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Experimental Investigation on the Mechanical Characterization and Impact Behavior of Shot-Peened Al7068 Hybrid Composites Reinforced with SiC and Si₃N₄

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Abstract

This study investigates the effects of Silicon Nitride (Si₃N₄) and Silicon Carbide (SiC) particles on the mechanical properties of Al7068 alloy. It aims to evaluate the potential of hybrid composites to meet engineering needs, such as aerospace applications. The Al7068- Si₃N₄/SiC composite was fabricated using the stir casting technique, with varying percentages of micro-Si₃N₄ (0%, 1%, 0.5 %, 0.5 % & 1%) and micro SiC (0%, 1%, 1.5%, 2.5% & 2%) particles. Mechanical tests were conducted to determine the impact strength before and after shot peening of the developed hybrid composites. These mechanical properties of the developed Al7068 reinforced with Si₃N₄ & SiC micro particles show the high potential for resistance to impact failure. A microstructural analysis shows a uniform dispersion of Si₃N₄ and SiC reinforcement particles within both the as-cast material and the Al7068 metal matrix composites. Integrating Si₃N₄ & SiC micro particles can create a high-performance composite suitable for aerospace applications that require a combination of lightweight properties and enhanced tensile strength.

Keywords: Al7068, SiC, Si₃N₄, Stir Casting, Optical Microscopic, shot peening, Impact Strength.

1. Introduction

Engineering materials play a crucial role in shaping human civilization with continuous development, and the emphasis is given on improving efficiency, performance, and the responsible use of resources. In today's scenario, the shortage of natural resources has been

witnessed, which is a key indicator that innovation in material science and engineering is required.[1] [2] In recent years, materials have been carefully developed to solve challenges in aerospace engineering and space exploration. Simultaneously, material science, particularly the field of nanomaterials, has experienced significant growth in research and development.[3] At present, aluminum matrix composites are widely used in the aerospace industry, automobile industry, and many other engineering applications due to their excellent properties.[4] In this regard, lightweight composite materials are developed by combining two or more different materials reinforced with micro and nanoparticles to obtain enhanced physical and mechanical properties compared to the individual materials. These composites meet the requirements of various industries and modern engineering applications.[5].[6] Aluminum alloys are lightweight materials and possess excellent thermal and mechanical properties. The properties of aluminum alloys can be significantly improved by adding suitable reinforcement materials. [7] The properties can be further modified by adding reinforcements such as nanoparticles, microparticles, and fibers. It escalates the toughness, tensile strength, hardness, and porosity. To intensify the tensile strength, hardness, and yield strength of composite materials, the commonly used reinforcement particles are Si_3N_4 , MgO , SiO_2 , SiC , TiC , BN , Al_2O_3 , TiB_2 , and graphite.[8][9].

P Pugalenth et al. (2026) studied AA332 aluminium alloy reinforced with ZrB_2 particles (0–7.5 wt%), which showed significant improvements in hardness, tensile strength, and wear resistance due to grain refinement and uniform particle distribution. The optimum wear performance was achieved at 7.5 wt% ZrB_2 reinforcement.[10] Y. M. Shivaprakash et al. (2026) investigated the Al7075 composite reinforced with 2 wt% granite powder and varying Si_3N_4 content (3–9 wt%), which was fabricated by using double-step stir casting. Results showed that hardness increased with reinforcement content. The composite containing 6 wt% Si_3N_4 exhibited the best wear resistance under different loading conditions.[11] Kamran Dehghani et al. (2025) developed $\text{Ti}_{35}\text{Nb}_{25}\text{Zr}_{15}\text{Mo}_{15}\text{V}_{10}$ bio-high entropy alloy as the best alternative to conventional Ti6Al4V and 316L stainless steel implant materials. The alloy exhibited a single BCC solid-solution structure, low elastic modulus (115 GPa), improved wear resistance, enhanced mechanical properties, and superior corrosion resistance.[12] Nilesh H. Khandare et al. (2025) investigated the wear behavior of three composite formulations (T1, T2, and T3) using the Taguchi L27

experimental design. The optimum wear performance was achieved at 5% reinforcement, 15 N load, 160 rpm speed, and 41 m sliding distance. ANN modeling predicted wear behavior with 99.72% accuracy.[13]

