Experimental Investigation on Drilling of AA2219-TiB$_2$/ZrB$_2$
In-situ Metal Matrix Composites
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Abstract
Composite material is a development of high performance materials system, which posses the metallic and ceramic material characteristics. Aluminum matrix composites are attracted many researchers due to its improved mechanical properties and wear resistance with minimal weight. Among the various processing route, flex assisted synthesis is a highly potential and low cost method to produce in-situ composites. In-situ aluminum matrix composite has superior performance than the ex-situ composite because of the chemically dispersed reinforcements. The reinforcement phase created by this route is thermodynamically stable and chemically pure. These composites offer many advantages, including more bonding strength, fine, lack of agglomeration and uniform distribution of reinforcements. As a result, the mechanical properties, such as strength and stiffness, increase significantly. In the present work, flex assisted synthesis process is used to produce AA2219 - TiB$_2$/ZrB$_2$ in-situ aluminum matrix composite with the different reinforcement ratio. The present paper is aimed to study the effect of speed, feed rate, drill bit diameter and point angle on surface roughness and delamination in drilling the AA2219 - TiB$_2$/ZrB$_2$ in-situ aluminum matrix composite with the different reinforcement ratio. The experimental investigation was carried out to study effect of one machining parameter, other parameters are kept constant. The major contribution of this work was to study the effect of hybrid TiB$_2$ and ZrB$_2$ reinforcements in AA2219 alloy in drilling the composites.

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Key words : Hybrid in-situ reinforcements, Flex assisted synthesis ,Drilling, Surface roughness, Delamination,
The increasing application of metal matrix composite for structural and wear resistance component in aerospace, automotive and recreational fields necessitated an in depth analysis of machined surface.

**Nomenclature**

| Symbol | Description |
|--------|-------------|
| N      | Spindle speed (rpm) |
| f      | Feed rate (mm/rev) |
| PA     | Point Angle (°) |
| d      | Drill bit diameter (mm) |
| Fd     | Delamination factor |
| D      | Maximum hole diameter (mm) |

which determines the ability of the material to withstand severe conditions of stress, temperature, corrosion and controls its durability and reliability. The machined surface quality of the composite is one of the most important factors affecting the actual application of the composites. Plastic deformation of the fine particle composite is more uniform, which cause low tool wear and lower cutting temperature during machining. However there is a challenge exists to achieve the composites material with fine and small size ceramic particles. The metal matrix composites fabricated by in-situ route has gained considerable attention for its superior performance. Metal matrix composites produced by the conventional method have the lack of distribution of reinforcements, poor wetting, agglomeration of reinforcements and low interfacial strength (Prasad and Asthana 2004). Such technology is confined by adding reinforcement particulates in the molten matrix. In in-situ technique, the reinforcement is formed in the host matrix via chemical reaction between matrix and reinforcements (Zhang et al.1998). These composites offer many advantages, including more bonding strength, fine, lack of agglomeration and uniform distribution of reinforcements. As a result, the mechanical properties, such as strength and stiffness, increase significantly (Cui et al.2000). Aluminium alloy AA2219 is a high strength alloy most widely used for aerospace applications, cryogenic rocket fuel tank and light weight structures (Srinivasa Rao et al. 1996). Synthesis of AA2219-TiB₂/ZrB₂ in-situ metal matrix composite, quantitative elemental analysis, micro-structure characteristics and micro-hardness analysis are reported in literature (Mahamani et al. 2010).

Drilling is the most common machining operation, since many holes must be drilled in order to install mechanical fasteners. As structural materials, fastening of composite structures cannot be avoided. The fastening efficiency is largely dependent on the quality of machined holes. During drilling, the material ahead of the drill point undergoes bending and cause delamination. Machining of composite materials is an important and current topic in modern researches on manufacturing processes. Optimization has significant practical importance particularly for operating the machineries. In order to increase the accuracy of drill holes, the tool must be in good condition always as much as possible. To achieve good condition of tool, the optimization of machining parameters like drill bit diameter, spindle speed, and feed rate are mandatory.

