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Numerical-hydrodynamic analysis, vickers hardness, and tensile test of cast-brass alloy for boat propellers

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Abstract

Computational Fluid Dynamics (CFD) has been applied to simulate boat propellers. The material for boat propellers generally uses a brass alloy metal which is produced by a casting process. The purpose of this study was to simulate CFC propellers, evaluate the hardness and tensile strength of samples cast from the brass alloy used to produce ship propellers. The methods show that turbulent kinetic energy, density streamline characteristic, and velocity distribution are simulated boat propellers with CFD applications. Furthermore, the propeller is cast to observe the surface hardness and tensile strength of the cast alloy. The results revealed that the boundary conditions - which served as the simulation's input parameters, the geometry of the rotating and stationary domains, the geometry and type and number of gratings, the geometric accuracy of the propeller model, mass flow rate, rotational angular velocity, and stationary angular velocity - all had a significant impact on the parameters. Brass alloy and cast alloy raw material hardness values were measured on the surface of the propeller casting product. While 128 HV was attained after casting, the average hardness value for solid cylinders manufactured of the raw metal alloy was 171.67 HV. The three test sessions' stress vs. strain graphs were produced using the Cu-Zn alloy metal's tensile test results. The cast Cu-Zn alloy has a maximum tensile strength of 352 MPa and a maximum yield stress of 330 MPa.

Keywords: CFD numerical analysis, hydrodynamic, vickers hardness, tensile, cast brass alloy, boat propeller.

1 Introduction

Theoretical methods for predicting propeller performance developed starting from Rankine's momentum theory, followed by Froude's blade element theory. In the 1990s, scientists simplified the propeller model with a computational model and began research to calculate the real geometry of the propeller with the RANS (Reynolds Averaged Navier Stokes) formula model. In addition, it opens a wide space in the calculation of propeller hydrodynamics with other series types. The complexity and high cost of predicting propeller characteristics by testing propeller models in open water in drag ponds can be reduced by applying the CFD method, with this method reducing time and cost in investigating several propeller characteristic parameters.

Several studies on numerical analysis for ship propellers have been reported. The maneuver of a twin-screw ship due to the interaction between the hull, engine, and propeller has been analyzed through CFD using the RANS method. The parameters given include the total load on the propeller, the flow field, and the hydrodynamic characteristics of the propeller. The result is that there is an effect of the interaction of the hull, engine, and propeller on the maneuvering behavior of the ship and the characteristics of the propeller [1]. CFD simulation is used to model accurate ship maneuvers for motion prediction and autonomous navigation. Vessel maneuvers were analyzed through Mathematical Model Group (MMG) models with data from free-run tests and virtual captive models. The data needed to identify the MMG model are the Dynamic Circular Motion Test (CMT) and the Static Oblique Towing Test (OTT). The unstable Reynolds-Averaged Navier–Stokes (RANS) equation is used to solve for the forces and moments acting on the hull. The results obtained in the form of movement predictions and the results of free-running maneuvers are under experimental data [2]. A new fully coupled three-dimensional hydrodynamic model has been used to analyze the CFD of underwater towing systems under complex flow disturbances. The result is that the model offered is feasible for the application of underwater towing systems [3]. Exploration of the effect of tip vortex cavitation (TVC) on propeller-induced URN using the hybrid CFD method. Cavitation flows around full-scale models and reference vanes operating under uniform inclined, and non-uniform flow conditions were solved using DES and mass transfer models. The recently developed advanced mesh refinement (V-AMR) technique was incorporated into the calculations to suitable model the eddy flow and realize the TVC in the slipstream vanes. The results show that the contribution of TVC to the overall propeller URN is minimal under conditions where there is a stable and structured TVC (ie, under uniform flow conditions) [4].

