

EFFECT OF STIRRING SPEED, TEMPERATURE, AND REINFORCEMENT FRACTION ON THE MICROSTRUCTURAL CHARACTERISTICS OF AL-SI/FE₂O₃ COMPOSITES

Dewi Izzatus Tsamroh^{a*}, Cepi Yazirin^b, Agus Suprpto^c

^aDiploma Program of Manufacturing Engineering Technology, Faculty of Vocational Studies, Universitas Negeri Malang, Jalan Semarang 5 Malang, 65145, Indonesia

^bDepartment of Mechanical Engineering, Faculty of Engineering, Universitas Islam Malang, Jalan MT Haryono 193 Malang, 65144, Indonesia

^cDepartment of Mechanical Engineering, Faculty of Engineering, Universitas Merdeka Malang, Jalan Terusan Raya Dieng 62-64 Malang, 65146, Indonesia

Article history

Received

28th August 2025

Revised

23rd November 2025

Accepted

13th January 2026

Published

2nd June 2026

*Corresponding email: dewi.tsamroh.fv@um.ac.id

ABSTRACT

This study investigates the influence of stirring speed, melting temperature, and reinforcement fraction on the microstructural characteristics of Al-Si/Fe₂O₃ composites produced using the stir casting method. A Taguchi-based experimental approach was employed to optimize the process variables through an orthogonal array design, enabling a systematic and efficient evaluation of parameter effects. The cast specimens were characterized using optical microscopy and SEM-EDX to examine morphology, particle distribution, and elemental composition. Grain size analysis was performed using Python-based image processing to obtain a more comprehensive quantification of the microstructure. The Taguchi analysis identified the optimal parameter combination at a stirring speed of 1000 rpm, a processing temperature of 600 °C, and a reinforcement fraction of 1 wt%. This setting produced a grain size of 235.92 μm, representing the most consistent performance based on the signal-to-noise ratio and demonstrating strong agreement between the predicted optimum and the observed microstructural results.

Keywords: Al-Si, Optimization, Reinforcement, Stir-Casting, Taguchi

© 2026 Penerbit UTM Press. All rights reserved

1.0 INTRODUCTION

Aluminium-silicon (Al-Si) alloys are pivotal materials in industries such as automotive, aerospace, and marine due to their favorable properties including lightweight, excellent corrosion resistance, and good castability [1]. However, the mechanical properties of Al-Si alloys, such as hardness, tensile strength, and wear resistance, often do not meet the stringent requirements of high-performance applications. To augment these properties, researchers have increasingly turned to aluminium matrix composites (AMCs), which incorporate various ceramic reinforcements. Among these, iron (III) oxide (Fe₂O₃) has gained considerable interest due to its advantageous characteristics, which include high hardness, thermal stability, and compatibility with the aluminium matrix. The addition of Fe₂O₃ not only enhances load-bearing capacity but also contributes to the refinement of the microstructure, ultimately leading to improved mechanical performance in Al-Si composites [2].

The mechanisms of reinforcement in AMCs hinge on several critical factors, mainly the type and fraction of reinforcing material, as well as the processing methods employed [3]. Fe_2O_3 particles contribute to load transfer mechanisms due to their rigidity, which restricts the motion of dislocations within the aluminium matrix, resulting in enhanced strength and wear resistance. Varying particle size and volume fraction could substantially influence the strengthening mechanisms in reinforced aluminium composites [4]. Furthermore, adequate dispersion of reinforcement particles is critical, insufficient mixing during the stir casting process could result in non-homogeneous particle distribution, adversely affecting the mechanical properties [5].

Stir casting is one of the most commonly employed techniques for fabricating AMCs due to its cost-effectiveness and scalability [3]. This method involves mechanically stirring the reinforcement particles into molten aluminium, which is then cast into molds. However, this technique presents challenges, particularly in achieving uniform distribution of ceramic particles, minimizing porosity, and avoiding particle clustering. These factors are critical to the performance of the resulting composite; stirring speed and temperature significantly impact the microstructural integrity and mechanical properties of the composites produced. Insufficient stirring speed can lead to sedimentation of reinforcement particles, while excessively high stirring can create air bubbles, increasing porosity [6].

Despite advancements in understanding the fabrication of Al–Si composites with Fe_2O_3 reinforcement, systematic investigation into how process parameters influence microstructural characteristics remains limited. Existing studies have generally focused on improvements in hardness and mechanical behavior without thoroughly correlating these enhancements with variations in particle dispersion or porosity [7]. Furthermore, the effects of interactions between Fe_2O_3 and the aluminium matrix on critical features such as primary Si phase formation and Fe_2O_3 distribution uniformity have not been fully explored [8]. Therefore, a focused examination on optimizing these variables is imperative to harness the full potential of Al–Si/ Fe_2O_3 composites for engineering applications.

