International Journal of Scientific Engineering and Science
Volume 9, Issue 7, pp. 79-82, 2025. ISSN (Online): 2456-7361

The Effect of Cooling Medium on Heat Treatment on the Hardness and Toughness of Used Cylinder Block Casting Materials with Copper Addition

Sinarep[1], Rudy Sutanto[2]
[1, 2]Department of Mechanical Engineering, Faculty of Engineering, Mataram University, Mataram, Indonesia

Abstract— *This study aims to examine the effect of variations in cooling media in the heat treatment process on the mechanical properties, especially hardness and toughness, of used cylinder block casting materials combined with copper elements. Three types of cooling media were used in this heat treatment process, namely air (normalizing), mineral water, and water with a mixture of 90% water and 10% salt. The heat treatment process was carried out in a controlled manner to ensure the homogeneity of the treatment on each specimen. Hardness tests were carried out using the Vickers method, while toughness was tested using the Charpy method. The results showed that the cooling media had a significant effect on the hardness of the treated metal. The salt solution cooling media gave the highest average hardness value of 27.2697 kg/mm², followed by mineral water at 26.7216 kg/mm², and air (normalizing) at 26.183 kg/mm². This increase in hardness is directly correlated with the faster cooling rate in the liquid media, especially the salt solution, which accelerates the formation of a harder martensitic structure. However, the increase in hardness is not always accompanied by an increase in toughness. Air cooling (normalizing) provided the highest toughness value of 7100 J/m², followed by mineral water at 6300 J/m², and brine also at 6300 J/m². This indicates a compromise between hardness and toughness, where a slower cooling rate in normalizing results in a more ductile structure. These findings suggest that the choice of cooling medium in the heat treatment process should be tailored to the desired mechanical properties. Brine is suitable for applications that emphasize hardness, while mineral water can be used for applications that require a balance between hardness and toughness.*

Keywords— *Heat treatment, cooling medium, Vickers hardness, toughness, used cylinder block, copper.*

I. INTRODUCTION

The development of the modern metal manufacturing industry continues to promote efficiency, sustainability, and material reconditioning to reduce reliance on virgin raw materials. One key emerging strategy is the application of heat treatment to improve the mechanical properties of metal materials, particularly scrap materials from automotive components. Heat treatment, which includes austenitization, quenching, and tempering, significantly affects the hardness and toughness of alloys through the manipulation of precipitation and microstructural phase transformations [1].

The cooling medium, or quenching medium, plays a crucial role in determining the cooling rate and, in turn, influences the final heat treatment outcome. Water and oil are the two most commonly used media, each offering different cooling characteristics. Studies have shown that the use of coconut oil-based bio-quenchant can achieve a cooling rate of approximately 49°C/s, higher than mineral oil, and result in increased hardness in aluminum alloys [2].

The application of this technique to scrap metals such as cast cylinder blocks is still relatively limited in the literature. However, these scrap materials have significant potential for reuse with appropriate processing. The primary challenges are the possibility of internal flaws caused by the casting process and the varied initial structure. Treatment through heat treatment techniques combined with appropriate cooling media can restore or even improve the mechanical performance of the material [3].

Copper-based materials and their alloys are frequently used in various applications due to their high thermal conductivity and mechanical properties. However, the combination of hardness and toughness is often problematic, as increasing one property can degrade the other. This phenomenon is known as the hardness-toughness trade-off, which is strongly influenced by precipitate morphology and heat treatment parameters [4].

In a recent study, a Cu–Ti–Fe alloy subjected to cold-rolling and heat treatment demonstrated significant improvements in mechanical performance. These results were achieved by controlling the distribution and orientation of the precipitates, which are influenced by aging temperature and cooling rate [5]. This study reinforces the importance of selecting quenching parameters in achieving optimal mechanical properties.

The influence of extreme thermomechanical conditions on microstructural transformations has also been demonstrated in titanium-based alloys, explaining how shock loading and crystal orientation can produce complex twinning phenomena in β-Ti alloys, providing important insights into controlling plastic deformation in alloys [6]. Although this study was conducted on titanium alloys, the same microscopic principles are relevant in explaining the effects of heat treatment on copper-based alloys.

