EXPERIMENTING AND OPTIMIZING CUTTING PARAMETERS FOR A HIGH-SPEED MACHINE ON AA8011 REINFORCED WITH TiB2 AND ZrO2

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ABSTRACT

MMCs are known for their superior strength and lightweight properties, making them valuablein aerospace and automotive applications, but they pose significant challenges in terms of machining and achieving a high-quality surface finish. The experimental design involves varying the speed, and feed rate on a CNC five-axis milling machine to determine their effects on surface roughness. The outcomes are contrasted with those derived using FSP, an enhanced method widely recognized for its capacity to generate superior surface treatments on intricate materials. To provide accurate and reliable findings, surface roughness is assessed using sophisticated metrology equipment. The research indicates the ideal machining parameters to obtain the best surface quality on AA8011 of ZrO2 and TiB2 reinforcement using CNC five-axis milling. The necessary MMC is fabricated using the stir casting technique. Highlighting how adjustments to speed and feed rate can significantly impact the outcome. The relative efficacy of friction-based versus traditional machining methods can be understood through comparisons with FSP data. The goal of the study is to provide manufacturing professionals with useful advice on how to work with MMCs to improve surface quality through this investigation. In the end, the results assist industries in making better-informed decisions regarding their production processes by expanding our understanding of how machining parameters affect surface smoothness. The study also addresses future work that could be done, such as investigating different machining methods and doing more optimization research.

Keywords:
AA8011, ZrO_2, TiB_2, Stir casting, CNC Five-axis milling, Friction Stir Process (FSP), Surface Finish.

I. Introduction

Composites are a combination of several materials with distinct physical and chemical characteristics [1, 2]. Composites have unique features compared to their basic materials [3]. Materials like aluminum and copper need improved mechanical and wear characteristics to expand their applications. Aluminum and its alloys are widely used in industries owing to their excellent strength-to-weight ratio [4, 5]. Aluminium matrix composite (AMC) offers superior performance at a cheap cost. The AMC's remarkable qualities, including high temperature resistance, high specific strength, wear and corrosion resistance, stiffness, and low thermal coefficient, have resulted in exceptional performance throughout service. To improve the application of AMCs, Al is reinforced with both metallic and non-metallic components, including difficult-to-dispose industrial waste. Researchers worldwide use many methods to create composites, including stir casting [1, 2], powder metallurgy [3, 4], spray automation and deposition [5, 6], pellet technique [7], and semi-solid powder densification.

Composite materials improve upon their parent material's qualities. Metal matrices are reinforced with TiC, SiC, Al2O3, and B4C to enhance their performance [6, 7]. Aluminum metal matrix composites (AMMC) are widely employed in aerospace and marine sectors, as well as for cylinder liners, braking rotors, and pistons [8, 9]. Researchers are becoming interested in AMMCs, with numerous aluminum composites being made and analyzed. Aluminum Metal-Matrix Composites (MMCs) are highly promising engineering materials due to their superior physical and mechanical properties. With appropriate reinforcements, MMCs can improve wear, hardness, creep, specific strength, and fatigue properties compared to traditional materials [2-3]. Aluminium 8011 alloy has unique benefits, including low weight, corrosion resistance, and ease of maintenance. Aluminum 8011 has a low density, non-toxic composition, and high thermal conductivity (4-6). Nano material-reinforced composites have been widely favored in the automotive and aerospace industries for their wear resistance, damping properties, and mechanical strength [7]. Aluminum reinforced with Nano ZrO2 Composite was successfully developed through casting. The dispersion of nano particles in an aluminium matrix strengthens the base metal [8].

1.1 Related work

Kar, Chinmayee, and B. Surekha(2020) In this research, titanium carbide (TiC) and red mud are supplemented with aluminum 7075 (Al7075) at 3, 6, 9, and 12 percent by weight of the matrix to generate a flat casting using the stir casting technique. Mechanical parameters including yield strength, ultimate tensile strength, microhardness, and percentage elongation are evaluated and compared. The distribution pattern of the samples' reinforced particles is investigated using a scanning electron microscope (SEM) and X-ray diffraction (XRD) method. Finally, the micrographs of the fractured surface highlight the fractured composite's characteristics, which include dimples, fissures, voids, ridges, and particle fractures [1]. *Srivastava et.al. (2014)* SEM study demonstrates the effective incorporation of Nano Zro2 particles into the matrix of aluminum 8011, with uniform distribution. Adding Nano Zro2 particles to the matrix of aluminum 8011 resulted in increased mechanical characteristics, including tensile strength, compression strength, and hardness.

