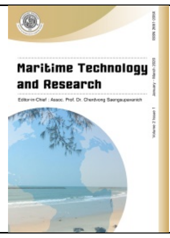
Maritime Technology and Research
https://so04.tci-thaijo.org/index.php/MTR



Research Article

Study on carburized steel used in maritime industry: The influences of carburizing temperature

Thee Chowwanonthapunya[1], Xin Mu[2] and Chaiyawat Peeratatsuwan[3,*]

[1]*Faculty of International Maritime Studies, Kasetsart University, Sriracha, Chonburi 20230, Thailand*
[2]*Environmental Corrosion Research Centre of Materials, Institute of Metal Research, Chinese Academy of Science, China*
[3]*Faculty of Engineering and Architecture, Rajamangala University of Technology Isan, Nakhonratchasima 30000, Thailand*

Article information
Received: April 3, 2019
Revised: July 18, 2019
Accepted: July 26, 2019

Keywords
Carburizing treatment,
Mild steel,
Maritime industry

Abstract
This paper aims to examine the influence of carburizing temperature on carburized mild steel. Carburizing treatment was carried out at carburizing temperatures of 800 and 900 °C with fixed carburizing time of 1 h. The results indicated that carburization treatment could improve the hardness of the samples. However, it was found that the hardness profile of mild steel was almost unchanged after treatment at the carburizing temperature of 800 °C. Carburization treatment carried out at the carburizing temperature of 900 °C could significantly enhance the hardness conditions and also increase the case depth of carburized mild steel. Carburized steel can provide a tough and durable surface to protect against severe degradations, such as marine erosion, wear, and cavitation in maritime applications.

1. Introduction

Mild steel is a tough material which is soft and ductile. Thus, it is frequently utilized for a variety of components in ships and the marine industry (Aondona & Offiong, 2014). Nevertheless, the inherent characteristics of the steel mean that the surface can be vulnerable to erosion and wear. Both kinds of failure are known as causes of the major degradation of steel used in the marine industries. Hence, the improvement of the steel surface in marine applications, especially hardness, is obviously required (Aramide et al., 2010). Basically, heat treatment can be applied to improve the performance of this steel. After the appropriate heat treatment is selected and properly conducted, the enhanced properties of this steel can be obtained.

Pack carburization is a kind of case hardening process which can notably enhance the hardness property of mild steel (Oyetunji & Adeosun, 2012). Once the hardness of the surface of the mild steel increases, the resistance to erosion and wear will be significantly improved. The pack carburization of the mild steel is normally composed of 3 processes (Thammachot et al., 2014). The first process is to heat up the steel in the carbon containing environment at a temperature range of 800 - 1100 °C. The second process is to hold this steel at the selected temperature for an appropriate

*Corresponding author: Faculty of Engineering and Architecture, Rajamangala University of Technology Isan, Nakhonratchasima 30000, Thailand
E-mail address: chaiyavat66@gmail.com*

period. The third process is to quench the steel with a suitable cooling rate to obtain the hard surface of the steel. Usually, the desired property of the steel surface depends on the formation of a carbon-enriched layer on the surface of the steel. Technically, the development of this layer is determined by the concentration of carbon diffused into the steel during the carburizing process (Wise et al., 2000). Theoretically, the diffusion rate of carbon in the steel is related to several parameters. Among many, the carburizing temperature in heat treatment is one of the significant parameters for providing adequate hardness on the steel surface (Canale et al., 2014). Therefore, it is imperative to understand the influence of temperature on the hardness of carburized mild steel. However, this influence has not been widely studied. For this reason, this paper aims to investigate the effects of temperature on the hardness profile of pack carburized mild steel. The results from this study can be used to be a reference in the further development of steel used in marine applications, particularly the improvement of the hard surface of steel subjected to attack from marine erosion and wear from marine environments.

2. Materials and methods

2.1 Material

Mild Steel grade AISI 1008 was employed in this experiment and its chemical composition is presented in **Table 1**.

Table 1 Chemical compositions of specimens.

Element	C	Mn	Si	S	P	Fe
%	0.078	0.51	0.20	0.012	0.004	Balance

AISI 1008 was then prepared as specimens with dimensions of 10×10×4 mm^3, as shown in **Figure 1**. **Figure 1** also provides the positions where the hardness measurement was performed.