The delamination factor (Fd) is defined as the ratio of the maximum diameter (D, in \( \mu m \)) of the damage zone to the standard hole diameter (d, in \( \mu m \)) of the drill bits.

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Fd = \frac{D}{d}
\]

Delamination factor is mainly affected by drilling speed, flute length, and feed rate within the range of factors are examined. The machinability behavior metal matrix composites composite widely reported in the literatures (Pramanik et al. 2008, Manna and Bhattacharyya 2003 and Ozben et al. 2003). Basavarjappa et al. (2008) presented the influence of cutting parameters on thrust force, surface finish and burr formation in drilling A12219/15SiCp and A12219/15 SiCp-3gr composites, using the tools carbide and coated carbide drills. They revealed that feed rate had a major influence on thrust force, surface roughness and exit burr formation. Paulo Davim et al (2008) studied cutting parameters (cutting velocity and feed rate) under the techniques of Taguchi. The analysis of variance (ANOVA) was performed to investigate the cutting characteristics of GFRP’S using cemented carbide (K10) drills. As a function of using cutting parameters, it was possible to predict surface quality. Tosun (2006) proposed a grey
relational analysis to predict the optimal drilling parameter. The various drilling parameters such as feed rate, cutting speed, drill and point angles of drill were considered. Optimal machining parameters were determined by the grey relational grade obtained from the grey relational analysis for multi performance characteristics. They found that the surface roughness and the burr height in drilling process can be improved effectively. Paulo Davim (2003) presented a study on influence of cutting velocity and cutting time on drilling metal-matrix composites using drill bit. A plan of experiments were based on Taguchi orthogonal array. The objective was to establish correlation between cutting velocity, feed rate and cutting time in order to evaluate the tool wear, specific cutting pressure and the holes surface roughness. These correlations were obtained by multiple linear regression. Tasun and Muratogue (2004) studied the surface integrity of drilled Al/17% SiC particulate MMCs by using HSS, TiN coated HSS and solid carbide drills. Dry drilling tests at different spindle speeds, feed rates, point angles of drill and heat treatment were conducted in order to investigate the effect of various cutting parameters on surface quality and extend of deformation of drilling. It was observed that increase in drill hardness and feed rate decrease surface roughness of drilled surface for all heat treated condition. Tsao (2008) studied thrust force and surface roughness of core drill with drill parameters (grit size of diamond, thickness, feed rate and spindle speed) in a drilling carbon fiber reinforced plastic (CFRP) laminate experimentally studied by using Taguchi method. The confirmation tests demonstrated a feasible and an effective method for evaluation of drilling-induced thrust force and surface roughness (errors with 10%) in drilling of composites materials. Noorul Haq et al (2008) proposed a multiple response optimization using grey relational analysis in drilling of SiC composites. Cutting speed, feed rate and point angle are considered as machining parameter. They found that the responses in drilling process can be improved effectively through this approach.

Ozcatalbas (2003) carried out an experimental investigation on machinability behavior of Al-Al4C3 in-situ composites. The micro crack propagation at particle-matrix interface facilitates the fracturing through the chip cross section this effect reduce the cutting force. The homogeneous microstructure and high hardness of the composite reduce the build up edge formation that improves the surface roughness. Ozcatalbas (2003) investigated the chip and buildup edge formation in machining of the in-situ Al-Al4C3 composites. The morphologies of chip routes were determined by using the quick stop device. It was observed that the small size particle and high hardness of the composite cause discontinuous chip formation and increasing the chip cutting ratio. Rai et al. (2006) conducted the experiments on machining of Al-TiC in-situ composite. They reported the chip formation and cutting force measurements during shaping operation. High volume fraction of the TiC particles causes discontinuous and favorable chip formation without any build up edge formation. The cutting force was minimized due to the propagation of micro cracks at particle-matrix interface. Size and morphology of the TiC particle present in the composite have been found to influence surface roughness. Anandakrishnan and Mahamani (2010) investigated machinability of the in-situ Al6061-TiB2 composites. They reported the effect of speed, feed and depth of cut on flank wear, cutting force and surface roughness. It was observed that presence of small and fine TiB2 particles have offered significant influence on machinability. Mahamani et al (2012) proposed grey relational analysis to optimize the machining parameters in turning the Al6061-ZrB2 in-situ metal matrices composites.

