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Original Article

Experimental Study of the Abrasive Flow Machining Process on Surface Finishing and Material Remove Rate of Aluminium Alloy 6061/SiC Nano Metal Matrix Composites

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Abstract

One of the most important and costly procedures in today's manufacturing sectors is precision surface finishing, especially for parts with intricate geometries and complex internal pathways. Uniform surface finishing in such hard-to-reach areas is made possible by Abrasive Flow Machining (AFM), a sophisticated non-traditional finishing technique. In this work, stir casting was used to create AA6061/SiC Nano Metal Matrix Composites (NMMCs) reinforced with 1-6 weight percent nano-SiC particles, which were then completed using a specifically designed AFM setup with a silicon-based abrasive medium. Surface roughness (Ra) and material removal rate (MRR) were examined experimentally in relation to extrusion pressure (50-200 MPa), abrasive mesh size (60-240 mesh), and number of machining cycles (1,000-5,000). With a maximum MRR of 0.124 g/min and a surface roughness reduction from 1.82 µm to 0.42 µm, the ideal finishing conditions were achieved at 8 MPa extrusion pressure, 500-mesh abrasive, and 25 cycles. When compared to the unreinforced AA6061 alloy, mechanical characterization showed that the addition of 4 weight percent nano-SiC generated the best overall attributes, increasing hardness by about 28%, improving ultimate tensile strength by 24%, and reducing wear rate by about 32%. While X-ray diffraction patterns indicated the presence of Al and SiC phases without unwanted reaction products, scanning electron microscopy and energy-dispersive X-ray spectroscopy investigations revealed the uniform dispersion and strong interfacial bonding of nano-SiC particles. The results demonstrate that AFM significantly enhances the surface integrity of AA6061/SiC NMMCs while maintaining controlled material removal, making it an effective finishing process for high-precision aerospace, automotive, and advanced engineering components.

Categories: Advanced Manufacturing Technologies, Advanced Materials, Materials Engineering

Keywords: aa6061/sic nano metal matrix composites (nmmcs), energy dispersive x-ray spectroscopy (edxs), x-ray diffraction (xrd), scanning electron microscopy (sem), and abrasive flow machining (afm)

Introduction

The need for parts with high dimensional precision, better surface integrity, and longer service life has grown dramatically in advanced manufacturing sectors like aerospace, automotive, marine, and defense. Surface attributes like wear behavior, fatigue resistance, dimensional correctness, and surface roughness have a significant impact on the performance and dependability of engineering components. Because of high tool wear, poor surface quality, and dimensional inaccuracies, conventional machining and finishing procedures frequently encounter difficulties when

treating complicated geometries, interior passages, and sophisticated composite materials [1,2]. In order to achieve better surface qualities in materials that are challenging to machine, non-traditional finishing techniques have drawn a lot of interest.

Abrasive Flow Machining (AFM), one of several sophisticated finishing methods, has become a successful precision finishing procedure that can enhance the surface quality of intricate components. AFM uses regulated hydraulic pressure to push a semi-solid viscoelastic abrasive medium with fine abrasive particles through or across the workpiece surface. Through micro-cutting and micro-polishing processes, the abrasive particles eliminate minute surface imperfections, improving dimensional accuracy and surface smoothness [3,4]. AFM has been effectively used to finish hydraulic components, turbine blades, dies, molds, aerospace components, and complex interior channels where traditional finishing methods are challenging to apply [5,6]. Process variables including extrusion pressure, abrasive particle size, abrasive concentration, media viscosity, and the number of machining cycles are the primary determinants of AFM performance. These factors have a major impact on the processed component's overall surface integrity, surface roughness (Ra), and material removal rate (MRR) [7]. Achieving a balance between outstanding surface finish and efficient material removal requires optimizing these parameters.

Because of its exceptional strength-to-weight ratio, corrosion resistance, weldability, and outstanding machinability, AA6061 aluminum alloy has drawn a lot of attention among aluminum alloys. Because of these qualities, AA6061 is appropriate for structural applications in the defense, automotive, aerospace, and marine industries [8]. However, monolithic AA6061's comparatively low strength, hardness, and wear resistance restrict its use in harsh loading and wear scenarios. Aluminum matrix composites (AMMCs) are created by adding ceramic reinforcement particles including silicon carbide (SiC), alumina, boron carbide, and graphite to the aluminum matrix in order to get over these restrictions [9,10]. Because of its high hardness, superior wear resistance, low density, thermal stability, and strong mechanical strength, SiC is regarded as one of the most promising reinforcement elements for aluminum matrix composites. By increasing load transmission capability and limiting plastic deformation of the aluminum matrix, SiC particles added to AA6061 improve hardness, tensile strength, stiffness, and tribological parameters [11]. SiC reinforcement greatly enhances the mechanical and wear behavior of AA6061 composites, according to several studies [12,13]. However, due of increased tool wear, poor machinability, and the creation of surface defects during traditional machining processes, the presence of hard ceramic particles makes machining more difficult [14]. Because of its ease of use, affordability, and capacity to produce consistent reinforcement distribution, stir casting is one of the most popular fabrication methods for AA6061/SiC metal matrix composites. To increase the interfacial connection between the matrix and reinforcement, ceramic particles are added after the molten aluminum alloy is mechanically stirred [15,16]. Stir-cast AA6061/SiC composites are superior to unreinforced aluminum alloys in terms of hardness, tensile strength, wear resistance, and microstructural features, according to numerous research [17].

The mechanical and tribological performance of aluminum matrix composites is largely dependent on their microstructural features. Techniques including X-ray diffraction (XRD), energy dispersive X-ray spectroscopy (EDS/EDX), and scanning electron microscopy (SEM) are frequently used to analyze phase formation, interfacial bonding, reinforcement distribution, and the existence of secondary compounds in composite materials [18]. While particle aggregation may result in flaws and decreased performance, correct dispersion of SiC particles within the aluminum matrix enhances mechanical characteristics. The presence of hard ceramic particles makes AA6061/SiC composites difficult to machine and polish, despite their improved mechanical qualities. Conventional machining techniques can lead to poor surface integrity and quick tool deterioration. As a result, cutting-edge finishing methods like AFM offer a practical way to enhance the surface quality of aluminum matrix composites without compromising their dimensional accuracy. The impact of AFM process parameters on surface roughness and material removal characteristics has been examined in recent studies. After analyzing the evolution of surface texture during abrasive flow machining, Wang et al. [18] found that optimal process conditions significantly improved surface quality. In their experimental study of AFM of aluminum alloys, the authors showed how extrusion pressure and abrasive properties affect finishing performance. The significance of choosing appropriate finishing parameters to attain better surface integrity and dimensional accuracy was emphasized in reviews of abrasive machining of SiC-based composites and SiCp/Al composites [19,20].

