Performance Evaluation of Conventional Abrasive Wheels for Grinding Ti-6Al-4V

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Abstract. The present experimental study represents comparative performances in between aluminium oxide and silicon carbide wheels for grinding Ti-6Al-4V, considering dry environment as well as using alkaline soap water, applied through a newly developed delivery technique, restricted quantity lubrication (RQL) in drop by drop (DBD) mode. Experiments have been performed on a surface grinding machine in up-grinding mode during which the wheels are passed 20 times over the workpiece substrate for each environmental condition with infeed, 10 µm per pass. The variations of tangential and normal force components have been accurately measured using strain gauge dynamometer for each set of experimentations. Grinding ratios have been evaluated after accurately estimating the volume of material removal of wheel and workpiece. The qualities of the ground surfaces are compared based on the surface roughness parameters, measured using contactile mechanical stylus and observations of the ground surface under high resolution microscope. The outcome of the present investigation indicates silicon carbide wheel is superior to alumina wheel for grinding Ti-6Al-4V in terms of grinding force, grinding ratio, surface quality and the form of chips, obtain herein.

Keywords: Grinding, Ti-6Al-4V, Alumina Wheel, Silicon Carbide Wheel, RQL-DBD

1. Introduction
Titanium, or its alloys as materials have find wide applications in many industries and are pertinently supported by their interesting properties like high corrosive resistance, low specific gravity, high specific strength, non-magnetic property and bio-compatibility (1). Wide applicability of the material is severely challenged by the difficulty of the material to be machined. Titanium and its alloys are considered difficult to machine due to low thermal conductivity, low volume specific heat and chemical affinity at elevated temperatures shown by the material (2). These adverse effects may give rise to problems such as surface damage, induced stresses, reduced tool life etc. Majority of the industries require titanium converted to products having high surface finish and tight tolerance making grinding an important manufacturing operation.

Grinding itself is a very complex machining operation owing to the large number of negatively raked abrasive grits taking part in the material removal process. If the process parameters are not properly optimised then this operation can prove to be even more challenging (3), (4). Inappropriate
process parameters can lead to formation of defects like surface damage, workpiece burn, induces residual stresses, tool breakage etc. Along with adopting proper process parameters, introduction of coolant is also an important consideration to improve grindability (5)(6)(7). Use of apposite grinding wheel also affects the grinding performance to a large extent. The selection of grinding wheels depends mainly on the grinding application and requirement. The general trend suggests using softer grinding wheel for harder material and vice-versa which debates in favour of employing silicon carbide wheel for titanium alloys (4). According to many renowned researchers also, silicon carbide wheel is better suited for grinding titanium alloy (8)(9). On the contrary, some studies have shown aluminium oxide grinding wheel to have performed better than silicon carbide wheel for titanium because it may give lower residual stresses in the workpiece (10)(11). Thus, it becomes necessary to establish a comparative study between the performances of conventional abrasive wheels to arrive at a conclusion. Another important factor to reduce the detrimental effect of grinding and make the process relatively easier is the use of coolant. As the metalworking fluids are destructive to the ecology, restricting their use becomes important (12). Supporting that, some studies have indicated that using MQL/RQL technique to have resulted in decent grinding performance for grinding titanium alloys (13)(14).

This article presents a comparative study of performance of conventional abrasive wheels, viz. aluminium oxide and silicon carbide for grinding Ti-6Al-4V, which is a widely used titanium alloy in dry and RQL condition. The cooling technique adopted is an economical and effective technique. Alkaline soap water is used as a coolant which holds an economical and environmental friendly edge over conventional coolant.

2. Experimental Details
The grinding experiments have been done on a horizontal surface grinder. Grinding has been performed in up-grinding mode with 10 micron infeed value for 20 passes in each condition. Aluminium oxide and silicon carbide wheel of exactly same specifications were used. Ti-6Al-4V was chosen as the workpiece. The chemical composition of the material and other experimental details are shown in Table 1.