Brass Cu-Zn alloy is widely used as the main material for producing ship propellers because it has good corrosion resistance. Brass alloy is a metal alloy whose dominant components consist of copper (Cu) and zinc (Zn). Brass alloy is a strong, hard, malleable, good conductor of heat and corrosion resistance, and can be recycled. Several studies on brass alloys have been reported. The tensile strength of the cast samples with variations in pouring temperature has been evaluated and the results show that the maximum tensile strength is 443 MPa at 1210 °C, the solidification range affects the tensile properties of the cast samples [5]. The effect of pouring temperature on the Vickers hardness of CuZn brass alloys through metal casting has been studied. The resulting hardness increases with increasing pouring temperature. The effect of pouring temperature results different solidification rates and solidification intervals for brass alloys. Furthermore, it affects the growth of the grain structure of the brass alloy which causes differences in Vickers hardness [6]. The impact toughness of brass (CuZn) with variations in pouring temperature during the production of casting samples has been studied. The results show a maximum impact toughness of 20.67 J at a pouring temperature of 1110 °C, then a minimum impact toughness of 17.67 J at a pouring temperature of 1260 °C. Mostly, it can be concluded that the impact toughness decreases with increasing pouring temperature [7].

Production of propellers has been reported through the casting process. Evaluation of casting defects in the production of ship propellers through metal casting has been studied. Macroporosity, misrun, and cold shut defects formed in the cast product of ship propellers were observed for location, geometric shape, and size. Defects are generally formed at the tip of the blade with various geometries and sizes, and shrinkage cavity defects are observed at the tip of the blade. No defects were found in the product when the die mold was preheated [8-9].

Based on the background, the purpose of this research is first to predict the characteristics of the propeller by testing the propeller model in water, second to analyze the hardness of the boat propeller from brass cast metal, third to evaluate the tensile strength of the propeller product boat, brass alloy boat propeller, and finally macro and micrograph evaluation of the fracture surface due to a tensile test.

2 Materials and Methods

The propeller simulation in steady flow is divided by the calculation zone into two cylinders: the stationary area: this area is the cylinder and includes the boss, propeller and moving area. According to (Yoshihisa Takekoshi), the upstream length, the downstream length, and the zone diameter [10]. Rotating area: the length and diameter of this area depends on the diameter of the propeller and boss. In this simulation, water is a compressed stream with two different approaches to test. Boundary conditions, namely mass flow, inlet flow, mass flow velocity selection, and inlet flow conditions are adjusted to the actual physical conditions. The pressure has been used to simulate the outlet boundary conditions because the outlet pressure conditions are in the stationary zone modeling.

The geometric discretization of the propeller is made for maintenance. A structured tetrahedral cell is used to determine the control volume (symmetric about the vane axis). Small nets cannot be said to be good because they have to consider time and cost calculations. The propeller surface is triangular with various sizes because the cells near the root- and the propeller tip is smaller than the other parts - is divided into several areas including a turning zone, stationary area, inlet, outlet wall, shaft, front and back, as well as the interface. Finally, all computational zones and domains converge to a tetrahedral lattice.

A cylindrical brass ingot with a length of 609.6 mm and a diameter of 25.4 mm is cut into small pieces and melted down in a gas furnace. The combustion chamber of this furnace is sprayed with oxygen through an air compressor for complete combustion. After the brass metal is melted in the crucible, then the molten is poured into a metal mold (permanent mold) in the shape of a propeller boat (Fig. 1).

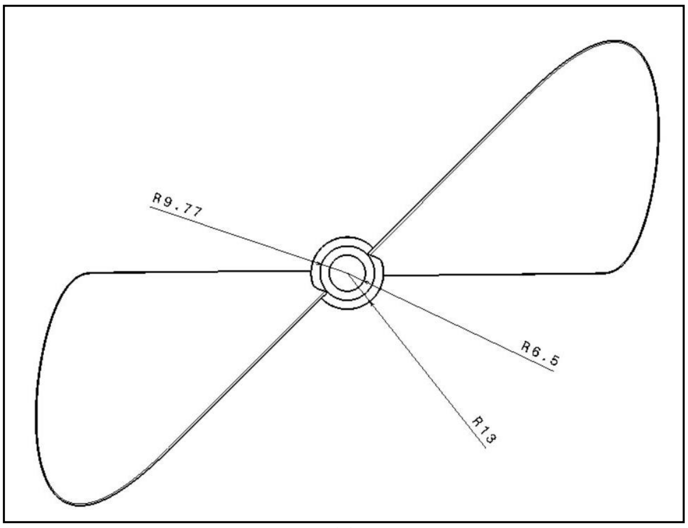
The propeller boat from cast brass alloy is produced through a gravity casting process. This furnace was built at the Metal Casting Laboratory, Department of Mechanical Engineering, Faculty of Engineering, Universitas Syiah Kuala, Indonesia. The K-type thermocouple is used for the pouring temperature during the experiment. The pouring temperature used is 1160 ºC and the mold temperature used is 225 ºC. The chemical composition of the cast brass alloy was tested with the Spectrolab Jr CCD Spark Analyzer. The chemical composition of the alloy is shown in Table 1.