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In the current study, stir casting was used to create AA6061 reinforced with 1-6 weight percent nano-sized SiC particles. To enhance the internal cylindrical surface polish of manufactured composites, a specially created abrasive flow machining setup was created. MRR and Ra were examined experimentally in relation to the main AFM factors, such as extrusion pressure, abrasive mesh size, and number of machining cycles. Additionally, SEM, EDS, and XRD studies were used to describe the manufactured composites in order to assess phase composition and reinforcement distribution. To determine the connection between composite qualities and AFM performance, mechanical attributes such as density, hardness, tensile strength, and wear behavior were also examined.

It is clear from the literature that AFM and AA6061/SiC composites have been the subject of much investigation. Nevertheless, little research has been done on the AFM finishing behavior of AA6061 reinforced with nano-SiC particles, especially when taking into account the combined effects of extrusion pressure, abrasive mesh size, machining cycles, MRR, surface roughness, mechanical properties, and microstructural features. Thus, by experimentally examining the precision finishing behavior of AA6061/nano-SiC metal matrix composites using abrasive flow machining, the current study seeks to close this research gap.

Materials And Methods

Because of its great mechanical qualities, favorable strength-to-weight ratio, outstanding corrosion resistance, and numerous industrial uses, AA6061 Aluminium Alloy was chosen as the matrix material. To improve the performance of the composite, nanoscale SiC particles with an average particle size of 50 nm were used as the reinforcement material. By adding different weight percentages of SiC reinforcement - 0 weight percent, 1 weight percent, 2 weight percent, 3 weight percent, 4 weight percent, 5 weight percent, and 6 weight percent - the AA6061/SiC Nano Metal Matrix Composites (NMMCs) were effectively created using the stir-casting technique. The goal of adding nanoscale SiC particles was to enhance the created composites' mechanical, tribological, and surface finishing properties (Tables *1* and 2).

Element	Mg	Si	Fe	Cu	Mn	Cr	Zn	Ti	Al
Weight (%)	1.1	0.7	0.8	0.29	0.16	0.21	0.11	0.09	Balance

TABLE 1: Chemical composition of AA6061 Alloy

Material	Density (g/cc)	Thermal expansion (10^{-6}/K)	Thermal conductivity (W/m K)	Elastic modulus (GPa)	Melting Point temp (◦C)
Sic	3.9	11	24	129	1,559

TABLE 2: The properties of nano-SiC

SiC, Silicon Carbide

Experiment set up

Workpiece fixtures, reciprocating pistons, hydraulic drive systems, upper and lower media cylinders, abrasive media chambers, and a pressure control unit make up the developed AFM configuration. The Al 6061/SiC NMMC specimens were machined by repeatedly extruding a viscoelastic abrasive medium with abrasive particles via their interior cylindrical tube under carefully regulated extrusion pressure settings. A thorough examination of the impact of key process variables, such as extrusion pressure, abrasive mesh size, and the number of machining cycles, on critical performance attributes, such as Ra and MRR, was made possible by the specifically built AFM system. For the purpose of assessing the developed composites' finishing ability, the setup offered regulated and reproducible finishing conditions (Figure *1*).

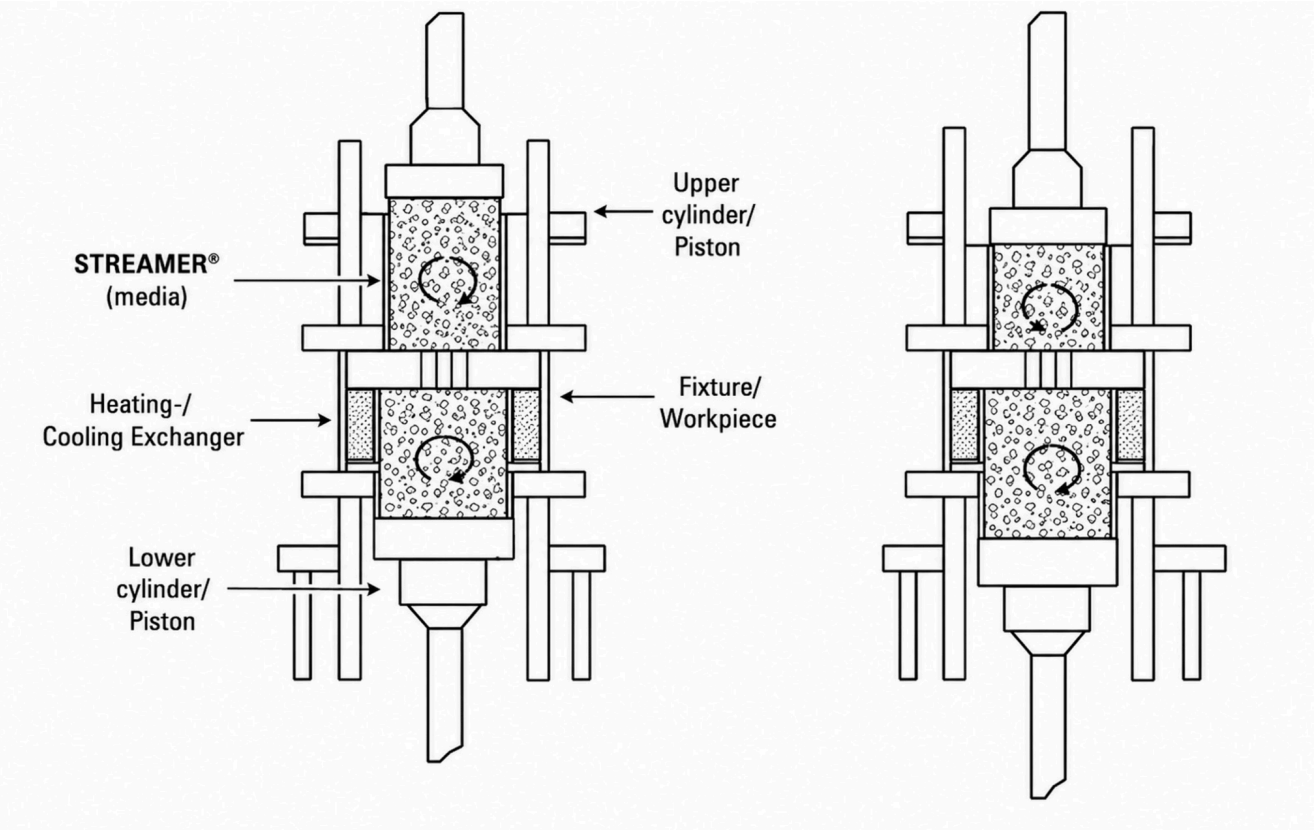


FIGURE 1: Schematic diagram of abrasive flow matching process

Preparing the workpiece

Stir-casting was used to create specimens of AA6061/SiC NMMC. The necessary amount of AA6061 aluminum alloy was first melted at a temperature between 750°C and 800°C in an electric resistance furnace. To guarantee that the reinforcement particles were evenly distributed throughout the melt, preheated nano-sized SiC particles were progressively added to the molten aluminum matrix while constant mechanical stirring was carried out. The molten composite slurry was then transferred into moulds that had been heated and left to harden under carefully monitored circumstances. Figure *2* shows the stir-casting process. Following solidification, the cast specimens underwent standard machining procedures such as facing, drilling, boring, and reaming to provide cylindrical workpieces appropriate for testing AFM.

