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RESEARCH PAPER

EFFECTS OF HEAT TREATMENT ON THE IMPROVED WEAR RESISTANCE OF SHOT BLAST MACHINE BLADE MATERIAL

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ABSTRACT

The blade is a component of the shot blast machine that functions as a thrower of small steel balls (steel shot). During its use, the blade undergoes impacts and friction with the steel shot, causing wear and a shortened lifespan. The material typically used for blades is white cast iron. Hence, the blade must possess good hardness and wear resistance. This study analyzed the causes of blade failure and proposed solutions in the form of hardening and tempering treatments. The tests conducted in this research included composition analysis, metallographic examination, hardness testing, and wear resistance testing. Based on the composition and hardness tests, the failure was attributed to material composition and hardness not meeting the ASTM A532 standards. The solution to this failure involves heat treatment to achieve hardness that complies with ASTM A532 standards, specifically hardening at 900°C for 40 minutes, followed by cooling with oil as the quenching medium. Then, the tempering process was carried out at 200°C, 250°C, and 300°C with holding times of 80 and 120 minutes. Post-heat treatment, the optimal hardness value, and the lowest wear rate were obtained at a tempering temperature of 300°C with a holding time of 120 minutes. The hardness value of the blade material under these conditions reached 63.8 HRC, and the wear rate was 1,21E-04 $mm^3.kg^{-1}.m^{-1}$. A low wear rate indicates that the material has high wear resistance.

Keywords: blade; hardening; tempering; hardness; wear resistance

INTRODUCTION

The metal casting industry is one of the industrial sectors that is essential for the progress of technology and the economy in Indonesia. This industry is a major supplier of raw materials and necessary parts for multiple industries such as manufacturing, construction, heavy machinery, and automotive [1]. Metal casting involves melting metal and pouring it into molds to create various products and components with complex shapes and sizes [2]. In carrying out the production process, the metal casting industry uses advanced equipment to ensure quality and efficiency. One crucial machine in this industry is the shot-blasting machine. The shot blasting machine is used to clean the surface of metal materials by continuously shooting small metal balls (steel shot) at high speed toward the material surface. This process not only cleans but also strengthens and prepares the metal surface for further processes such as coating or painting.

One important factor in the successful operation of the shot blasting machine is the wear resistance of the blade components used as steel shot throwers. The steel shot will be thrown and experience friction with the surface of the blades. The quality of the blade is crucial because if wear or early failure occurs, the shot blasting machine must be stopped for blade repair or replacement. This can lead to reduced production capacity and cause very high operational costs [3]. The blades on shot blasting machines are typically made of white cast iron [4,5]. These blades are attached to an impeller that rotates at very high speeds. The rotating impeller generates a strong blast of air, providing pressure to propel the small metal balls it releases [6]. Due to the potential impact and friction on the blade surface during use, blades must be designed with optimal hardness and wear resistance properties to ensure a longer time [7,8]. Material properties in blades can be enhanced by adjusting various processing parameters through heat treatment procedures [9,10]. Two crucial processes in heat treatment are hardening and tempering. Hardening involves heating the metal to a specific temperature, and then rapidly cooling it (quenching) to increase the material's hardness. Subsequently, tempering is carried out, which entails reheating the metal to a lower temperature and slowly cooling it to reduce the brittleness caused by quenching, achieving a balance between hardness and toughness [11].

Many studies have been conducted on the topic of the effect of heat treatment on the mechanical properties of white cast iron. For example, research by Purba et al. [12], Barutcuoglu et al. [13], and Sarac et al. [14]. Shows that the heat treatment process is an appropriate way to change the mechanical properties, the hardening process can increase the surface hardness of white cast iron, while proper tempering can reduce the risk of cracking due to brittleness. However, each metal casting industry in Indonesia has its standards for material composition and heat treatment processes on blade materials, leading to frequent failures or short lifespans of blades. Therefore, the purpose of this research is to investigate the impact of heat treatment, specifically hardening and tempering, on the material of shot blasting gun blades to enhance their wear resistance. After undergoing heat treatment, the results of the hardening and tempering processes from this study can serve as a solution to blade material failures in shot blasting applications.