Pradyumn Kumar Arya et al. (2025) highlight various methods for strengthening the properties of titanium alloys, particularly for high-temperature applications above 600 °C. It discusses phase transformations, alloying elements, surface modification techniques, and additive manufacturing approaches that improve strength, wear resistance, and corrosion resistance. [14] Hanan. S et al. (2025) showed that the combination of sulfanilic acid into ZnO/GO composites improved ZnO nanoparticle distribution, enhanced interfacial interactions, and reduced particle agglomeration. [15] J. Sharma et al. (2025) showed that adding nano and micro ZrO₂ particles to Al7075 improved its mechanical properties. The highest peak stress was obtained with 0.34% nano ZrO₂, showing a 59% increase from 125 MPa to 153 MPa, while strain decreased from 4.9% to 3.7%. The composite with 0.51% nano ZrO₂ exhibited the highest load-bearing capacity, indicating its suitability for aerospace applications.[16]. K. R. V. Gudipalli et al. (2024) showed that increasing Silicon Carbide content improved the micro-hardness and tensile strength of the composites. Uniform distribution of Silicon Carbide and Silicon Nitride reinforcements was observed in Al-7068 composites. Addition of graphite particles (3–9 wt.%) in Al 7075 improved self-lubricating properties and reduced friction and wear.[17] K. B. S. Lovevanshi et al. (2024) added sustainable and synthetic reinforcements to hybrid Al7075 composites, which improved compressive strength, hardness, and wear resistance. FESEM analysis showed wear debris, grooves, micro-cracks, and small pits on the worn surfaces [18]. A. Kumar et al. (2022) have done work on Al7068 nanocomposites reinforced with Si₃N₄ (0.5%, 1%, 1.5% & 2 wt.%), which were fabricated using ultrasonic-assisted stir casting. Optimal mechanical properties were achieved at 1.5 wt.% Si₃N₄, showing significant improvements in hardness, tensile, and compressive strength.[19].S. Kolappan et al. (2022) found that the addition of 8% SiC and 4% coconut shell fly ash increased the hardness of the composite by 32%. Similarly, adding 6% SiC with 4% coconut shell fly ash improved the tensile strength by 65%, but reduced the ductility of the material. [20]. M. Madhusudhan et al. (2017) added the Zirconium dioxide particles (0 to 8 wt.%) to Al7068, significantly improved the hardness and tensile strength of the composites fabricated using the stir casting technique [21]. Syed Akbar Ali et al. (2021) focus on the fabrication of Al7068 composites by using the powder metallurgy route with rice husk ash (RHA) (0%, 4%,

6% & 8%) and silicon carbide (SiC) (0%, 4% & 6%) as reinforcements in different weight percentages. The results showed that hardness improved with an increase in SiC content, but decreased with the addition of rice husk ash.[22].

Table 1 effectively summarizes the latest research on Metal Matrix Composites (MMCs), highlighting their fabrication methods, types of reinforcement, specific MMCs studied, and key findings. This table provides a snapshot of recent MMC research, allowing for an easy comparison of different reinforcement materials and fabrication methods. It reflects current trends in the MMC field, particularly for aerospace and automotive applications, where strength, wear resistance, and thermal stability are prioritized.

Table. 1 Summary of various reinforcements with aluminium alloy metal matrices.

S.No	Al Alloy	Fabrication methods	Investigation Approach	Reinforcement	Key Findings	Ref. No.
1	Al 7075	Stir casting	Taguchi method, ANOVA	SiC, Graphite	Addition of 9% graphite content reduces both the coefficient of friction and wear rate, Improved self-lubricating properties	[17]
2	Al 7075	Ultrasonic transducer, two-stage stir casting	SEM, Optical microscopy	Synthetic	Compressive strength and micro-hardness were both increased, and the highest values were found to be 569.172 MPa and 178.86 HV.	[18]
3	Al 7068	Stir casting	UTM	SiC, Coconut shell fly ash	Addition of SiC and coconut shell fly ash to Al 7068 increases the tensile strength of the composites with 6 % and hardness reaches	[20]

					173 BHN at 8 wt% SiC and 4 wt% CSFA	
4	Al 7068	Stir casting	Vickers hardness test, UTM	ZrO ₂	13% increase in tensile strength of AA7068 and 40% hardness improved at 8wt% ZrO ₂ when compared with Al7068.	[21]
5	Al7075	Stir casting	Taguchi method	SiC, Al ₂ O ₃	Optimum value of Hardness SiC at 9% and Wear Rate SiC at 3% , Al ₂ O ₃ keep constant at 2%	[23]
6	Al7075	Ball milling and semi-solid stirring	SEM, EDX	Al ₂ O ₃	Tensile strength and hardness increase from 0 to 1.5% and then begin to decline when it exceeds 1.5%.	[24]
7	Al7075	Ball milling	SEM, EDX, XRD	SiC	YS of 559 MPa and UTS of 609 MPa for 1.0 vol% SiC improved by 72 MPa and 53 MPa compared with matrix.	[25]