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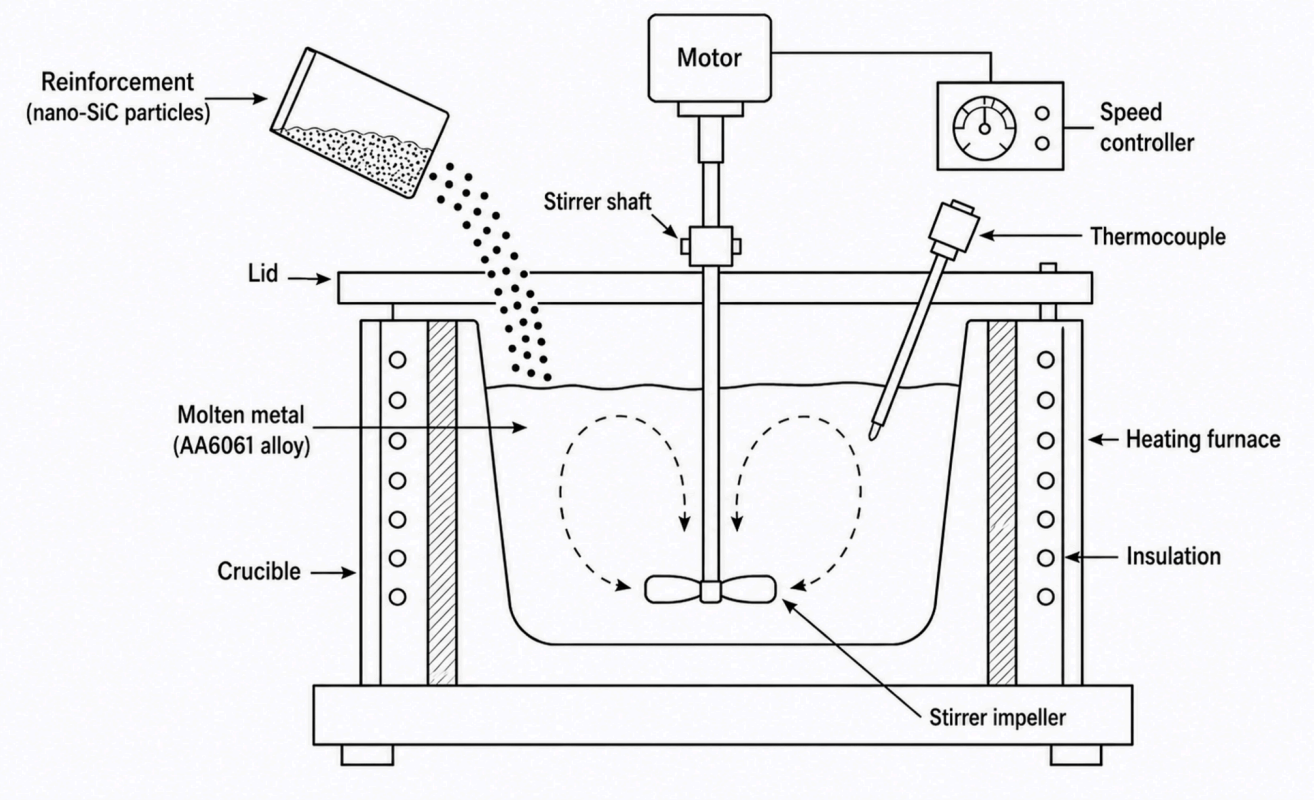


FIGURE 2: Stir-casting process method

Results And Discussion

The experimental study showed that AFM process settings have a substantial impact on the Ra and material removal properties of AA6061/SiC NMMCs. Because of better interfacial bonding, efficient load transfer, and uniform dispersion of reinforcement particles within the AA6061 aluminum alloy matrix, the mechanical characteristics of the composites gradually improved with the addition of nano-sized SiC reinforcement up to 4 weight percent (Table *3*). However, a minor decline in mechanical and surface finishing performance was noted above 4 weight percent SiC reinforcement. The overall composite integrity and machining performance were negatively impacted by particle agglomeration, increased porosity, and non-uniform distribution of reinforcement particles at higher reinforcement concentrations.

S. No.	SiC Reinforcement (wt.%)	Density (g/cm^3)	Hardness	Tensile Strength (MPa)
1	AA6061with 0%Sic	2.70	95	265
2	AA6061with 1% SiC	2.69	108	278
3	AA6061with 2% SiC	2.68	121	292
4	AA6061with 3% SiC	2.67	135	306
5	AA6061with 4% SiC	2.66	148	321

6	AA6061with 5% SiC	2.67	141	309
7	AA6061with 6% SiC	2.68	133	296

TABLE 3: Mechanical properties of AA6061/SiC NMMCs

NMMC, Nano Metal Matrix Composite; SiC, Silicon Carbide

Effect of reinforcement particles

The impact of nanoscale SiC reinforcement on the microstructural behavior of AA6061 aluminum alloy was methodically examined using an optical microscope (OM). Grain structure, porosity, fracture development, and overall surface morphology of the produced composites were assessed in relation to various reinforcement levels of 0 weight percent, 1 weight percent, 2 weight percent, 3 weight percent, 4 weight percent, and 5 weight percent nano-SiC (Figure *3*).