MATERIAL AND METHODS

Material

The material used in this study's shot blasting blade component is white cast iron with the chemical composition content shown in **Table 1**.

Specimen Preparation

The preparation stage is necessary before carrying out tests to determine the cause of damage or wear on the shot-blasting blade material. This preparation process involves cutting the material using a micro-cutting machine to create specimens with dimensions of 23 mm x 19 mm x 9 mm.

Macroscopic Observation

Macroscopic observations were carried out to determine the appearance, location, and shape of failed shot-blasting blade components from a macro perspective using a digital camera. This type of observation is typically performed to obtain a general overview before conducting more in-depth analyses through other methods such as microstructural examination or chemical analysis.

Chemical Composition Testing

Chemical composition testing aims to determine the chemical composition of components that failed. Identification of the chemical composition of the shot blasting blade material using the Thermo ARL 3560 Optical Emission Spectroscopy (OES) tool with the Conc-Fe program. Abrasive wear is caused by the removal of material from the surface of an object by another, harder material. There are two types of wear and tear, namely Two Body Abrasion. This wear is caused by loss of material due to the rubbing process by another material that is harder than the other material. So that the soft material will be abraded, and Three Body Abrasion Wear is caused by the galling process so that the fragments resulting from friction that are formed (debris) harden and play a role in the loss of material due to the friction process which occurs repeatedly. So the meaning of "three objects" here is two materials that rub against each other and an object that is the result of friction.

Table 1 Chemical composition of shot blasting blade material

Element content, % *by weight*							
C	Mn	Si	Ni	Cr	P	Mo	Fe
2.43	1.18	0.85	0.11	3.63	0.02	0.05	91.52

Microstructure Observation

The microstructure observation was conducted to identify the microstructure of the test material that experienced failure and to compare the differences in microstructure before and after heat treatment. Before microstructure analysis, the surface of the test material underwent a sanding process, which involved using multi-grit sandpaper (240 to 1000 grit) and 5% Nital (HNO_3 + Alcohol) polishing solution for 2-5 seconds. Subsequently, the specimen was observed using an optical microscope at 100x lens magnification to determine the microstructure of the samples.

Hardness Testing

The hardness testing was conducted to ascertain the hardness distribution by performing indentations at three test points on the material sample. The instrument utilized was a Digital Rockwell Hardness Tester, type MHRS-45A. This hardness test was carried out on the Rockwell C hardness scale, with a diamond cone-shaped indenter and a main load of 150 kgf. Before testing, the sample must have a flat surface to prevent indentation defects.

Wear Testing

Wear testing is carried out to determine the test specimen's wear resistance level. This test was carried out using a universal wear tool (Riken Ogoshi's, Tokyo, Japan) for 30 m with a load of 6.36 kg.

Heat treatment

The heat treatment performed to increase the hardness of the shot blasting blade material was hardening at 900°C and continuing with quenching using oil cooling media. After that, the specimens were tempered at 200°C, 250°C, and 300°C with a holding time of 80 minutes and 120 minutes, respectively, and continued with normal air cooling. The heat treatment diagram can be seen in **Figure** 1.

