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Characteristics of Hardness and Microstructure of Recycled Pistons Manufactured by Sand Casting Process

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ABSTRACT

Motorcycle piston waste, made from aluminum, is often poorly managed despite its advantages in corrosion resistance and thermal conductivity. This study aims to enhance the economic value of piston waste through recycling using the sand casting method. The melting process was conducted at a temperature of 843°C, followed by casting into sand molds. The recycled product is intended for use as a ship propeller component. Tests performed included Vickers hardness testing and microstructural analysis to evaluate the mechanical properties and material characteristics. The results showed that the recycled material exhibited an average hardness of 77.2 kg/mm², consistent with standard aluminum hardness. Microstructural analysis revealed the presence of porosity which may affect mechanical strength; however, this porosity did not reduce the material's resistance to mechanical damage and provided good toughness. Based on these findings, it can be concluded that motorcycle piston waste recycled by sand casting at 843 °C has potential for use in manufacturing high-value components such as ship propellers, considering the hardness quality and microstructural characteristics of the material.

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INTRODUCTION

The global automotive industry, particularly in developing countries such as Indonesia, has experienced rapid growth over the past decades. Along with the increasing number of motor vehicles, especially motorcycles, the volume of produced components and consequently their waste has also risen. One of the most abundantly produced components is the motorcycle piston. The motorcycle piston is a critical part of the internal combustion engine system, functioning by converting thermal energy into mechanical energy. Therefore, the quality and strength of the piston significantly influence the vehicle's engine performance. Typically, motorcycle pistons are made from aluminum alloys that possess lightweight characteristics, corrosion resistance, and good thermal conductivity (Sukahar et al., 2024).

However, over time, as many vehicles reach their end of service life, component waste such as pistons is often suboptimally managed, contributing to the increasing burden of metal waste in the environment.

Waste from pistons, which are predominantly made from aluminum materials, has potential for recycling and reutilization as high-value materials. Metal recycling, particularly aluminum, has been proven to offer numerous benefits, including reducing the demand for raw materials, saving energy, and minimizing environmental impacts. Metal recycling represents one of the best solutions to address the growing problem of metal waste (Shi et al., 2022). One widely used method in metal recycling processes is sand casting. This process involves melting the metal to a sufficiently high temperature, followed by pouring the molten metal into sand molds to form new components.

Sand casting is recognized as one of the most commonly employed casting methods in manufacturing industries, especially for metals with high melting points such as aluminum. It is a relatively inexpensive, flexible method capable of producing metal components in various shapes and sizes, ranging from small to large parts (Andrijono & Sufiyanto, 2018). This process also allows the reuse of recycled materials, making it more environmentally friendly. Additionally, the method enables the fabrication of components with complex geometries, making it ideal for diverse industrial applications, including automotive and marine industries.

Previous studies have indicated that metal waste, especially aluminum-based waste, holds significant potential for recycling through sand casting. Motorcycle piston waste that has been melted and re-cast using sand casting can produce components with satisfactory mechanical properties, although some defects such as porosity may occur, which can affect material strength (Nugroho et al., 2022). Despite the influence of porosity on material strength, sand casting remains an efficient and economical choice, particularly for mass production of metal components. Therefore, this study aims to further explore the potential of recycled motorcycle piston waste via sand casting to produce components with high commercial value, such as ship propellers (Priyambodo, 2024).

The application of ship propellers as a product of recycled motorcycle piston waste is based on the aluminum material properties lightweight, corrosion resistance, and durability in harsh marine environments. Ship propellers require materials that not only possess high mechanical strength but also exhibit resistance to corrosion caused by highly corrosive seawater exposure. Hence, aluminum is considered an ideal choice for this application (Samudro, 2024). This study aims to utilize aluminum-based motorcycle piston waste as raw material for manufacturing ship propellers, which is expected to enhance the economic value of the waste.

The recycling process of piston waste via sand casting involves melting the piston waste at temperatures up to 843°C. This temperature is sufficiently high to melt aluminum and its alloying elements, which are then cast into sand molds to form new components. A crucial step in this research is testing the mechanical properties of the recycled material, especially hardness and microstructure. Hardness testing is performed using the Vickers method, which provides information on the material's resistance to indentation, while microstructural analysis aims to examine element distribution within the material and detect defects such as porosity that may affect material quality (Partono et al., 2024).

