Studies on Machining Characteristics and Microbiological Growth over Stir Casted A356-Graphite Metal Matrix Composites
(A Comparison between Pure Metals and Composite)

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Abstract. The need of Metal Matrix Composites (MMCs) are increasing day by day due to their good properties like light weight, high strength, durability, corrosion resistance etc. In the present work A356 is taken as main base material due to its excellent mechanical properties and graphite as fortifying material because of high conductive property to form MMC. Machining is done with and without cutting oil by using automatic feed lathe machine by varying the speed and depth of cuts to find out the cutting forces, cutting tool temperatures and surface roughness and found that these values are gradually increased in many cases. Also done microbiological check and found that the colony count is gradually increased from fresh oil usage to used cutting oil after machining. These tests also done on MMCs, pure brass and pure aluminum and compared the results with MMCs. Novelty focused in present research work is regarding Microbial Organism Growth and its pattern over a period of time since these organism are cancerogenic for the operator and in health and hygiene point of view, lot of research work is going on over this organism growth on combination of several cutting fluids and materials. With the evolvement of composite materials, effect of cutting fluids on the above phenomenon is focused in present work. As a routine work, effect of cutting forces also established by changing machining parameters and presented.

1. Introduction
The MMC is composite material with in any event two constituent parts, one being a metal essentially, the other material might be an alternate metal or another material, for example, an artistic or natural compound. When at any rate three materials are available, it is known as a hybrid composite. A MMC is correlative to a cermet. MMCs are made by scattering a fortifying
material into a base material or matrix which is a monolithic material and is completely continuous. The fortifying material sometimes coated to avoid any reactions with the base material. In structural uses the matrix is generally a lighter metal such as magnesium, aluminum etc., which provides the support to the fortifying material [1].

The strength, stiffness, and density of the composite is depends on its constituent materials properties, the fortifying material’s size, shape, quantity & distribution and the bond between base and fortifying material. The base material forces sharing the load among all the fibers. The main types of fortifying materials are fibers of continuous, discontinuous (short fibers), whiskers, and particulates, which are shown in Figure 1 [2].

The composite materials are classified into Metal Matrix Composites (MMC) of metals based, Ceramic Matrix Composites (CMC) of ceramic materials based and Polymer Matrix Composites (PMC) of plastic materials based [3].

Aluminum metal matrix composites are getting much importance especially for aerospace, automobile, agriculture farm machinery industries etc., due to their good properties such as high strength, low density, good wear resistance compared to any other metal [4].

The role of cutting fluid is increasing day by day due to finding and innovating new materials in engineering and to use the high speed machining. These cutting fluids reduces the cutting temperature by minimizing the friction between work piece and cutting tool, so that the life of both cutting tool and machine apart from improving the efficiency of the machine, lubrication, cleaning and corrosion protection [5].

In the present work the Graphite powder is used as fortifying material and Al 356 as base material synthesized by using stir casting machine

2. Materials

A356 Alloy

Al 356 alloy is used as a base material or matrix, used in the fields of automotive and avionics industries, has excellent wear resistance and good mechanical properties [6] and selected as matrix material owing to good and readily castable [7, 8]. The chemical composition of Al 356 alloy is given in Table 1.
### Table 1. Chemical composition of Al 356 Alloy

| Element | Si | Cu | Mg | Mn | Fe | Zn | Ni | Ti | Al   |
|---------|----|----|----|----|----|----|----|----|------|
| Wt. (%) | 7.20 | 0.02 | 0.29 | 0.01 | 0.18 | 0.01 | 0.02 | 0.11 | Balance |

**Fortifying material (Graphite)**

Graphite, taken as a fortifying material, is a crystalline form of the element carbon with its atoms arranged in a hexagonal structure, arises naturally and most stable form of carbon under standard conditions, which is used in pencils and lubricants. It converts to diamond under high pressures and temperatures. Due to its high conductivity of heat and electricity, it is most useful in electronic products such as electrodes, batteries, and solar panel. Also used the components made by Al MMCs with graphite in the fields of aerospace and automobile industries due to its anti-friction nature and high melting point [9].

