heat treatments often used to modify the microstructure and mechanical properties of engineering materials particularly steels. Annealing is the type of heat treatment most frequently applied in order to soften iron or steel materials and refines its grains due to ferrite-pearlite microstructure; it is used where elongations and appreciable level of tensile strength are required in engineering materials [1, 2]. In normalizing, the material is heated to the austenitic temperature range and this is followed by air cooling. This treatment is usually carried out to obtain a mainly pearlite matrix, which results into strength and hardness higher than in as received condition. It is also used to remove undesirable free carbide present in the as-received sample [3]. Steels are normally hardened and tempered to improve their mechanical properties, particularly their strength and wear resistance. In hardening, the steel or its alloy is heated to a temperature high enough to promote the formation of austenite, held at that temperature until the desired amount of carbon has been dissolved and then quench in oil or water at a suitable rate. Also, in the harden condition, the steel should have 100% martensite to attain maximum yield strength, but it is very brittle too and thus, as quenched steels are used for very few engineering applications. By tempering, the properties of quenched steel could be modified to decrease hardness and increase ductility and impact strength gradually. The resulting microstructures are bainite or carbide precipitate in a matrix of ferrite depending on the tempering temperature. Steel is an alloy of iron with definite percentage of carbon ranges from 0.15-1.5% [4], plain carbon steels are those containing 0.1-0.25% [5]. There are two main reasons for the popular use of steel: (1) It is abundant in the earth's crust in form of Fe_2O_3 and little energy is required to convert it to Fe. (2) It can be made to exhibit great variety of microstructures and thus a wide range of mechanical properties. Although the number of steel specifications runs into thousands, 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 casting, working and machining properties, which is also amenable to simple heat treatments to produce a wide range of properties [3]. They are found in applications such as train railroads, beams for building support structures, reinforcing rods in concrete, ship construction, tubes for boilers in power generating plants, oil and gas pipelines, car radiators, cutting tools etc [5].

II. EXPERIMENTAL WORK

All specimens of medium carbon steel of dimension 8×8×3 mm was cut using power hacksaw. Then they are grinded, polished. Samples were subjected to different heat treatment sequences: annealing, oil quenching, and tempering at three different temperatures at 200°C, 400°C and 600°C for 1 hr. Heat treated specimens were mechanically tested for tensile properties, ductility, and hardness.

III. HEAT TREATMENT

Heat treatment was carried out in line with the standard procedure outlined below.

1) Annealing: To remove any preexisting anomalies of material properties, all samples were first subjected to a careful annealing cycle:

- Preheating to 200^0C; hold for 15 min.
- Slow (stepwise) heating to 950^0C;→200^0 →400^0 →600^0 → 950^0C; hold for 15 min at each step.
- Holding for 1 hr at 950^0C.
- Slow cooling; shutoff furnace and leave samples inside until cooled to 520^0C.
- Brisk cooling; open furnace door, cool to room temperature.

2) Quenching:

- After holding for 20 minutes, shut off the furnace and open the furnace door to allow the samples to cool inside the furnace until red heat is gone.
- In the case of oil quenching, take out the samples and submerge in oil bath, and oil-quench to room temperature.

3) Tempering:

- Load the samples inside the furnace immediately after they reach to room temperature for oil-quenched samples. Set the furnace to the desired tempering temperature. The samples are tempered at 200°C, 400°C and 600°C for 1 hr

A. Mechanical testing

Heat-treated samples (different heat treatment sequences) were tested for various mechanical properties. For hardness testing, oxide layers etc formed during heat treatment were removed by stage-wise grinding. Average *HRC* readings were determined by taking five hardness readings at different positions on the samples, using a digital Rockwell hardness tester. For tensile properties, standard tensile specimens were loaded into a 60-kN universal testing machine hooked up to a data logger. Load-elongation data were recorded and converted into stress-strain graphs. Ultimate (tensile) strength, and ductility (% elongation) were determined from these graphs, reported values being average of three readings. All testing was done in accordance with ASTM standard test procedures.

