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Effect of Cutting Parameters on Surface Roughness of LM2 (Al-9%Si) –Al_2O_3 Metal Matrix Composite fabricated by Squeeze Casting Method

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ABSTRACT

Metal matrix composites are replacing the monolithic materials in many applications because of their unique balance of physical and mechanical properties. The MMCs are fabricated by various technologies in order to fulfil the market demand such as lower density, higher wear resistance, low cost etc. But machining of MMCs became challenge as the hard particles of reinforcement makes machining difficult. In this work, LM2 (Al-9% Si) alloy is used as matrix and alumina powder (Al_2O_3) is used as reinforcement and the specimens are fabricated by squeeze casting method. The effect of cutting parameters on surface roughness of these specimens were studied and found that the surface roughness decreases as the cutting speed increases. The surface roughness at cutting speed of 1000 rpm is high. The cutting speeds of 2000 rpm and 3000 rpm gives considerably good surface finish. The surface finish is observed to be very good at depth of cut 0.5 mm. Feed 0.5mm/rev and 3000 rpm gave the highest surface finish.

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Introduction

Despite rapid advances in the development of new and improved production techniques such as precision casting, directional solidification, and net shape forming, traditional metal machining processes continue to play a role in the manufacture of the majority of items in our modern technological society. It is well acknowledged that machining alters the surface region of a material, causing it to differ from the bulk material. Because mechanical qualities like fatigue, creep, and stress corrosion cracking are material properties that are extremely surface sensitive, it's critical to get a thorough picture of the surface characteristics of machined components. It's also crucial to figure out which cutting parameters would result in a high-quality surface. In this research work, it has been attempted to find out the cutting parameters i.e. cutting speed, feed rate and depth of cut in turning operation for various compositions of metal matrix composites of LM2 (al-9%Si) -Al2O3 fabricated by squeeze casting process.

Squeeze casting is a process by which molten metal is solidified under applied pressure that is maintained until the end of solidification. In squeeze casting of metal matrix composites, after adding the reinforcement to the molten matrix, the pressure is applied to the mixture while it solidifies. With reference to the phase diagram, this pressure is applied between the liquidous and solidus lines. In addition to improving mechanical qualities, the squeeze casting technique eliminates shrinkage and porosity flaws.

Literature Review

In case of Metal matrix Composites (MMCs), due to the presence of two or more different phases, one of which is extremely abrasive, as well as considerable differences between the two constituents: the ductile metal matrix and the hard ceramic reinforcement, their machining is notoriously difficult. As a result, various attempts have been made to produce metal matrix composite components in nearnet-shape geometries. However, such components must be machined to fulfill the final design criteria.

Extensive research has been made on the machinability of stir casted specimens, while the machinability of squeeze casted specimens is the subject of only a small study. Dry turning operation is used in most of the research work. The input cutting parameters used are cutting speed, feed rate and depth of cut whose effect is studied on surface roughness of the machined specimens. The average surface roughness was observed to be decreasing with increasing cutting speed [1-5]. The surface roughness increased with increase in feed rate [3-5] and the surface roughness was observed to increase with depth of cut [3-5]. Some researchers investigated the effect of type and particle size of reinforcement on surface roughness. The increase in size of abrasive reinforcement like SiC increased the average surface roughness [6] and as far as the type of reinforcement is concerned the reinforcement like BN acts like lubricant which will help to obtain good surface finish [7]. In case of hardness, when the amount of hard reinforcement is increased, the hardness is increased and so was observed in case of squeeze pressure [1]. However, in this experiment the hardness remained almost constant irrespective of the squeeze pressures and amount of reinforcement.

