Machinability Investigations on Al6063+TiO_2 Metal Matrix Material

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Abstract— *Investigations into the machinability of Al6063 alloy reinforced with TiO_2 particles typically focus on understanding how the addition of TiO_2 affects the machining characteristics of the metal matrix material compared to the base Al6063 alloy. Here are some aspects that such studies would typically explore: Tool Wear, cutting forces, Material removal rate, surface roughness. These investigations are crucial for understanding how the addition of TiO_2 particles modifies the machinability of Al6063 alloy and for optimizing machining processes to ensure efficient production of components with desirable mechanical and surface properties.*

Keywords— DoE, MRR, Process parameters, Resultant Force.

I. INTRODUCTION

Aluminium alloy 6063, often referred to simply as Al6063, is a popular metal matrix alloy known for its excellent combination of mechanical properties and workability. Al6063 primarily consists of aluminium (Al) as the base metal, with significant additions of magnesium (Mg) and silicon (Si). Typical composition ranges are approximately: Al: 97.0 - 98.5%, Mg: 0.45 - 0.9%, Si: 0.2 - 0.6%

Other trace elements like iron (Fe), titanium (Ti), Zinc (Zn) and chromium (Cr) in small amounts.

II. LITERATURE

Abdul Nazeer et al.'s study [1] attempted to examine the impact of alumina Al_2O_3 when reinforced with aluminium 6063 matrix. The composite was prepared using the liquid metallurgical approach (Stir Casting Technique), with the reinforcement varying from 0 to 8wt% in increments of 2wt%. Research on prepared composite systems includes mechanical, wear, fractography, and X-ray diffraction, as well as testing carried out in accordance with ASTM and ISO standards. Following the discovery that the reinforcement was distributed uniformly throughout the matrix alloy, the mechanical test revealed that the mechanical properties, such as hardness, toughness, and tensile strength, improved with an increase in contain reinforcement. A similar finding was made in the wear test, where an increase in contain reinforcement led to improved wear resistance. A fractured tensile specimen was examined under a scanning electron microscope. Reactions in Al–10 weight percent TiC metal matrix composites have been studied by A.R. Kennedy et al. [2]. Samples were heated between 600 and 900°C for 48 hours and then held at 700°C for up to 240 hours. The composition, shape, and amounts of the reaction phases present have been determined using X-ray diffraction, scanning electron microscopy, and image analysis. By varying the percentage of the reinforced element alumina in the base matrix alloy Al 6063, Bhavana Mathur et al. [3] focused on the mechanical properties of the metal matrix composite, such as tensile behavior, hardness, and surface characteristics of Al 6063/Al2O3 Alumina reinforced metal matrix composites. The samples prepared by stir casting process by varying the percentage of alumina in the base matrix alloy Al 6063 were tested for finding the ultimate tensile strength, followed by hardness and surface characteristics.

