Synthesis and Comparative Machining Characterization of A356 - Graphite, A356 – SiC and A356 – $CaSiO_3$ Composites

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Abstract - *Metal matrix composites play an important role in automotive engineering, railway or subway cars, aerospace industry and military. At present investigation, the specimens of aluminum [A356] reinforced separately with 5% graphite powder,5% SiC powder and 5% calcium silicate powder were prepared using stir casting machine. These three different types of specimens were tested in on lathe for machinability studies in which cutting forces and machining capabilities like metal removal rate, surface roughness and also power consumption were studied at various cutting speeds and depth of cuts.*

The cutting forces have shown increasing trend up to a speed of 50 m/min due to work hardening of composite and then decreased at high speeds due to softening of material. Metal removal rate and power consumption has shown increasing trend with respect to cutting speed as well as depth of cut. Machining times were calculated using CATIA V5R20 software and they were compared with practical values. A356- Graphite composite have shown better machining characteristics compared to other two composites

Key Words: (Size 10 & Bold) Key word1, Key word2, Key word3, etc (Minimum 5 to 8 key words)…

1. INTRODUCTION

1.1 Metal Matrix Composites

Now a days metal matrix composites (MMCs) are replacing conventional materials in many applications because of their superior properties such as high strength to weight ratio, hardness, stiffness and wear and corrosion resistances over conventional materials. Silicon carbide particle (SiC) reinforced aluminium-based MMCs are among the most common MMC and commercially available ones due to their economical production. In addition, the development of stir casting route for synthesis has brought down their cost to an acceptable level compared to those processed by powder metallurgy and spray casting process Particulate metal matrix composites have produced economically by conventional casting techniques. However, the stiffness, hardness and strength to weight ratio of cast MMCs are increased, but a substantial decrease in ductility has obtained.

Composites are material consisting two or more natural or artificial materials to maximize their useful properties and minimize their weaknesses. Composites are typically used in place of metals because they are equally strong but much lighter. It consists of two or more distinct phases (matrix phase and reinforcing phase/phases) where individual phase retains its properties (physical, mechanical and chemical).Properties such as high stiffness, high strength to weight ratio, low density, high temperature stability, high electrical and thermal conductivity, adjustable coefficient of thermal expansion, corrosion resistance, improved wear resistance etc. make composites attractive materials.

The composite materials are classified into three categories. They are Polymer Matrix Composites (PMC), Metal Matrix Composites (MMC) and Ceramic Matrix Composites (CMC) based on matrix phase .At present work our experimental specimens are MMC's and here matrix material is A356 and graphite, SiC, CaSiO3 are the reinforcement powders.

1.2 Machinability

Machinability is a consideration in the materials selection process for different machine parts. The ease with which a metal can be machined is one of the principle factors affecting a product's utility, quality and cost. The usefulness of a means to predict machinability is obvious. Unfortunately, machinability is so complex a subject that it cannot be unambiguously defined. Depending on the application, machinability may be seen in terms of tool wear rate, total power consumption, attainable surface finish or several other benchmarks. Machinability - therefore depends a great deal on the viewpoint of the observer; in fact, the criteria for one application frequently conflict with those for another.

At our present experiment the machining capabilities of three different metal matrix composites were tested at various cutting speeds and depth of cuts.

2. MATERIAL AND EXPERIMENTAL METHOD

The specimens used in these experiments are metal matrix composites which are fabricated by reinforcing 5% of graphite or SiC or CaSiO3 powder of 40-50µ size into aluminum [A356] using stir casting technique.

2.1 Matrix Material

Aluminiun[A356] is used as matrix material in this experiment in which reinforcing powder is to be added during its molten state. A356 is a grade of aluninium and this alloy consists 92.05% of Al, 7% of Cu , 0.35% of Mg ,0.1% of Zn and 0.1% of Mn. The following factors should be considered while choosing a matrix material.