Mechanical testing such as hardness and Charpy impact testing are the primary methods for evaluating heat treatment results. International standards such as ISO 148-1 [7] ensure that tests are performed consistently and that results are comparable. This combination of hardness and toughness data provides the basis for selecting the optimal cooling medium that not only increases hardness but also maintains or even improves the toughness of the material.

Despite this, most research focuses on solid materials or metal panels (Al, steel, Cu alloys) produced through casting or hot rolling. However, research on used cylinder blocks cast with other materials, particularly copper-based ones, remains limited. These materials have complex initial structures, casting pores, and compositional inhomogeneities that require appropriate heat treatment techniques and cooling strategies to improve their mechanical properties without compromising material integrity.

In the context of recycling and sustainable manufacturing, the reuse of used cylinder blocks is relevant. In addition to adding value, it also has the potential to reduce waste in the automotive and energy industries. Therefore, understanding the effect of varying cooling media on the mechanical properties of these used materials is crucial.

This study aims to systematically examine how varying cooling media affects the final hardness and toughness properties of used cylinder blocks cast with copper. The experimental approach employed control of the cooling media, cooling rate, and initial material conditions, measured through Vickers and impact tests in accordance with international standards. The uniqueness of this study lies in its focus on recycled materials, a previously little-explored area, and is expected to provide novel contributions to the field of materials engineering.

The expected result is a significant correlation between the cooling medium and the improvement of mechanical properties, which can serve as a practical reference for heat treatment optimization in the automotive and metal manufacturing industries. Theoretically, this study also enriches the literature on the heat treatment of Cu alloys on recycled materials and strengthens the argument that the cooling medium is a critical parameter in modifying the final properties of the material.

II. METHODOLOGY

This study used a quantitative experimental approach to analyze the effect of varying cooling media on the mechanical properties of used cylinder blocks made from cast copper alloy. This approach was chosen to allow for precise measurements and strict variable control, in accordance with engineering materials testing principles used in thermal research on metal alloys [1].

1. Materials and Specimen Preparation

The raw material, used cylinder blocks from motor vehicles, was collected from a local reconditioning workshop. The used cylinder block material was then mixed with copper, with a composition of 85% by weight of used cylinder block and 15% by weight of copper. The two materials were then melted in a heating furnace. Subsequently, specimens were formed with standard hardness test dimensions (10 mm × 10 mm × 10 mm) and toughness test dimensions (10 mm × 10 mm × 55 mm with a 2mm V-notch) using a water-cooled bandsaw to avoid thermal deformation. This cutting procedure was based on practices used in recycled metal research [3].

2. Heat Treatment Design

The heat treatment process was carried out in three main stages: austenitization, quenching, and tempering. The specimens were heated in an electric furnace at 850°C for 60 minutes to ensure phase homogenization. This temperature and duration refer to the optimum parameters for Cu–Ti–Fe alloys as described by Xu et al. (2024). After reaching the austenitization temperature, the specimens were immediately quenched in three media: air (normalizing), mineral water, and a water–salt mixture (9:1 by volume) as a moderate treatment. The quenching was carried out at room temperature (±27°C) in a 5-liter stainless steel tank. Each medium was lightly stirred to avoid stagnation and accelerate quenching uniformity; this technique is based on recommendations from bio-quenchant-based quenching experiments [2].

3. Hardness and Toughness Testing

After tempering at 300°C for 1 hour, the specimens were tested using a Vickers microhardness tester (10 kgf, 15 seconds) in accordance with ISO 148-1 [7] and ASTM E92-17 [8] standards. Test points were taken three times on different surfaces, and the results were averaged. For toughness, the Charpy impact test method was used based on ISO 148-1 [7] and ASTM E23-23 [9] standards. The testing machine used a 300J energy pendulum and was conducted at room temperature.

4. Validity and Reproducibility

To ensure internal validity, all specimens were tested under identical conditions and by the same operator to reduce human variability. External validity was maintained by using international standards and methodologies proven in previous studies in metallurgy [4]. Replications for each type of cooling medium also aimed to increase the accuracy and reproducibility of this study.

III. RESULTS AND ANALYSIS

Metal hardness is a key indicator of a material's resistance to plastic deformation. In this study, three different cooling media variations exhibited different effects on the hardness of used cylinder blocks alloyed with copper. Vickers hardness test results showed that water with a 10% salt content produced the highest hardness, at 27.2697 kg/mm², followed by mineral water at 26.7216 kg/mm², and the lowest was air (normalizing) at 26.183 kg/mm² (Figure 1).