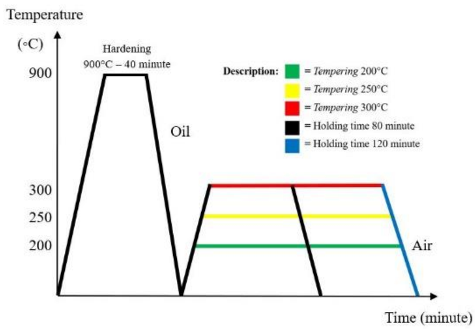


Fig. 1 Heat treatment process

RESULTS AND DISCUSSION

Chemical Composition Test Results

Based on the results of the chemical composition testing, it was found that the failed blade shot blasting material is white cast iron, with its composition detailed in **Table 1**. The material that should be used as the standard for blade shot blasting components is white cast iron as specified in ASTM A532 [15]. The discrepancy in material composition led to the failure (wear) of the material. The results of the chemical composition test indicate that the blade shot blasting material does not conform to the ASTM A532 standards for classes IA, IB, IC, ID, IIA, IIB, IID, and IIIA. However, in terms of chromium content and carbon content, the blade shot blasting material is closer to class IB. The chromium content in the blade shot blasting material is 3.7%, while the standard range is 1-4%. Judging from the carbon content, the blade shot blasting material has 2.4%, which aligns with the ASTM A532 standard of 2.4-3.0% max. Judging from the nickel content, the shot blasting blade material has a nickel content of 0.11%, lower than the standard nickel in ASTM A532 of 3.3-5.0% max.

This difference in composition is one of the factors contributing to the lower hardness and strength of the blade shot blasting material compared to the standard material. Adding nickel can enhance wear resistance and toughness in steel [16]. Nickel is added to form an austenitic microstructure, as it is an excellent austenite stabilizer [17]. The standard composition for blades should have a minimum nickel content of 3.3%. Therefore, this study was conducted to improve the hardness of the blade shot blasting material to meet the established standards. The types of treatments applied to the blade shot blasting material are shown in **Table 2**.

Table 2 Specimen code and type of treatment on shot blasting blade material

Specimen code	Heat Treatment Type
Failure	Hardening 830 ° C - Tempering 320° C holding time 180 minute
AC	As-Casting
AQ	Hardening 900° C holding time 80 minute
A1	Hardening - Tempering 200° C holding time 80 minute
A2	Hardening - Tempering 200° C holding time 120 minute
B1	Hardening - Tempering 250° C holding time 80 minute
B2	Hardening - Tempering 250° C holding time 120 minute
C1	Hardening - Tempering 300° C holding time 80 minute
C2	Hardening - Tempering 300° C holding time 120 minute

Results of Macroscopic Observations

The material blade shot blasting is examined macroscopically using a camera to identify failures. Failure occurs in the blade component in the form of wear on the surface, where there is direct contact between the blade and the steel shot. **Figure 2** shows the location of the failure that occurs on the shot blasting blade, the circled part is the part that is experiencing wear, and there is a reduction in thickness until there is a part that is eroded out. Additionally, there are scratches aligned with the direction of the falling load on the surface of the thinned material. Both phenomena indicate that the material of the blade shot blasting undergoes abrasive wear during its use. If small, hard, sharp particles such as dust or hard particles from certain machining processes abrasion the surface of another material, and observations on the abraded surface reveal scratches, it signifies an indication of abrasive wear [18,19].

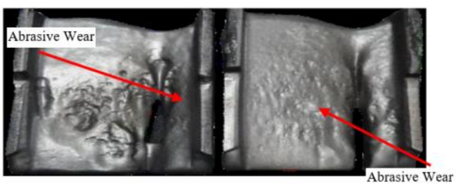


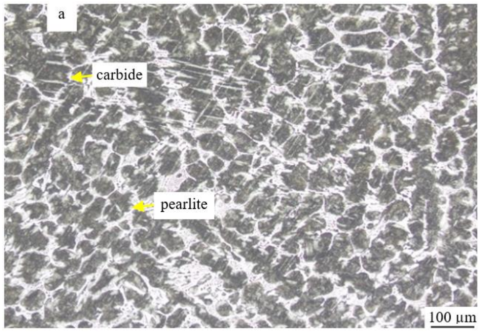
Fig. 2 Macroscopic photograph of failed shot blasting blade material

