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FABRICATION, MECHANICAL CHARACTERIZATION AND STATISTICAL OPTIMIZATION OF ALUMINIUM 7075 METAL MATRIX COMPOSITE REINFORCED WITH COPPER, SILICON CARBIDE AND FLY ASH

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Abstract - *Aluminum 7075 alloy is widely applicable to the aerospace, automotive, and structural industries as it has a high ratio, but its wear resistance and hardness on the surface are not sufficient to withstand extreme service conditions. In the current study, a hybrid metal matrix composite through the stir casting method was made using Aluminum 7075 reinforced with Copper (Cu), Silicon Carbide (SiC) and Fly Ash. A Taguchi L9 orthogonal array was used to design three levels of reinforcement so as to make the experiments fewer in number but still statistically reliable. The artificial composites were machined as per the ASTM standards, and the strength and hardness of the composite were evaluated in terms of tensile strength. Signal-to-noise (S/N) ratio analysis and Analysis of Variance (ANOVA) were used to statistically optimize between all of these reinforces to assess their contribution to the mechanical performance. As the experimental findings indicate, the addition of SiC leads to great improvement in hardness and tensile strength owing to the high degree of stiffness and load-bearing capacity, which, on the other hand, Copper strengthens the interfacial bonding and ductility by solid solution strengthening effects. The fly ash also helps improve stiffness and reduce weight; therefore, it makes the composite economical and sustainable to the environment. The optimum composition, which is obtained through Taguchi and ANOVA analysis, has better mechanical performance than the base alloy. The research verifies that stir casting is a convenient and economical process in the manufacturing of high-performance Aluminum 7075 hybrid composites that are applicable in high engineering purposes.*

Keywords: Hybrid metal matrix composite, Silicon carbide, fly ash, Stir casting, Aluminum 7075, Taguchi method, ANOVA.

Introduction

The aluminum alloys are important in present-day engineered applications because they are low-density, have high specific strength, possess good corrosion resistance, and are well machinable [1]. Aluminum 7075, among them, is one of the strongest heat-treatable aluminum alloys and has found wide application in aerospace structures, automotive parts and defense applications where the ratio of strength to weight is the most vital [2]. Even though Aluminum 7075 has superior strength and fatigue resistance, Aluminum 7075 has limited wear resistance and average hardness on the surface, limiting its use in components that require high friction and abrasive conditions [3].

Over the recent years, metal matrix composites (MMCs) have been receiving considerable attention due to the fact that they possess better mechanical and tribological characteristics than monolithic alloys [4]. The effectiveness of load transfer and suppression of plastic deformation has been known to help harden, stiffen and increase the wear resistance of aluminum matrices by incorporating hard ceramic reinforcements like Silicon Carbide (SiC) into them [5]. The added content of ceramic particles may, however, render it brittle and ductile in nature. To address this drawback, hybrid metal matrix composite, i.e., mixtures of metallic and ceramic reinforcements have also been suggested to provide a balanced strength, hardness and toughness [6].

Copper finds extensive application as a strengthening agent or an alloying element in aluminum alloys due to its ability to enhance strength by solid solution strengthening as well as precipitation strengthening mechanisms [7]. Recently, fly ash, a by-product of thermal power plants, because of its industrial waste, has also received attention as a low-cost and lightweight reinforcing material and has been shown to contribute to the stiffness increment and environmental friendliness [8]. Adding Copper, SiC and Fly Ash into Aluminum 7075 simultaneously is hence likely to make it a cost-effective hybrid composite with higher mechanical performance.

The current paper is devoted to the production of Aluminum 7075 hybrid metal matrix composites using the stir casting method, along with an assessment of the mechanical characteristics of the obtained materials. Also, a Taguchi-based statistical method, along with ANOVA, is utilized to find the best reinforcement mixture and determine the most significant parameters on tensile strength and hardness.

Literature Review

Aluminum 7075 is a high-strength Al-Zn-Mg-Cu series alloy that has been significantly explored in the context of superior structural use as it shows a superb strength-to-weight ratio and boasts good fatigue performance [1]. Nevertheless, its relatively low wear resistance and moderate surface hardness have prompted researchers to come up with Aluminum 7075-based metal matrix composites (MMCs) and hybrid composites that have better mechanical and tribological properties [2]. Silicon Carbide (SiC) is one of these reinforcements that have been highly adopted due to its high hardness, thermal stability, and good load-bearing capacity, among other things [3].

It has been found by various researchers that the introduction of SiC particles in Aluminum 7075 greatly increases hardness, tensile strength and wear resistance because of the effective mechanisms of transferring loads and grain refining [4]. Bharathi et al. [5] prepared Al7075-SiC composites by the powder metallurgy method, where they noted that there was a significant rise in the hardness and refinement of the grain structure with a rise in SiC content. On the same note, Mulugundam et al. [6] documented enhanced mechanical and tribo logical behavior of Al7075 composites with 15 wt% SiC, which was attributed to dispense homogeneity and high interfacial bonding.

