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# An Experimental Study of the Effect of Machining Parameters on $TiB_2$ /Graphite/Magnesium Reinforced Aluminum 7075 Fabricated Composite by Stir Casting on CNC Lathe for Surface Roughness and Cutting Force by using Taguchi Design

**Rajender Singh, Anil Kumar Sharma, Dilip Gahlot**

***Abstract*— In this experimental study, three $TiB_2$,Graphite and Magnesium reinforced aluminum 7075 matrix composite with 20 µm in mean size were fabricated by using bottom pouring stir casting technique. Experimental test was conducted to find the machining parameter influencing surface roughness ($R_a$) and Cutting Force ($F_Z$) on machining the $TiB_2$,Graphite and Magnesium reinforced aluminum 7075 composite material. The orthogonal array, the signal-to-noise ratio and analysis of variance were employed to study the performance characteristic in turning on CNC machine of 0, 4, 8 and 12 wt% of $TiB_2$ and Graphite and 1 wt% of Magnesium particles reinforced aluminum 7075 metal matrix composite. Taguchi technique was used to find the optimal cutting factors for surface roughness ($R_a$) and cutting force ($F_Z$).The factors considered were wt% of reinforcement, spindle speed, feed rate and depth of cut. The experimental plan and analysis was based on the Taguchi $L_{16}$ orthogonal array with four factors. The optimal parametric combination for surface roughness and cutting force was found to be wt% reinforcement, spindle speed, feed rate and depth of cut. The analysis of variance (ANOVA) results show that the feed is the most significant factor for surface roughness followed by depth of cut/reinforcement. From cutting force data also, it is clear that the spindle speed is most significant factor followed by depth of cut.**

***Index Terms*—$TiB_2$ and Graphite reinforced aluminum 7075 metal matrix composite, Taguchi Method, Surface roughness, Cutting Force.**

## I. Introduction

To fulfill the demands of modern engineering applications, the ceramic fillers were mixed in metal matrix such as aluminum and its alloys. By mixing these ceramic fillers in the metal matrix properties such as high strength, stiffness and wear and corrosion resistance of metal matrix composites were increased as compared to base metal matrix. Of these properties; the tensile strength is the most important and vastly quoted measurement and is of central importance in number of applications [1]. Also these metal matrix composites have some important properties like low density, high modulus and thermal conductivity as well as low thermal expansion which make this composite to fulfill the increasing demand in engineering component manufacturing in different areas of applications like stator vanes, annulus filler, fan, valve assembly, sliding contacts, cylinder liners, and automobile pistons [2] [3] [4].

Machining is commonly considered as a finishing process, to obtain desired dimension, tolerance and surface finish. Metal Matrix Composites are fabricated by using different methods. With available fabrication techniques, it is also possible to make Metal Matrix Composite component nearer to the net shape. But additional machining is cannot avoid to get surface finish and to ensure for perfect assembly between the different parts. Therefore machining of Metal Matrix Composite is must be required to achieve desired dimensional accuracy, form accuracy and surface finish for proper functional requirements [5]. Amongst all the conventional machining process, precision turning plays an important role for the machining of composite materials [6]. The problem associated in conventional machining of Metal Matrix Composite is, it contained soft matrix reinforced with very hard reinforced particles, machining of these material is not easy and put challenges in the machining sectors [7].
Among all liquid state processing methods, conventional stir casting is an attractive method to aluminum metal matrix composites [8]. Because, it is relatively cheap process and different type of material can be processed at different processing conditions [9].Also stir casting offers better matrix particle bonding due to stirring action. It is also possible to get homogenous and uniform mixing and better wetting property by selecting suitable processing parameters like speed of stirring and time, and temperature of molten metal, temperature of preheating the mould and uniform feed rate of reinforced particles [10].
Since physical as well as mechanical properties are mostly effected due to work piece surface condition. Hence, machining effect on type of surface defect as well as on their distribution has great role on machining component performance. Such type of machining defect could be a major concern whenever using metal matrix composite in very precise or critical application.
There are different types of reinforcement material, titanium di-boride is a newly emerging and promising reinforcement for aluminum based composites because of it is a hard, stiff as

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well as does not react with aluminum during the mixing process. Also it is a refractory compound which has excellent features such as higher melting point, hardness, resistance to plastic deformation at higher temperature and high modulus make it to be a good reinforcing element in an aluminum based matrix.