2.0 EXPERIMENTAL PROCEDURE

The experimental work in this study can be seen in Figure 1.

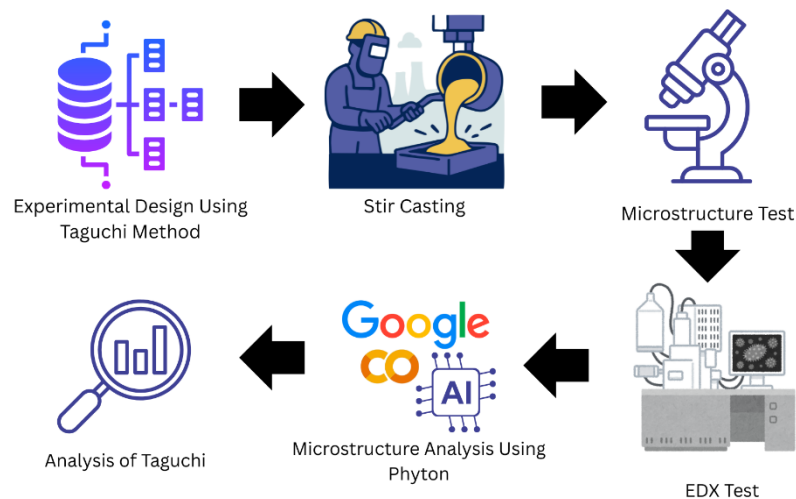


Figure 1: Research procedure.

The study was initiated by an optimization stage using the Taguchi method to determine the most suitable combination of processing parameters for the stir casting technique [9]. This statistical approach was selected to systematically evaluate the influence of key factors

and their interactions on the quality of the casting, while minimizing the number of experimental trials required.

Based on the optimized parameters obtained from the Taguchi analysis, the stir casting process was then carried out to fabricate the composite specimens. The molten matrix and reinforcement materials were prepared and mixed under the controlled conditions defined in the optimization stage, ensuring reproducibility and consistency. Following the casting process, the specimens were subjected to microstructural characterization. The results of the microstructural tests provided essential insights into the effectiveness of the optimized parameters in improving material quality.

2.1 Experimental Design

The optimization of stir casting parameters was carried out using the Taguchi method with an orthogonal array design [10]. Three main process parameters were selected: stirring speed (rpm), stirring temperature (°C), and weight fraction of Fe₂O₃ reinforcement (%wt). Each parameter was assigned three levels based on preliminary studies and literature review. The objective was to minimize the average grain size of the composite, where “Smaller-is-Better” was applied as the quality characteristic in the Signal-to-Noise (S/N) ratio analysis.

2.2 Stir Casting Process

Based on the optimum parameter combination obtained from the Taguchi analysis, the stir casting process was conducted as follows:

- 1) Material Preparation
This study used Aluminum-Silicon (Al-Si) as the matrix, and Fe₂O₃ powder as the reinforcement material.
- 2) Melting
The Al-Si alloy was melted in an electric resistance furnace at a temperature slightly above its liquidus.
- 3) Reinforcement Addition
Preheated Fe₂O₃ powder was gradually introduced into the molten alloy to improve wettability and minimize thermal shock.
- 4) Stirring
The molten mixture was stirred at the specified stirring speed and stirring temperature for a predetermined duration to ensure homogeneous distribution of reinforcement particles.
- 5) Casting
The stirred molten composite was poured into a preheated metallic mold and allowed to solidify under ambient cooling.

2.3 Microstructural Characterization

The cast specimens were sectioned, polished, and etched for microstructural observation. Optical microscopy was employed to capture images of the grain structure. Image analysis was performed to quantify the average grain size. The test was followed by EDX test to obtain the composition of specimen after casting process.

2.4 Data Analysis Using Python in Google Colab

The microstructural images were processed and analysed using Python in Google Colab [11]. The procedure involved:

- Image Pre-processing: Conversion to grayscale, noise filtering, and thresholding to enhance grain boundaries.
- Segmentation: Identification of grain boundaries using edge detection algorithms.
- Grain Size Measurement: Calculation of average grain size using ASTM E112 intercept method adapted in Python.
- Statistical Processing: Aggregation of grain size measurements for each experimental condition.

2.5 Taguchi Analysis

The grain size results obtained from image analysis were further processed using the Taguchi method to determine the effect of each process parameter on grain size and optimal parameter combination for minimum grain size.

3.0 RESULTS AND DISCUSSION

The results of this study demonstrate the influence of various stir casting process parameters on the microstructure of Al-Si composites reinforced with Fe₂O₃ particles. Process optimization was carried out using the Taguchi method with three main factors: stirring speed, stirring temperature, and weight fraction of the reinforcement. Experimental data were obtained based on an orthogonal array design and subsequently analyzed to determine the optimal combination of parameters.