During the last several years, hybrid metal matrix composites have become of interest since the reinforcements can be tailored more easily when two or more are combined [7]. Fly ash has also become a promising low-cost and lightweight reinforcement whose two-fold benefits are a reduction in the cost and waste use [8]. According to Rajesh et al. [9], the hardness and tensile strength of Al7075 composites reinforced with SiC and fly ash were better than those of the base alloy. Equally, Sathishkumar et al. [10] indicated that fly ash-based aluminum composites exhibited better wear resistance, higher stiffness and acceptable ductility.

The addition of copper into alloys of aluminum is frequently done to increase strength by solid solution strengthening as well as being precipitation hardened [11]. Sravanthi et al. [12] have shown that tensile strength and hardness are greatly enhanced with the controlled addition of copper in Al7075. It has also been reported that the interface bonding and efficiency of load transfer are enhanced by the combined effect of Copper and SiC reinforcements [13].

Though numerous studies have been done on the Al7075 composites with reinforcements using either single or two reinforcements, there is little research done on the use of Copper, SiC and Fly Ash combined with statistical optimization methods, including the Taguchi method and ANOVA [14]. Hence, this research will fill this research gap by formulating and refining an Al7075-Cu-SiC-Fly Ash hybrid composite through an experimental and statistical procedure.

Materials and Methodology

Aluminum 7075 alloy was chosen as the matrix in the current investigation as it has a high strength-weight ratio, excellent fatigue resistance, and a large range of use in the aerospace and structural applications [1]. Zinc, magnesium, and copper are the main alloying elements of the chemical composition of Al7075. Copper (Cu), Silicon Carbide (SiC) and Fly ash were selected as reinforcements to come up with a hybrid metal matrix composite. Solid solution strengthening was done using copper powder to increase strength and interfacial bonding, and to increase hardness, stiffness, and wear resistance. SiC particles were used [2]. The industrial waste by-product, fly ash, was included to enhance the stiffness and sustainable development of materials as a lightweight and low-cost reinforcement [3]

Table 0-1 Composition of Al 7075

Material	Weight %
Copper.	1.53%
Chromium.	0.20%
Magnesium	2.50%
Zinc.	5.45%
Iron.	0.20%
Manganese.	0.25%
Silicon.	0.30%
Titanium.	0.16%
Aluminum.	Remaining

The composites were made by the stir casting method, which happens to be one of the cheapest, in addition to the most common liquid metallurgy pathways of fabricating aluminums matrix composites [4]. The ingots of aluminum 7075 were melted in an electric resistance furnace with the temperature around 800-850 degC. To enhance wettability, the reinforcement particles were preheated at 400-600 degC in order to remove moisture. A vortex was formed in the molten-aluminums by mechanical stirring, and the reinforcements to be used were preheated and in the molten-aluminum and added gradually at a stirring rate of 300-600 rpm to allow even distribution to take place within a period of 8-10 minutes.

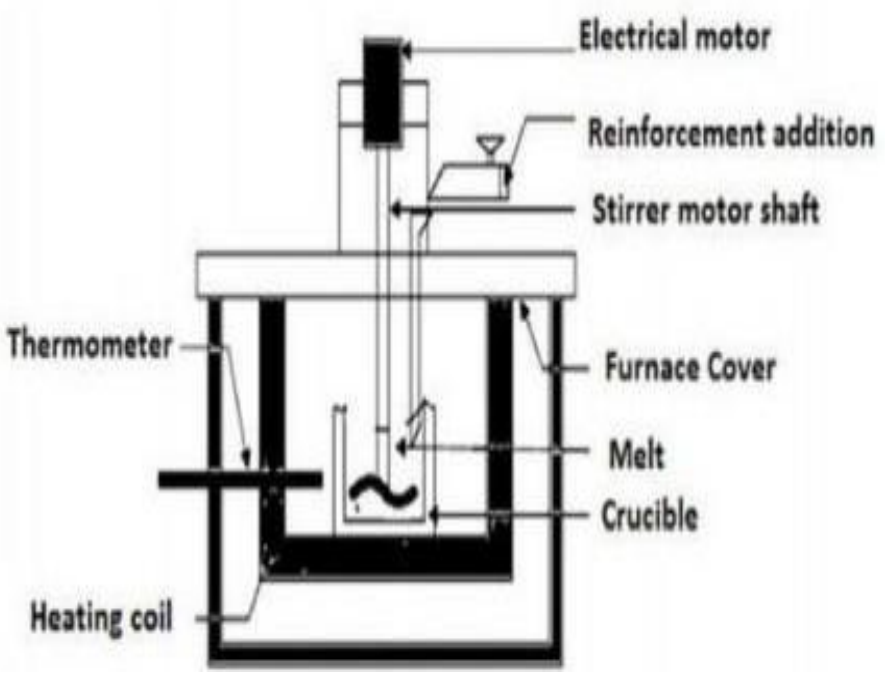

***Figure 0-1** Stir Casting Experimental Setup*

According to the Design of Experiments introduced by Taguchi, an L9 orthogonal array was used, and three control factors (Cu, SiC and Fly Ash) were selected, and three levels were used to design the experimental matrix [5]. The molten mix was then carefully mixed, and then the mixture was poured into preheated metallic molds and left to dry at ambient temperature.

