วิศวกรรมสารฉบับวิจัยและพัฒนา
Engineering Journal of Research and Development
วิศวกรรมสถานแห่งประเทศไทย ในพระบรมราชูปถัมภ์
The Engineering Institute of Thailand under H.M. The King's Patronage
ปีที่ 31 ฉบับที่ 4 ตุลาคม-ธันวาคม 2563
Volume 31 Issue 4 October-December 2020
Received 11 December 2019
Revised 13 January 2020
Accepted 30 June 2020 Physical Sciences

# MICROSTRUCTURE AND HARDNESS EVOLUTION OF CARBURIZED MILD STEEL

Thee Chowwanonthapunya[1] and Chaiyawat Peeratatsuwan[2*]
[1]Faculty of International Maritime Studies, Kasetsart University, Chonburi
[2]Faculty of Engineering and Architecture, Rajamangala University of Technology Isan
*Corresponding author: chaiyavat66@gmail.com

**บทคัดย่อ**

*งานวิจัยนี้มีวัตถุประสงค์ในการศึกษาการเปลี่ยนแปลงโครงสร้างจุลภาคและค่าความแข็งของเหล็กกล้าคาร์บอนที่ผ่านการทำแพ็คคาร์บูไรซิ่ง โดยเหล็กกล้าที่นำมาศึกษาเป็นเหล็กกล้าคาร์บอน AISI เกรด 1020 ซึ่งได้เตรียมให้เป็นชิ้นทดสอบที่มีขนาด กว้าง 5 มม ยาว 25 มม และ หนา 2 มม โดยชิ้นทดสอบจะทำการบรรจุในภาชนะปิดที่มีการเตรียมบรรยากาศของคาร์บูไรเซชั่น โดยการใช้สารเพิ่มคาร์บอนจากส่วนผสมของผงถ่านไม้มะขาม การทำแพ็คคาร์บูไรซิ่งสำหรับชิ้นงานเหล็กกล้าทำที่อุณหภูมิ 950 องศาเซลเซียส เป็นเวลา 2 ชม. จากผลการทดลองแสดงอย่างชัดเจนว่าการทำแพ็คคาร์บูไรซิ่งสามารถสร้างเฟสที่แข็งในระดับโครงสร้างจุลภาคได้ ซึ่งทำให้ชิ้นงานเหล็กกล้ามีค่าความแข็งสูงขึ้น โดยโครงสร้างจุลภาคที่เหมาะสมที่เกิดในชิ้นงานมีผลโดยตรงต่อการเปลี่ยนแปลงความแข็งของเหล็กกล้าคาร์บอน กระบวนการเทมเปอร์ริ่งสามารถปรับปรุงความเหนียวของเหล็กกล้าคาร์บอนที่ผ่านการทำแพ็คคาร์บูไรซิ่ง ดังนั้น กระบวนการนี้ควรทำกับเหล็กกล้าคาร์บอนที่ผ่านการทำแพ็คคาร์บูไรซิ่งภายหลังจากกระบวนการชุบแข็ง*

**คำสำคัญ:** การเพิ่มคาร์บอนที่ผิว เหล็กกล้าคาร์บอน โครงสร้างจุลภาค ความแข็ง

**ABSTRACT**

*This paper aims to study the microstructure and hardness evolution of the carburized mild steel. The mild steel grade AISI 1020 was employed to be samples with dimension of 5 mm X 25 mm X 2 mm and then packed in the tightly sealed steel container where carburization environment was provided by using mixtures of powdered charcoal and tamarind catalysts. The pack carburizing was performed at carburizing temperature of 950 °C with fixed carburizing time of 2 hrs. The results indicate that pack carburization treatment can favor the formation of the hard phase, which can improve the hardness of samples. The appropriate microstructures of samples subjected to every stage determines the evolution of hardness profiles of the mild steel. The tempering process can improve the toughness of the carburized mild steel. Thus, it should be carried performed after quenching process.*

**KEYWORDS:** Carburizing treatment, Mild Steel, Microstructure, Hardness

## 1. Introduction

Mild steel is tough, but ductile and malleable. Therefore, this material is often selected and applied in many different industries, for examples, automobile, shipbuilding, and transportation [1-2]. However, this materials is soft in nature. This means that the surface of this material is prone to the surface degradations, e.g. wear or local distortion [3-4]. Hence, the improvement in the hardness of the mild steel subjected such degradations is obviously in need. Nowadays, the heat treatment is a common way, which can be employed to improve the hardness of this steel. Usually, the hardness of this steel, especially at the surface, can significantly be increased if the appropriate microstructure from the heat treatment is obtained [1-4].

