The effect on the tool flank wear width $VB_{\text{max}}$ during turning of Hybrid Mg/(8wt% SiC(p) +2wt% Al2O3(p) +1wt% Gr(p)) MMC using PVD coated cermet tool

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Abstract. In this study Taguchi Optimization Technique was used, followed by ANOVA to evaluate the machinability i.e. turning of a hybrid Mg/(8wt%SiCp+2wt%Al2O3p+1wt%Grp) MMC using PVD coated cermet tool under the dry turning conditions. Several experiments were conducted using the L27 (3¹³) orthogonal array on NH26 automated lathe machine. ANOVA was used to determine the impression of the turning parameter on the $VB_{\text{max}}$ of the tool flank. The finding of the research work investigated that the cutting speed in the dominant factor influence the tool wear width. The confirmation test revealed that the Taguchi technique has been successful in the optimization of the machining parameters for minimum tool wear. The optimal parameter arrangement for minimum tool wear width is at cutting speed of 120 m/min, with the feed rate of 0.4 mm/rev and depth of cut at 0.75 mm. The scanning electron microscope images revealed notches, groves and pits on the tool flank face that is clearly visible at different magnification units. Herein, this paper discuss about several reported synthesis techniques, various characterization techniques used for structural and surface properties identifications, different morphologies and various potential applications of transition metal oxide based nanocomposites.

Keywords: Hybrid MMC, Taguchi, Anova, S/N ratio, PVD coated cermet tool

1. Introduction

Hybrid metal matrix composite has gained tremendous attention in the manufacturing industry meeting the latest industrial requirements. These materials have inherited properties, such as high specific strength, higher rigidity and higher characteristics that the pure alloys. Despite having higher strength values, hybrid MMC are challenging to machine due to the presence of hard reinforced particles. Machining these metal matrix composites is a huge challenge and industries are working to develop an optimal solution in which machining parameters must be optimally suited to achieve the desired results. The physical interaction of hard reinforced particles on the tool causes a variety of tool failures, including high-temperature shearing, diffusion wear, abrasive wear, fatigue wear, oxidation effect, flank wear,
crater wear, and chipping action. Holmberg et al [1] investigated the outstanding strains in TiN, DLC and MnS2 coated material surface and discovered that the PVD coated surface compressional residual stress range from 0.5 to 4 GPa and can reach up to 11 GPa. Yang et al [2] discovered that the carbon, nitride cermet coated material coated with TiAlN and TiAl/Cr AlN showed the improved adhesion, wear resistance and abrasive wear. During machining, Bushlya et al [3] discovered that the presence of SiCp in the Al-SiCp MMC deteriorated the protective layers on diamond and boron nitride tools. TiAIN coatings deposited on Si3N4 cutting inserts via PVD technique demonstrated higher adhesion strength than Cr-AlN coatings, according to the author [4]. Vaxiour et al [5], reviewed machinability of hybrid MMC, and observed that the presence of graphite material in the MMC enhances the surface finish and studied the improvement of the machinability due to its low heat expansion coefficient. Lim et al [6] explored the wear of the magnesium composite reinforced with nano sized Al particles and discovered the wear resistance increases with the increase in particles during higher machining operations. Rajesh et al [7] utilized L9 orthogonal array for conducting the machining on the red mud Al MMC, and this particular orthogonal proves to be beneficial in determining the best turning parameter combinations. Rubio et al. [8] used an L27 orthogonal array to optimise the parameters for the dry facing of magnesium in order to evaluate surface roughness, and they discovered that 0.04 mm/rev feed rate, 280 rpm spindle speed, and TP2500 tool coating are the best combinations for minimizing surface roughness. Hasan et al [10] examined the effect of the reinforcement, i.e. chopped fibres and woven roving, and discovered that as the particle strength and specimen hardness increased, so did the impact strength and specimen hardness. Barman et al [11] investigated the impact of the laser interferometry technique and demonstrated that these laser measurement systems provide higher accuracy and quality. Kumar et al found out the during the turning of nanocomposites Al2219 alloy matrix there is a formation of build up edge at lower cutting speed values. Kumar et al [13] investigated the effect of during parameters on the turning of Al 7075/10/SiCp and Al 7075 composite and found that the most significant parameters are the lower feed rate and high cutting speed. In view of the above research study an attempt has been done to find out the effect of machining parameters on hybrid MMC workpiece specimen using Taguchi design of experiments (DOE) and ANOVA methods.