Table I : MATERIAL COMPOSITION

All are in wt %	C	Si	Mn	Cr	Cu	S	P
Grade A	.51	.19	.65	.58	.41	.03	.031
Grade B	.54	.23	.75	.65	-	.05	.04

IV. RESULT AND DISCUSSIONS

As described above, samples were subjected to four types of heat treatment sequences: annealing, normalizing, quenching and tempering, Variation of mechanical properties of medium carbon steel after these heat treatments is presented below in a graphic format. All mechanical testing was performed at room temperature.

A. Hardness

Variation of hardness against tempering temperature is shown in Fig. 1 for two grades of medium carbon steel. The Fig.1 shows that hardness decreases as the tempering temperature increases in both cases (with Cu and without Cu additions). This is due to the transformation of martensite to tempered martensite.the hardness values of steel material with copper are high compared to the steel material without copper as shown in fig.1

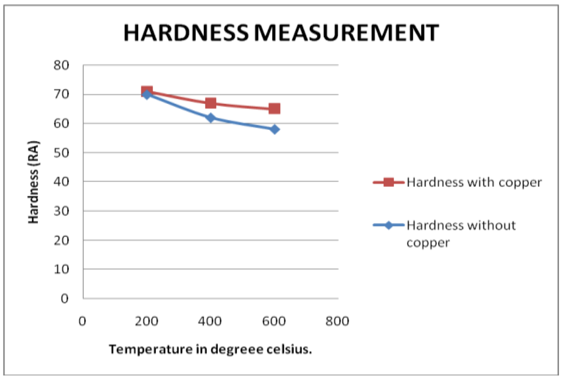

Fig. 1. Variation of hardness against tempering temperature.

B. Ultimate tensile strength

Comparing the tensile strength of Steel material with copper and steel material without copper of samples with different treatments, it is observed that, there is a slight change in their properties. The U.T.S of normalized samples was greater than the annealed samples but less than the tempered and quenched samples. The tensile properties vary with the matrix type, i.e. - pearlitic (in case of normalized samples), martensitic (in case of quenching and tempering) and bainitic matrix. and U.T.S increases but elongation decreases depending on pearlite content of the matrix. Tempered samples have higher tensile properties than the normalized samples, but as the tempering temperature is increased there was a decrease in U.T.S as shown in fig.18,19

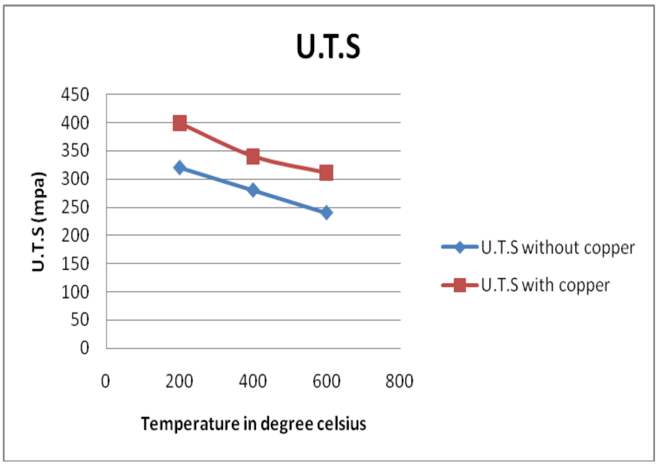

Fig. 2. Variation of U.T.S. against tempering temperature.

C. Ductility

The elongation of tempered samples is less than annealed sample but higher than normalized samples, because of the formation of martensite and tempered martensite etc.. On the other hand, the ductility (% elongation) increases with the tempering temperature as shown in figure.

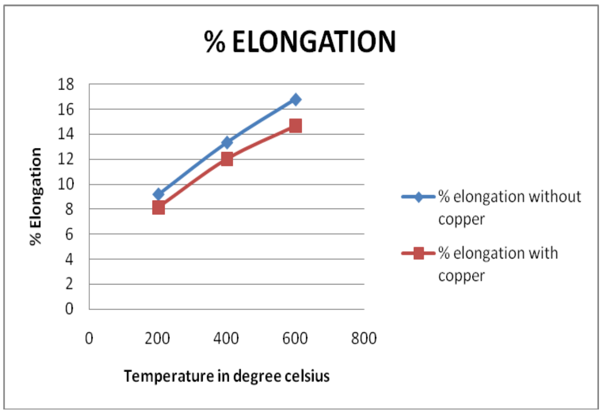

Fig. 3 Variation of % elongation against tempering temperature.