Comparatively coarse grains, as well as observable pores and microcracks, were present inside the aluminum matrix in the unreinforced base alloy condition (0 weight percent nano-SiC). Lower hardness and less resistance to grain deformation were the outcomes of the lack of reinforcing particles. Furthermore, the alloy's structural integrity was negatively impacted by non-uniform solidification and localised porosity. Significant improvements in the microstructure were noted with the addition of nano-SiC particles in the range of 1-3 weight percent. A more consistent particle distribution throughout the matrix was made possible by the hard ceramic reinforcement particles, which also improved bonding between the matrix and reinforcement phases. There was a significant decrease in surface flaws such as pits, holes, and microcracks. Additionally, by limiting grain growth, the reinforcement particles improved structural stability and matrix strength. Grain refinement was noticeable at higher reinforcement levels of 3-4 weight percent nano-SiC, leading to microstructures that were denser, more compact, and finer. The overall homogeneity of the composite structure was enhanced by the nano-SiC particles' efficient occupation of matrix voids. Additionally, the micrographs showed decreased fracture propagation and increased particle dispersion, suggesting better load transfer capacity and stronger interfacial bonding between the SiC reinforcement particles and the AA6061 Matrix. Thus, the maximum hardness and tensile strength were obtained at 4 wt.% nano-SiC, with values of 148 HV and 321 MPa, respectively. Compared with unreinforced AA6061, the hardness improvement was 55.79%, and the tensile-strength improvement was 21.13%. The subsequent decrease at 5 and 6 wt.% SiC was associated with increased particle agglomeration, porosity, and non-uniform reinforcement distribution. The manuscript discusses the resulting reduction in composite integrity and machining performance at higher reinforcement concentrations. Therefore, the conclusion that 4 wt.% nano-SiC provides the best measured mechanical performance has been retained. We agree with the general conclusion that AFM is effective for finishing internal cylindrical surfaces. The developed AFM system uses a reciprocating abrasive medium that is extruded through the internal cylindrical passage of the specimens under controlled conditions. However, during our detailed review of the submitted manuscript, we identified inconsistencies between the previously stated AFM parameters and the actual plotted experimental results.

Effect of extrusion pressure

By examining the differences in material removal and Ra under various reinforcement compositions, the impact of extrusion pressure on the AFM performance of AA6061/nano-SiC composite was examined. The flow behavior of the abrasive media and the finishing action on the interior surfaces of the composite specimens were found to be significantly influenced by extrusion pressure. There was less interaction between the abrasive particles and the composite surface at lower extrusion pressures because the abrasive media flowed through the workpiece passage somewhat slowly. Lower material removal and relatively higher surface roughness values resulted from insufficient cutting and polishing actions. In these circumstances, surface imperfections, machining marks, and micro-defects on the composite surface could not be successfully removed by the abrasive particles.

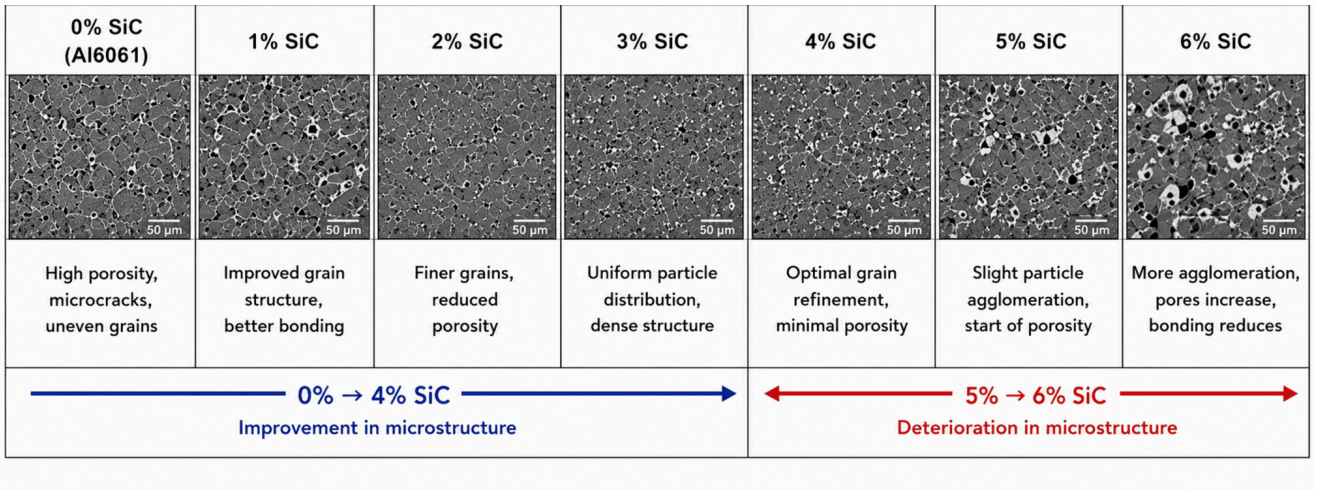


FIGURE 3: Optical microscope (OM) effect of reinforcement particles

SiC, Silicon Carbide

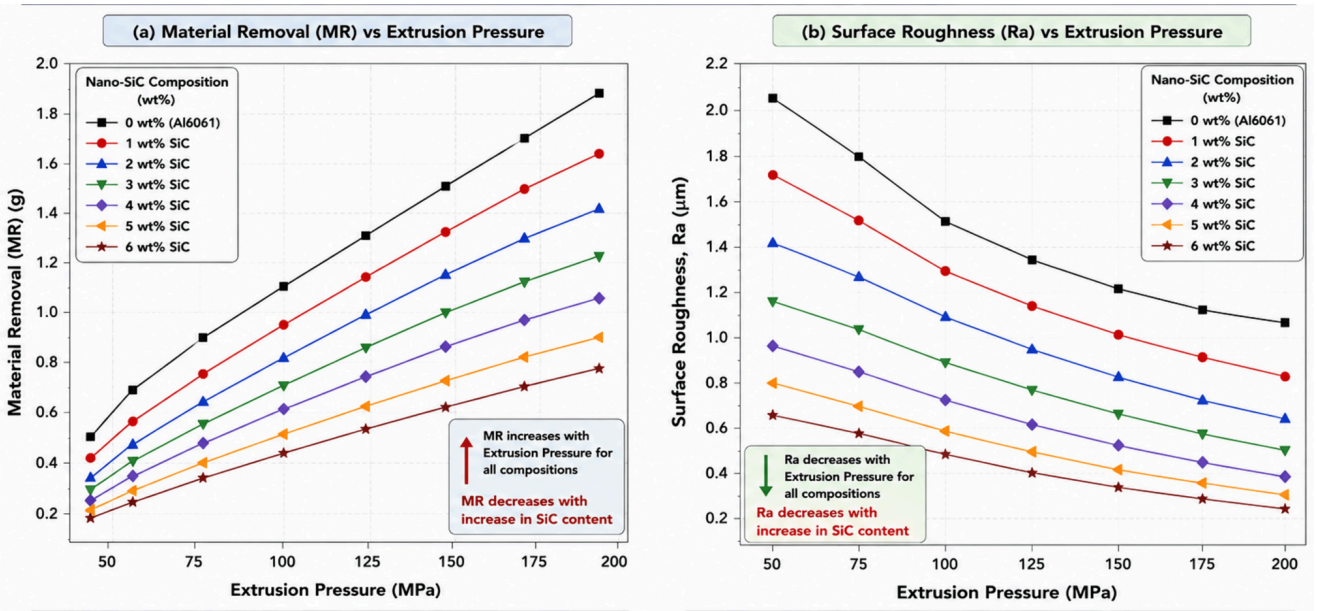


FIGURE 4: Variation between (a) material removal (MR) with extrusion pressure and (b) change in surface roughness (µm) with extrusion pressure of aluminum under different compositions