Following the optimization process, stir casting was performed using the best parameter combination, and microstructural examinations were conducted to observe the grain size. Microstructural image analysis was carried out using Google Colab (Python-based) to obtain quantitative grain size data [12]. The results were further processed using the Taguchi method to identify the relative influence of each process parameter on the outcome.

3.1 Orthogonal Array (Design of Experiments – Taguchi)

Table 1. Orthogonal Array L9

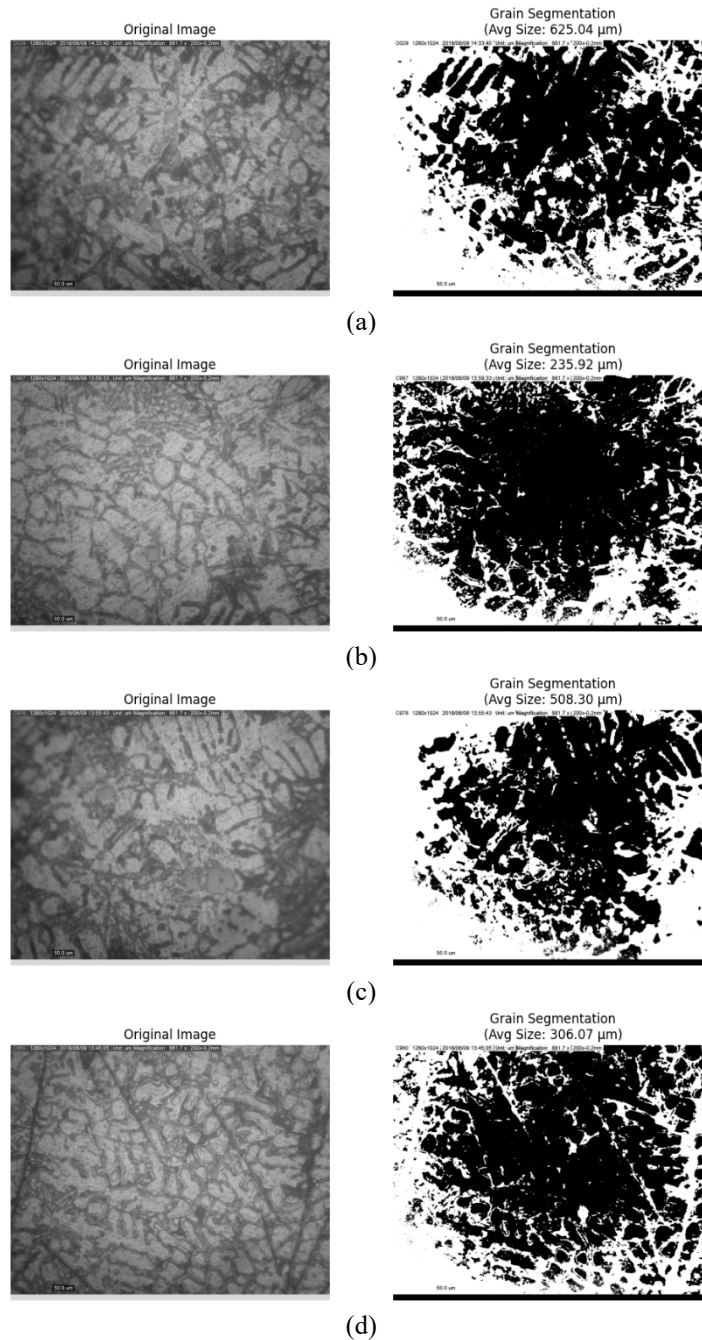
Run	Stirring speed (rpm)	Stirring temperature (°C)	Weight fraction (wt% Fe ₂ O ₃)
1	1000	600	0.5
2	1000	700	1.0
3	1000	800	2.0
4	1500	600	1.0
5	1500	700	2.0
6	1500	800	0.5
7	2000	600	2.0
8	2000	700	0.5
9	2000	800	1.0

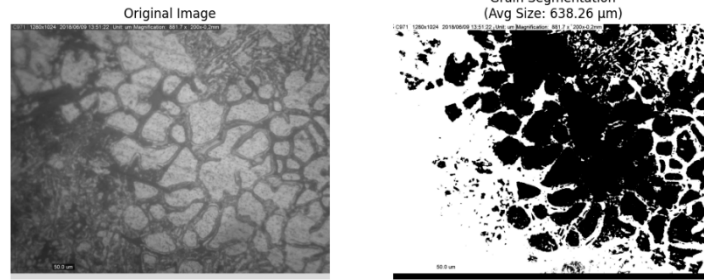
Table 1 presents the experimental runs based on the L9 orthogonal array of the Taguchi method, involving three factors—stirring speed, stirring temperature, and weight fraction of Fe₂O₃ reinforcement—each at three levels.