Pack carburizing is a heat treatment process, which is related to the addition of carbon to the surface of the mild steel to modify it to the high carbon containing steel, which can further be hardened to gain the increased hardness of the surface [5-6]. This method normally consists of three steps [7-8]. The first step is to pack mild steel parts in a sealed steel container for being exposed to the carbon- rich environment at the appropriate temperature with the certain holding time. The second step is to quench carburized steel parts in a cooling media to obtain the hardening effect. The final step is to temper the hardened steel parts for obtaining the desired conditions so that steel after pack carburizing can be hardened at surface, but the center of the steel remain is still tough and ductile. Usually, the hardness of the steel treated by the pack carburizing technique depends on the microstructures getting from every step. If the appropriate microstructures from each step of the carburizing is acquired, the desired properties of the carburized mild steel can be gained. Thus, the understanding in the evolution of microstructure and the hardness of the carburized mild is of great significance. Nevertheless, few studies have been carried out to gain the insight in the microstructure and hardness evolution of the carburized steel.

In this present work, microstructural evolution of carburized mild steel was analyzed. Hardness test was conducted to indicate the hardness evolution of mild steel during pack carburizing process. The comparison of the toughness of quenched and tempered mild steel was also offered. One aim of this research was to investigate the microstructure transition from the surface to core and the microstructure evolution during the carburizing process. The other aim is to study the change of the hardness of mild steel subjected to the pack carburizing process. Besides, the significance of the tempering process was also discussed.

## 2. Experimental procedures

The Material used for this work was the mild steel grade AISI 1020. The chemical composition of this mild steel is listed in Table 1. The mild steel grade AISI 1020 was prepared to be samples which have a rectangular cross section with dimensions of 5 mm X 25 mm X 2 mm, as depicted in Figure 1(a).

**Table 1** Chemical Compositions of mild steel used in this experiment

| Element | C | Mn | Si | S | P | Fe |
|---|---|---|---|---|---|---|
| % | 0.18 | 0.51 | 0.20 | 0.05 | 0.04 | Balance |

