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Effect of Carburization on the Mechanical Properties of the Mild Steel

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ABSTRACT: The properties of metals and alloys can be changed by heating followed by cooling under definite conditions to make them suitable for specific applications. Carburization is a method of producing mild steel having tough inner core and hard outer surface. Three Heat Treatment process namely Quenching, Carburizing and Tempering were done. The mild steels are carburized at temperature range of 850 to 950 ^{o}C and then it is tempered at 200 ^{o}C for thirty minutes after that it subjected for different kind of tests such as hardness, tensile and toughness. The results indicated that the process of carburization greatly improves the mechanical properties like hardness and tensile strength and these properties increases with increase in the carburization temperature but apart from this, the toughness property decreases and it is further decreases with increase in carburization temperature. The mild steels carburized at the temperature of 950 ^{o}C gives the best results for the mechanical properties because at this temperature it gives the highest tensile strength and hardness, so it must be preferred for the required applications.

KEYWORDS: Carburization, hardness, tensile strength, toughness and impact test.

1 INTRODUCTION

Engineers usually require a material with a blend of high yield strength and good elongation, but these properties are often mutually exclusive. It has been shown that the yield strength of normalized low carbon mild steel can be increased by inducing strain ageing effects in the steel, until the yield stress attains values up to and beyond the ultimate tensile strength, but unfortunately, the elongation is correspondingly reduced [1]. Steels are alloys of iron and carbon together with any other alloying elements. The steel is being separated as low carbon steel, high carbon steel and medium carbon steel. The controlled heating and cooling processes used to change the structure of a material and alter its physical and mechanical properties [2, 3]. Heat treatment is generally employed for the purpose such as to improve mechanical properties like tensile strength, hardness, ductility, yield strength and so on. The heat treatment and carburization increases the mechanical and wear resistance. The heating of a metal at a constant temperature for a suitable duration of time is called soaking time. Mechanical properties of mild steels were found to be strongly influenced by the carburizing temperature and soaking time at carburizing temperature. The mechanical properties of mild steel were found to be strongly influenced by the process of carburization, carburizing temperature and soaking time at carburizing temperature [4-7].

Carburizing is a metal treatment process that adds carbon to the surface of metal that has a low carbon content to increase the hardness of the metal. The metal is heated at an elevated temperature in an atmosphere rich with carbon. Heat will cause carbon atoms to diffuse into the metal surface. The process is done below the melting point of the metal being carburized. There are five carburizing methods—pack, gas, liquid bath, vacuum, and plasma. Pack carburizing uses a furnace to heat the metal parts to be carburized that are packed inside a container with a sufficient amount of carbon powder. The heating process will last for 12 to 72 hours at a high temperature. This method is noted to be slow compared to the other methods and has heating inefficiencies because of the difficulty in maintaining an even temperature. Gas carburizing follows the same procedure applied in pack carburizing. It, however, feeds carbon monoxide (CO) to the furnace to improve diffusion, which is not done in the pack method. The process has safety issues because CO is a poisoning gas that is odorless and colorless and could be inhaled by persons working inside the plant. The gas method is preferred in carburizing large volumes of metal [8–14]. Hardening is accomplished when the high-carbon surface layer is quenched to form martensite so that a high-carbon martensitic case with good wear and fatigue resistance is superimposed on a tough, low-carbon steel core. Carburizing steels for case hardening usually have base-carbon contents of about 0.2%, with the carbon content of the carburized layer generally being controlled at between 0.8 and 1% C. However, surface carbon is often limited to 0.9% because too high a carbon content can result in retained austenite and brittle martensite. Carburizing steel is widely used as a material of automobiles, form implements, machines, gears, springs and high strength wires etc. which are required to have the excellent strength, toughness, hardness and wear resistance, etc. because these parts are generally subjected to high load and impact. Such mechanical properties and wear resistance can be obtained from the carburization and quenching processes. This manufacturing process can be characterized by the key points such as: it is applied to low carbon work pieces, work pieces are in contact with high carbon gas, liquid or solid, it produces hard work piece surface, work piece cores retain soft [15].

Hardness is the property of a material to resist permanent indentation. Because there are several methods of measuring hardness, the hardness of a material is always specified in terms of the particular test that was used to measure this property. Although hardness testing does not give a direct measurement of any performance properties, hardness correlates with strength, wear resistance, and other properties. Hardness testing is widely used for material evaluation due to its simplicity and low cost relative to direct measurement of many properties.