2. Experimental Procedure

Hira et al [14], used the gas injection liquid stir casting to create an experimental workpiece specimen including the hard reinforced particles, which has been utilized for the work study. The dimension of the workpiece including the length 250 mm and diameter 90 mm respectively. The tool insert technical specifications has been inserted in the Table 1 and the chemical composition that is also listed in Table 2. Figure 1 (a) and (b) shows the schematic layout of the PVD coated cermet tool during turning and actual mounting of the tool holder. Figure 2(a) shows the schematic layout showing the instruments measuring the tool flank wear width VBmax and (b) instrument for measuring the value of the wear.

![Figure 1. Schematic layout of the PVD coated cermet tool turning hybrid Mg-MMC; (b) Actual mounting of tool with tool holder.](image-url)
Figure 2. Schematic representation of the flank face of the PVD cermet tool with flank wear land VBmax and depth of cut line; (b) tool maker microscope for measurement of wear

Table 1. PVD coated cermet tool detail specifications

| Tool shape       | Tool Type | Cutting tool specification | Tool Material and Grade | Rake angle (°) | Clearance angle (°) | Cutting Edge angle (°) | Nose radius (mm) |
|------------------|-----------|-----------------------------|-------------------------|---------------|---------------------|------------------------|-----------------|
| Rhombic          | TMax positive insert | CCMT09 T308WF1525 | PVD coated cermet tool | 6            | 7                   | 80                     | 0.8             |

Table 2. Chemical composition of hybrid Mg/(8wt%SiC(p)+2wt%Al2O3(p)+1wt%Gr(p)) MMC

| Type of MMC       | Size of reinforced particles (µm) | % SiC(p) | % Al2O3(p) | % Gr(p) | Mg     |
|-------------------|----------------------------------|---------|------------|---------|--------|
| Discontinuous MMC | SiC(p)=23                        | 8       | 2          | 1       | Balance|
|                   | Al2O3(p)=69 Gr(p)=53             |         |            |         |        |

Table 3. Mechanical Properties

| Material | Density (p) | Tensile strength (σt) | Yield strength (σy) | Elongation % (ε) | Hardness (HV) |
|----------|-------------|-----------------------|--------------------|------------------|---------------|
| Mg/(8wt%SiC(p)+2wt%Al2O3(p)+1wt%Gr(p)) | 2.9         | 230                   | 210                | 5                | 63            |

3. Taguchi Design Approach

A strong experimental design tool, method based Taguchi design has been utilized for finding out effect of machining parameters on the workpiece specimen Mg/(8wt% SiCp+2wt% Al2O3+1wt% Gr) MMC. For a factorial design an orthogonal array L27 (313) has been utilized for the study and ANOVA has been utilized for important parameters. The Mathematical model has been developed considering the significant parameter and using multiple regression. Table 4 and table 5 shows the turning parameters and their level for detailing experimentation in order to optimize the significant parameters and also the result for the tool flank wear width VBmax.
Table 4. Turning (machining) parameters and their levels

| Sr.No. | Machining Parameters | Unit  | Level  |
|--------|----------------------|-------|--------|
| 1.     | A: Cutting Speed     | m/min | 40     |
| 2.     | B: Feed              | mm/rev| 0.08   |
| 3.     | C: Depth of cut      | mm    | 0.2    |