The Vickers hardness test was carried out on the surface of the cast propeller product according to ASTM E92. The tensile test sample for the propeller product is cut (machined) from the cast brass propeller product according to the standard dimensions for tensile testing (ASTM E8/E8M) as shown in Fig. 2. The tensile test was carried out using a Computer Servo Hydraulic Universal Testing Machine, Model: HT-9501 at 25 ± 2 ºC, and a 500 kN load is applied to the sample.

The fracture surface of the tensile test sample was observed using a macro camera, while the surface of the cast product was observed through a scanning electron microscope (SEM) after sample preparation was carried out following metallographic procedures.

Table 1. Chemical composition of cast brass alloy of ship propeller (wt.%).

Zn	Pb	Sn	Fe	Cu
28.7	2.09	1.33	1.16	Bal.



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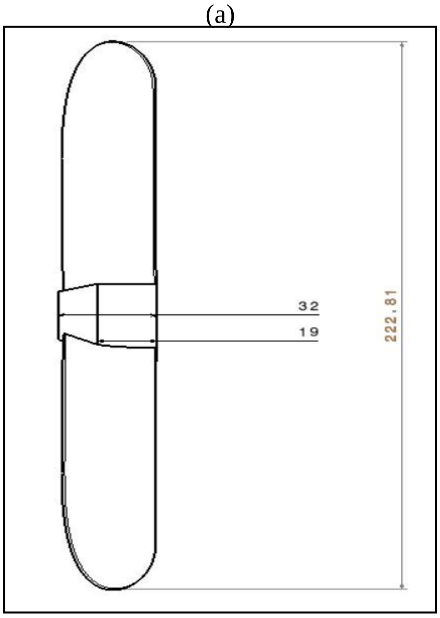

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Fig. 1. Schematic of boat propeller: (a) upper view, (b) front view, and (c) Boat propeller cast product from Cu-Zn alloy.

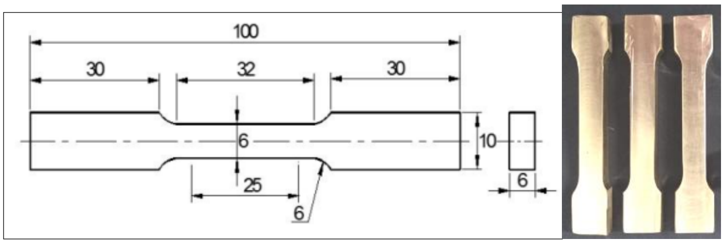
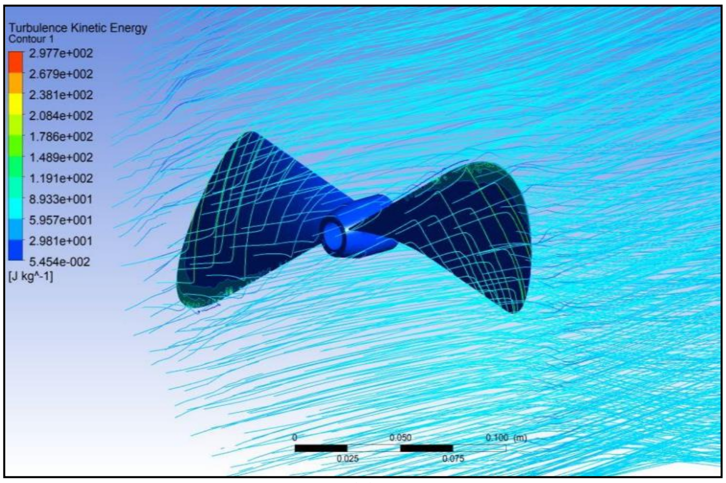


Fig. 2. ASTM E8-09 tensile test sample.