Summary of published work indicates the need for innovation in the mechanical characteristics of Al7068-based composites, specifically the effects of micro reinforcement, Silicon Nitride (Si₃N₄), and Silicon Carbide (SiC) particles. This study investigates and analyzes the mechanical behavior of Al7068 matrix after the reinforcement of Silicon Nitride (Si₃N₄) and Silicon Carbide (SiC) particles. The objective of this work is to develop a new Al7068/SiC/Si₃N₄ composite material to observe its mechanical behavior, in terms of impact strength and tensile strength by the stir casting method. Mechanical stirring helps to distribute the SiC and Si₃N₄ particles uniformly throughout the molten Al7068 matrix, resulting in a more uniform composite structure. [26]

Therefore, this study presents extensive research involving the blending of micro SiC/Si₃N₄ particles in varying proportions with Al7068, followed by a comprehensive analysis of the resulting alloy's mechanical properties.

2. Experimental Procedure

A hybrid composite was fabricated by using Al7068 as the matrix material through the stir casting technique. The developed composites were characterized by mechanical testing and FESEM analysis. The workflow (as shown in Fig. 1) used in the experimentation is presented below.

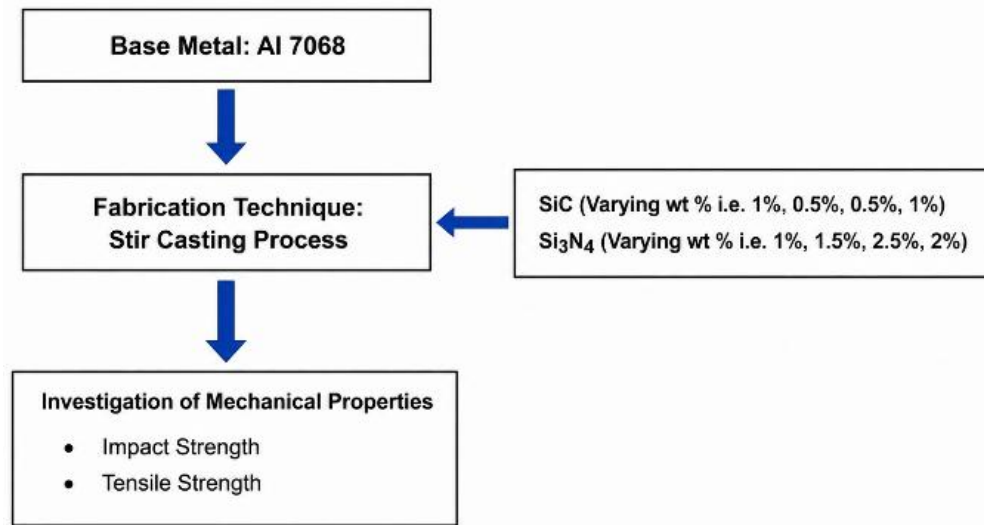


Fig. 1 Flow Chart of Casting Sample Preparation

2.1. Material & Reinforcement Selection

Silicon carbide (SiC) and silicon nitride (Si₃N₄) as shown in Fig. 2(a) and Fig. 2(b) are two commonly used ceramic reinforcements in aluminum metal matrix composites (MMCs), known for their ability to improve key mechanical properties like hardness, strength, wear resistance, and thermal stability. [27] When added to aluminum alloys, such as Al7068 or Al7075, these reinforcements yield composites with several modified properties, which make the composite valuable in industries like aerospace and automotive.

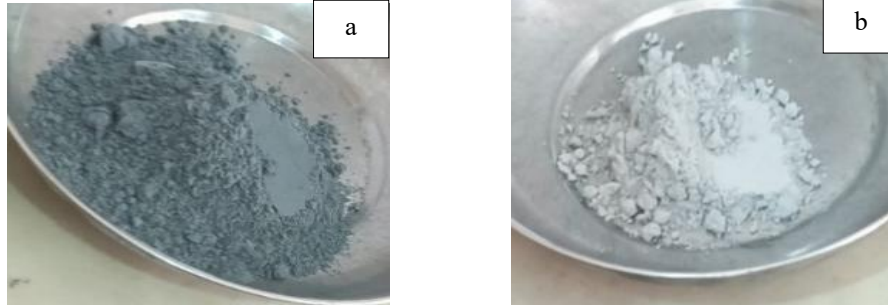


Fig. 2 (a) Silicon Carbide SiC (Size: 10 μm) Fig. 2 (b) Silicon Nitride Si₃N₄ (Size: 10 μm)

Table 2 provides the information of the chemical composition of Al-7068.

