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A Study of Heat Treatment of Steel

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ABSTRACT: The importance of various form of heat treatment operations on steels in order to forester the problem that may arise in making a wrong choice of these steel materials or faulty heat treatment operations which may give rise to serious disruption in terms of human safety, higher cost and untimely failure of the machine components is of great concern. The mechanical properties such as ductility, toughness, strength, hardness and tensile strength can easily be modified by heat treating the steels to suit a particular design purpose. Tensile specimens were produced from medium carbon steel and were subjected to various forms of heat treatment processes like annealing, normalizing, hardening and tempering. The stiffness, ductility, ultimate tensile strength, yield strength and hardness of the heat treated samples were observed from their stress-strain curve. The value of the yield strength (σ y) was observed to be higher for the tempered specimen possibly as a result of the grain re-arrangement, followed by the hardened, normalized and annealed specimens. The ultimate tensile strength were also observed to be in the order – Hardened > Tempered > Normalized > Annealed.

KEY WORDS: Hardness, Brittleness, Pearlite, Bainite, Marten site.

I.INTRODUCTION

It is impossible to determine the precise number of steel compositions and other variations that presently exist, although the total number probably exceeds 1000; thus, any rigid classification is impossible. According to American Iron and Steel Institute (AISI). Steels are arbitrarily divided into five groups, which has proved generally satisfactory to the metalworking community. These five classes are: 1) Carbon steels 2) Alloy steels (sometimes referred to as low-alloy steels) 3) Stainless steels 4) Tools steels 5) Special-purpose steels.

II. SIGNIFICANCE OF THE SYSTEM

The paper mainly focuses on how heat treatment process is applied in different steel according to requirement. In section III a literature review is explained and Methodology &experimental results of the study are explained in section IV, and section V discusses the future study and Conclusion.

III. LITERATURE SURVEY

Steel is an important material because of its tremendous flexibility in metal working and heat treating to produce a wide variety of mechanical, physical, and chemical properties. Pure iron solidifies from the liquid at 1538 _C (2800 _F) (top of Fig.1). A crystalline structure, known as ferrite, or delta iron, is formed (point a, Fig. 1). This structure, in terms of atom arrangement, is known as a body-centered cubic lattice (bcc), shown in Fig. 2(a). This lattice has nine atoms—one at each corner and one in the center. As cooling proceeds further and point b (Fig. 1) is reached (1395 _C, or 2540 _F), the atoms rearrange into a 14-atom lattice a shown in Fig.2(b). The lattice now has an atom at each corner and one at the center of each face. This is known as a face-centered cubic lattice (fcc), and this structure is called *gamma iron.* As cooling further proceeds to 910 _C (1675 _F) (point c, Fig. 1), the structure reverts to the nine-atom lattice or alpha iron. The change at point d on Fig. 1 (770 _C, or 1420 _F) merely denotes a change from nonmagnetic to magnetic iron and does not represent a phase change. The entire field below 910 _C (1675 _F) is composed of alpha ferrite, which continues on down to room temperature and below. The ferrite forming above the temperature range of austenite is often referred to as *delta ferrite*; that forming below A3 as *alpha ferrite,* though both are structurally similar. In this

Greek-letter sequence, austenite is gamma iron, and the interchangeability of these terms should not confuse the fact that only two structurally distinct forms of iron exist. Figures 1 and 2 thus illustrate the allotropy of iron.

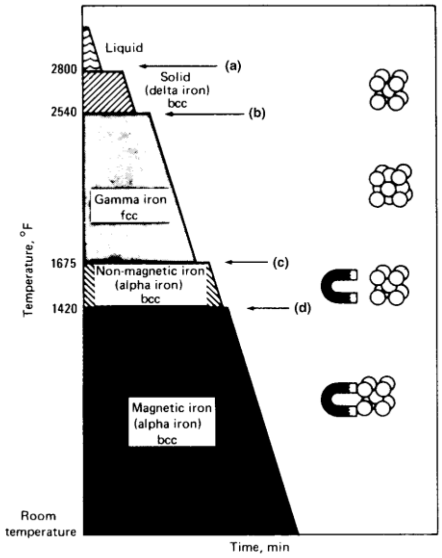

Fig. 1 Changes in pure iron as it cools from the molten state to room temperature.