Although metal recycling, especially aluminum, offers many benefits, several challenges remain, particularly in quality control of the recycled material. Porosity is a common issue encountered in the sand-casting process. It can lead to reduced mechanical strength and lower the component's resistance to stress and wear. Some previous studies have shown that while sand casting can produce components with adequate mechanical strength, porosity remains a concern that requires attention (Samuel et al., 2021). However, this study expects that with proper process control, recycled piston waste can meet the required quality standards for applications such as ship propellers.

The primary objective of this research is to increase the economic value of motorcycle piston waste through recycling using the sand-casting method, by testing and analyzing the mechanical properties and microstructure of the recycled material. This study is anticipated to contribute to metal waste management, particularly motorcycle piston waste, and provide an environmentally friendly alternative solution to mitigate the environmental impact of metal waste. Furthermore, it aims to provide evidence that recycled motorcycle piston waste can be utilized to produce high-value components such as ship propellers, applicable in marine and manufacturing industries.

Overall, this research holds potential to open new opportunities in metal waste utilization, yielding environmental as well as economic benefits. By applying sand casting in piston waste recycling, this study seeks to enrich the literature on metal recycling processes and deliver practical insights for industries aiming to reduce waste and improve production efficiency.

METHODOLOGY

This study aims to evaluate the potential of aluminum alloy motorcycle piston waste to be recycled into high-value components, such as ship propellers, through the sand-casting recycling process. The detailed methodology employed in this research is described below.

Materials

The primary material used in this study is motorcycle piston waste made from aluminum alloy. The piston waste utilized in this research was obtained from workshops or motor vehicle manufacturing sites where the pistons are no longer in use. Prior to the recycling process, the piston waste was cleaned thoroughly to remove dirt and oil residues on the surface to ensure optimal melting.

Recycling Process by Sand Casting

The recycling process of motorcycle piston waste was conducted using the sand-casting method. At this stage, the cleaned piston waste was placed into a melting furnace, and the heating process was carried out until reaching a temperature of 843°C, which corresponds to the onset of metal melting. This step is crucial to ensure that the entire aluminum alloy melts homogeneously before being poured into the sand mold. Once molten, the liquid metal was carefully poured into the pre-prepared sand mold. The casting process was performed cautiously to ensure even distribution of the molten metal within the mold and to minimize defects.

Casting and Cooling

After the molten aluminum alloy was poured into the sand mold, the casting was allowed to cool and solidify naturally at room temperature. The cooling phase is critical as it influences the microstructure and mechanical properties of the final component. Controlled cooling helps to minimize internal stresses and reduce the occurrence of casting defects such as cracks and porosity.

Chemical Composition Testing

To analyze the chemical composition of the recycled material, spectrometry was employed. This method is used to identify and quantify the concentration of elements such as silicon (Si), copper (Cu), iron (Fe), manganese (Mn), and magnesium (Mg), which are commonly found in aluminum alloys. The results of the chemical composition analysis aim to characterize the recycled material and ensure the consistency and suitability of the components for intended applications, such as ship propeller manufacturing.

Vickers Hardness Test

The hardness test was conducted using the Vickers method in accordance with ASTM E92 standards. A load of 10 grams was applied to the recycled metal specimen. This test aims to measure the material's resistance to indentation and to provide a representative hardness value. Multiple indentation points were tested on the material surface to obtain accurate and reliable results.

Microstructure Observation

Specimens that had been sectioned and polished with abrasive materials were observed under an optical microscope. Microstructural analysis was conducted to assess the distribution of metal grains and to detect the presence of porosity or other defects within the material. A good microstructure is essential to ensure that the produced components possess adequate strength for applications such as ship propellers.

Data obtained from chemical composition tests, hardness tests, and microstructure observations were statistically analyzed to evaluate the effect of the recycling process on the quality of the resulting material.

RESULTS AND DISCUSSION

Chemical Composition Test Results

Chemical composition testing was conducted to determine the concentration of important elements in the recycled material. The chemical composition test data are presented in Table 1.