The interaction between the abrasive particles and the workpiece surface improved as the extrusion pressure increased because the abrasive medium passed through the internal passage with more force and velocity. As a result, the MRR gradually increased and the surface roughness significantly decreased as the micro-cutting and micro-polishing processes became more intense. The overall surface polish of the composites was improved by the efficient removal of surface peaks, porosity, and machining marks through repeated abrasive action. Because of their increased hardness, greater load-bearing capacity, and uniform reinforcement distribution, composites reinforced with 1 to 4 weight percent nano-sized SiC particles showed a more noticeable improvement in finishing performance (Figure *4*). While retaining controlled material removal capabilities, the reinforced composites demonstrated enhanced resistance to surface damage during AFM processing. However, minor abnormalities in finishing performance were noted at very high extrusion pressures and reinforcement concentrations exceeding 4 weight percent nano-SiC. Particle agglomeration and

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increased resistance to the flow of abrasive media caused by an excessive amount of reinforcement decreased the finishing action's homogeneity. Because of the clustering of reinforcing particles inside the matrix, localized surface flaws and non-uniform material removal were seen in some areas. After cross-checking the numerical values against Figures *4-6*, the values 1.82 µm and 0.42 µm could not be directly traced to the corresponding parameter axes and plotted experimental points.

Effect of number of cycles

One important AFM process parameter that significantly affects the surface finishing properties of AA6061/nano-SiC composite specimens is the number of cycles. The current study examined how different AFM cycles affected material removal and surface roughness for various compositions of nanoscale SiC reinforcement. There was less abrasive interaction and finishing action at lower cycle numbers because the abrasive medium was in contact with the workpiece surface for comparatively shorter periods of time. Surface imperfections such as machining marks, porosity, and surface flaws were not entirely eliminated from the composite surface as a result of inadequate micro-cutting and micro-polishing processes. As a result, during the first machining cycles, decreased material removal and relatively greater surface roughness values were noted.

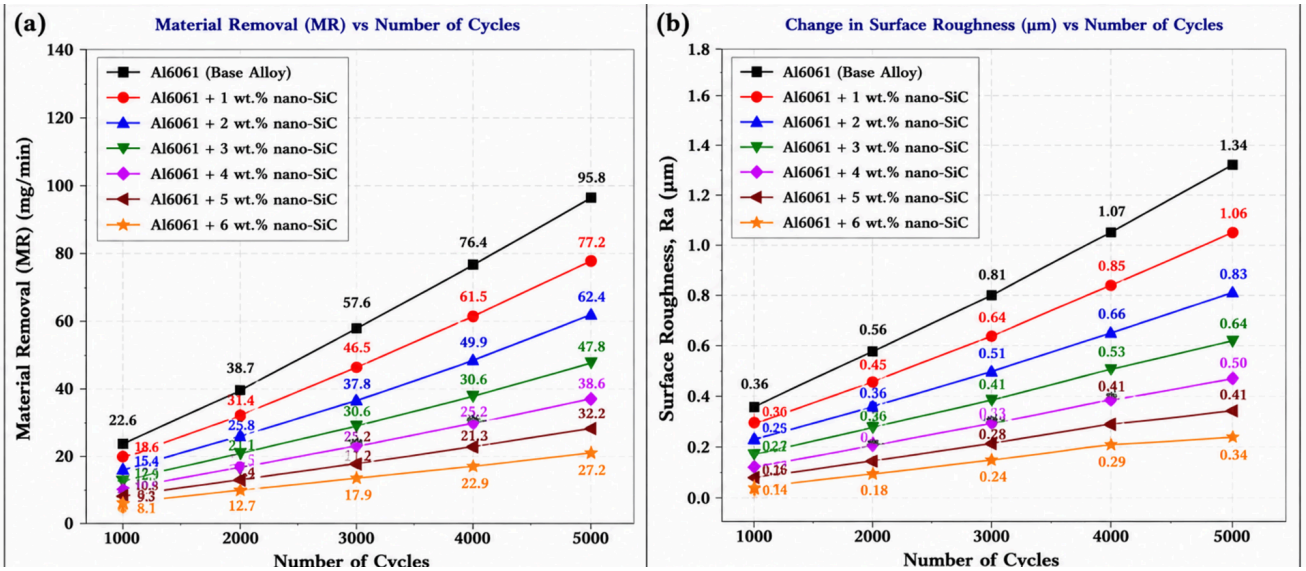


FIGURE 5: Variation between (a) material removal (MR) with number of cycles and (b) change in surface roughness (µm) with number of cycles of aluminum under different compositions

Repetitive extrusion of the abrasive media improved the interface between abrasive particles and the internal surface of the composite specimens as the number of AFM cycles increased. Surface asperities, burrs, and machining markings were gradually eliminated from the workpiece surface through continuous micro-cutting and micro-polishing operations. Increased material removal and a notable improvement in surface finish quality were the outcomes of this. Because of the abrasive particles' repeated smoothing activity, surface roughness values gradually decreased as the number of cycles increased. For AA6061/SiC NMMCs with 1-4 weight percent nano-SiC particles, the improvement in finishing performance was more noticeable. Better finishing qualities and greater resistance to surface deformation during AFM processing were made possible by the increased hardness, higher interfacial bonding, and uniform dispersion of reinforcement particles inside the matrix (Figures *5* and 6). However, because of particle agglomeration and higher resistance to abrasive media flow, the improvement in finishing performance became relatively less significant at reinforcement levels over 4 weight percent nano-SiC. Overly high reinforcement content decreased the abrasive action's homogeneity, which occasionally led to localized surface flaws and uneven material removal during extended machining cycles.

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SEM evaluation

The microstructure and surface morphology of AA6061 alloy and nano-SiC reinforced composites were examined using SEM. The samples were cleaned with an acetone solution and allowed to air dry in order to eliminate surface pollutants and impurities before to SEM analysis. Due to the high porosity and poor wettability of the aluminum matrix, the SEM micrograph of the base alloy without reinforcement (0 weight percent nano-SiC) revealed the presence of pores, microcracks, and an uneven grain structure. In close proximity to the AFM-treated area, a nugget zone development was also noted. Grain structure and particle distribution significantly improved with the addition of 1 weight percent nano-SiC reinforcement. Improved bonding between the matrix and reinforcement particles, decreased porosity, and improved thermal stability all contributed to the reinforced composite's improved microstructural properties. Figure *7* presents the microstructure and surface morphology of the AA6061 alloy and nano-SiC-reinforced composites. The microstructural analysis reveals the distribution of nano-SiC particles within the aluminum matrix and their influence on grain refinement. A relatively uniform dispersion of nano-SiC particles can be observed in the reinforced composites, contributing to improved interfacial bonding and enhanced mechanical properties. The surface morphology indicates reduced defects and better surface integrity with increasing reinforcement content. These observations confirm the effectiveness of nano-SiC reinforcement in improving the microstructural characteristics of AA6061 composites.