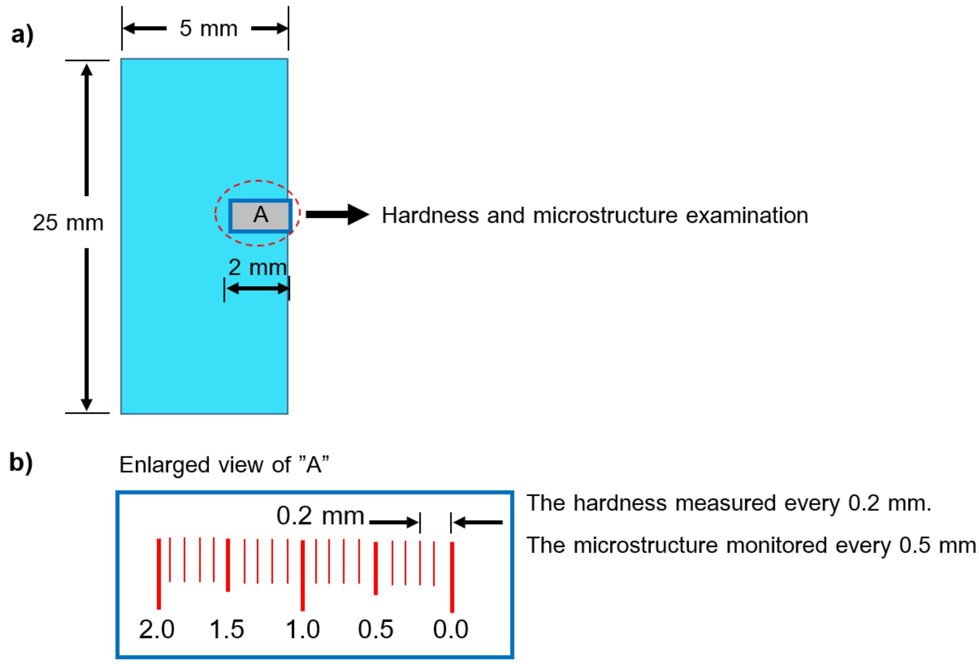


**Figure 1** Prepared specimens: (a) sketch of specimens, (b) the enlarged view of "A" and positions where hardness and microstructure were measured

The microstructural and hardness evolution were performed at the area labelled "A", as shown in Figure 1(a). The microstructure and hardness investigation were performed at every 0.5 mm and 0.2 mm from the surface of the samples, as schematically explained in Figure 1(b).

For the pack carburizing treatment performed in this study, the samples were embedded in a tight container which was made of carburized steel. The container was tightly sealed with clay to make sure that CO from the reaction cannot be escaped. The power charcoal mixed with tamarind catalysts was used to prepare the carbon – rich atmosphere in the steel container. In this experiment, pack carburized treatment was composed of three following sub-processes: carburizing process at temperature of 950 °C with the holding time of 2 hrs., rapid cooling process in water, and tempering process at 150 °C for 1 hr. All of temperature and time conditions are advised by the heat treatment guide of steel [9]. As-received samples and treated samples from each sub-process were taken out for microstructure and hardness investigation, as schematically shown in Figure 2.

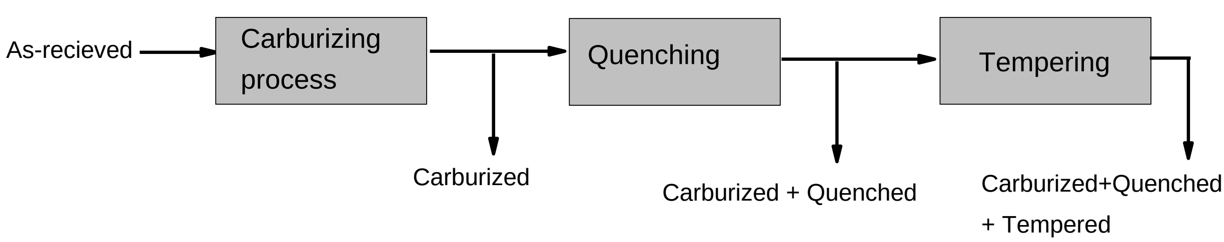


**Figure 2** Schematic diagram for the investigation of the sample conditions

The light optical microscopy was utilized to explore the insight in the microstructure evolution of the carburized steel samples in each carburizing stage. The hardness evolution of mild steel subjected to the carburizing process was conducted by using Micro vicker hardness test model MHT-2. Another set of samples, sized at 1cm x 1cm x 5.5cm with a 2mm deep U-shaped notch at the middle of a specified flat surface, was also prepared for the pack carburizing treatment and then subject to the charpy V-notch impact test. This test was assigned to indicate the toughness of the quenched samples and tempered samples.

## 3. Results and discussions

### 3.1 The microstructural evolution of carburized mild steel

Figure 3 exhibits the microstructural evolution of carburized steel in every stage of pack carburizing process and microstructure transition taking place from the surface to the center of samples. Clearly, AISI 1020 without pack carburizing or as received samples contains mixtures of pearlite and ferrite. After AISI 1020 was subjected to carburizing process, its microstructure is altered to be pearlite at the surface. However, when the distance from the surface increased, the amount of pearlite decreased but the amount of ferrite increased. It is also clear that the microstructure at the center contained low pearlite fraction and high ferrite fraction. This finding indicates that the greatest carbon content should occur at the surface, but as the distance from the surface increased, the carbon content became lower, attributing to the formation of ferrite-pearlite microstructures. After quenched, the microstructure at the surface became fine martensite with the distribution of precipitated carbides (white). As the distance from the surface increased, the amount of martensite decreasd ,but the amount of ferrite increased. The area whose distance from the surface is greater than 1 mm shows the low martensite and high ferrite fraction. The highest ferrite and the lowest martensite fraction was found at the center of sample. This observation suggests that the highest carbon at the sample surface can be transformed to fine martensite and the excess of carbon favored the formation of carbides. The carbon content would be lower as the distance from the surface increased, especially at the center of the sample, contributing to the decreased martensite fraction and the increased ferrite fraction.