Experimental

Composite Preparation: The chemical composition of aluminium alloy matrix (LM2) is given in Table-1 and the reinforcement used is Al_2O_3. The reinforcement used is particulate type of average particle size 40µ. Thirteen specimens are prepared varying the weight percentage of reinforcement as R1=2%, R2= 3% and R3= 5% and squeezing pressures P1= 100kg/cm^2, P2= 200kg/cm^2 and P3= 300kg/cm^2. The die temperature is kept constant 180^{0}C. (Refer Fig.1)

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Table 1: Chemical analysis of LM2 matrix

S.No.	Element	Observed Value
1	% Mn (Mangenese)	0.16
2	% Si (Silicon)	9.64
3	% Cr (Chromiun)	0.030
4	%Ni (Nickel)	0.070
5	%Cu (Copper)	1.34
6	%Sn (Tin)	< 0.010
7	%Pb (Lead)	0.30
8	% Al (Aluminium)	Remainder
9	%Fe (Iron)	0.80
10	%Zn (Zinc)	0.89
11	%Mg (Magnesium)	< 0.030
12	Ti (Titanum)	0.045
13	Total other elements	< 0.50

Two specimens having no reinforcement R0 and no squeeze pressure P0 are also prepared for reference of pure alloy in comparison with metal matrix composite.

Figure 1: Specimens prepared by varying the weight % of reinforcement and Squeeze Pressure

The HRB hardness of all specimens is tested using 1.6 mm ball diameter and load 100kg on Rockwell cum Brinell Hardness machine FIE make. The hardness of all specimens are specified in Table 2.

Table 2: Hardness of Specimens

P0R0	P0R1	P0R2	P0R3	P1R1	P1R2	P1R3	P2R1	P2R2	P2R3	P3R1	P3R2	P3R3
126	124	125	116	126	123	125	124	127	128	122	127	126

For turning operation DOE Taguchi method is followed and created 3 parameters and 27 arrays for further experimentation process using Minitab 19.

CNC (SMARTRUN, Fanuc-5.5/7.5, Spindle Speed 4500 rpm) is used for carrying out the turning operation under dry machining conditions. The CNC machine specifications are given in table 3. The turning of the specimens is performed at three different cutting speeds 1000rpm, 2000 rpm and 3000 rpm. The feeds chosen are 0.12, 0.15 and 0.18 mm/rev. The depth of cut used for machining is 0.25 mm, 0.50 mm and 0.75 mm. To avoid the variability in tool geometry, re-sharpening effect of tool on machining in number of readings , specifically Tungsten carbide tipped shank is used. The tool insert specifications are given in Fig.2. The average surface roughness Ra corresponding to every run is recorded. The surface roughness of all specimens is measured using a surface roughness tester Mitutoyo SJ-210.

Table 3: CNC machine Specifications

SNo.	Make	LMW- SMARTURN
1	Max Turning Length	262 mm
2	Max Turning Diameter	200 mm
3	Swing over bed	480 mm
4	Max. Chuck Diameter	169 mm
5	Turret No. of Stations	8
6	Tool Shank Size	20 x 20 mm
7	Controller	Fanuc
8	Max Spindle Speed	4500 rpm
9	Spindle Motor Power	Fanuc 5.5 / 7.5 kW
10	Machine Size mm	2275 x 1640 x 1620

Figure 2: Tool Insert Specifications

TaeguTec Turning Insert TNMG 160408 MT Grade TT7310
Type: Turning Insert
Grade: TT7310
ISO Designation: TNMG 160408 MT
Style: TNMG
Insert IC Size Id: 9.52 mm

Results and Discussion

Hardness

Fig.-3 shows the HRB Hardness of all specimens with different reinforcements and pressures. It is observed that irrespective of amount of reinforcement and pressure, the hardness remained same. The hardness is observed in the range of 123 to 128 HRB for all samples. The applied pressure is dispersed throughout the squeeze casting process to accomplish three functions: the first is the breaking of the cast dendritic structure, the second is the filling and sealing of the shrinkage voids, and the third is the formation of fine grain structure. Only dendrites are broken and shrinkage cavities are filled during low pressure squeeze casting. There is no refining of grains, hence no difference is noticed under given conditions of reinforcement Al_2O_3 additions in various percentages.