**Cutting fluid**

Despite the advantages of cutting fluids of cooling, lubrication, flushing away the chips, reduce the adhesion wear, extended tool life with surface finish to enhance the efficiency of machining process causes increase in productivity, there are some precautions to be followed while using these cutting fluids as these are degrading its quality gradually while in use, its disposal and consequently the pollution to the environment, mist generation etc. Especially, the water based cutting oils are fully contaminated with the microorganisms, which deteriorate the cutting fluids properties causes corrosion of work pieces, choking of fluid flow lines etc. And also chances of getting skin deceases and health issues to the workers who are exposed to these contaminated oil [10]. Used Power fist Cutting Oil/Coolant in this work, which is shown in Figure 2. This water-soluble oil provides protection against rust and corrosion, while also reducing surface tension and improving cooling in cutting areas. Emulsions can be prepared at water-to-oil ratios ranging from 5:1 to 100:1 [11]. In this work, taken this ratio as 20:1 and used for machining as shown in Figure 3.

![Figure 2. Cutting Oil Tin](image)

![Figure 3. Machining of MMC bar with cutting oil](image)

After machining, the used oils were taken and stored in sterilized bottles and tested to study the microbial contamination.
3. Equipment

**Surface Roughness Tester**
The Surftest SJ-210 Portable Surface Roughness Tester shown in Figure 4, is used for testing the surface roughness of the work pieces in microns (µm) after machining on the lathe machine.

![Surface Roughness Tester with work piece](image1)

**Figure 4.** Surface Roughness Tester with work piece

**Automatic feed lathe machine with Coolant Pump Facility**
The machining process is done by using Banka 35 Automatic feed lathe machine, shown in Figure 5, along with a coolant pump of 40 LPM capacity with 2900 rpm used to circulate the coolant oil.

![Automatic feed lathe machine with coolant pump](image2)

**Figure 5.** Automatic feed lathe machine with coolant pump

**Tool dynamometer**
IEICOS (India) make electronic machine tool dynamometer, shown in Figure 6, used to find out the cutting forces while machining the MMC bar samples on the lathe machine.
Microbial Growth
Cutting fluid samples are collected in the sterilized bottles shown in Figure 7 after machining Al-Graphite MMC bars, Pure Al and Pure Brass each with 5 hours machining per day to find the microbial growth.

Petri Plates
A Petri dish or petri plate is a transparent lidded dish used to find bacteria, fungi or small mosses. It is the most common type of culture plate [12, 13]. Standard plate count which is conventional method for monitoring microbial levels in Cutting fluids is used. In the present work, Petri plates duly sterilized were taken and filled with nutrient Agar which is liquid and the temperature is above 45°C. Upon on cooling of this to the room temperature, it will be dried and hardened like a gel.
Incubation
An incubator shown in Figure 9 is a device used to grow and maintain microbiological cultures or cell cultures. The incubator maintains optimal temperature, humidity and other conditions such as the CO₂ and oxygen content of the atmosphere inside. As both agar media and fluids are easily attacked by the bacteria present in the air, in order to prevent the contamination, the Laminar Air Flow chamber is used to transfer the fluid samples to the Petri plates in the presence of blue flame. The samples were then kept in the Incubator (incubation kept at 37°C for 24 hours, the bacteria formed is known as colonies shown in Figure 10. These colonies (figure naked eye and counted). A colony-forming unit (CFU, cfu, Cfu) is used

4. Experimentation
To prepare the MMC with long durability, strength and less weight, selected the A356 alloy material as base, graphite powder of 50 microns size as fortifying material and stir casting route for melting these materials due to lengthy interaction between base material and fortifying material causes good uniform spreading, which gives MMC with good mechanical properties. Chosen the Bottom Pouring Type Stir Casting Machine (Make: M/s. Swam Equip, Chennai, India) to melt the both the raw materials.

Initially, dropped the pieces of A356 material into the furnace. After melting the same, poured the preheated graphite powder of 5% by weight into the furnace through the feeder and use the stirrer for even mixing of both the A356 and graphite powder. After that poured the liquid material into the die and allowed for solidification. Machined that solidified rough A356-Graphite MMC bar into the required 30 mm dia, which is further tested to find the Microbial Organism Growth apart from establishing the cutting parameters by using Banka 35 Automatic feed lathe machine, with a coolant pump to circulate the Power fist Cutting Oil (in the ratio of 20:1 of water: oil) for improving cooling in cutting areas. In parallel, found the surface roughness values by using the SurfTest SJ-210 Portable Surface Roughness Tester and cutting forces by using IEICOS electronic machine tool dynamometer. And, after that machined both the pure aluminum and brass bars and done the similar tests of MMC bar, compared all the results.
5. Results and Discussions
The prepared samples were tested and the results are tabulated