Table 2. Chemical composition of Al 7068

Composi tes	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Pb	Sn	Ni	Co	V	Bi	Be	Zr
Wt%	0.0	0.2	1.8	0.0	2.38	0.0	8.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0
	70	00	20	11	0	06	60	36	40	30	06	20	10	30	35	80
Purity	99.99%															
Melting Point	597 ⁰ C															

2.2. Sample Preparation:

The stir casting technique was used to prepare a metal matrix composite (MMC) reinforced with nano SiC and Si₃N₄ in an Al 7068 alloy matrix. The alloy was heated above its melting temperature to facilitate the addition of reinforcement particles with varying weight percentages of SiC (0%, 1%, 0.5%, 0.5%, and 1%) and Si₃N₄ (0%, 1%, 1.5%, 2.5%, and 2%). These reinforcement particles were introduced into the molten alloy to achieve uniform distribution and strong interfacial bonding within the matrix.

Table 3 presents the detailed weight percentages of the reinforcement materials added to the base aluminum alloy, enabling a systematic comparison of the developed composite compositions.

Table 3. SiC and Si₃N₄ Compositions

Samples ID	Sample-Composition (wt% SiC + wt% Si ₃ N ₄)	Al7068 (in grams)	SiC Weight (in grams)	Si ₃ N ₄ Weight (in grams)
S0	Al7068/ (0.0% SiC+0.0%Si ₃ N ₄)	1600	0	0
S1	Al7068/ (1% SiC+1%Si ₃ N ₄)	1600	16	16
S2	Al7068/ (0.5% SiC+1.5%Si ₃ N ₄)	1600	8	24
S3	Al7068/ (0.5% SiC+2.5%Si ₃ N ₄)	1600	8	40
S4	Al7068/ (1% SiC+2%Si ₃ N ₄)	1600	16	32

**Fig. 3 Sample Preparation Process with SiC & Si₃N₄**

To evaluate the mechanical properties of Al7068/SiC/Si₃N₄ composites, an impact test specimen was prepared by using the stir casting method. These specimens were fabricated



Fig. 4 Al7068 Casted Sample and its Composites

3. Results and Discussion

3.1. Microstructural & SEM Study

Microstructural studies were conducted by using Carl- Zeiss Axio Scope 5 at MANIT, Bhopal. This Microstructural analysis is carried out through optical micrographs to investigate particle distribution, grain boundaries, and interfacial bonding. This optical micrograph image is captured at 500 X magnification, with a scale of 56 microns as shown in Fig. 5. The presence of dendritic and irregular patterns suggests a solidification process typical in cast alloys or composites; the dispersion of reinforcements directly correlates to improvements in hardness and tensile strength. SiC particles are distributed more evenly due to being well-dispersed in composites, whereas Si_3N_4 particles are in clusters in regions due to agglomeration during processing. Si_3N_4 often shows larger clusters compared to SiC. The integration of SiC and Si_3N_4 improves properties such as wear resistance, hardness, and high-temperature stability of the composite. The SiC particles looked as larger, dark, angular particles mainly located at the grain boundaries, while the Si_3N_4 particles appear as fine, uniformly distributed dark dots within the Al7068 alloy. These composites are suitable for aerospace, automotive, and structural applications requiring lightweight materials with enhanced wear and thermal resistance.