The samples of cast were machined according to the ASTM standards to obtain mechanical testing samples. Universal Testing Machine was used to apply tensile tests in compliance with ASTM E8/ E8M, and hardness was determined through the use of Vickers hardness testing. Signal-to-noise ratio and Analysis of Variance (ANOVA) were also used to analyse the experimental results in determining the significance of each parameter of reinforcement.

Table 0-2 *Design of Compositions – 3 Levels*

Experimental No.	Aluminium 7075 (wt%)	Copper (wt%)	SiC (wt%)	Fly Ash (wt%)	Level
1	94	2	2	2	Low
2	94	1	3	2	Low
3	94	2	1	3	Low
4	92	3	3	2	Medium
5	92	2	4	2	Medium
6	92	3	2	3	Medium
7	90	4	4	2	High
8	90	3	5	2	High
9	90	4	3	3	High

Analysis

1.1 Taguchi Method of Design of Experiments.

In the current study, the Taguchi technique has been incorporated to effectively examine the effect of the reinforcement parameters on the mechanical properties of the Aluminium 7075 hybrid composite at the least number of experiments [1]. The control factors were taken to be three, i.e. Copper (Cu), Silicon Carbide (SiC) and Fly Ash and each of them at three levels. A nine-experiment orthogonal array was chosen, a design that would only need 9 experimental runs rather than 27 that would be needed in a complete factorial design. This method provides major savings in terms of cost and time of the experiment and preserves the statistical reliability [2].

Design Summary
Taguchi Array L9(3^3)
Factors: 3
Runs: 9
Columns of L9(3^4) array: 1 2 3

Table 0-1 *Experimental Results*

WT% OF COPPER	WT% OF SILICON CARBIDE	WT% OF FLY ASH	TENSILE STRENGTH	HARDNESS
2	3	2	332	126
2	4	2	339	124
2	5	3	335	125
3	3	2	358	138
3	4	3	368	140
3	5	2	362	137
4	3	3	396	144
4	4	2	388	140
4	5	2	392	141

The performance properties that were to be optimized were ultimate tensile strength (UTS) and Vickers hardness. The signal-to-noise (S/N) ratio calculation is based on the larger-the-better criterion, as both of the properties are to be maximized. The standard Taguchi formulation used to compute the S/N ratio of each response enables simultaneous consideration of both the average and the variation in one statistic [3].

1.2 Signal-to-noise ratio analysis

The analysis of the signal-to-noise ratio was conducted to determine the best combination of the reinforcement parameters that are able to maximize the tensile strength and hardness.
Larger is better

Table 0-2 *Response Table for Signal To Noise Ratios For Tensile Strength*

Level	WT% OF COPPER	WT% OF SILICON CARBIDE	WT% OF FLY ASH
1	50.51	51.15	51.15
2	51.19	51.23	51.26
3	51.87	51.18	
Delta	1.36	0.08	0.10
Rank	1	3	2

Response table for signal to noise ratio is tabulated in Table 4-2 for TENSILE STRENGTH, and observed that the delta value for signal to noise ratio is higher for Copper, followed by Silicon Carbide and Fly Ash.

Table 0-3 *Response Table For Means For Tensile Strngth*

Level	WT% OF COPPER	WT% OF SILICON CARBIDE	WT% OF FLY ASH
1	335.3	362.0	361.8
2	362.7	365.0	366.3
3	392.0	363.0	
Delta	56.7	3.0	4.5
Rank	1	3	2

Response table for means is tabulated 4-3 for TENSILE STRENGTH and found that standard deviation is higher for Copper follwed by Silicon Carbide and Fly Ash. Copper has more effect on the response compared to other two factors.

