Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 8, No. 08, August, 2022

Effects of Stir Casting Baffles on Hardness and Microstructure: Investigation of Designed Aluminum Composites

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Received 25 May 2022; Revised 22 July 2022; Accepted 30 July 2022; Published 01 August 2022

Abstract

The increasing demand for lightweight material specifications has forced researchers to develop lightweight materials that are inexpensive, can be produced on a large scale, and are environmentally friendly. One solution that has been developed is an aluminum composite reinforced with sea sand. Indonesia has the second longest coastline in the world, which means that the country is rich in maritime resources, one of which is sea sand. The ceramic contents of SiO_2, SiC, and Al_2O_3 allow sea sand to be used as a reinforcement in aluminum composites for engineering purposes. The most effective manufacturing method of AA6061–sea sand composites is stir casting, but the homogeneity and distribution of particles are the main disadvantages of the stir casting method. Various factors affect particle distribution and homogeneity, one of which is the flow during the stirring process. The increase in turbulent flow in the stirring process affects the homogeneity and distribution of the particles. One way to create a turbulent flow when stirring is to add baffles. This paper examines the effect of adding baffles during the stir casting process on the mechanical properties of AA6061–sea sand composites. The mechanical properties of AA6061–sea sand composites were characterized using the Brinell hardness test according to ASTM E-10. The test results show that the addition of baffles during the stir casting process decreases the hardness of the AA6061–sea sand composites due to the turbulent flow that occurs. This makes the material more porous, which makes the AA6061–sea sand composites less hard.

Keywords: AA6061; Sea Sand; Mechanical Properties; Stir Casting; Baffle.

1. Introduction

The need for light and strong materials increases year by year. The automotive and manufacturing industries, as well as various industries, including sports, health, and food and beverage industries, are starting to switch to using lightweight materials. One of the materials that continues to be developed is metal matrix composites. Generally, the composites used in various industries are aluminum matrix composites because aluminum has an excellent strength-to-weight ratio that can be increased [1–3]. Aluminum composites use ceramic particles and oxides as reinforcement in the manufacturing process. Ceramics or oxides of Al_2O_3, SiC, SiO_2, and Fe_2O_3 are widely used as reinforcements due to their superior mechanical properties and good thermal properties. One of the natural resources containing many SiO_2 and Fe_2O_3 oxides is sea sand. Sea sand found on the south coast of Java has a SiO_2 and Fe_2O_3 content of 42.2% [4, 5]. The southern coast of Java contains many magnetic and non-magnetic minerals. Based on the XRD results, ceramic compounds and oxides such as Al_2O_3, SiO_2, TiO_2, and Fe_2O_3 are contained in sea sand on the south coast of Java. [6]. The distribution of sea sand containing ceramics and oxides stretches from the southern coasts of West Java, Central

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http://dx.doi.org/10.28991/CEJ-2022-08-08-04

Java, Yogyakarta, and East Java to the southern coast of Nusa Tenggara. [7, 8]. These various compounds can be used as raw materials for engineering purposes, such as magnets and metal matrix composites.

Aluminum composites are manufactured by various methods, such as 1) liquid state, 2) powder metallurgy, and 3) spontaneous infiltration [9, 10]. However, the liquid state processing method, especially stir casting, is preferred due to its ease of operation and ability to produce large quantities of aluminum [11]. Despite its convenience, stir casting has a weakness, namely the distribution of particles that are not homogeneous in the material [1, 12]. The non-uniform distribution of particles results in a decrease in the strength of composites that prevents the desired properties from being achieved. In addition, an inhomogeneous distribution of particles can be caused by the agglomeration of particles, thus initiating porosity and causing material failure [13]. Figure 1 shows the factors that influence the occurrence of porosity in the stir casting process. Among these factors is the stirring process; the stirring factor depends on parameters such as the stirrer angle, agitation speed, agitation time, stirrer diameter, and stirrer position. All of this aims to create a vortex so that the particles can be dispersed in molten metal, thereby minimizing the occurrence of agglomeration.

In stir casting, particle agglomeration and the dead zone are often observed due to the lack of interaction between solids and molten metal [14]. Particle sedimentation depends on the characteristics of the particles and the flow in the crucible, and the flow that occurs in particle sedimentation is a turbulent flow [15]. To prevent particle sedimentation, baffles are generally used to improve the performance of the mixture [16]. Baffles can suppress the stable vortex flow and increase the intensity of drag and turbulent flow on the surface of molten metal. A strong circulation from the top to the bottom of the crucible makes the particles traverse a longer flow path [17]. Numerical modeling in previous studies resulted in better CFD modeling for a system interface with baffles compared with no baffle mixing [18]. Better SiC distribution was obtained in the SiC–water mixture using baffles at low-rotation stirring [19]. Inhomogeneous distribution can minimized by adding baffles during the stirring process in the stir casting method. The addition of baffles to the crucible walls during the stirring process is intended to cause a turbulent flow of molten metal. This turbulent flow initiates the dispersion of reinforcing particles into the molten aluminum matrix during agitation [18–20].