The high hardness of the brine-quenched specimens can be explained by the mechanism of accelerated cooling. Media with higher thermal conductivity, such as salt solutions, accelerate heat transfer from the metal to the medium, triggering the formation of a more dominant martensitic structure. This structure is harder but also more brittle than pearlite or ferrite [10]. This is consistent with the theory of rapid cooling in quenching processes, where the addition of solutes such as salt can lower the local boiling point and increase cooling efficiency [11].

In contrast, air cooling in the normalizing process causes a slower rate of temperature decrease, allowing the formation of a microstructure in the form of fine pearlite and ferrite, which tends to be softer but has a more balanced internal stress distribution [12]. Thus, the lower hardness results in this process are still within acceptable limits, considering that

International Journal of Scientific Engineering and Science
Volume 9, Issue 7, pp. 79-82, 2025. ISSN (Online): 2456-7361

increased softness is often accompanied by an increase in other mechanical properties, such as toughness.

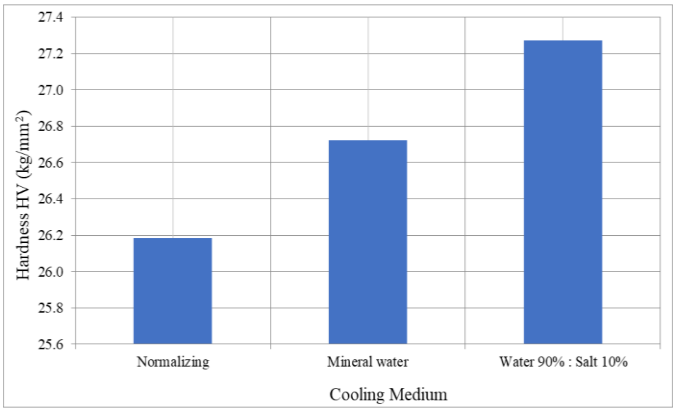


Figure 1. Relationship between cooling medium and hardness

A material's capacity to absorb energy before breaking under shock loads is its toughness. Toughness data show that specimens cooled by normalizing produced the highest toughness values, at 7100 J/m², while specimens cooled using brine and mineral water produced average values of 6300 J/m² (Figure 2).

The high toughness of normalizing can be attributed to the balanced microstructure formed during cooling. Normalizing involves a moderate cooling rate, fast enough to inhibit large grain growth but slow enough to prevent the formation of brittle structures such as full martensite [13]. Therefore, the resulting final structure tends to be smoother and denser, increasing the metal's ability to withstand impact energy.

On the other hand, brine, which produces the highest hardness, actually exhibits a decrease in toughness, as seen in Figure 2. This is due to the large amount of martensite formed, which is hard but brittle, making it susceptible to microcrack propagation under shock loads [14]. Such extreme quenching processes often produce residual stresses in the material, significantly reducing toughness even though hardness increases [15].

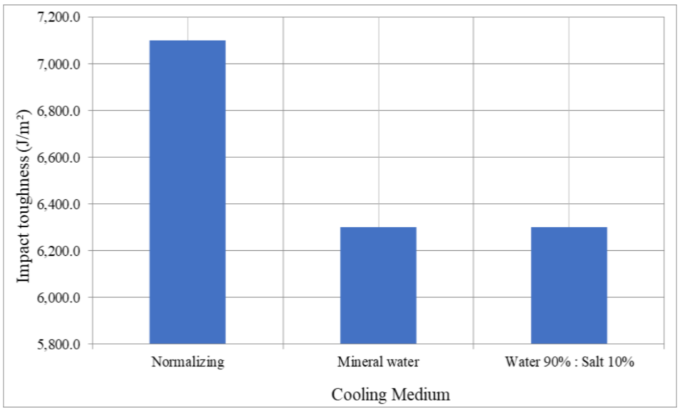
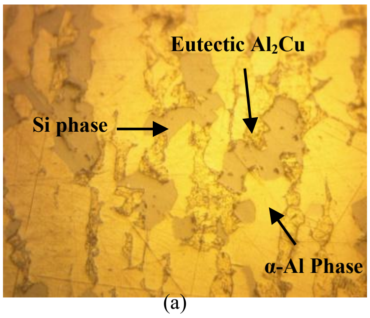


