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Research paper

Carburizing of Rolled and Non-Rolled High Manganese Steel

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Abstract

High manganese steel is a steel type with manganese content of 15 – 30 %. It is applied to various industries based on various properties inclusive of high strength ability. Problems or defects occur during the deformation of this steel include tearing and cracking. High loads applied during the deformation process lead to the increase the problems and damages of the machine components. In order to resolve this, carburizing was introduced. Carbon diffused into the steel surface changes the strength and microstructure. The research is carried out to reduce the load and defect of the product and machine component along the deformation process. In this paper, an experimental work was undertaken to compare the results of tensile test of pack carburizing (non-rolled) and gas carburizing (rolled). The objective of this work is to investigate the effect of carburizing on the strength-ductility properties of rolled and non-rolled Fe-24Mn steel. Investigation of the stress – strain relationships of three specimens for rolled and non-rolled with different carburizing time is the aim of this paper. For the purpose of achieving this aim, the measurements and evaluation of yield strength, ultimate tensile strength, elongation and hardness were performed on the steel samples subjected to tensile loading. The finding witnesses that the carbon improves the mechanical properties of this steel. The most commonly accepted method in evaluation of the mechanical properties of material would be the tensile test. This test explains the different results of stress-strain relationship with and without rolling processes with different carburizing time. Finally, this research indicates some future investigations required in order to support the quality of the findings.

Keywords: *High Manganese Steel; Fe-24Mn; Gas and Pack Carburizing; Rolled and Non-rolled; Mechanical Properties.*

1. Introduction

In this era, with highly competitive market, major, medium as well as small local manufacturing companies are experiencing rapid growth in terms of innovation and material development, resulting in tight competition to fulfill the market demands [1]. To win the market share, the requirement for material with outstanding mechanical properties emerges particularly in the manufacturing area [1].

Due to this, high manganese steel was introduced. High manganese steel is a steel type with Mn content of 15 – 30 % [2][3]. It is applied to various industries based on various properties particularly the high strength capacity [1][2].

In the past two decades the commercial and scientific interest in high-manganese steels have constantly increased due to its outstanding mechanical properties [4]. The combination of high strength, high ductility, and work-hardening makes this steel especially suitable as crash-relevant structural components in automobiles in order to increase passengers' safety [4], and to reduce cost [5]. For these reasons, most of the research dedicated to high manganese steels have focused on the mechanical properties [4]. In previous studies, the comparison of mechanical properties of high manganese steel with and without rolling process was carried out. The high manganese steels for both rolled and non-rolled were carburized for 1 and 2 hours.

High manganese steels (10 – 14 wt. %) was introduced by Sir Robert Hadfield in 1885 [6]. These steels are used in many applications which required high strength, high impact and high wear resistance [7]. These steels have been developed by previous researchers to improve the ductility properties in which the manganese composition varies from 18 to 30 wt. % [8][9]. These steels become competitive and used as components which required a combination of strength-ductility properties [10]. The examples of products include the reinforced and car body used for impact absorption [11]. However, the issues related to these steels are cracking tendency and utilization of higher load during their deformation. This will lead to higher cost of components and maintenances.

A significant increase in the research activities committed to the carburization of Fe-24Mn based steel has happened in the previous five years, propelled by the combination of strength and ductility, controlled by these alloys [6]. The requirement for material with excellent mechanical properties can be improved through the carburizing process. The carbon was introduced into the Fe-24Mn steel through carburizing process. The role of carbon is to change the strength-ductility properties when diffused into this steel. The content of carbon in Fe-Mn (24 % manganese) stabilize the austenite structure (soft layer), thus decrease the load applied during deformation processes. Lower deformation load results in increasing the component life and reducing the component cost [12]. The crack and other defects occurrences can also be avoided [12].

Gas carburizing is theoretically similar to pack carburizing aside from the supply of carbon monoxide gas to the heated furnace and the carbon decomposition [13]. Many problems with pack carburizing are eliminated in this process. The carbon monoxide gas needs to be contained safely. The components are enclosed in a carbon bearing environment that is replenished continuously to maintain a high carbon content. Gas carburizing is one of the most successful and popular carburizing techniques used when large quantities of parts are required. The schematic diagram of gas carburizing is displayed in Figure 1.