Table 1. Experimental details and apparatus used

| Surface Grinding Machine | Make : HMT, Praga Division; Model : 452 |
|--------------------------|----------------------------------------|
| Spindle Speed(max)       | 2800 rpm                               |
| Grinding Wheel           |                                        |
| Make: Carborundum Universal LTD; Specification : CGC60K5V8 |
| Alumina: Make: Carborundum Universal LTD; Specification : AA60K5V8 |
| Work Material            |                                        |
| Material : Ti-6Al-4V;    |                                        |
| Composition: Ti – 88.77%; Al – 6.19%; V – 4.25%; Fe – 0.34% |
| Dry                      |                                        |
| RQL using drop by drop (DBD) method |
| Setup: Saline bottle with infusion tube |
| Nozzle diameter: 2.1 mm; Flow rate: 16 ml/min |
| Graining Environment     |                                        |
| Coolant Used             | Alkaline Soap water: Mixture : Clinic plus shampoo and water; Mixing ratio : 1:20 |
2.1. RQL using drop by drop (DBD) setup

In this setup cutting fluid is applied obeying the principle of RQL in drop by drop mode. It is made by mixing clinic plus shampoo with water in a ratio of 1:20. The cutting fluid is applied at a constant flow of 16 ml/min on the workpiece surface in drop by drop mode before every grinding pass. This is done with the help of a saline bottle with infusion tube arrangement as shown in Figure 1. The setup was made by investing only 300 INR (approx.) compared to 30000 INR (approx.) required by conventional flood cooling setup. It reduced the setup cost to upto 99%.

![Figure 1. MQL in drop-by-drop arrangement](image)

3. Results and discussion

Grindability of any material depend on analysing factors like force requirement, surface quality, grinding ratio, chip form obtained etc. Grinding force requirement is an important criterion to take into consideration. Figure 2 and figure 3 shows tangential (Ft) and normal (Fn) force requirement respectively for different grinding environments. From figure 2 and figure 3 it can be clearly seen that normal force is always greater than tangential force, which is expected because of the larger rubbing and ploughing action associated with the operation due to the presence of abrasive grits having high negative rake angle. Another phenomenon which can be clearly seen is that for the initial few passes, grinding force requirement is constantly increasing. This happens due to the inability of the system to overcome the relative stiffness. A considerable amount of reduction in force requirement can be observed with the introduction of the RQL based cooling system. Obviously with the application of the coolant cooling and lubrication rises, resulting in lesser force requirement.
Comparing the performance of the different wheels used, it can be seen that grinding using silicon carbide wheel required less force than grinding using alumina wheel in both dry and DBD setup. This is due to the higher friability of SiC abrasives. More friability indicates that abrasives should regenerate sharp cutting edges as the grits dull by attrition during use, thus maintaining the sharpness of the grits by auto-sharpening [4]. Grinding ratio shown in figure 4 further clarifies the comment.

Figure 2. Tangential force (Ft) requirement for 20 passes during different grinding conditions

Figure 3. Normal force (Fn) requirement for 20 passes during different grinding conditions

Figure 4 clearly indicates that when we compare the different wheels performance in each environmental condition, silicon carbide has shown better grinding ratio values. This proves that lesser
wheel material removal and greater workpiece material removal has taken place when grinding has been carried out using silicon carbide wheel. As silicon carbide wheel has more friability index than alumina wheel so the grits have remained sharper in case of silicon carbide wheel. Surface roughness values obtained, as shown in figure 5 also indicates to the theory.

**Figure 5.** Average surface roughness measured for each grinding environment after 20 passes

Figure 5 reveals that the corresponding surface roughness value obtained by grinding using alumina wheel is lesser than the value obtained by using silicon carbide wheel. As already stated above due to lesser friability the abrasive grits of alumina wheel experiences glazing and give rise to rubbing of the workpiece. This rubbing action results in a polishing effect on the workpiece substrate, thus decreases the surface roughness. Workpiece substrate quality, as shown in figure 6 also directs toward similar supposition.

**Figure 6.** Surface morphology obtained during different grinding conditions

The workpiece substrate images as shown in figure 6 reveals that with the introduction of coolant works surface quality has improved. Surface obtained using silicon carbide wheel show more prominent grinding marks than alumina wheel. This is due to higher grit sharpness retention power of
silicon carbide grits. Due to that small fragmented type chips are obtained using silicon carbide wheel, as shown in figure 7(ii)(b). Figure 7 shows the ground chips obtained during different grinding conditions.

4. Conclusion
The experimental investigation, comparing performances of conventional abrasive wheels for grinding of Ti-6Al-4V in dry and RQL (DBD) mode using alkaline soap water as coolant reveals:
- Introduction of DBD method of cooling resulted in considerable reduction of grinding force and surface roughness. It also improved grinding ratio irrespective of the grinding wheel type.
- Grinding force requirement using silicon carbide wheel was lower than grinding using alumina wheel for both the environmental conditions.
- Better grinding ratio was observed when silicon carbide is used for grinding of the material.
- Surface roughness was better in case of using alumina wheel because of expected glazing phenomenon due to its lower friability which resulted into polishing action.

From the experimental investigation it can be concluded that for the given set of condition silicon carbide wheel is better suited for grinding of Ti-6Al-4V compared to aluminium oxide wheel.

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