The literature review shows that the drilling characteristics of the in-situ composites with multiple ceramic reinforcements were not addressed. Therefore an attempt has been made to study the influence of drilling parameters on surface roughness as well as delamination factor in machining the AA2219- TiB2/ZrB2 in-situ metal matrix composite.

2. Synthesis and Characterization of Metal matrix composites

2.1 Synthesis

AA2219 was selected as a matrix material for this study. The chemical composition of the matrix was shown in Table 1. AA2219 alloy was reinforced with TiB2 and ZrB2 reinforcement particles. Flux assisted synthesis method was followed to fabricate the composites. Three types of halide salt, namely potassium hexa-fluoro-titanate (K2TiF6), potassium hexa-fluoro-zirconate (K2ZrF6) and potassium tetra-fluoro-borate (KBF4) were used to synthesize the composites. The quantity materials required to produce the composite is shown in the Table 2. During
the synthesis, the preheated halide salts introduced into the aluminium alloy melt at 850°C. The melt is stirred up to 15 minutes and allowed for chemical reaction. Molten aluminium alloy reacts with halide salts by exothermically, and releases the temperature up to 1300°C. Due to this exothermic reaction, the TiB₂ and ZrB₂ particulates are formed and dispersed in the aluminium grain boundaries. KAlF₄ and K₃AlF₆ formed by the chemical reaction are removed as slag. Then the molten composite is poured into graphite-coated cast iron mould. The composites ejected from the mould are shown in Fig.1.

Table 1. Chemical composition of AA2219 alloy

| Elements | Cu   | Mn  | Fe  | Zr  | V  | Si  | Ti  | Zn  | Al  |
|----------|------|-----|-----|-----|----|-----|-----|-----|-----|
| Wt. %    | 6.33 | 0.34| 0.13| 0.12| 0.07| 0.06| 0.04| 0.02| Bal |

Table 2. Amount of materials required for producing composite

| S.No | Name of the material | 0% TiB₂/ZrB₂ | 3% TiB₂/ZrB₂ |
|------|----------------------|---------------|---------------|
| 1    | AA2219               | 2250          | 2250          |
| 2    | K₂TiF₆               | Nil           | 40            |
| 3    | K₂ZrF₆               | Nil           | 45            |
| 4    | KBF₄                 | Nil           | 30            |

Fig 1. Composite ejected from the mould
2.2 Quantitative Elemental Analyses

Quantitative elemental analyses of in-situ AA2219- TiB<sub>2</sub>/ZrB<sub>2</sub> metal matrix composites are carried out by Energy Dispersive X ray spectroscopy (EDAX) analysis. Hitachi S-300H model (CECRI, Karikudi, India) is used for the analysis. EDAX spectra of the samples were recorded by lithium drift silicon detector analyzer with the operating voltage of 20KV and 500x magnification. Fig. 2. shows EDAX spectra of AA2219- 6 % TiB<sub>2</sub>/ZrB<sub>2</sub>. It is seen from Table 3 the composition of various elements presents in composites. Fig. 2 indicates that the detection of Aluminum, copper, Titanium boride and zirconium boride elements present in the sample. The other small peaks are the elements Mn and V present in the AA2219 alloy. Table 3 indicates that 4.31 % titanium boride and 2.42 % zirconium boride elements detected in the AA2219- 6 % TiB<sub>2</sub>/ZrB<sub>2</sub> sample.