Table 5. Test results for cutting tool flank wear width (VBmax) mm

| Experiment No. | Y1   | Y2   | Y3   | Test results for cutting tool flank wear width |
|----------------|------|------|------|-----------------------------------------------|
| 1              | 0.078| 0.079| 0.083| 0.08                                         |
| 2              | 0.089| 0.087| 0.094| 0.09                                         |
| 3              | 0.09 | 0.091| 0.119| 0.1                                          |
| 4              | 0.1  | 0.11 | 0.12 | 0.11                                         |
| 5              | 0.13 | 0.139| 0.151| 0.14                                         |
| 6              | 0.129| 0.13 | 0.131| 0.13                                         |
| 7              | 0.149| 0.15 | 0.151| 0.15                                         |
| 8              | 0.148| 0.149| 0.153| 0.15                                         |
| 9              | 0.19 | 0.2  | 0.21 | 0.2                                          |
| 10             | 0.2  | 0.21 | 0.22 | 0.21                                         |
| 11             | 0.189| 0.19 | 0.191| 0.19                                         |
| 12             | 0.187| 0.19 | 0.193| 0.19                                         |
| 13             | 0.239| 0.24 | 0.241| 0.24                                         |
| 14             | 0.269| 0.27 | 0.271| 0.27                                         |
| 15             | 0.289| 0.29 | 0.291| 0.29                                         |
| 16             | 0.3  | 0.31 | 0.32 | 0.31                                         |
| 17             | 0.32 | 0.33 | 0.34 | 0.33                                         |
| 18             | 0.31 | 0.319| 0.331| 0.32                                         |
| 19             | 0.19 | 0.21 | 0.23 | 0.21                                         |
| 20             | 0.289| 0.29 | 0.291| 0.24                                         |
| 21             | 0.259| 0.26 | 0.261| 0.26                                         |
| 22             | 0.341| 0.35 | 0.359| 0.35                                         |
| 23             | 0.369| 0.37 | 0.371| 0.37                                         |
| 24             | 0.389| 0.39 | 0.391| 0.39                                         |
| 25             | 0.38 | 0.42 | 0.43 | 0.41                                         |
| 26             | 0.489| 0.49 | 0.491| 0.49                                         |
| 27             | 0.49 | 0.5  | 0.51 | 0.5                                          |

4. Results and Discussion

4.1 ANOVA

Table 6 describes the ANOVA an F test results for the tool flank wear width (VBmax) it has been found that the percentage contribution of the cutting speed is approximately 32.78%, the feed rate contribution is 19.4% and the depth of cut is 23.05% which is equally responsible and has significant resulting in the performance of cutting tool flank wear width (VBmax). Through the Table 6 and analysis it is found that the highest contribution among various machining parameters is the cutting speed during the turning of hybrid Mg/MMC workpiece specimen.
Table 6. ANOVA and "f” test for tool flank wear width (VB\textsubscript{max})

| Sr.No. | Control Factor | DOF | Sum of Square | Variance | F Test Percentage contribution |
|--------|----------------|-----|---------------|----------|-------------------------------|
| 1.     | A: cutting speed | 2   | 0.14768       | 0.073484 | 25.8                          | 32.78 |
| 2.     | B: Feed rate    | 2   | 0.08625       | 0.043125 | 15.11                         | 19.14 |
| 3.     | C: Depth of cut | 2   | 0.10375       | 0.051875 | 18.185                        | 23.05 |
| 4.     | AB Interaction  | 4   | 0.0281        | 0.007025 | 2.462                         | 6.24  |
| 5.     | AC Interaction  | 4   | 0.0468        | 0.0117   | 4.10                          | 10.39 |
| 6.     | BC Interaction  | 4   | 0.015         | 0.00375  | 1.314                         | 3.34  |
| 7.     | Error           | 8   | 0.02282       | 0.002853 | -                             | 5.06  |
| 8.     | Total           | 26  | 0.4504        | -        | -                             | 100.00|

4.2 Signal to Noise Ratio (S/N)

Figure 3 shows the signal to noise ratio (dB) for the tool flank wear width (VB\textsubscript{max}) and it can be seen through the figure that A3B3C3 are the optimizing parameters intended for minimum tool flank wear width (VB\textsubscript{max}).

![S/N ratio (dB) for tool flank wear width (VB\textsubscript{max})](image)

4.3 Development of Mathematical Model

Eq (1) depicts the developed mathematical model using the Gauss elimination method which is taking three parameters into consideration i.e. the cutting speed, feed rate and depth of cut:

\[ Y_{Flankwear} = -0.07348 + 0.00289*A + 0.24085*B + 0.07041*C + 0.0026*AB - 0.00101*AC + 0.00602*BC + 0.00101*A^2 - 0.2865*B^2 + 0.00134*C^2 \] (1)

Table 7 shows the assessment of the experimental investigation and the mathematical model, it has been found that the percentage error was discovered to be less than 10% which is indicating that the developed mathematical model described by Montgomery and Douglas was successful [15]. Through the confirmation and results its clear that the we can use this mathematical model to predict the machining parameters for obtaining preferred machining results in which the tool wear is minimum.
Table 7. Confirmation test results for cutting tool flank wear width VBmax

| Confirmation testno. | Experimental results | Results as per developed mathematical model | % Error |
|----------------------|----------------------|---------------------------------------------|---------|
| 1.                   | 0.148                | 0.151968                                    | 2.6     |
| 2.                   | 0.32                 | 0.345589                                    | 7.9     |
| 3.                   | 0.44                 | 0.465806                                    | 5.8     |

4.4 Interaction plots of tool wear

Figure 4 (a), (b) and (c) demonstrate the different color region indicating in the figure which are representing the required machining groupings for achieving the minimum cutting tool flank value, the red color zone is representing the adverse conditions. The physical significance of the interaction plots are the interference values generated through the contact of tool tip which bears high temperature at high cutting speeds. The more the cutting speed the more the tool wear. The deformation in the tool is due to these high speeds and also interaction of hard reinforced particulates in the hybrid Mg/MMC workpiece specimen 5.