3.2 Microstructure Result

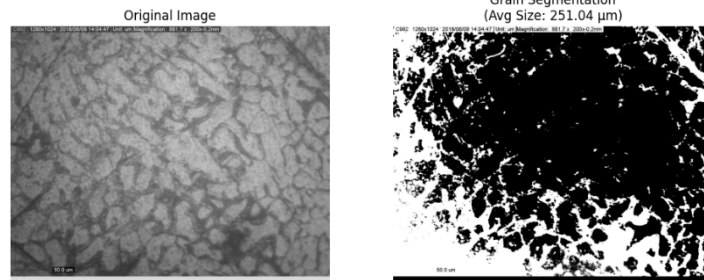
It is essential to examine how the microstructure evolves under different combinations of stirring speed, temperature, and reinforcement content. In this study, nine experimental runs were designed to capture a broad range of parameter variations, allowing a direct

comparison of their effects on grain morphology and overall structural uniformity. Each run presents a distinct microstructural response, shaped by the interplay between thermal energy, mechanical agitation, and reinforcement percentage. By examining these variations, it becomes possible to identify trends, highlight the mechanisms responsible for microstructural changes, and determine the optimal balance of parameters for achieving the desired material performance. The microstructural image presented in this study was generated through an automated analysis workflow developed using Python on Google Colab. This computational approach enabled precise segmentation, measurement, and visualization of grain boundaries based on high-resolution metallographic images. The resulting image reflects the processed output produced directly from the Python script, serving as a reliable representation of the composite's grain morphology.

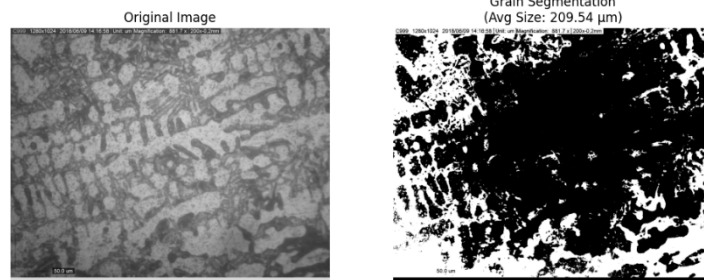




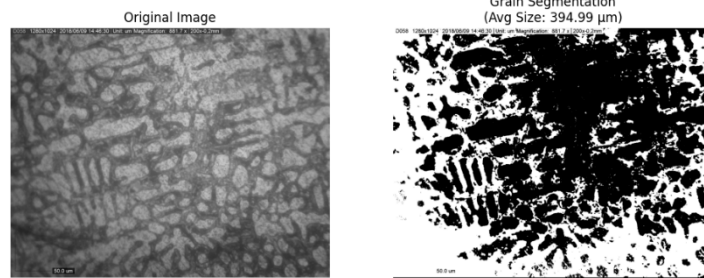
(e)



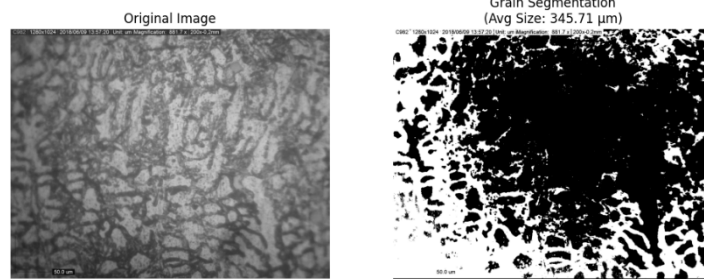
(f)



(g)



(h)



(i)

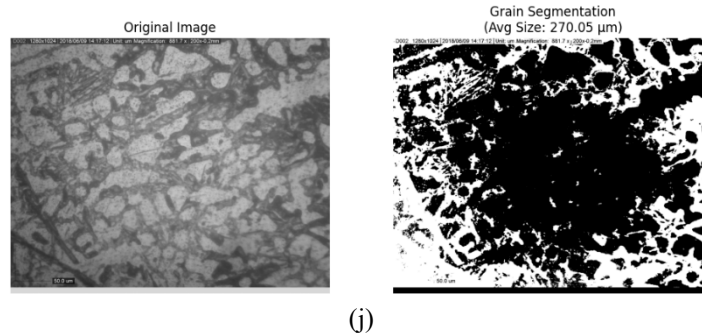


Figure 2: Microstructure of Al-Si/Fe₂O₃ (a) raw material; (b-j) specimen in variation 1-9

The microstructural evaluation begins with the raw aluminium-silicon (Al-Si) alloy, characterized by a coarse eutectic structure with elongated silicon particles and an average grain size of approximately 625 μm . This baseline serves as a reference point for understanding the microstructural evolution that occurs during stir casting under various processing parameters.