II. MATERIALS AND METHODOLOGY

AA8011-based hybrid composite materials were made via stir casting. The composite castings were subsequently processed using friction stir processing to enhance the surface characteristics of the hybrid composites. The experimentation strategy applied in this investigation.

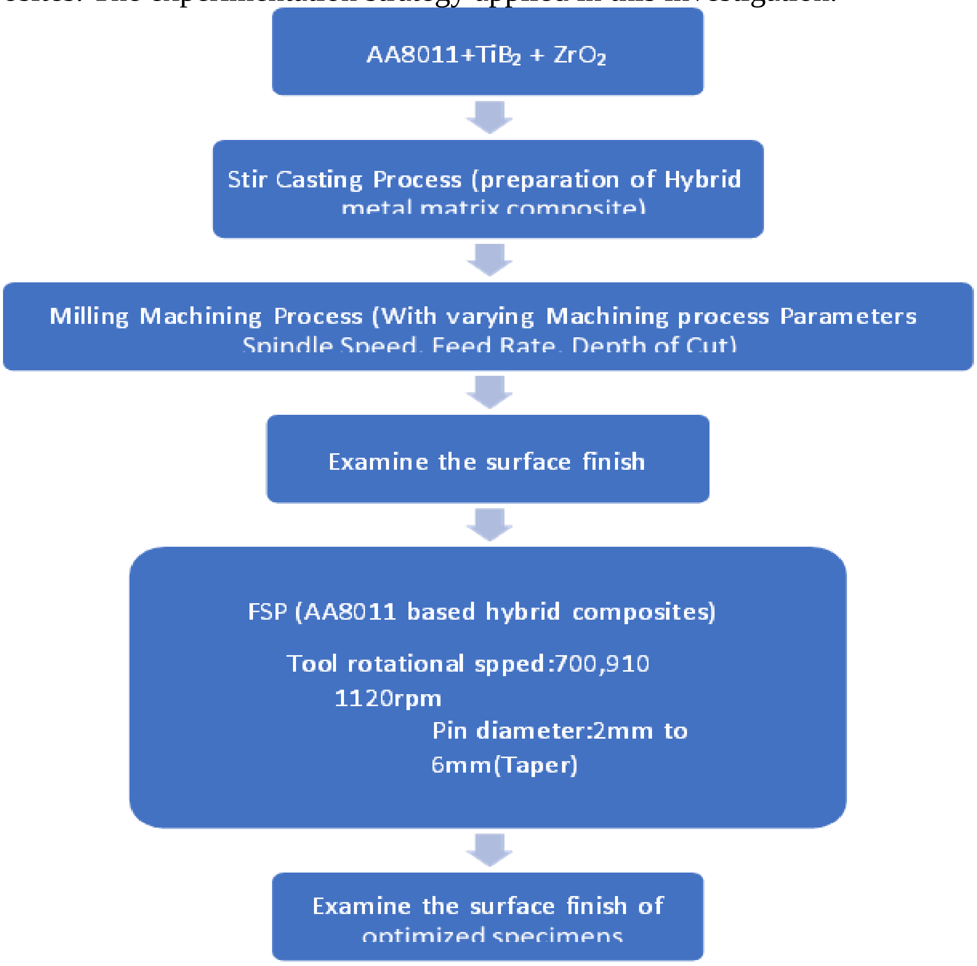

Fig 1 Flow chart for Methodology

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2.1 MATERIALS

2.1.1 Analysis of matrix and reinforcement used

To fabricate the composite, the matrix used is AA8011 and the reinforcement used is Titanium Diboride (TiB2) and Zirconium Oxide (ZrO2) ,Matrix: AA8011 (an aluminium alloy). Reinforcement: Titanium Diboride (TiB2) and Zirconium Oxide (ZrO2).