After tempered, the sample surface containing the coarse martensite without the presence of carbide formation. The amount of martensite decreased with increasing the distance from the surface. The microstructure at the center also exhibited the martensite-ferrite structure.

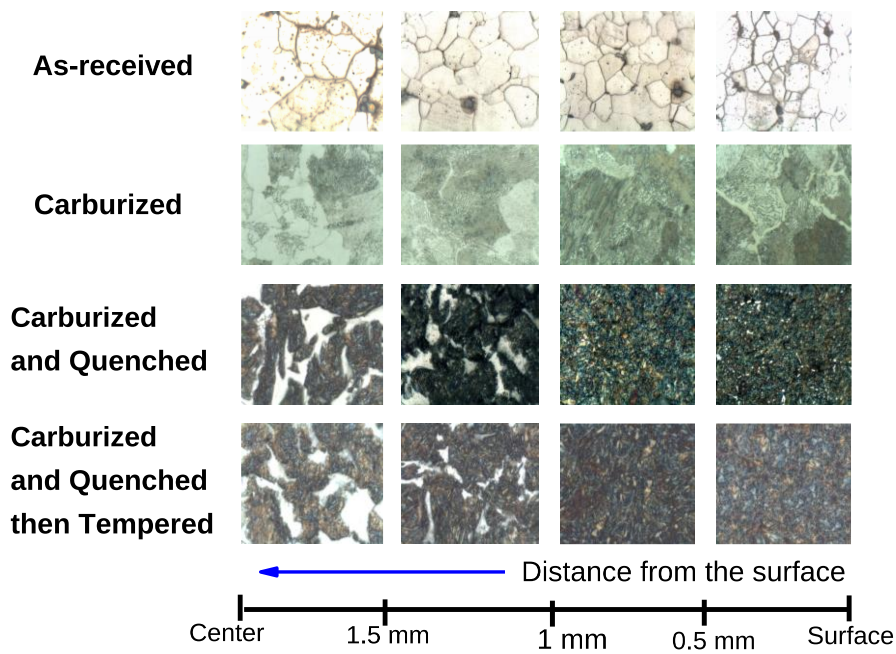


**Figure 3** Microstructural evolution of carburized steel

### 3.2 The hardness evolution

Figture 4 shows the hardness evolution of samples with different treatment conditions. As-received sample containing mixtures of pearlite and ferrite shows the lowest hardness profile. After carburized , samples shows the higher hardenss at the surface and then the decreased hardness with increasing the distance below surface. This result indicates that the surface of carburized sample contained the highest carbon content , which can be tranformed to be pearlite as shown in Figure 3. Thus , the formation of pearlite contributes to the increased hardness at the surface. The decreased hardness as the distance below surface increases reflects the decreased carbon content which subsequently promote the formaiton of more ferrite. Hence , the increased amount of ferrite attributes to the decreased hardness profile of carburized samples. Samples which are carburized and quenched show the highest hardness at the surface. This means that the surface containing highest carbon content is transformed into the martensite and carbides after quenching process , as previously shown in Figure 3. The decreased hardness profile indicates the presence of mixture martensite and ferrite. The greater the distance below the surface is , the less the martensite content becomes. Therefore, the decreased amount of martensite and the increased amount of ferrite are responsible for the decreased harness profile. Samples after carburization , quenching and tempering displays the high hardenss profile , but the hardenss from the surface to 1 mm is lower than that of quenched samples. The result from Figure 3 shows that the transformation of fine martensite to coarse matensite after the tempering process is carried out. In addition , no carbide precipitation is detected in the surface of tempered samples. So, the presence of coarse martensite and the absence of the carbide precipitation causes the decreased hardness from the surface to 1 mm of tempered samples. This observed result obviously displays the role of the tempering process on the pack carburizing process of AISI 1020 by modifying the hard phase composed of coarse martensite and carbide precipitation to the soft pahse , fine martensite without precipitated carbides. In order to understand the significane of the tempering process , the toughness test (charpy impact test) of the quenched samples and tempered samples is provided in Figure 5.