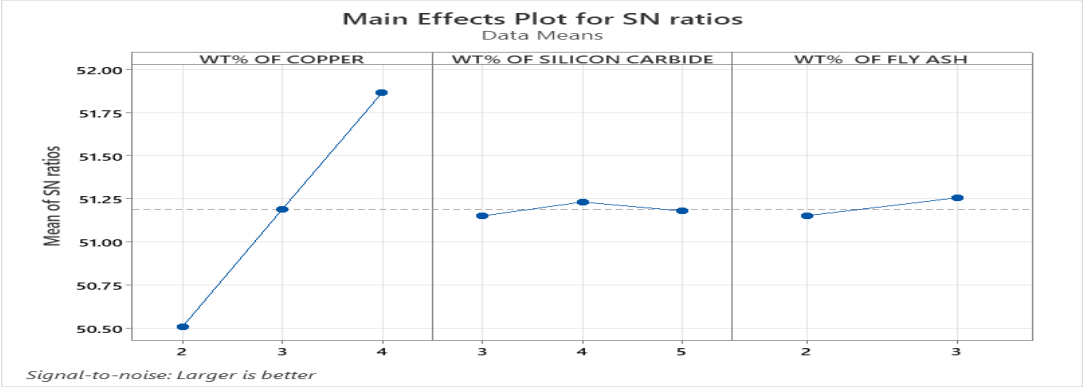

Figure 0-1 *Main Effects Plot For S/N Ratios Of Tensile Strength*

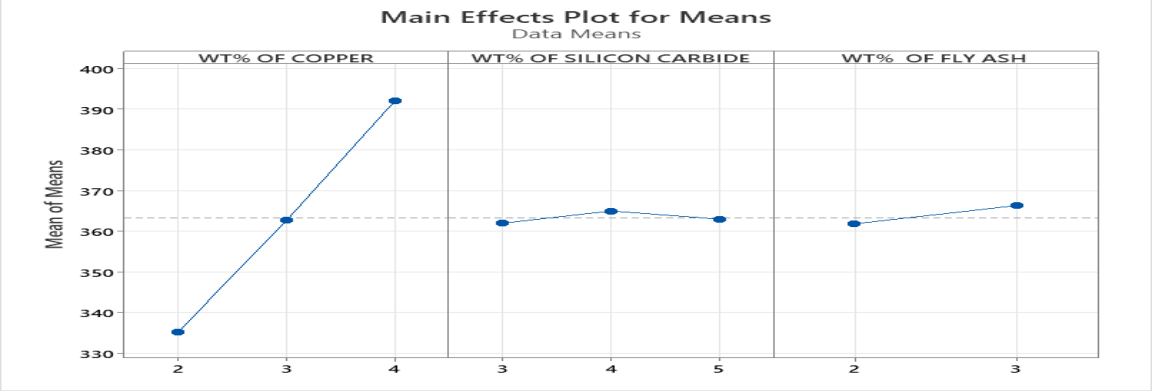

Figure 0-2 *Main Effects Plot For Means Of Tensile Strength*

Where is the value of the measured response, and is it the number of observations. The greater the S/N ratios, the higher the performance and the reduced sensitivity to the noise factors.

Table 0-4 *Response Table for Signal To Noise Ratios For Hardness*

Level	WT% OF COPPER	WT% OF SILICON CARBIDE	WT% OF FLY ASH
1	41.94	42.66	42.55
2	42.82	42.57	42.68
3	43.02	42.55	
Delta	1.09	0.11	0.12
Rank	1	3	2

Response table for signal to noise ratio is tabulated table 4-4 for HARDNESS and observed that delta value for signal to noise ratio is higher for Copper, followed by Silicon Carbide and Fly Ash.

Table 0-5 *Response Table for Means For Hardness*

Level	WT% OF COPPER	WT% OF SILICON CARBIDE	WT% OF FLY ASH
1	125.0	136.0	134.3
2	138.3	134.7	136.3
3	141.7	134.3	
Delta	16.7	1.7	2.0
Rank	1	3	2

Response table for means is tabulated 4-5 for HARDNESS and found that standard deviation is higher for Copper follwed by Silicon Carbide and Fly Ash. Copper has more effect on the response compared to other two factors.