- Formability
- Weldability
- Machinability
- Corrosion resistance
- Heat treating

The reasons for choosing A356 as matrix material are; alloys have very good casting and machining characteristics. Typically they are used in the heat-treated conditions. Corrosion resistance is excellent and it has very good weldability characteristics. Mechanical properties are rated excellent particularly if given a solution and aging treatment. The anodized appearance is gray in color. Typically this alloy is used in castings for aircraft parts, pump housings, impellers, high velocity blowers and structural castings where high strength is required. It can also be used as a substitute for aluminum alloy 6061.The fact that 356 and A356 have good castability makes it a logical choice for intricate and complex castings where lightweight, pressure tightness and excellent mechanical properties are needed.

2.2 Reinforcement Material

At this present work three different types of reinforcement powders were used which were discussed below

2.2.1 Graphite powder

The first type of specimen is fabricated by reinforcing5% of graphite powder of particle size 40-50µ. The key property of commercial graphite is given below.

Table – 1: Properties of graphite

Bulk density	1.3-1.95 [g/cm^3]
Porosity	0.7-5.3 %
Young's modules	8-15 [GPa]
Compressive strength	20-200[MPa]
Flexural strength	6.9-100 [MPa]
Coefficient of thermal expansion	1.2-8.2 [X10^{-6} ^{0}c]
Thermal conductivity	25-470 [W/m K]
Specific heat capacity	710-830 /Kg K]

2.2.2 Silicon Carbide [Sic] Powder

5% of silicon carbide particles of size 40-50µ were added into matrix material in second type of specimens. The characteristics of silicon carbide were given below.

- Low density
- High strength
- Good high temperature strength (Reaction bonded)
- Oxidation resistance (Reaction bonded Excellent thermal shock resistance
- High hardness and wear resistance
- Excellent chemical resistance
- Low thermal expansion and high thermal conductivity

2.23Calcium Silicate[CaSiO3] Powder

In third type of specimen reinforcement material is 5% of calcium silicate powder of particle size 40-50µ. It can exhibit high condutvity, high stability, high purity, good wear resistance, low coefficient of thermal expansion and resistant to oxidation at high temperature.

2.3 Stir Casting Method

The required three types of specimens were synthesized using a bottom pouring type stir casting furnace which contains the following components.

A graphite stirrer is used to mix the matrix phase in molten state and preheated reinforcement powders homogenously by mechanical stirring. It will have both rotary and reciprocating motions at a time. There is a separate unit called stirrer height controller by means of which motion of stirrer can be controlled. Melting furnace will heat the crucible in which solid matrix material is converted into molten metal. The reinforcement powder will be placed in another preheated furnace from which powder is released gradually into molten metal during the process of stirring. There a measuring and control unit which displays the temperature of furnace, melt, mould and reinforcement powder and also stirring speed. By using this unit the above parameters can be varied. The following procedure should be fallowed to synthesize the required specimens using stir casting machine.

Set the temperature of furnace, melt, die and reinforcement powder according to the experimental conditions given below. Cut the aluminium ingots of 356 grade small pieces enough to place into the crucible. Heat the matrix material to attain molten state up to 790^{0}C. Place the reinforcement powder in the corresponding furnace and heat it up to 200^0C to 300^0C based on type of powder. Keep the stirrer in ON position after the temperature of melt reached to 790^0C which enables the stirrer to mix the molten metal with reinforcing powder homogeneously which is released gradually into the crucible. Stirrer can also be moved up and down by operating corresponding switches. After that switch on the pour button on control unit which enables the pouring of molten composite into the die or mould and then allow it to solidify after that remove the solid shaft [required specimen or work piece] from the die

Fig - 1: Stir casting machine

. **Table – 2:** Casting conditions

Furnace Temperature	850^0C
Melt Temperature	790^0C
Powder Temperature	200^0C for graphite 300^0C for SiC 400^0C for CaSiO3
Mould Temperature	250^0C
Pouring Temperature	790^0C
Stirring Speed	400 rpm
Stirring Time	5 min