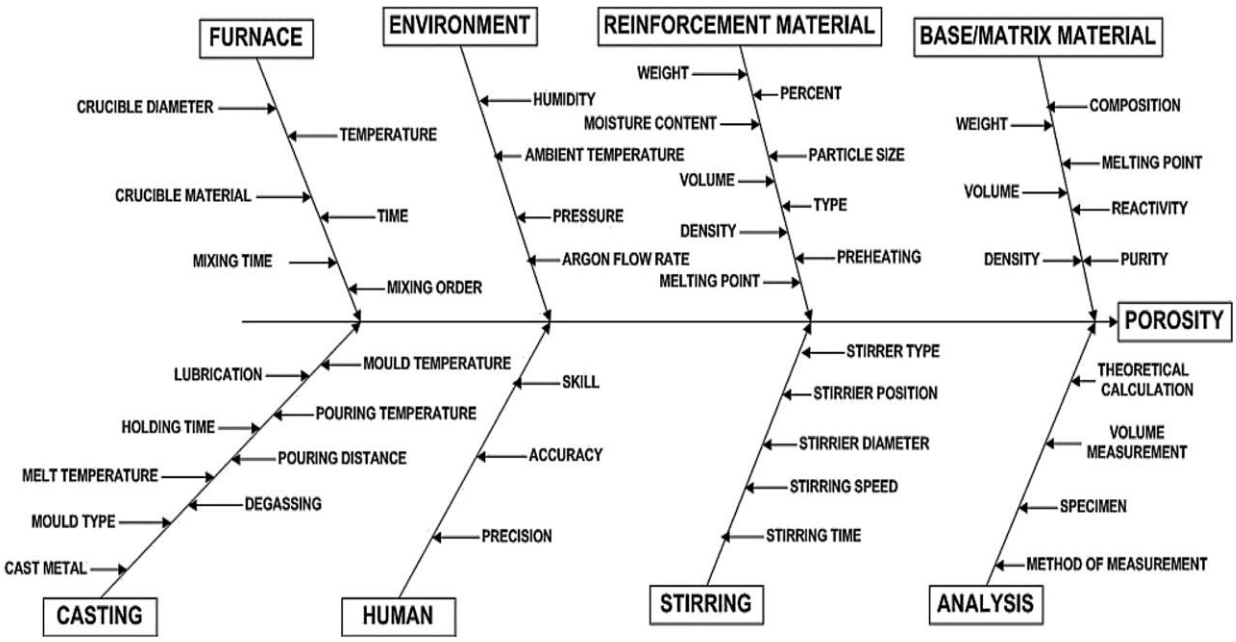


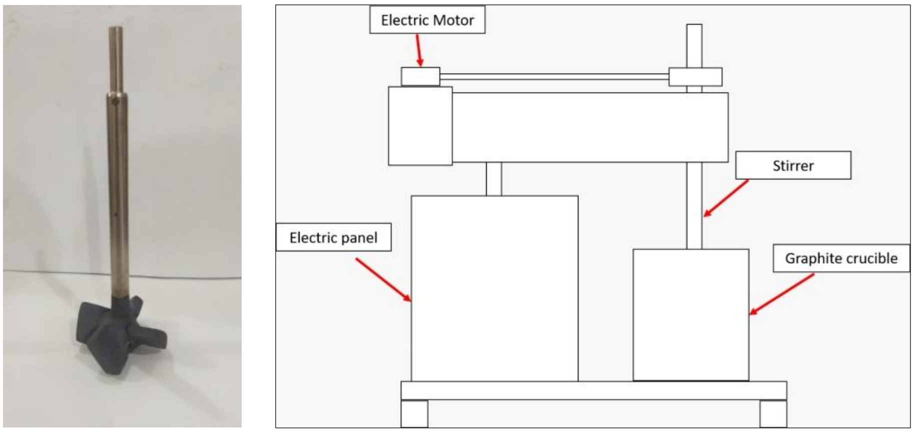
Figure 1. Fishbone diagram of porosity occurrences in stir casting by Suthar & Patel (2018) [21]

Previous studies examined the simulation of stir casting in the stirring process with a focus on the size, position, and angle of the stirrer. References to the use of baffles in stir castings are very limited and are only found in research that uses numerical simulations. However, there are still knowledge gaps in the development of composites with baffle intervention in stir casting experiments. Therefore, it is important to experimentally study the effect of using baffles on aluminum stir casting to achieve effective production and to increase the homogeneity of composite products. This paper aims to investigate the effect of baffle intervention on the production of aluminum composites using the stir casting method.

2. Materials and Methods

Aluminum alloy 6061 was used as the matrix in this study. Sea sand obtained from the south coast of Java (Yogyakarta, Indonesia) was used as a reinforcement for aluminum matrix composites with a fraction of 2 to 6% wt. The experiment procedure followed these steps:

- Firstly, sea sand was ball milled to obtain 200 mesh sea sand particles.
- Then, sea sand was washed with alcohol to remove impurities.
- After that, 40 g of sea sand was treated with an electroless coating with a mixture of 40 mL of HNO_3, 1 g of magnesium fine powder, and 0.5 g of aluminum fine powder. The treatment with an electroless coating aims to increase the wettability of sea sand particles in molten aluminum [22].
- The last step is the stir casting process, which entailed the use of a four-blade impeller coated with TiO_2, as shown in Figure 2. The agitation process was carried out at 400 rpm for 5 minutes. After that, 1% wt magnesium powder was added as a wetting agent; then, agitation was continued for 5 minutes. Figure 3 shows the baffle configuration when the agitation process was used.



(a) (b)

Figure 2. Stir casting apparatus: (a) technical drawing (unit in mm) and (b) laboratory setup

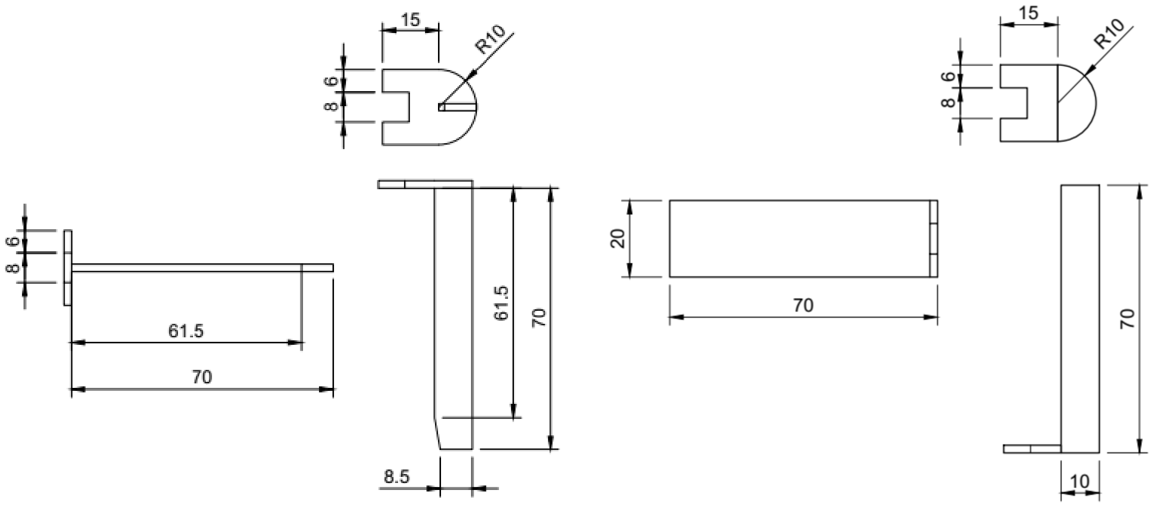


Figure 3. Baffle configuration

For the calculation of density and porosity, the Archimedes method was used following Equations 1 and 2, where ρth symbolizes the theoretical density, ρm, and ρp are the density of the matrix and reinforcement, Vm and Vp are the volume fraction of the matrix and reinforcement, ρa symbolizes the actual density of the composite, and ms and mg represent specimen mass in air and water. Next, the porosity (P) was calculated using Equation 3. The density was measured using Vibra AJ-620E Precision Balance Analytical Scales (Shinko Denshi Co. Ltd., Tokyo, Japan), and the measurement scheme is shown in Figure 4. The tensile test was measured with SUNPOC WEW-300D Hydraulic Universal Testing Machine (Guizhou Sunpoc Tech Industry Co., Ltd., Guiyang City, China) according to JIS Z 2201: 1998, No. 14a test piece.

$$\rho_{th} = \rho_m V_m + \rho_p V_p \tag{1}$$

$$\rho_a = \frac{m_s}{m_s - m_g} \times \rho_{H_2O} \tag{2}$$

$$P = \left(1 - \frac{\rho_a}{\rho_{th}}\right) \times 100\% \tag{3}$$

$$BHN = \frac{2P}{(\pi D)(D-\sqrt{D^2-d^2})} \tag{4}$$

Figure 4. The measuring scheme of density using the Archimedes method

Hardness testing was carried out using the Brinell hardness test with reference to ASTM E-10 with a 2.5 mm steel ball indenter and 62.5 kg load. Brinell hardness was calculated based on Equation 4, where P symbolizes the load, D symbolizes the diameter of indenter, and d symbolizes the width of indentation diameter on the specimen. The Brinell hardness test apparatus was a Contorlab Dia Testor 2RC (Controlab, Paris, France). The research flowchart is shown in Figure 5.