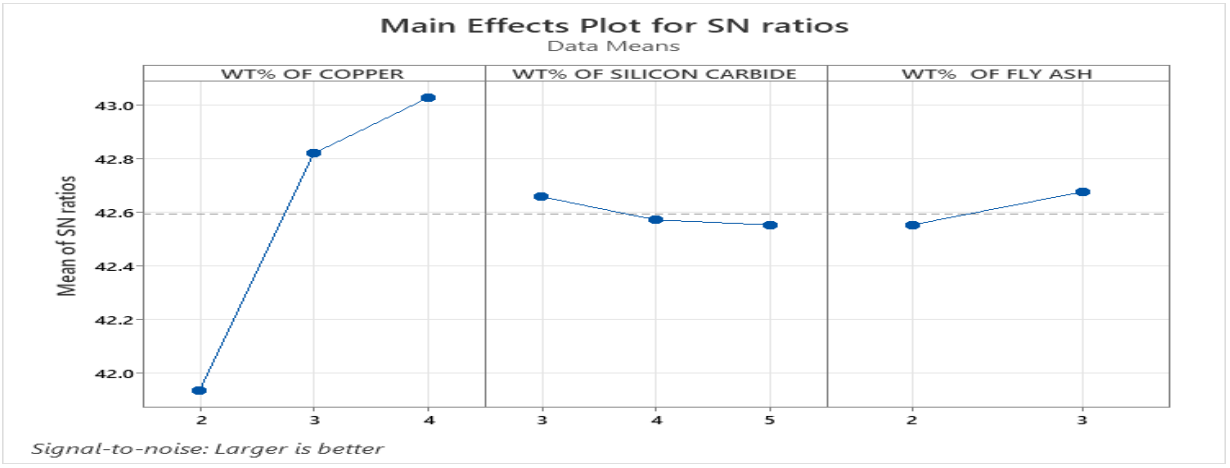

Figure 0-3 *Main Effects Plot For S/N Ratios Of Hardness*

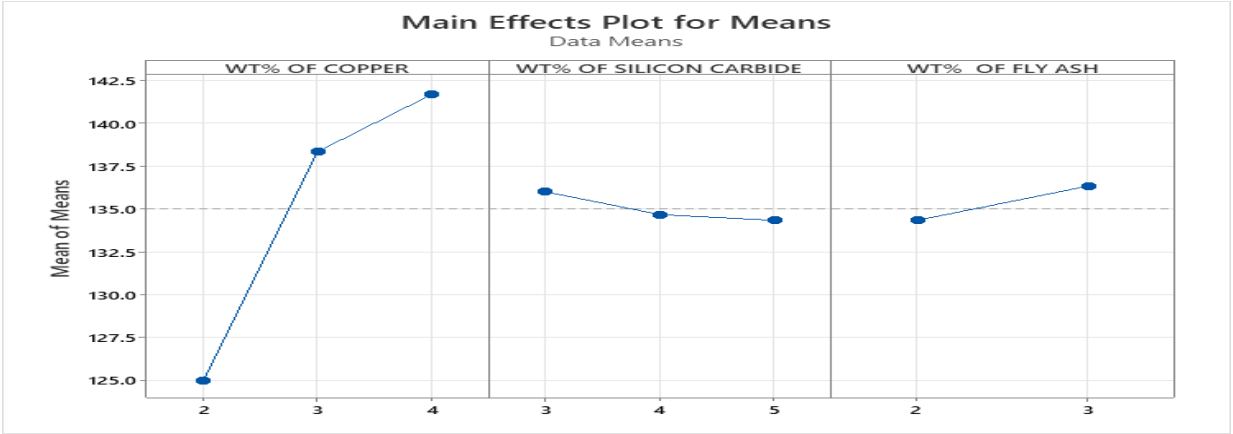

Figure 0-4 *Main Effects Plot For Means Of Hardness*

Based on these plots, it was found that the most substantive impact on both tensile strength and hardness is on the SiC content, which is then succeeded by Copper, and Fly Ash has a relatively lesser impact. This was found to be the level combination that would give the best S/N ratio in both responses.

1.3 Analysis of Variance (ANOVA)

The statistical significance and the contribution of the percentage of each parameter of reinforcements on the mechanical properties were analysed using Analysis of variance (ANOVA). ANOVA divides the overall variation of experimental outcomes into the parts of contributions of each of the control factors, as well as experimental error. The F-test was employed in determining whether a factor has a noticeable impact on the response at a certain level of confidence.

Table 0-6 *Analysis Of Variance For Tensile Strength*

SOURCE	DF	Adj SS	Adj MS	F-Value	P-Value
WT% OF COPPER	2	4818.67	2409.33	136.81	0.001
WT% OF COPPER	2	14.00	7.00	0.40	0.703
WT% OF COPPER	1	40.50	40.50	2.30	0.227
Error	3	52.83	17.61		
Total	8	4926.00			

Regression Equation

TENSILE STRENGTH = 364.08 - 28.00 WT% OF COPPER_2 - 0.67 WT% OF COPPER_3
+ 28.67 WT% OF COPPER_4 - 1.33 WT% OF SILICON CARBIDE_3
+ 1.67 WT% OF SILICON CARBIDE_4 - 0.33 WT% OF SILICON CARBIDE_5
- 2.25 WT% OF FLY ASH_2 + 2.25 WT% OF FLY ASH_3

Figure 0-5 *Regression Equation Of Tensile Strength*

Table 0-7 *Analysis Of Varaince For Hardness*

SOURCE	DF	Adj SS	Adj MS	F-Value	P-Value
WT% OF COPPER	2	466.667	233.333	262.50	0.000
WT% OF COPPER	2	4.667	2.333	2.62	0.219
WT% OF COPPER	1	8.000	8.000	9.00	0.058
Error	3	2.667	0.889		
Total	8	482.00			