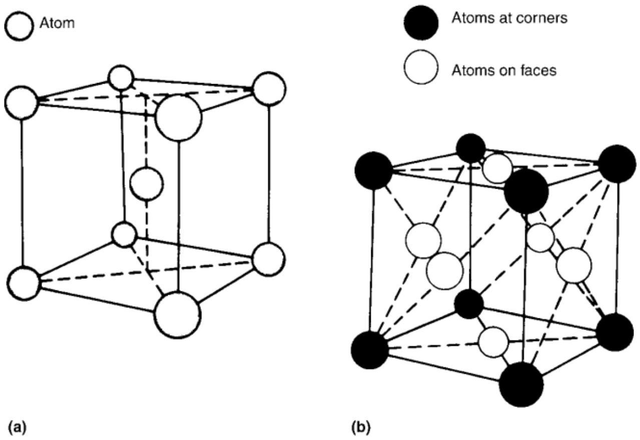

Fig. 2 Arrangement of atoms in the two crystalline structures of pure iron.
(a) Body-centered cubic lattice. (b) Face-centered cubic lattice

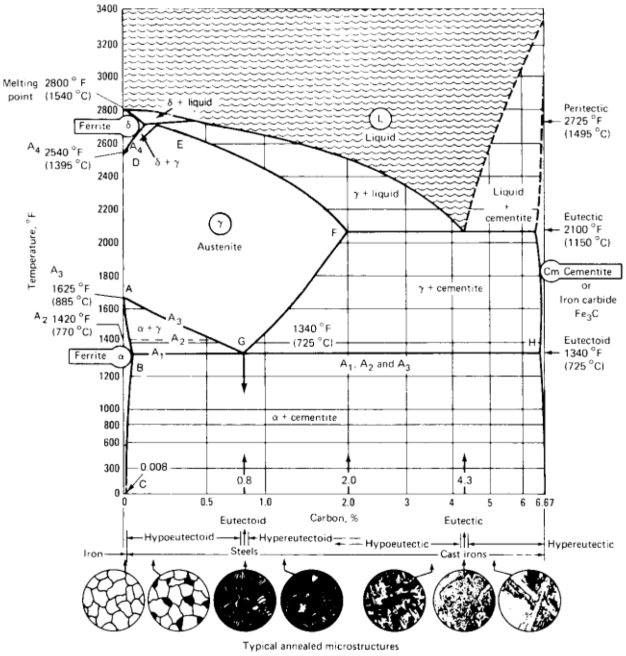

Fig. 3 Iron-cementite phase diagram

A phase diagram is a graphical representation of the equilibrium temperature and composition limits of phase fields and phase reactions in an alloy system. In the iron-cementite system, temperature is plotted vertically, and composition is plotted horizontally. The iron-cementite diagram (Fig. 3), deals only with the constitution of the iron-iron carbide system, i.e., what phases are present at each temperature and the composition limits of each phase. Any point on the diagram, therefore, represents a definite composition and temperature, each value being found by projecting to the proper reference axis. Although this diagram extends from a temperature of 1870 _C (3400 _F) down to room temperature, note that part of the diagram lies below 1040 _C (1900 _F). Steel heat treating practice rarely involves the use of temperatures above 1040 _C (1900 _F). In metal systems, pressure is usually considered as constant.

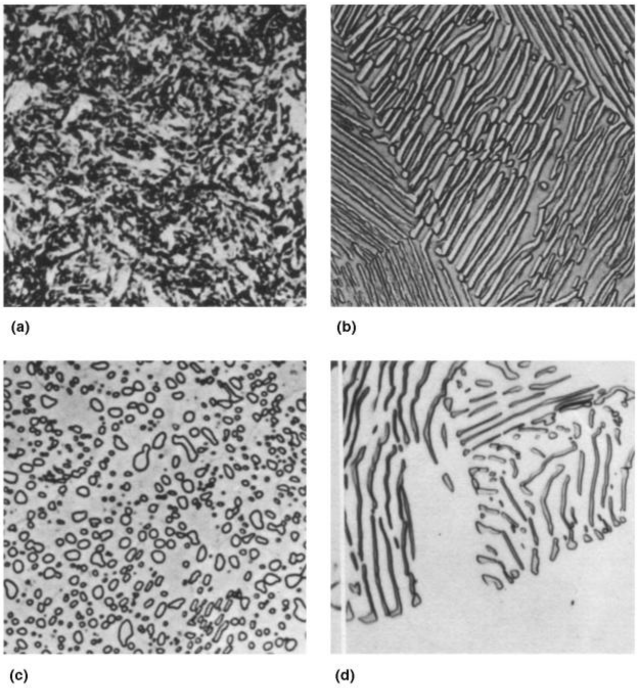

Fig. 4 Effects of carbon content on the microstructures of plain-carbon steels.(a) Ferrite grains (white) and pearlite (gray streaks) in a white matrix of a hypoeutectoid steel containing 0.4% C. (b) Microstructure (all pearlite grains) of a eutectoid steel containing 0.77% C. (c) Microstructure of a eutectoid steel containing 0.77% C with all cementite in the spheroidal form. (d) Microstructure of a hypereutectoid steel containing 1.0% C containing pearlite with excess cementite bounding the grains.

