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Investigation on grindability of medical implant material using a silicon carbide wheel with different cooling conditions

P.Suya Prem Anand[a*] N.Arunachalam[b] and L.Vijayaraghavan[c]

[a]*Research Scholar, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, India*

[b]*Assistant Professor, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai,India*

[c]*Professor, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, India*

[a]*suyaprime@yahoo.co.in,* [b]*chalam@iitm.ac.in,* [c]*lvijay@iitm.ac.in*

Abstract

Zirconia is the preferred material used in many applications including biomedical implant. The zirconia in its sintered form is the most preferred one to manufacture a near net shaped implant material with minimal work. But it is very difficult to shape as the material chip away during the machining or grinding process. Hence zirconia in a pre-sintered form is used to achieve the required shape and size for a specific application. Then it is sintered and used. In this work, the grindability of the presintered zirconia was evaluated using a dense vitreous bond silicon carbide wheel. The grinding parameters such as wheel speed, radial depth of cut and feed rate are varied to investigate its grindability in terms of force ratio, specific energy, surface finish, G-ratio and ground surface under both wet and MQL cooling conditions. The forces produced during the grinding of pre-sintered zirconia was observed lower in the MQL (Minimum Quantity Lubrication) technique due to the reduction of friction, when compared to the wet cooling condition. The calculated specific energy was less in MQL cooling condition, due to the reduction in heat generation and friction. The surface finish of the workpiece obtained from the wet cooling condition was better due to the reduction in wheel loading. The percentage difference of the G-ratio between both the wet and MQL cooling conditions was observed to be 24 percent. This was due to the active participation of grains and less wheel loading in wet grinding condition. The ground surfaces obtained from the wet cooling condition were smooth and regular, compared to the MQL grinding condition.

Keywords: Force Ratio; Wheel Wear; Surface Finish; Grinding Fluid

1. Introduction

Recently zirconia based ceramics are used in the medical implants due to their advanced mechanical properties like high fracture toughness compared to other alternatives, which provides resistance to crack formation during the grinding process. The various compounds such as magnesium oxides, yttrium oxides and cerium oxides are added to pure zirconia to retain the tetragonal phase at room temperature and to enhance the properties of the

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material. Yttria stabilized tetragonal zirconia (Y-TZP) is predominantly used as the base material for manufacturing dental crown, hip joints and fixed dentures of biomedical application [1]. Both the pre-sintered and fully sintered blocks are frequently used in this fabrication process, where porous components are easy to machine due to their soft nature as compared to the sintered zirconia. As the pre-sintered block has lesser hardness, when compared to the sintered zirconia, it improves the machinability of the sample without the formation of chipping. Pre-Sintered zirconia is used in dentistry for making dental crowns and fixed partial dentures. The components are machined in the pre-sintered block prior to sintering at high temperature or in fully sintered blocks. Machining of sintered block is extremely difficult because of its densely packed grains, high hardness and low machinability [2,3].

The fine grit abrasive of silicon carbide paper is used to finish the pre-sintered block to the required tolerance limit and surface finish [4]. The experiments were conducted under the wet cooling condition to analyze the grindability of silicon carbide wheel on different forms of zirconia. The grindability of ceria added zirconia is studied by using different types of grinding wheel, such as diamond, CBN and silicon carbide grinding wheels. The grinding forces, specific energy and surface finish are estimated and the results showed that the silicon carbide wheel is used effectively to grind zirconia [5]. Silicon carbide wheel of grit size 220 with low porosity vitreous bonds is used to grind the zirconia, because it reduces the necessity of dressing by producing the least amount of wheel wear while grinding zirconia. Also the cost of SiC wheel is cheaper than using the diamond grinding wheel [6].

During grinding of both fully and partially stabilized zirconia using a fine grain vitreous bond silicon carbide wheel, the phase transformation analysis is performed on the chips and the ground surfaces using the X-ray diffractometer. The result shows a decrease in the thermal conductivity of zirconia chips and silicon carbide grinding wheel, which supports the softer material removal and reduces the wheel wear [7]. The fine grain dense vitreous bond silicon carbide wheel can be used to grind silicon nitride ceramics, where the grinding force and the wheel wear are increased to a higher level during the grinding process. It supports the precision form of grinding, which improves the G-ratio and surface integrity of the workpiece. When the radial depth of cut and material removal rate increases, it leads to higher wheel wear [8].

Another problem associated with the wet grinding of zirconia is the phase transformation, which takes place due to the difference in temperature and the hydrothermal loading that occurs during the grinding process. When yttrium stabilized tetragonal zirconia is subjected to a moisture environment, it increases the percentage of the monoclinic phase, which is the weakest form of phase among all the three phases in zirconia. Although the tetragonal phase helps in favor of resisting the external stress by increasing the fracture toughness, the strength degradation takes place due to the changes in the microstructure of the material such as microcracks, voids and grain growth [9]. To investigate the impact of portable grinding on Y-TZP (Yttria stabilized tetragonal zirconia) in terms of phase transformation, ground surface and aging process, the experiments are carried out in water cooling condition with various grit sizes. The percentage of the monoclinic phase increases due to the effect of grinding and the aging process, which affects the mechanical properties of the material [10]. The Zirconia (Y-TZP) material is subjected to a hydrothermal loading by varying the temperature and the time. Raman spectroscopic analysis is performed on the samples to detect the depth of the transformation zone. Due to this coolant assisted heating, the phase transformation takes place on the surface and extends to a certain depth. When the samples are tested by Vicker hardness test, the hardness value decreases with the depth of transformation zone [11].

The MQL is used to deliver a minimum quantity of fluid at the contact zone and concentrate more on lubrication by reducing the friction rather than cooling the surfaces. The lubricant applied in the contact zone reduces the friction and minimizes the thermal damages caused by grinding. Minimizing the amount of coolant in the grinding process leads to the reduction of environmental effects and cost. The surface finish improves in the MQL technique by supplying a small amount of fluid at the contact zone. When the MQL technique is compared with the wet grinding process, the grinding force, surface roughness and surface damages are reduced and the surface quality is improved in the MQL grinding process, as the cutting fluid in the wet grinding process does not fully penetrate into the grinding contact zone [12]. The MQL technique is used along with cleaning compressed air to replace the wet coolant process in cylindrical grinding of tempered and quenched steel. When using the minimum quantity of fluid, it provides insufficient cooling and the chips are not completely washed away by the fluid, which brings harmful effect to the surface of the workpiece and increases the heat generation. The output variables such as wheel wear, roundness error and workpiece surface roughness are analyzed, which shows a improvement in MQL fluid flow by implementing a jet of compressed air at different angles for cleaning the wheel surface [13]. The impact of