Ersan Aslan, et al., [4] conducted an experimental study to achieve this by employing Taguchi techniques. Combined effects of three cutting parameters, namely cutting speed, feed rate and depth of cut on two performance measures, flank wear (VB) and surface roughness (Ra), were investigated employing an orthogonal array and the analysis of variance (ANOVA). Optimal cutting parameters for each performance measure were obtained; also the relationship between the parameters and the performance measures were determined using multiple linear regression. To reduce surface roughness (Ra and Rz), İlhan Asiltürk, et al. [5] concentrated on optimizing turning parameters based on the Taguchi method. A CNC turning machine's L9 orthogonal array has been used in experiments. Tests for dry turning are performed using coated carbide cutting tools on hardened AISI 4140 (51 HRC). K. Hemalatha et al. [6] studied the stir casting technique, which is used to cast Al 6063 plates with different masses of Al_2O_3 (3%, 6%, and 9%). In addition, the material's mechanical properties, such as tensile strength and hardness, are tested, and the distribution of aluminium and alumina is investigated through microstructure analysis and hardness distribution. The impact of alumina volume percentage and solution heat-treatment on the corrosion behavior of Al (6063) composites and its monolithic alloy in basic and acidic environments was examined by K. K. Alaneme et al. [7]. Using two-step stir casting, Al (6063) - Al_2O_3 particulate composites with volumes of 6, 9, 15, and 18 percent alumina were created. Mass loss and corrosion rate measurements were utilized as criteria for evaluating the corrosion behavior of the composites. According to M. Amrutha Pavani et al. [8], a meager effort would be made to create silicon carbide particulate MMCs based on aluminium with the goal of creating a traditional, low-cost technique of generating MMCs and achieving uniform dispersion of ceramic material. In order to accomplish these goals, a two-step stir casting procedure has been suggested, and a property study has since been conducted. SiC particles and aluminium 6063 T6 have been selected as the matrix and reinforcing materials, respectively. The weight fraction of SiC will be varied in experiments (in 5% steps) while all other parameters will remain constant. Tests for Hardness and Impact (including microstructure) would be used to evaluate the outcomes for this "development method." Al-MMC has been created by combining 5wt% ZrO2 and Al2O3 reinforcement into the Al6063 aluminium alloy matrix, according to Munmun Bhaumik et al.'s [9] research. The process of stir casting has been used to create MMC. X-ray diffraction analysis and scanning electron microscopy (SEM) have been used to characterize the prepared casted MMC. For the manufactured MMC, measurements have been made of its mechanical (hardness, tensile test, bend test, and compression test) and physical (density) characteristics. Analysis of the fracture surface has been done. Al-MMC fractures are found to be brittle in nature. Tests for Hardness and Impact (including microstructure) would be used to evaluate the outcomes for this "development method." The creation of multi-phase hybrid composites made of polyester reinforced with E-glass fiber and ceramic particles was reported by S.S. Mahapatra et al. [10]. It also looks at how these composites respond to erosion and wear. Finally, it compares the effects of three distinct particle fillers—silicon carbide (SiC), alumina (Al_2O_3), and cement by-pass dust (CBPD)—on the wear properties of glass-polyester composites. To do this, Taguchi's orthogonal arrays are used in the design of experiments approach to create the erosion test schedule for an air jet type test rig. The Taguchi technique makes it possible to identify the ideal parameter combinations that minimize the rate of erosion. W.H. Yang, et al., [11] employed the Taguchi approach, a strong tool to design optimization for quality, is used to identify the ideal cutting parameters for turning operations. An orthogonal array, the signal-to-noise (S/N) ratio, and the analysis of variance (ANOVA) are applied to evaluate the cutting properties of S45C steel bars employing tungsten carbide cutting tools.

III. EXPERIMENTATION

3.1 Introduction:

The following composition of Al6063 was used based on strength criteria, and the same material is used for this experimentation by reinforcing TiO_2 in varying percentages 2% and 6% prepared by using stir casting method. The dimensions of the work piece after machining are, length is 180mm and diameter is 22mm. Conducted trials on a lathe with a casted workpiece and HSS single point cutting tool. Optimum composition of Al 6063 alloy having highest tensile strength is shown in tables 1 below:

TABLE 1
Weight Percentage of metals in Al6063

Metal	Al	Mg	Si	Fe	Cu	Zn	Ti	Mn	Cr
Weight %	98.65	0.45	0.2	0.3	0.1	0.1	0.05	0.05	0.1

FIGURE 1: Work piece and experimental setup

Taguchi L8 Orthogonal Array is used for conduct of machining trails. Table 2 represents the number of trials considering two levels for each factor.

TABLE 2
Taguchi Design Matrix

Trail No	s (rpm)	f (mm/rev)	d (mm)	r (^{0})
1	150	0.21	0.2	15
2	150	0.21	0.5	20
3	150	0.421	0.2	20
4	150	0.421	0.5	15
5	445	0.21	0.2	20
6	445	0.21	0.5	15
7	445	0.421	0.2	15
8	445	0.421	0.5	20

Where **s** is cutting speed(rpm), **f** is feed(mm), **d** is depth of cut(mm) and **r** is rake angle of tool (in degrees)

3.2 Material Removal Rate (MRR):

It is a key metric in manufacturing and machining processes that indicates the volume of material removed from a workpiece over a given period.