*Forces in X, Y & Z Directions with & without coolant, Temperature and Surface roughness studies*

*Al 356 / Graphite MMC with variable D.O.C and at Fixed speed*
The Table 2 gives the tested values of forces in X, Y & Z directions, cutting tool temperature and roughness values of Al 356 / Graphite MMC with variable D.O.C and at fixed speed and found that all the parameters of cutting Forces, cutting tool temperatures and surface roughness values are gradually increased.

| Variable D.O.C (mm) | Fixed speed in RPM | F_x (N) | F_y (N) | F_z (N) | Temperature °C | Surface Roughness in Microns |
|---------------------|------------------|--------|--------|--------|---------------|-----------------------------|
| 1.5                 | 685              | 5      | 15     | 6      | 9             | 22                         |
|                     | Without Coolant  | With Coolant | Without Coolant | With Coolant  | Without Coolant | With Coolant  | Without Coolant | With Coolant  | Without Coolant | With Coolant |
|                     |                 | 6       | 17     | 9      | 22            | 36             | 34             | 4.965          | 4.8            | 62             |
|                     |                 |         |        |        |               |                |                | 5.97           | 5.819          | 5.791          |
| 2                   | 685              | 7      | 19     | 8      | 21            | 10             | 23             | 45             | 40             | 6.95           |
|                     | Without Coolant  | With Coolant | Without Coolant | With Coolant  | Without Coolant | With Coolant  | Without Coolant | With Coolant  | Without Coolant | With Coolant |
|                     |                 | 8       | 21     | 10     | 23            | 45             | 40             | 6.8            | 6.817          | 6.312          |
|                     |                 |         |        |        |               |                |                | 6.477          | 6.317          | 6.312          |
| 2.5                 | 685              | 7      | 22     | -9     | 23            | 11             | 26             | 60             | 47             | 7.105          |
|                     | Without Coolant  | With Coolant | Without Coolant | With Coolant  | Without Coolant | With Coolant  | Without Coolant | With Coolant  | Without Coolant | With Coolant |
|                     |                 | 7       | 22     | -9     | 23            | 11             | 26             | 60             | 47             | 7.205          |
|                     |                 |         |        |        |               |                |                | 7.015          | 7.015          | 7.015          |

*Al 356 / Graphite MMC with variable speed and at Fixed D.O.C*
The Table 3 gives the tested values of forces in X, Y & Z directions, cutting tool temperature and roughness values of Al 356 / Graphite MMC with variable speed and at fixed D.O.C and found that parameters of cutting Forces of Fx and cutting tool temperatures are gradually increased, Fy & Fz are varied and surface roughness values are gradually decreased.
### Table 3 Graphite MMC with variable speed and at Fixed D.O.C

| Variable Speed (RPM) | Fixed D.O.C (mm) | F_x (N) | F_y (N) | F_z (N) | Temperature °C | Surface Roughness in Micro Meters |
|----------------------|------------------|---------|---------|---------|----------------|----------------------------------|
|                      | With out Coolant | With Coolant | With out Coolant | With Coolant | With out Coolant | With Coolant | Without Coolant | With Coolant | Individua Values | Avg value | Individua Values | Avg value |
|                      | 1025             | 1.5     | 12      | 18      | 14            | 21            | 17            | 32            | 38            | 36            | 5.165 | 5.215                         | 5.319 |
|                      | 685              | 1.5     | 15      | 21      | 16            | 27            | 18            | 31            | 40            | 38            | 4.192 | 4.135                         | 4.012 |
|                      | 303              | 1.5     | 19      | 24      | 21            | 28            | 20            | 33            | 45            | 41            | 3.492 | 3.393                         | 3.195 |