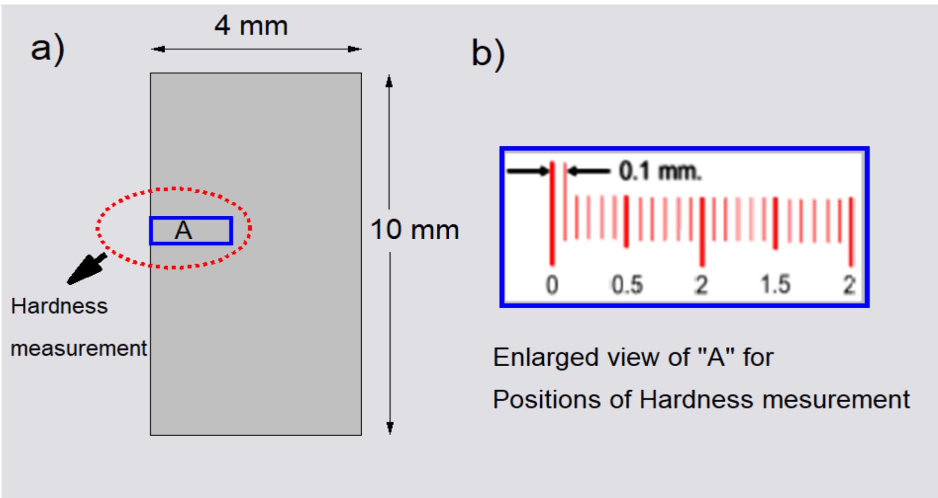


Figure 1 Prepared specimens (a) dimension and positions of hardness measurement “A”, (b) enlarged view of “A” and scales.

2.2 Carburizing treatment and hardness profile measurement

For the carburizing treatment employed in this study, the specimens were prepared and put in a tight container made of carburized steel. The carburization environment in the container was prepared by using powdered charcoal mixed with tamarind catalysts. The specimens were then subjected to carburizing treatment at carburizing temperatures of 800 and 900 °C with fixed carburizing time of 1 h for investigating the influence of carburizing temperature.

For hardness measurement in this experiment, the Micro Vickers hardness test was employed to monitor the hardness profile of the uncarburized and carburized steel specimens at every 0.2 mm, the positions of which are clearly indicated in **Figure 1**.

3. Results and discussion

3.1 The hardness profile of uncarburized steel

As clearly seen from **Figure 2**, the hardness profile of uncarburized mild steel is in the harness range of 225 - 165 HMV, suggesting that uncarburized mild steel is soft and very ductile. The hardness range of this result also reflects the presence of ferrite as the main phase of the uncarburized mild steel. Usually, ferrite is a soft phase in the steel. So, the presence of Ferrite and the low hardness profile indicates a lack of surface strength and hardness in mild steel without carburization. In fact, this result agrees with a number of accepted academic papers. Qin et al. (2004) studied the microstructure and mechanical properties of carburizing-quenched steel and found that low carbon steel consists primarily of ferrite. This phase is the softest phase among many. Duka et al. (2012) carried out hardness measurements of low carbon steel, and their results showed that the range of hardness was between 145 - 240 HMV, indicating the presence of ferrite in low carbon steel. Thus, this kind of steel is not hard enough to withstand heavy loading, like erosion and wear. Obviously, improvement of the surface quality, in terms of hardness, is required.