Tensile strength, hardness, toughness, elasticity, plasticity, brittleness, and ductility and malleability are mechanical properties used as measurements of how metals behave under a load. These properties are described in terms of the types of force or stress that the metal must withstand and how these are resisted. The ability of material to absorbed energy and deform plastically before fracture is called “toughness”. It is usually measured by the energy absorbed in a notched impact test like charpy or izod tests. In present work for each of the sample, test was conducted for 3 times and the average of all the samples was taken as the observed values in each case.

2 MATERIALS AND METHODS

2.1 MATERIALS SELECTION

Mild steels test specimens of the required dimensions were prepared. The chemical composition of mild steel is C-0.16%, Si-0.03%, Mn-0.32%, S-0.05%, P-0.2%, Ni- 0.01%, Cu-0.01%, Cr-0.01% and Fe-balance.

2.2 PREPARATION OF TEST SPECIMENS

Carburization of mild steel samples

The prepared test samples were embedded in the activated carbon inside a steel pot which was then tightly sealed with clay cover to prevent the CO from escaping and prevent unwanted furnace gas from entering the steel pot during heating. The furnace temperature was adjusted to the required temperature range and the loaded steel pot was charged into the furnace. When the furnace temperature reaches the required carburizing temperature, it was then held/soaked for thirty minutes. After that, the steel pot was removed from the furnace and the material was quenched in industrial engine oil (which was initially at the ambient atmospheric temperature).

The hardness of all the samples has been done using a Vickers hardness testing machine. The applied load during the testing was 100 N, with a dwell time of 10 s. It has a square-base diamond pyramid indenter. Ten hardness readings are taken at different location to circumvent the possible effects of particle segregation. The impact tests were performed on various sample determine the impact strengths by using the Impact Testing Machine. Tensile properties of the alloys were analyzed by carrying out test on the universal testing machine. The test specimen for analysis of different mechanical properties (tensile strength, toughness and hardness test results) was prepared as per ASTM standard as below:

1. **Specimen for hardness test** is prepared having the dimensions (4cm x 2.5cm x 0.5cm).
2. **Specimen for tensile strength test** is prepared based on the following equation: $L_o = 5.65\sqrt{A_o}$

   Where, L_o = Gauge length and A_o = Cross sectional area
3. **Specimen for toughness test** is prepared having the dimensions; Length – 5.5 cm, Width – 1 cm, Thickness – 1 cm and Notch depth – 0.5 cm

3 Results And Discussion

3.1 Hardness

The hardness values varied in the range of 551 Hv – 694 Hv as shown in figure (1). With increase of carburization temperature the hardness values increases. The hardness value is higher for the mild steel carburized at temperature of 950 °C and is lower for the mild steels carburized at 850 °C, so with increase of carburization temperature the hardness values increases as shown in figure (1). I.e., the carburized mild steel at 950 °C is giving the best results for the mechanical properties like tensile strength and hardness except the case of toughness test.

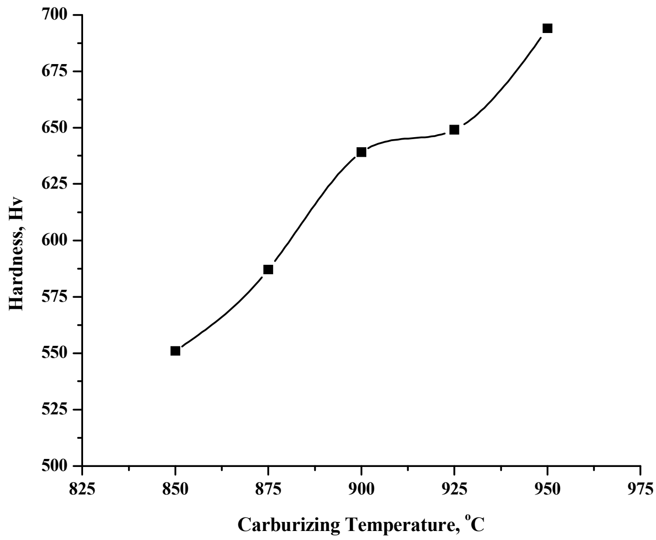

Figure (1): Variation of hardness with the carburization temperature

3.2 Mechanical properties results (tensile strength, Impact and toughness test results)

The results of different mechanical characteristics like tensile strength, toughness and hardness under different carburization temperatures are shown in figures (2–8) and summarized in the following:

3.2.1 Tensile strength

The tensile strength is varied between the ranges of 441MPa – 1960 MPa and is higher for the mild steel carburized at temperature of 950 °C and lower for the uncarburized simple mild steel. This shows that the carburization greatly improved the tensile strength of mild steels. That's leads to the increase in the carburization temperature, the tensile strength of carburized mild steels increases, as shown in the figure (2).