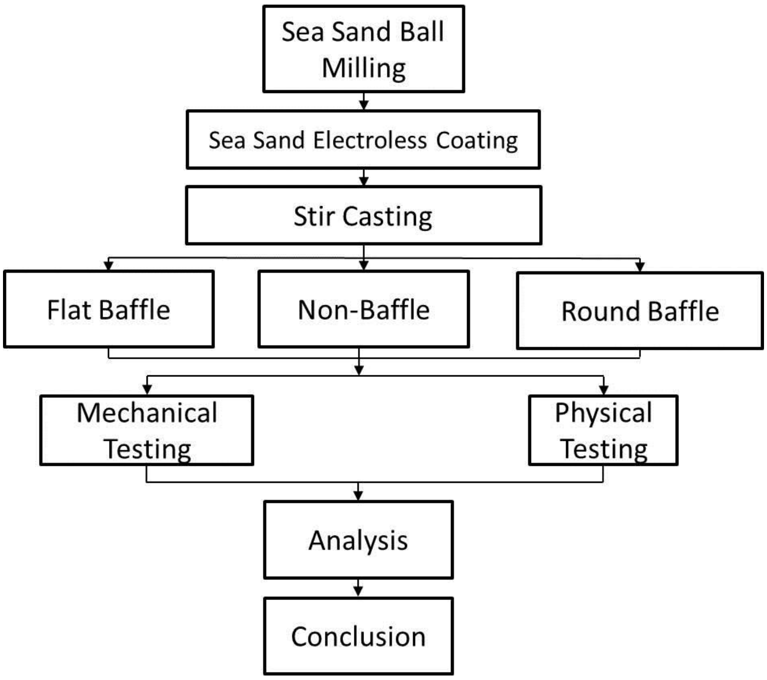


Figure 5. The flowchart of our research method

3. Results and Discussion

The XRD test results show that sea sand contains SiO_2 and Fe_2O_3, as shown in Figure 6. The presence of a silicon oxide compound, which has a higher hardness than the aluminum matrix also affects the mechanical properties of the composite. The use of baffles in the stir casting process affects the physical and mechanical properties of the AA6061–sea sand composite. In general, baffles are used to improve the attribution of stirring results [18]. The use of flat baffles and round baffles increases the porosity and decreases the composite density in all variations compared to the stir casting process without using baffles. The results of calculating the composite density are shown in Figure 7, and the results of calculating the percentage of porosity are shown in Figure 8.