Figure 2. Relationship between cooling media and impact resistance

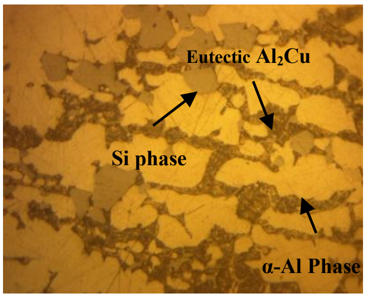
Meanwhile, mineral water produces toughness comparable to that of salt water (6300 J/m²), but through a different mechanism. Rapid cooling allows for larger grain growth, which can reduce resistance to microcracking. The pearlite and ferrite structures formed in large quantities during rapid cooling tend to be softer and more ductile, but are not optimal for absorbing high shock energy in the short term [16].

These findings have significant implications for the reengineering of automotive components, particularly cylinder blocks. Cylinder blocks require high hardness to withstand combustion pressures, but also require toughness to prevent damage from vibration or cyclic loads. Therefore, the choice of coolant must be tailored to the final product's requirements.

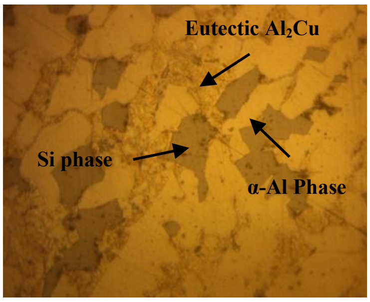
Cooling with mineral water has been shown to provide the best balance between hardness and toughness, making it recommended as the coolant of choice for heat treatment of automotive components requiring balanced mechanical performance [17]. Meanwhile, salt water can be used for components that prioritize high hardness, such as friction surfaces, but is less suitable for parts subjected to repeated shock loads.



(a)



(b)



(c)

Figure 3. Microstructure at 400X magnification (a) normalizing, (b) mineral water, (c) 90% water and 10% salt

Figure 3(a) shows the observation of the microstructure formed in the normalized specimen at 400X magnification. The image shows three distinguishable regions, defined by gray, dark, and light colors. The bright yellow region represents the α-Al structure, representing aluminum, which is the primary matrix throughout the image. The dark microstructure represents the small, diffuse, and non-uniform Al_2Cu eutectic structure. The gray region represents the Si phase, representing silicon, which is often seen between the arms of aluminum dendrites, occupying cavities or gaps, and has an irregular and smooth shape.

Figure 3(b) shows the observation of the microstructure formed in the mineral water-cooled specimen at 400X magnification. The image shows three distinguishable regions, defined by gray, dark, and light colors. The bright yellow area represents the α Al structure, while the dark area represents the Al_2Cu eutectic structure. The gray area represents the Si phase, which is silicon, often found between the arms of aluminum dendrites and occupies cavities or gaps, and has an irregular and rough shape, following the eutectic pattern. The microstructure is dominated by large α Al and a small amount of random Si phase, and the Al_2Cu eutectic appears sharp and rough.

Figure 3(c) shows the observation of the microstructure formed in the specimen with a 90% salt and 10% water cooling medium at 400X magnification. The image shows three gray, dark, and light areas. The bright yellow microstructure represents the α Al structure, while the dark area represents the Al_2Cu eutectic structure located at the grain boundaries, which generally appear non-uniform. And for the gray area representing the Si phase structure, silicon is often seen between the arms of aluminum dendrites and occupies cavities or gaps and has an irregular shape, is smoother and has a net-like shape and a finer grain size.

IV. CONCLUSION

The highest hardness value was obtained in specimens cooled with 90% water and 10% salt, which was 27.2697 kg/mm². The lowest hardness value was found in air (normalizing) media, which was 26.183 kg/mm². Variations in cooling media have an effect on specimen hardness, although the difference between media is relatively small. The highest impact toughness value was obtained in normalizing cooling specimens, which was 7100 J/m². The lowest toughness value was found in specimens cooled with 90% water and 10% salt, which was 6300 J/m². Cooling treatment with salt solution tends to reduce the impact toughness value of the specimen and the type of microstructure formed greatly affects the toughness value of the material. The ferrite-pearlite microstructure shows ductile and impact-resistant characteristics, while martensite produces a hard but brittle material. The results of microstructural observations indicate the presence of three main phases in all specimens, namely: the main aluminum matrix (α-Al) which appears as a light-colored area. The eutectic phase-Al_2Cu appears dark and is located at the grain boundaries. The gray silicon (Si) phase is distributed between the dendrite arms and occupies the voids. Although the types of structures formed are similar, variations in the cooling medium affect the distribution and morphology of the phases, which can impact the mechanical properties of the material. The quenching medium influences the morphology and distribution of the phases, where rapid cooling (such as 90% water 10% salt) produces a sharper eutectic structure and a finer distribution, as well as a larger and more dominant α-Al structure.