The formula to calculate Material Removal Rate is:

$$\mathrm{MRR} = \frac{\mathrm{w}_1 - w_2}{\mathrm{t}}$$

Where, w_1 is the weight of the workpiece before machining (gm) w_2 is the weight of the workpiece after machining (gm) tm is the machining time (min).

From the experimental investigation, the following tabular calculation for MRR has been developed.

TABLE 3
MRR respected to Al6063+TiO_2 (2%)

Trail No.	s (rpm)	f (mm/rev)	d (mm)	r (^{0})	w1	w2	t (min)	MRR (gm/min) $\frac{w_1 - w_2}{t}$
1	150	0.21	0.2	15	135	134.142	0.54	1.588
2	150	0.21	0.5	20	134.142	131.788	0.511	4.606
3	150	0.421	0.2	20	131.788	130.977	0.233	3.48
4	150	0.421	0.5	15	130.977	130.069	0.233	3.896
5	445	0.21	0.2	20	130.069	127.799	0.171	13.27
6	445	0.21	0.5	15	127.799	126.736	0.167	6.365
7	445	0.421	0.2	15	126.736	126.222	0.076	6.763
8	445	0.421	0.5	20	126.222	125.628	0.103	5.766

TABLE 4
MRR respected to Al6063+TiO_2 (6%)

Trail No.	s (rpm)	f (mm/rev)	d (mm)	r (^{0})	w1	w2	t (min)	MRR (gm/min) $\frac{w_1 - w_2}{t}$
1	150	0.21	0.2	15	136	134.402	0.467	3.421
2	150	0.21	0.5	20	134.402	133.377	0.495	2.07
3	150	0.421	0.2	20	133.377	132.792	0.231	2.532
4	150	0.421	0.5	15	132.792	131.522	0.246	5.162
5	445	0.21	0.2	20	131.522	130.587	0.15	6.233
6	445	0.21	0.5	15	130.587	129.538	0.152	6.901
7	445	0.421	0.2	15	129.538	128.89	0.072	9
8	445	0.421	0.5	20	128.89	127.662	0.082	14.975

Dynamometer is used in to measure machining forces. Based on the recorded values, the resulting forces are computed and are listed in tables 5 and 6 for each case, respectively.

TABLE 5
Force response of Al6063+TiO_2(2%)

Trail No.	t (min)	F_x (Kgf)	F_y (Kgf)	Resultant Force RF (kgf)
1	0.54	0	5	5
2	0.511	13	30	32.695
3	0.233	0	7	7
4	0.233	3	11	11.401
5	0.171	10	23	25.079
6	0.167	3	9	9.486
7	0.076	1	2	2.224
8	0.103	0	3	3

TABLE 6
Force response of Al6063+TiO_2(6%)

Trail No.	t (min)	F_x (Kgf)	F_y (Kgf)	Resultant Force RF (kgf)
1	0.467	7	18	19.313
2	0.495	0	6	6
3	0.231	0	4	4
4	0.246	5	20	20.61
5	0.15	0	7	7
6	0.152	3	8	8.544
7	0.072	0	6	6
8	0.082	4	4	14.566

IV. DEVELOPMENT OF A MATHEMATICAL MODEL

A statistical technique called Taguchi design of experiments is used to create effective trials that optimize procedures and end products with the least amount of experimentation possible.

4.1 Taguchi Design for Al6063+TiO_2(2%):

Taguchi Orthogonal Array Design

L8(2^4), Factors: 4, Runs: 8

Regression Equation for MRR:

MRR = -2.90 + 0.01576 s - 7.02 f - 3.72 d + 0.425 r

Regression Equation for RF:

RF = -5.5 - 0.0138 s - 57.6 f + 14.4 d + 1.98 r

4.2 Taguchi Design for Al6063+TiO_2(6%):

Taguchi Orthogonal Array Design

L8(2^4), Factors: 4, Runs: 8

Regression Equation for MRR:

MRR = -8.09 + 0.02027 s + 15.45 f + 6.60 d + 0.066 r

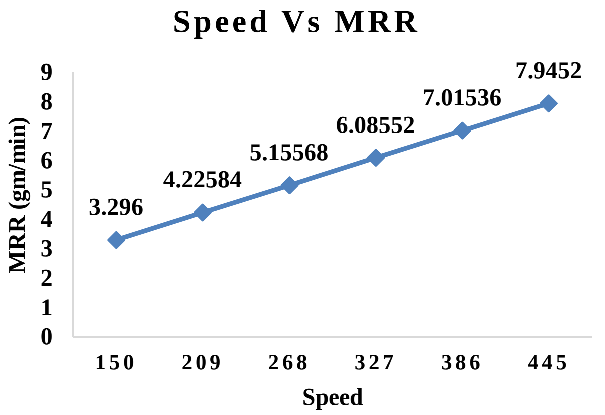
Regression Equation for RF:

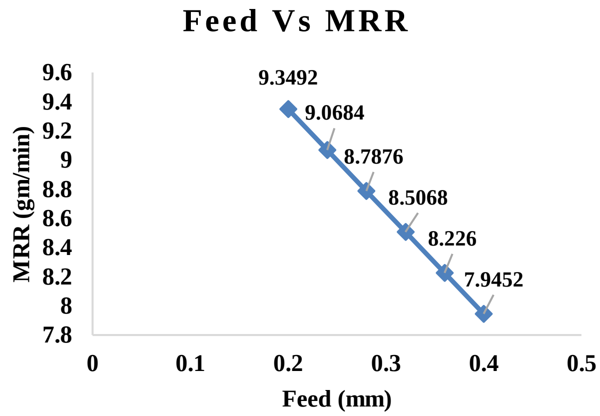
RF = 28.8 - 0.0117 s + 5.1 f + 11.2 d - 1.15 r

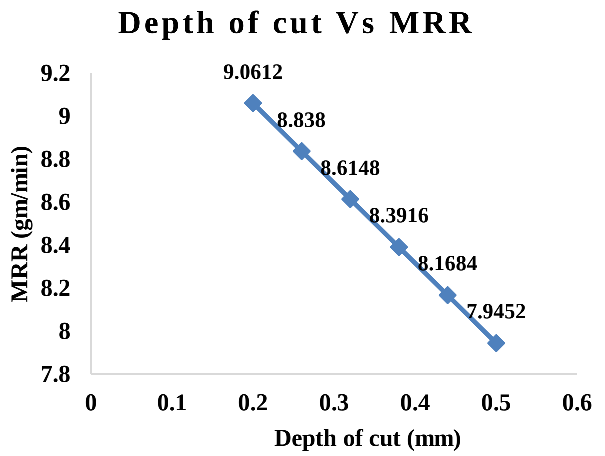
V. GRAPHICAL ANALYSIS

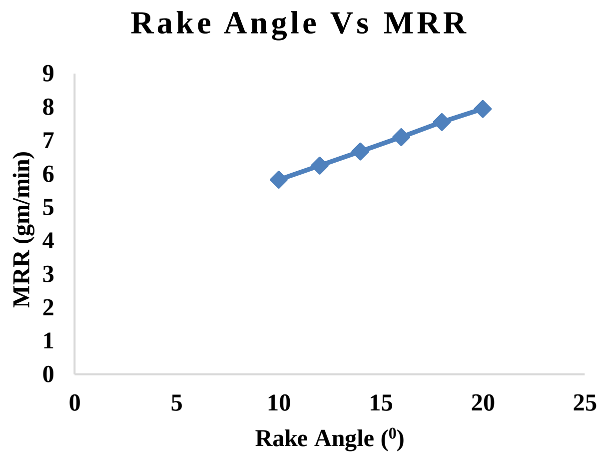
Following graphs shows the relationship between each parameter, the material removal rate, and the resultant force for Al6063+ TiO_2 (2%) and Al6063+ TiO_2 (6%).