Throughout Runs 1 to 9, a systematic and clear trend emerged from the combined effects of stirring speed, processing temperature, and reinforcement fraction. It was observed that stirring speed primarily influenced dendrite fragmentation and particle dispersion; a higher speed facilitated finer distributions of reinforcement particles throughout the alloy. Meanwhile, processing temperature played a crucial role in governing atomic mobility and grain growth behaviors. Increased temperatures generally led to enhanced atomic diffusion but also risked promoting excessive grain growth unless carefully monitored [13]. Furthermore, the introduction of Fe₂O₃ reinforcement contributed to heterogeneous nucleation and Zener pinning mechanisms. The reinforcing particles acted as nucleation sites for new grains, which effectively hindered the movement of other grains and thus refined the overall microstructure; however, the specific effect of Fe₂O₃ in Al-Si systems requires further corroboration in this context [8].

At lower to intermediate parameter levels (Runs 1-3), the specimens exhibited finer and more uniform grain structures compared to the raw alloy. Moderate stirring speeds, particularly at 1000 rpm, along with controlled processing temperatures, facilitated dynamic recrystallization processes. In this regime, the introduction of Fe₂O₃ provided boundary pinning, which inhibited the uncontrolled growth of grains. However, as temperatures increased beyond 700–800 °C, particularly when reinforcement content was not sufficiently high, grain coarsening began to be evident. This phenomenon illustrated the sensitivity of microstructural characteristics to both thermal and compositional factors, consistent with findings where thermal effects lead to coarsening unless managed carefully.

In the mid-range parameter group (Runs 4-6), the microstructural response was strongly influenced by temperature conditions. Run 4 resulted in the formation of the largest average grain size (638 μm), indicating that high stirring speed, coupled with relatively low temperatures, limited nucleation effectiveness and allowed for significant grain growth. Conversely, Runs 5 and 6 showcased substantial grain refinement, with sizes notably reduced to between 209–251 μm . This refinement can be attributed to the increase in particle loading or a favorable balance between nucleation rates and controlled grain growth enhanced by sufficient stirring and elevated temperatures.

At higher parameter levels (Runs 7-9), the specimens exhibited a mixture of refined and partially coarsened microstructures. Very high stirring speeds (2000 rpm) facilitated dendrite breakdown, enhancing the dispersion of particles, yet the corresponding high temperatures often promoted grain expansion unless adequately countered by the presence of Fe₂O₃. Notably, Run 9 yielded the finest grain size within this group (270 μm), reflecting the effective synergy where high stirring speed, elevated temperature, and moderate

reinforcement content converged to achieve optimal microstructural conditions [14]. The following table presents the microstructure data.

Table 2. Grain size of specimen

Specimen	Grain size (μm)
Raw	625.04
1	235.92
2	508.30
3	306.07
4	638.26
5	251.04
6	209.54
7	394.99
8	345.71
9	270.05

Overall, the trends illustrate that optimal grain refinement occurs under intermediate processing conditions where mechanical deformation and thermal activation are balanced. This balance maximizes recrystallization processes while minimizing excessive grain growth [2]. Such behavior aligns with established principles of thermomechanical processing, which emphasize the competing influences of strain-induced nucleation and temperature-driven coarsening in determining the final grain morphology. Future investigations may benefit from focusing on the precise interaction mechanisms between processing parameters to further refine the understanding of microstructural behavior in Al–Si/Fe₂O₃ composites.

3.3 Elemental Analysis

The elemental analysis that conducted by EDX, provided complementary insight into the surface morphology and elemental distribution of the Al–Si/Fe₂O₃ composite specimens. The SEM micrographs reveal the morphological characteristics of the matrix, reinforcement particles, and interfacial regions, while the EDX spectra confirm the elemental composition and verify the successful incorporation of Fe₂O₃ into the aluminum–silicon matrix. The following figure presents the results of the EDX analysis.