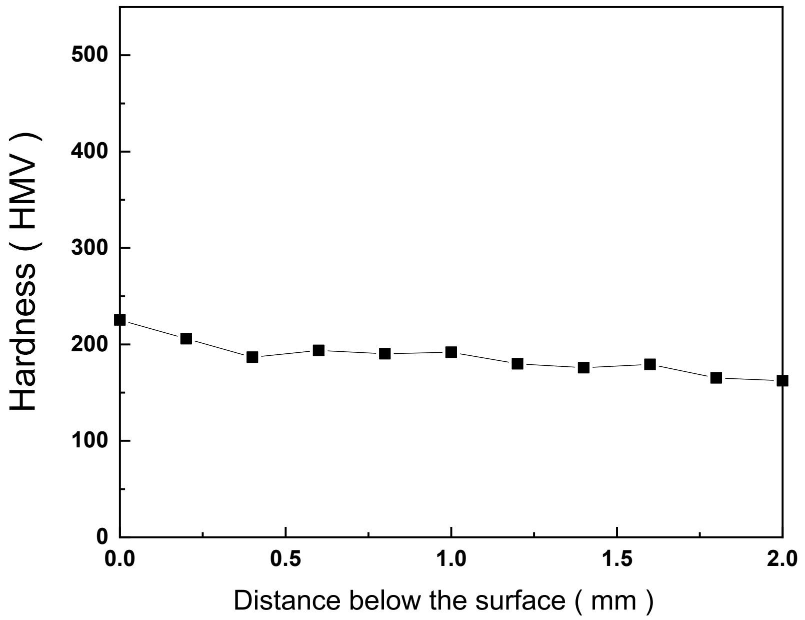


Figure 2 Hardness profile of uncarburized steel.

3.2 The hardness profile of carburized steel

In this experiment, the influences of carburizing temperature was emphasized. Then, we carried out the experiment at carburizing temperatures of 800 and 900 °C with fixed carburizing time of 1 h. **Figure 3** exhibits the hardness profile of mild steel carburized at 800 °C for 1 h. For comparison, the hardness profile of uncarburized mild steel is also re-plotted in **Figure 3**.

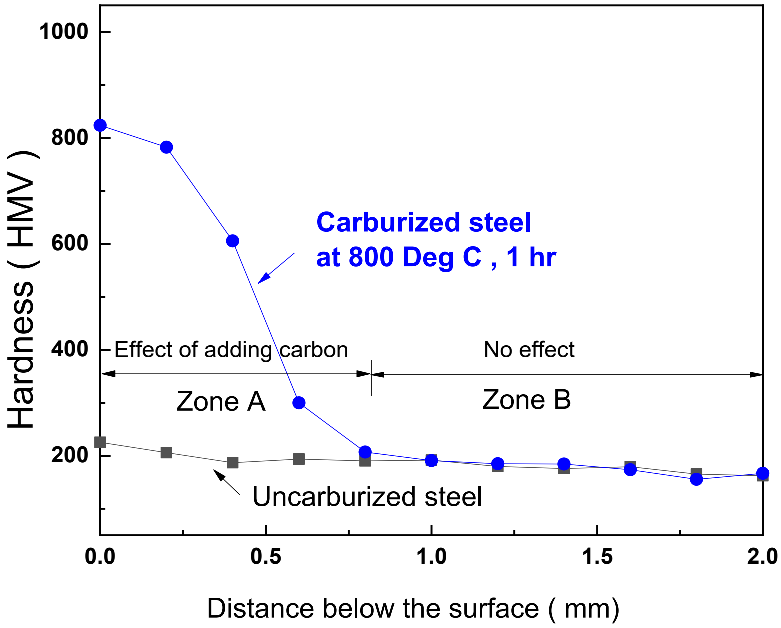


Figure 3 Hardness profile of carburized steel at carburizing temperature of 800 °C with 1 h of carburizing.

From **Figure 3**, carburizing treatment at 800 °C with carburizing time of 1 h can increase the hardness of mild steel, as can be seen in Zone A. Principally, the carburizing treatment involves putting carbon atoms into the surface of the mild steel to form a carbon rich layer. Hence, the increased hardness can be attributed to the carbon atoms added during the carburization process. On the other hand, Zone B shows an almost unchanged hardness of the carburized steel, indicating the lack of the adding carbon during the carburization process. The results of the hardness profile in this present experiment can be found by detailed analysis of many academic papers (Aondona & Offiong, 2014; Aramide et al., 2010; Oyetunji & Adeosun, 2012; Thammachot et al., 2014; Wise et al. 2000; Canale et al., 2014; Qin et al., 2004; Duka et al., 2012). Their results indicated that steel after carburization contains 2 distinguished zones: the surface and the core. The surface is the area of steel subjected to chemical change by introducing a high carbide content. In contrast, the core is the area where its chemical compositions remains unaffected. Clearly, the hardness profile of the steel in this work is in accordance with the accepted results from these pioneering metallurgists.