Fig – 2: Experimental Specimens

- A356+ [5% wt] Graphite composite
- A356+[5% wt] SiC composite
- A356+[5% wt]CaSiO3 composite

2.4 Machinability Test

The turning experiments were carried out for the three by using HSS tool bits in a automatic lathe machine. The machining trials were performed with three cutting speeds (N) 202, 303, and 455 r.p.m with a constant feed (f) of 0.4 mm/rev and a depth of cut of 0.5 mm under dry environment. Cutting forces were measured on lathe tool dynamometer facility at NEC college. At the same time surface roughness values were also measured. The above machining trails were repeated with three depths of cut [Dc] 0.5, 0.75, 1 mm at a constant speed of 303 r.p.m and constant feed of 0.4 mm/min.

Fig - 4: Experimental set up

The above procedure is repeated for three different specimens

2.4.1 Input Parameters

We have given various cutting speeds, depth of cuts and feed as input parameters in order calculate various machining characteristics.

- Cutting speed [rpm]
- Depth of cut [mm]
- Feed [mm/rev]

2.4.2 Responses Measured

During the machining, the values of cutting forces developed are taken from lathe tool dynamometer and by using these values metal removal rate and power were calculated. Surface roughness was also checked.

- Axial force [F_x] in N
- Cutting force or Tangential force [F_y] in N
- Radial force [F_z] in N

- Power [P] in W
- Metal removal rate [MRR] in mm^3/min
- Surface roughness in µm

Fig – 3: lathe tool dynamometer

2.5 Determination of Machining Time Using CATIA

The following procedure should be followed this experiment was done using CATIA V5R20.Open two separate components one is for design part and other one is for stock element. Design the required shaft and stock part according to the dimensions of real specimens. Apply material tooth of them Unhide the sketch of the both parts which must visible during part selection. GO to machining and select lathe machining. Click on the part operation and select type of lathe machine and give maximum speed. The icons related to several lathe operations will be appeared on the screen and click on rough turning and give values of depth of cut, speed and feed as input. Select the tool geometry, axes. Give the path for both design part and stock and run the programme,we will get machining time as output at a given feed rate. Repeat the above procedure for various cutting speeds and depth of cuts according to the practical experiment

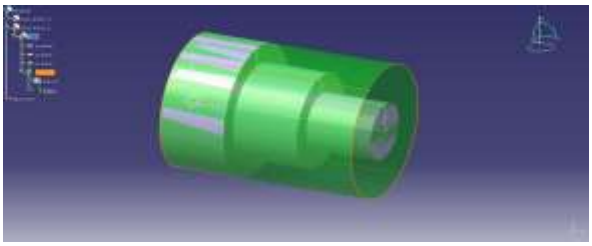


Fig -3: Design part with stock

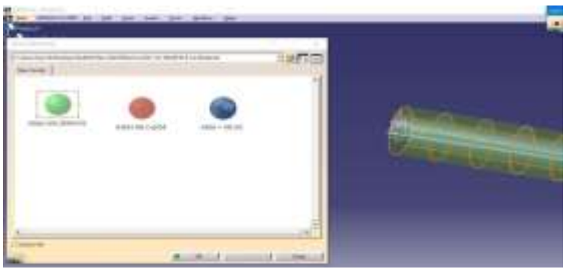


Fig – 4: applying material

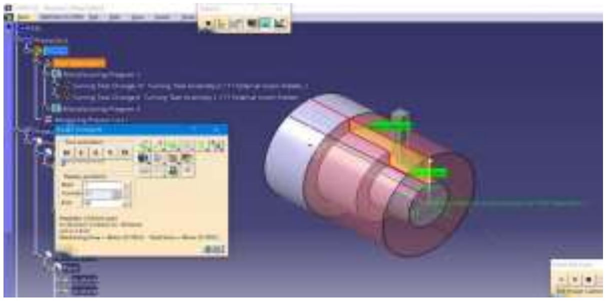


Fig – 6: output machining time

Table – 3: machining time in sec [practical vs. CATIA]