The machining of a material is called effective if mach inability of that material is high. It cannot be determined accurately, it lies on different factors as surface finish, cutting forces, power consumptions, produced chips and tool wear[11][12]. Amongst these factors, surface finish and cutting force are the two critical factors to affect mach inability of any material. The surface roughness is also known as index of quality of any product and major technical requirement of any mechanical part or component [13]. There are several investigators carried out experiments on machining of metal matrix composite.

Manna et al investigated that wear of tool is more and surface roughness increased when carbide tools is used for machining the SiC reinforced aluminum metal matrix composite [14]. Ozben et al experimented that surface roughness is commonly affected by spindle speed and feed rate when machining on SiC particulate reinforced aluminum metal matrix composites for different volume fraction [15]. Channakesava Rao et al has investigated with different cutting tools and suggest that crater wear is low in K10 tools and show better wear resistance and deliver continuous chips during machining [16].

El-Gallab and Sklad et al conducted the experiments on 20% of SiC reinforced Al metal matrix compositesand found that higher chip depth and speed reduced the surface roughness [17]. K.Krishnamurthy and J.Venkatesh et al experimented on $TiB_2$-Al 6063 composite fabricated by stir casting and turning on CNC machine. They concluded that feed rate is most significant factor for surface roughness, followed by cutting speed. Also suggested that for MRR , the feed rate and spindle speed are most significant [18].

Johny Jmes.S et al experimented on Al matrix composite reinforced by SiC and $TiB_2$ for machining and mechanical properties and found that $TiB_2$ reinforcement increases the wear resistance of composite as well as hardness. Also percentage of $TiB_2$ is most significant factor on surface roughness, with increment of $TiB_2$ surface roughness and tensile strength is better than SiC [19].

K.Ramadevi et al investigated on Al-7075/$TiB_2$/TiC metal matrix composite with wt% 0 , 2.5 and 5% reinforcement of $TiB_2$ and TiC for cutting parameter in turning & found that high MRR when spindle speed, feed rate ,depth of cut and lower percentage of reinforcement and lower cutting force when lower spindle speed, higher feed and depth of cut and percentage reinforcement. Also found that tensile strength and hardness increase with increment of reinforcement and ductility is decreased [20]. S.J. Rayker et al investigated of high speed turning of Al7075 and concluded that feed is the most significant factor followed by speed, machining condition ,insert type and least significant factor is depth of cut[21]. S. Sasikumar et al experimented on aluminum 7075/$TiB_2$ 3% composite fabricated by liquid metallurgy and found that impact strength and hardness of composite increased by 25% and 10% as comparing to aluminium7075 base matrix due to the $TiB_2$.He also suggested that surface roughness is more for higher spindle speed and feed rate compare to base 7075 matrix. Also investigate that if feed rate is increased then chip is thin, smooth and uniform as well as continuous , as required force for turning leads to heat generation and vibration[22].

Taguchi suggested that quality gives immune and robustness to factors which are uncontrollable in the manufacturing stage. This technique of design of experiment reduce the large quantity of trials for experiment when process parameters increase in numbers [8] [9] [23].In this experimental work, a method has been adopted to evaluate and optimize the selected factors to acquired the minimum surface roughness and cutting force by using response table and response graph as well as analysis of variance (ANOVA) technique.

## II. EXPERIMENTAL PROCEDURE AND DETAILS

### *A. Materials and Method of fabrication*

Aluminum 7075 alloy was chosen as base matrix material in this experimental work due to its superior properties amongst all types of Al alloy. The chemical composition of Al7075 alloy is shown in table 1.The commercially available Al 7075 alloy in the form of round bar cut into 100mm piece and placed into the bottom pouring stir casting furnace and melted on $800^0$C followed by mixing of pre heated reinforcements material at $50^0$C-$150^{0C}$ as titanium diboride and graphite in equal wt% 4,8 and 12% as well as constant 1% magnesium then sttiring by mechanical stirrer at 350-450 RPM for 5-7 minutes. After stirring pouring metal is ejected by bottom pouring mechanism into the metal die which is 30x300 mm in size to fabricate the composite. After the cooling of die solid composite withdrawn from the die in the form of round bar in the size of dia30mm and 300mm length.