Table 1 Chemical Composition of AA8011

Chemical element	Content (%)
Aluminium (Al)	97.5～99.1
Iron (Fe)	0.60～1.0
Silicon (Si)	0.50～0.90
Copper (Cu)	0～0.1
Manganese (Mn)	0～0.1
Magnesium (Mg)	0～0.1
Zinc (Zn)	0～0.1
Chromium (Cr)	0～0.1
Titanium (Ti)	0～0.05
Residuals	0～0.15

Aluminium 8011 is an alloy of aluminium that is commonly used in the packaging industry to produce beverage can lids, wine bottle caps, and other food packaging materials. It is a wrought alloy, meaning it is formed by rolling, extruding, or forging.The chemical composition of Aluminium 8011 includes 0.5-0.9% silicon,0.6-1% iron, 0.1% copper, 0.2-0.6% manganese, and 0.05% magnesium. It has good mechanical properties, good corrosion resistance, and is easily workable, making it a popular choice for packaging applications Aluminium 8011 can be easily fabricated into various shapes and sizes, and is often used in conjunction with other materials, such as plastic, to create lightweight and durable packaging solutions. It is also widely used in the construction industry for roofing, cladding, and insulation purposes.

Table 2 Mechanical Properties of AA8011

Tensile strength:	**90-120 MPa**
Yield strength:	**50-80 MPa**
Elongation:	**5-8%**
Hardness:	**25-50 HB**
Modulus of elasticity:	**69 GPa**
Poisson's ratio:	**0.33**

AA8011 is made with a high percentage of magnesium, which gives it its strength. It also contains small amounts of silicon and copper, which improve its corrosion resistance and weldability.AA8011 is available in a variety of forms, including sheet, plate, bar, and tube. It can be processedusing a variety of methods, including rolling, forging, and welding.AA8011 is a versatile alloy that can be used in a wide range of applications. It is an excellent option for uses where weldability, strength, and resistance to corrosion are crucial.

2.1.2 Titanium Diboride (TiB2)

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Titanium boride, also known as titanium diboride (TiB_2), is a ceramic compound composed of titanium and boron. It has a high melting point, excellent electrical conductivity, and good mechanical properties, making it useful in a variety of applications. Titanium boride is a hard, brittle material with a Mohs hardness of around 9, making it one ofthe hardest known materials. It has a high melting point of around 2,950°C, which makes it useful in high-temperature applications. It also has a very low coefficient of thermal expansion, which makes it resistant to thermal shock. Apart from its electrical characteristics, titanium boride possesses remarkable mechanical attributes such as elevated strength, resilience to wear, and hardness. It can be used in abrasives, cutting tools, and other wear-resistant applications because of these qualities. Titanium boride is also being investigated for its potential as a material for nuclear fusion reactors. It has a high melting point and excellent corrosion resistance, making it a promisingcandidate for use in the harsh conditions of a fusion reactor. Overall, titanium boride is a versatile material with a wide range of applications in variousindustries, including aerospace, automotive, electronics, and energy.

Fig 2 Titanium Boride Powder

2.1.3 Zirconium Oxide (ZrO_2)

Zirconium oxide, also known as zirconia (ZrO_2), is a ceramic material that exhibits high strength, toughness, and thermal stability. It is a white crystalline solid with a very high melting point of about 2,700°C. Zirconium oxide is a versatile material that finds many applications in various industries. Inits pure form, it is used as a refractory material in high-temperature applications, such as in furnace linings and crucibles. Because of its strength and biocompatibility, it is also utilized as a ceramic material in artificial joints, dental implants, and other medical equipment. High fracture toughness, or the ability to withstand breaking and cracking, is one of zirconium oxide's special qualities. A new class of advanced ceramics known as transformation-toughened zirconia (TTZ), which have increased toughness and strength, has been developed as a result of this characteristic. Zirconium oxide's excellent thermal stability and low thermal conductivity make it a useful component in high-temperature coatings, such as thermal barrier coatings used in gas turbine engines.

Fig 3 Zirconium Oxide Powder

2.2 PROCEDURE FOR SAMPLE PREPARATION

In accordance with a previous study, 16 kg of AA8011 was made by dividing silicon and iron into equal parts and creating four samples with 2, 4, 6, and 8% ZrO_2 and TiB_2, respectively.