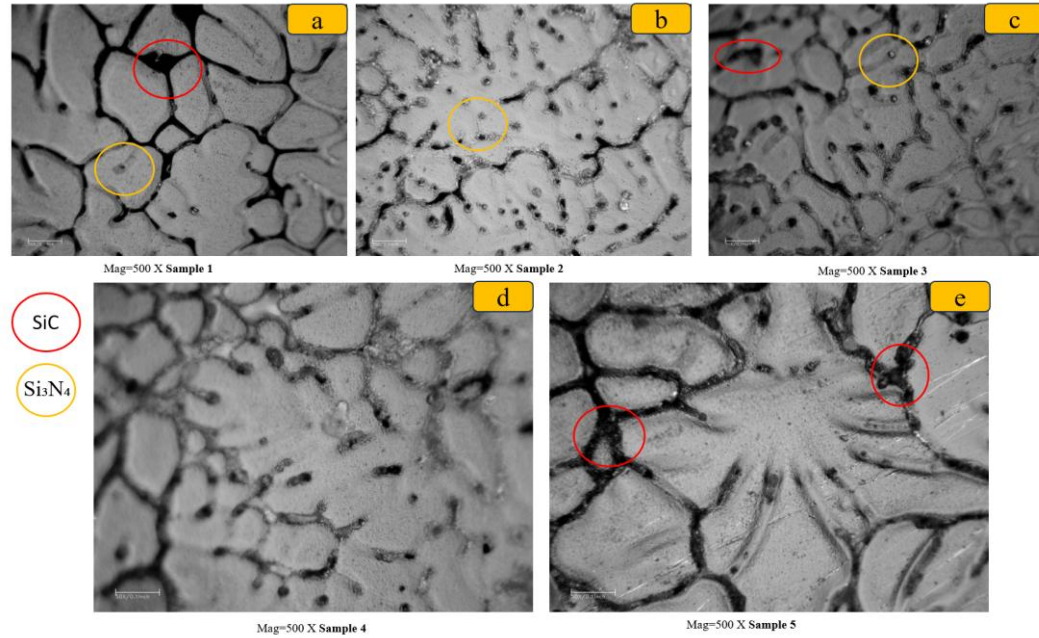


Fig.5 Optical Micrographs Images (Mag=500 X) for Al 7068 (a) Al7068 alloy [S0] (b) Al7068/(1% SiC +1% Si3N4) [S1], (c) Al7068/(0.5% SiC +1.5% Si3N4) [S2], (d) Al7068/(0.5% SiC +2.5% Si3N4) [S3] & (e) Al7068/(1.0% SiC +2.0% Si3N4) [S4]

FESEM was studied by using a Carl Zeiss make ultra Plus coupled with an energy dispersive X-ray. spectroscopy (EDX) at IISER, Bhopal. The Fig. 6 FESEM micrographs (at 500 X magnification) analysis showed that successful mixing of both SiC and Si₃N₄ reinforcements into the Al 7068 matrix. SiC particles appear as larger angular reinforcements mainly distributed along grain boundaries, while Si₃N₄ particles appear as fine, uniformly dispersed particles within the matrix. From all the samples, Sample 4 shows the most uniform reinforcement distribution, whereas Sample 3 exhibits particle clustering due to insufficient mixing during the stir casting process.

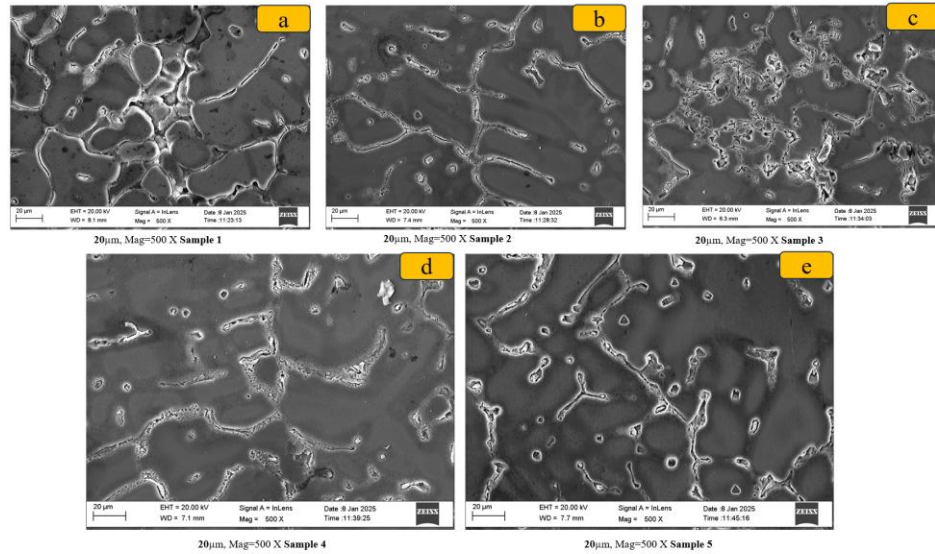


Fig. 6 SEM Images (Mag=500 X) for Al7068 (a) Al7068 alloy [S0] (b) Al7068/(1% SiC +1% Si3N4) [S1], (c) Al7068/(0.5% SiC +1.5% Si3N4) [S2], (d) Al7068/(0.5% SiC +2.5% Si3N4) [S3] & (e) Al7068/(1.0% SiC +2.0% Si3N4) [S4]

3.2. Charpy Impact Testing before Shot Peening

The Charpy testing was done by means of a Digital Impact Testing Machine as shown in Fig. 7 (Machine Model: SE-IT 300, SR NO: 503/17-18), Max Capacity: 300 J) in room temperature at Material Testing Laboratory, MANIT, Bhopal.



