Jurnal Polimesin
Department of Mechanical Engineering
State Polytechnic of Lhokseumawe
http://e-jurnal.pnl.ac.id/polimesin

e-ISSN	: 2549-1999	No.	: 5	Month	: October
p-ISSN	: 1693-5462	Volume	: 22	Year	: 2024

Article Processing Dates: Received on 2024-09-04, Reviewed on 2024-10-17, Revised on 2024-10-26, Accepted on 2024-10-29 and Available online on 2024-10-30

Combined carburizing and shot peening to increase gear sprocket surface hardness

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Abstract

The sprocket is a crucial motorcycle component that transfer engine rotational force to the wheels. However, friction between the chain and gear during the operation leads to wear. This study aimed to enhance the surface hardness of sprocket by combining pack carburizing and shot peening. Pack carburizing was conducted by embedding the sprocket in coconut shell charcoal powder and heating it to 850°C for 60 minutes, followed by quenching in water at 30°C. Shot peening was then applied to the carburized specimen using steel ball particles for 20 minutes at a pressure of 8 bar. Hardness testing was performed according to the ASTM 92-17 Vickers method, and microstructural analysis was conducted using Scanning Electron Microscopy (SEM) on the best specimen results. The hardness values for untreated, carburized, and carburized + shot peened specimens were found to be 284, 302, and 424 VHN, respectively. In this study, transverse observation of the specimen showed a carburizing layer with a depth of about 8 µm. The phenomenon was related to the increase in hardness of the carburized specimen, while the effect of shot peening for 20 minutes was about 100 µm from the surface of the specimen. This caused the hardness of the combined carburizing and shot peening specimen with a pressure of 8 bar for 20 minutes to increase hardness by about 49% compared to the non-treatment specimen. This combination significantly improved the surface hardness, potentially increasing the sprocket’s wear resistance and operational lifespan. Transverse analysis revealed an approximately 8 µm deeo carburized layer, with the shot peening effect penetrating about 100 µm from the surface. This treatment combination increased the specimen’s, suggesting a significant improvement in surface hardness, wear resistance, and overall durability of the sprocket.

Keywords:
Carburizing, shot peening, gear-sprocket, surface-hardness.

1 Introduction

Gear sprocket is an important component in various mechanical transmission systems, which play a crucial role in both the automotive industry and heavy machinery [1-2]. This component functions to transmit power from one part to another with high efficiency. The quality and durability of the gear sprocket greatly affect the total performance of the transmission system [3]. The performance and durability of the gear sprocket are highly dependent on the strength and surface hardness of the material used [4]. Moreover, the main problem that often occurs is wear and surface damage caused by friction and extreme operational conditions. This issue can cause a decrease in performance and shorten the life of the component [5].

Increasing the surface hardness of the gear sprocket is an important step to extend the service life and improve the performance of the components. A method used to increase surface hardness is carburizing. In addition, carburizing is the process of adding elemental carbon to the surface of steel material which aims to increase surface hardness [6-7]. This process includes heating the material in a carbon-rich environment, allowing the carbon to penetrate the steel surface and produce a hard layer capable of resisting wear [8].

Although carburizing increases surface hardness, the process is often accompanied by changes in the microstructure of the material. This phenomenon also affects general mechanical properties, and a common effect is a decrease in material strength. The strength can increase the risk of cracking or failure of the material when exposed to high dynamic loads or vibration. Therefore, finding a balance between increasing surface hardness and maintaining other mechanical properties is necessary. Following this discussion, gear sprockets have good properties in receiving loads in combination which cause wear resistance on the surface, but still have tough properties on the inside [9].

To improve the performance of the carburizing process, the shot peening method can be applied as an additional process. Shot peening is a method of impacting steel ball particles fired at high speed on the surface of the material [10]. Moreover, the method increases the hardness as well as fatigue resistance of the material through the formation of compressive residual stress on surface material [11] and also creates plastic deformation on surface material. This method can strengthen the surface and reduce the possibility of cracks or damage due to repeated loads. The main advantage of the shot peening method is the ability to improve mechanical properties. In addition, shot peening is also effective in extending the service life of components by minimizing the risk of material failure under severe operating conditions. Residual compressive stress enables the material surface to become more resistant to crack initiation which usually occurs under the influence of cyclic or repetitive loads [12-13].