Table 1.Chmical composition of base matrix aluminum alloy 7075

| S.NO. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| CON TENT | Al | Si | Mn | Mg | Ti | Fe | Cu | Cr | Zn | Others |
| Wt.% | 87.1-91.4 | Max 0.40 | Max 0.30 | 2.1-2.9 | Max 0.20 | Max 0.50 | 1.2-2.0 | 0.18-0.28 | 5.1-6.1 | Max 0.15 |

### *B. Microscopy*

To know the presence and distribution of $TiB_2$ and graphite as well as magnesium in Al 7075 , all samples were tested by using field emission scanning electron microscope (FESEM) , EDS and Mapping.

### *C Cutting condition*

The experimental investigation was carried out with four factors at four level which are shown in Table 2.The design of experiment in this experimental work used is a standard L16 orthogonal array. This array is selected due to less number of experiments as well as its capacity to investigate the interactions among factors. The turning operations were performed on the (Simple Turn-5045 SPM) CNC lathe in the dry machining condition, shown in Figure 1. The machining insert used in this work is CCGT120408-FN-27 make ceratizit , shown in Figure 2. The surface roughness on the turned surface of all samples were measured by using SurfTest SJ-301 (make MITUTOYO) instrument as shown in Figure 3 and during the turning ,cutting force values were measured by using tool dynamometer make kistler as shown in Figure 4.

| Level/Factor | Spindle Speed RPM | Feed Rate mm/rev. | Depth of Cut Mm | Reinforcement % |
|---|---|---|---|---|
| 1 | 400 | 0.05 | 0.5 | 0 |
| 2 | 800 | 0.10 | 1.0 | 4 |
| 3 | 1200 | 0.15 | 1.5 | 8 |
| 4 | 1600 | 0.20 | 2.0 | 12 |

Table 2 Levels and Factors used in the experiments

**Figure 1: CNC Lathe**

**Figure 2: Insert CCGT120408-FN-27**

**Figure 3: Surface Roughness Tester SurfTest SJ-301 MITUTOYO**

**Figure 4: Tool Dynamometer Kistler make**

## III. RESULTS AND DISCUSSION

### *A. FESEM, EDS and MAPPING Result Report of composites*

Generally metal matrix composites properties not only depend on the particle, matrix and fraction of volume but also depend on the reinforcements as well as particle-matrix bonding.In general practically homogenous distribution achievement is difficult. The photomicrograph of 0,4,8 and 12% $TiB_2$ and graphite with 1% magnesium of FESEM results are shown in figure 5 (a ),5(b) , 5(c) and 5(d) respectively. The average particle size of 20 µm, in the surface showed in the photographs homogeneous and uniform distribution.

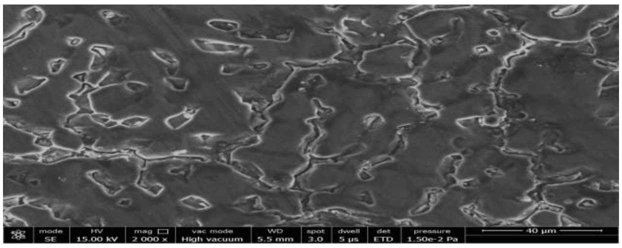


Figure 5(a)

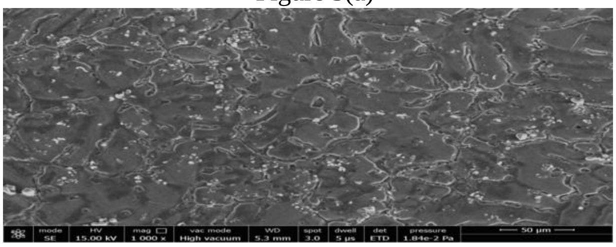


Figure 5(b)