Table 1. Chemical Composition Test Results of Recycled Piston Elements

No.	Material Composition	Testing (%)			Average Content (%)
		I	II	III	
1	Si	12.34	12.31	12.61	12.42
2	Fe	0.450	0.405	0.423	0.426
3	Cu	1.410	1.412	1.519	1.447
4	Mn	0.177	0.175	0.177	0.176
5	Mg	0.990	1.029	0.967	0.995
6	Cr	0.030	0.028	0.029	0.029
7	Ni	0.826	0.810	0.819	0.818
8	Zn	0.117	0.113	0.108	0.113
9	Ti	0.036	0.035	0.038	0.036
10	Pb	<0.0040	<0.0040	<0.0040	<0.0040
11	Sn	<0.0100	<0.0100	<0.0100	<0.0100
12	V	0.11	0.11	0.12	0.011
13	Sr	<0.0030	<0.0030	<0.0030	<0.0030
14	Zr	0.011	0.011	0.012	0.011
15	Co	0.0088	0.0080	00076	0.0082
16	Ca	0.0030	0.0027	0.0034	0.0030
17	Al	83.58	83.64	83.27	83.49

The test data in Table 1 show that the three predominant elements in the recycled motorcycle piston waste material are Aluminum (Al), Silicon (Si), and Copper (Cu), with respective percentages of 83.49%, 12.42%, and 1.447%. This composition indicates that the motorcycle piston waste contains the primary elements commonly found in aluminum alloys, making it highly suitable for applications requiring durability and favorable mechanical properties, such as ship propeller manufacturing (Permata et al., 2024; Kim & Kim, 2024; Louis & Louis, 2020).

Vickers Hardness Test Results

The hardness test on the recycled material was conducted using the Vickers method in accordance with ASTM E92 standards, applying a load of 10 grams. The Vickers hardness test at several points on the material surface yielded an average hardness value of 77.2 kg/mm². This value falls within the expected hardness range for aluminum materials, indicating that the recycling process via sand casting produces material with adequate resistance to indentation (Mat Nasir, 2008; Akhyar et al., 2023; Endramawan et al., 2020).

The hardness values obtained indicate that the recycled material can be used for applications requiring standard hardness in aluminum metals, such as in the manufacturing of ship propeller components. However, slight variations were observed at different test points, which are attributed to the heterogeneous distribution of alloying elements within the material (Parameswaran et al., 2018; Tang et al., 2004). The Vickers hardness values of the recycled piston surface are presented in Table 2.

Table 2. Vickers Hardness of the Recycled Piston Surface

Point no.	D1(µm)	D2(µm)	HV(kg/mm²)
1	14.75	15.94	79.1
2	14.32	14.38	84.6
3	16.94	14.88	73.6
4	15.94	16.58	70.8
5	15.69	15.52	77.9
	Hardness average		77.2

Microstructural Analysis Results

Microstructural analysis was conducted to evaluate the grain distribution and presence of porosity in the recycled material. Microscopic observations revealed that the microstructure of the recycled material is dominated by uniformly distributed aluminum alloy grains, although several small porosity sites were detected along the metal grains.

The presence of porosity, although not immediately causing mechanical failure, must be addressed seriously. Porosity can significantly impact the mechanical integrity of the material and may compromise its competitiveness compared to alternative raw materials. Quality degradation caused by porosity can typically be mitigated through further processing or tighter control during the casting process. Overall, the microstructure of the recycled material exhibits characteristics that meet the requirements for practical applications such as ship propeller components. The microstructure observation at 100× magnification on the surface of the recycled piston is presented in Figure 1.

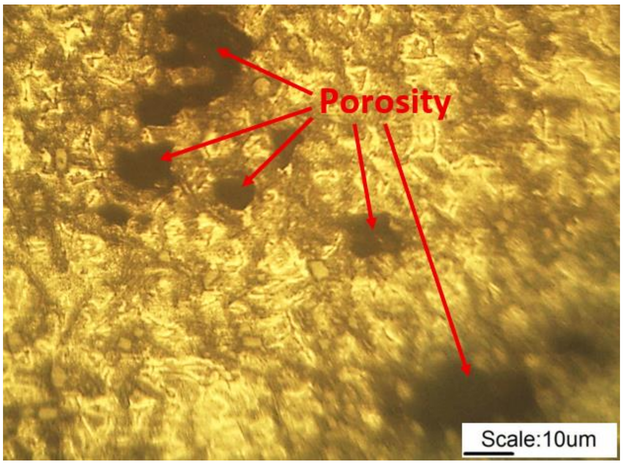

Figure 1. Surface microstructure of the recycled piston

Discussion

The results obtained from hardness testing, microstructural analysis, and chemical composition testing indicate that recycled motorcycle piston waste processed via sand casting yields a material that meets the desired standards for both hardness and chemical composition. Although microstructural analysis revealed the presence of porosity, this does not significantly diminish the potential of the material for use in mechanical components such as marine propellers.