Regression Equation

HARDNESS = 135.333 - 10.000 WT% OF COPPER_2 + 3.333 WT% OF COPPER_3 + 6.667 WT% OF COPPER_4
+ 1.000 WT% OF SILICON CARBIDE_3 - 0.333 WT% OF SILICON CARBIDE_4
- 0.667 WT% OF SILICON CARBIDE_5 - 1.000 WT% OF FLY ASH_2
+ 1.000 WT% OF FLY ASH_3

Figure 0-6 *Regression Equation Of Hardness*

According to the ANOVA results, all the factors that affect tensile strength and hardness are dominated by SiC owing to its high stiffness and bearing capacity. Second, but not least, copper contributes primarily because it enhances interfacial bonding and strengthens precipitation. Fly Ash also contributes a minor, however, not negligible factor that is mainly related to the enhancement of stiffness and the reduction of weight.

1.4 Interpretation of statistical results

The hybrid Taguchi and ANOVA analysis assures that the mechanical behavior of the hybrid composite of Al7075 is highly controlled by the ceramic reinforcement level, especially SiC. The existence of Copper is, however, important in the balancing of strength and ductility, where Fly Ash would be involved in the economical and sustainable factors without drastically impairing the mechanical performance. The optimized combination of the parameters offers a sensible process of choosing the reinforcement levels in the application of engineering practice.

Results and Discussion

1.5 Tensile Strength Behavior

The tensile test outcome of the Aluminum 7075 hybrid composites reinforced with Copper, Silicon Carbide, and Fly Ash has a clear improvement in comparison with the unreinforced base alloy. This tensile strength improvement is largely due to the hard SiC particles, which successfully shift the load off of the ductile aluminum matrix to the hardening reinforcement phase.

Table 0-1 *Tensile Tests Of Aluminum Mmc's*

S.No	Sample ID	Ultimate Tensile Strength (MPa)
1	A	332
2	B	339
3	C	335
4	D	358
5	E	368
6	F	362
7	G	396
8	H	388
9	I	392

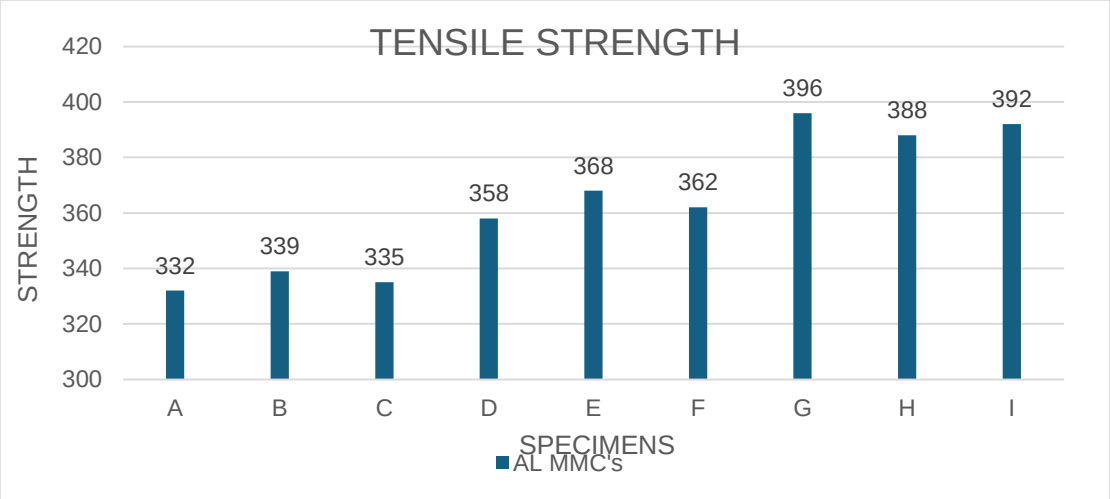

Figure 0-1 *Tensile Strength Graph*

An increase in the content of SiC between low and medium contributes to a significant increase in UTS because of an increase in the load-bearing capacity and the limit of plastic deformation. But at extremely large reinforcement levels, the improvement rate is marginal, and this can be linked to particle clustering and a decrease in matrix continuity. This is further reinforced by the use of Copper as tensile strength is increased by both interfacial bonding and the precipitation hardening of the aluminum matrix. Fly Ash modestly enhances strength, but also excess usage of the same is likely to lower the ductility because it is stiff and brittle.

1.6 Hardness Characteristics

The values of hardness of the fabricated composites exhibit a steady rise with an increment in the reinforcement content, especially SiC. As Figure 5-2 shows, the Vickers hardness values are much greater in the case of specimens with a high content of SiC. This is possible because of the inherent hardness of SiC particles and their even distribution in the aluminum base, which acts as a resistance to a localized plastic deformation.