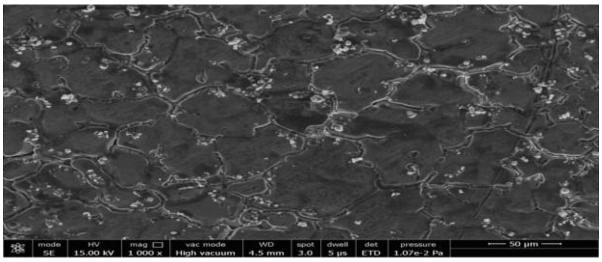


Figure 5(c)

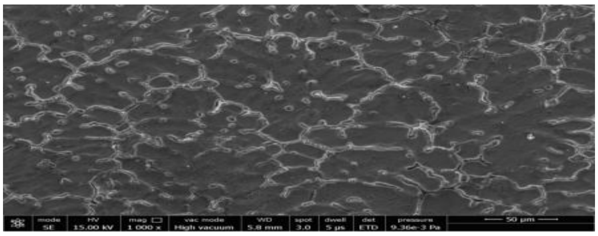


Figure 5(d)

The photomicrograph of 0, 4, 8 and 12% $TiB_2$ and graphite with 1% magnesium of EDS results are shown in figure 6 (a ),6(b) , 6(c) and 6(d) respectively.

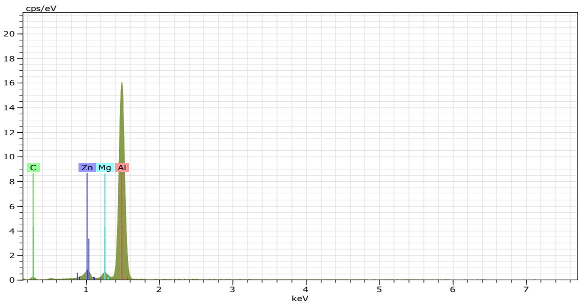



Figure 6(a)

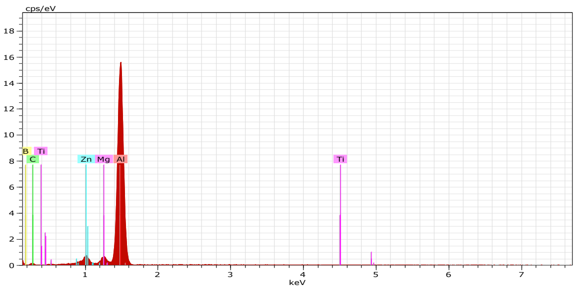



Figure 6(b)

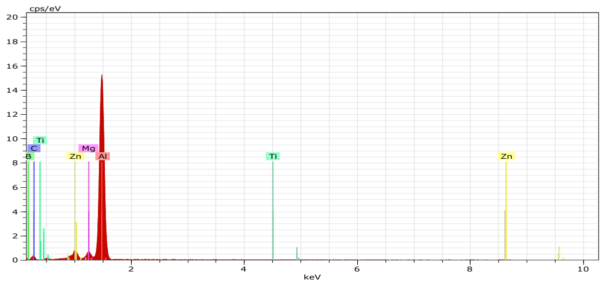



Figure 6 (c)

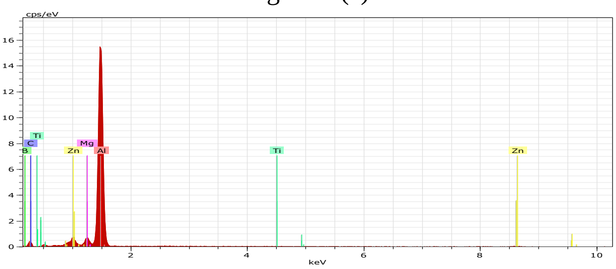



Figure 6(d)

The photomicrograph of 0,4,8 and 12% $TiB_2$ and graphite with 1% magnesium of Mapping results are shown in figure 7 (a ),7(b) , 7(c) and 7(d) respectively.

