Effect of machining parameters on average surface roughness $R_a$ while turning hybrid Mg-MMC- An experimental approach

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Abstract. Hybrid metal matrix composite (MMC) reinforced with silicon carbide (SiC$_p$), alumina (Al$_2$O$_3$) and graphite (Gr$_p$) are being preferred for industrial applications due to their lightweight, and lower densities of these combined materials and high strength at the molecular level. These developed hybrid composite materials have been utilized in the wide range of applications in automotive and aerospace industries. The manufacturing industries that are utilizing the hybrid Mg-MMC also go through the machining turning operations for application products. Therefore, it is very important for machining the hybrid Mg-MMC for the desired dimensional accuracy. The present experimental research was therefore aimed at investigating the average surface roughness height $R_a$ while turning the hybrid Mg-MMC using the CCMT 09 T3 08 WF 1525 tungsten carbide insert. The machining parameters includes the cutting speed was 40 m/min, 80 m/min and 120 m/min, the feed rate was 0.08 mm/rev, 0.2 mm/rev, 0.4 mm/rev and the depth of cut was 0.2 mm, 0.5 mm and 0.75 mm. The average surface roughness height $R_a$ was measured using surfcom 130A (profilometer). Experimental investigation found that the average surface roughness height $R_a$ was lower at a higher cutting speed and at a lower feed rate. In addition, the built-up edges were formed at a lower feed rate with all cutting speed values.

Keywords: Hybrid Mg-MMC, Average surface roughness heights $R_a$, Tungsten Carbide, Turning.

1. Introduction

Hybrid magnesium metal matrix composites have become a leading material in composite materials, and due to their superior physical (density) and mechanical (strength) properties, these lightweight materials have gained significant attention. Owing to the presence of hard-reinforced abrasive particles in the Mg-MMC and their abrasive nature, these materials are difficult to machine and the cutting tools have been worn out faster. Hard-reinforced particles such as silicone, alumina and graphite have a higher hardness value and are difficult to machine using a standard cutting tools. To properly analyse the materials, the surface and its properties are the most significant properties of the materials that need to be well studied. The surfaces have been exposed to the environments such as the tools and dies during processing or service life. Measurement and description of the surface feature are the most important aspect of the manufacturing process. In engineering the most common surface roughness measurement is the arithmetical mean value or average surface roughness height $R_a$. Using Taguchi approach, Das et al [1] studied the turning performance of Al 7075/SiC$_p$ MMC and
found that feed rate was the most important parameters followed by spindle speed for multi-response characteristics, also they discovered that the insignificant parameter was depth of cut.

During turning T6 tempered Al 7075 alloy, Das et al [2] investigated the material removal rate and chip formation and found that the optimum parameters were obtained at 1575-rpm spindle speed, 0.2 mm/rev feed rate and 0.2 mm cutting depth. Furthermore, the most important parameter was the spindle speed. The machining behaviour of Al6061 fly ash composites was investigated by Rao et al [3] and found that the build-up edges and built-up layer formation were primarily difficulty when turning the aluminium alloy and its composites. The effect of machining parameters on the machinability of particulate reinforced Al/SiC MMCs turning through a rhombic uncoated carbide tool was investigated by Manna and Bhattacharya [4], and found that high speed, low feed rate and lower cutting depth are suggested parameters for achieving better surface finish. Mohan et al [5] conducted an experimental investigation to optimise the machining parameters of 20 vol % SiC Al-MMC by K20 carbide tool during hot machining and found that the minimum flank wear on the cutting tool was observed at 150 m/min cutting speed and 150°C temperature when machining was performed. The effect of machining parameters on tool wear was investigated by Cifti et al [6] during the machining of SiC/Al MMC using CBN cubic boron Nitrate and found that there was a lowest cutting flank wear ranging from 30-45 µm at cutting speed of 150m/min. A lower cutting speed for machining coarse particle reinforced MMCs and a higher cutting speed for fine particle reinforced MMCs were proposed by Sahin and Sur [7].

The main aim of performing the experimental analysis has to determine the influence of the machining parameters on the average surface roughness height $R_a$ of the hybrid Mg-MMC.