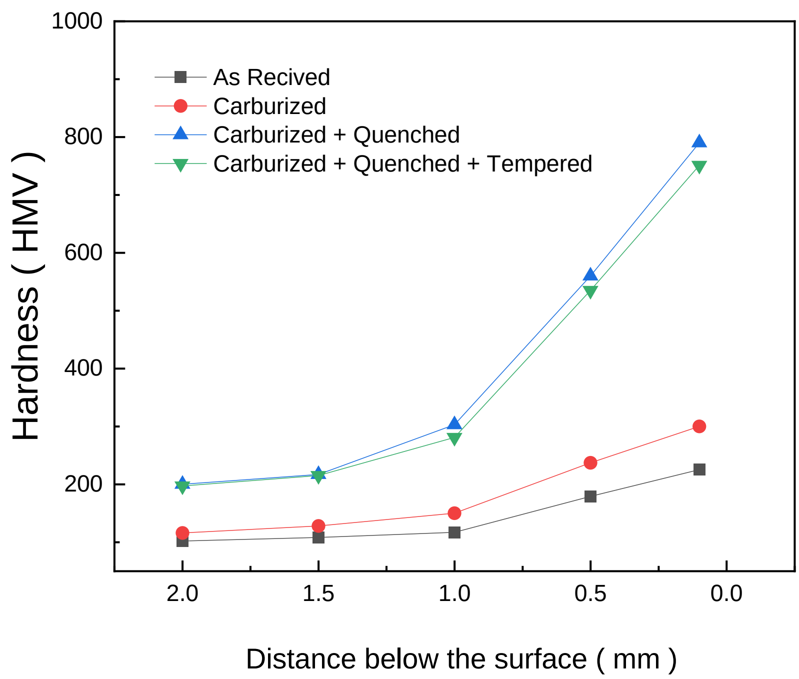


**Figure 4** Hardness evolution of carburized steel

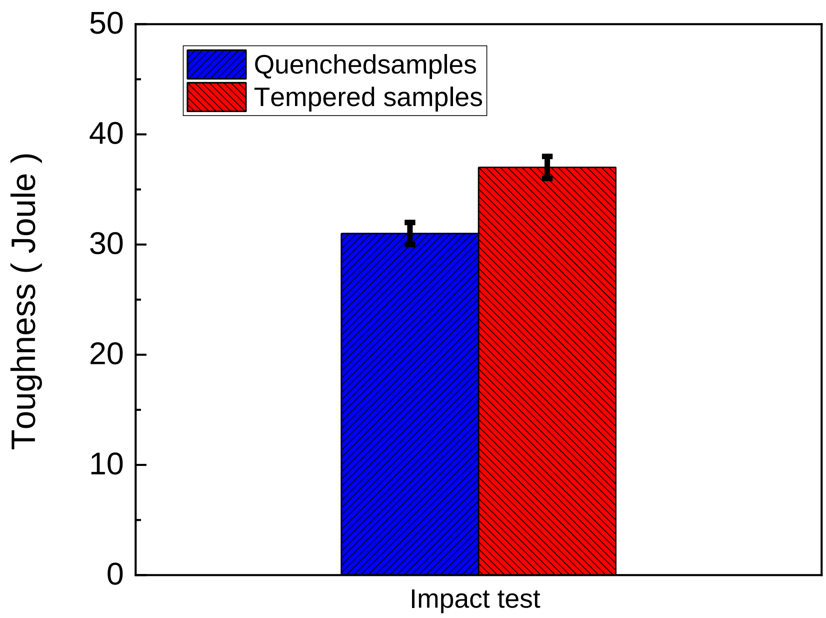


**Figure 5** Impact test of quenched samples ( Blue ) and tempered samples ( Red)

Figure 5 exhibits the results from the impact test of quenched samples and tempered samples. Basically , tougness means the ability of materials to absorb energy and plastically deform before the fracture. From Figure 5 , the toughness of tempered samples is higher than that of quenched samples, meaning that the tempering process added after quenching process can improve the touhgness. This kind of results has also been agreeable with several pioneer works. A. Oyetunji et al. [3] indicated the ductility of the low carbon steel after carburization can be improved with the tempering process. J.P. Wise et al. [7] suggested that the tempering process increased the ductility , which was useful for the carburized steel subjected to the fatigue. Therefore, applying the tempering process promotes the formation of the coarse martensite and the disolution of preciptiated carbides , resulting in the improvement of the toughness of AISI 1020 after submitted to the carburizing and quenching.

## 4. Conclusion

The main conclusions drawn from the results of this work are as follows.

- The pack carburizing treatment can modify the low carbon steel to the high carbon containing steel, which subsequently enhance the hardenability of this material, especially at the surface of samples.
- The variation of the microstructure from the surface to the core indicates the difference in carbon content in samples. The greatest carbon content occurs at the surface, contributing to the formation of the hardest phase, martensite. However, as the distance from the surface increases, the carbon content decreased, resulting in the presence of the softer phases, i.e. Ferrite.
- The microstructure of samples subjected to every stage of the treatment corresponds to the variation of the hardness. Thus, the presence of the appropriate microstructure in each step of the treatment determines the evolution of hardness profiles of AISI 1020