3 Results and Discussion

3.1 Velocity Distribution of Boat Propeller



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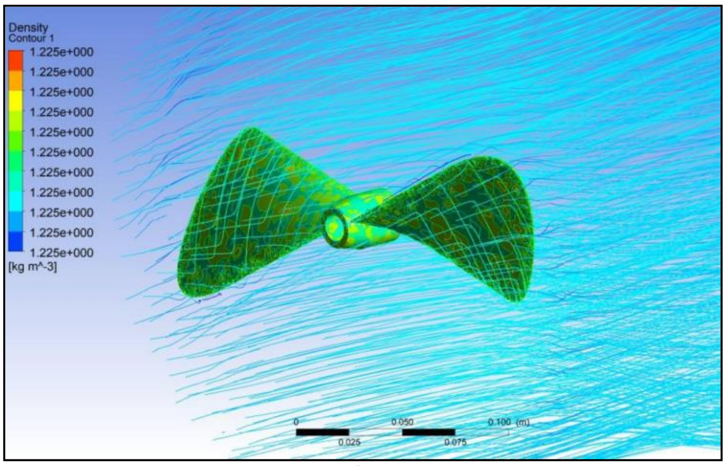

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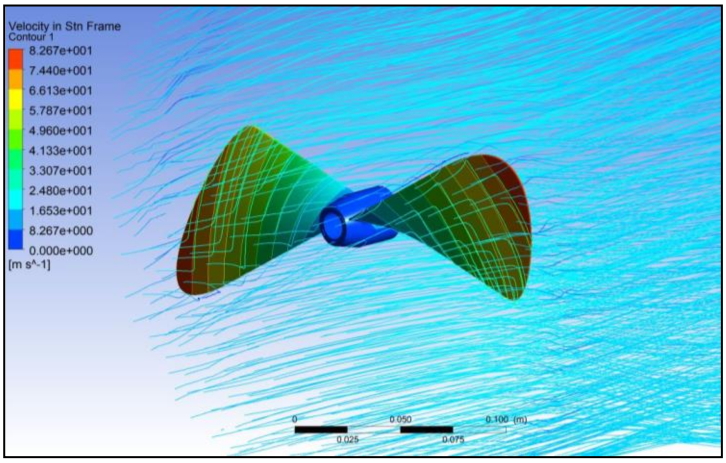


(c)

Fig. 3. (a) Turbulent kinetic energy, (b) density streamline characteristic, and (c) velocity distribution for the propeller.

The kinetic energy turbulence on the surface of the propeller blade is carried out using the CFD application, to estimate the density and velocity that occur most frequently and to detect other turbulence. Fig. 3a shows a graph of Turbulence Kinetic Energy on a two-blade propeller boat. The color gradient shown in Fig. 3a is from the turbulent kinetic energy distribution on the face of the boat propeller. The blue color shows the smallest value, while the red color shows the biggest value. The propeller boat generates high-intensity turbulence near the tip of the propeller blades, which means it produces good propulsion. The CFD simulation for propeller boats is related to the water flow rate on the surface.

The distribution of density and speed on the propeller boat is shown in Fig. 3b and Fig. 3c. Contours represent axial velocity units, and vectors represent velocity units and plane directions. Fig. 3c shows that the velocity distribution changes significantly at the center of the plane. The magnitudes of the axial and rotational speeds at the center of the plane are reduced, and there is even a small amount of back rotation.

3.2 Hardness and Tensile Behavior of Boat Propellers

Vikers hardness is one of the mechanical properties of metal alloys which shows its resistance to indentation deformation. The hardness value of the raw material brass alloy and alloy cast was evaluated on the surface of the propeller cast product as shown in Table 2. The average hardness value obtained on raw metal alloys from solid cylinders is 171.67 HV, while after casting the hardness value decreased to 128 HV (Fig. 5a). This is caused by the porosity that is formed during metal bookkeeping (SEM as shown in Fig. 6).

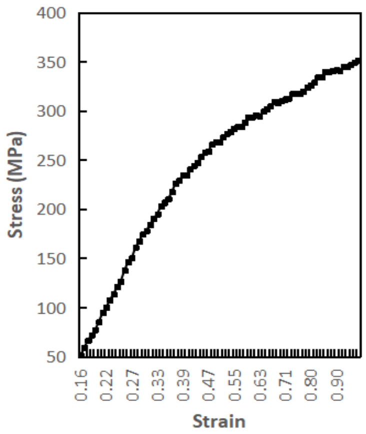
Table 2. Vickers hardness numbers of brass alloy before and after the casting process.