Table 0-2 *Vickers Hardness Tests Of Aluminum Mmc's*

S.No	Sample ID	3 Trails of Hardness Tests (HV)	MAXIMUM HARDNESS (HV)
1	A	124 126 122	126
2	B	123 121 124	124
3	C	121 125 123	125
4	D	135 133 138	138
5	E	140 139 136	140
6	F	134 137 135	137
7	G	138 139 144	144
8	H	140 138 136	140
9	I	139 141 140	141

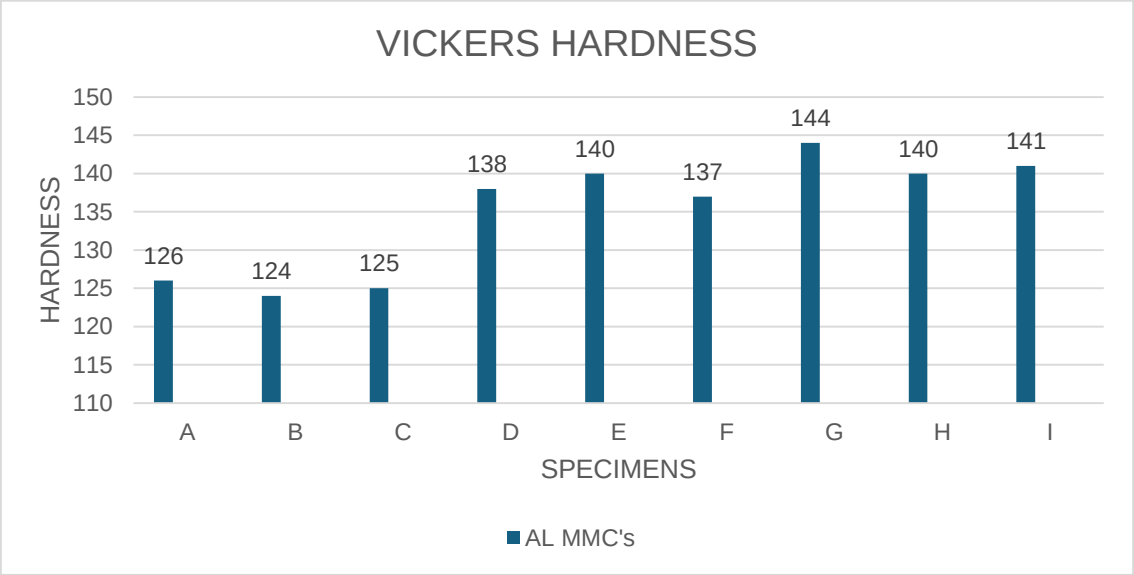

Figure 0-2 *Vickers Hardness Graph*

The other process of hardening is through solid solution strengthening and precipitation, which copper also helps in. Surface resistance to indentation is also increased further by fly Ash particles, which are relatively hard and lightweight. The resultant effect of these reinforcements is that the resultant composite material has a significantly higher surface hardness than the underlying Al7075 alloy.

1.7 Impact of Synergy of Reinforcement.

A synergistic effect on the mechanical properties is present in the hybrid reinforcement system. Although hardness and strength are mainly controlled by SiC, Copper is very important in ensuring that the ductility is acceptable and that the transfer of load across the matrix-particle interface is enhanced. Fly Ash, besides lowering the cost and density of the material, helps in the advancement of stiffness and stability of the microstructure. The statistical optimization technique is proven to be effective by the fact that the optimized composition determined using the Taguchi and ANOVA analysis demonstrates the optimum tensile strength and hardness. The data obtained reflects that the ceramic and metallic reinforcements should have a balanced ratio to prevent a high degree of brittle nature and, at the same time, attain a high strength and surface hardness.

1.8 Fracture and Failure Considerations.

The tensile behavior of the fracture reveals that the tensile specimens deformed under a mixed mode of failure. Lower reinforcement content composites have more ductile fracture properties compared to those with higher SiC and Fly Ash content, which exhibit relatively brittle fractures because of the existence of rigid particles, which hinder plastic deformation. This fact also contributes to the necessity of optimization and not mere maximization of the content of reinforcement. In general, the findings attest to the fact that the Al7075-Cu-SiC-Fly Ash hybrid composite prepared via stir casting possesses much better mechanical characteristics and can be adjusted to complex engineering purposes by use of a good control over the reinforcement content.

