Experimental Studies of Aluminum Metal Matrix Composite Surface Roughness ($A356-Al_2O_3$)

Yogavardhanswamy G N[a], Kashinath S V H[b], Lavanya K V[c], Darshan G[d],Ashok Kumar M S[e]

[a.b.] Senior Scale Lecturer, Department of Mechanical Engineering, Government Polytechnic Channapatna, Karanataka, India-562160.

[c.] Senior Scale Lecturer, Department of Mechanical Engineering, Government Polytechnic Channasandra, Karanataka, India-560067.

[d.] Senior Grade Lecturer, Department of Mechanical Engineering, Government Polytechnic Krishnarajapete, Karanataka, India-560067.

[e]Assistant Professor, Department of Mechanical Engineering, Dayananda Sagar Academy of Technology & Management, Bangalore, Karnataka, India-560082.

Abstract: Deteriorated surfaces are usually attributed to three main causes: vibration of the work fixture due to lack of rigidity in the manufacturing system which produces a chatter, tool feed marks and lumps of edge built-up due to overheating. By optimizing the parameters like nose radius, clearance angle, speed of cutting and cutting edge lapping can lead to enhance the surface finish. Moreover, improvements in surface quality can also be attained by reducing feed and depth of cutting, approach and end cutting edge angles. Aluminum metal matrix composites are finding applications in many areas. The study deals with the surface roughness characteristics of $A356-Al_2O_3$ metal matrix. The experimental studies were carried out in a lathe machine. Where composites were synthesized using the liquid metallurgy route with 9 percent Al_2O_3 particles incorporated in the base matrix. The fabricated cast composites were finished using precision machining. Based on the parameters namely feed rate, depth of cut and cutting speed that influence the surface roughness, It was determined that surface roughness rose with increasing feed rate and reduced with increasing cutting speed.

Keywords: MMC, Machining, Cutting Speed, Depth of Cut, Feed Rate, Surface Roughness.

Nomenclature:

S - Cutting speed in m/min, F - Feed rate in mm/rev, DOC - Depth of cut in mm, Ra - Average surface roughness in µm.

I. Introduction:

Because of their superior qualities, which include a higher strength to weight ratio, outstanding low-temperature performance, remarkable corrosion resistance, chemical inertness to commonly used cutting tools, etc., aluminum alloys have found extensive use in the automotive and aerospace industries. They also have a high machinability index. Nonetheless, the primary drawbacks of aluminum alloys are their inadequate resistance to wear and high-temperature performance. Metal matrix composites (MMCs), which are aluminum alloys reinforced by tougher particles, have been developed to address these issues.

When defining the surface finish, surface roughness, waviness, and lay are the most crucial terms. The finely spaced surface irregularities are referred to as roughness. In the case of machined surfaces, it is the outcome of machining operations. Waviness is defined as surface irregularities that are more widely spaced than rough [1–2]. Warping, vibrations, or the workpiece being pushed out in process is a possibility. The assessment of asymmetry of roughness is performed by determining the height of the line of the average roughness profile within the range of micrometers or micro inches. This is referred to as the ‘cutoff’ roughness height. This is represented by the symbol Ra – average roughness value. These are referred to as lay marks of the work piece on the tool. Roughness is normally measured in a crosswise fashion.

Variables affecting surface roughness in turning: The term surface finish is used to simply mean smoothness of a machined part. It is contributed by three parameters combined; surface of the part roughness, waviness and the surface defects. It encompasses the normal smaller spaced imperfections which are left on a part surface after the manufacturing process, this is referred to as roughness. With tool wear comes an even worse surface finish then what was achieved during a particular machining operation in question. In normal circumstances, when a tool instrument has flank-land wear, it creates a good finished surface. However, this is not entirely the case for a tool that experiences chipping. The following are a few variables that affect surface roughness during turning activities [3-4]:

(i) Depth of cut: The cutting resistance and vibration amplitude both rise with increasing depth of cut.