Fig. 7 Digital Impact Testing Machine



Fig. 8 Charpy Impact Test Readings

The Charpy Impact Test before shot peening aimed to evaluate the energy absorbed by different material samples (S0 to S4) when subjected to sudden impact forces. This test provides insights into the toughness of the materials before undergoing the shot peening process. S4, with the highest impact resistance, likely possesses superior mechanical properties or a microstructure favorable

for withstanding impact forces. From the Table 2, it is clearly seen that from the charpy impact testing, net energy absorbed has been increased with the increases content of reinforcement silicon carbide and silicon nitride from 1 to 2.5 %. The base Al7068 alloy (S0) exhibited the lowest impact energy of 1.0 J and, therefore, was taken as the reference material.

The base Al7068 alloy (S0) had the lowest impact energy of 1.0 J and was used as the reference for comparison. When reinforcement was added, the toughness improved in all the composite samples from S0 to S4. Sample S1 absorbed 1.6 J of energy, showing a 60% increase over the base alloy. Sample S2 reached 1.4 J, which is a 40% improvement, while sample S3 showed a smaller rise to 1.2 J, indicating a 20% increase in toughness. From all the samples, S4 performed the best with an impact energy of 2.0 J, which is double that of the base alloy (100% improvement) as shown in Fig. 10. This shows that the combination of reinforcements in S4 helps the material absorb more energy and slows down crack formation during impact. This significant increase in impact energy suggests that the reinforcement combination in S4 effectively enhances energy absorption and delays crack propagation during impact loading.

The results confirm that the mixing of reinforcement particles plays an important role in improving the impact resistance of the Al7068 matrix. In particular, sample S4 exhibited the most favorable toughness characteristics, making it a promising material for applications where resistance to sudden impact and dynamic loads is required.

The improvement trend supports the hypothesis that suitable reinforcement selection and distribution within the aluminum matrix play a crucial role in resisting crack propagation and increasing energy absorption capacity.

Table 2. Charpy Impact Testing Reading before Shot Peening

Sample	Energy Absorbed (J)	Air Resistance & other losses (J)	Net Energy Absorbed (J)
S0	5.5	4.5	1
S1	6.1	4.5	1.6
S2	5.9	4.5	1.4
S3	5.7	4.5	1.2
S4	6.5	4.5	2



Fig. 9 Specimen after Charpy Test before shot peening

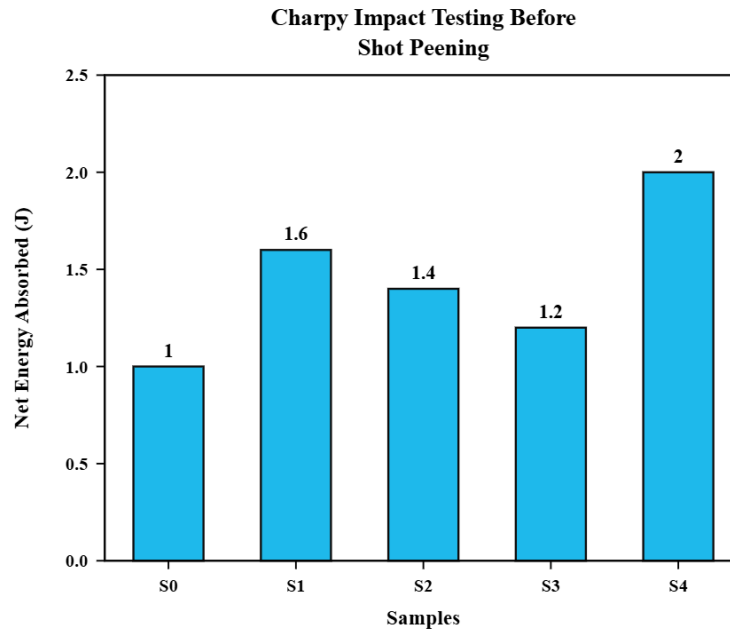


Fig. 10 Variation in Impact Value for Al7068 and its composites before Shot Peening