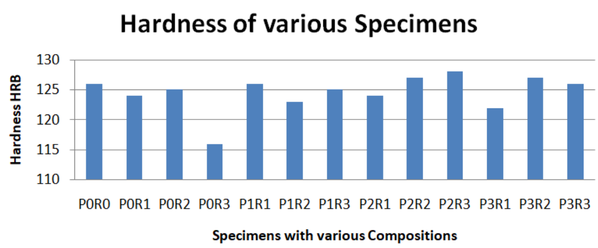

Figure 3: Hardness (HRB) for all compositions

Average Surface Roughness and Cutting speed

The average surface roughness is remarkably observed to be low at higher cutting speed. In Fig. 4, it is observed that at 1000 rpm, the average surface roughness varies around

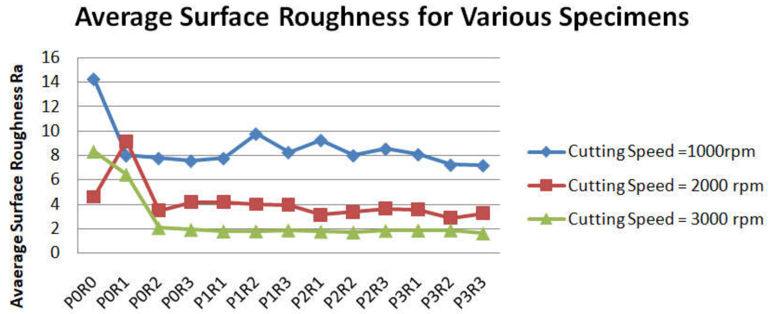

Figure 4: Average Surface Roughness (Ra) for all compositions at feed 0.12 mm/rev and Depth of cut 0.25 mm

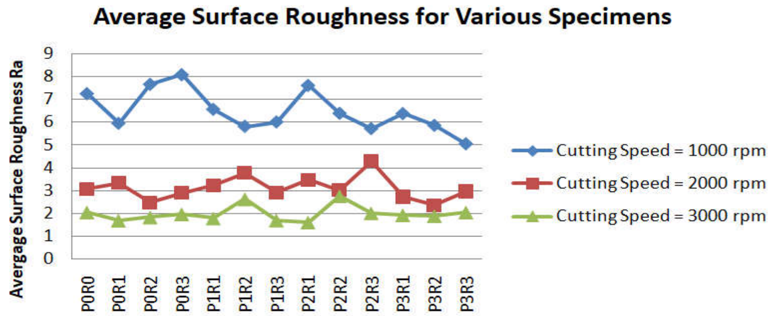

Fig.ure 5: Average Surface Roughness (Ra) for all compositions at feed 0.12 mm/rev and Depth of cut 0.5 mm

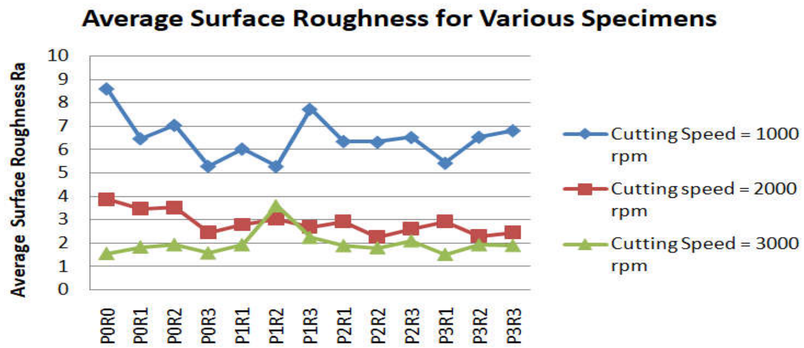

Figure 6: Average Surface Roughness (Ra) for all compositions at feed 0.12 mm/rev and Depth of cut 0.75 mm