2. Experimental details

The fabricated hybrid Mg-MMC ingots of 40 mm diameter x 150 mm length with ultimate tensile strength of 214MPa [8-9] were used as workpiece materials for the turning operations. The turning operations were performed on the fabricated hybrid Mg/(8wt%SiC_p+2wt%Al_2O_3p+1wt%Gr_p) MMC with CCMT 09 T3 08WF 1525 carbide insert on the NH 26 automatic lathe machine. The average surface roughness heights ($R_a$) were measured using Surfcom 130 A (profilometer) as illustrated in Fig. 1. The Taguchi design of experiments with $L_{27}(3^{13})$ orthogonal array was employed for experimentation, the variance analysis (ANOVA) was performed on acquired results and mathematical models for surface roughness heights $R_a$ were developed.

![Fig. 1 Profilometer for measuring the average surface roughness height ($R_a$)](image-url)
3. Results and discussion

Taguchi-based system design, a powerful experiment design technique was performed to optimize the turning parameters for successful machining of manufactured hybrid Mg/(8wt%SiC\textsubscript{P}+2wt%Al\textsubscript{2}O\textsubscript{3}P+1wt%Gr\textsubscript{P}). For 3\textsuperscript{3} factorial design, an orthogonal L\textsubscript{27} (3\textsuperscript{13}) array was used, and ANOVA was performed to characterize the relevant parameters and effect of cutting speed, feed rate and cutting depth on various machining response parameters. Mathematical models for surface roughness heights were developed using multiple linear regression and considering important parameters, R\textsubscript{a}. The developed models will help to further setting of parameters for effective machining of Mg/(8wt%SiC\textsubscript{P}+2wt%Al\textsubscript{2}O\textsubscript{3}P+1wt%Gr\textsubscript{P}).

3.1 Taguchi Methodology for Parameter Design

Parametric design is an influential method for Taguchi's reliable theory of design for the conception of an efficient and systemic framework. Optimizing the output characteristics of the system by setting design parameters to reduce the sensitivity of the system performance to the sources of variance by choosing the optimal ranges of the process parameters involved. The basic values for the function parameter are set in the parametric design state. Several parameters can influence the product's response quality characteristics. Table 1 shows the turning parameters and their stages considered for detailed testing for process parameter optimisation. Table 2 shows Taguchi L\textsubscript{27} (3\textsuperscript{13}) orthogonal array architecture experiment.

| Sr. No. | Cutting parameter and their levels |
|---------|-----------------------------------|
| Sr. No. | Machining Parameters | Unit | Level |
| 1       | A: Cutting Speed | m/min | 40 | 80 | 120 |
| 2       | B: Feed | mm/rev | 0.08 | 0.2 | 0.4 |
| 3       | C: Depth of cut | mm | 0.2 | 0.5 | 0.75 |

| Exp. No. | Y\textsubscript{1} | Y\textsubscript{2} | Y\textsubscript{3} | Test results for R\textsubscript{a} (\mu m) |
|----------|----------------|----------------|----------------|--------------------------------------|
| 1        | 1.77           | 1.98           | 2.01           | 1.92                                 |
| 2        | 2.31           | 2.67           | 3.01           | 2.66                                 |
| 3        | 3.13           | 3.17           | 3.23           | 3.2                                  |
| 4        | 3.02           | 2.69           | 2.78           | 2.83                                 |
| 5        | 3.11           | 3.48           | 3.02           | 3.17                                 |
| 6        | 4.02           | 3.78           | 3.44           | 3.74                                 |
| 7        | 4.09           | 3.84           | 3.85           | 3.92                                 |
| 8        | 3.94           | 3.86           | 4.21           | 4                                    |
| 9        | 4.58           | 4              | 3.59           | 4.05                                 |
| 10       | 1.8            | 1.75           | 1.56           | 1.7                                  |
| 11       | 2.55           | 2.13           | 3.76           | 2.81                                 |
| 12       | 2.75           | 3.21           | 3.56           | 3.17                                 |
| 13       | 2.71           | 2.56           | 1.96           | 2.42                                 |
During turning of hybrid Mg-MMC workpiece specimens, the mathematical relations were used to assess the S / N ratio for average surface roughness height $R_a$. MATLAB version 7.10 (R2010 a) was used to create mathematical models using the results obtained.