3.3. Charpy Impact Testing After Shot Peening

In shot peening process, all the five specimens of Al7068/SiC/Si₃N₄ kept together and placed in shot blasting chamber as shown in Fig. 11 & Fig. 12 to perform the shot blasting process to clean, strengthen, or polish metal surfaces by propelling abrasive materials (such as steel shots, glass beads, or sand) at high velocity onto the surface of the workpiece. The shot blasting chamber provides a controlled environment where the shot blasting process can be conducted safely and efficiently. Shot peening is a powerful surface treatment technique that enhances the fatigue strength, wear resistance, and durability of metal components by introducing beneficial compressive residual stresses. This operation performed at Material Testing Laboratory, MANIT, Bhopal.



Fig. 11 Shot Blasting Chamber



Fig. 12 Specimen's placed in the Shot Blasting Chamber

After shot blasting process, one by one Charpy impact testing performed on the specimen to found the impact value as shown in Table 3.

Table. 3 Charpy Impact Testing Reading after shot peening

Sample	Energy Absorbed (J)	Air Resistance & other losses (J)	Net Energy Absorbed (J)
S0	5.7	4.5	1.2
S1	6.5	4.5	2
S2	6.0	4.5	1.5
S3	5.9	4.5	1.4
S4	7.1	4.5	2.6



Fig. 13 Specimen after Charpy Test after shot peening

The graph Fig. 14 displays the results of Charpy impact testing conducted on five different samples (S0 to S4) post-shot peening. The test measures the net heat absorbed by each sample, reflecting their toughness and resistance to sudden impact. Sample S0, the unreinforced base

alloy, absorbed 1.2 J of impact energy. After shot peening, all the composite samples showed better toughness. Sample S1 absorbed 2.0 J, which is about a 66.67% increase compared to S0. Sample S2 showed a moderate improvement with 1.5 J (about 25% higher than the base alloy) as well as sample S3 absorbed 1.4 J, giving a 16.67% improvement. Among all the samples, S4 gave the best result by absorbing 2.6 J of energy as shown in Fig. 14. This is a significant increase of about 116.67% compared to the base alloy, showing that it has the highest ability to withstand impact after treatment.

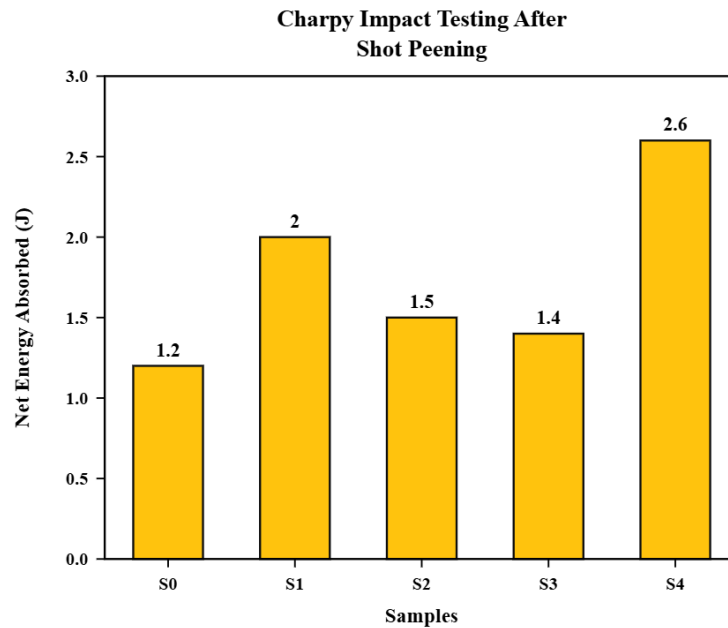


Fig. 14 Variation in Impact Value for Al7068 and its composites after Shot Peening

The shot peening process clearly improves the impact resistance of the material with S4 showing the highest improvement. Comparison of Charpy impact test before and after shot peening as shown in Fig. 15. Among all samples, S4 shows the best performance after treatment, while S2 shows only marginal improvement. Overall, shot peening enhances the material's ability to absorb impact energy and resist fracture, making it suitable for applications requiring higher durability and fatigue resistance.