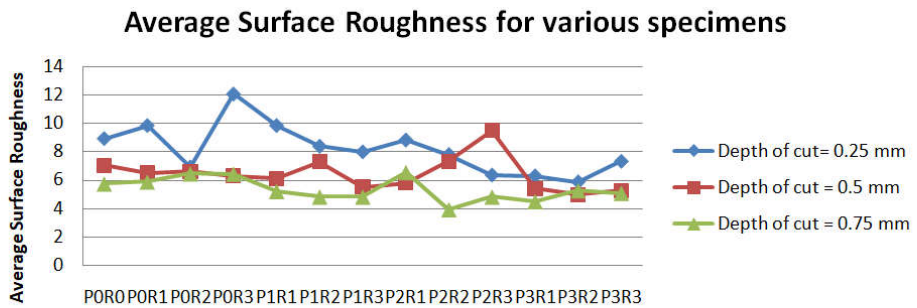

Figure 7: Average Surface Roughness (Ra) for all compositions at feed 0.18mm/rev and Cutting Speed = 1000 rpm

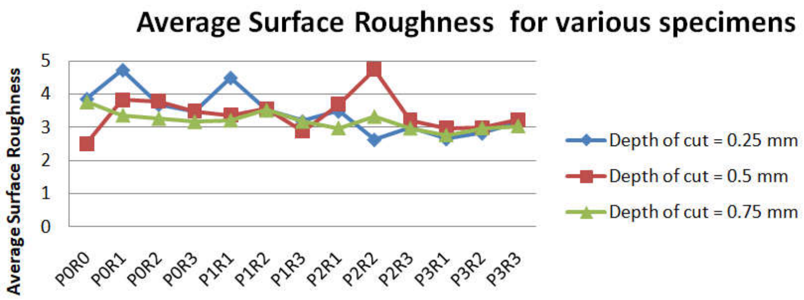

Figure 8: Average Surface Roughness (Ra) for all compositions at feed 0.18mm/rev and Cutting Speed = 2000 rpm

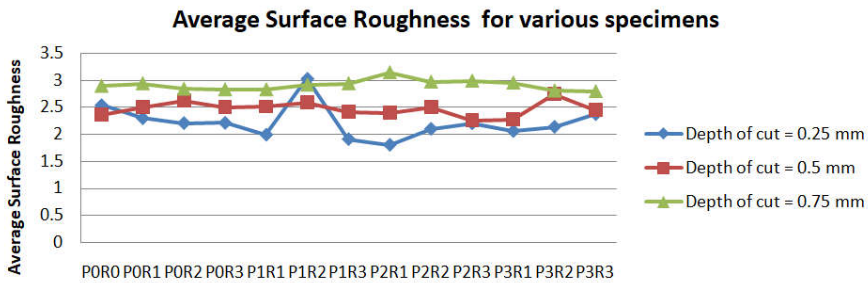

Figure 9: Average Surface Roughness (Ra) for all compositions at feed 0.18mm/rev and Cutting Speed = 3000 rpm

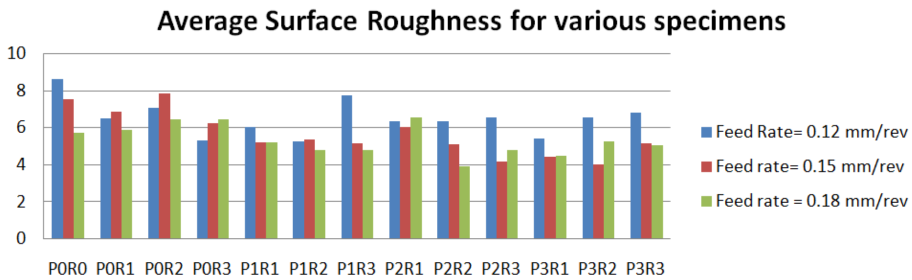

Figure 10: Average Surface Roughness (Ra) for all compositions at depth of cut= 0.75 mm and Cutting Speed = 1000 rpm