![EDAX spectra of AA2219- 6 % TiB<sub>2</sub>/ZrB<sub>2</sub>](image)

Table 3 Quantitative Elemental Analysis of AA2219- 6 % TiB<sub>2</sub>/ZrB<sub>2</sub>

| Elements | Net counts | Weight % | Atom % |
|----------|------------|----------|--------|
| Al       | 210739     | 88.20    | 94.33  |
| Ti       | 4226       | 4.31     | 2.60   |
| Cu       | 2175       | 5.07     | 2.30   |
| Zr       | 1941       | 2.42     | 0.77   |
| Total    | 100        | 100      |        |

2.3 Microstructure Analysis

The microstructure analysis of the fabricated composites is done by the scanning electron microscope. Micrographs are recorded by JEOL6360 LV Model scanning electron microscope. (P.S.G.Tech, Coimbatore, India). Composites are polished by fine emery sheets and etched by Keller’s solution. Fig. 3 shows a microscopic view of interdendritic region of AA2219- 3 % TiB<sub>2</sub>/ZrB<sub>2</sub> composite. TiB<sub>2</sub> and sub micron ZrB<sub>2</sub> reinforcement distribution is observed in the SEM graph. These reinforcement particles are focused over 5000 X magnification. The average size of TiB<sub>2</sub> is recorded around 1μ where as the size of ZrB<sub>2</sub> is 0.7 μ. The figure also indicates that there is good interfacial integrity between the reinforcements, CuAl<sub>2</sub> and Aluminium matrix. Microstructure analysis shows that there is no detectable interface is observed in the microstructure.
Hardness evaluation of composites was done by using the Vickers’s micro hardness tester, MH06 model (CECRI, Karikudi, India), at a load of 25 grams with 3 seconds dwell time. Table V shows the Vickers micro hardness value evaluated for AA2219alloy, AA2219-3% TiB$_2$/ZrB$_2$ and AA2219-6 % TiB$_2$/ZrB$_2$ composites. Addition of reinforcements in AA2219 alloy increases the hardness of material. It is also seen that the hardness value increased by increasing the reinforcement ratio. Presence of 6% multiple ceramic reinforcements in AA2219 alloy, increase hardness value from 122.1 to 155.6 as shown in Table 4.

### Table 4. Micro Hardness Evaluation

| S.No | Composites       | Trail 1 | Trail 2 | Trail 3 | Average |
|------|------------------|---------|---------|---------|---------|
| 1    | AA2219 0% TiB$_2$/ZrB$_2$ | 122     | 125     | 119     | 122.1   |
| 2    | AA2219 3% TiB$_2$/ZrB$_2$ | 148     | 143     | 139     | 143.3   |
| 3    | AA2219 6% TiB$_2$/ZrB$_2$ | 156     | 152     | 159     | 155.6   |

### 3. Experimental Work

During experiments, only one parameter was varied while others were held constant to observe the effects of variation of an individual input parameter on the output parameter. Speed, feed rate, drill bit diameter and point angle are considered as considered as machining parameters. The response to be studied here is surface roughness and delamination. The level of the machining parameters is given in the Table 5. SJ210 surface roughness tester was used for this studying surface and while metallurgical microscope is used for measuring delamination. The travel speed and the measured length of the tip of the roughness tester was 0.5mm/s and

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Fig. 3 Microstructure of AA2219-3 % TiB$_2$/ZrB$_2$ composite
Experimental work was carried out as per the given scheme and the drilled composites are shown in Fig. 4.

| Factor          | Notation | Unit   | 1   | 2   | 3   | 4   |
|-----------------|----------|--------|-----|-----|-----|-----|
| Spindle speed   | N        | Rpm    | 695 | 1200| 2000| 3390|
| Feed rate       | f        | mm/rev | 0.05| 0.10| 0.15| 0.20|
| Point Angle     | PA       | °      | 100 | 110 | 120 | 130 |
| Drillbit diameter | d      | mm     | 6   | 8   | 10  | 12  |