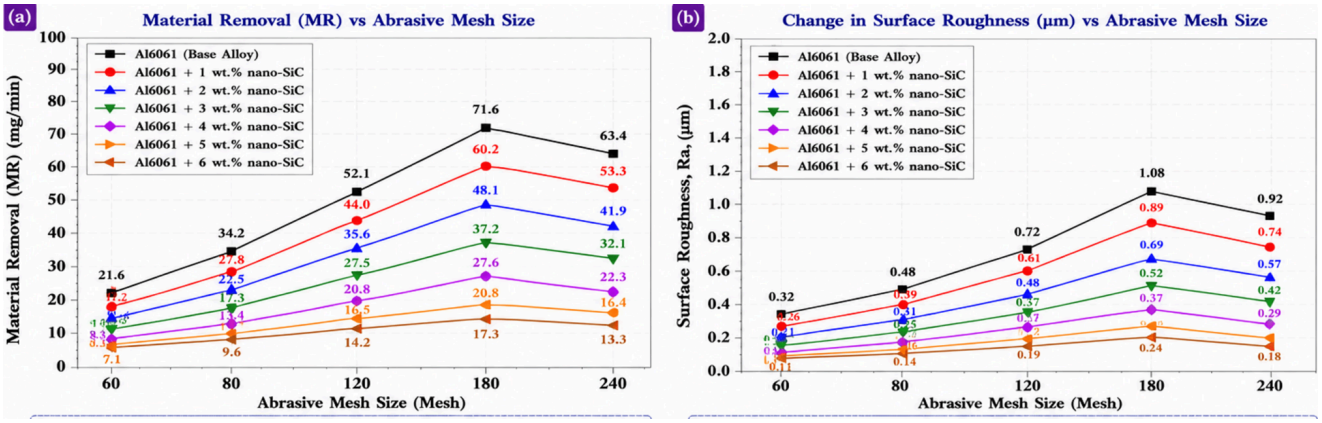


FIGURE 6: Variation between (a) material removal (MR) with abrasive mesh size and (b) change in surface roughness (µm) with abrasive mesh size of aluminum under different compositions

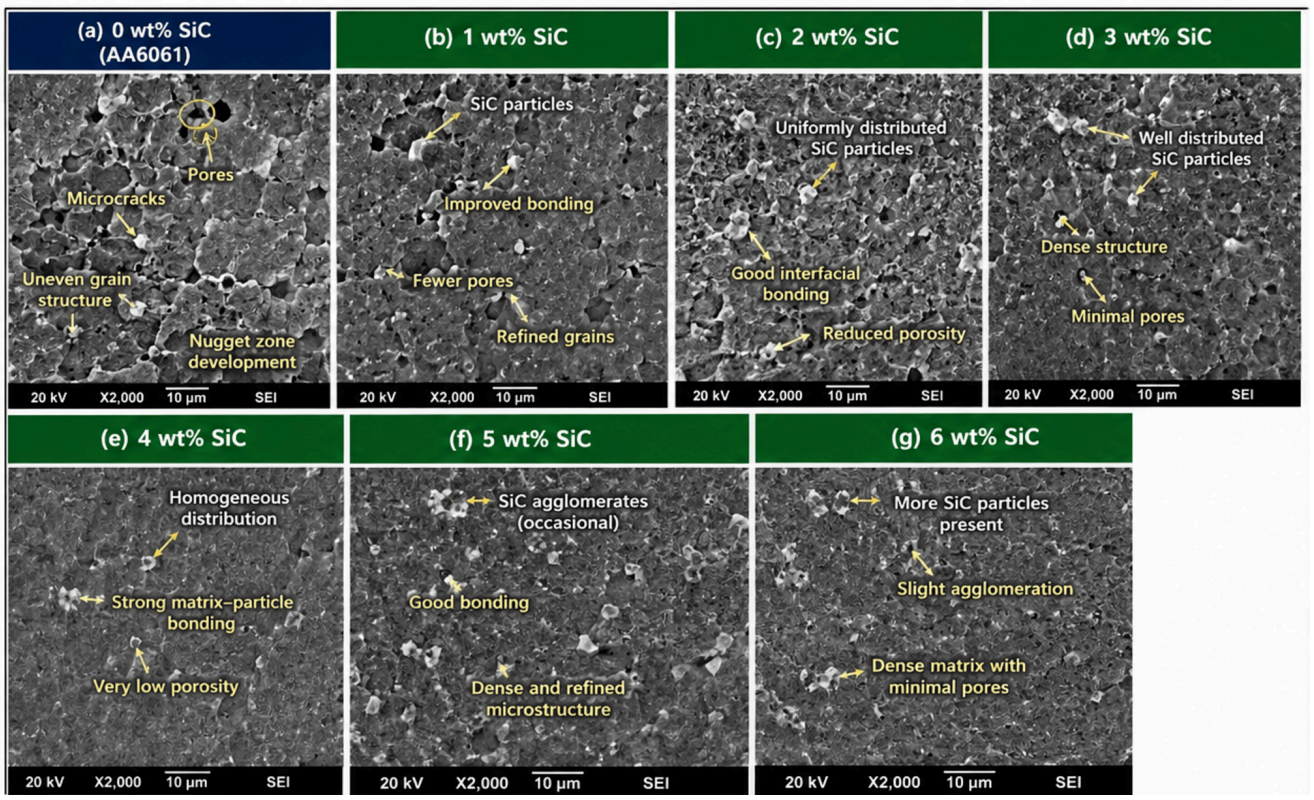


FIGURE 7: The microstructure and surface morphology of AA6061 alloy and nano-SiC reinforced composites

SiC, Silicon Carbide

EDS/EDX analysis

The elemental makeup of the base alloy and the created composites was ascertained by EDS/EDX analysis. This method verifies the addition of reinforcing particles and assists in identifying the chemical constituents contained in the substance. Al 6061 alloy (base material) and Al 6061 reinforced with nano-SiC in the range of 1-4 weight percent are among the samples examined.