Brass alloy	Vickers Hardness Number (HV)
Cu-Zn raw material (test 1)	170.00
Cu-Zn raw material (test 2)	172.00
Cu-Zn raw material (test 3)	173.00
Cu-Zn cast alloy (test 1)	130.00
Cu-Zn cast alloy (test 2)	126.00
Cu-Zn cast alloy (test 3)	128.00

Table 3. Yield and tensile strength of the cast brass alloy.

Brass alloy	Yield strength (N/mm^2)	Tensile strength (N/mm^2)
Cu-Zn cast alloy (test 1)	326	351
Cu-Zn cast alloy (test 2)	341	372
Cu-Zn cast alloy (test 3)	322	332

Fig. 4a-c (4a first test, 4b second test, and 4c third test) shows the stress vs strain curve for the three times of testing obtained from the tensile test results of the Cu-Zn alloy metal. It can be categorized as a ductile material based on the profile. The image of the fracture surface from the tensile test results in Figure 6a-b confirms this. Because the fracture surface appears fibrous and absorbs light, the photograph appears blurry. The maximum yield stress recorded was 330 MPa and the maximum tensile strength of the cast Cu-Zn alloy was 352 MPa (shown in Fig. 5b).



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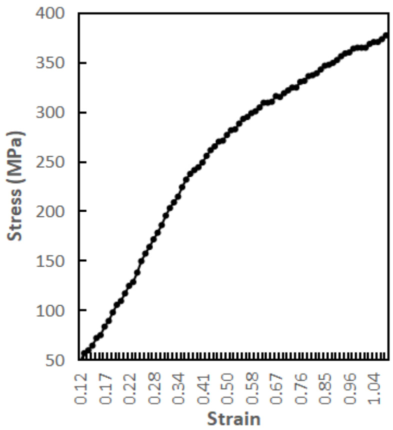

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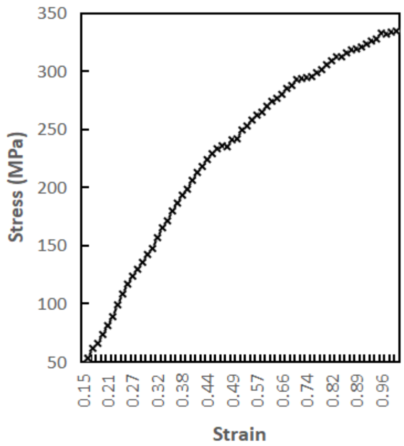
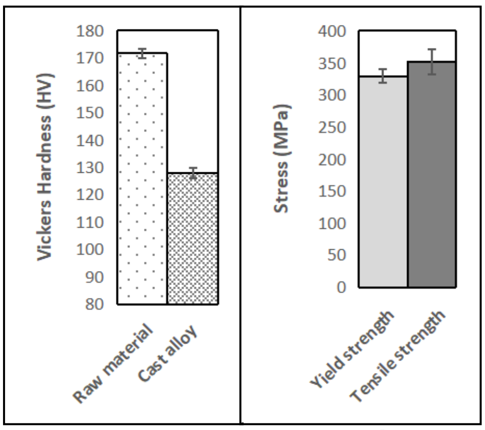


(c)

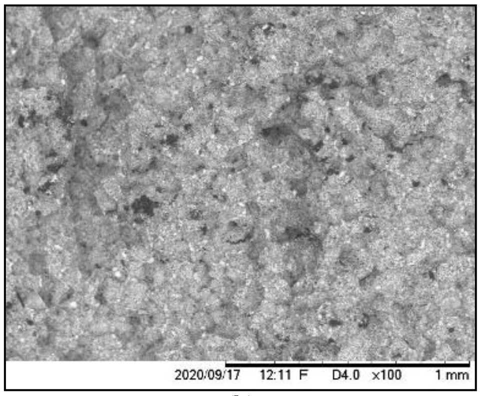
Fig. 4. Stress and strain profiles of Cu-Zn cast alloys, (a) first test, (b) second test, and (c) third test.



(a) (b)

Fig. 5. (a) Vickers hardness, and (b) Tensile strength of the Cu-Zn alloy.