D. microstructure of two grades of steel material

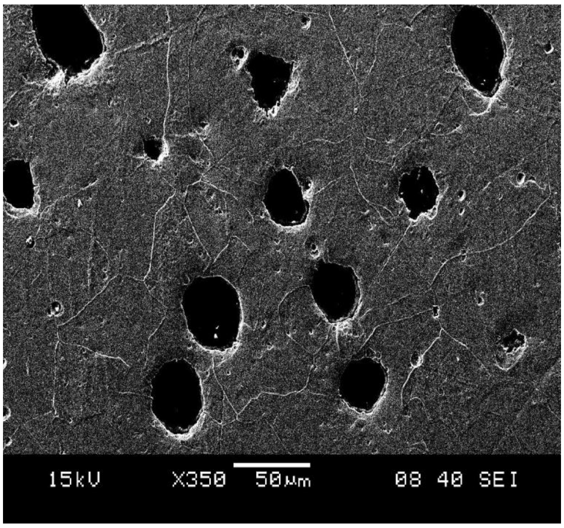

Fig.4 Annealed with copper

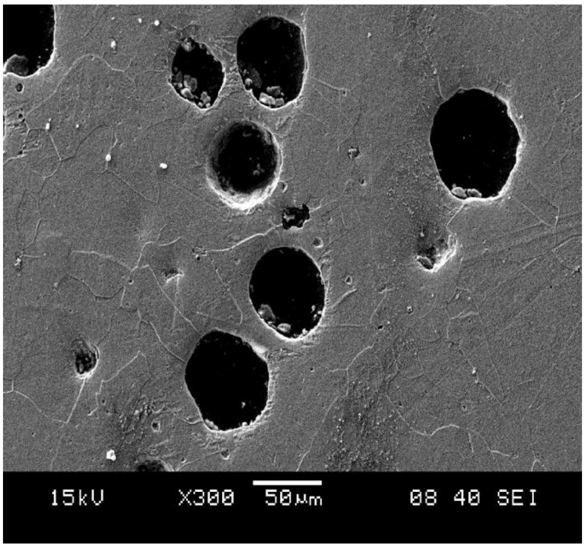

Fig.5 Annealed without copper

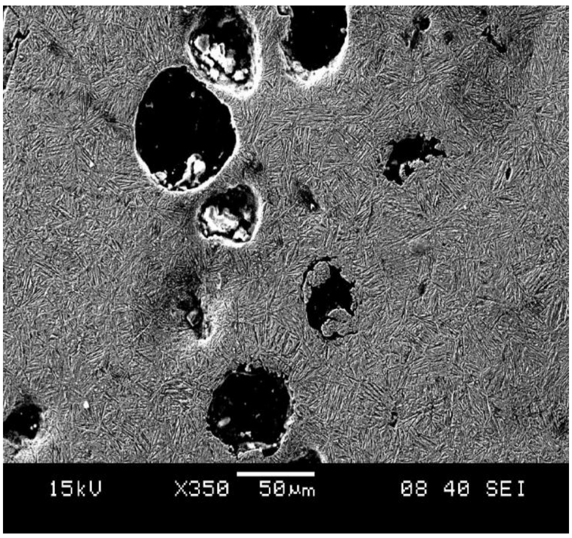

Fig.6 Normalized with copper

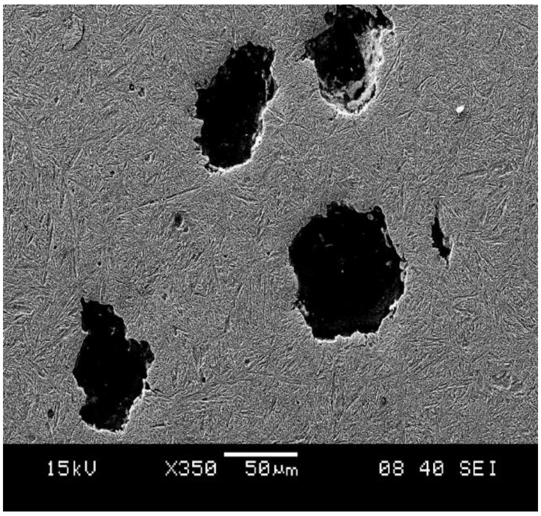

Fig.7 Normalized without copper

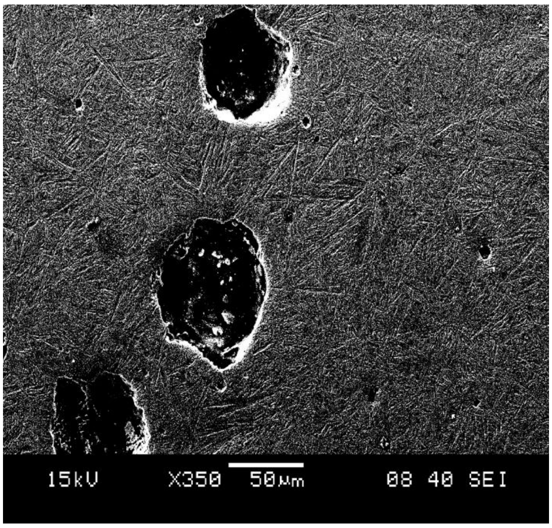

Fig.8 Tempered at 200^0c with copper

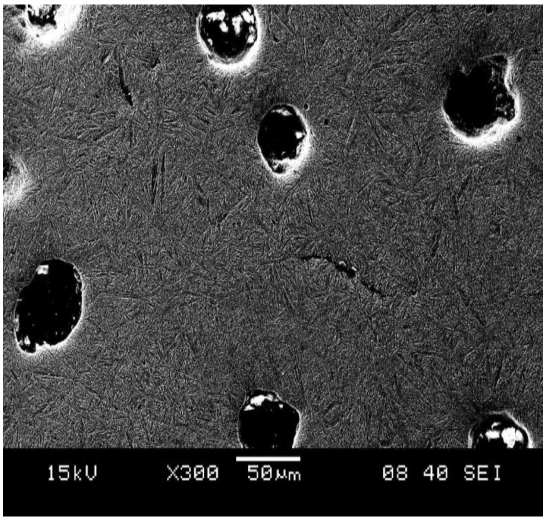

Fig.9 Tempered at 200^0c without copper

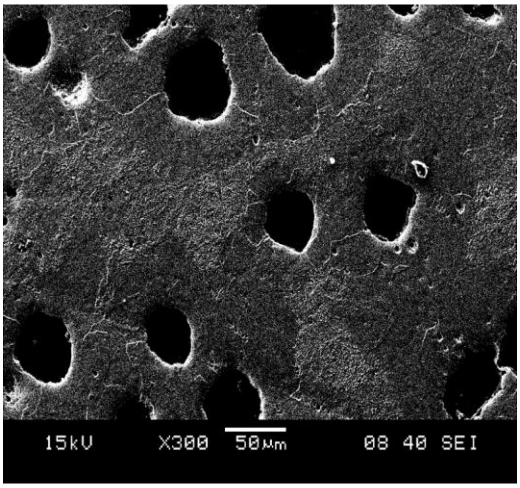

Fig.10 Tempered at 400^0c with copper

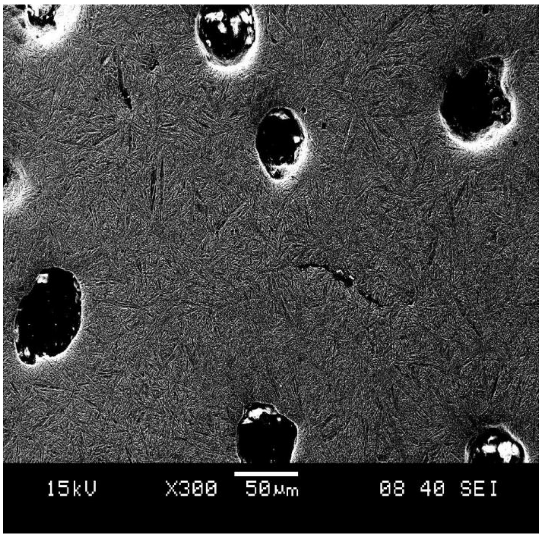

Fig.11 Tempered at 400^0c without copper

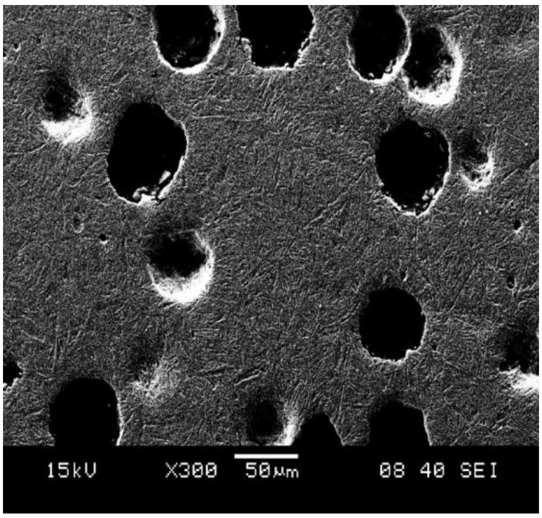

Fig.12 Tempered at 600^0c with copper

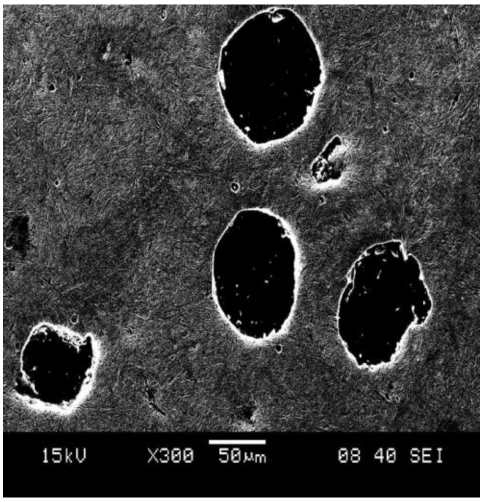

Fig.13 Tempered at 600^0c without copper