Microstructure Observation Result

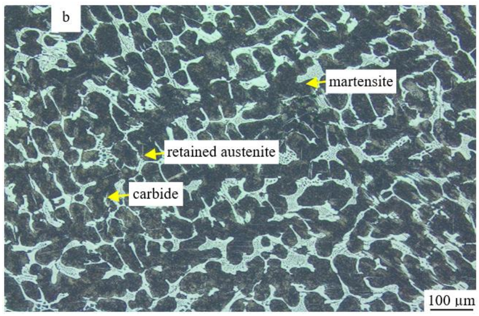
The microstructure of both the as-cast blade material and the failed material was examined using an optical microscope. The results can be seen in **Fig. 3**, with image (a) showing the microstructure of the as-cast blade material and image (b) showing the microstructure of the failed blade material. The microstructure of the as-cast blade material reveals the presence of perlite and carbides, while the microstructure of the failed blade material consists of martensite, carbides Cr_7C_3, and retained austenite.

Table 3. Comparison Traetment material

Before	After
High Abrasive	Low abrasive
Light and Microstructure is coarse	Dark and smooth microstructure



(a) As-cast blade component



(b) Failed blade component

Fig. 3 Microstructure of (a) as-cast blade component (b) failed blade component.

After the blade shot blasting material undergoes heat treatment, microstructure testing is performed again. This testing is carried out to determine the final structure formed on the blade shot blasting material after heat treatment. The microstructure in the as-quenched condition can be seen in **Fig. 4**. In this figure, it can be observed that the microstructure of the blade shot blasting material in the as-quenched condition consists of austenite, Cr_7C_3 carbides, and martensite [20]. Martensite is formed due to the rapid non-equilibrium cooling process at the austenitizing temperature [21]. Rapid cooling does not always produce martensite, but can also produce retained austenite, namely austenite that does not change to martensite during rapid cooling [22,23]. One factor contributing to the formation of retained austenite is the quenching process that does not reach the martensite finish on the Continuous Cooling Temperature (CCT) diagram. This can occur due to the low martensite finish temperature influenced by alloying elements.

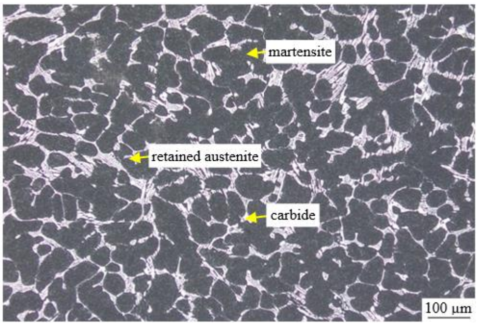


Fig. 4 Microstructure of as-quenched blade material.

Fig. 5 shows the microstructure in various as-tempered conditions. This picture demonstrates that in the tempered condition, the blade shot blasting material has austenite, martensite, and Cr_7C_3 carbide phases.

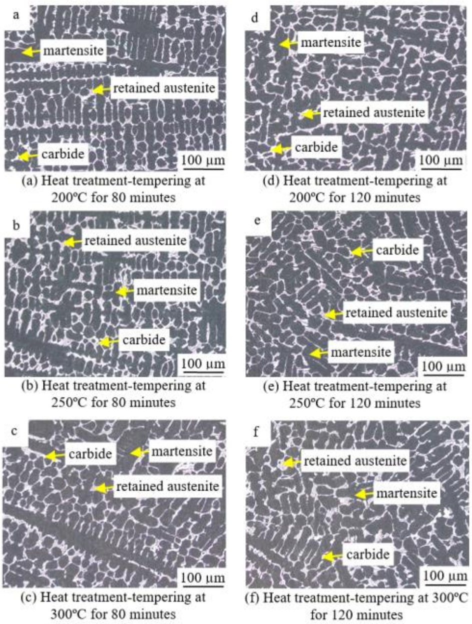


Fig. 5 Microstructure of shot blasting blade material at various as-tempered conditions.