REFERENCES

[1]. Grigorian, C. M., & Rupert, T. J. (2020). Critical cooling rates for complexion transitions in Cu-rich nanocrystalline alloys. arXiv.
[2]. Adekunle, A. S., Adeleke, A. A., Ikubanni, P. P., Omoniyi, P. O., Gbadamosi, T. A., & Odusote, J. K. (2020). Effect of copper addition and solution heat treatment on mechanical properties of aluminum alloy using formulated bio-quenchant oils. Engineering and Applied Science Research, 47(3), 297–305.
[3]. Jo, H., Kang, M., Park, G.-W., Kim, B.-J., Choi, C. Y., Park, H. S., … Jeon, J. B. (2020). Effects of cooling rate during quenching and tempering conditions on microstructures and mechanical properties of carbon steel flange. Materials, 13(18), 4186.
[4]. Xia, C., Pang, Y., Jia, Y., Ni, C., Sheng, X., Wang, S., et al. (2022). Orientation relationships between precipitates and matrix and their crystallographic transformation in a Cu–Cr–Zr alloy. Materials Science and Engineering A, 850, 143576.
[5]. Xu, B., Wang, Q., Wang, W., Wang, K., Wang, L., & Hu, J. (2024). Precipitation behavior and performance evolution of cold-rolled Cu–Ti–Fe alloy during heat treatment. Materials Characterization, 204, 114388.
[6]. An, X., Jiang, W., Ni, S., Chen, Z., Wang, Z., & Song, M. (2023). Origin of twinning and twin-twin intersections in a shock-load metastable β Ti-12Mo alloy. Materials Characterization, 198, 112674.
[7]. ISO 148-1. (2021). Metallic materials — Charpy pendulum impact test — Part 1: Test method. International Organization for Standardization.
[8]. ASTM International. ASTM E92-17: Standard Test Methods for Vickers Hardness and Knoop Hardness of Metallic Materials. ASTM International, 2017.
[9]. ASTM International. ASTM E23-23: Standard Test Methods for Notched Bar Impact Testing of Metallic Materials. West Conshohocken, PA: ASTM International, 2023.
[10]. Li, S., Huang, T., & Deng, H. (2020). Experimental analysis on quenching media effect in steel hardening process. Journal of Materials Engineering and Performance, 29(4), 2487–2494.
[11]. Zhou, Y., Zhang, L., & Li, X. (2022). Effect of quenching media on the mechanical properties and microstructure of heat-treated steels. Materials Science Forum, 1053, 45–51.
[12]. Wang, J., Liu, Z., & Xu, Q. (2021). Normalizing treatment and its impact on impact strength and microstructure of ductile iron. Journal of Iron and Steel Research International, 28(1), 56–63.
[13]. Ahmed, A., Bashir, A., & Farooq, M. U. (2023). Microstructural evolution and toughness degradation in quenched steels. Journal of Metallurgical Engineering, 10(2), 80–88. https://doi.org/10.1080/21663831.2023.1215670
[14]. Chen, D., Yu, S., & Lin, W. (2024). Influence of alloying and quenching parameters on the mechanical performance of recycled ferrous alloys. Engineering Research Express, 6(1), 015701.
[15]. Prasanna, R., Kumar, M. P., & Rajendran, N. (2021). Influence of copper addition and heat treatment on the microstructure and hardness of grey cast iron. Materials Today: Proceedings, 45, 4678–4682.
[16]. Rao, K. S., & Kumar, R. (2022). Enhancing recycled cast components through copper alloying and thermal treatment. Materials Research Express, 9(3), 035602.
[17]. Zhang, Q., Liu, W., & He, T. (2025). Performance optimization of recycled automotive castings through controlled quenching techniques. Automotive Materials Journal, 8(1), 23–30.