Step 1: Adding 160gms TiB_2 + 160gms ZrO_2.

Step 2: Properly mixing reinforcement and removing 4kgs for sample preparation.

Step 3: Combine 120gms TiB_2 and 120gms ZrO_2.

Step 4: Thoroughly mix the reinforcement and remove the 4kgs for sample processing.
Step 5: Combine 80gm TiB2 and 80gm ZrO2.
Step 6: Thoroughly mix the reinforcement and remove the 4kgs for sample processing.
Step 7: Combine 40gm TiB2 and 40gm ZrO2.
Step 8: Thoroughly mix the reinforcement and remove the 4kgs for sample processing.

Table 3 Sample Preparation

Sample	%AA8011	% TiB2	% ZrO2
S1	98	1	1
S2	96	2	2
S3	94	3	3
S4	92	4	4

2.2.1 Stir Casting

The stir casting method is used to cast AA8011 with TiB2 and ZrO2. In this investigation, aluminium AA8011 was used as the matrix material, and its composition is detailed in Table. The pure aluminum solids and other metal components of Al AA8011 were added to the furnace once the temperature of the aluminum stir casting machine reached 700 degrees Celsius. The metal introduced into the furnace melts slowly, and argon gas is continuously supplied inside the furnace. The Set up was madein frequency of 60HZ and stirring speed of 3000rpm. When stirred above the temperature of the liquid, porosity, particle clusters, and high oxide inclusions may develop. To reduce conventional casting, a modification of stir casting called Semi Solid Stir Casting was developed and pouring temperature into the die was 710 ^{0}Celsius to avoid solidification which takes (2-5 minutes)

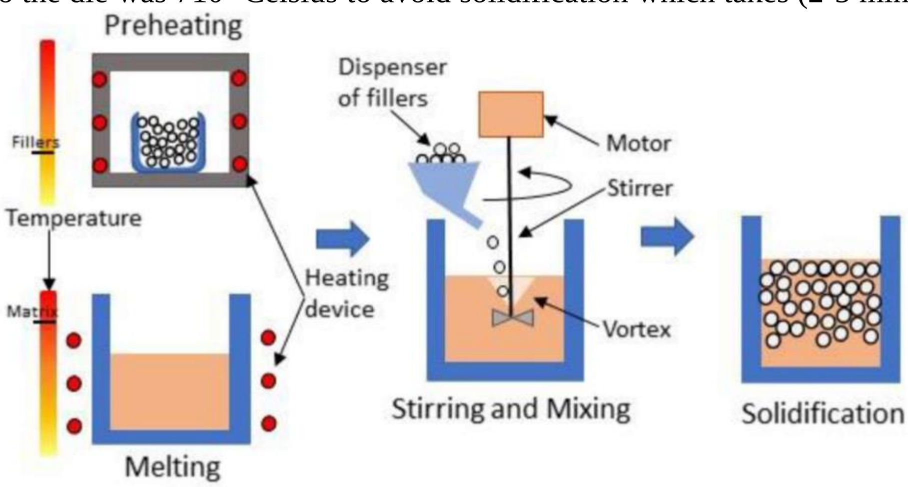

Fig 4 Stir Casting Process

Fig 5 Stir Casting Furnace

Fig 6 Molten Metal

Fig 7 Pre Heat Cast Iron Die

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Fig 8 Filling into die for samples

Fig 9 Sample 1
(2% composition)

Fig 10 Sample 2
(4% composition)

Fig 11 Sample 3
(6% composition)

Fig 12 Sample 4
(8% composition)

2.2.2 Friction Stir Processing

Cleaning and debarring are done to prepare the work piece. There should be no impurities, like dirt, oil, or grease, on the work piece's surface. To guarantee that it remains in place throughout the FSP procedure, the work component is secured into a fixture. The work piece's whole surface should be accessible to the FSP tool through the fixture's design. Based on the material being processed and the intended outcomes, the FSP tool is chosen. A pin and shoulder that are the proper size for the material of the work piece should be on the tool. Based on the material being processed and the intended outcomes, the process parameters—such as the rotating speed, feed rate, and plunge depth—are chosen. After inserting the FSP tool into the work piece, the rotating speed is accelerated.Next, while maintaining the rotational speed, the tool is translated along the length of the work piece. Upon completion of the intended procedure, the tool is extracted from the work item. The work piece is examined to make sure the FSP procedure went well. Reprocessing the area will allow for the rectification of any problems discovered.