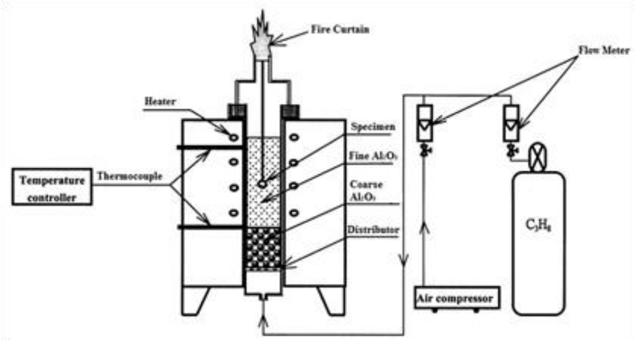

Fig. 1: Schematic diagram of the gas carburizing process [14]

In pack carburizing, components are packed in an environment with high carbon content such as cast iron shavings or carbon powder [15]. The components are heated with the production of carbon monoxide, which is a reducing agent [16][17]. The reduction occurs on the steel surface with the release of carbon that is diffused into the surface because of high temperatures. With the carbon absorption, the materials are hardened. The surface carbon is in the range of 0.7% to 1.3% depending on the process environment [13]. The case depth is approximately 0.1 to 1.5 millimeters [13]. To control pack carburizing is difficult because uniform temperatures is impossible to be maintained. A schematic diagram of the pack process is as shown in Figure 2 [18].

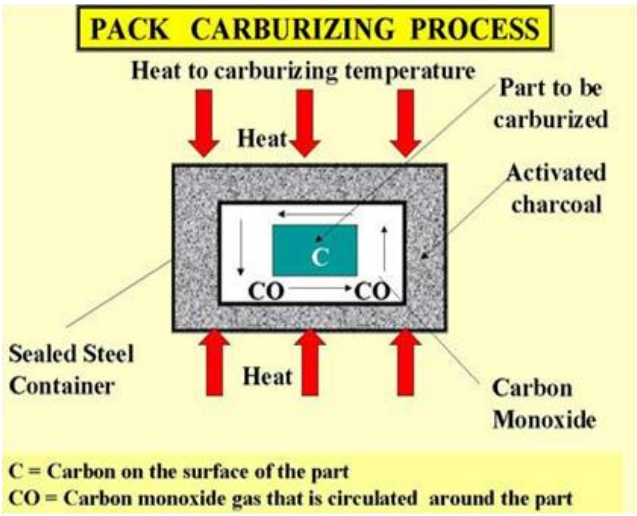

Fig. 2: Schematic diagram of the pack carburizing process [18]

Pack carburizing is a simple, inexpensive and high activation energy process. The set-up of pack carburizing involves less capital investment [18]. The probability of obtaining a carburized layer is higher because the chemical reaction does not depend on carrier gas. The furnace used in this process does not require the atmosphere control.

Rolling of steel is one of the most important manufacturing processes for steel [19]. It is usually the first step in the processing of steel after it is made and cast either in Ingot or continuous cast product in a steel melting shop. The rolling is the process of plastically deforming steel by passing it between rolls. This process is defined as the reduction of the cross sectional area of the steel piece being rolled, or the general shaping of the steel products, through the use of the rotating rolls.

2. Methodology

2.1. Sample preparation

Tensile sample of Fe-24Mn steel with 5 mm width x 25 mm gauge length x 1.5 mm thickness was prepared using Electrical Discharge Machine (EDM) wire cut.

2.2. Homogenization

The homogenization was performed by heating the samples to 1180ºC at 400ºC/h and soaked at 1180ºC for 10 hours, then cooled to room temperature in the vacuum furnace.

2.3. Carburizing

Carburizing for both rolled and non-rolled Fe-24Mn steel samples were prepared. These samples were carburized for 1 and 2 hours. The parameters for gas and pack carburizing are listed in Table 1.

Table 1: Carburizing Parameters

Process	Regular	Bold
Carburizing Type	Gas Carburizing	Pack Carburizing
Temperature (°C)	930	930
Carburizing Agent	Propane (C3H8)	Charcoal
Type of Furnace	Fluidized Bed Furnace	Muffle Furnace
Carburizing Time (Hours)	1 and 2	1 and 2

Gas carburizing of Fe-24Mn steels was performed in a fluidized bed furnace at 930ºC. 1 and 2 hours carburizing times were used. The propane gas (C3H8) was used to provide the carburizing atmosphere. Carburizing reactions are as follows:

$$C_3H_8 \rightarrow C + 2CH_4 \quad (1)$$

$$CH_4 \rightarrow C_{Fe} + 2H_2 \quad (2)$$

For pack carburizing, the samples to be carburized were placed in a box containing the carbon. The samples are packed in a steel container and completely surrounded by granules of charcoal. The samples were then heated in the furnace at 930ºC for 1 and 2 hours. Due to high temperature, carburizing medium was oxidized to produce CO2 and CO and carbon diffused into the surface of sample. The CO gas will react with the steel surface to form a carbon atom which then diffused into the steel as shown in the following equation:

$$2CO + Fe \rightarrow Fe\,(C) + CO_2 \quad (3)$$

2.4. Tensile test

Tensile tests were conducted using AG-IS MS Shimmadzu Autograph machine. A tension force was applied to the tensile samples until failure occured. Simultaneously, the applied tension force and elongation of tensile samples were recorded. A plot was created from the stored load-elongation data.