**Table 3 ANOVA and ‘F’ test for $R_a$ (µm)**

| Sr. No. | Control Factor | Degree of Freedom | Sum of Square “SS” | Variance “V” | ‘F’ test value “ $F_o$” | % of contribution |
|---------|----------------|-------------------|-------------------|-------------|----------------|-------------------|
| 1       | A: Cutting speed | 2                 | 3.7094            | 1.8547      | 18.219** * * | 23.09             |
| 2       | B: Feed rate    | 2                 | 2.8246            | 1.4123      | 13.873*       | 17.58             |
| 3       | C: Depth of cut | 2                 | 3.0682            | 1.5341      | 15.069*       | 19.09             |
| 4       | AB Interaction  | 4                 | 0.6878            | 0.1719      | 1.689         | 4.28              |
| 5       | AC Interaction  | 4                 | 4.4059            | 1.1015      | 10.820*       | 27.42             |
| 6       | BC Interaction  | 4                 | 0.5592            | 0.1398      | 1.373         | 3.48              |
| 7       | Error           | 8                 | 0.8144            | 0.1018      | -             | 5.06              |
| 8       | Total           | 26                | 16.0695           | -           | -             | 100.00            |

* * * Most significant, * * Significant, and * comparatively less significant.

Table 3 refers to the ANOVA and ‘F’ test for $R_a$, where the percentage contribution of cutting speed (P = 23.09 %), feed rate (P = 17.58 %) and cutting depth (P = 19.09 %) is more or less equally liable and has a significant impact on the surface roughness height of $R_a$ (µm). Here too, the interface of cutting speed (parameter, A) and cutting depth (parameter, C) is the second most influential function on the surface roughness height $R_a$. 
Fig. 2 shows the S/N ratio graph for different factor levels of $R_a$. It is evident that the optimal parametric setting for $R_a$ is $A_3B_1C_2$ i.e. at a cutting speed of 120 m/min, feed rate of 0.08 mm/rev and depth of cut of 0.5 mm.

### 3.3 Mathematical model for the ($R_a$)

Considering three parameters, namely cutting speed as $A$, feed rate as $B$ and depth of cut as $C$ and using the Gauss elimination method, the mathematical model developed. The mathematical model for $R_a$ ($\mu$m) of the fabricated Mg/(8wt%SiC_p+2wt%Al_2O_3p+1wt%Gr_p)--MMC is as follows:

$$Y_{Ra_a} = 1.40345 + 0.00598 A + 0.48514 B + 1.27819 C - 0.00396 AB - 0.02974 A C - 3.496 95 B C - 0.00001 A^2 - 6.43518 B^2 + 1.95959 C^2$$

(1)

Where, $A$ = cutting speed, m/min, $B$ = Feed rate, mm/rev and $C$ = Depth of cut, mm

| Confimation No. | Cutting Speed (m/min) | Feed Rate (mm/rev) | Depth of cut (mm) |
|---------------|-----------------------|-------------------|------------------|
| 1.            | 30                    | 0.33              | 1                |
| 2.            | 100                   | 0.25              | 1.25             |
| 3.            | 150                   | 0.1               | 0.6              |

### Table 4 Machining conditions for confirmation

**Table 5** Confirmation test results for surface roughness height, $R_a$ ($\mu$m)

| Confirmation test No | Experimental value | Predicted value as per developed model | % Error |
|----------------------|--------------------|---------------------------------------|---------|
| 1                    | 6.01               | 6.2271298                             | 3.6%    |
| 2                    | 4                  | 4.17524375                            | 4.3%    |
| 3                    | 2.6                | 2.7375594                             | 5.2%    |

From the above confirmatory test results and tested with the developed mathematical model for $Ra(\mu$m), it is found that the findings obtained using the developed model have a direct correlation to the test results. Accordingly, this mathematical model can be successfully used to predict the turning parameter in advance to obtain the desired surface finish.
3.4 Interaction effects of the turning parameters on $(R_a)$