In terms of hardness testing, the recycled material exhibited adequate resistance to penetration, with an average hardness value of 77.2 kg/mm². This result suggests that the recycled metal possesses characteristics comparable to those of conventional aluminum materials commonly used in the manufacture of mechanical components (Hsu et al., 2008). The measured hardness also indicates that the recycled material has sufficient strength for maritime applications requiring resistance to mechanical loads and corrosion. Previous studies have confirmed that recycled aluminum materials can attain hardness levels suitable for maritime industry demands, particularly for ship propellers, which require high resistance to wear and corrosion (Du et al., 2024).

Moreover, the importance of high-quality recycled aluminum for heavy industrial applications, including marine propeller manufacturing, has been emphasized by several studies. High-grade aluminum recycling not only reduces the depletion of natural resources but also provides a cost-effective material with performance comparable to virgin metal, which is vital in ship component production (Stelter & Morgenstern, 2007). This recycling approach also contributes to the sustainability of the maritime industry by reducing waste and carbon emissions associated with primary aluminum production.

However, microstructural analysis also revealed that, despite relatively uniform grain distribution, the presence of minor porosity could impact the material's mechanical strength. The observed porosity is attributable to casting defects, typically caused by trapped air or incomplete gas release during the casting process (Biegler et al., 2021). Such porosity may lead to localized material weaknesses, although in many cases, these effects can be mitigated through process optimization or post-processing treatments such as heat treatment or hardening.

The degradation in quality due to porosity may affect structural integrity, especially in high-load applications such as maritime components. Therefore, for commercial implementation, stricter control of casting parameters is essential to minimize porosity. This finding aligns with previous research highlighting the necessity of precise casting control to reduce structural defects in marine components exposed to high mechanical loads and corrosive marine environments (Altunsaray et al., 2021).

Overall, this study demonstrates that motorcycle piston waste can be successfully recycled through sand casting to produce aluminum material suitable for manufacturing components with adequate mechanical strength and durability, such as ship propellers. Consequently, this recycling process not only offers an environmentally friendly waste management solution but also enhances the economic value of discarded materials. However, this study is limited by the presence of porosity in the cast components, which may affect long-term performance under extreme loading or marine conditions. Future research should focus on optimizing process parameters such as melt treatment, degassing techniques, and mold design to minimize defects and further improve the quality and reliability of recycled aluminum components.

CONCLUSION

This study confirms that recycled motorcycle piston waste processed via sand casting yields aluminum material with characteristics appropriate for marine propeller applications. The hardness test yielded an average value of 77.2 kg/mm², which falls within the standard range for aluminum, indicating sufficient resistance to penetration. Although microstructural analysis revealed some porosity, proper control of the casting process can minimize its adverse effects on material quality. The chemical composition of the recycled material includes primary elements such as Aluminum (Al), Silicon (Si), and Copper (Cu), which are consistent with aluminum alloys used in engineering applications.

In conclusion, recycled motorcycle piston waste has the potential to serve as a sustainable and economical alternative raw material for producing marine components such as propellers, offering adequate mechanical strength and durability. Therefore, utilizing this waste not only provides an environmentally responsible approach to waste management but also adds economic value to materials previously considered as scrap.

REFERENCE

Sukahar, Hafid, A., & Suparja. (2024). Analisis Perbandingan Sifat Fisis dan Mekanis pada Piston Motor Produk China (Kanzen) dan Motor Produk Jepang (Honda GL). *Jurnal Mekanikasista,* Vol. 11 No. 2.

Shi, M., Li, Y., & Ni, P. (2022). Recycling valuable elements from aluminum dross. International Journal of Environmental Science and Technology,19:12069–12078.

Andrijono, D., & Sufiyanto. (2018). Bimtek Mutu Produk Cor Baling-Baling Kapal Nelayan Hasil Cetakan Pasir dengan Bahan Dasar Skrap Aluminium bagi IKM Disperindag Kota Pasuruan. *Jurnal ABDIMAS Unmer Malang*, Vol. 3, No. 2.