The combination of the methods is expected to increase surface hardness without affecting other mechanical properties. As a result, gear sprockets that have been carburized and shot peened have better strength and higher fatigue resistance. These abilities can improve gear performance and service life under a wide range of operating conditions [14-15].

This study aims to determine the effect of carburizing and shot peening on the sprocket gear surface. Carburizing was conducted with 200 mesh coconut shell carbon powder media, followed by heating the specimen to a temperature of 850ºC by holding time for 60 minutes. The specimen was cooled at room temperature, and the advanced shot peening process was performed with a pressure of 8 bar and variations in duration of 10, 15, and 20 minutes. In this study, Vickers hardness testing (ASTM 92-17) was conducted on the surface and cross-section of the specimen. SEM observations were analyzed to determine the phenomenon of changes in the microstructure of the specimen by the highest hardness value. A recommendation was made that this study could add understanding into the effect of carburizing and shot peening on gear sprocket surface hardness.

2 Study Materials and Methods

2.1 Specimen

A gear sprocket was used as a specimen in this study, which was cut to a size of 20×20×5 mm. The Specimen surface was organized by preparing and smoothed by gradually using 400, 600, 800, 1000, and 2000-size sandpaper.

2.2 Chemical Composition

The chemical composition test of the specimen was conducted to discover the content of the elements that make up the specimen. Moreover, the composition test was conducted with a spectrometer in line with ASTM 415-08. The results of the chemical composition test were used to determine specimen material type.

2.3 Carburizing

Carburizing is the process of diffusing carbon atoms into the surface of metal at high temperatures. The specimen was buried in 200 mesh carbon powder and heated to 850ºC for 1 hour. Additionally, carbon atoms dissolved in the austenite phase and diffused with the specimen surface. After the carburizing process occurred, it was continued by cooling the specimen at room temperature. A schematic of this process is shown in Fig. 1.

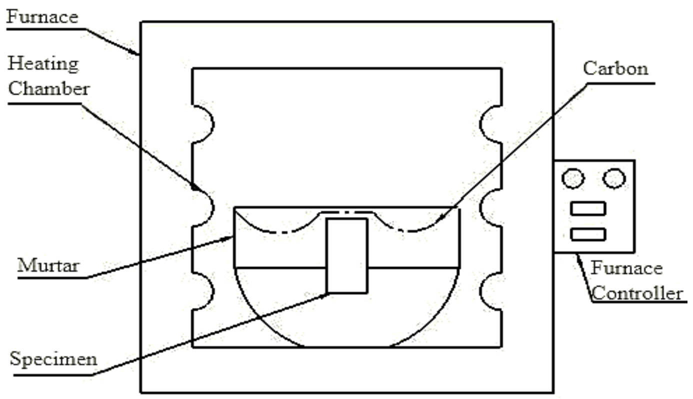

Fig. 1. Schematic diagram of the carburizing process.

2.4 Shot Peening

Shot peening was a method of surface treatment by shooting particles of steel balls on the surface of a specimen in a measured manner. The steel shot used was 0.5 mm in diameter and 40-50 HRC in hardness. In addition, shot peening parameters were performed at a distance of 100 mm for 20 minutes with a pressure variation of 8 bar. This method was conducted on specimens that were carburized. A schematic of the shot peening process is shown in Fig. 2.