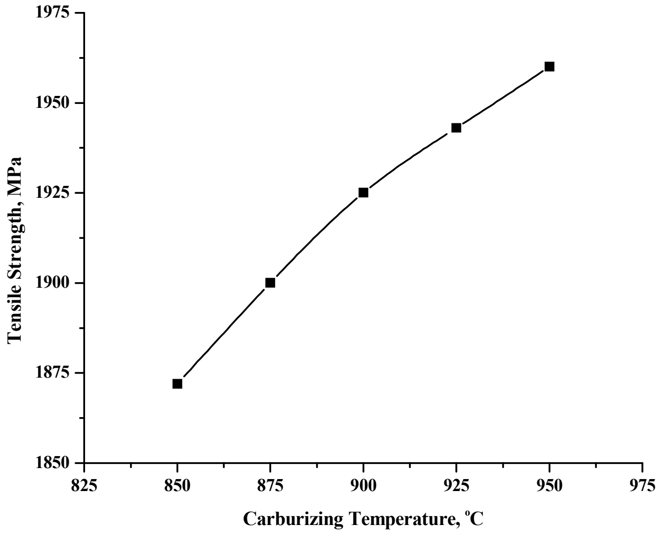

Figure (2): Variation of tensile strength with carburization temperature.

In figure (3), it is observed that, the ultimate tensile strength (UTS) initially decreased from 751.81 Nmm^{-2} (at the carburizing temperature of 850°C) to 655.97 Nmm^{-2} when the carburizing temperature increased to 900°C. It then increased to its maximum value of 789.76 Nmm^{-2} as the carburizing temperature increased to 950°C. This shows that the UTS of the samples soaked for 30 minutes was reduced by the carburization process. Similarly, for both series the carburization process reduced the UTS of the treated samples at carburizing temperature of 850°C when compared with the UTS of the untreated as received sample which has a UTS of 800.07 Nmm^{-2} and impact energy of 61.25 J. This relationship of the UTS with the carburizing temperature is similar to its relationship with the percentage carbon content of steel in both annealed and tempered conditions [16, 17]; it can be reliably assumed that the amount of carbon that diffused into the samples increases with the carburizing temperature. The behavior of the samples in figure (6), is similar to the discoveries of Ward, (1981) [17] where he found that the UTS of carburized samples of some steel grades were some reduced.

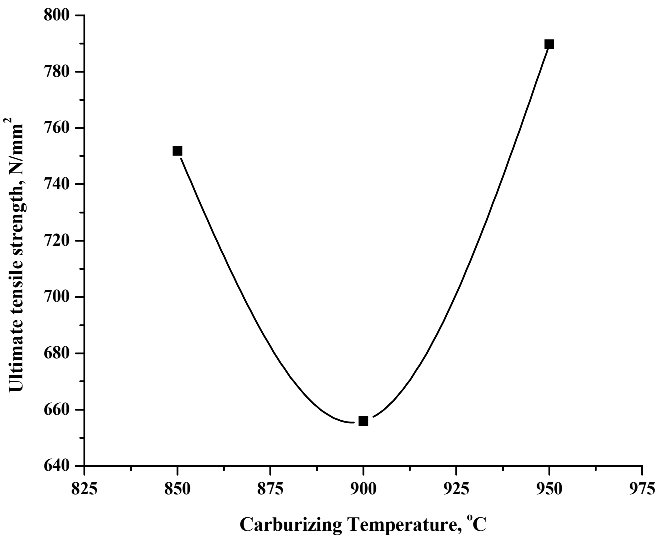

Figure (3): The effect of carburizing temperature on the ultimate tensile strength of the samples

In figure (4), the strain for the samples initially increased from its minimum level of 0.02421 (i.e. 2.421 % elongation) at 850°C, to its maximum of 0.15987 (i.e. 15.987 % elongation) as the carburizing temperature is increased to 900°C which then reduced to 0.10977 (i.e. 10.977 % elongation) with further increase in the carburizing temperature to 950°C. This is due to an increased interface area produced by the carbide formation at grain boundaries which lead to the impurities (cavities and cracks) being redistributed, because their concentration is low the problem of embrittlement is negligible [18].