The critical temperatures (A1, A6, and Acm) are “arrests” in heating or cooling and have been symbolized with the letter A, from the French word *arret*meaning arrest or a delay point, in curves plotted to show heating or cooling of samples. Such changes occur at transformation temperatures in the iron-cementite diagram if sufficient time is given and cab be plotted for steels showing lags at transformation temperatures, as shown for iron in Fig. 4. However, because heating rates in commercial practice usually exceed those in controlled laboratory experiments, changes on heating usually occur at temperatures a few degrees above the transformation temperatures shown in Fig. 4 and are known as Ac temperatures, such as Ac1 or Ac3. The “c” is from the French word *chauffage,* meaning heating.

Thus, Ac1 is a few degrees above the ideal A1 temperature. Likewise, on slow cooling in commercial practice, transformation changes occur at temperatures a few degrees below those in Fig. 4. These are known as Ar, or Ar3, the “r” originating from the French word *refroidissement,* meaning cooling. This difference between the heating and cooling varies with the rate of heating or cooling. The faster the heating, the higher the Ac point; the faster the cooling, the lower the Ar point. Also, the faster the heating and cooling rate, the greater the gap between the Ac and Ar points of the reversible (equilibrium) point A. Going one step further, in cooling a piece of steel, it is of utmost importance to note that the cooling rate may be so rapid (as in quenching steel in water) as to suppress the transformation for several hundreds of degrees. This is due to the decrease in reaction rate with decrease in temperature. As discussed subsequently, time is an important factor in transformation, especially in cooling.

The foregoing discussion has been confined principally to phases that are formed by various combinations of composition and temperature; little reference has been made to the effects of time. In order to convey to the reader the effects of time on transformation, the simplest approach is by means of a time-temperature-transformation (TTT) curve for some constant iron-carbon composition.

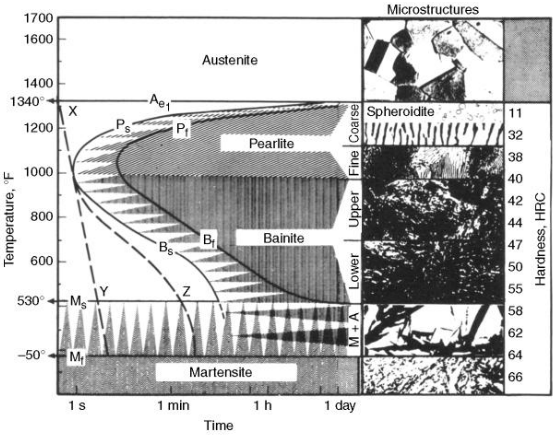

Fig. 5 Time-temperature-transformation (TTT) diagram for a eutectoid (0.77%) Carbon steel

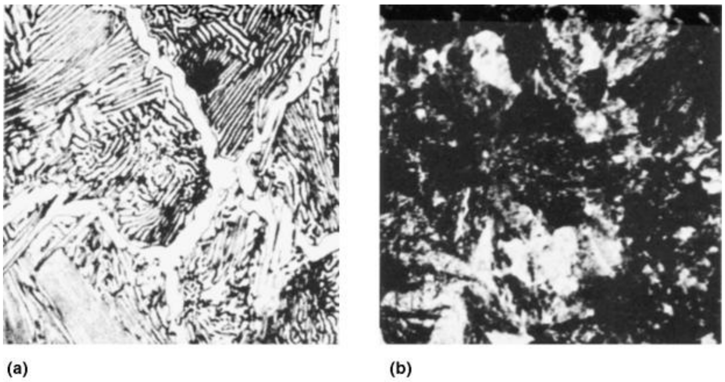

Fig. 6 (a) Microstructure of quenched 0.95% carbon steel. Structure is martensitic. (b) Bainitic structure in a quenched 0.95% carbon steel.

A) **The heat treatment process is done are as follows:**

[1] Hardening process: in this process the specimen is heated in furnace upto the temperature 850°C after this they were poured to different water container for rapid cooling to room temperature.
[2] Tempering process: in this process the hardened steel is heated to 350° C by this process macrostructure modification is there by this hardness is improved and ductility is increased.
[3] Annealing process: full annealing is carried out in material by heating it to 870°C. and the tested surface is put at this temperature for around 1 hour. The grain structures are now coarse pearlite
[4] Normalizing process: each sample is now placed in furnace and heated upto 850°C and the sample were cooled for two hours for full transformation to austenite.