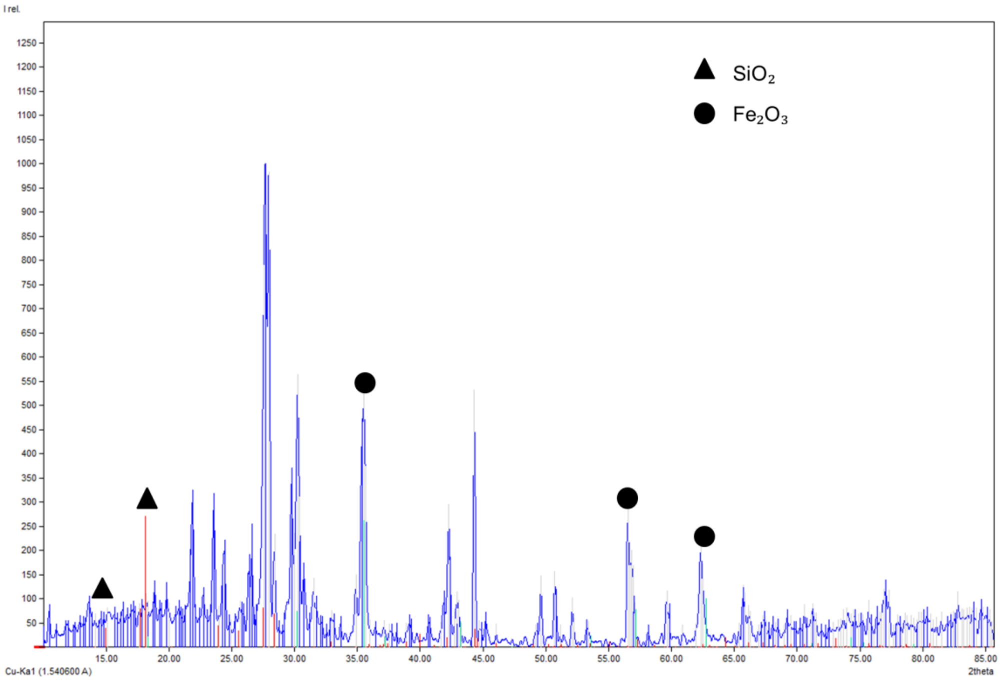


Figure 6. XRD result of sea sand

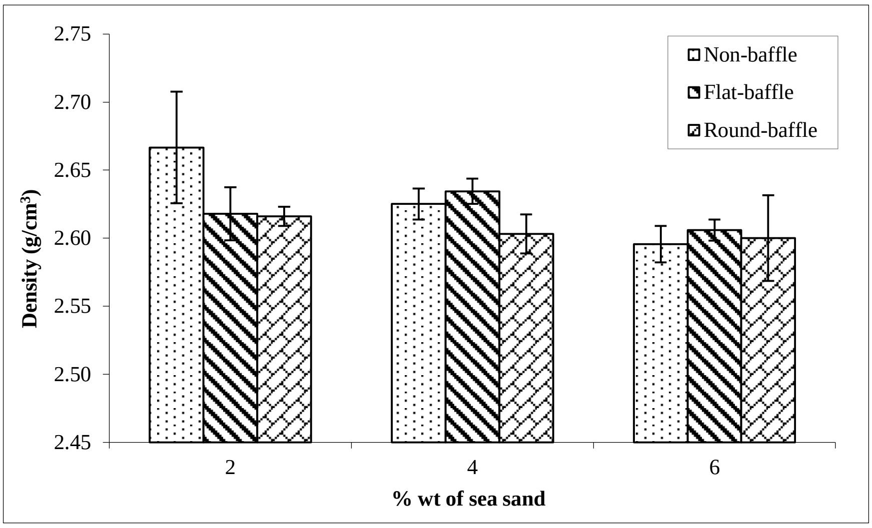


Figure 7. The density of the aluminum composite

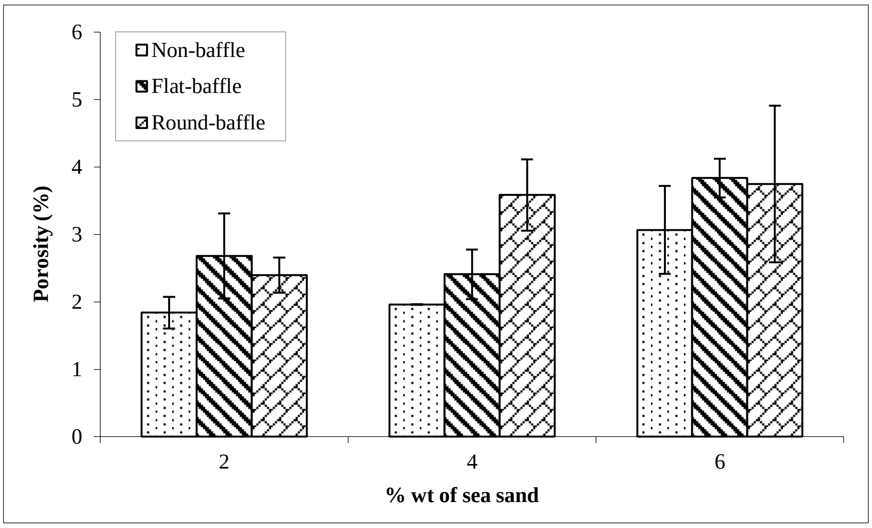


Figure 8. The porosity of the aluminum composite

The highest density in the use of flat baffles was achieved with the addition of 4% wt sea sand, and the lowest density was obtained with the addition of 6% wt sea sand. Furthermore, the lowest porosity was achieved with the addition of 4% wt sea sand, and the highest porosity was obtained with the addition of 6% wt sea sand. The use of round baffles in the stir casting process produces the highest density with the addition of 2% wt of sea sand and the lowest density with the addition of 6% wt of sea sand. The lowest percentage of porosity was achieved with the addition of 2% wt sea sand. From the results, it can be concluded that baffles are present during the agitation process, increasing the likelihood of entrapped gas. This is because the baffles not only eliminate swirling but also increase turbulence intensity, which promotes porosity [20].

The results of the Brinell hardness test on the composites are shown in Figure 9. The results of the Brinell hardness test show that the hardness of flat baffle configuration increases with the addition of 2-4% wt sea sand by 60.4 and 62.2 HB and then decreases to 58.8 HB when 6% wt of sea sand is used. This decrease was caused by the increase in porosity when 6% wt sea sand was added, whereas in the round baffle configuration, the composite hardness decreases with the addition of sea sand, namely 62.4, 60.5, and 60.1 HB, and the highest hardness is achieved at 2% wt sea sand. This shows that, as more particles of sea sand are added, the hardness of the AA6061–sea sand composite decreases compared to the hardness of the composite with stir casting but without baffles.

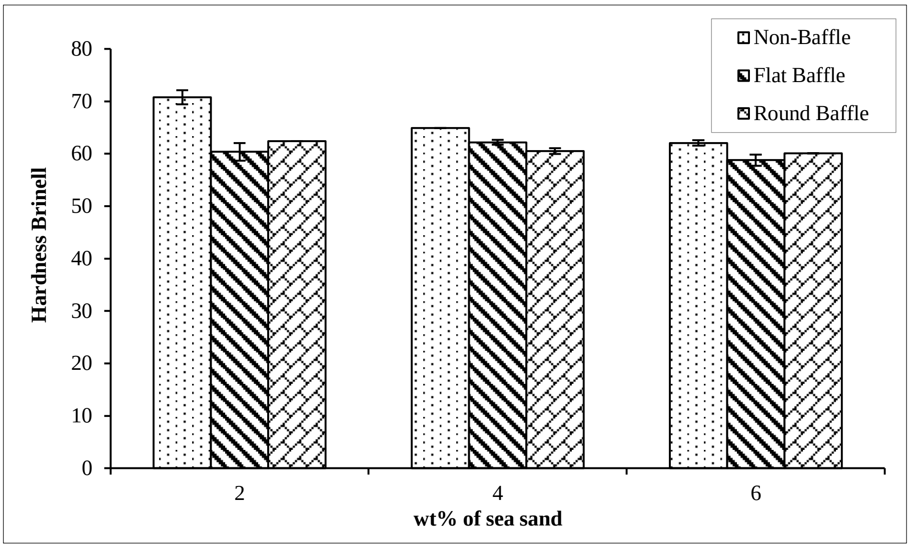


Figure 9. Hardness of aluminum composite

A similar phenomenon occurs in the ultimate tensile strength (UTS), as shown in Figure 10. The highest UTS values for flat baffle and round baffle configuration were achieved with the addition of 4% wt sea sand and 2% wt sea sand, respectively. From the results of the hardness test and the UTS of the composite, it can be concluded that the use of baffles reduces the mechanical properties of the Al6061–sea sand composite compared with manufacturing composites without baffles.

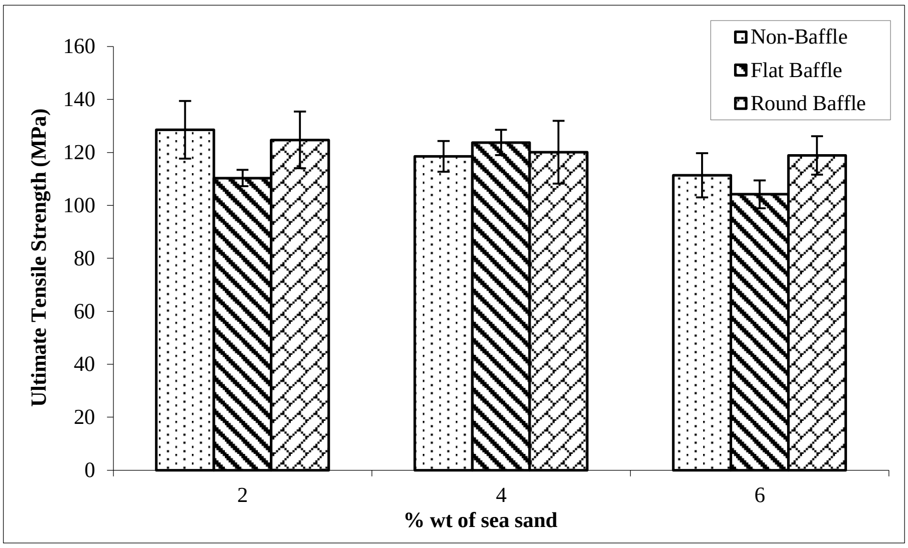


Figure 10. UTS of the AA6061–sea sand composite

From the test results, it can be concluded that the use of baffles reduces the mechanical properties of the Al6061–sea sand composite. This phenomenon is consistent with the density and porosity characterizations shown in Figures 5 and 6. Generally, molten metal is stirred to create a surface vortex to mix the particles into the liquid [19]. Individual particles can form clusters on the surface of the vortex before they are added to the molten metal. This causes light particles to move around the stirrer and heavy particles to be stirred away from the stirrer due to the centrifugal force generated during the stirring process. This phenomenon damages the uniformity of the mixture [20]. The presence of baffles converts the mixed circulation into a vertical circulation, ensuring that the particles pass through the agitation zone where there is maximum agitation, resulting in a more homogeneous mixture [23]. In the agitation process without baffles, the particles travel according to the vortex path that is formed, whereas in the agitation process with baffles, particles experience more movement when agitation occurs [18].