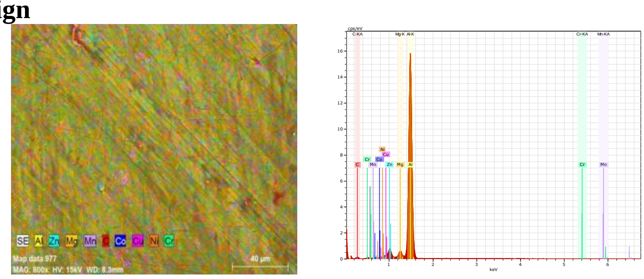


Figure 7(a)

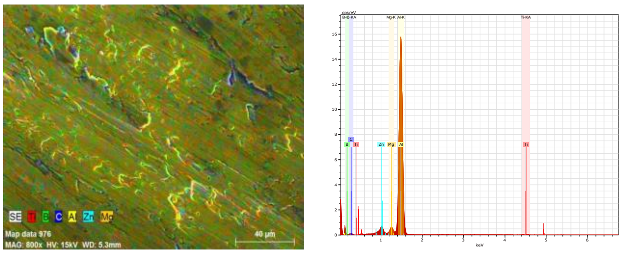


Figure 7 (b)

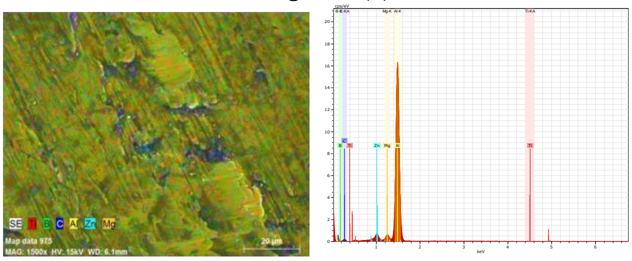


Figure 7 (c)

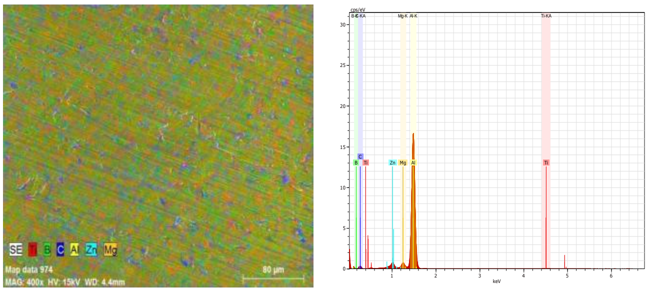


Figure 7 (d)

### *B. ANOVA of Surface Roughness and Cutting Force*

The estimating of effects of factors on surface roughness and cutting force of Al-7075/$TiB_2$/Graphite metal matrix composite machining has been carried out by responses table and graphs and ANOVA (Analysis of Variance) technique. The effect of machining parameter on surface roughness and cutting force has been studied by using responses tables. In this experimental study response table are used to simplify the all calculation which are required for analyze the data of experiments. The final response table in which four levels, four factors by using $L_{16}$ orthogonal array is shown in table 3.