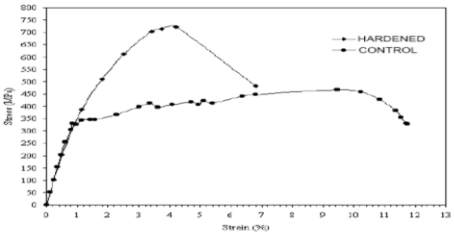

Fig.7: Stress versus strain curve for hardened and control specimen

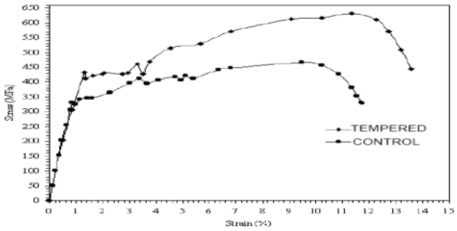

Fig. 8: Stress versus strain curve for tempered and control specimen.

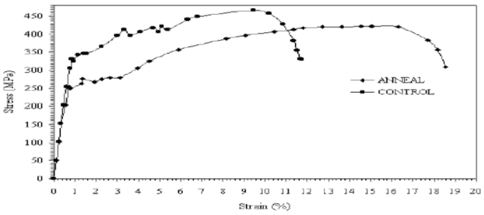

Fig. 9: Stress versus strain curve for annealed and control specimen

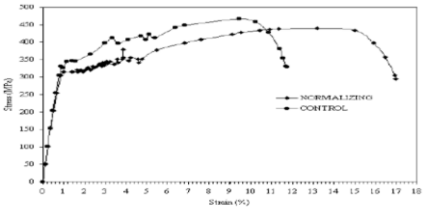

Fig. 10: Stress verses strain curve for normalized and controlled specimen

B) The results were: The heat treatment specimen is then subjected for tensile testing under universal testing machine. And the results were shown in graphical form for hardened, tempered, annealed, and normalized specimens. The value of ultimate tensile strength were in order of hardened was first one then tempered then normalized and the last one was annealed. This was refined after primary phase when subsequent cooling is done. The higher the toughness of the material the material has lower curve in stress curve in the plastic region, there is lower in strain hardening parameter when the strain hardening parameter increases and the stress of the material also increases. And the conclusion after the result obtained is that the mechanical properties depend largely upon the various forms of heat treatment process done and also on the cooling rate. Hence depending upon the application they may be used for any design procedure but suitable amount of process should be adopted for getting the properties like high ductility and minimum toughness annealing would give the satisfactory results and the final result are shown the graph above.

IV. METHODOLOGY

S.K. AKAY, M. YAZICI, A. AVINC Proposed research paper on effect of heat treatment processes on mechanical property of low grade steel. In this he proposed that new classes of the HSLA (high-strength low alloy steels) known as DPS (dual phase steels) are developed to improve safety standards and fuel economy. Dual phase steel microstructures can be produced by annealing steel in the region of equilibrium phase diagram. The steel microstructures have a ferrite matrix along with particle of marten site. The physical properties are depending upon morphology of two phases. This can be determined by changing the annealing temperature with time the annealing procedure quenching medium and alloying element. In this the author has discussed about of heat treatment followed by quenching on the physical properties of Fe 0.055% C steels. The experimental procedure was the specimen used in this is 2.5mm thick and the chemical composition is specified firstly it was normalized at 910^{o}C hold for 45 minute and then air cooling is done.

Table1: Chemical composition of specimen

The chemical composition of a studied material (wt. %). C	Mn	Si	P	Al	Fe
0.055	0.272	0.016	0.005	0.034	Balance

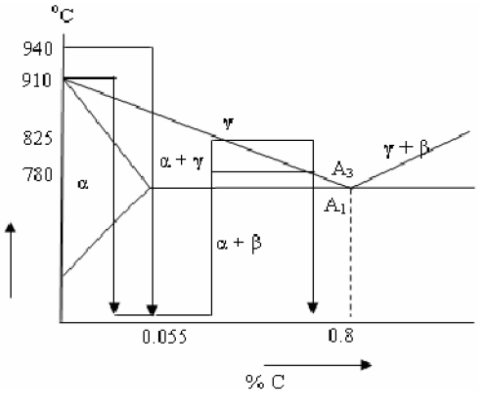

Fig. 11: Schematic heat treatment diagram: As received and intermediate quenching process α Ferrite, β: Cementite, γ: Austenite