In addition, the use of baffles in the stir casting process also increases the turbulence of the mixture, which causes the sea sand particles to disperse in the matrix [19]; on the other hand, the use of baffles in the stirring process causes air to become trapped in the liquid metal, causing an increase in porosity, and thus a decrease in the mechanical strength of the composite [21, 24].

Microstructural observations show that the distribution of particles in composites manufactured using baffles is more even than un-baffled manufacturing. On the other hand, baffles increase the tendency for gas to become trapped in the liquid metal during stirring, as shown in Figures 11-a and 11-b. This trapped gas causes porosity, which results in lower composite hardness. Furthermore, in composites with no baffle manufacturing, the distribution of sea sand particles is uneven, as shown in Figure 11-c. Agglomeration and interfacial debonding occurs when a higher number of sea sand particles are added, as shown in Figures 12 to 14. A comparison of the mechanical properties of aluminum composites is shown in Table 1. The results in Table 1 show that the AA6061–sea sand composite produces a higher hardness than in previous research because the addition of sea sand particles provides a strengthening effect. The dispersion of particles between the aluminum atoms activated the Orowan mechanism, which increases the hardness of the composite [25]. On the other hand, the tensile strength of the composite reinforced by sea sand has not yet reached the maximum tensile strength due to the coarse particle size of the sea sand. A coarse particle size has a lower surface area compared to finer particle size. This lower surface area causes weaker interfacial bonds, so that the mechanical bond between the matrix and the coarse particles is lower when compared to the reinforcing particles with a finer size. It is this low mechanical bond that results in a lower tensile strength [1].

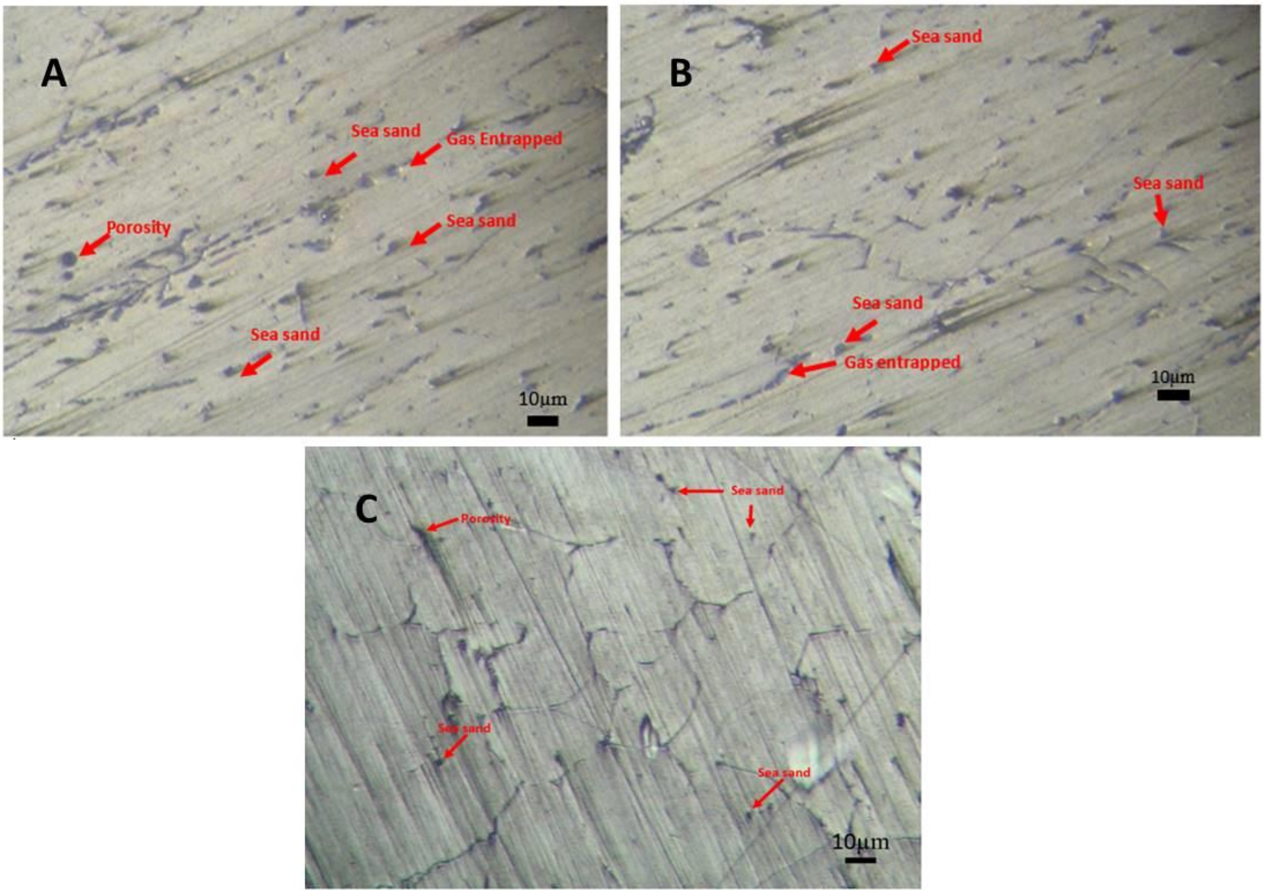


Figure 11. Microstructure observation of 6% wt sea sand with a) flat baffle; b) round baffle; and c) without baffle

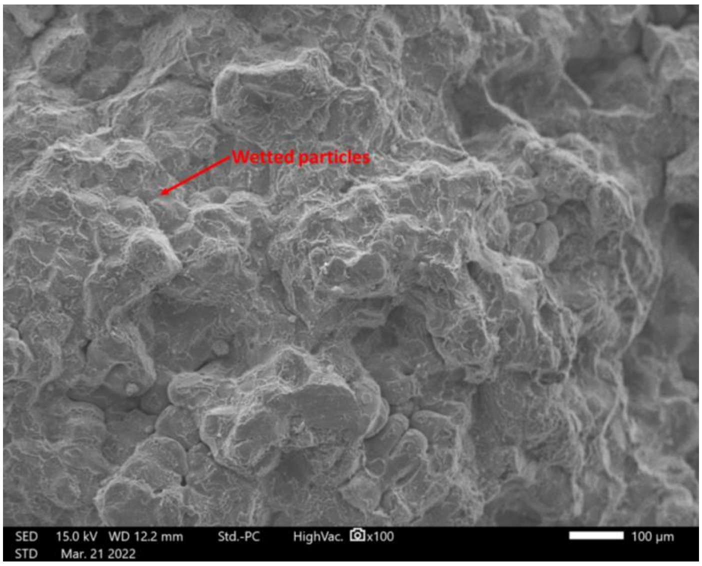


Figure 12. SEM observation of the AA6061–sea sand 2% wt composite with round baffle