![Interaction plots of tool wear](image)

Figure 4. (a). Interaction effect of feed rate and cutting speed on tool flank wear, (b). Interaction effect of depth of cut and cutting speed on tool flank wear, (c). Interaction effect of depth of cut and feed rate on tool flank wear in machining (turning) hybrid Mg/(8wt%SiC(p)+2wt%Al2O3(p)+1wt%Gr(p)) MMC

5. Scanning Electron Microscope of the tool

SEM of a PVD coated cermet tool was performed at various magnifications. The magnification depths were 3mm, 500μm, 50μm and 100 μm respectively. The effect of excessive forces, mechanical vibrations, intense stresses, and temperature rise on the PVD tool has been studied using SEM. At 3mm magnification, Figure 5(a) depicts the worn-out edge. The worn-out edge was caused by a decrease in yield intensity caused by high-temperature generation during turning. The cutting edge has softened and deformed resulting plastic deformation. This has been observed at high cutting speed. In the figure 5(b) the wear in the upper coated layer can been seen significantly.
Figure 5. (a) SEM of the PVD tool showing tool wear on the cutting edge at 3mm; (b) Wear of coated surface 500µm; (c) Grooves and Notches at rake face 100 µm; (d) Crater wear at 50 µm.

Figure 5(d) depicts the tool's crater wear and discoloration patterns caused by high temperatures. This is the movement of atoms across the tool-workpiece chip interface via a diffusion mechanism. This crater wear significantly reduces the tool's strength, which may lead to further failure. The crater is formed as a result of adhesion and diffusion of hard reinforced particulates on the tool face flank. This crater wear significantly reduces the tool's strength, which may lead to further failure. The crater was formed at great cutting speed 120 m/min, higher feed rate 0.4 (mm/rev) and with lower depth of cut i.e. 0.2 mm during turning of Mg/MMC workpiece specimen.

6. Intensive Discussion

The current study is concerned with the wear of the PVD-coated cermet tool during hybrid Mg-MMC turning. Excessive forces and mechanical vibrational shocks are typically the primary causes of cutting tool failure. During machining, the intense stresses raise the temperature, causing plastic deformation. The machining parameters play a crucial role in turning as high velocity, are not favorable during turning of hybrid Mg-MMC as they add peak tool wear (edge chipping) later is the cutting depth and feed rate. The PVD cermet tool coating has the advantages for machining hybrid Mg-MMC. The tool wears enhanced with rises in cutting velocity, feed rate and cutting depth and with cutting speeds of 40 to 120 mm/min the tool wear increased as of 0.21 to 0.425 mm respectively. The inherent properties of hard reinforced particulates in the matrix magnesium resulting higher the weight fraction of particles resulting in the tool flank wear. The notches, groves, and pits formed on the tool flank face during machining at high cutting speeds. Mechanical wear of a cutting tool includes abrasion, chipping, delamination, adhesion, fracture, and flaking. The thermochemical wears on the tool are mass dissolution and atomic migration. The main factor in resisting damage such as grooving wear is chemical stability.
7. Conclusion

During machining, i.e., hybrid Mg-MMC turning under dry operating conditions, PVD-coated cermet instrument has been used effectively. The cutting speed (m/min) has the greatest percentage contribution in the cutting tool flank wear width while machining of hybrid Mg-MMC. The optimal parametric arrangement for minimum (VBmax) is A3B3C3 for minimum the tool wear width (VBmax). After turning at high cutting speeds, SEM revealed notches, grooves, and pits on the tool surface. The preceding study used standard tools, such as conventional High-Speed Steel tools, to machine hybrid MMC that would otherwise be difficult to machine. The PVD-coated cermet tool discovers the ability to cut materials with elevated hardness level values. The fields of tool geometry, difficult profile turning, and interrupted surfaces need more effort to fulfill future demand through turning.

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