**Pure Al with variable D.O.C and at fixed speed**

### Table 4 Pure Al with variable D.O.C and at fixed speed

| Variable D.O.C (mm) | Fixed speed in RPM | F_x (N) | F_y (N) | F_z (N) | Temperature °C | Surface Roughness in Micro Meters |
|---------------------|-------------------|---------|---------|---------|----------------|----------------------------------|
|                     | With out Coolant  | With Coolant | With out Coolant | With Coolant | With out Coolant | With Coolant | Without Coolant | With Coolant | Individua Values | Avg value | Individua Values | Avg value |
| 1.8                 | 303               | 4       | 3       | 5       | 5              | 27            | 18            | 37            | 34            | 4.811 | 4.507                         | 4.44  |
| 2                   | 303               | 4       | 12      | 7       | 15             | 30            | 21            | 43            | 39            | 4.128 | 4.344                         | 4.845 |
| 2.8                 | 303               | 7       | 14      | 12      | 17             | 28            | 20            | 53            | 44            | 3.925 | 3.825                         | 3.736 |

| Temperature °C | Surface Roughness in Micro Meters |
|---------------|----------------------------------|
|               | With out Coolant | With Coolant |
| 36            | 5.165 | 9.505 | 36.2 |
| 38            | 5.215 | 9.105 | 36.7 |
| 40            | 4.192 | 8.704 | 36.8 |
| 42            | 4.135 | 8.105 | 36.3 |
| 44            | 4.012 | 7.996 | 36.1 |
| 46            | 3.492 | 4.665 | 36.6 |
| 48            | 3.393 | 4.325 | 36.5 |
| 50            | 3.195 | 4.105 | 36.1 |

| Temperature °C | Surface Roughness in Micro Meters |
|---------------|----------------------------------|
|               | With out Coolant | With Coolant |
| 23.1          | 4.811 | 23.2 | 33 |
| 23.7          | 4.269 | 23.6 | 33 |
| 22.9          | 4.44  | 23.6 | 33 |
| 23.9          | 4.128 | 23.5 | 33 |
| 24.6          | 4.058 | 24.7 | 33 |
| 22.3          | 4.845 | 25.0 | 97 |
| 24.24         | 3.925 | 24.23 | 97 |
| 24.05         | 3.814 | 24.23 | 97 |
| 27             | 3.736 | 24.23 | 97 |
The Table 4 gives the tested values of forces in X, Y & Z directions, cutting tool temperature and roughness values of Pure Al with variable D.O.C and at fixed speed and found that the parameters of cutting Forces of Fx & Fy, cutting tool temperatures and surface roughness values with coolant are gradually increased. But, Fz and surface roughness values without coolant are varied.

5.1.4. Pure Al with variable speed and at Fixed D.O.C

| Variable Speed (RPM) | Fixed D.O.C (mm) | Fx (N) | Fy (N) | Fz (N) | Temperature °C | Surface Roughness in Micrometers |
|---------------------|-----------------|--------|--------|--------|----------------|----------------------------------|
|                     | Without Coolant | With Coolant | Without Coolant | With Coolant | Without Coolant | With Coolant | Without Coolant | Av. value | With Coolant | Individ. Values | Av. value |
| 1025                | 2               | 3       | 3       | 4       | 5               | 4                 | 3                 | 37.6      | 35.2        | 7.2           | 7.5       |
|                     |                 |         |         |         |                 |                   |                   |           |             | 67            |           |
| 685                 | 2               | 4       | 4       | 7       | 5               | 20                | 9                 | 41.2      | 41.2        | 2.2           | 2.4       |
|                     |                 |         |         |         |                 |                   |                   |           |             | 67            |           |
| 303                 | 2               | 6       | 9       | 9       | 13              | 27                | 22                | 44        | 44          | 3.1           | 3.4       |
|                     |                 |         |         |         |                 |                   |                   |           |             | 67            |           |
|                     |                 |         |         |         |                 |                   |                   |           |             | 3.7           |           |

The Table 5 gives the tested values of forces in X, Y & Z directions, cutting tool temperature and roughness values of Pure Al with variable speed and at fixed D.O.C and found that all the parameters of cutting Forces, cutting tool temperatures and surface roughness values are gradually increased. But, Fz and surface roughness values without coolant are varied.