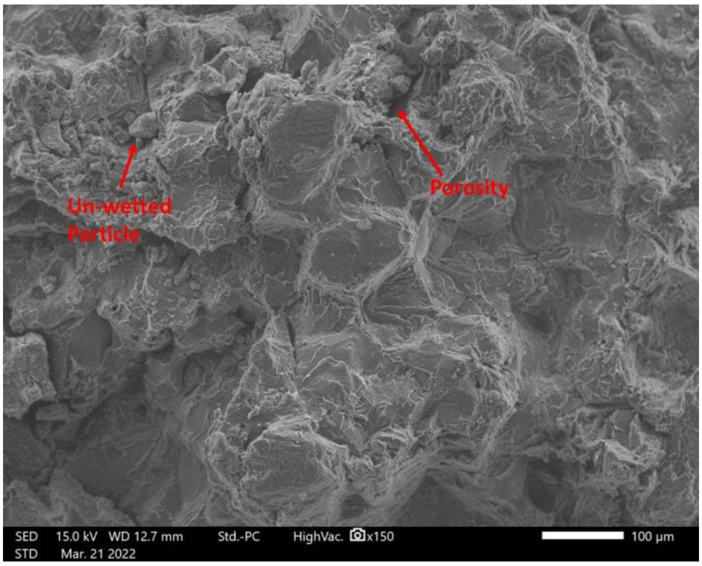


Figure 13. SEM observation of the AA6061–sea sand 4% wt composite with round baffle

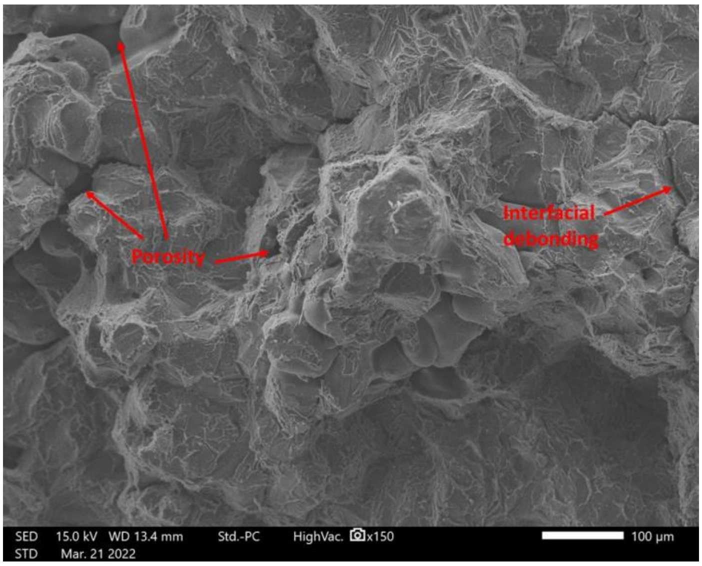


Figure 14. SEM observation of the AA6061–sea sand 6% wt composite with round baffle

Table 1. A comparison of the mechanical properties of aluminum composites [12]

Composite	Result
AA6061–2% wt sea sand (EC) without baffle	71 BHN and 128.57 MPa
AA6061–4% wt sea sand (EC) with flat baffle	62,2 BHN and 123.7 MPa
AA6061–2% wt sea sand (EC) with round baffle	62,4 BHN and 124.72 MPa
Al–3Mg–5% wt fly ash [26]	54.96 BHN
Al6061–5% wt Al_2O_3–8% wt bagasse ash [27]	180 MPa
AlSi10Mg + 10% fly ash + 10% rice husk ash [28]	410 MPa
Aluminum–bottom ash [29]	19 BHN and 87 MPa

The particle distribution in the specimens with and without baffles is reflected by the hardness distribution in the cross section of the specimen with the test scheme, as shown in Figure 15. There are twelve test points on the cross-section of the specimen, which represent the distribution of sea sand particles when stir casting is carried out with baffle variations; the test results are presented in Table 2. These results show that specimens with a stir casting process using baffles showed lower deviations than specimens manufactured without baffles. However, the average hardness obtained by specimens manufactured without baffles obtained a higher hardness level than specimens manufactured using baffles. This is because the uses of baffles increases the flow path of the particles, so that they become evenly distributed during stir casting [20].

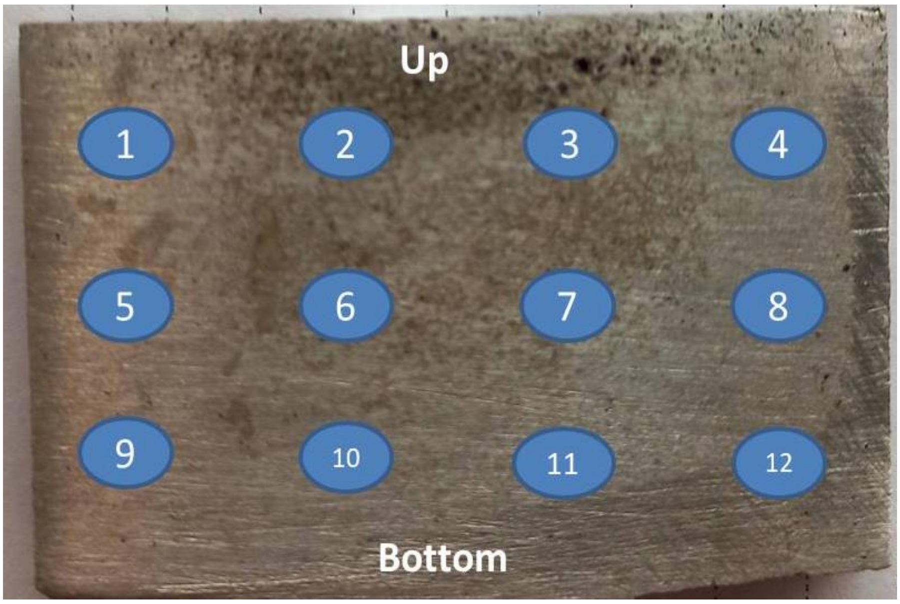


Figure 15. Testing scheme of the hardness distribution of composites

Table 2. The hardness distribution of composites

	1	2	3	4	5	6	7	8	9	10	11	12	Mean (BHN)	Deviation
Non-baffle	57.2	56.3	36.8	52.9	56.3	49.7	37.3	54.5	54.5	55.4	44.2	52.1	50.6	6.94
Flat baffle	47.5	45.5	48.3	49.0	47.5	51.3	49.0	52.1	57.2	54.5	49.0	53.7	50.4	3.28
Round baffle	49.0	47.5	49.0	49.0	46.2	49.0	46.8	48.3	50.5	49.7	44.8	50.5	48.4	1.66

The use of baffles that increase the intensity of turbulence also increases the level of trapped air. This is evident from Figure 16, which shows cross sections of flat-baffle and round-baffle specimens with porosity in specimens. The trapped air that forms porosity is a side effect of the use of baffles, the percentage of porosity that occurs in this specimen causes a decrease in the mechanical properties of the AA6061–sea sand composite, although the distribution of sea sand particles is more uniform when the stir casting process is carried out using baffle variations.