The result of this experimental procedure shown by optical metallurgy is that the dual phase steel microstructures are made of marten site (light area) distributed in ferrite in (dark area) as shown in figure 12. The ferrite phases do not have any structure change after quenching from austenite + ferrite region. As the temperature increases the volume fraction of marten site increases. The same result was seen by Bayrametal .And the final conclusion from this was when intermediate annealing of low carbon steel is done then ferrite plus marten site structure grain structure is formed. As the intermediate temperature time increases the volume fraction of marten site increases. When XRD analysis is done it shows that as compared to α′ marten site there were large amount of γ- retained austenite forms in dual phase microstructure.

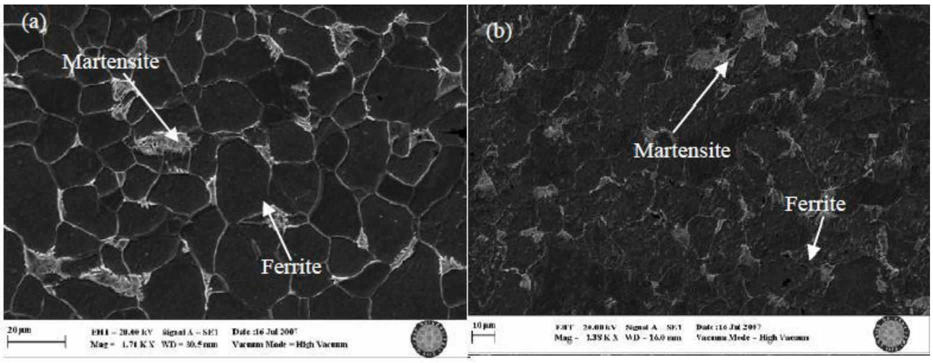

Fig. 12: Optical micrograph of (a) DPS-780˚C (b) DPS -825˚C

B.S. Motagi, Ramesh Bhosle proposed a research paper on effect of heat treatment processes on mechanical property of medium carbon steel .Steel specimen was allowed to heat treatment processes alternately as: 1.Annealing, 2.oil quenching, and 3.tempering at different temperature as 200℃, 400℃ and 600℃ for around 1hr. Now steel specimens were mechanically testing as tensile, ductility and hardness. So, all the variation in the mechanical properties as shown in figure13. So, the mechanical testing was perform at room temperature and conclusion is that: on increasing the tempering temperature, the hardness of the steel is decreasing shown in fig.7.On increasing the tempering temperature, the ultimate tensile strength of both the grades i.e. with copper and without copper. But steel with copper has high ultimate strength as compared to without copper. Also, on increasing the tempering temperature, the ductility of the steel is increased. But steel with copper has low ductility as compared to without copper.

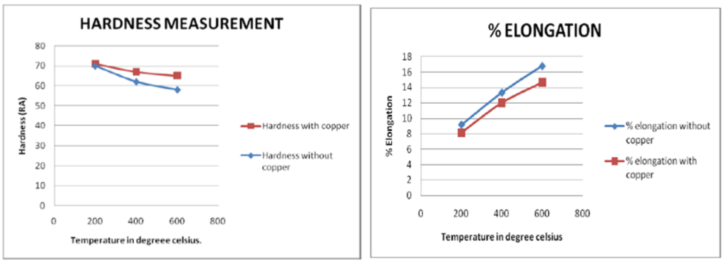

Fig. 13: Hardness and Elongation measurement

V.CONCLUSION AND FUTURE WORK

On increasing the tempering temperature, the hardness of the medium carbon steel with copper is high as compared to the steel without copper. On increasing tempering temperature , the ductility of both the steel grade is increasing . The steel with copper has low ductility as compared to steel without copper . The optimum heat treatment for the tested managing stainless steel is at 1050° C for 1 h at 780° C for 8h at 535° C for 4 h. By this treatment, the yield stress of the steel could reach 1774 MPa and 1932 MPa. In the holding temperature range of 850 to 1150°C, increasing holding time could result in slight increase in prior austenite grain size until at 1 050° C for 1 h. Whereas, abnormal grain growth was seen at 1050° C for 3 h or longer holding time .The ductile brittle transition temperature measured in smaller size specimen was 95°C and it was lower than the 83°C in the standard specimen.

From the above study it is concluded that according to need of Industry the engineer can design a proper route for heating and cooling during manufacturing steel. The Iron Carbon Equilibrium diagram and TTT diagram are the basic tools for designing the manufacturing process of steel and cast iron.

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