2.5. Hardness test (HV test)

The diamond shaped indenter was perpendicularly pressed onto to the surface of the cross-sectional of the sample for three different points (surface, core and back surface). A small diamond-tipped cone was forced into the test sample by a predetermined load. The force applied on each point was 1 kg with 15 seconds of duration. The depth of penetration was measured and compared.

3. Results and discussion

3.1. Tensile test

The material characteristics for all the three specimens for both rolling and non-rolling specimens are demonstrated in the figure below. The stress-strain curves are also drawn for the specimens used in the test as in Figure 3 to 5. Referring to the stress-strain curve used in this study, the specimens have definite spring constant based on Hooke's Law.

3.2. Rolling vs. non-rolling

The stress-strain curves of rolling and non-rolling Fe-24Mn steel samples before carburized are shown in Figure 3.
Rolling without carburizing has higher strength compared to non-rolling sample without carburizing. This is because when rolling process was completed, the samples were plastically deformed by compressive forces. These forces acted to reduce the thickness of the samples by affecting its grain structure.

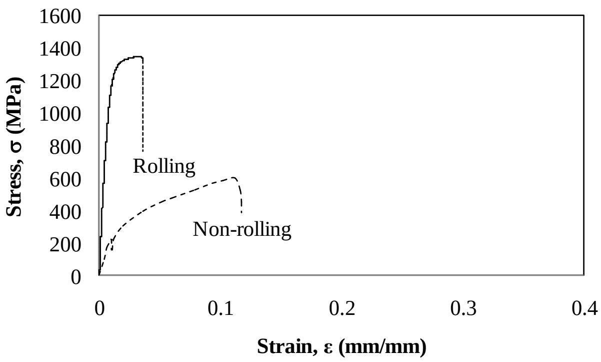

Fig. 3: Stress-strain curves of rolling and non-rolling sample before carburizing

3.3. Mechanical properties

Figure. 4 and 5 show the stress-strain curves of rolling and non-rolling sample after carburized. According to the stress-strain curve obtained from the test in this study, it is evident that the non-carburizing sample has a high yield stress with the lowest strain. This is because the carburizing process increases the ductility of the Fe-24Mn steel. The carbon diffuses below the carbon surface stabilize the austenite region.
After carburizing, the non-rolling steel samples still has a lower stress as shown in Figure. 5. This implies that the carburizing process (surface strengthening) has a little effect to increase the entire strength of the sample compared to the rolling process.

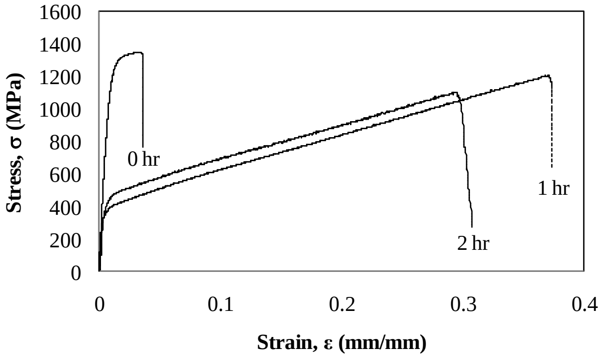

Fig. 4: Stress-strain curves of rolling sample with gas carburizing for 1 and 2 hours.

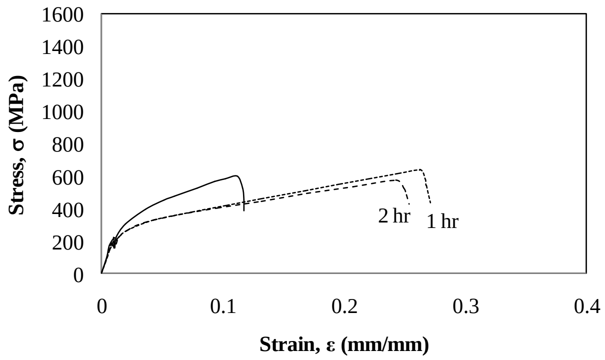

Fig. 5: Stress-strain curves of non-rolling sample with pack carburizing for 1 and 2 hours.