(a)



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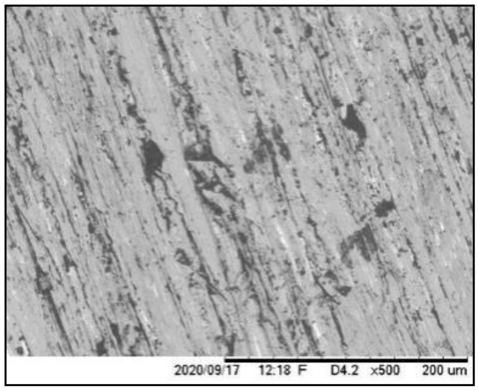

(c)

Fig. 6. Tensile test sample: (a) fracture surface photograph, fracture surface SEM (c) SEM of the Cu-Zn cast sample.

Experiments on the evaluation of the Vickers hardness value of cast brass alloys have been observed at five different pouring temperatures. The results showed that changes in pouring temperature can have an impact on the hardness value of brass alloys. The higher the pouring temperature, the lower the Vickers hardness value. The maximum Vickers hardness value for cast samples is 616 HV at a pouring temperature of 1,210 ºC and the lowest hardness value is 574 HV for pouring temperature and 1,260 ºC [6]. The results show that the maximum tensile strength is 443 MPa at 1.210 ºC, and the freezing range has an impact on the tensile strength characteristics of the cast samples [5]. A recent study also found that porosity increases with increasing temperature in a Cu(20-24)wt%Sn casting [11-12]. The thixotropic castalloy method was used to study the bulk porosity of cast ingots caused by temperature fluctuations. As a result, the bulk porosity of casting ingots decreases slightly with increasing temperature [13].

The fracture surfaces of the tensile test results were observed with an optical microscope (OM), scanning electron microscope (SEM), and SEM of the surface of the cast sample shown in Fig. 6. It is known that the cooling rate affects the ductility of metal alloys. Furthermore, the slow cooling rate during solidification promoted the formation of more nuclei, leading to a smaller and uniform grain size [14]. The effect of pouring temperature on Al-Cu and Al-Si alloys was analyzed, where three different behaviors of the temperature on grain size were identified, namely (i) at low superheat, the grain size is small and relatively constant, (ii) a transition at the intermediate level, where the grain size increases rapidly and non-linearly, and (iii) at high superheat, the grain size increases linearly with increasing temperature [15]. Brass alloys produced by low pressure die casting have been the subject of studies on microstructural evolution. The smooth distribution of the β-phase has been shown to increase the hardness of the alloy [16]. So that the fine stress of β-phase when casting brass alloys will affect the strength and hardness of cast metal products. The tensile strength of cast samples at five different pouring temperatures has been observed in casting brass alloys.

4 Conclusions

Prediction of propeller characteristics by testing propeller models in water has been simulated by using CFD application. Hardness test and the tensile strength of cast brass alloy from boat propellers have been experimented, as well as macro and micrographic observations of fracture surfaces due to tensile tests have been carried out. Furthermore, several conclusions can be drawn are the magnitude of the parameter values above is strongly influenced by the geometry accuracy of the propeller model, geometry shape of the rotating and stationary domains, geometry and type and the number of gratings, boundary conditions which are simulation input parameters (matter, mass and momentum-mass flow rate, the angular velocities of the rotating and stationary parts. The surface of the propeller cast product was tested for the hardness value of the raw material brass alloy and alloy cast. The average hardness value for solid cylinders made of raw metal alloys is 171.67 HV, while 128 HV was attained after casting. The stress vs. strain curve for the three testing sessions was derived from the results of the Cu-Zn alloy metal's tensile test. The cast Cu-Zn alloy's maximum tensile strength was 352 MPa and its maximum yield stress was 330 MPa.

References

[1] H.P. Guo, Z.J. Zou, "CFD and system-based investigation on the turning maneuver of a twin-screw ship considering hull-engine-propeller interaction," *Ocean Engineering*, vol. 251, 2022, https://doi.org/10.1016/j.oceaneng.2022.110893.

[2] S. Li, C. Liu, X. Chu, M. Zheng, Z. Wang, J. Kan, "Ship maneuverability modeling and numerical prediction using CFD with body force propeller," *Ocean Engineering*, vol. 264, 2022, https://doi.org/10.1016/j.oceaneng.2022.112454.

[3] X. Yang, J. Wu, S. Xu, "Study on dynamic response of underwater towed system in ship propeller wakes using a new hydrodynamic model," *Ocean Engineering*, vol. 265, 2022, https://doi.org/10.1016/j.oceaneng.2022.112599.