Figure 4 illustrates the hardness profile of mild steel carburized at 900 °C for 1 h. As compared to the hardness profile of mild steel without carburizing treatment, the hardness of carburized mild steel with carburizing conditions of 900 °C and holding time of 1 h increased significantly. **Figure 4** also shows the absence of the unaffected zone. When the temperature increases, diffusion of carbon atoms can be accelerated, as described by Fick's laws. The growth of the carbon layer is basically proportional to the temperature. Thus, the higher carburizing temperature enhances the formation of the carbon rich layer and, thus, improves the surface conditions of the carburized mild steel.

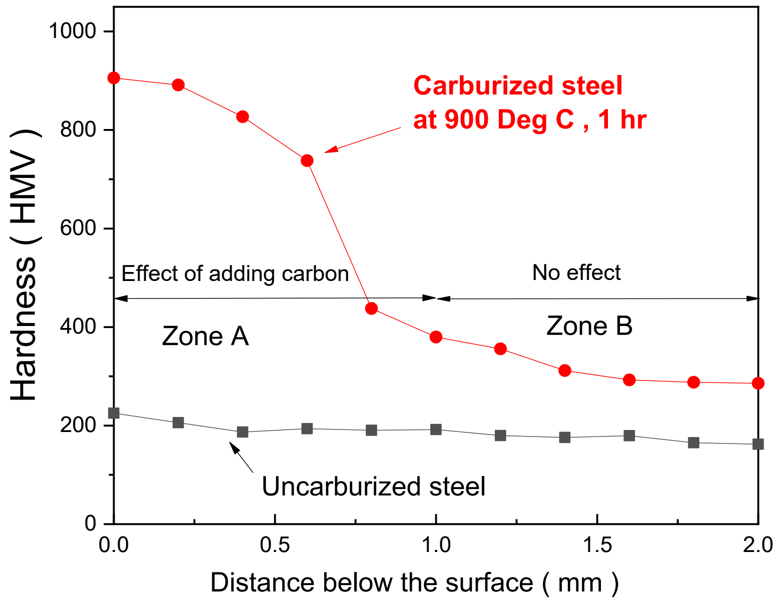


Figure 4 Hardness profile of carburized steel at carburizing temperature of 900 °C with 1 h of carburizing.

3.3 The case depth of carburized steel

Figure 5 shows the hardness profile of carburized steel with carburizing temperatures of 800 and 900 °C and fixed carburizing time of 1 h. The results suggest that the hardness of carburized steel with a carburizing temperature of 900 °C is higher than that with a carburizing temperature of 800 °C in all positions of the hardness measurement. In this study, not only hardness profile, but also the effective case depth of the carburization in carburized mild steel was measured. Basically, case depth means the effective rich carbon layer under the surface of the carburized steel. In this study, the hardness of 550 HMV was set to be the indicator of the case depth measurement (Edenhofer et al., 2015; International Organization for Standardization, Technical Committee ISO 2639, Acoustics, 2002). In other words, case depth of carburized steel will be effective when the hardness is higher than 550 HMV. **Figure 5** also provides the estimated case depth of carburized steel. For carburization at a temperature of 800 °C, the case depth is estimated to be X_L. In the case of a carburizing temperature of 900 °C, the approximated case depth is X_H. As can be seen in **Figure 5**, X_H is longer than X_L. This means that the higher carburizing temperature can increase the case depth of the carburized steel, resulting in increased surface hardness of mild steel.