5.1 Graphs Obtained for Al6063+TiO_2(2%):

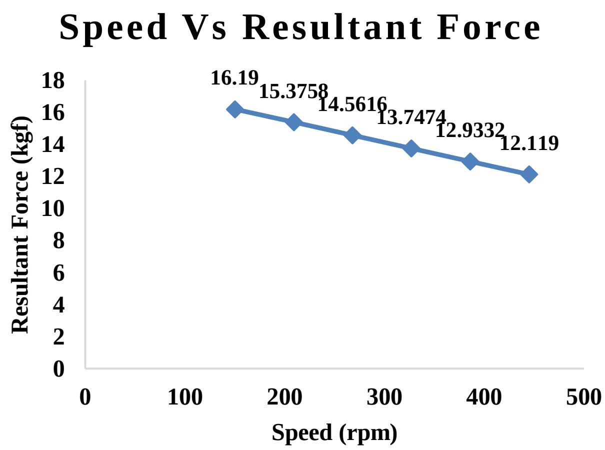


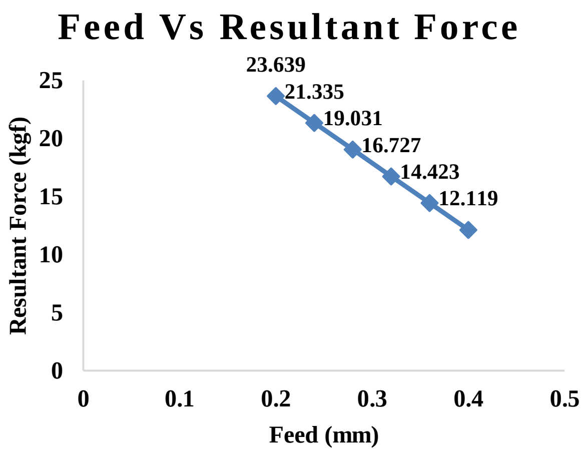


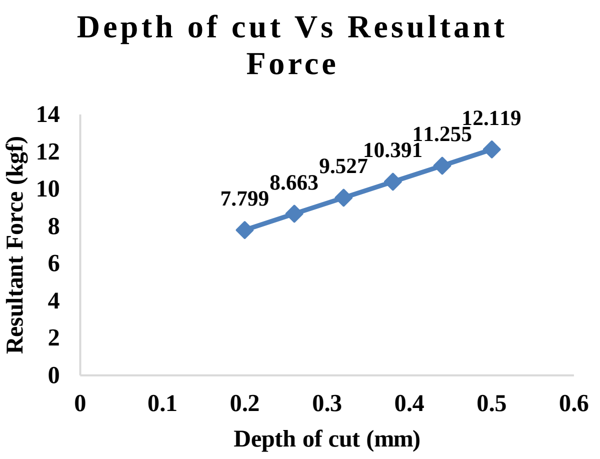


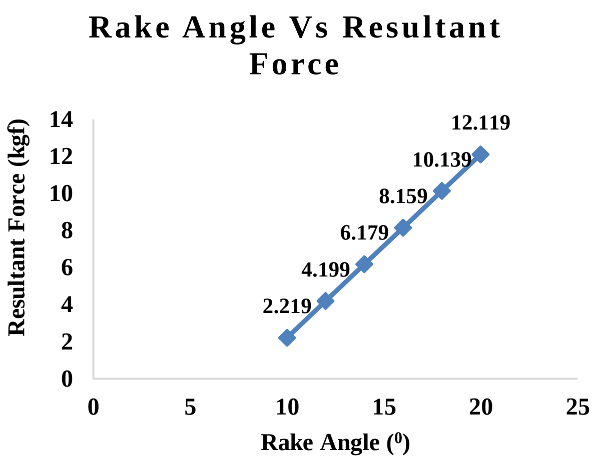


5.2 Graphs Obtained for Al6063+TiO_2(2%) for RF:

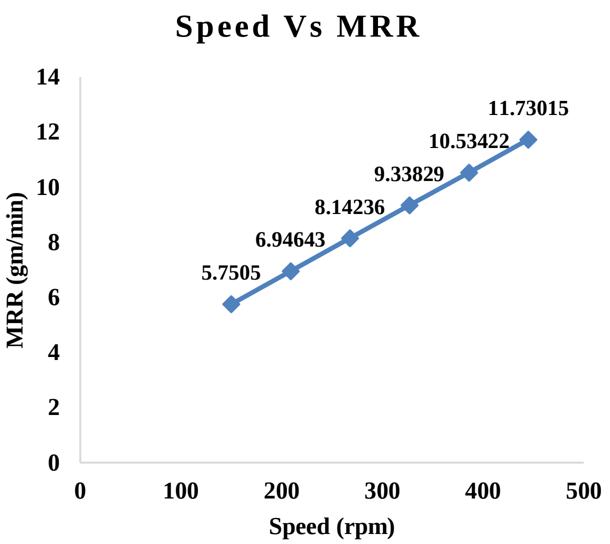


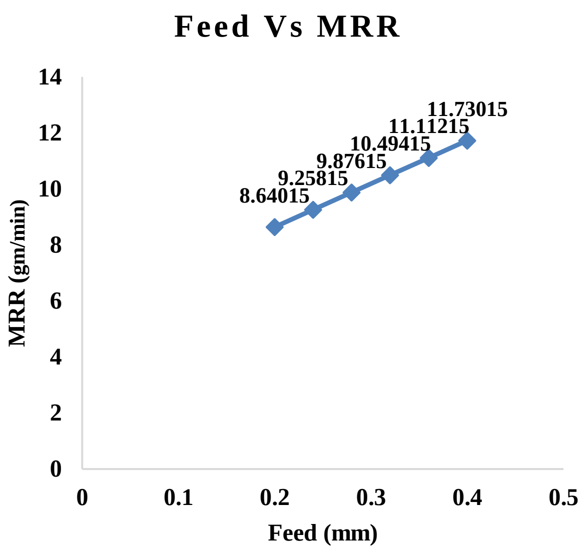


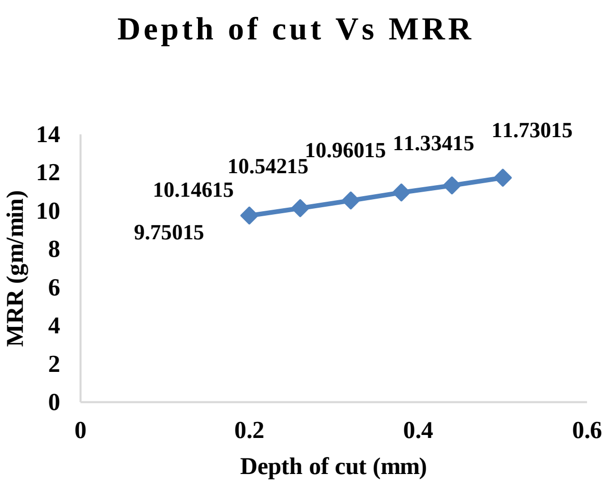


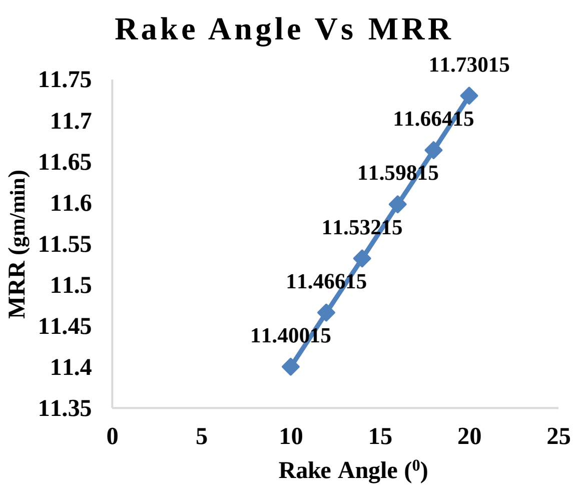


5.3 Graphs Obtained for Al6063+TiO_2(6%) for MRR:

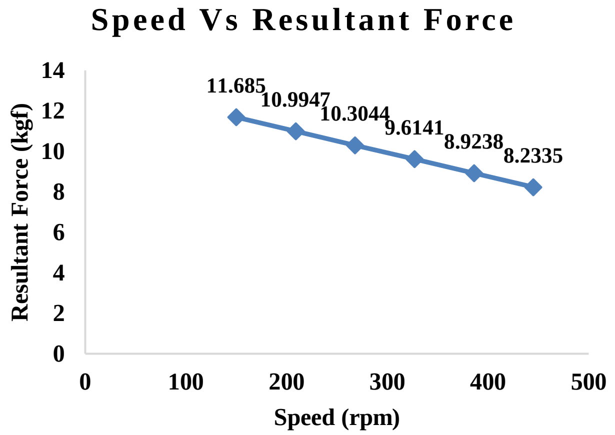


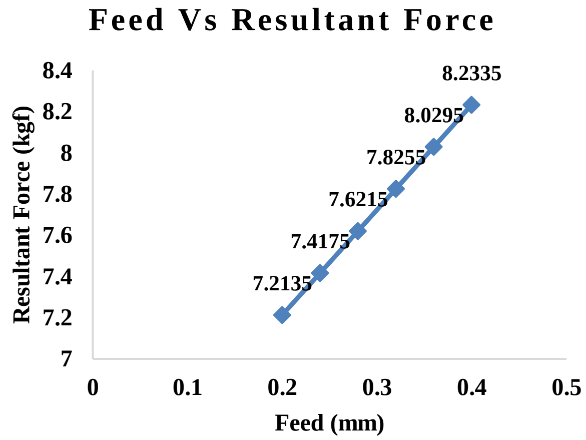


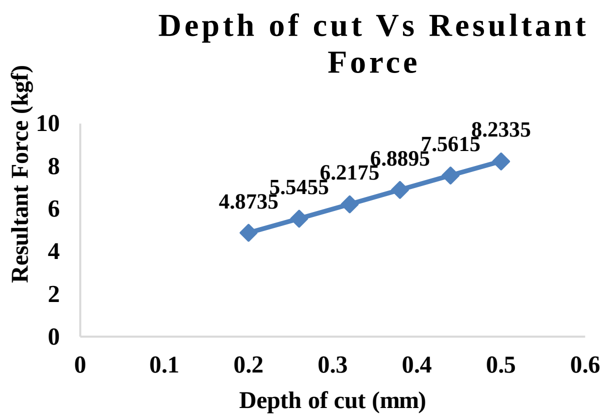