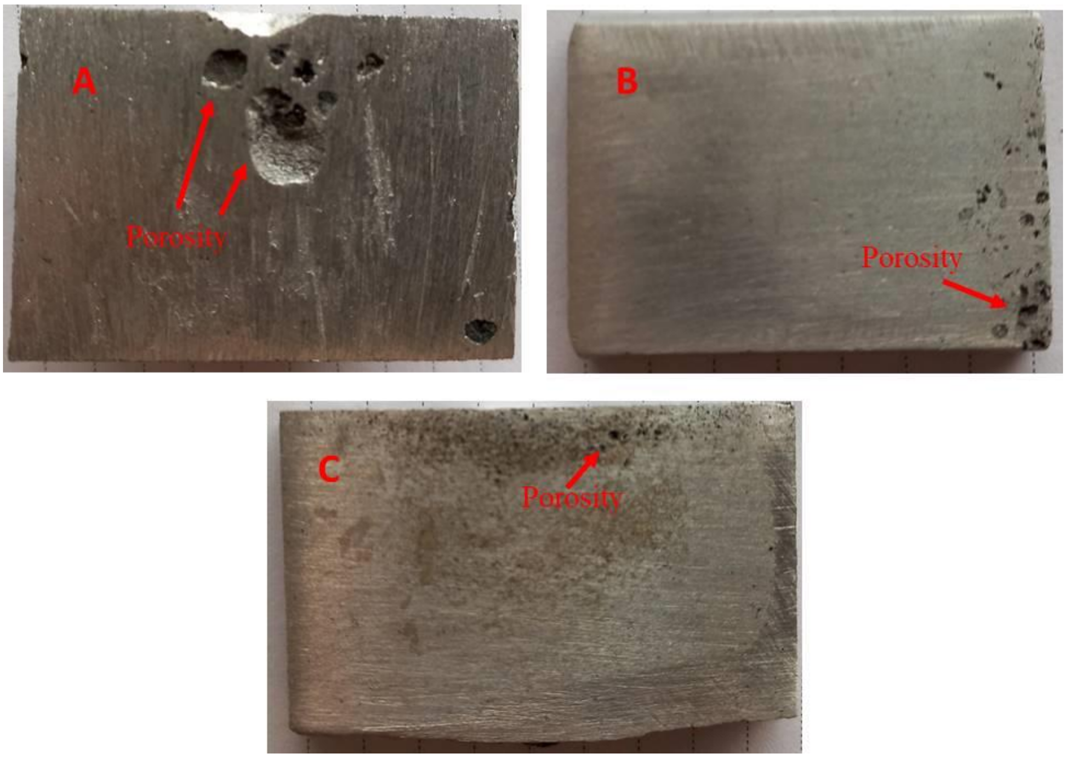


Figure 16. Cross section of the specimen: a) flat baffle; b) round baffle; and c) without baffle

4. Conclusion

The use of baffles in the stir casting process for AA6061–sea sand composites resulted in a more homogeneous distribution of sea sand particles. However, baffles have an influence on the porosity of composites. An increase in porosity correlates with a decrease in the hardness of AA6061–sea sand composites. Composites with the best mechanical properties had approximately 2% wt of sea sand particles without baffle manufacturing. For the variation using baffles, manufacturing using flat baffles increased mechanical properties with the addition of up to 4% wt sea sand particles and then decreased when 6% wt sea sand particles were added. For round baffles, the results of mechanical properties have a different tendency compared to flat baffles. The mechanical properties decreased with the addition of sea sand particles of more than 2% wt. According to the particle distribution evaluation, manufacturing with baffles has a more positive effect than manufacturing without baffles. However, further research must be conducted to compensate for the effect of porosity by the use of baffles in stir casting. Based on the current results, other sets of testing are required, e.g., bending, tensile, and impact testing, to quantify the effect of baffles on the composites subjected to destructive tests. These experiments will provide mechanical characteristics, which are beneficial for studying newly introduced composite materials as part of industrial commodities. The processes of matching and linking with market demand, especially in the mechanical engineering field, are recommended for future studies as an important reference for the mass production of materials.

5. Declarations

5.1. Author Contributions

Conceptualization, E.S., H.I.A., and D.A.; methodology, E.S., H.I.A., D.A., and A.R.P.; formal analysis, E.S., H.I.A., D.A., and F.I.; investigation, H.I.A. and F.I.; resources, E.S., D.A., and T.T.; data curation, H.I.A. and F.I.; writing-original draft preparation, H.I.A. and A.R.P.; writing-review and editing, H.I.A. and A.R.P.; visualization; H.I.A., F.I., and T.T.; supervision, E.S., D.A. and A.R.P.; funding acquisition, E.S. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding and Acknowledgements

This work was supported by RKAT PTNBH Universitas Sebelas Maret 2022 under scheme ‘Penelitian Unggulan Terapan (PUT-UNS)’ with research Grant Number: 254/UN27.22/PT.01.03/2022. The support is gratefully acknowledged by the authors.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Verma, V., Tewari, P. C., Ahamed, R. Z., & Ahmed, S. T. (2019). Effect of addition of fly ash and Al2O3 particles on mechanical and tribological behavior of Al MMC at varying load, time and speed. Procedia Structural Integrity, 14, 68–77. doi:10.1016/j.prostr.2019.05.010.

[2] Koli, D. K., Agnihotri, G., & Purohit, R. (2015). Advanced aluminium matrix composites: the critical need of automotive and aerospace engineering fields. Materials Today: Proceedings, 2(4-5), 3032-3041. doi:10.1016/j.matpr.2015.07.290.

[3] Zulfia, A., & Ajiriyanto, M. K. (2011). Effect of artificial aging (T6) on microstructure of Al-AC8H/Al 2O3 MMC produced by stir casting route. Advanced Materials Research, 328–330, 1552–1555. doi:10.4028/www.scientific.net/AMR.328-330.1552.

[4] Akbar, H. I., Surojo, E., Ariawan, D., Prabowo, A. R., & Imanullah, F. (2021). Fabrication of AA6061-sea sand composite and analysis of its properties. Heliyon, 7(8), 7770. doi:10.1016/j.heliyon.2021.e07770.

[5] Fanani, E. W. A., Surojo, E., Prabowo, A. R., & Akbar, H. I. (2021). Recent progress in hybrid aluminum composite: Manufacturing and application. Metals, 11(12). doi:10.3390/met11121919.

[6] Rusianto, T., WIldan, M. W., Abraha, K., & Kusmono, K. (2012). Magnetic Ceramic Materials from Iron Sand of the South Coast Bantul Yogyakarta. Proceeding Seminar Nasional Tahunan Teknik Mesin XI, XI, 16–17 October, 2012, Yogyakarta, Indonesia.