(ii) Feed: Research indicates that as feed rate rises, surface roughness rises as well because of an increase in vibration and cutting force.

(iii) Cutting speed: It has been discovered that surface quality generally improves with increased cutting speed.

(iv) Wear on the cutting tool: The machined surface replicates the wear-induced imperfections of the cutting edge. In addition, other dynamic phenomena like excessive vibrations will happen as tool wear grows, further degrading surface quality.

(v) Cutting fluid use: The cutting fluid has three distinct effects on the cutting process, making it typically beneficial for surface finish. First, it cools the work surface and the tool point primarily, absorbing the heat produced while cutting. Furthermore, the cutting fluid can lessen the friction between the flank and the machined surface, as well as between the rake face and the chip. Finally, the cutting fluid's washing action is significant since it aids in the removal of wear particles and chip fragments. As a result, it is anticipated that a surface machined with cutting fluid present will have higher quality than one produced by dry cutting.

(vi) The cutting force consists of three parts: Force is not an input factor; rather, it is an indicator of the dynamic properties of the work piece, cutting tool, and machine system.

This research employs materials which were recently combined, otherwise referred to as MMCs. The purpose of reinforcement is not limited to strengthening the compound; it can also be employed to alter its physical characteristics. Compared to traditional materials, this new class of materials is distinguished by its high strength, low weight, and resistance to wear [5-6]. In a number of aerospace and automotive applications, MMCs compete with super-alloys, ceramics, polymers, and redesigned steel parts because of their appealing qualities and capacity to function at high temperatures [7].

Particles of silicon carbide (SiC) or aluminum oxide (Al_2O_3) are typically employed to strengthen aluminum alloys, but because of their abrasive and hard character, they are expensive to machine. Because of their extremely abrasive qualities, aluminum oxide (Al_2O_3) reinforced mmc are challenging to manufacture, including turning, milling, drilling, and threading. Aluminum metal matrix composites that contain Al_2O_3 are challenging to manufacture and result in rapid tool wear, which reduces tool life and raises tooling costs. Additionally, after the composite is machined, a poor surface finish is seen. The wear properties of various tool materials during the machining of aluminum metal matrix composites are the focus of the majority of research projects [8–9].

The feed rate, cutting speed, and volume fraction of reinforcement all have a significant impact on the aluminum metal matrix composite's surface roughness. The roughness of the machined surfaces is more affected by the size of the reinforcements in the composite than by the feed rate and tool nose radius.

Machining of MMCs poses a great challenge to researchers in terms of selection of suitable cutting tools and machining parameters for optimizing the Machinability characteristics. Review of the some of the literatures has shown that there is wide scope for studying the parametric influence on machining characteristics of MMCs. The present work is a small attempt in this regard.

II. Experimental Work:

Composite Preparation by Liquid metallurgy – Stir Casting Method

Cast composites with improved wettability and particle distribution were created using a liquid metallurgical process. In a graphite crucible, the bar-shaped aluminum alloy was sliced into tiny pieces and melted. Using a motor-driven stirrer, the preheated, determined amount of matrix material was added to the crucible and blended uniformly. The following stage involves adding the heated aluminum oxide particles to the liquid melt and starting the mixing process. Following adequate mixing, the melt must be heated once more to a temperature higher than liquidus. During this time, stirring was done for almost half an hour at an average speed of 300–350 rpm.

After that, the slurry was put into a permanent cast iron mold that had been heated. Table 1 lists the aluminum material's chemical makeup.

Elements	Percentage
Al	91.1-93.3
Cu	<=0.2
Iron	<=0.2
Mg	0.25-0.45
Mn	<=0.1
Other each	<0.05
Silicon	6.5-7.5
Titanium	<=0.2
Zinc	<=0.1

Table 2.1: Composition of Work Material

Tooling Details: HSS tools have been selected for carrying out the machinability study of the Aluminium mmc reinforced with the alumina particles. Table 2.1 - 2.2 shows the percentage composition of HSS elements and the melting temperature along with the hardness of the tool.