The mechanical behaviors of Fe-24Mn steel samples are demonstrated in Figure 6 to 8. It is evident that the sample after carburization, for both rolled and non-rolled decrease yield strength compared to the samples before carburization and the value increases as the carburizing time increases from 1 to 2 hours. The ultimate tensile strength of both Fe-24Mn steel samples show a slight decrease when carburized for 2 hours. The elongation of the sample increases after an hour carburization. This value decreases when the steel are carburized for longer time. This is due to the effect of carbon which transforms the martensite to austenite at the surface of this steel. It shows that both types of carburizing processes reveal promised good mechanical properties for rolled and non-rolled of Fe-24Mn steel. The requirement of the process depends on the applications. The plot in Figure 6 to 8 show that the yield strength, ultimate tensile strength and elongation of non-rolling Fe-24Mn steel samples are always below than the plot of rolled steel samples before and after carburizing. These results are consistent with [20] who found that the rolled sample has excellent combination of strength-ductility properties.
Carbon is considered an effective austenite stabilizer and is added in the modified steels [21]. It is notable that the solubility of carbon is high in austenite, so that carbon can be used to stabilize the austenite and also to strengthen by hardening [21].

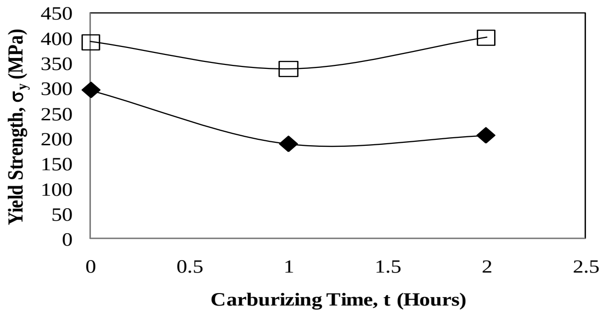

Fig. 6: Yield strength of Fe-24Mn steel samples before and after carburizing.

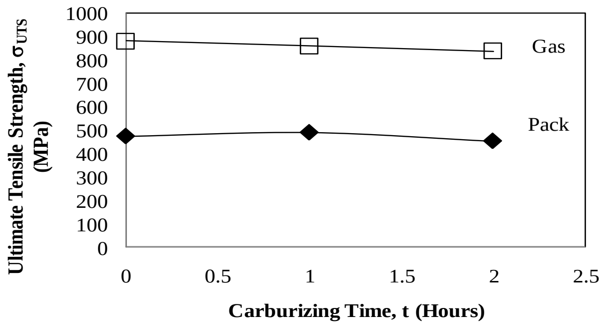

Fig. 7: Ultimate tensile strength of Fe-24Mn steel samples before and after carburizing.

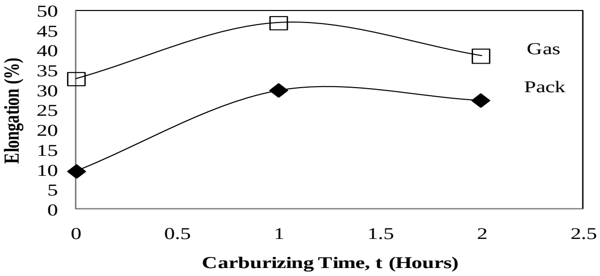

Fig. 8: Elongation of Fe-24Mn steel samples before and after carburizing.

The carbon addition shows the effect on yield strength and ultimate tensile strength. This is consistent with the work done by [22]. The effects of carbon on the mechanical properties of high manganese steel reported in their works are displayed in Fig. 9.

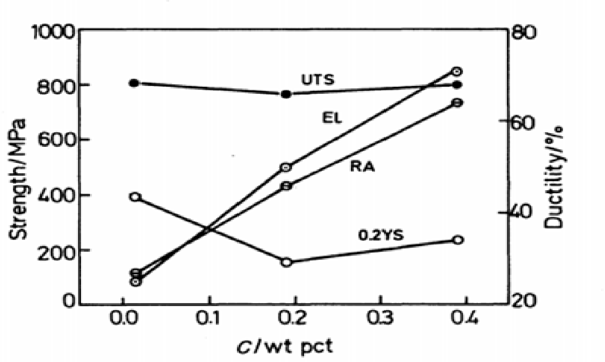

Fig. 9: Tensile properties of Fe-24Mn alloys with different C content [22].