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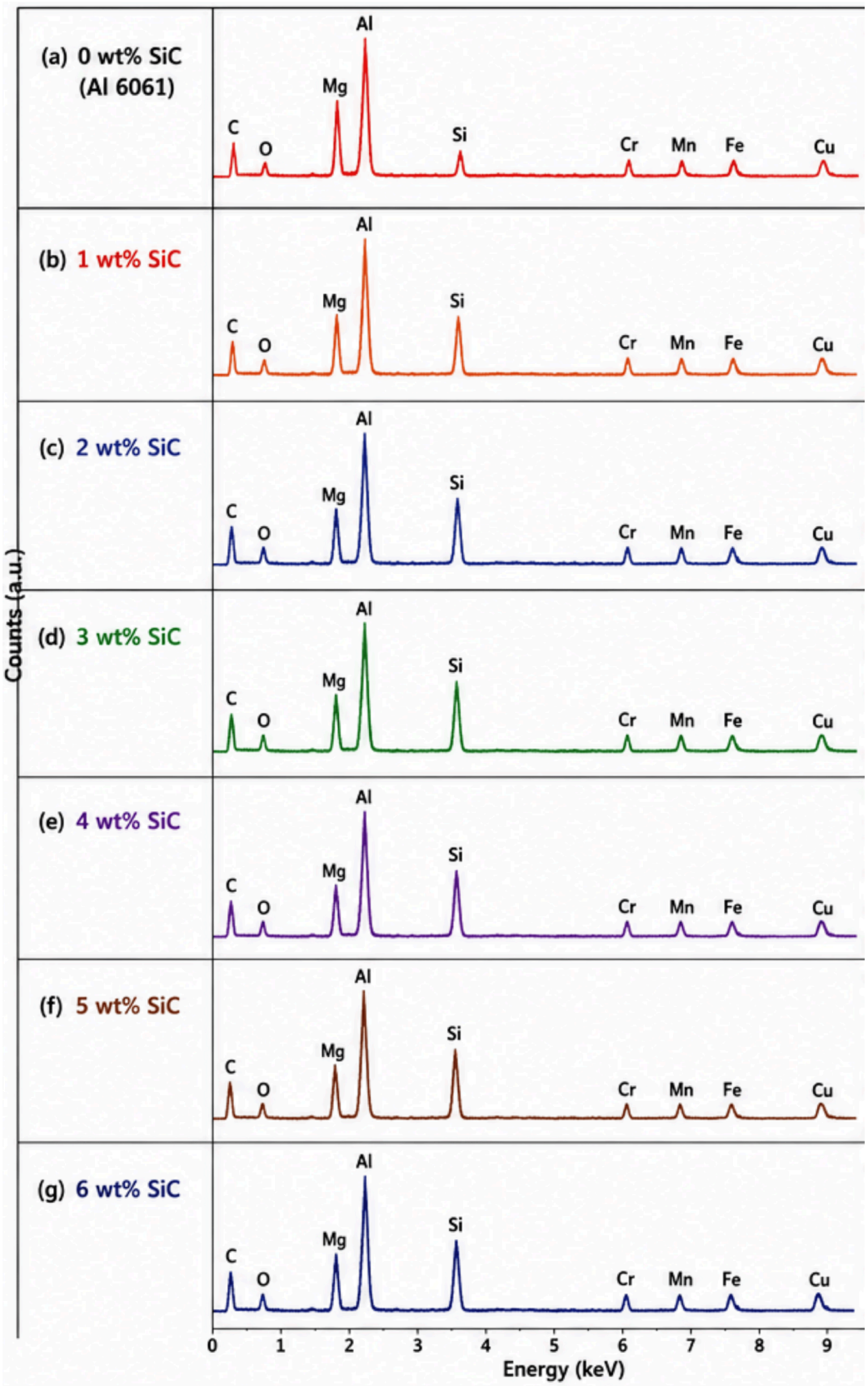


FIGURE 8: EDS/EDX analysis of Al 6061 with SiC reinforcement (0% to 6%)

EDS/EDX, Energy Dispersive X-ray Spectroscopy

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Aluminium (Al) and magnesium (Mg) have large peaks in the base alloy's EDS spectrum (Figure *8a*), indicating that these are the alloy's main constituent elements. On the other hand, the spectra of the composites (Figure *8b*-e) show additional peaks of silicon (Si), carbon (C), and oxygen (O) in addition to Al and magnesium. This clearly shows that the nano-SiC reinforcement was successfully incorporated into the matrix.

The Si peak intensity rises with increasing reinforcement content, particularly at 4 weight percent SiC, while the Al peak intensity decreases with the addition of nano-SiC. This validates the efficient and gradual dispersion of SiC nanoparticles in the aluminium matrix. The SiC reinforcement is responsible for the carbon's existence; however, organic residues from sample preparation may also play a role. Overall, by strengthening interfacial bonding, lowering flaws, and increasing wettability, the inclusion of nano-SiC greatly enhances the composite structure and improves the material's mechanical qualities.

XRD analysis

XRD analysis was used to confirm the development and inclusion of reinforcement phases as well as to identify the crystalline phases found in the base alloy and the produced composites. The samples examined included the base alloy and AA6061 reinforced with nano-SiC at levels of 1-4 weight percent. The Al phase is represented by prominent diffraction peaks at 2θ values of roughly 41°, 45°, 67°, and 80° in the base alloy's XRD pattern (Figure *9a*). The presence of a single-phase Al matrix in the base material is confirmed by these peaks' good match with the standard JCPDS card (89-4017). Additional diffraction peaks arise at about 2θ values of 40°, 66°, and 89° in composites containing 1-3 weight percent nano-SiC (Figure *9b* and c). These peaks belong to SiC and are compatible with the JCPDS card (83-1759). This demonstrates unequivocally that the SiC reinforcement was successfully incorporated into the Al matrix. Without dissolving the primary Al phase, the presence of SiC and Al phases verifies the creation of a composite structure. Peak intensity increases with increasing SiC content, suggesting stronger phase presence and better crystallinity.

The strength of Al peaks reduces and SiC peaks become more noticeable at higher reinforcement levels (4 weight percent) (Figure *9d* and e), indicating a greater contribution of reinforcement phases inside the matrix. Due to the higher reinforcement content, the SiC peak intensity increases further in the case of 5 weight percent SiC, while the Al peaks marginally drop. The overall mechanical performance of the composite may be impacted by excessive reinforcing, though, as it may cause particle agglomeration, uneven distribution, and increased brittleness.