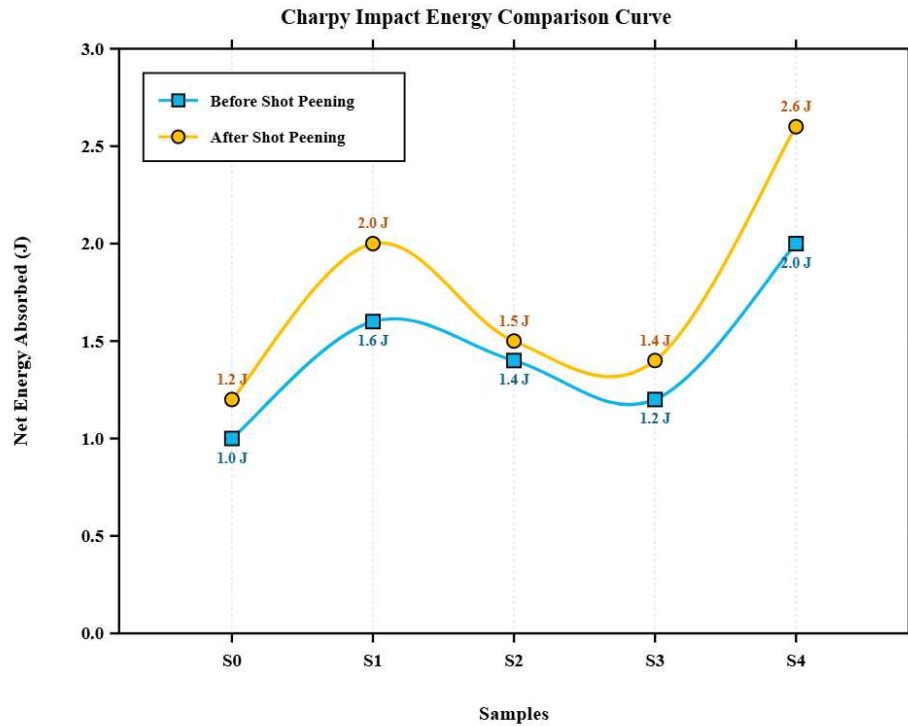


Fig. 15 Comparison Graph of Charpy Impact Strength before and after Shot Peening

4. Conclusion and Future Scope

- Reinforcement silicon carbide (SiC) and silicon nitride (Si_3N_4) is very important microparticles to improving the mechanical properties of Al7068 composites alloy, specially under the action of impact loading. Sample S4 exhibited the highest impact toughness, absorbing 2.0 J of energy, which corresponds to a 100% increase over the base alloy. highly suitable for structural and aerospace applications where excellent toughness is required.
- The Charpy impact test results confirm that after shot peening operation on the charpy specimen significantly improves the impact toughness of Al7068 alloy and its composites. Sample S4 showed the highest improvement, with a 116.67% increase in absorbed energy compared to S0, indicating excellent resistance under dynamic loading. These outcomes results proposed that microstructural changes happened by shot peening process, with reinforcement effects, effectively inhibit crack propagation and enhance energy absorption. Therefore, shot peening process proves that it is a valuable post-processing technique to strengthen the aluminum matrix composites for structural and impact-critical applications.

- Composite Al7068/1 % SiC /2 % Si₃ N₄ demonstrates the best performance in terms of toughness, making it the most suitable for applications requiring high impact resistance after shot peening.
- Microstructural analysis has been performed to visualize and examine the distribution of the Si₃ N₄ & SiC particles surrounded by the aluminum matrix and good bonding between them. Overall, the SEM results confirm that controlled hybrid reinforcement of silicon carbide and silicon nitride microparticles is crucial for achieving a balanced microstructure of Al7068 alloy, to enhanced toughness without impacting structural integrity.
- Future studies can be focused on industrial validation through collaborative research with leading organization. This will help assess its practical performance and promote its use in industrial applications.

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Ethical Statement

The current research belongs to the contributors, and related works are properly cited in the article.

Availability of data and material

Data and materials that have been generated and/or analyzed during the course of the current study are available and can be requested from the corresponding author upon reasonable request

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Not Applicable

Authors' contributions

Prem Prakash Pnadit contributed to conceptualization, data collection, data analysis, data interpretation, and manuscript preparation. Premanand Singh Chauhan and Anupma Agarwal advised the research methodology, critically reviewed the manuscript, and helped interpret and discuss results. The Rajendra Kumar Shukla supervised the work, gave methodological advice, and made critical revisions to the manuscript.

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