After annealing treatment, the microstructure of steel material with and without copper consists of spheroidal graphite embedded in a ferrite matrix but the number of nodules is higher in the copper enriched grade. So, both the structures show high ductility but lower values of hardness and strength. After air cooling or normalizing, the microstructures in both the cases show a typical "bull's eye" structure in which most of the graphite nodules are surrounded by a ferritic envelope. Both the graphite nodules and ferritic envelopes are embedded in a pearlitic matrix. When quenching and tempering is done, the microstructure consists of a martensite matrix with graphite nodules. After tempering at higher temperatures, the matrix phase changes to tempered martensite, thus relieving the internal stresses and increasing the strength and ductility, compromising with hardness.

V. CONCLUSION

The following conclusion has been drawn from the experimental result and discussion is made. In this work two grades of steel are used, one with copper and another without copper and the samples of two grades of steel are subjected to different heat treatment sequences: annealing, normalizing, quenching and tempering at different temperatures at 200^0C, 400^0C, 600^0C. Heat treated specimens were mechanically tested for tensile properties, ductility, and hardness.

- As the tempering temperature increases the hardness of both grades of steel is **decreasing.** The medium carbon steel with copper has the **high** hardness compared to the medium carbon steel without copper.
- As the tempering temperature increases the ultimate tensile strength of both grades of steel is **decreasing.** The medium carbon steel with copper has the **high** ultimate tensile strength compared to the medium carbon steel without copper.
- As the tempering temperature increases the ductility of both grades of steel is **increasing**. The medium carbon steel with copper has the ductility **low** compared to the medium carbon steel without copper.

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