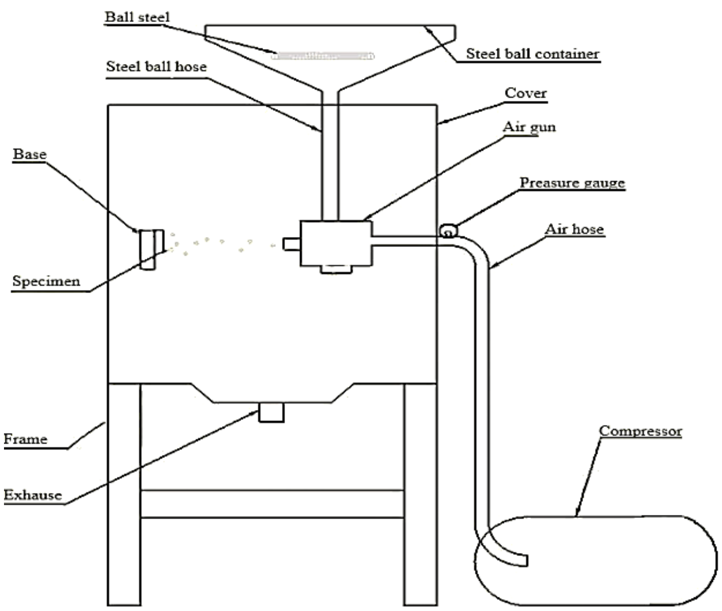

Fig. 2. Schematic diagram of shot peening process.

2.5 Hardness Tests

The hardness test was performed by a microhardness tester according to ASTM-92-17, where the indentation load was 0.098 N for 10 seconds. The indentation trace was measured in diagonal length to determine hardness measurement. Moreover, surface hardness tests were conducted on non-treated, carburized, and combined carburizing with shot peening specimens. Each hardness value was used to analyze the change in hardness between raw material and treated material. The transverse surface hardness test was also conducted on the combined carburizing and shot peening specimens having the highest surface hardness value. This examination was performed to determine the effect of shot peening on depth. The transverse hardness test was 25 µm apart which measured a distance of 200 µm from the specimen surface.

2.6 Microstructure Test

A cross-section of the specimen surface was used to observe the microstructure. The cross-section surface of the specimen before observing the microstructure was the etching process. In this study, a solution of 10 ml of Alcohol and 2 ml of HNO_3 served as an etching solution with an immersion duration of 3 seconds. Microstructure observations were conducted to determine phase changes and grain density of carburizing and shot peening specimens transversely.

3 Results and Discussion

3.1 Chemical Composition

A chemical composition test was an analysis that showed sprocket specimens contained existing compounds or elements. To identify the elements contained in gear-sprocket material, data was collected for the chemical composition test as shown in Table 1.

Table 1. Chemical composition of gear-sprocket

Elements	Specimen	
	Concentration (%)	Deviation standard (%)
C	0.115	0.0055
Si	0.114	0.0057
Mn	0.248	0.0048
P	0.068	0.014
S	0.050	0.0039
Cr	0.013	0.0021
Mo	<0.0100	0.0019
Ni	0.017	0.0020
Cu	0.010	0.0055
Al	0.0056	0.0002
Co	<0.0050	0.0018
Mg	<0.0050	0.00004
Nb	0.020	0.0030
Ti	<0.0030	0.0003
V	<0.0050	0.0006
W	<0.100	0.013
Fe	99.31	0.012

Based on the chemical composition test results in the Table, the gear-sprocket material was medium carbon steel [16]. This result showed that the material could be treated with carburizing.

3.2 Surface Hardness

Hardness testing was conducted on non-treatment, carburizing, combined carburizing, and shot peening specimen surfaces. Moreover, the surface hardness value of each specimen is shown in Fig. 3.

Fig. 3 shows the hardness value of each specimen, where the non-treatment gear-sprocket value was 285 kg/mm^2. Subsequently, hardness test results were used as a comparison reference for other specimens. The value of carburizing specimen was 302 kg/mm^2, representing a 6% increase in hardness compared to the non-treatment specimen. The increase in surface hardness in carburizing specimens occurred because carbon had a primary impact on the formation of hard properties in carbon steel materials. Moreover, activated carbon was a material in the form of amorphous carbon, which consisted mainly of free carbon and had good hardness as well as wear resistance. As the carbon content in the material became higher, the material became harder and more wear-resistant [17]. The amount of carbon diffused to the surface of carbon steel was highly dependent on the carbon content of the carburizing medium [18]. According to Fick's Law, carbon diffusion in a substrate material was a function of the diffusion coefficient and concentration gradient. The diffusion coefficient depended on the type of substrate material, specifically on the type of atoms. Typically, the concentration gradient showed the number of atoms or molecules present around the substrate compared to the number present in the substrate. Therefore, the number of carbon atoms in carburizing medium varied in the carburizing process [19].