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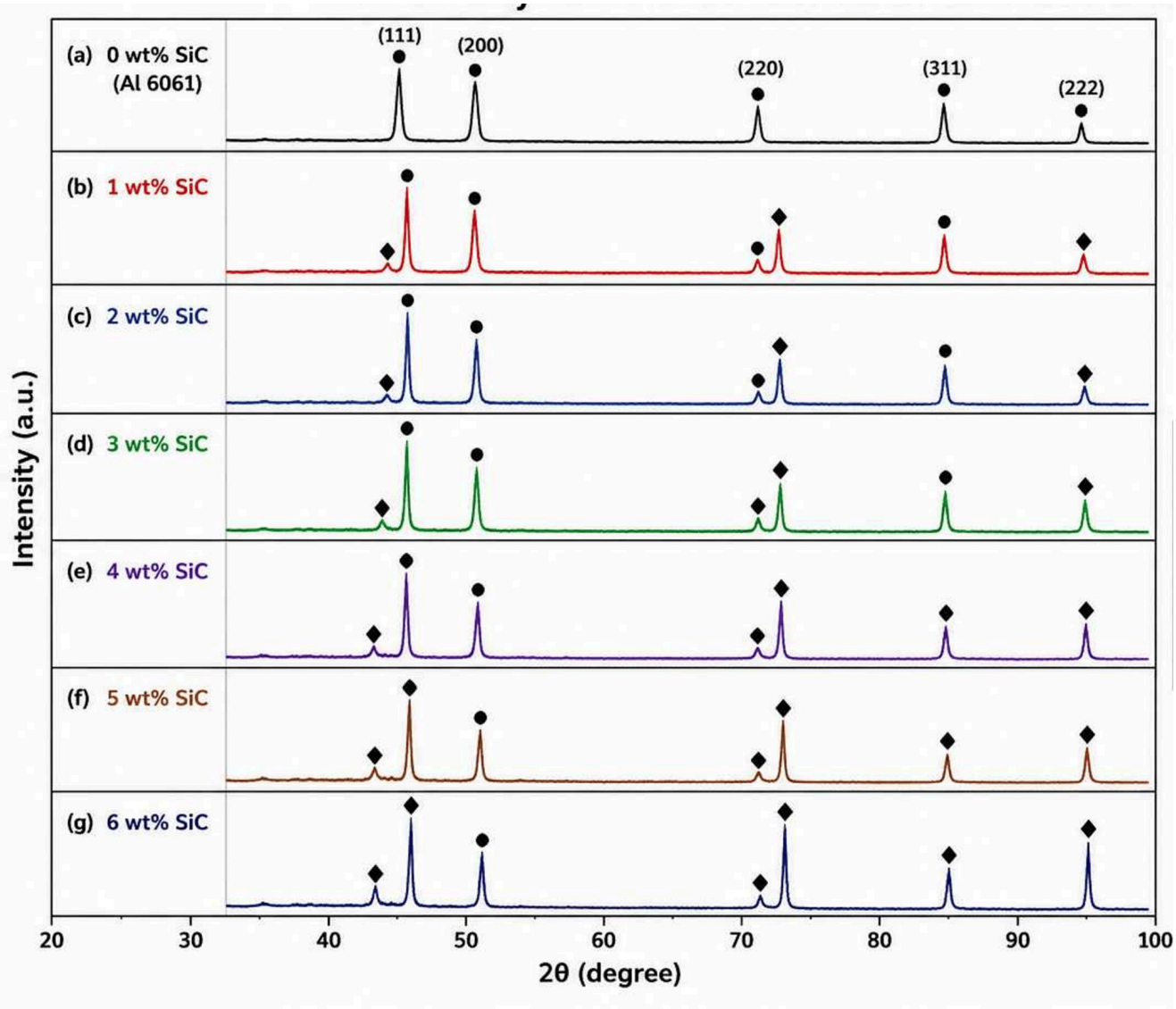


FIGURE 9: XRD Analysis of Al 6061 with SiC reinforcement (0% to 6%)

XRD, X-ray diffraction; SiC, Silicon Carbide

Declaration of Artificial Intelligence (AI) Use

During the preparation of this manuscript, the authors used OpenAI's ChatGPT solely to assist with improving the grammar, language, sentence structure, and overall readability of the manuscript. The AI tool was not used to generate, analyze, interpret, or validate the experimental data, research findings, figures, tables, or scientific conclusions. All experimental work, data collection, analysis, interpretation, and manuscript content were performed and verified by the authors, who take full responsibility for the accuracy, originality, and integrity of the work.

Conclusions

The experimental investigation of AA6061/nano-SiC metal matrix composites and their finishing by AFM led to the following key findings. The mechanical performance of AA6061 was enhanced by the addition of nano-SiC up to 4 weight percent. In comparison with unreinforced AA6061, which showed 95 HV and 265 MPa, the 4-weight-percent SiC composite showed the maximum hardness (148 HV) and tensile strength (321 MPa). Effective load transfer, grain

refinement, and strong interfacial bonding brought about by comparatively uniform SiC dispersion are responsible for this improvement. The performance of the composite decreased at reinforcement levels greater than 4 weight percent. Particle agglomeration, increased porosity, and uneven reinforcement distribution are the primary causes of the loss in hardness and tensile strength at 5-6 weight percent SiC. Overall, 4 wt.% nano-SiC provided the best balance between mechanical properties and AFM finishing performance, owing to its effective particle dispersion and interfacial strengthening, while higher reinforcement contents adversely affected composite integrity through agglomeration and porosity.

The composites' interior surface polish was greatly enhanced using AFM. Surface roughness was decreased by increasing extrusion pressure and machining cycles, which improved abrasive-workpiece interaction and encouraged micro-cutting and micro-polishing. Because of their stronger polishing action, finer abrasive particles further enhanced surface smoothness. With a maximum MRR of 0.124 g/min and a reported surface roughness reduction from 1.82 µm to 0.42 µm, the optimal AFM setting resulted in a significant increase in surface quality. Repetitive abrasive action eliminated machining marks and surface imperfections, resulting in an enhanced polish. The experimental results demonstrate that the incorporation of nano-SiC significantly influences the mechanical and surface finishing performance of AA6061 composites. Among the investigated compositions, 4 wt% nano-SiC exhibited the highest hardness of 148 HV and tensile strength of 321 MPa, attributed to improved interfacial bonding, effective load transfer, grain refinement, and relatively uniform particle dispersion. Further addition of nano-SiC beyond 4 wt% reduced the mechanical performance because of particle agglomeration, porosity, and non-uniform distribution. AFM effectively improved the surface finish by removing surface asperities through micro-cutting and micro-polishing mechanisms, with increased abrasive interaction resulting in improved material removal and reduced surface roughness. Overall, 4 wt% nano-SiC provided the most favorable balance of mechanical properties and AFM surface finishing performance.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Peram Kondalarao, Ginka Ranga Janardhana

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Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue.

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- **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work.
- **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work.
- **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

Data Availability Statements

All data generated or analyzed during this study are included in this published article and/or its appendices.

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