- The tempering process favored the formation of the coarse martensite and the dissolution of precipitated carbides, thus improving the toughness of AISI 1020 after the carburizing and quenching

**References**

[1] Ihom P. Aondona, Aniekan Offiong , The Effect of Holding Time on the Hardness of Case Hardened Mild Steel , *Materials Science and Metallurgy Engineering*, 2014, Vol. 2, No. 3, 31-34.

[2] Fatai Olufemi ARAMIDE, Simeon Ademola IBITOYE, Isiaka Oluwole OLADELE and Joseph Olatunde BORODE, Pack Carburization of Mild Steel, using Pulverized Bone as Carburizer: Optimizing Process Parameters, *Leonardo Electronic Journal of Practices and Technology*, 2010, Vol (16), pp. 112.

[3] A. Oyetunji and S.O. Adeosun, Effects of Carburizing Process Variables on Mechanical and Chemical Properties of Carburized Steel, *journal of Basics and Applied Science*, 2012, Vol 8, pp. 319-324.

[4] L.C.F.Canale , L. .Albano , G.E. Totten , L.Meekisho , Hardenability of Steel , *Comprehensive Materials Processing* , 2014, Volume 12, pp. 39-97.

[5] Thee Chowwanonthapunya, Narongsak Thammachot and Chaiyawat Peeratatsuwan, A Study on Microstructure and Mechanical properties of the pack carburized low carbon steel used as an alternative material for agricultural knife blade, *Journal of Science and Technology Kasetsart University*, 2017, Vol 6, issue 2, pp. 36-45.

[6] Narongsak Thammachot, Wanna Homjabok and Naruedom Thadee, The efficiency of different types of wood charcoal on increasing carbon content on surfaces of low carbon steel in the pack carburizing process, *KKU Engineering Journal, 2014,* Vol 3, pp. 383-391.

[7] J.P. Wise, G. Krauss, D.K. Matlock, Microstructure and Fatigue Resistance of Carburized Steels, *20th ASM Heat Treating Society Conference Proceedings*, 2000, pp. 1152-1161.

[8] Thee Chowwanonthapunya, Xin Mu and Chaiyawat Peeratatsuwan, Study on carburized steel used in maritime industry: The influences of carburizing temperature, *Maritime Technology and Research*, 2020, vol 2, issue 1, pp. 33-39.

[9] Harry Chandler, *Heat Treater's Guide: Practices and Procedures for Irons and Steels*, ASM International, Dec 31, 1996