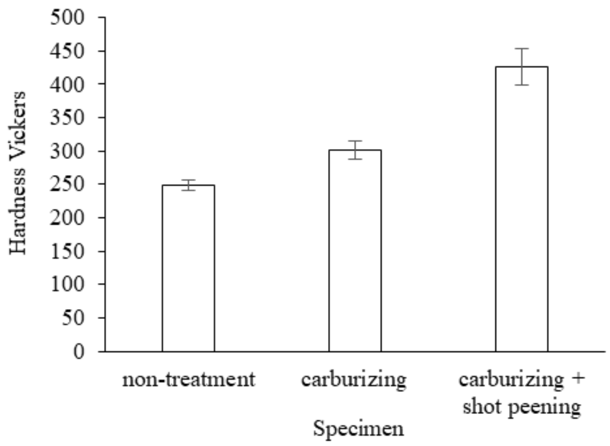

Fig. 3. Surface hardness graph of non-treated, carburized, combined carburizing, and shot peening gear-sprocket specimen.

The hardness of the specimen combined with carburizing and shot peening was 427 kg/mm^2. The hardenability value represented 49% increase in hardness compared to the non-treated specimen. This phenomenon occurred because when the steel ball particles hit the surface of the specimen, plastic deformation was created in the surface layer [20]. However, the process led to compressive residual stress on the metal surface [21]. This compressive residual stress improved hardness, wear resistance, and corrosion resistance [22]. The surface under the residual stress was more resistant to cracking and further deformation [23]. In this study, shot peening produced compressive residual stress on the specimen surface. The residual stress led to an improvement in the hardness, density, and interplanar distance of the crystal lattice [24]. The product also increased the ability of the specimen surface to resist plastic deformation [25]. Moreover, shot peening created repetitive plasticity on the metal surface, known as work hardening. When dislocations in the metal crystal increased due to this deformation, the crystal structure became more impenetrable [26]. Consequently, the process was responsible for the increase in surface hardness [27].

3.3 Cross-Section Surface Hardness

Cross-sectional hardness testing was performed to determine how deep the effect of carburizing and shot peening was on the surface of the specimen. Following this process, an examination was conducted on the hardness of the cross-section with a distance of 25 μm between each point, up to 200 μm from the surface of the specimen. The hardness value of the cross-section is shown in Fig. 4.

The hardness value was 301 HV at a distance of 25 μm from the surface and gradually decreased as the distance increased. Around 125 μm, the value was stabilized until about 150 μm, then it reduced again up to 200 μm. Moreover, at 125 μm, the effect of shot peening formed compressive residual stress, leading to higher hardness compared to non-treated specimens. Between 125 to 150 μm, a transition occurred or experienced a neutral condition, with hardness becoming similar to that of the non-treatment specimen. Meanwhile, from 150 to 200 μm, the hardness value decreased further due to the presence of tensile residual stress, with surface residual stress reaching equilibrium.

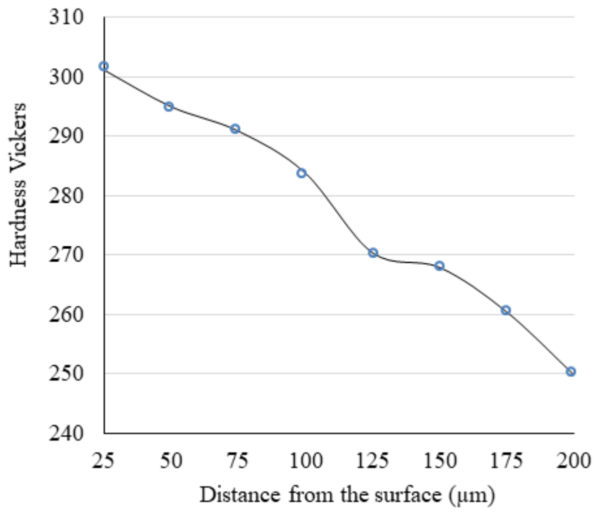

Fig. 4. Cross-section hardness of the combined carburizing and shot peening specimen surface.