Pure Brass with variable D.O.C and at fixed speed

The Table 6 gives the tested values of forces in X, Y & Z directions, cutting tool temperature and roughness values of Pure Brass with variable D.O.C and at fixed speed and found that all the parameters of cutting Forces, cutting tool temperatures and surface roughness values are gradually increased.
### Table 6 Pure Brass with variable D.O.C and at fixed speed

| Variable D.O.C (mm) | Fixed Speed in RPM | $F_x$ (N) | $F_y$ (N) | $F_z$ (N) | Temperature °C | Surface Roughness in Micro Meters |
|---------------------|--------------------|-----------|-----------|-----------|---------------|----------------------------------|
|                     | Without Coolant    | With Coolant | Without Coolant | With Coolant | Without Coolant | With Coolant | Without Coolant | Avg. value | Without Coolant | Avg. value | With Coolant | Avg. value |
| 1.5                 | 303                | 0          | 8         | 3          | 5              | 6             | 4              | 34         | 31         | 7.179       | 5.599      | 9.1         | 10.85      |
|                     |                    | 5.212      | 4.394     | 8.138      | 7.452          | 13.3          | 14.5           | 13.7       | 67         |
| 2                   | 303                | 3          | 12        | 3          | 8              | 4             | 32             | 41         | 52         | 5.131       | 10.275     | 7.8         | 13.5       |
|                     |                    | 7.0000     | 7.217     | 16.361     | 14.862         | 15.3          | 16.6           | 15.6       | 67         |
| 2.5                 | 303                | 3          | 17        | 3          | 12             | 3             | 11             | 10         | 36         | 4.421       | 8.164      | 4.395       | 9.32       |
|                     |                    | 11.643     | 9.132     | 9.211      | 8.511          | 14.4          | 15.5           |            |            |

### Table 7 Pure Brass with variable speed and at fixed D.O.C

| Variable Speed (RPM) | Fixed D.O.C (mm) | $F_x$ (N) | $F_y$ (N) | $F_z$ (N) | Temperature °C | Surface Roughness in Micro Meters |
|---------------------|------------------|-----------|-----------|-----------|---------------|----------------------------------|
|                     | Without Coolant  | With Coolant | Without Coolant | With Coolant | Without Coolant | With Coolant | Without Coolant | Avg. value | Without Coolant | Avg. value | With Coolant | Avg. value |
| 1025                | 2                | 3          | 3         | 0         | 11            | 3              | 31.2            | 30         | 2.839       | 2.67        | 2.67         | 7.977       | 7.526       | 7.607       |
| 685                 | 2                | 3          | 8         | 3         | 13            | 10             | 33.5            | 31.3       | 6.704       | 6.615       | 6.5          | 7.016       | 7.202       | 7.181       |
| 303                 | 2                | 4          | 11        | 4         | 17            | 15             | 32.6            | 32         | 4.225       | 4.315       | 4.3          | 5.985       | 5.625       | 5.608       |

**Pure Brass with variable speed and at Fixed D.O.C**

The Table 7 gives the tested values of forces in X, Y & Z directions, cutting tool temperature and roughness values of Pure Brass with variable speed and at fixed D.O.C and found that the parameters of cutting Forces of $F_x$ & $F_y$, cutting tool temperatures are gradually increased. But, $F_z$ and surface roughness values are varied.
**Bacterial Count:**
Each cutting fluid was tested for Bacterial Count after using for 5 hrs. of machining and waited for 24 hrs. of each machining and results are tabulated in Table 8 and Figure 11. It is found that the colony count is gradually increased from fresh oil to Cutting Oil after machining Al 356 + Graphite MMC bar, Pure Al bar and Pure Brass bars.

| Sl. No. | Cutting Fluid Details                                      | Colony Count |
|---------|------------------------------------------------------------|--------------|
| 1       | Fresh Cutting Oil                                          | 10           |
| 2       | Cutting Oil after machining Al 356 + Graphite MMC          | 20           |
| 3       | Cutting Oil after machining Pure Al                        | 31           |
| 4       | Cutting Oil after machining Pure Brass                     | 50           |

**Figure 11. Bacterial Count**

**CONCLUSIONS**

The various testings were done on Al 356- Graphite Metal Matrix Composite, Pure Al & pure Brass and below is the summary
- In majority of cases, all the parameters of cutting forces of Fx, Fy & Fz, Cutting tool temperatures and Surface roughness values are gradually increased
- The colony count is gradually increased from fresh oil to used Cutting Oil after machining. Found colony count of 10 in fresh oil, 20 in Cutting Oil after machining Al 356 + Graphite MMC, 31 in Cutting Oil after machining Pure Al and 50 in Cutting Oil after machining Pure Brass.

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