Table 3.Surface Roughness Data, Cutting Force Data and Factor Settings

| S.NO. | Exp .No. | Material Reinforcement (%) | Spindle Speed RPM | Feed (mm/rev) | Depth of Cut (mm) | Surface Roughness (μm) | | | Cutting Force(N) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Ra | Rz | Rq | $F_x$ | $F_y$ | $F_z$ |
| 1 | 1 | 0 | 400 | 0.05 | 0.5 | 0.22 | 1.23 | 0.26 | 6.182359 | 9.855895 | 31.8159 |
| 2 | 2 | 0 | 800 | 0.10 | 1.0 | 0.27 | 1.63 | 0.32 | 11.04303 | 13.61924 | 36.71163 |
| 3 | 3 | 0 | 1200 | 0.15 | 1.5 | 1.18 | 4.60 | 1.34 | 16.77282 | 14.38671 | 68.18957 |
| 4 | 4 | 0 | 1600 | 0.20 | 2.0 | 1.68 | 5.80 | 1.83 | 9.435871 | 3.363813 | 37.81614 |
| 5 | 5 | 4 | 400 | 0.10 | 1.5 | 0.84 | 4.22 | 0.98 | 12.10917 | 10.06677 | 36.6327 |
| 6 | 6 | 4 | 800 | 0.05 | 2.0 | 0.30 | 2.20 | 0.38 | 14.14962 | 7.870607 | 23.91485 |
| 7 | 7 | 4 | 1200 | 0.20 | 0.5 | 1.06 | 5.85 | 1.29 | 4.600394 | 9.721551 | 12.25717 |
| 8 | 8 | 4 | 1600 | 0.15 | 1.0 | 0.69 | 3.99 | 0.84 | 5.834551 | 7.525807 | 8.724028 |
| 9 | 9 | 8 | 400 | 0.15 | 2.0 | 0.42 | 2.90 | 0.53 | 27.06696 | 17.77209 | 82.67398 |
| 10 | 10 | 8 | 800 | 0.20 | 1.5 | 1.08 | 5.70 | 1.34 | 26.64971 | 29.34787 | 92.06371 |
| 11 | 11 | 8 | 1200 | 0.05 | 1.0 | 0.29 | 2.31 | 0.37 | 7.330836 | 7.03847 | 12.72999 |
| 12 | 12 | 8 | 1600 | 0.10 | 0.5 | 0.30 | 2.46 | 0.39 | 3.799343 | 3.816528 | 3.028076 |
| 13 | 13 | 12 | 400 | 0.20 | 1.0 | 1.68 | 7.46 | 2.00 | 12.71514 | 21.34847 | 40.4409 |
| 14 | 14 | 12 | 800 | 0.15 | 0.5 | 0.74 | 4.92 | 0.97 | 5.702801 | 12.68197 | 7.341031 |
| 15 | 15 | 12 | 1200 | 0.10 | 2.0 | 0.36 | 2.54 | 0.45 | 18.19717 | 12.23926 | 33.64656 |
| 16 | 16 | 12 | 1600 | 0.05 | 1.5 | 0.26 | 1.84 | 0.33 | 11.02757 | 10.60345 | 4.991833 |

### *C. Surface Roughness ($R_a$)*

The recorded data of response in Table 3, for surface roughness subjected to analysis of variance (ANOVA) for determining the significant factors at 90 % confidence level and ANOVA result for these response are mentioned in the

Tables 4 and 5, for cutting force subjected to analysis of variance ANOVA) for determining the significant factors at 90% confidence level and ANOVA result for the response parameters are mentioned in the Table 6 and 7. The response table of S/N ratio for surface roughness is shown in table 4.The feed rate and depth of cut are two factors ,have maximum different values as 14.062 and 3.652, according to Taguchi prediction that the biggest different value of S/N ratio will have greater effect or more significant value.

In the turning of 0, 4, 8 and 12 wt% $TiB_2$ and graphite with 1% magnesium reinforced Al-7075 composite material, the most significant factor is the feed rate with the tool insert CCGT120408-FN-27 in dry condition for the surface roughness. With suitable feed rate surface roughness can be controlled. Previous investigators suggested the same results. They concluded that surface roughness depends on the feed rate strongly [18] [21] [22].

Table 4 Response Table for S/N Ratio of Surface Roughness

| Level | Composition | Spindle Speed | Feed | Depth of Cut |
|---|---|---|---|---|
| 1 | 4.645 | 4.424 | 11.515 | 6.430 |
| 2 | 3.672 | 5.944 | 8.055 | 5.210 |
| 3 | 7.019 | 4.421 | 2.984 | 2.777 |
| 4 | 4.671 | 5.219 | -2.547 | 5.590 |
| Delta | 3.347 | 1.524 | 14.062 | 3.652 |
| Rank | 3 | 4 | 1 | 2 |

Table 5 ANOVA Table for S/N Ratio for Surface Roughness

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| composition | 3 | 24.295 | 24.295 | 8.098 | 0.40 | 0.762 |
| Spindle Speed | 3 | 6.430 | 6.430 | 2.143 | 0.11 | 0.951 |
| Feed | 3 | 451.198 | 451.198 | 150.399 | 7.49 | 0.066 |
| Doc | 3 | 29.508 | 29.508 | 9.836 | 0.49 | 0.714 |
| Residual Error | 3 | 60.237 | 60.237 | 20.079 | | |
| Total | 15 | 571.667 | | | | |

Table 5 shows that the feed rate and depth of cut have larger influence on the surface roughness value. The significant factor (P) value for both is 0.066 and 0.714 as well as F value for both are 7.49 and 0.49. In the Taguchi statistics analysis the smallest P value or the biggest F value will give larger significant effect on the responded parameter surface roughness.