Table 2.2: Percentage composition of HSS tool.

Fe	C	Si	Mn	Cr	W	Mo	V
81.63	0.88	0.25	0.30	4.04	6.13	4.92	1.85

Table 2.3: Melting temperature and Hardness

TOOL	Melting Temperature in ^{0}C	Hardness RC
HSS	1130	55-60

Table 2.4: Geometry of test specimen

Back Rake angle	7°
Side Rake angle	14 °
End Relief angle	6 °
Side Relief angle	6 °
End Cutting edge angle	18 °
e Cutting Edge angle	
Nose Radius	

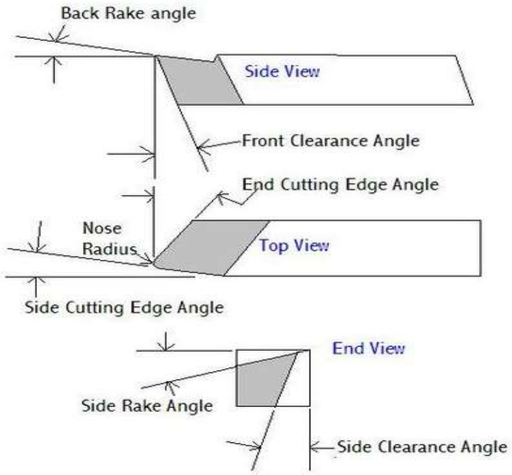

Fig 2.2 HSS TOOL

Fig 2.1: Geometry of cutting tool.

Fig 2.3: Handy Surf

Handy Surf Device:

The surface finish value (μm) was obtained by measuring the mean absolute deviation from the average surface level using a Handy surf E-35A /Portable surface measuring unit. There are 16 choices of parameters available in the surface measuring instrument. But in the present study, the parameter Ra was considered. Using the Handy surf E-35A instrument surface roughness along the length was measured. Generally surface roughness is measured parallel to movement of the tool. In the present study, Figure shows the surface roughness measuring device.

Cutting conditions: The following machining conditions have been chosen for the current investigation based on the literature review.

Table 2.5: Cutting conditions

Cutting speed in rpm	140, 310, 500
Cutting speed in m/min	8.7, 19.46, 31.4
feed rate in mm/rev	2, 2.5, 3.75
Depth of cut in mm	0.5

III. Results and Discussion:

Influence of Feed rate on Average surface roughness (Ra) of the work piece:

Figure 3.1 illustrates how the feed rate affects the MMC's roughness. At different cutting speeds at a 0.50 mm depth of cut. Surface roughness rises in tandem with the feed rate. When cutting at 500 rpm (31.4 m/min), the average surface roughness is higher than when cutting at 310 rpm (19.46 m/min).

At a depth of cut of 0.50 mm, Fig. 3.2 illustrates the fluctuation of average surface roughness against various cutting speeds for various feed rates. In general, the average surface roughness of the material reduces as the cutting speed increases. The MMC's surface roughness reaches its maximum in this experiment at a cutting speed of 8.7 m/min, taking into account a 0.50 mm depth of cut.