Nugroho, B. S., Budiarto, U., & Kiryanto, K. (2022). Analisa Kekuatan Material Aluminium Daur Ulang Dari Bahan Velg dan Piston Motor sebagai Bahan Komponen Jendela Kapal. *Jurnal Teknik Perkapalan,* vol. 10, no. 2, pp. 98-105.

Priyambodo, B. H., Yaqin, R. I., Fattah, R. N., & Slamet, S. (2024). Pemanfaatan dan Rekayasa Limbah Piston dengan Metode Shot Peening sebagai Bahan Alternatif Propeler Perahu Nelayan. *Aurelia Journal*, Vol. 6, No. 2.

Samudro, M. A. (2024). Perhitungan Kekuatan Mekanik dari Pemanfaatan Limbah Aluminium untuk Pembuatan Bracket pada Mesin Tempel Kapal Patroli. *INOVTEK Polbeng*, vol. 14, no. 02, pp. 216-227.

Partono, P., Prakoso, D. A., Masyrukan, Wiyono, S., Pratiwi D. A., Kultsum, U., Istiqama, N. A., & Gustiani, D. (2024). Methods of gravity die casting and gravity investment casting on density, porosity, microstructure, and hardness in aluminum casting. AIP Conf. Proc. 2838, 060011.

Samuel, A., Zedan, Y., Doty, H., Songmene, V., Samuel, F. H. (2021). A Review Study on the Main Sources of Porosity in Al-Si Cast Alloys. Advances in Materials Science and Engineering, Issue 1 1921603.

Permata, A. N. S., Nayaka, M. D., Zulhazmi, A., et al. (2024). Corrosion and Microstructure on the Casting Product Propeller Shaft Model of Al6063 Aluminum Alloy Base Materials. The 18th International Conference.

Kim, M. S., & Kim, J. (2024). Development of Low-Pressure Die-Cast Al-Zn-Mg-Cu Alloy Propellers-Part I: Hot Tearing Simulations for Alloy Optimization. MDPI Materials.

Louis, S., & Louis, P. P. (2020). Experimental study on strength comparison of light weight aluminium alloy propeller blade with metal propeller blade. IOP Conference Series: Materials Science and Engineering.

Mat Nasir, M. F. (2008). Cavitation Failure of Local Made Propellers and Suggestion for Improvement. Utp.edu.my.

Akhyar, A., Iqbal, I., Bahi, M., & Farhan, A. F. (2023). Numerical-hydrodynamic analysis, vickers hardness, and tensile test of cast-brass alloy for boat propellers. *Jurnal Polimesin*.

Endramawan, T., Sifa, A., & Dionisius, F. (2020). Characteristics of hardness at local propellers with variations of timing by using sandblasting method. IOP Conference Series: Materials Science and Engineering, vol. 850, no. 1, p. 012038.

Parameswaran, P., Rameshbabu, A. M., et al. (2018). Study of the corrosion properties in a hot forged Cu-Al-Ni alloy with added Cr. *Journal of Materials Engineering and Performance*, vol. 27, no. 12, pp. 5557-5567.

Tang, C. H., Cheng, F. T., & Man, H. C. (2004). Improvement in cavitation erosion resistance of a copper-based propeller alloy by laser surface melting. Surface and Coatings Technology, vol. 177, no. 1, pp. 16-24.

Hsu, C. Y., Huang, C. K., & Tzou, G. J. (2008) Using metallic resin and aluminum alloy molds to manufacture propellers with RP/RT technique. Emerald, vol. 16, no. 3, pp. 154-160.

Du, S., Zhang, S., Wang, J., et al. (2024). Sustainable recycling of aluminum scraps to recycled aerospace-grade 7075 aluminum alloy sheets. ScienceDirect, pp. 1-8.

Stelter, M., & Morgenstern, G. (2007). Investigations of Possibilities for Cleaning of Aluminium Bronze for the Recycling of Cast Alloys. Kupferinstitut, pp. 1-9.

Biegler, M., et al. (2021). Analysis and recycling of bronze grinding waste to produce maritime components using directed energy deposition. WLT, pp. 1-15.

Altunsaray, E., Sözen, A., & Doğru, A. (2021). Structural Performance of Lightweight Ship Propellers with Sustainable Materials and Additive Manufacturing. SSRN, pp. 1-12.