[4] S. Sezen, M.t Atlar, "Numerical investigation into the effects of tip vortex cavitation on propeller underwater radiated noise (URN) using a hybrid CFD method," *Ocean Engineering*, vol. 266, Part 1, 2022, https://doi.org/10.1016/j.oceaneng.2022.112658.

[5] Akhyar, Iqbal, N. Ali, H. Husin, "Effect of variations in pouring temperature on tensile strength of CuZn cast alloys," *Materials Letters: X*, vol. 17, 2023, https://doi.org/10.1016/j.mlblux.2023.100182.

[6] Iqbal, N. Ali, H. Husin, Akhyar, Khairil, A. Farhan, Differences in Pour Temperature Affect Hardness Properties of CuZn Brass Alloy through Metal Casting, *IOP Conference Series: Materials Science and Engineering*, vol. 1082, The 2nd International Conference on Experimental and Computational Mechanics in Engineering (2nd ICECME 2020) 13th-14th October 2020, Banda Aceh, Indonesia, DOI 10.1088/1757-899X/1082/1/012001

[7] Iqbal, N. Ali, H. Husin, Akhyar, Khairil, A. Farhan "Effect of pouring temperature on impact toughness on brass (Cu-Zn) through metal casting." *Metalurgija*, vol. 60, no. 3-4, pp. 223-226, 2021, https://hrcak.srce.hr/255995

[8] Akhyar, I. Hasanuddin, M. Ibrahim, A. Farhan, Z. Jalil, "Evaluation of cast defects in ship propeller of recycled aluminum alloy," *Metalurgija*, vol. 61, no. 2, pp. 309-312, 2022, https://hrcak.srce.hr/265908

[9] Akhyar, Khairil, A. Farhan, M. Ibrahim, Suhaeri, "Produksi Baling-Baling Kapal dari Logam Daur Ulang melalui Teknik Pengecoran Logam," *Jurnal Teknik Mesin (JTM)*, vol.8, no.2, pp. 32-35. 2020.

[10] Y. Takekoshi, T. Kawamura, H. Yamaguchi, M. Maeda, N. Ishii, K. Kimura, T. Taketani, A. Fujii, "Study on the design of propeller blade sections using the optimization algorithm," *Journal of Marine Science and Technology*, vol. 10, pp. 70–81, 2005, https://doi.org/10.1007/s00773-005-0197-y

[11] M.A. Irfa'i, Dzulkiflih, D. Wulandari, A.N.F Ganda, Supardiyono, "The effect of pouring temperature on the porosity of sand casted Al – Si alloy" *IOP Conf. Ser. Mater. Sci. Eng.* Vol. 494 012076.

[12] S. Slamet S.I. Kusumaningtyas, "Effect of composition and pouring temperature of Cu(20-24)wt.%Sn by sand casting on fluidity and mechanical properties," Journal of Mechanical Engineering and Sciences, vol. 13, no. 4, pp.6022-6035, 2019.

[13] I.S. El-Mahallawi, T.S. Mahmoud, A.M. Gaafer, F.H. Mahmoud, "Effect of pouring temperature and water cooling on the thixotropic semi-solid microstructure of a319 aluminium cast alloy," *Mat. Res.* Vol. 18, no. 1, pp/170–176, 2015, https://doi.org/ 10.1590/1516-1439.304114.

[14] Benjunior, A.H Ahmad, M.M Rashidi, "Direct thermal method pouring temperature and holding time effect on aluminium alloy 6061 microstructure," *IOP Conf. Series: Materials Science and Engineering*, vol. 788, 2020, doi:10.1088/1757-899X/788/1/012017

[15] J.B. Ferguson, M. Tabandeh-Khorshid, J.C. Mantas, P.K. Rohatgi, K. Cho, C.S. Kim, "Predicting the Effect of Pouring Temperature on the Crystallite Density, Remelting, and Crystal Growth Kinetics in the Solidification of Aluminum Alloys," *Metallurgical and Materials Transactions B*, vol. 45B, pp. 2014-1407, 2014.

[16] C. Yang, W. Ye, Y. Yang, F. Wang, Y. Ding, Q. Zhu, W. Zhang, "Microstructural Evolution and Mechanical Behavior of Lead-Free Silicon Brass Manufactured by Low-Pressure Die Casting," *Journal of Materials Engineering and Performance*, vol. 27, pp.5478–5488, 2018, https://doi.org/10.1007/s11665-018-3615-0