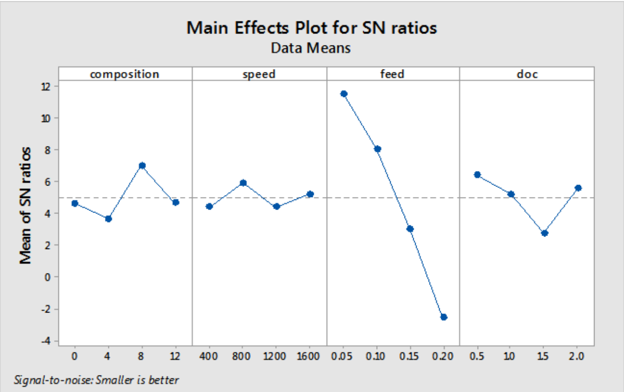
Figure 8 (a) shows that the S/N ratio of surface roughness is minimum for 4% reinforcement (second level of reinforcement) and then increased continuously up to 8% of reinforcement(third level of reinforcement) , then dramatically surface roughness decresed from 8% to 12% 0f reinforcement( third to fourth level of reinforcement).

Figure 8 (b) shows that the S/N ratio of surface roughness is minimum for minimum spindle speed at 400 RPM (first level of spindle speed) and then it is incresed and maximum at the second level of spindle speed at 800 RPM , suddenly surface roughness decreasing up to spindle speed at 1200 RPM (third level of spindle speed) and then it is dramatically increased up to 1600 RPM spindle speed (fourth level of spindle speed).

Figure 8(c) shows that the S/N ratio of surface roughness is maximum at the feed rate 0.05 mm/rev (first level of feed rate) and then decreased continuously and minimum at 0.20 mm/rev feed rate (fourth level of feed rate).

Figure 8(d) shows that the S/N ratio of surface roughness is maximum at the 0.5 mm minimum depth of cut (first level of depth of cut) but then it is decreased continousely and minimum at the 1.5mm depth of cut (third level of depth of cut) ,suddenly it is increased steeply up to 2.0mm depth of cut.

From the results of S/N ratio for surface roughness variation values and analysis, the optimal turning parameters for $TiB_2$/graphite/magnesium/Al-7075 metal matrix composite are achived for minimum surface roughness. The optimal conditions for turning are arrived as: (i) % wt of reinforcement (4%) (ii) Spindle speed (400 RPM ) (iii) Feed rate (0.20mm/rev ) (iv) Depth of cut (1.5mm ) shown in Table 8.




(a) ( b) (c) (d)

Figure 8. Main effect plots for S/N Ratio for Surface Roughness

### *D. Cutting Force ($F_Z$)*

During the machining operation, minimizing the cutting forces is a very important criterion. The results of experiments for turning the 0, 4, 8, and 12 wt% of $TiB_2$ and graphite as well as with 1wt% of magnesium reinforced Al-7075 composite with different machining parameters are shown in Table 6. The spindle speed and the depth of cut are the most significant factors that affect the cutting force with the value of 14.46 and 12.31.

Table 6 Response Table for S/N Ratio of Cutting Force

| Level | Composition | Spindle Speed | Feed Rate | Doc |
|---|---|---|---|---|
| 1 | -32.39 | -32.95 | -23.42 | -19.69 |
| 2 | -24.86 | -28.87 | -25.68 | -26.09 |
| 3 | -27.34 | -27.77 | -27.79 | -30.30 |
| 4 | -23.49 | -18.49 | -31.18 | -32.00 |
| Delta | 8.91 | 14.46 | 7.76 | 12.31 |
| Rank | 3 | 1 | 4 | 2 |

Table7. Shows that the spindle speed and the depth of cut values are more significant with P value for both are 0.038 and 0.051 as well as F values for both are 11.32 and 9.12.