Hardness Testing results

Hardness testing is conducted on each surface of the specimens in both the as-quenched and as-tempered states. Indentation points are made on the blade shot blasting material with dimensions of 23 mm x 19 mm x 9 mm at three indentation points. The hardness testing results for each specimen are displayed in **Table 3**.
After subjecting the blade shot blasting material to hardening treatment at 900˚C, followed by cooling with an oil cooling medium and subsequent tempering at various temperatures and holding times, differences in the hardness values of the material between the as-quenched and as-cast conditions were observed. In the as-quenched state, the hardness of the blade shot blasting material increased to 66.7 HRC, a value higher than the hardness of the as-cast blade material, which only reached 45.1 HRC.

Table 3 Hardness testing results of test specimens

Specimen code	Point 1	Point 2	Point 3	Average Hardness (HRC)
Failure	51.5	53.5	53.6	52.9
AC	44.0	45.1	46.2	45.1
AQ	67.2	66.2	66.7	66.7
A1	65.2	65.3	65.4	65.3
A2	65.2	64.9	65.0	65.0
B1	64.7	64.2	64.5	64.5
B2	64.0	64.4	64.5	64.3
C1	63.8	63.4	63.9	63.7
C2	63.2	64.2	63.9	63.8

This increase is partially due to the formation of martensite structure during rapid cooling, trapping carbon in the martensite phase and increasing the stress within the grains, resulting in hard and brittle properties. The formation of martensite is not determined by its growth time but is observed by the temperature drop. However, in the transformation process, some of the austenite that is not transformed into martensite is known as retained austenite. To understand the occurrence of martensite transformation, one can refer to the continuous cooling transformation diagram of the tested material. When the cooling rate reaches the point of full martensite formation, a complete martensite phase will be formed. However, if the cooling rate only reaches the martensite start line without reaching the martensite finish line, retained austenite will appear in its microstructure. The hardness of martensite is also influenced by the carbon content present in the material. The higher the carbon content, the higher the hardness of the martensite [24]. The increase in hardness is also attributed to the presence of chromium carbide structures. During the austenitisation process, chromium in the matrix reacts with carbon to form Cr_7C_3 carbide compounds.

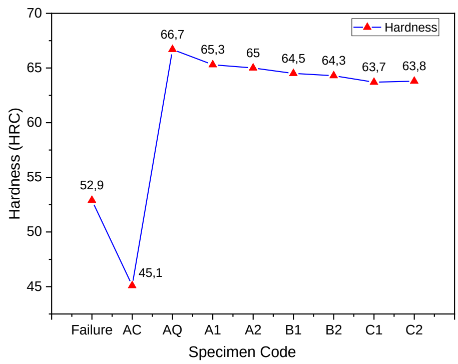


Fig. 6 Hardness value of shot blasting blade material after heat treatment

The material's hardness decreases after being subjected to heat treatment in the form of tempering at 200°C, resulting in hardness levels of 65.3 HRC and 65 HRC for holding times of 80 minutes and 120 minutes, respectively. These hardness values decrease compared to the as-quenched condition. Tempering is applied to restore toughness and reduce residual stress caused by the quenching process [25,26]. At a tempering temperature of 250°C with holding times of 80 minutes and 120 minutes, the material's hardness decreases to 64.5 HRC and 64.3 HRC, respectively, with no significant changes in the microstructure compared to tempering at 200°C. Subsequently, at a tempering temperature of 300°C, the hardness decreases again to 63.7 HRC for an 80-minute holding time. However, there is a slight increase in blade material hardness at a tempering temperature of 300°C with a 120-minute holding time, reaching 63.8 HRC, but still below the hardness values at 200°C and 250°C. This is due to the formation of secondary carbides during tempering at that temperature. A high concentration of carbide-forming elements will provide secondary hardness to the steel during the tempering process, leading to increased hardness at specific tempering temperatures [24]. **Fig. 6** displays a graph depicting the contrast in hardness levels of the blade shot blasting material following heat treatment for a clearer understanding.