While compressive residual stress generally enhances the hardness and fatigue resistance of materials, it is important to consider its uneven distribution. Uneven compressive residual stress can lead to localized stress concentrations, which may initiate cracks or failures under applied loads. This phenomenon occurs because, in areas where the compressive stress is higher than the surrounding regions, the material may be unable to accommodate additional tensile stress, resulting in an increased likelihood of structural weaknesses. For example, during processes like shot peening, if the peening intensity is inconsistent, it can create gradients in residual stress. Areas with excessive compressive residual stress may experience strain concentrations when subjected to external loading, leading to potential premature failure at those points. This contrasts with uniform compressive stress, which can distribute loads more evenly across the material, reducing the risk of stress concentration. Furthermore, during fatigue loading, these localized stress concentrations can become critical sites for crack initiation, exacerbating the effects of fatigue and leading to failure. Thus, while compressive residual stresses generally improve material properties, ensuring a uniform distribution is crucial to preventing detrimental stress concentration effects. Future studies could explore methods to achieve a more uniform residual stress distribution, enhancing the performance and reliability of treated materials.

3.4 Microstructure Observation

Carburizing was a heat treatment process used to improve the surface hardness of steel components through the diffusion of carbon into the surface layer of the material. Following the process, carbon was added to the surface to form a carbon-rich layer. This layer produced a hard surface layer while maintaining a ductile core. Microstructure observations were made on the cross-section of the combined carburizing and shot peening specimen as shown in Fig. 5.

The cross-section microstructure of the specimen that passed through the carburizing process showed variations in microstructure from surface to core. Carburizing produced a thin layer on the surface of the specimen. In the study, a transition zone was formed, located between the carburized surface layer and the substrate [28]. The carbon content also decreased gradually from the layer towards the medium. Fig. 5 shows the delamination layer between the carbon and the substrate because of the difference in expansion coefficient between these two areas. Moreover, the stress could cause separation of the coating from the substrate [29]. The formed layer did not have a good bond with the medium, causing gaps or voids. Impurities or oxides on the surface of the substrate before carburization also delayed the formation of a good bond between the areas which caused delamination [30].

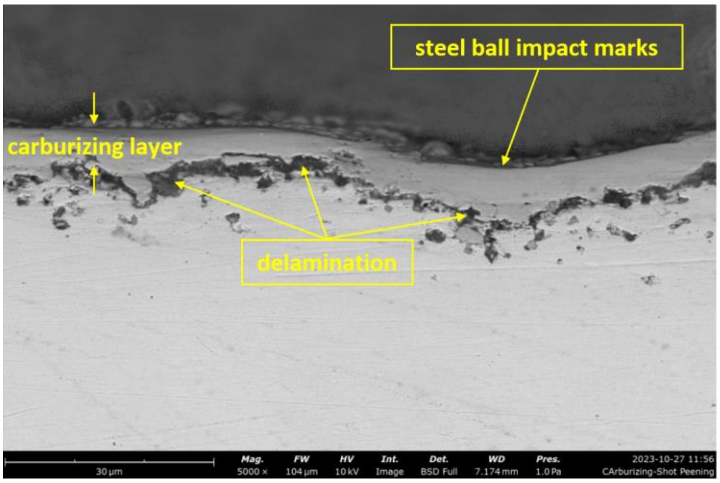

Fig. 5. Cross-section microstructure of combined carburizing and shot peening specimen.

The surface layer had traces of steel ball impact during the shot peening process. This impact caused an increase in the density of the microstructure on the surface of the specimen. Following this discussion, shot peening caused grain refinement in the surface layer, as smaller grains produced harder and stronger materials [31]. This occurred due to the formation of more grain boundaries which acted as barriers to dislocation movement. In addition, the phenomenon was associated with an increase in the surface hardness value of the combined carburizing and shot peening specimen.

4 Conclusion

In conclusion, combined carburizing and shot peening was an effective method to increase the surface hardness of materials, particularly in gear sprocket components. Carburizing improved the surface layer with carbon elements and produced a hard microstructure. Moreover, shot peening strengthened the surface layer by creating compressive residual stress and increasing hardness. This method also improved resistance to cracking and fatigue and extended the service life of the gear sprocket. In this study, the hardness value of the combined carburizing and shot peening specimen increased by 49% compared to the non-treated specimen.

The combination of the two methods resulted in an extremely hard and wear-resistant surface, thereby improving resistance to fatigue and cracking. This process was perfect for applications where components need to endure high mechanical loads and tough operating environments, such as in gear sprocket components.

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