2.3 METHODOLOGY FOR EVALUATION OF SURFACE FINISH

After being prepared, the specimens are now prepared for examination. Contact profilometry is used to measure the surface finish of the composite structures. In order to characterize the surface finish of the composites, the tests were conducted accordingly.

2.3.1 How Contact Profilometry Works

In contact profilometry, a workpiece's surface is traced with a tiny, accurate stylus or probe. The stylus creates a profile that depicts the topography of the surface by detecting height differences in the surface as it moves. In order to produce a precise depiction of the surface profile, the stylus is usually positioned on a moving platform or measurement arm, and sensors monitor its movements. A contact profilometer's output is a graph or digital data that displays the surface's height fluctuations across its whole length. Afterwards, different surface roughness characteristics are computed using this data, giving information on the surface's texture and smoothness. Ra (Average Roughness), Rz (Maximum Height of Profile), Rt (Total Height of Profile), and Rq (Root Mean Square Roughness) are some of the important roughness characteristics that may be assessed with contact profilometry.

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Fig 13 Contact Profilometry

III. RESULTS AND DISCUSSIONS

The Surface Finish Results of AA8011 Matrix Composites Reinforced with (TiB2+ZrO2) are discussed in this part along with the impact of varying factors like Spindle speed and feed rate. Graphs will be created and conclusions formed after the results have been gathered.

3.1 Surface Roughness results for Stir Casting specimens with varying speed

The spindle speed is varied from 5000 rpm to 12500 rpm in order to quantify the surface roughness of the specimens with the different reinforcement of S1-(2% of TiB2+ZrO2), S2-(4% of TiB2+ZrO2), S3-(4% of TiB2+ZrO2), and S4-(8% of TiB2+ZrO2). Surface roughness is measured using contact profilometry, and the results are expressed in terms of Ra. The Ra values can be defined as the arithmetic mean of the absolute values of the deviations in surface height from the surface profile's mean line, or average height, over a certain length.The Ra values of different compositions are tabulated with the varying range of speed.

Table 4 Surface Roughness of 2, 4, 6, and 8% compositions at different speeds

Speed (rpm)	Ra values of S1 (Microns)	Ra values of S2 (Microns)	Ra values of S3 (Microns)	Ra values of S4 (Microns)
5000	5.841	5.341	4.546	3.725
5500	5.634	5.134	4.464	3.635
6000	5.521	4.921	4.421	3.21
6500	5.108	4.848	4.148	3.042
7000	4.921	4.753	4.009	2.983
7500	4.727	4.627	3.967	2.9
8000	4.500	4.350	3.826	2.856
8500	4.451	4.306	3.765	2.794
9000	4.345	4.200	3.641	2.456
9500	3.929	3.712	3.368	2.123
10000	3.863	3.525	3.12	2.36
10500	3.778	3.484	2.964	1.964
11000	3.684	3.394	2.72	1.706
11500	3.558	3.229	2.63	1.759
12000	3.457	3.158	2.589	1.633
12500	3.261	2.978	2.196	1.489