Speed [rpm]	A356+Graphite		A356+SiC		A356+CaSiO3	
	p	C	P	C	p	c
202	151.12	148.51	145	148.51	153	148.51
303	95.34	99.00	95	99.00	98	99.00
455	62.12	65.93	65	65.93	64	65.93

2.6 Results and Discussions

After loading the component on the lathe machine plane turning operation has performed and specimen is divided into six divisions to perform six operations by varying speed and depth of cut parameters. Feed is kept constant in every time.

2.6.1 Effect Of Speed On Cutting Forces

this situation turning operation is carried out at different cutting speeds like 202, 303 and 455 rpms at the same time feed and depth of cut are kept constant. Cutting forces values are taken from lathe tool dynamometer

Table – 3: Effect of Speed on Cutting Forces

Cutting speed (rpm)	**Fx (N)**	**Fy (N)**	**Fz (N)**
For A356+[5% wt] Graphite composite			
202	39.24	147.15	176.58
303	78.48	235.44	225.63
455	68.48	196.2	186.01
For A356+[5% wt] SiC composite			
202	117	304	255
303	137	343	294
455	78	215	186
For A356+[5% wt]CaSiO3 composite			

202	58.86	294.3	245.25
303	176.58	382.59	274
455	117.72	313.92	255

2.6.2 Effect of depth of cut on cutting forces:

Under this situation turning operation is carried out by giving different depth of cuts like 0.5, 0.75 and 1 mm. while cutting speed and feed are constant. Again cutting forces values are taken from lathe tool dynamometer

Table – 4: Effect of depth of cut on Cutting Forces

Depth of Cut (mm)	Fx (N)	Fy (N)	Fz (N)
For A356+ [5% wt] Graphite composite			
0.5	88.29	196.01	184
0.75	92	206.2	215.82
1.0	147.15	294.3	274.68
For A356+ [5% wt] SiC composite			
0.5	156	196.01	313
0.75	176	226.2	333
1.0	186	294.3	372
For A356+ [5% wt] CaSiO3 composite			
0.5	58.86	196.2	225.63
0.75	137.34	304.11	284.49
1.0	147.15	333.54	313.92

2.6.3 Machining Results

By using the values collected from lathe tool dynamometer we calculated power and material removal rate and by using surf test instrument we checked surface roughness of machining specimen.

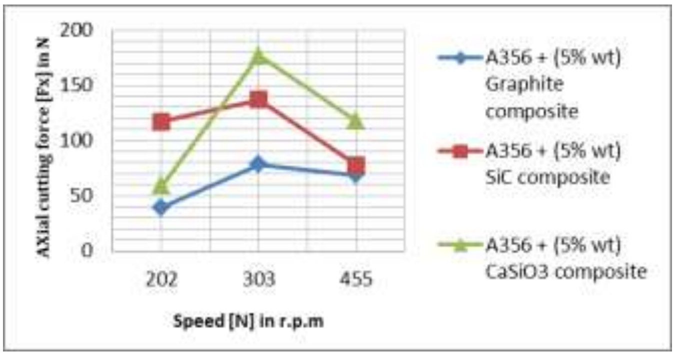
Table – 5: Effect of speed on machining capabilities

Cutting speed (rpm)	Power (W)	MRR (mm^3/min)	Surface roughness (µm)
For A356+[5% wt] Graphite composite			
202	71.5	8.42	25.5
303	171.6	14.52	18
455	215	20.5	14.55
For A356+ [5% wt] SiC composite			
202	174.33	8.75	29.09
303	223.83	13.92	19.01
455	246	18.19	17.02
For A356+ [5% wt]CaSiO3 composite			
202	147.83	9.138	28.16
303	288.16	13.70	25.54
455	354.6	20.08	15.27