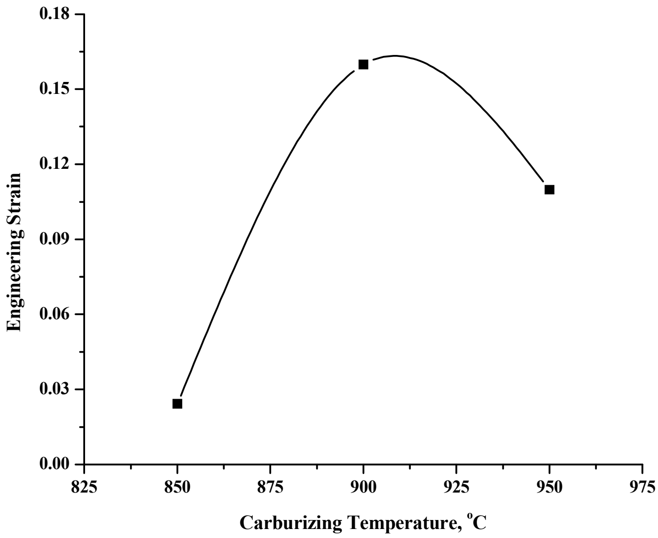

Figure (4): The effect of carburizing temperature on the engineering strain of the samples

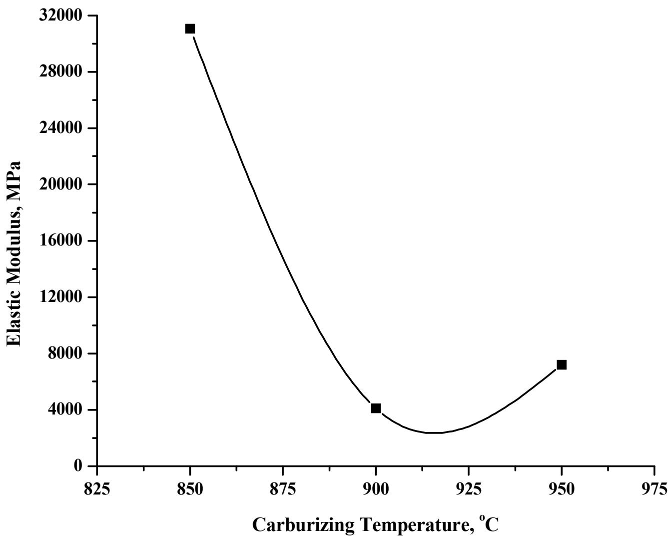

Figure (5): The effect of carburizing temperature on the Young's modulus of elasticity of the samples

From figure (5) it is clearly seen that for the samples, the Young's' modulus at carburizing temperature of 850°C reduced from its maximum value of 31,053.7 Nmm^{-2} to the minimum value of 4,103.15 Nmm^{-2} as the carburizing temperature is increased to 900°C and then increased to 7,194.68 Nmm^{-2} as the carburizing temperature is increased to 950°C. Comparing these with the Young's' modulus of the as received sample which has a value of 12,973.86 Nmm^{-2} show that the stiffness of the carburized samples were initially higher than the as received samples. This shows that the samples lost their stiffness with increase in the carburizing temperature.

3.2.2 Impact Test and Toughness

From figure (6), it is observed that the absorbed (impact) energy increases with increase in the carburizing temperature.

The toughness is varied in the range of 54 J – 32 J. It is higher for the uncarburized mild steels and lower for the carburized mild steel at temperature of 950 ^{o}C, so the carburization process decreases the toughness of the mild steels, as shown in figure (7). This is expected and supported from the literature [14].