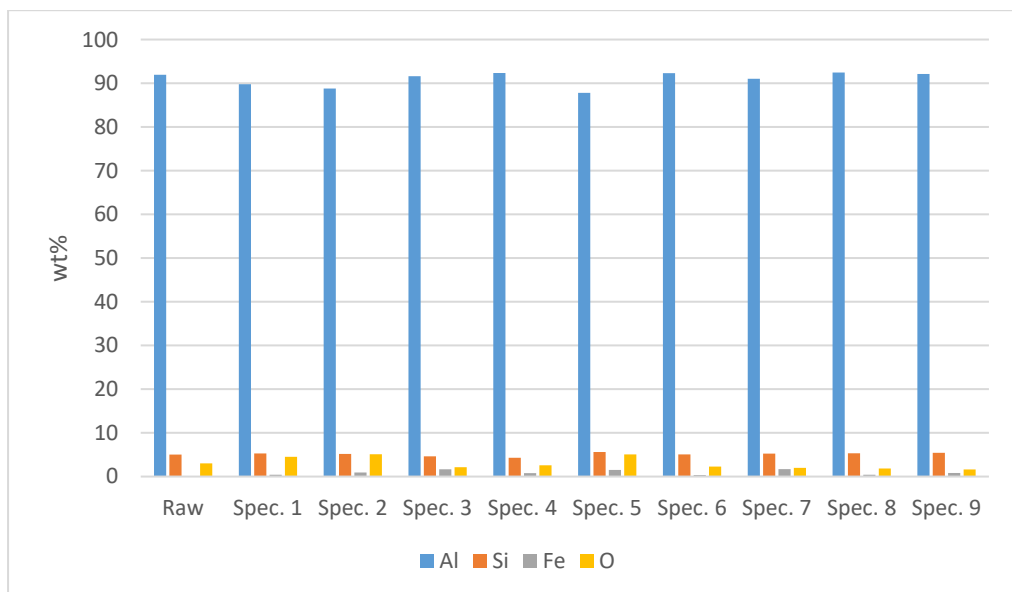


Figure 3: Result of EDX analysis

The Energy Dispersive X-ray Spectroscopy (EDX) analysis for the stir-cast Al–Si/Fe₂O₃ specimens revealed a consistent elemental composition across all samples, with aluminum (Al) identified as the primary matrix element. As indicated by the EDX charts, Al content consistently exceeds 85–90 wt% in every specimen, suggesting that the stir casting and stirring processes did not significantly alter the matrix composition. This finding correlates with literature emphasizing the effectiveness of proper stirring techniques in maintaining matrix integrity during the casting process [15].

Silicon (Si) content also exhibited stability across all specimens, remaining within a narrow range reflective of the typical eutectic composition of Al–Si alloys. The steady Si levels imply that the thermal and mechanical conditions during stir casting did not lead to significant segregation or dissolution of the Si phase, in agreement with findings that highlight the importance of process conditions in preserving the phase integrity of Al–Si alloys. This uniformity in silicon content is critical, as fluctuations can adversely affect the mechanical properties and overall performance of the composite material.

The presence of iron (Fe) and oxygen (O) in the EDX results confirms the successful incorporation of Fe₂O₃ reinforcement particles into the composite. While the overall percentages of Fe and O remain relatively low compared to Al and Si, their presence across all specimens indicates effective retention of the reinforcement within the final solidified structure. This retention supports earlier studies that stress the importance of adequate dispersion of reinforcement particles to avoid sedimentation and ensure mechanical integrity in metal matrix composites (MMCs) [16]. Variations in Fe and O levels among the specimens are reflective of differences in reinforcement content and dispersion effectiveness, which are influenced by stirring speed, temperature, and weight fraction.

Moreover, the interaction between the stirring parameters and the incorporation of Fe₂O₃ is crucial in understanding the microstructural characteristics of the composites. Elevated stirring speeds can enhance particle dispersion through increased dynamic stresses, potentially improving the overall performance of the cast composite [17]. However, it is vital to maintain a balance; excessively high stirring speeds could lead to defects such as porosity or particle clustering, negatively affecting the mechanical properties of the composites.

Additionally, the findings indicate that EDX analysis is essential for validating successful reinforcement incorporation in the matrix and correlating compositional changes with the mechanical properties of the composites. Insights gained from EDX can inform further optimization of stir casting parameters to improve dispersion and effectiveness of reinforcement materials, contributing to desired mechanical performance and microstructural characteristics [18].

3.4 Taguchi Analysis

Before presenting the main effects plot, it is important to highlight that the Taguchi method was employed to evaluate the influence of key process parameters on the experimental response. The factors considered in this analysis include stirring speed, stirring temperature, and weight fraction of reinforcement. By plotting the signal-to-noise (S/N) ratios for each factor, it becomes possible to visually identify the trend and relative impact of each parameter on the outcome. The “smaller is better” criterion was applied, indicating that a lower S/N ratio corresponds to improved performance in the measured response [9]. The following figure presents the main effects plot, which serves as a basis for determining the optimal parameter settings.