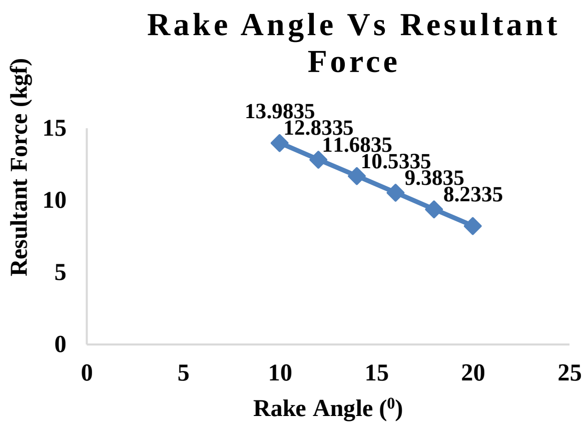


5.4 Graphs Obtained for Al6063+TiO_2(6%) for RF:









VI. CONCLUSIONS

The following conclusions are drawn from the work carried out

- The maximum material removal rate observed is 13.27 gm/min for trail-5 in case of TiO_2(2%), for the machining parameters s = 445 rpm, f = 0.21 mm, d =0.2mm, at r= 200 and corresponding cutting force is 25.079 kgf.
- The maximum material removal rate observed is 14.975 gm/min for trial-8 in case of TiO_2(6%), where the machining parameters are s = 445 rpm, f = 0.421 mm, mm, d =0.5mm, at r= 20° and corresponding cutting force is 14.566 kgf.
- From the graphs it is evident that in case of machining Al6063 with TiO_2 (2%) increase in speed and rake leads to higher MRR whereas for depth of cut and feed shows decline trend.
- Resultant in case of machining Al6063 with TiO_2 (2%) is increasing for increase in depth of cut and rake angle, however it has down trend in case of increase in speed and feed.
- Al6063 with TiO_2 (6%) machining has uptrend behaviour of MRR with all input parameters
- While machining Al6063 with TiO_2 (6%) resultant for has uptrend with depth of cut and feed but has downtrend with speed and rake angle.

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