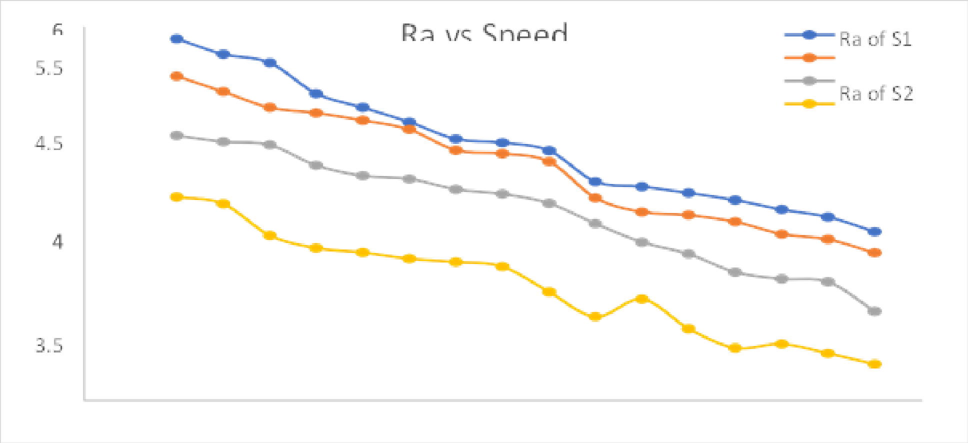

Fig 14 Surface roughness (Ra) Vs Speed(rpm)

Using the speed on the x-axis and the Ra values of compositions with reinforcement 2,4,6,8 percentages, represented as S1, S2, S3, and S4 on the y-axis, respectively, allows for the creation of the graph. The graph makes it evident that when speed increases, surface roughness decreases and surface polish increases. When ZrO2 and TiB2 reinforcement increases by 2,4,6, and 8%, the Ra levels decrease in sequence.In comparison to the other two, the S4, or reinforcement with 8% ZrO2 and TiB2 has a better surface finish with an increase in rpm, whereas the reinforcement with 2% has a poorer surface finish.

3.2 Surface Roughness results for Stir Casting specimens with varying Feed rate

The specimens with variable reinforcement levels, namely S1-(2% of TiB2+ZrO2), S2-(4% of TiB2+ZrO2), S3-(4% of TiB2+ZrO2), and S4-(8% of TiB2+ZrO2), had their surface roughness assessed by altering the feed rate within the range of 4000 mm/rev to 10000 mm/rev.

Table 5 Surface roughness of percentage compositions with 2, 4, 6, and 8 variations in feed rate.

Feed rate (mm/rev)	Ra values of S1 (microns)	Ra values of S2 (microns)	Ra values of S3 (microns)	Ra values of S4 (microns)
4000	4.184	2.968	2.019	1.515
4400	3.945	2.996	1.703	1.567
4800	4.096	3.126	1.963	1.496
5200	4.209	3.224	2.165	1.678
5600	4.29	3.279	2.226	1.694
6000	4.347	3.314	2.319	1.703
6400	4.427	3.336	2.4	1.756
6800	4.558	3.333	2.465	1.826
7200	4.789	3.442	2.52	1.947
7600	4.706	3.482	2.77	2.139
8000	4.888	3.527	2.799	2.244
8400	4.96	3.784	2.845	2.4
8800	4.993	3.805	3.216	2.419
9200	5.26	3.884	3.338	2.42
9600	5.496	3.97	3.491	2.568
10000	5.585	4.156	3.546	2.796

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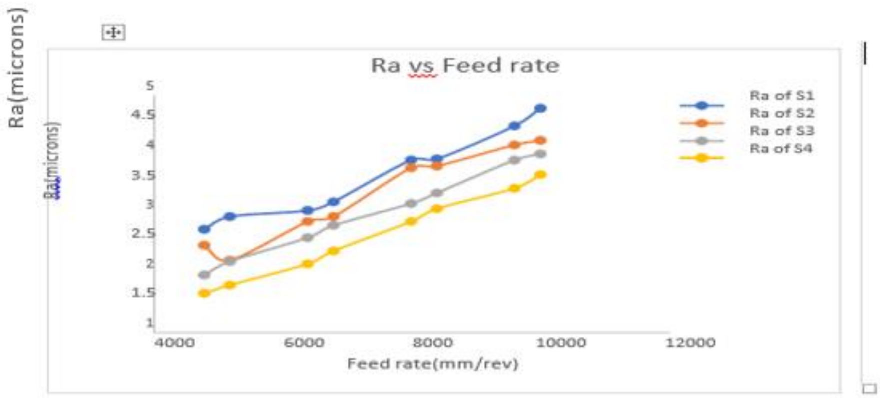

Fig 15 Surface roughness (Ra) vs. feed rate (mm/rev)

The feed rate (x-axis) and the Ra values of compositions with reinforcement (2,4,6,8) percentages (represented as S1, S2, S3, and S4 respectively) on the y-axis are used to generate the graph. As the feed rate increases, the graph clearly shows that surface roughness increases and surface finish decreases. When ZrO2 and TiB2 reinforcement increases by 2,4,6, and 8%, the Ra levels decrease in sequence. When it comes to surface finish, the S4, or reinforcement with 8% ZrO2 and TiB2 reinforcement, performs better at the lowest feed rate than the other reinforcements, while the 2% reinforcement performs poorly at higher feed rates.