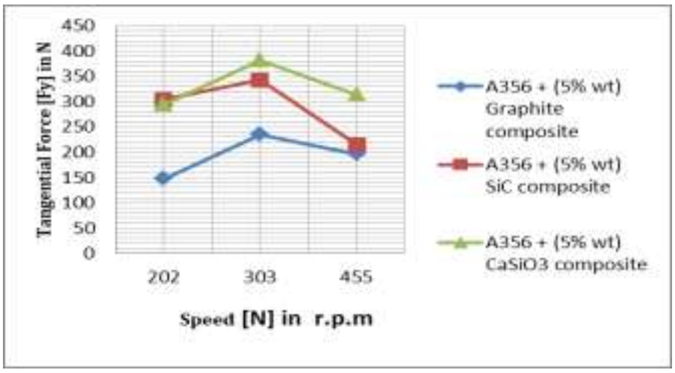
Table – 5: Effect of depth of cut on machining capabilities

Depth of cut (mm)	Power (W)	MRR (mm^3/min)	Surface roughness (µm)
For A356+[5% wt] Graphite composite			
0.5	101.16	8.42	11.22
0.75	143	14.52	13.16
1.0	322.5	18.276	18.06
For A356+[5% wt] SiC composite			
0.5	204.16	8.75	13.67
0.75	268.92	13.92	14.08
1.0	403.83	16.15	25.40
For A356+[5% wt] CaSiO3 composite			
0.5	54	6.092	10.17
0.75	229	13.707	14.77
1.0	377	16.09	21.16

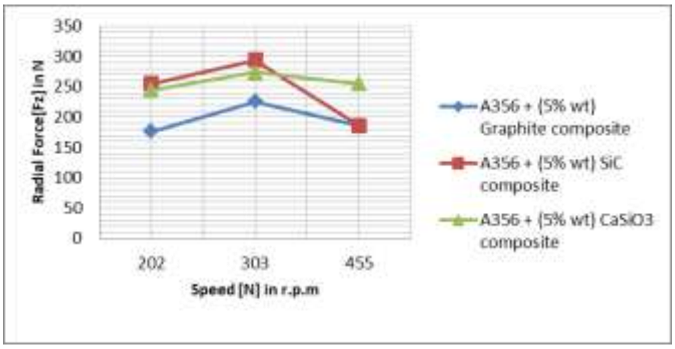
Graph – 1: Axial force Vs. Speed



Graph – 2: Tangential force Vs. Speed

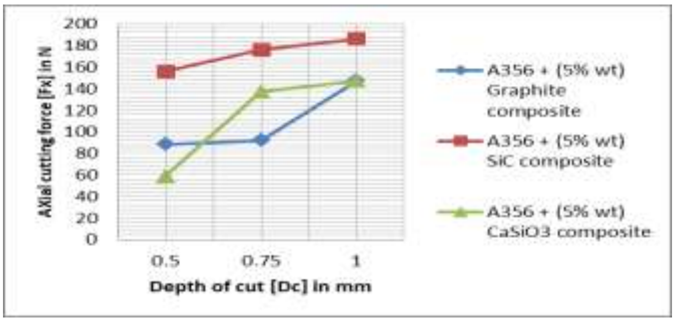


Graph – 3: Radial force Vs. Speed

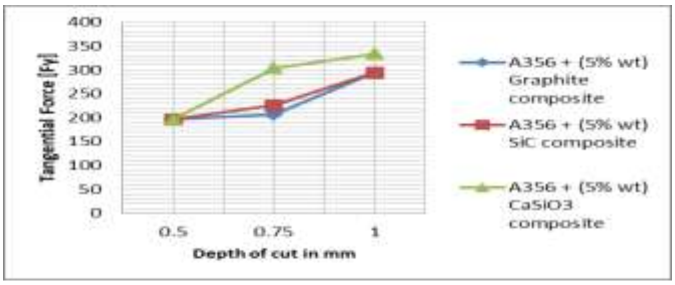


The above three graphs show the comparision of cutting forces at diferent cutting speeds in which all the cutting forces increases up to a speed of 303 rpm and then decreased at higher speeds.The cutting forces developed in graphite composite are less than that of other two composites

