Influence of grinding parameters on grinding force and temperature in grinding of AA6061-TiB$_2$/ZrB$_2$ in-situ composite

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Abstract: In-situ composite material synthesis has been widely recognized by the researchers owing to fine particle size, clean interface, and smart wettablility of the reinforcement with the matrix. Variation of wheel speed, work speed, depth of cut and feed rate on grindability of AA6061-5%TiB$_2$/ZrB$_2$ in-situ composite are investigated. The present work is aimed to investigate the grinding force and grinding temperature of the AA6061-TiB$_2$/ZrB$_2$ in-situ composite under various grinding parameters and wheel materials. A hike of wheel speed decreases the grinding force an increase in temperature. Increase in work speed, depth of cut and feed rate increase the grinding force and grinding temperature. This experimental investigation helps to control the grinding force and grinding temperature at the various grinding condition.

1. Introduction

Composite materials are received the worldwide attention of material scientists owing to the potential for weight reduction, superior properties and tailorability [1]. These extreme properties motivate the aerospace and automotive industrialists to consider the composites to replace the conventional materials [2]. In-situ composites manufactured by the halide salt- aluminum melt reaction offers many advantages including low cost, easy to manufacture and single step processing [3]. The existence of micro size, coarse free and freshly generated reinforcements have enhanced the wettablility and interfacial strength between the particles and matrix and thereby increase the mechanical properties of the composites [4]. Excessive addition of reinforcements into the matrix dilutes the mechanical properties and restricts the widespread application. In-situ composites may prevail over this problem by the way of obtaining the highest mechanical properties at lower reinforcement ratio. TiB$_2$ possess high melting temperature, incomparable corrosion resistance, and exceptional chemical stability, venerable creep resistance [5]. Adding an additional reinforcement into matrix helps to explore the benefits of both ceramics. The combination of ZrB$_2$ and TiB$_2$ ceramics reinforced into the aluminum matrix is expected to put forward a typical high-temperature structural application [6]. In spite of countless miraculous properties, the machining of the composite is still challenging to industries [7]. In-spite of many near net shape manufacturing technology, the composite components require finishing operation to meet the desired dimensional tolerances, surface roughness and surface integrity [8]. Cylindrical grinding is one of the processes to finish the surface of the machined components with the cylinder, hollow shaft and pipes. Grinding is a time-consuming machining process among the conventional machining category and it is associated with some challenge to attain the optimal surface finish with economic machining rate. The generated surface should have an ability to withstand the fatigue load, creep load, friction, temperature, and corrosion during the service condition. Quality of grounded surface is completely re-laid on the product performance [9]. The mechanism of the grinding of the composite is associated with the ceramic compound available with the grinding wheel makes physical contact with all regions of the composite namely: matrix, reinforcements and matrix-reinforcement interface, and facilitates material removal in form of small chips. Grinding process is allied with many parameters: wheel speed, work speed, feed rate, grinding depth, number of passes, wheel material, grit size, nature of grinding matrix material, type of
reinforcement, size of reinforcement and fineness of the reinforcement also influence the grounded surface. The components of grindability include grinding force, temperature, surface roughness, subsurface material removal rate. Grindability studies on ex-situ composites widely reported in the literature. Performed an experimental work by grinding of Al/SiC composites. The effect of cylindrical grinding parameters including speed of the wheel, the speed of workpiece, rate feed, grinding depth and SiC content on the grinding force, surface roughness, and grinding temperature are examined. Analysis of the experimental result depicts that, the superior surface finish and scratch free surfaces are found at high wheel speed and workpiece speed [11]. Reported the grindability study of the Al-Al₂O₃ composites. SiC verified and diamond resin bonded matrix grinding wheels used for the experimental work. Surface roughness, grinding force, and subsurface damage are evaluated under different grinding parameters. The experimental result reveals that the SiC wheel well for rough grinding and diamond wheel for finish Grinding [12]. Established the response of grinding operation on the surface smoothness in machining of particles fiber reinforced aluminum matrix composites. Size, orientation, and method of manufacturing are considered for investigation. Microscopic examination of the grounded surface reveals the subsurface damage due to particle or fiber pulling effect and crack formation [13].