Table 7. ANOVA Table for S/N Ratio for Cutting Force

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| composition | 3 | 184.50 | 184.50 | 61.50 | 4.66 | 0.119 |
| Speed | 3 | 447.82 | 447.82 | 149.27 | 11.32 | 0.038 |
| Feed | 3 | 130.67 | 130.67 | 43.56 | 3.30 | 0.176 |
| Doc | 3 | 360.78 | 360.78 | 120.26 | 9.12 | 0.051 |
| Residual Error | 3 | 39.55 | 39.55 | 13.18 | | |
| Total | 15 | 1163.31 | | | | |

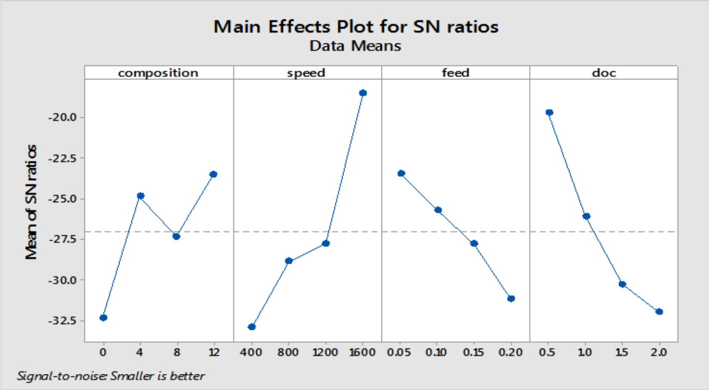
Figure 9(a) shows that the S/N ratio of cutting force is minimum at the 0% reinforcement (first level of reinforcement percentage) , then it is steeply increased up to 4% of reinforcement percentage(second level of reinforcement percentage) , dramatically it is decreased continuously up to 8% of reinforcement percentage and again suddenly cutting force increased and reached at the maximum value at 12% of reinforcement (fourth level of reinforcement percentage).

Figure 9(b) shows that the S/N ratio of cutting force is minimum at the minimum spindle speed 400 RPM (first level of spindle speed) and then it is continuously increased up to 1600 RPM (fourth level of spindle speed) reached at maximum value of cutting force.

Figure 9(c) shows that the S/N ratio of cutting force is maximum at the 0.05mm/rev feed rate(first level of feed rate) and then steeply reduced 0.20 mm/rev (fourth level of feed rate) feed rate and reached at the minimum value of cutting force.

Figure 9(d) shows that the S/N ratio of cutting force is maximum at the 0.5mm depth of cue (first level of depth of cut) and then continuously decreased the cutting force value and rached at the minimum value at the 2.0mm depth of cut(fourth level of depth of cut).

From the results of above S/N ratio for cutting force variations values and analysis, the optimal turning parameters for $TiB_2$ /Graphit /Magnesium /Al-7075 metal matrix composite are achieved for minimum cutting force. The optimal conditions are arrived as: (i) % wt of reinforcement of $TiB_2$ and graphite (0% ) (ii) Spindle speed (400RPM ) (iii) Feed rate (0.20mm/rev.) (iv) Depth of cut(2.0mm) shown inTable8.




(a) (b) (c) (d)

Figure 9 Main effects plots for S/N Ratio of cutting force

## IV. CONCLUSIONS

1. By using experimental design of Taguchi , the parameters which affect the surface roughness and cutting force on the turning of $TiB_2$/Graphit/Magnesium/Al-7075 metal matrix composite have been evaluated.
2. The Micro structural tests showed that reinforcement particles are distributed homogeneously and a little porosity could be seen when observed.
3. The significant factors for surface roughness are feed rate and followed by depth of cut, % reinforcement and spindle speed is the least significant factor.
4. The significant factors for cutting force are spindle speed and followed by depth of cut, % reinforcement and feed rate is the least significant factor.
5. The optimal conditions for surface roughness are 4% reinforcement, spindle speed 400 RPM, feed rate 0.20 mm/rev. and 1.5 mm depth of cut.
6. The optimal conditions for cutting force are 0% reinforcement, spindle speed 400 RPM, feed rate 0.20mm/rev. and 2.0 mm depth of cut.

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