![Interaction of turning parameters on $(R_a)$](image)

Fig. 3 Interaction of turning parameters on $(R_a)$

Fig. 3 (a) shows the interaction of cutting speed and feed rate at surface roughness height, $R_a$ (μm). Fig. 3 shows that the blue color zone is the optimal machining combination to attain a minimum surface roughness height, $R_a$ (μm) and the red color area is an unfavorable condition. Figure 3(b) shows the interface effect of cutting speed and cutting depth on average surface roughness height, $R_a$ (μm). Figure 3(b) shows that the blue color zone is the optimal machining combination to attain a minimum surface roughness, $R_a$ (μm) and the red color area is the unfavorable condition. Figure 3(c) shows the relationship between the feed rate and the cut depth at the surface roughness height, $R_a$ (μm). Figure 3 (c) indicates that the blue color zone is the ideal machining combination to attain a minimum surface roughness, the $R_a$ (μm) and the red color area are adverse conditions.

4. Conclusions

1. The developed mathematical model for $R_a$ (μm), showed that the findings obtained using the developed model had a strong correlation with the test results. Hence, this mathematical model can therefore be used for predicting the turning parameter in advance to obtain desired surface finish.

2. The percentage contribution of cutting speed ($P = 23.09\%$), feed rate ($P = 17.58\%$) and cutting depth ($P = 19.09\%$) is more or less equally liable and has a significant impact on $R_a$ (μm).

3. The $R_a$ (μm) is minimum at high cutting speed i.e. 120 m/min and low feed rate value i.e. 0.08 mm/rev during turning of hybrid Mg/(8wt%SiC$_p$+2wt%A1$_2$O$_3$p+1wt%Gr$_p$) MMC.
References

1. Das, D., Chakraborty, V., Nanda, B. K., & Routara, B. C. (2018). Turning performance of Al 7075/SiCp MMC and multi-response optimization using WPCA and Taguchi approach. Materials Today: Proceedings, 5(2), 6030-6037.

2. Das, D., Sahoo, B. P., Bansal, S., & Mishra, P. (2018). Experimental investigation on material removal rate and chip forms during turning T6 tempered Al 7075 alloy. Materials Today: Proceedings, 5(2), 3250-3256.

3. Rao, C. P., Bhagyashekar, M. S., & Viswanath, N. (2014). Machining behavior of Al6061-fly ash composites. Procedia Materials Science, 5, 1593-1602.

4. Manna, A., & Bhattacharayya, B. (2005). Influence of machining parameters on the machinability of particulate reinforced Al/SiC–MMC. The International Journal of Advanced Manufacturing Technology, 25(9-10), 850-856.

5. Mohan, B., Venugopal, S., Rajadurai, A., & Mannan, S. L. (2008). Optimization of the Machinability of the Al-SiC Metal Matrix Composite Using the Dynamic Material Model. Metallurgical and Materials Transactions A, 39(12), 2931-2940.

6. Ciftci, I., Turker, M., & Seker, U. (2004). CBN cutting tool wear during machining of particulate reinforced MMCs. Wear, 257(9-10), 1041-1046.

7. Sahin, Y., & Sur, G. (2004). The effect of Al2O3, TiN and Ti (C, N) based CVD coatings on tool wear in machining metal matrix composites. Surface and Coatings Technology, 179(2-3), 349-355.

8. Hira, J., Mangal, S. K., & Manna, A. (2015). Fabrication of Hybrid Mg/(Al 2 O 3p+ SiC p+ Gr p) Metal Matrix Composite on Developed Gas Injection Liquid Stir Casting Setup. Arabian Journal for Science and Engineering, 40(9), 2729-2738.

9. Hira J., Manna A., Kumar P., Singla R. (2020). Optimizing Gas Injection Stir Casting Process Parameters for Improving the Ultimate Tensile Strength of Hybrid Mg/(SiCp + Al2O3p + Grp) Through Taguchi Technique. In: Pandey P.M., Kumar P., Sharma V. (eds) Advances in Production and Industrial Engineering. Lecture Notes in Mechanical Engineering. Springer, Singapore. https://doi.org/10.1007/978-981-15-5519-0_10