2. Materials and Method

AA6061-TiB₂/ZrB₂ in-situ composites with 0%, 2.5%, 5% and 7.5% reinforcement ratio are used for experimental work. These composites are made by reacting K₂TiF₆, KBF₄, and K₂ZrF₆ salts. The microstructure and XRD pattern of the composites is presented in the Figures 1 and 2. Small size (1-2μm) reinforcement particles, the clean interface between particle and matrix, and uniform distribution of particle are seen in the microstructure. Al, TiB₂ and ZrB₂ phases are detected in the XRD pattern. The dimension of the workpiece is Φ30x300mm. Grinding experiments are conducted by using horizontal spindle cylindrical grinding machine (Heavy duty machine, Indian make). Al₂O₃, CBN, and Diamond grinding wheels are used for the experimental work. Grinding force values are measured by using Variable Frequency Drive and grinding temperature values are measured using Non-contact infrared thermometer. The experimental work is conducted with various grinding parameters as per Table 1. A parametric study is planned in such a way that influence of one parameter is assessed by keeping other parameters as constant.

![Figure 1. SEM image](image-url)
3. Result & Discussion

3.1. Grinding force

The effect of wheel speed on grinding force as a function of wheel materials are shown in Figure 3. This investigation is carried out by fixing the work speed as 12m/min, depth of cut 20μm, feed rate 0.09m/min and 5% reinforcement ratio. It is seen from the Figure 3 the diamond wheel performed better than other wheels in terms of generating very low grinding force. Al₂O₃ wheel generating higher grinding force for the given experimental conditions. It also is seen from the Figure 3 increase in wheel speed decrease in grinding force. The grinding force, that is the tangential one, has the strong influence on the removal modes of the reinforcements and the matrix of PTMCs during grinding. The grinding force increases with an increase in workpiece speed and depth of cut. Higher force ratio always corresponds to severe tool wear; therefore, low tool sharpness in the super-high-speed grinding process [14]. Diamond gives lesser grinding force and better surface finish compared to SiC wheel. Also grinding of MMC reinforced with SiC, using SiC wheel usually result in clogging and attrition wear of SiC abrasive. Although it is known that electroplated bond is hard (prevents pull out of abrasive) compared to resin bonded wheel, during
grinding, the resin bonded diamond wheel will enable self-sharpening of the diamond abrasive, enabling better grindability [10].

Figure 3. Wheel speed vs Grinding force

Figure 4. Work speed vs Grinding force

Figure 5. The depth of cut vs Grinding force

Figure 6. Feed rate vs Grinding force

The effect of work speed on grinding force as a function of wheel materials are shown in Figure 4. This investigation is carried out by fixing the wheel speed as 33.7m/s, depth of cut 20μm, feed rate 0.09m/min and 5% reinforcement ratio. It is seen from the Figure 4 the diamond wheel performed better than other wheels in terms of generating very low grinding force. Al₂O₃ wheel generating higher grinding force for the given experimental conditions. It also is seen from the Figure 4 increase in work speed increase in grinding force. As the increase of workpiece speed, the moving speed of grinding source is increasing. So the heat source works little time on the workpiece and a large amount of grinding heat transfer quickly into the atmosphere. Increasing workpiece speed and grinding depth result in the increase of the maximum undeformed chip thickness and grinding force [15]. Both the normal and the tangential components of the grinding force show moderate increases with increasing workpiece speed. Thus the grinding force is inversely related to the material hardness, topography after machining non-reinforced Al and Al-SiC composites [16].

The effect of depth of cut on grinding force as a function of wheel materials is shown in Figure 5. This investigation is carried out by fixing the wheel speed as 33.7m/s, work speed as 12m/min, feed rate 0.09m/min and 5% reinforcement ratio. It is seen from the Figure 5 the diamond wheel performed better than other wheels in terms of generating very low grinding force. Al₂O₃ wheel generating higher grinding force for the given experimental conditions. It also is seen from the Figure 5 increase in Depth of cut increase in grinding force. As the grinding wheel velocity increases, the heat generated in the deformation zone increases and thereby softening the aluminium matrix thus reducing the force required to remove the material, the surface roughness decreases with an increase in wheel velocity and workpiece velocity. This
is due to the increase in relative velocity between the wheel and workpiece and the reduction in contact time thereby reducing the chip thickness, tangential grinding force and surface roughness increase with an increase in feed and depth of cut, increase in material removal rate and the increase in chip thickness account for the increase of the tangential force \( F_T \) increase with an increase of percentage of \( \text{SiC} \) volume fraction [11].