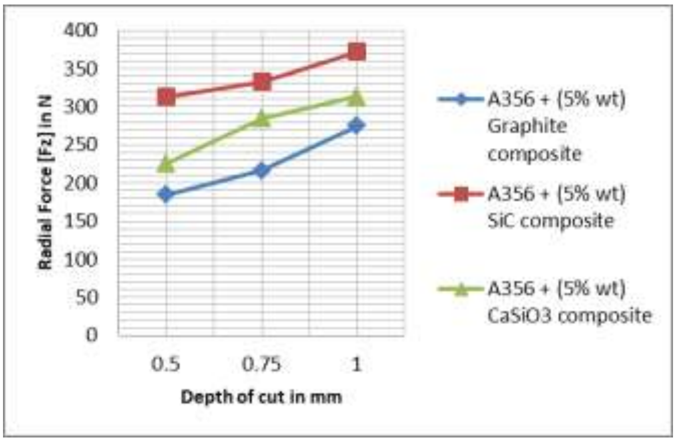
Graph – 4: axial force Vs. Depth of cut



Graph – 5: Tangential Force Vs. Depth Of Cut

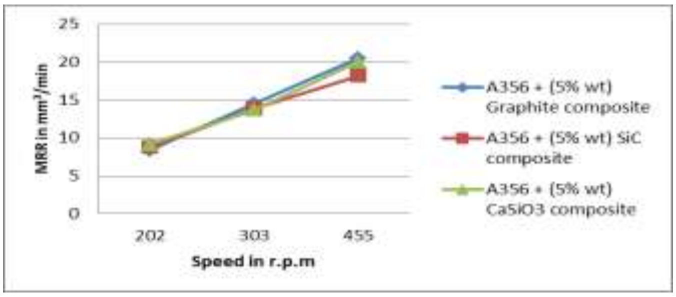


Graph – 6: Radial Force Vs. Depth Of Cut

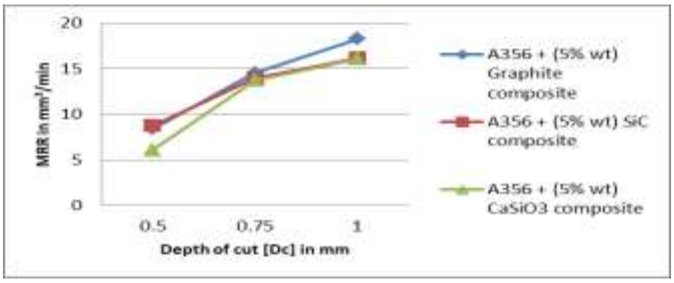


The above three graphs show the comparison cutting forces at various depths of cuts. The induced cutting forces h ofas been completed, Out of three composites SiC composites involves more cutting forces than the other two composites.