Conclusions

Conclusions made are based on the experimental study and statistical analysis of Aluminum 7075 hybrid metal matrix composites reinforced with Copper, Silicon Carbide, and Fly Ash. The following conclusions are made:

1. The hybrid composites that were made through the stir casting technique successfully produced aluminum 7075-based composites and showed that the technique is easy, cost-effective and appropriate when it comes to mass production of particulate reinforced MMCs.
2. The impact of Silicon Carbide on tensile strength and hardness is greatly enhanced by its high stiffness and load-bearing, which proves the dominant position of the material among the chosen reinforcements.
3. The addition of copper increases interfacial bonding between the aluminum matrix and the reinforcements and also helps in increasing the strength of the material through solid solution and precipitation strengthening processes.
4. Fly Ash is a low-cost and lightweight type of reinforcement, which enhances stiffness and hardness and allows industrial waste to be utilized more sustainably, but when used in excessive quantities, it slightly decreases ductility.
5. Signal-to-noise ratio analysis and Taguchi L9 design have been useful in ensuring fewer experiments were done, and the best combination of reinforcements was found to maximize mechanical performance.
6. The results of the Analysis of Variance (ANOVA) showed that SiC has the most significant effect on the tensile strength and the hardness, followed by Copper, and the Fly Ash has an intermediate but significant effect.
7. The optimized hybrid composite has much better mechanical properties than the base Aluminum 7075 alloy, but has a reasonable ductile value.
8. Fracture behavior signals a ductile-brittle mode that is mixed, which points to the significance of strength reinforcement balance, but not the excessive addition of ceramic.
9. The Al7075-Cu-SiC-Fly Ash hybrid composite that is developed is applicable in high-end structures and tribological applications, in the aerospace, automotive and defense industries.

References

[1] Davis, J.R., 1993. *Aluminium and Aluminium Alloys*. ASM International, Materials Park, OH.

[2] Callister, W.D. and Rethwisch, D.G., 2018. *Materials Science and Engineering: An Introduction*. 10th ed. Wiley, New York.

[3] Surappa, M.K., 2003. Aluminium matrix composites: Challenges and opportunities. *Sadhana*, 28(1–2), pp.319–334.

[4] Hashim, J., Looney, L. and Hashmi, M.S.J., 1999. Metal matrix composites: Production by the stir casting method. *Journal of Materials Processing Technology*, 92–93, pp.1–7.

[5] Bharathi, P., Balamurugan, K. and Uthayakumar, M., 2023. Mechanical and microstructural behaviour of Al7075–SiC–B4C hybrid composites fabricated by powder metallurgy. *Materials Today: Proceedings*, 72, pp.2101–2107.

[6] Mulugundam, S.S., Reddy, A.C. and Kumar, A., 2021. Mechanical and tribological behaviour of Al7075–SiC composites fabricated by powder metallurgy. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, 43, pp.1–12.

[7] Miracle, D.B., 2005. Metal matrix composites – From science to technological significance. *Composites Science and Technology*, 65(15–16), pp.2526–2540.

[8] Rohatgi, P.K., 2006. Cast aluminium matrix composites for automotive applications. *Journal of Materials*, 58(11), pp.71–76.

[9] Rajesh, S., Senthilkumar, V. and Sabarish, R., 2020. Mechanical characterisation of Al7075 reinforced with SiC and fly ash hybrid composites. *Materials Today: Proceedings*, 27, pp.2553–2557.

[10] Sathishkumar, A., Stalin, B. and Ravichandran, M., 2020. Mechanical and tribological behaviour of stir-cast aluminium hybrid composites. *IOP Conference Series: Materials Science and Engineering*, 912, 032041.

[11] Totten, G.E. and Mackenzie, D.S., 2003. *Handbook of Aluminium: Vol. 1 – Physical Metallurgy and Processes*. Marcel Dekker, New York.

[12] Sravanthi, C., Reddy, P.R. and Rao, K.S., 2024. Optimisation of alloying elements and SiC addition in Al7075 using the Taguchi method. *Advances in Materials and Processing Technologies*, 10(2), pp.1–14.

[13] Prasad, S.V. and Asthana, R., 2004. Aluminum metal–matrix composites for automotive applications: Tribological considerations. *Tribology Letters*, 17(3), pp.445–453.

[14] Montgomery, D.C., 2017. *Design and Analysis of Experiments*. 9th ed. Wiley, New York.

[15] Roy, R.K., 2010. *A Primer on the Taguchi Method*. 2nd ed. Society of Manufacturing Engineers, Dearborn, MI.

[16] Ramesh, C.S., Ahamed, A., Channabasappa, B.H. and Keshavamurthy, R., 2009. Development of Al 6061–TiB2 in situ composites. *Materials & Design*, 30(6), pp.222–226.

[17] Sahu, M.K. and Sahu, R.K., 2019. Fabrication and characterisation of Al7075–B4C–fly ash hybrid composites by stir casting. *Materials Today: Proceedings*, 18, pp.2892–2900.

[18] Namdev, A.P., Joshi, S.S. and Patil, P.P., 2020. Friction stir processing of Al7075 with SiC and fly ash reinforcements. *Materials*, 13(3), pp.1–15.