3.3 Surface Roughness results for Stir Casting specimens with varying speed after the Friction Stir Process

To enhance the composite's physical characteristics, the specimens S1, S2, S3, and S4 are made using the friction stir process. following the FSP Spindle speed is varied to determine the surface roughness of specimens with variable reinforcement: S1-(2% of TiB2+ZrO2), S2-(4% of TiB2+ZrO2), S3-(4% of TiB2+ZrO2), and S4-(8% of TiB2+ZrO2).

Table 6 **After the FSP, surface roughness of 2, 4, 6, and 8% compositions with variable speeds**

Speed (rpm)	Ra values of S1 (Microns)	Ra values of S2 (Microns)	Ra values of S3 (Microns)	Ra values of S4 (Microns)
6000	4.375	4.011	3.465	2.864
6500	4.184	3.846	3.106	2.716
8000	3.196	3.101	2.687	1.864
8500	2.977	2.765	2.388	1.763
10000	2.16	2.019	1.816	1.564
10500	2.079	1.912	1.804	1.495
12000	1.965	1.9	1.766	1.387
12500	1.867	1.699	1.498	1.191

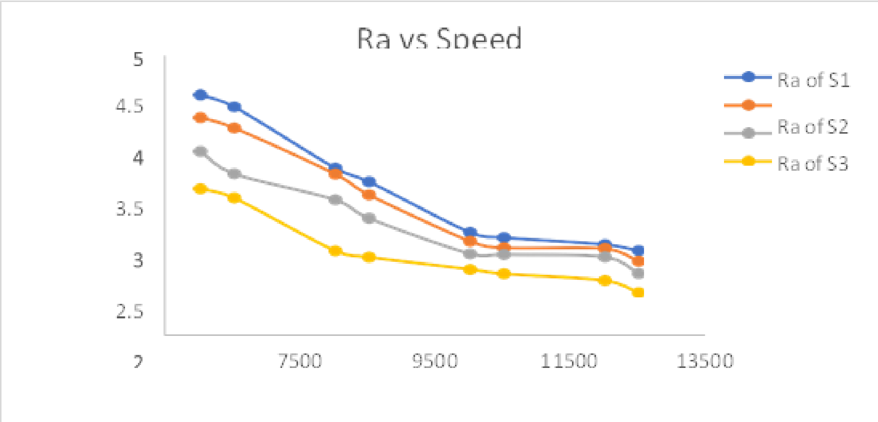

Fig 16 Surface roughness (Ra) Vs Speed(rpm) after the FSP

Using the speed on the x-axis and the Ra values of compositions with reinforcement 2,4,6,8 percentages, represented as S1, S2, S3, and S4 on the y-axis, respectively, allows for the creation of the graph. Because the Ra values are lower following the FSP, the surface finish is improved.The graph makes it evident that when speed increases, surface roughness decreases and surface polish increases. When ZrO2 and TiB2 reinforcement increases by 2,4,6, and 8%, the Ra levels decrease in sequence.In comparison to the other reinforcements, the S4, which has 8% ZrO2 and TiB2 reinforcement, has a superior surface finish at higher rpms, whereas the 2% reinforcement has a poorer surface quality.

3.4 Surface Roughness results for Stir Casting specimens with varying feed rate after the Friction Stir Process

To enhance the physical characteristics of the composite, the specimens S1, S2, S3, and S4 are made using the friction stir process. subsequent to the FSP By adjusting the feed rate, the surface roughness of the specimens with the varied reinforcement of S1-(2% of TiB2+ZrO2), S2-(4% of TiB2+ZrO2), S3-(4% of TiB2+ZrO2), and S4-(8% of TiB2+ZrO2) is measured.5.4 Table Surface Roughness following the FSP of 2, 4, 6, and 8% percentage compositions with different feed rates.