3.1 Surface Roughness

The experimental work was carried out in Radial Drilling Machine (Suraj make). High speed steel drill bit was this study. The length of drilling is 12mm for each experiment. All the experiments are carried out in dry condition. Fig. 5 shows Photographic view of surface roughness measurement. From the experimental investigation the following graph are drawn (Fig. 6-9).
3.2 Delamination Factor

The edge of the drill bit gets bending, when feeding the against work piece. Inaccuracy in the size of the hole is observed at the bottom of work piece. There is a small enlargement in the hole cause delamination. The delamination factor was measured by tool makers microscope. From the experimental investigation the following graph are drawn (Fig. 10-14).
4. Results and Discussion

The influence of spindle speed on surface roughness was evaluated by keeping the feed rate 0.15 mm/rev, drill diameter of 10mm and point angle 120°. Fig. 6. shows that increase in spindle speed increase the surface roughness of holes. At higher spindle speed, increase the tool vibration which causes scratches on drilled surface. The effect of feed rate on surface roughness was shown in Fig.7. The speed of the spindle 1200 rpm, drill diameter of 10mm and point angle 120° was maintained while doing experiments. Increase in feed rate increase the surface roughness of the holes. Higher feed rate increase the load on the drill cutting edge and leads to high surface roughness. The effect of tool geometry on the surface roughness was shown in Fig.8. These experiments are carried out at spindle speed of 1200 rpm, drill bit diameter of 10mm and 0.15 mm/rev with variable point angle. The point angle of 100° drill has lower surface roughens value than the other angles. Higher point angle increase the area of contact which increase the surface roughness. Fig.9. show that the increase in drill bit diameter increases the surface roughness. Increase in drill diameter increase the material removal rate and causes poor surface finish. It is also observed from the fig. 6-9 the increase in reinforcement ratio increase surface roughness.

The influence of spindle speed on delamination factor was evaluated by keeping the feed rate 0.15 mm/rev, drill bit diameter 10 and point angle 120°. Fig.10. shows that increase in spindle speed increases the delamination factor. At higher spindle speed increase the tool vibration which increases delamination factor. The effect of feed rate on Delamination factor was shown in Fig. 11. The speed of the spindle 1200 rpm and point angle 120° was maintained while doing experiments. Increase in feed rate cause increase the delamination factor. Higher feed rate
increase the load on the drill cutting edge and leads to high delamination factor. The tool geometry on the delamination factor was shown in Fig. 12. These experiments are carried out at spindle speed of 1200 rpm and 0.15 mm/rev with variable point angle. The point angle of 100° drill has lower delamination factor value than the other angles. Higher point angle increase the area of contact which increase the delamination factor. Fig.13. shows that the increase in drill diameter increases the delamination factor. Increase in drill diameter increase the material removal rate and causes high delamination factor. It is also observed from the Fig.10-13 the increase in reinforcement ratio increase surface roughness. This may be attributed to the occurrence more particle pulling or de bonding at higher reinforcement ratio. Fig. 14. shows the worn out surface of drill bit and broken reinforcement particles when machining the AA2219-6 % TiB₂/ZrB₂ composite with the feed rate of 0.15 mm/rev, spindle speed 1200 rpm, point angle as 100° and making use of drill diameters of 10 mm.

![Fig. 14. - SEM micrograph of worn-out drill bit](image)

5. Conclusion

The following conclusions are drawn from the experimental investigation of drilling of AA2219-TiB₂/ZrB₂ in-situ metal matrix composites. Increase in spindle speed decrease the surface roughness of holes. The surface roughness value increases by increasing the feed rate. Point angle of 100° drill has lower surface roughness value than the other angles. Increase in reinforcement ratio increase surface roughness. Increase in spindle speed increase the delamination factor. The delamination factor value increases by increasing the feed rate. Increase in point angle increases the delamination factor. Increase in drill diameter increases the delamination factor. Increase in reinforcement ratio increase delamination factor.
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