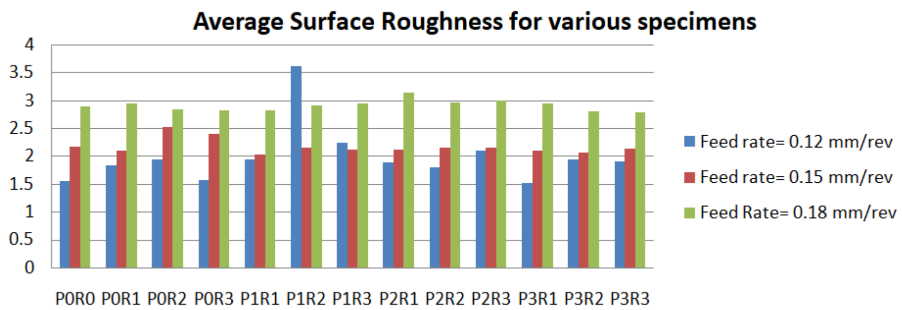

Figure 11: Average Surface Roughness (Ra) for all compositions at depth of cut= 0.75 mm and Cutting Speed = 3000 rpm

8 micron whereas it reduces to 4 microns at 2000 rpm and it is observed to be around 2 microns at 3000 rpm.

In Fig. 4 the average hardness value varies around 2 microns for 3000 rpm whereas it varies between 5 to 8 microns at the speed of 1000 rpm.

In Fig. 6, the average hardness value at 1000 rpm is observed to vary between 5 to 9 micron and the value varies between 1 to 2 microns at 3000 rpm.

Average Surface Roughness and Depth of cut

Influence of depth of cut on surface roughness is observed to be dependent on cutting speed also. At lower cutting speed, 1000 rpm, and highest level of depth of cut 0.75 mm, the surface roughness lies in the range of 4 to 6 microns and at lowest depth of cut i.e. 0.25 mm, the surface roughness lies between 5 to 8 microns (Fig. 7).

At the cutting speed of 2000 rpm, and depth of cut 0.75, the surface roughness was observed in the range of 2 to 3.7 microns (Fig. 8).

On the other hand, at maximum cutting speed of 3000 rpm, and maximum depth of cut 0.75 mm, the surface roughness was observed in the range of 2.7 to 3.14 micron and at depth of cut of 0.25 mm, the surface roughness was observed between 1.8 to 2.5 microns (Fig.9).

Average Surface Roughness and Feed rate

Influence of feed rate on surface roughness also depends on cutting speed. At lower cutting speed i.e. in this experiment at 1000 rpm and at depth of cut 0.75 mm, the surface roughness was observed lowest (below 6.5 microns) at highest feed rate i.e. 0.18 mm/rev. (Fig.10).

On the other hand at cutting speed of 3000 rpm, (Fig.11), the surface roughness is observed less than 2.3 microns at a feed rate of 0.12 mm/rev.

Conclusions

Number of experiments are conducted to study the effect of cutting parameters on surface roughness in machining of LM2 (Al-9% Si)–Al_2O_3 composite fabricated by squeeze casting process. There were 13 specimens prepared by the variation of squeeze pressure in three levels P1=100kg/cm^2 , P2=200kg/cm^2 and P3= 300kg/cm^2 and the weight percentage of reinforcement i.e. Al_2O_3 , particle size 40μ in three levels as R1= 2%, R2=3% and R3= 5%. From the experimental observations, the following conclusions are made.

1. Surface roughness decreases as the cutting speed increases. The surface roughness at cutting speed of 1000 rpm is high.
2. The cutting speeds of 2000 rpm and 3000 rpm gives considerably good surface finish.
3. The surface finish is observed to be very good at depth of cut 0.5 mm.
4. Depth of cut of 0.5mm and 3000 rpm gave the highest surface finish.

5. For all compositions, hardness remains same, irrespective of amount of reinforcement and squeeze pressure. The hardness is observed in the range of 123 to 128 HRB for all samples. The average hardness is observed 124 HRB. In low pressure squeeze casting, the pressure is utilized in breaking of dendrites and filling the shrinkage voids and a very little or no amount of pressure is utilized for grain refinement, therefore no drastic variations in the hardness is observed.

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