Table 7 Surface Roughness of 2,4,6,8 percentage compositions with varying feed rate after the FSP

Feed rate (mm/rev)	Ra values of S1 (microns)	Ra values of S2 (microns)	Ra values of S3 (microns)	Ra values of S4 (microns)
4800	2.732	2.463	1.965	1.659
5200	2.946	2.214	2.194	1.795
6400	3.049	2.864	2.591	2.152
6800	3.194	2.946	2.8	2.369
8000	3.896	3.765	3.165	2.863
8400	3.916	3.796	3.343	3.079
9600	4.468	4.149	3.894	3.421
10000	4.765	4.226	3.999	3.65

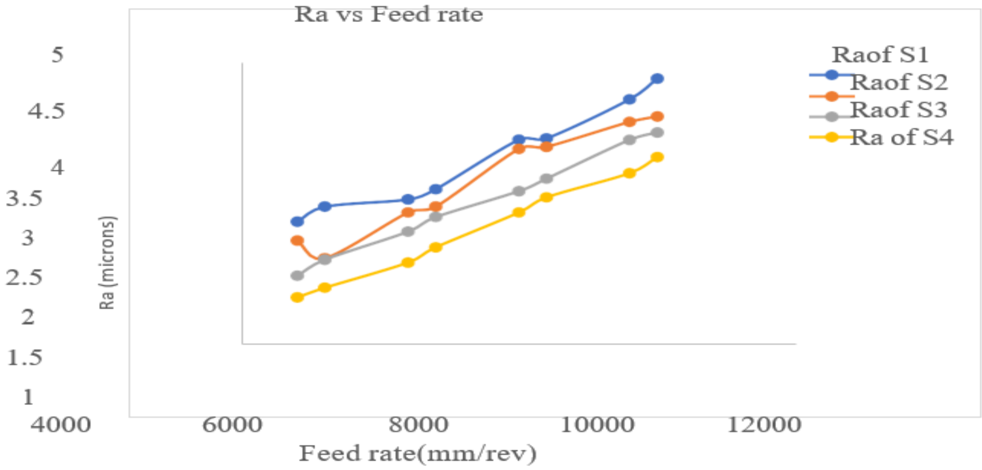

Fig 17 Surface roughness (Ra) vs. feed rate (mm/rev) after the FSP

The feed rate (x-axis) and the Ra values of compositions with reinforcement (2,4,6,8) percentages (represented as S1, S2, S3, and S4 respectively) on the y-axis are used to generate the graph.The improvement in surface finish following the FSP can be attributed to the decrease in Ra values. The graph makes it evident that when the feed rate decreases, surface roughness increases, indicating a loss in surface finish. As the percentage of ZrO2 and TiB2 reinforcement increases to 2,4,6,8%, the Ra values decrease in sequence. The S4, or the one with the 8% ZrO2 and TiB2 reinforcement, has a superior surface finish than the others at the lowest rpm, while the 2% reinforcement is less effective at high feed rates.

IV. Conclusions and future scope

The impact of different machining parameters on the surface finish of stir-cast AA8011 metal matrix composites (MMCs) reinforced with 2%, 4%, 6%, and 8% TiB2 and ZrO2 was examined in this article. The study investigated the effects of feed rate and spindle speed on surface roughness using a CNC five-axis milling machine. Higher speed with lower feed rates gives a good surface finish when compared to lower speed.The 8% Reinforcement has a good Surface finish because adding TiB2 and ZrO2 refine grains and improves particle distribution in AA8011 alloy, resulting in a smoother, less rough surface. After the Friction Stir Process, the surface finish of the composite is increased because of intense plastic deformation, refined grain structure, and controlled heat generation, which reduce surface irregularities and defects. As there are many other Process Parameters In FSP, Further Research by can be continued varying. Tool penetration depth, Number of Passes, Tool and Workpiece material, Tool Profile. Further Optimization can be continued by studying the Thermal analysis at Heat effected Zone in FSP. Optimization of Cutting Parameters for High-Speed Machining. Study about tribological and Corrosion tests. Study on surface roughness and material removal rate. Another component of hybrid composite research is further processing (such as extrusion, forging, and heat treatment) as well as evaluating mechanical, physical, and tribological properties.

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