[7] Ardiani, N. R., Setianto, S., Santosa, B., Wibawa, B. M., Panatarani, C., & Joni, I. M. (2020). Quantitative analysis of iron sand mineral content from the south coast of Cidaun, West Java using rietveld refinement method. 3rd International Conference on Condensed Matter and Applied Physics (Icc-2019). doi:10.1063/5.0003018.

[8] Arsyad, M., Tiwow, V. A., & Rampe, M. J. (2018). Analysis of magnetic minerals of iron sand deposit in Sampulungan Beach, Takalar Regency, South Sulawesi using the x-ray diffraction method. Journal of Physics: Conference Series, 1120(1). doi:10.1088/1742-6596/1120/1/012060.

[9] Garg, P., Jamwal, A., Kumar, D., Sadasivuni, K. K., Hussain, C. M., & Gupta, P. (2019). Advance research progresses in aluminium matrix composites: manufacturing & applications. Journal of Materials Research and Technology, 8(5), 4924–4939. doi:10.1016/j.jmrt.2019.06.028.

[10] Annigeri, U. K., & Veeresh Kumar, G. B. (2017). Method of stir casting of Aluminum metal matrix Composites: A review. Materials Today: Proceedings, 4(2), 1140–1146. doi:10.1016/j.matpr.2017.01.130.

[11] Satheesh, M., & Pugazhvadivu, M. (2019). Investigation on physical and mechanical properties of Al6061-Silicon Carbide (SiC)/Coconut shell ash (CSA) hybrid composites. Physica B: Condensed Matter, 572, 70–75. doi:10.1016/j.matpr.2017.01.130.

[12] Akbar, H. I., Surojo, E., Ariawan, D., Putra, G. A., & Wibowo, R. T. (2020). Effect of reinforcement material on properties of manufactured aluminum matrix composite using stir casting route. Procedia Structural Integrity, 27, 62–68. doi:10.1016/j.prostr.2020.07.009.

[13] Suresh, V., Vikram, P., Palanivel, R., & Laubscher, R. F. (2018). Mechanical and wear behavior of LM25 Aluminium matrix hybrid composite reinforced with Boron carbide, Graphite and Iron oxide. Materials Today: Proceedings, 5(14), 27852–27860. doi:10.1016/j.matpr.2018.10.023.

[14] Gu, D., Liu, Z., Qiu, F., Li, J., Tao, C., & Wang, Y. (2017). Design of impeller blades for efficient homogeneity of solid-liquid suspension in a stirred tank reactor. Advanced Powder Technology, 28(10), 2514–2523. doi:10.1016/j.apt.2017.06.027.

[15] Shahrokhi, M., Rostami, F., Md Said, M. A., Sabbagh Yazdi, S. R., & Syafalni. (2012). The effect of number of baffles on the improvement efficiency of primary sedimentation tanks. Applied Mathematical Modelling, 36(8), 3725–3735. doi:10.1016/j.apm.2011.11.001.

[16] Takahashi, K., Sugo, Y., Takahata, Y., Sekine, H., & Nakamura, M. (2012). Laminar mixing in stirred tank agitated by an impeller inclined. International Journal of Chemical Engineering. doi:10.1155/2012/858329.

[17] Atibeni, R., Gao, Z., & Bao, Y. (2013). Effect of baffles on fluid flow field in stirred tank with floating particles by using PIV. Canadian Journal of Chemical Engineering, 91(3), 570–578. doi:10.1002/cjce.21652.

[18] Pukkella, A. K., Vysyaraju, R., Tammishetti, V., Rai, B., & Subramanian, S. (2019). Improved mixing of solid suspensions in stirred tanks with interface baffles: CFD simulation and experimental validation. Chemical Engineering Journal, 358, 621–633. doi:10.1016/j.cej.2018.10.020.

[19] Rohatgi, P. K., Sobczak, J., Asthana, R., & Kim, J. K. (1998). Inhomogeneities in silicon carbide distribution in stirred liquids - A water model study for synthesis of composites. Materials Science and Engineering A, 252(1), 98–108. doi:10.1016/S0921-5093(98)00651-0.

[20] Tran, T. T., Vo, T. T., Cho, S. C., Lee, D. H., & Hwang, W. R. (2018). A stir casting system for drawdown of light particles in manufacturing of metal matrix composites. Journal of Materials Processing Technology, 257, 123–131. doi:10.1016/j.jmatprotec.2018.02.025.

[21] Suthar, J., & Patel, K. (2018). Identification, screening and optimization of significant parameters for stir cast hybrid aluminium metal matrix composite. Heliyon, 4(12). doi:10.1016/j.heliyon.2018.e00988.

[22] Sang, K., Yang, J., Shi, W., & Sun, H. (2014). Preparation of coatings on alumina ceramic for wettability. Ceramics International, 40(4), 5659–5663. doi:10.1016/j.ceramint.2013.11.002.

[23] Aqida, S. N., Ghazali, M. I., & Hashim, J. (2012). Effect of Porosity on Mechanical Properties of Metal Matrix Composite: An Overview. Jurnal Teknologi, 40, 17–32. doi:10.11113/jt.v40.395.

[24] Zhang, W. Y., Du, Y. H., & Zhang, P. (2019). Vortex-free stir casting of Al-1.5 wt% Si-SiC composite. Journal of Alloys and Compounds, 787, 206–215. doi:10.1016/j.jallcom.2019.02.099.

[25] Dareini, M., Jabbari, A. H., & Sedighi, M. (2020). Effect of nano-sized Al2O3 reinforcing particles on uniaxial and high cycle fatigue behaviors of hot-forged AZ31B magnesium alloy. Transactions of Nonferrous Metals Society of China, 30(5), 1249-1266. doi:10.1016/S1003-6326(20)65293-1.

[26] Fan, L. J., & Juang, S. H. (2016). Reaction effect of fly ash with Al-3Mg melt on the microstructure and hardness of aluminum matrix composites. Materials and Design, 89, 941–949. doi:10.1016/j.matdes.2015.10.070.

[27] Satish Kumar, T., Shalini, S., Kumar, K. K., Thavamani, R., & Subramanian, R. (2018). Bagasse Ash Reinforced A356 Alloy Composite: Synthesis and Characterization. Materials Today: Proceedings, 5(2), 7123–7130. doi:10.1016/j.matpr.2017.11.377.

[28] Narasaraju, G., & Raju, D. L. (2015). Characterization of hybrid rice husk and fly ash-reinforced aluminium alloy (AlSi10Mg) composites. Materials Today: Proceedings, 2(4-5), 3056-3064. doi:10.1016/j.matpr.2015.07.245.

[29] Mandal, A. K., & Sinha, O. P. (2018). New-Generation Aluminum Composite with Bottom Ash Industrial Waste. The Journal of the Minerals, Metals & Materials Society. JOM, 70(6), 811–816. doi:10.1007/s11837-018-2774-7.