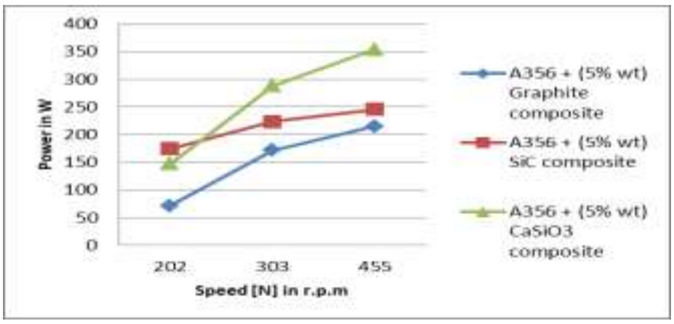
Graph – 7: MRR vs. Speed



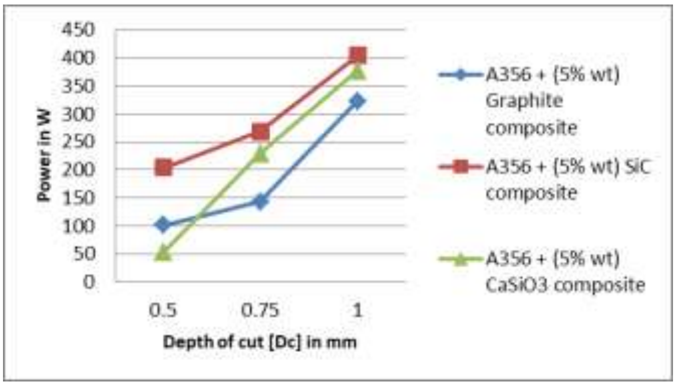
Graph – 8: MRR Vs. Depth of cut



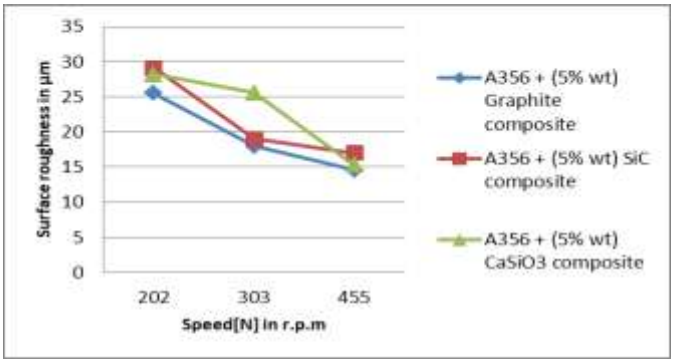
Graph – 9: Power vs. Speed



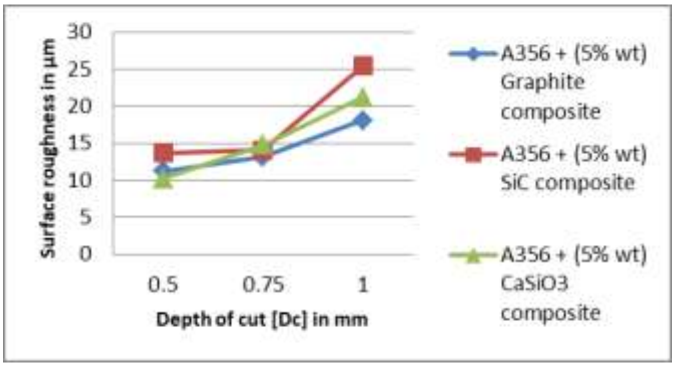
Graph – 10: Power vs. Depth of cut



Graph – 11: Surface roughness vs. Speed



Graph – 12: Surface roughness vs. Depth of cut



From the above graphs it is clear that MRR, power,increases non linearly with the cutting speed where as surface roughness is decreased case of all the three composites.It is also noticed that power, MRR suface roughneshh were incresed with depth of cut.

3. CONCLUSIONS

- A356matrix composites have successfully prepared by using stir casting technique.
- Cutting forces have shown increasing trend up to a speed of 50m/min due to work hardening of the composite, and then decreased at high speed due to softening of the material.
- MRR has shown increasing trend with respect to speed whereas surface roughness has shown decreasing trend
- Due to increase in depth of cut, the tool has to deal with higher volume of material which will ultimately result in an increase in the force as well as power consumption.
- MRR and surface roughness has shown increasing trend with respect to depth of cut for all the three composites.
- Machining time was calculated using CATIA and compared with practical values. It will take less machining time if use corresponding tool
- A356-graphite composite has shown best machinability characteristics when compared other two to composites.

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