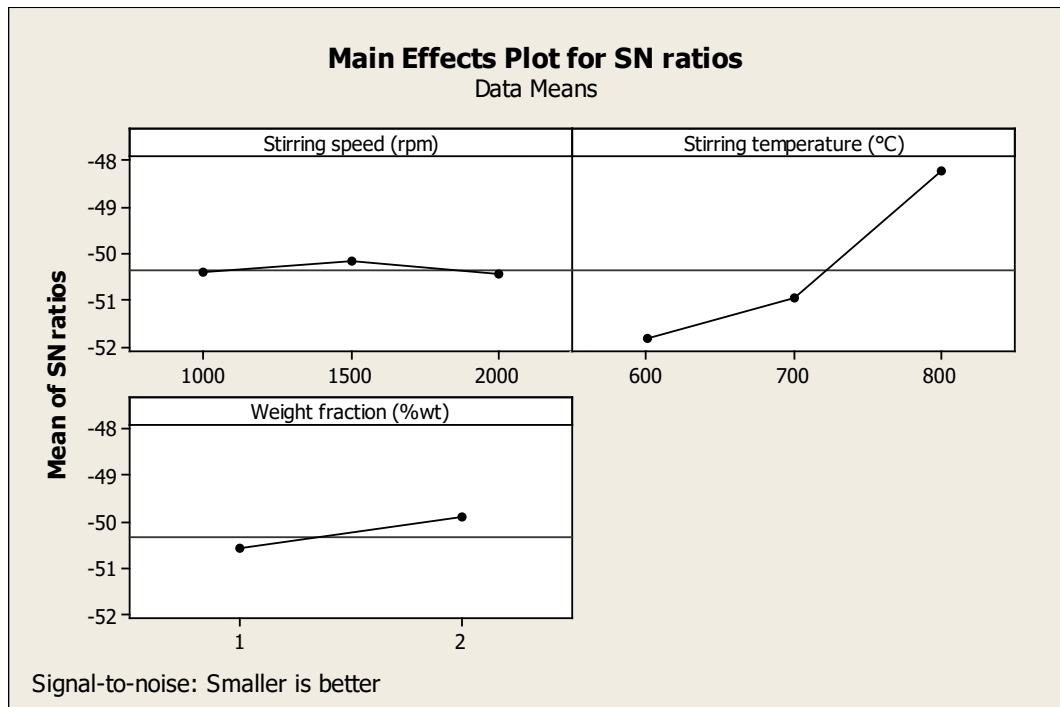


Figure 4. Main effects plot for signal-to-noise (S/N) ratios.

According to the Figure 4, the Taguchi analysis indicated that the optimal parameter setting consisted of 1000 rpm stirring speed, 600 °C processing temperature, and 1 wt% reinforcement. Although this combination corresponds to Run 1, which does not yield the smallest grain size among all experimental runs, it provides the most robust performance based on the S/N ratio. This implies that the selected factor levels generate consistently larger grain sizes while minimizing noise-induced variation.

In contrast, Run 6 produced the smallest grain size (209.54 μm). This is attributed to the high stirring temperature of 800 °C, which accelerates melt convection and promotes grain refinement, combined with the relatively high stirring speed (1500 rpm) that enhances dendrite fragmentation. The low reinforcement fraction (0.5 wt%) further reduces heterogeneous nucleation sites that typically contribute to grain coarsening, resulting in finer grain formation. Therefore, Run 6 represents the least favorable condition for maximizing grain size.

4.0 CONCLUSION

The microstructural observations demonstrate that variations in stirring speed, temperature, and reinforcement weight fraction significantly influence particle distribution and interfacial bonding within the Al-Si matrix. Lower stirring temperatures tend to produce finer and more uniformly dispersed particles, whereas excessive temperatures lead to particle agglomeration and reduced bonding quality. The Taguchi analysis confirms that stirring temperature is the most influential factor, followed by weight fraction, with stirring speed having a lesser impact. The optimal processing parameters derived from the Taguchi method—1000 rpm stirring speed, 600 °C stirring temperature, and 1 wt% reinforcement—correlate with microstructural features exhibiting uniform particle dispersion, minimal porosity, and improved matrix–reinforcement bonding, which are expected to enhance the composite’s mechanical performance.