The effect of feed rate on grinding force as a function of wheel materials are shown in Figure 6. This investigation is carried out by fixing the wheel speed as 33.7 m/s, work speed as 12 m/min, depth of cut 20 μm, and 5% reinforcement ratio. It is seen from the Figure 6 the diamond wheel performed better than other wheels in terms of generating very low grinding force. \( \text{Al}_2\text{O}_3 \) wheel generating higher grinding force for the given experimental conditions. It also is seen from the Figure 6 increase in Feed rate increase in grinding force. The relative velocity between the wheel and the workpiece and the reduction in contact time reduces the chip thickness. When the feed and depth of cut are increased, the increase in material removal rate and the increase in chip thickness account for the increase of the \( F_t \) and Ra values [17].

3.2. Grinding Temperature

The effect of varying the wheel speed on grinding temperature as a function of wheel materials are shown in Figure 7. An experimental investigation is conducted through varying each parameter and keep remaining parameters as constant and 5% reinforcement ratio. It is seen from the Figure 7 the diamond wheel performed better than other wheels in terms of generating very low grinding temperature. \( \text{Al}_2\text{O}_3 \) wheel generating higher grinding temperature for the given experimental conditions. It also is seen from the Figure 7 increase in wheel speed increase in grinding temperature. Higher grinding temperature as a result of the rise of the energy needed to grind a unit volume of the material [18].
The effect of varying the work speed on grinding temperature as a function of wheel materials are shown in Figure 8. An experimental investigation is conducted through varying each parameter and keep remaining parameters as constant and 5% reinforcement ratio. It is seen from the Figure 8 the diamond wheel performed better than other wheels in terms of generating very low grinding temperature. Al₂O₃ wheel generating higher grinding temperature for the given experimental conditions. It also is seen from the Figure 8 increase in work speed increase in grinding temperature. The greater depth of cut and the faster workpiece speed always result in the increase of the grinding temperature in the current investigation. Obviously, the grinding temperature in the super-high-speed grinding process of 120 m/s is always higher than that in the conventional speed grinding process of 20 m/s [14].

The effect of varying the depth of cut on grinding temperature as a function of wheel materials are shown in Figure 9. An experimental investigation is conducted through varying each parameter and keep remaining parameters as constant and 5% reinforcement ratio. It is seen from the Figure 9 the diamond wheel performed better than other wheels in terms of generating very low grinding temperature. Al₂O₃ wheel generating higher grinding temperature for the given experimental conditions. It also is seen from the Figure 9 increase in Depth of cut increase in grinding temperature. The increase of wheel speed and grinding depth results in an increasing trend of grinding temperature. More grains enter the grinding zone in unit time quantities of grains plowing and sliding on the workpiece surface become greater. Therefore, more energy is consumed which makes the increasing temperature [19].

The effect of varying the feed rate on grinding temperature as a function of wheel materials are shown in Figure 10. An experimental investigation is conducted through varying each parameter and keep remaining parameters as constant and 5% reinforcement ratio. It is seen from the Figure 10 the diamond wheel performed better than other wheels in terms of generating very low grinding temperature. Al₂O₃ wheel generating higher grinding temperature for the given experimental conditions. It also is seen from the Figure 10 increase in wheel speed, work speed, Depth of cut and feed rate increase in grinding temperature. As the cutting speed, feed rate and or depth of cut increase, the depth of the affected layer increases. Hence, the increase in cutting temperatures, which leads to thermal deformation in the matrix material, could be one reason behind the hardening of machined sub-surface [20].

4. Conclusion
The Grinding force and grinding temperature of the AA6061-5% TiB₂/ZrB₂ in-situ composite under different grinding parameters and wheel materials are experimentally evaluated. Increase in wheel speed decrease in grinding force due to the reduction in undeformed chip thickness. Increase in work speed, depth of cut and feed rate increase in grinding force. Increase in wheel speed, work speed, depth of cut and feed rate increase in grinding temperature due to excessive sliding action between grit and workpiece. The diamond wheel shows the lower grinding force and grinding temperature as compared to the other grinding wheels harder grits with the higher thermal conductivity of diamond wheel improves the grindability.

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6. References
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