3.4. Hardness test (HV test)

Figure 10 shows the comparison of hardness for five different Fe-24Mn steel samples which were carburized for 1 and 2 hours. The hardness of non-carburized steel samples were also plotted. The hardness of non-carburized sample indicates the harness value of 260 HV at the surface and 252 HV at the core. As the carburized time increased from 1 to 2 hours, the hardness values also increased. The increase of carburizing time causes more carbon atoms to diffuse into the steel surface resulting in increasing hardness. The hardness of the Fe-24Mn steel below the surface is higher than the core when carburized (gas) for 2 hours. This is due to the formation of carbide at this region. The high hardness beneath the surface is not shown by the steel sample carburized using pack carburizing for 2 hours. The carbon content below the surface of this sample is believed to stabilize the austenite structure, hence the surface is softer than the core.

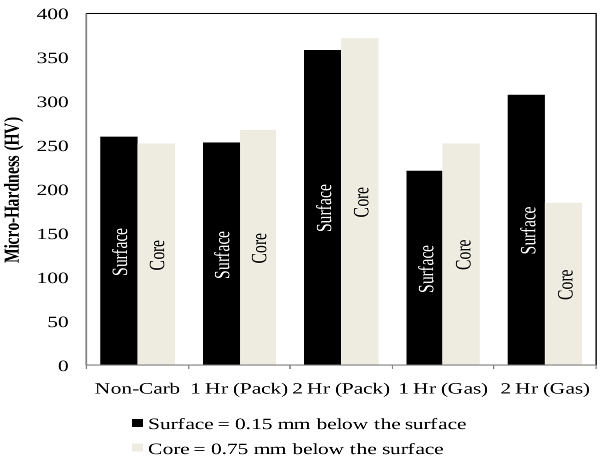

Fig. 10: Micro-hardness of the Fe-24Mn steel before and after carburizing.

3.5. Microstructure

In carburizing of Fe-24Mn steel, the carburizing layer at the surface is observed (as shown in Figure 11). The martensite structure is changed as the carbon stabilizes the austenite region below the surface of this steel. The strength and ductility of this steel decreases as the carbon level decreases. Extremely high carbon level lead to carbon soot which will be deposited onto the steel's surface.

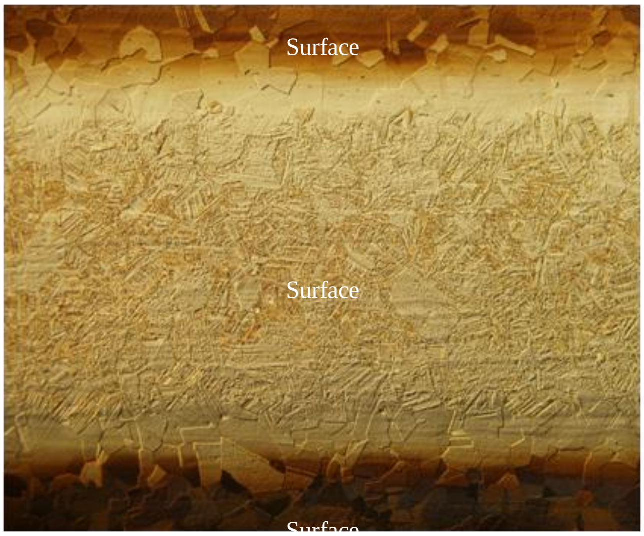

Fig. 11: Carburized layer of Fe-24Mn steel (austenite at the surface).

The carburizing process is one of the best manufacturing methods used for processes that require high strength and high wear resistance. The carbon introduced throughout this process can also improve the ductility of the steel. It has been proven that the ductility of high manganese steel (24% Mn) increases after carburizing. The Fe-24Mn steel form two layers (austenite at the surface and martensite at the core) after carburizing. The carbon below the surface stabilizes the austenite and results in increase of ductility compared to the core of the steel. Carburizing also improves the mechanical properties and micro-hardness of this steel. The carbon content below the surface (30 µm) after gas carburizing for 1 hour and 2 hours are 4.2 % and 4.6 wt. %, respectively.
The significance of carburizing is it provides two different layer properties. First is the soft layer at the surface and another is the hard layer at the core. Further deformation process using carburizing steel requires a lower deformation load. The carbon has stabilized the austenite at the surface of the steel. In terms of application, carburizing can increase the ductility property while retaining its high strength properties. These combinations within the properties of steel are useful especially when the steel's application required high impact absorption ability.

4. Conclusion

The mechanical properties of the steel are strongly influenced by carburizing. The carburizing of Fe-24Mn has the capability to produce a soft surface and a hard core for better strength and ductility. This will benefit the steel industries in which the lower load is required during the processing of steel. The rolling process can enhance the mechanical properties of this steel when the high strength applications are needed.

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