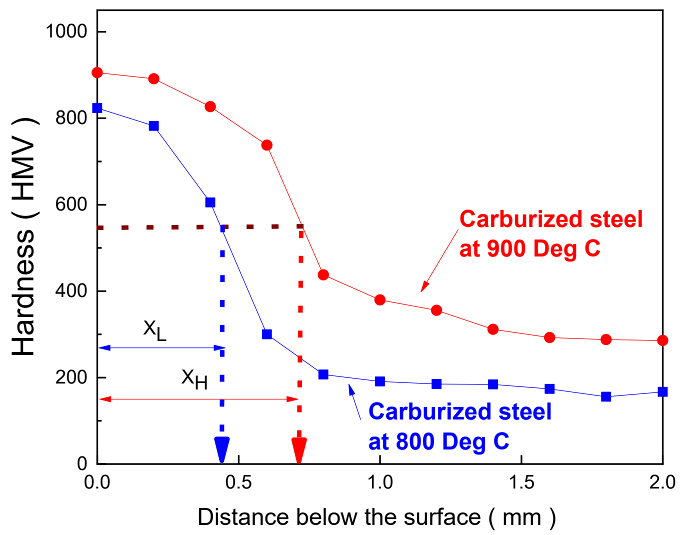


Figure 5 Hardness profile of carburized steel at carburizing temperatures of 800 and 900 °C with 1 h of carburizing.

4. Conclusions

The influences of the carburizing temperature of the carburized mild steel was conducted. The results suggested that carburization heat treatment at carburizing temperatures of 800 and 900 °C with constant carburizing time of 1 h. can improve the hardness of mild steel. Almost no change in the hardness profile of the carburized mild steel at 800 °C indicates a lack of added carbon atoms during the carburizing process. However, when the carburizing process was carried out at the carburizing temperature of 900 °C, the hardness substantially increased in all measured positions. Additionally, the case depth was also increased. Therefore, the higher carburizing temperature plays a role in the enhanced surface conditions by accelerating the diffusion of carbon atoms into the interior of the mild steel, which consequently enhances the formation of the carbon rich layer and increases the case depth of the carburized mild steel. The results also indicate the improved performance of the steel surface. The surface of the steel gets hard after carburizing, while the interior remains tough and malleable. This unique structure, modified by carburizing, can be used for strong components in marine applications. The modified steel can provide a tough and durable surface against severe degradations, such as marine erosion, wear, and cavitation in maritime applications.

References

Aondona, I. P., & Offiong, A. (2014). The effect of holding time on the hardness of case hardened mild steel. *Materials Science and Metallurgy Engineering, 2*(3), 31-34. doi:10.12691/msme-2-3-1

Aramide, F. O., Ibitoye, S. A., Oladele, I. O., & Borode, J. O. (2010). Pack carburization of mild steel, using pulverized bone as carburizer: Optimizing process parameters. *Leonardo Electronic Journal of Practices and Technology, 9*(16), 112.

Canale, L. C. F., Albano, L., Totten, G. E., & Meekisho L. (2014). Hardenability of steel, *Comprehensive Materials Processing, 12*, 39-97. doi:10.1016/B978-0-08-096532-1.01219-X

Duka, E., Oettel, H., & Dilo, T. (2012). Connection between micro and macro hardness pearlitic-ferritic steel. *AIP Conference Proceedings, 1476*, 88-91. doi:10.1063/1.4751563

Edenhofer, B., Joritz, D., Rink, M., & Voges, K. (2015). *Carburising of steels*. In Mittemeijer, E. J., & Somers, M. A. J. (Eds.). Thermochemical surface engineering of steels. Amsterdam, Netherlands: Woodhead Publishing, pp. 485-553. doi:10.1533/9780857096524.3.485

International Organization for Standardization, Technical Committee ISO 2639, Acoustics. (2002). *Steels: Determination and verification of the depth of carburized and hardened cases*. Geneva, Switzerland: International Organization for Standardization.

Oyetunji, A., & Adeosun, S. O. (2012). Effects of carburizing process variables on mechanical and chemical properties of carburized steel. *Journal of Basics and Applied Science, 8*(2), 319-324. doi:10.6000/1927-5129.2012.08.02.11

Qin, M., Ju, D. Y., Zhang, Y., & Bian, P. (2004). Evaluation of microstructure and mechanical properties in carburizing quenched SCr 420 by numerical simulation and experimental methods. *Journal of Material Science and Technology, 20*, 41-44.

Thammachot, N., Homjabok, W., & Thadee, N. (2014). 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, 41*(3), 383-391.

Wise, J. P., Krauss, G., & Matlock, D. K. (2000). *Microstructure and fatigue resistance of carburized steels*. In Proceedings of the 20th ASM Heat Treating Society Conference Proceedings, pp. 1152-1161.