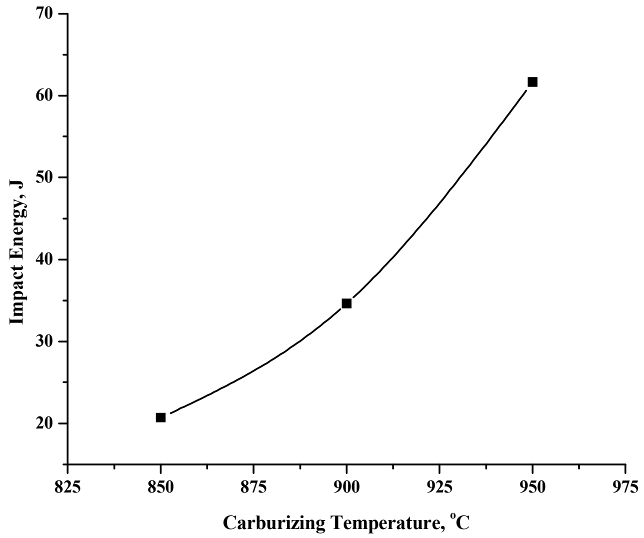

Figure (6): The effect of carburizing temperature on the impact energy of the samples.

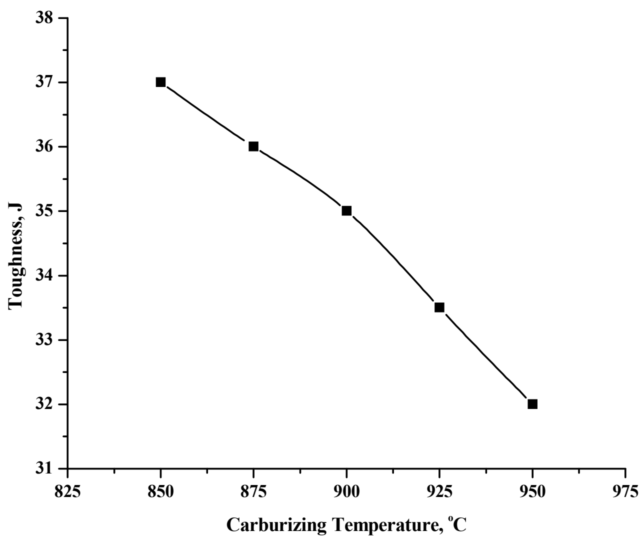

Figure (7): Variation of toughness with carburization temperature

3.3 Effect of hardness on the tensile strength of carburized mild steels

The variation between hardness and tensile strength is represented in the figure (8). The tensile strength is highly affected by the hardness and it varies directly with the hardness.

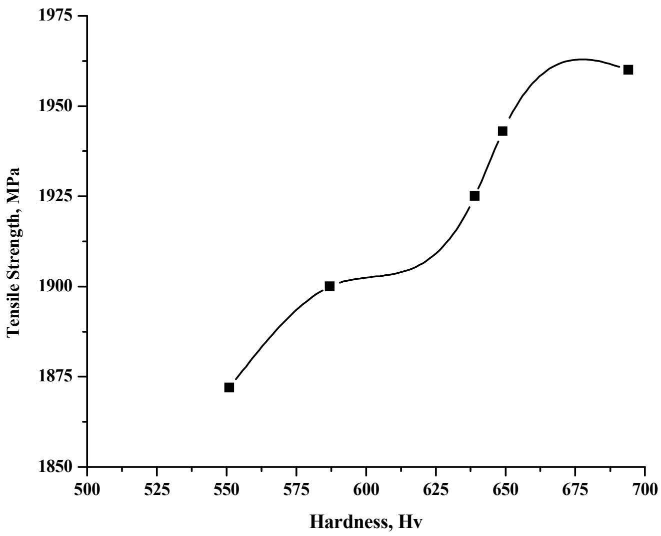

Figure (8): Variation of tensile strength with hardness for carburization temperature.

4 CONCLUSIONS

1. The mechanical properties of mild steels were found to be strongly influenced by the process of carburization and carburizing temperature.
2. Hardness and tensile strength increase, while toughness (impact energy) of the mild steels decreases as increase in the carburization temperature.
3. Carburization process reduced the impact toughness of mild steels, but contrary to the trend observed where activated carbon is the carburizer the impact toughness increases with the carburizing temperature where pulverized bone is used as the carburizer.
4. The stiffness of the mild steel is increased by the carburization process, but it decreases with increasing carburizing temperature.
5. As comparing for different carburization temperature. The mild steels carburized at the temperature of 950 ^{o}C shows the best combination of higher hardness and higher tensile strength.
6. Finally the net conclusion is that the mild steel carburized under the different temperature range of 850 to 950 ^{o}C in which the mild steel carburized at the temperature of 950 ^{o}C is giving the best results.

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