REFERENCES

- [1] C. Yazirin, P. Puspitasari, and M. F. Arif, "Comparison Study of Mechanical Properties of Al-Si Alloy with and without Nanoreinforce Iron Oxide (Fe₂O₃)," *J. Mech. Eng. Sci. Technol.*, vol. 3, no. 1, pp. 29–34, 2019, doi: 10.17977/um016v3i12019p029.
- [2] K. Aldawoudi, A. M. Nattah, N. S. Radhi, Z. S. Al-Khafaji, and M. K. Ibrahim, "Identify Microstructure and Mechanical Behavior of Aluminum Hybrid Nano Composite Prepared by Casting Technique," *Jordan J. Mech. Ind. Eng.*, vol. 19, no. 1, pp. 163–170, 2025, doi: 10.59038/jjmie/190112.
- [3] K. Pohnhan, P. Jiandon, K. Juntaracena, C. Potisawang, and M. Kongpuang, "Enhanced microstructures, mechanical properties, and machinability of high performance ADC12/SiC composites fabricated through the integration of a master pellet feeding approach and ultrasonication-assisted stir casting," *Results Eng.*, vol. 24, no. September, p. 102937, 2024, doi: 10.1016/j.rineng.2024.102937.
- [4] B. N. Akash Deep *et al.*, "Ultrasonic assisted stir squeeze casting of AA5456/Al₂O₃-SiC-Gr-MoS₂ hybrid nanocomposites: Microstructure and strengthening analysis," *J. Mater. Res. Technol.*, vol. 34, no. July 2024, pp. 1611–1635, 2025, doi: 10.1016/j.jmrt.2024.12.172.
- [5] C. Chen, X. Yin, W. Liao, Y. Xiang, M. Gao, and Y. Zhang, "Microstructure and properties of 6061/2A12 dissimilar aluminum alloy weld by laser oscillation scanning," *J. Mater. Res. Technol.*, vol. 14, pp. 2789–2798, 2021, doi: 10.1016/j.jmrt.2021.08.105.
- [6] A. A. Adebisi, M. A. Maleque, and M. B. Ndaliman, "Influence of Stirring Speed on Microstructure and Wear Morphology of SiCp-6061Al Composite," *Int. J. Eng. Mater. Manuf.*, 2016, doi: 10.26776/ijemm.01.01.2016.05.
- [7] S. Meng *et al.*, "Effect of local loading on microstructure and enhanced mechanical property of large complex castings prepared by Al-Si-Fe-Mn-Mg-Cu alloy during squeeze casting," *J. Mater. Sci. Technol.*, vol. 200, pp. 215–226, 2024, doi: 10.1016/j.jmst.2023.12.082.
- [8] F. Khosravi Maleki, M. KM Nasution, M. S. Gok, and V. Arab Maleki, "An experimental investigation on mechanical properties of Fe₂O₃ microparticles reinforced polypropylene," *J. Mater. Res. Technol.*, vol. 16, pp. 229–237, 2022, doi: 10.1016/j.jmrt.2021.11.104.
- [9] J. T. O. Florenciano, A. Ambrosi, D. Hotza, and S. Y. G. González, "Understanding centrifugal casting in the manufacture of functionally graded materials," *J. Eur. Ceram. Soc.*, vol. 42, no. 15, pp. 7089–7101, 2022, doi: 10.1016/j.jeurceramsoc.2022.08.042.
- [10] D. I. Tsamroh, P. Puspitasari, A. Andoko, A. A. Permanasari, and P. E. Setyawan, "Optimization of multistage artificial aging parameters on Al-Cu alloy mechanical properties," *J. Achiev. Mater. Manuf. Eng.*, vol. 87, no. 2, pp. 62–67, 2018, doi: 10.5604/01.3001.0012.2828.
- [11] M. Ackermann, D. Iren, S. Wesselmecking, D. Shetty, and U. Krupp, "Automated segmentation of martensite-austenite islands in bainitic steel," *Mater. Charact.*, vol. 191, no. July, p. 112091, 2022, doi: 10.1016/j.matchar.2022.112091.
- [12] X. Liu and C. Aldrich, "Automatic Microstructural Classification of Ultrahigh Carbon Steel with Vision Transformers and Convolutional Neural Networks," *IFAC Pap.*, vol. 58, no. 22, pp. 119–123, 2024, doi: 10.1016/j.ifacol.2024.09.301.
- [13] Z. Ma *et al.*, "Microstructural evolution and enhanced mechanical properties of Mg-Gd-Y-Zn-Zr alloy via centrifugal casting, ring-rolling and aging," *J. Magnes. Alloy.*, vol. 10, no. 1, pp. 119–128, 2022, doi: 10.1016/j.jma.2020.11.009.
- [14] R. Singh, "Progress of environment friendly cutting fluids/solid lubricants in turning-A review," *Mater. Today Proc.*, vol. 37, no. Part 2, pp. 3577–3580, 2020, doi: 10.1016/j.matpr.2020.09.585.
- [15] E. A. Diler, "Microstructure and Mechanical Properties of Al-Si-Cu-Fe Alloy-Based Ceramic Particle-Reinforced Nanocomposites and Microcomposites and a Modified Model to Predict the Yield Strength of Nanocomposites," *Proc. Inst. Mech. Eng. Part L J. Mater. Des. Appl.*, 2021, doi: 10.1177/14644207211009924.
- [16] F. Kamali and M. Azadi, "An Evaluation of Tribological and Mechanical Properties of Al-Si-Cu Alloy With Nano-Clay Particles Reinforcement," *Proc. Inst. Mech. Eng. Part C J. Mech. Eng. Sci.*, 2019, doi: 10.1177/0954406219869746.
- [17] A. A. Adediran, A. A. Akinwande, O. A. Balogun, B. J. Olorunfemi, and S. K. M., "Optimization studies of stir casting parameters and mechanical properties of TiO₂ reinforced Al 7075 composite using response surface methodology," *Sci. Rep.*, vol. 11, no. 1, pp. 1–20, 2021, doi: 10.1038/s41598-021-99168-1.
- [18] S.-S. Ahn *et al.*, "Enhancement of the Mechanical Properties in Al-Si-Cu-Fe-Mg Alloys With Various Processing Parameters," *Materials (Basel)*, 2018, doi: 10.3390/ma11112150.