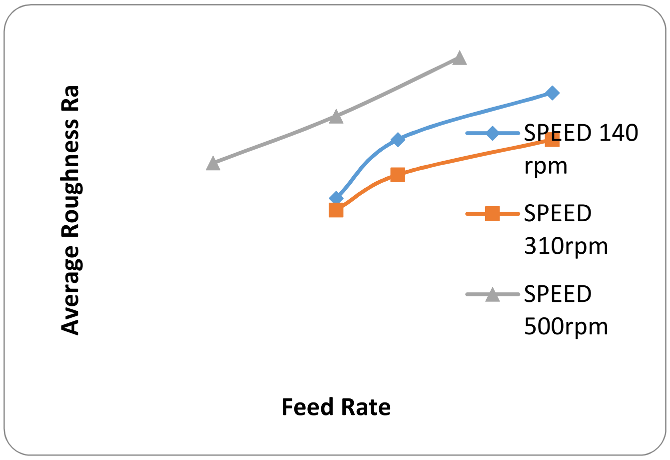

Fig 3.1: Roughness v/s Feed rate

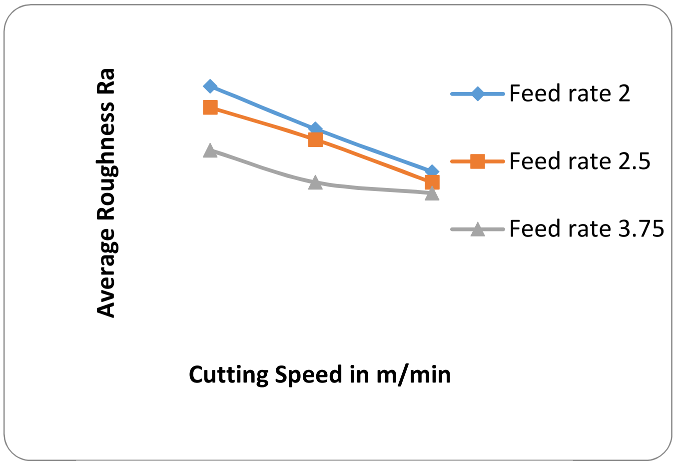

Fig 3.2: Roughness v/s Cutting speed

Influence of Cutting Speed on Average surface roughness (Ra) of the work piece:

The surface roughness value then progressively decreases as the cutting speed rises to 19.46 m/min, and at its highest, 31.4 m/min, it eventually reaches its minimum. It is clear that the average surface roughness Ra decreases with increasing cutting speed, while the roughness value's magnitude increases with increasing feed rate. According to the examination of the test findings, surface roughness is actually higher at lower cutting speeds and vice versa at higher cutting speeds.

It is occasionally noted that the surface roughness value significantly differs from the trend value when turning. In addition, the feed has an impact on surface roughness during machining MMC. According to the results of the experiments conducted for this study, surface roughness rose as feed increased.

IV: Conclusion: The experiment conducted to examine the effects of cutting parameters on surface roughness in metal matrix composite machining would yield the following findings:

1. The average surface roughness of the analyzed MMC specimen is at its lowest at a fast cutting speed of 500 rpm (31.4 m/min). The outcome shows that surface roughness decreases as cutting speed increases and vice versa.
2. When machining composites, feed rate is the most important factor affecting surface roughness. The outcome shows that surface roughness rises as feed rate increases.
3. It is advised to utilize medium cutting speed, minimal feed rate and lower depth of cut to achieve better surface roughness.

VI: References:

1. Marandet B., Verquin B., Saint-Chely J., Anderson C. and Ryckeboer M., http://aluminium.matter.org.uk (2011)
2. Bradley C., Automated Surface Roughness Measurement, *International Journal of Advanced Manufacturing Technology*, 16(9), 668-674 (2000).
3. N. Tomac, K. Tonnessen (1992) Machinability of particulate aluminium matrix composites, CIRP 41 (1):55–58.
4. Chandrasekaran H, Johansson JO (1997) Influence of processing conditions and reinforcement on the surface quality of finish machined aluminium alloy matrix composites. CIRP 46(1):493–496.
5. A.R. Boccaccini, G. Ondracek, P. Mazilu, D. Windelberg, J. Mech.Behav. Mater. 4 (1993) 119.
6. V.V. Ganesh, M. Gupta, Mater. Sci. Technology. 17 (2001) 1465.
7. Chadwich, G.A., Heath, P.J., 1990. “Machining of metal matrix composites”. Met Mater 2-6, 73-76.
8. Chambers, A.R., 1996. “The machinability of light alloy MMCs”. Composites Part A 27A, 143-147.
9. Chandrasekaran, H., Johansson, J.O., 1997. “Influence of processing conditions and reinforcement on the surface quality of finish machined aluminium alloy matrix composites”. Ann CIRP 46 (1), 493-496.