Wear Test results

The wear rate test was conducted using a friction and wear testing machine to determine the ability of the blade shot blasting specimen to withstand impact and friction loads. The wear test involved rubbing the specimen using a 3 mm thick revolving disk with 13 mm fingers under a load of 6.36 kgf. The amount of wear was assessed based on the volume lost when subjected to a 6.36 kgf load over a distance of 30 m. The results of the wear rate test can be observed in **Table 4**.

Table 4 Wear test results of test specimens

Specimen code	Wear Length (b) (mm)	Specific Wear (Ws) ($mm^3.kg^{-1}.m^{-1}$)
AC	1,07E+00	1,83E-04
AQ	7,94E-01	7,57E-05
A1	9,66E-01	1,36E-04
A2	9,74E-01	1,40E-04
B1	9,42E-01	1,26E-04
B2	9,82E-01	1,43E-04
C1	9,66E-01	1,36E-04
C2	9,29E-01	1,21E-04

The wear resistance of the blade shot blasting material in this study is represented by the wear volume in units of $mm^3.kg^{-1}.m^{-1}$. The highest wear rate was observed in the as-cast condition, measured at 1.83E-04 $mm^3.kg^{-1}.m^{-1}$, whereas the lowest wear rate was noted in the as-quenched condition, at 7.57E-05 $mm^3.kg^{-1}.m^{-1}$. In the as-quenched condition, there was a significant increase in the wear resistance of the test specimen. This is attributed to the formation of martensite structure during rapid cooling, enhancing the strength and surface hardness of the material.
Following quenching, tempering was carried out on the test specimen at various tempering temperatures and holding times.
The wear rate of the test specimen at a tempering temperature of 200°C increased again with holding times of 80 minutes and 120 minutes, measuring 1.36E-04 $mm^3.kg^{-1}.m^{-1}$ and 1.40E-04 $mm^3.kg^{-1}.m^{-1}$, respectively. At a tempering temperature of 250°C with an 80-minute holding time, the wear rate decreased to 1.26E-04 $mm^3.kg^{-1}.m^{-1}$. Meanwhile, at a tempering temperature of 250°C with a 120-minute holding time, the wear rate increased to 1.43E-04 $mm^3.kg^{-1}.m^{-1}$. For a tempering temperature of 300ºC, the wear rate again decreased successively at holding times of 80 minutes and 120 minutes to 1.36E-04 $mm^3.kg^{-1}.m^{-1}$ and 1.21E-04 $mm^3.kg^{-1}.m^{-1}$.
The fluctuation of the wear rate value after tempering with various variations in temperature and holding time is not much different. This is due to the carbon element (C) transforming as the material is heated with increasing tempering temperature and duration. Carbon (C) is also a non-metallic element, so it adapts very quickly to material conditions and circumstances (flexible). The wear rate graph is shown in **Fig. 7** to more clearly see the wear test results data.

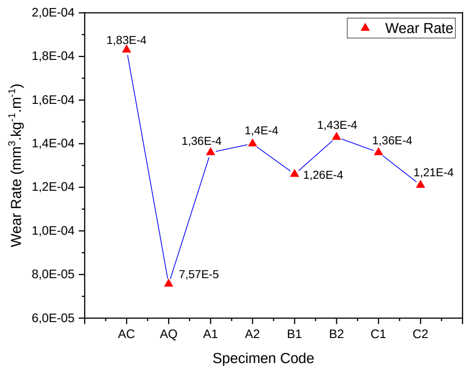


Fig. 7 Wear value of shot blasting blade material after heat treatment

CONCLUSION

Research on improving wear resistance in shot blast machine blade materials can be carried out well.
Post-heat treatment, the optimal hardness value and the lowest wear rate were obtained at a tempering temperature of 300°C with a holding time of 120 minutes. Under these conditions, the blade material's hardness value reached 63.8 HRC, and the wear rate was 1,21E-04 mm3.kg-1.m-1. A low wear rate indicates that the material has high wear resistance.
This heat treatment can be considered one answer to overcoming failures in shot-blasting blade materials.

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