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Development of "α-Al_2O_3 Embraced Grinding Wheel" for Achieving Nano Level Surface Finish

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Abstract

High surface finish is the requirement for most of the engineering products. High surface finish leads to closer tolerances and longer product life. However, most of the existing processes have their own limitations for producing product specific surface roughness in a cost effective manner. This limitation is primarily induced due to the particle size of constituent abrasive, which is directly reflected on the grinded surface. To overcome this limitation, use of nano size particle of α-$Al_2O_3$is proposed as a constituent of grinding wheel. The current research presents the development of α-Al_2O_3embraced grinding wheel for achieving surface finish of up to 0.09 micron which is difficult and requires skill with conventionally used grinding wheels. The wheel so produced results into the significant improvement over surface roughness values and thus demonstrates its superiority over conventional grinding wheels.

Keywords: α-Al_2O_3 abrasive, Surface grinding, super finishing, Nano particle, hydrolysis.

Introduction

Demand for superior surface finish and accuracy has been rapidly increasing in recent years. Nano-surface finish has become a significant parameter in the mechanical industries. Machining upto nano accuracy is a great challenge in the manufacturing industry[1]. Grinding is the most extensively used abrasive finishing process among all traditional processes used in production. It is a process of material removal in the form of very small chips by the mechanical action of abrasive particle bonded together in a grinding wheel. It is basically a finishing process employed for producing close dimensional and geometrical accuracies and smooth surface finish[2]. There are various types of abrasives material used to manufacture the grinding wheel like aluminum oxide, silicon carbide etc. Alumina (Al_2O_3) is broadly used in a variety of applications, because it has superior physical and chemical properties which are high heat resistance, excellent electrical isolation, abrasion resistance and high corrosion resistance[3]. In grinding process, the net effect is that the specific cutting energy is about 10 times greater than for turning or milling. In other cutting processes only 5 percent of energy input ends up in the finished surface whereas the bulk of it is wasted in the form of high chip temperature. In grinding, greater than 70 percent of energy goes into the finished surface. This results in significant temperature rise and generation of residual stresses[4].

Instead of micro size abrasive particles in commercially available grinding wheel, the surface finish can be improved by using the grinding wheel constituted of nano size abrasive particles.

The prominent factors for reducing the abrasive size are: i. Specific cutting energy in Grinding and ii. Grain depth of cut[5].

Materials and Methods

Specific Cutting Energy in Grinding: Specific grinding power or specific cutting energy is defined as the power required 6removing unit quantity of the material per unit time. The specific cutting energy is depends on the chip thickness and the nature of the workpiece material.

Specific cutting energy, $U_w = \frac{Fz.Vg}{Vw.b.d}$

Grain depth of cut: Grain depth of cut is acting a significant role in grinding. It determines the area of contact between the chip and the grain and the force on the abrasive grain. As grain depth of cut 't' decreases the rake angle become more negative and specific grinding energy 'U' increases. An increase in specific grinding energy increases the grain tip temperature, which cause the wear rate and the work piece temperature to increase.

For micro size grain abrasive.: The data with which the grinding on test specimen were taken as- diameter of grinding wheel D_g= 105mm; wheel depth of cut d= 0.01mm; velocity of grinding wheel v_g= 30m/s; velocity of the workpiece v_w= 0.1 m/s; ratio of chip width and height r = b/h = 10 to 20, For ASTM Number 0 the number of grain / mm^2C = 7.8 grains/ mm^2.

The grain depth of cut is given by Equation-1

$$t = 2\left[\frac{vw}{C.r.vg}\left(\frac{d}{Dg}\right)^{1/2}\right]^{1/2} = 2\left[\frac{0.1}{7.8\times15\times30}\left(\frac{0.01}{105}\right)^{1/2}\right]^{1/2}$$

= Grain depth of cut, t = 1.10 µm (1)

For nano size grain abrasive: Diameter of grinding wheel D_g= 105mm, wheel depth of cut d= 0.01mm; velocity of grinding wheel v_g= 30m/s, velocity of the workpiece v_w= 0.1 m/s; ratio of chip width and height r = b/h = 1 to 5, for ASTM Number 20, the number of grain / mm^2C = 8126040 grains/ mm^2 grain depth of cut is given by Equation-2

$$t = 2\left[\frac{0.1}{8126040\times1\times30}\left(\frac{0.01}{105}\right)^{1/2}\right]^{1/2}$$

= Grain depth of cut, t = 4 nm (2)

It is expected that with smaller abrasive particle the specific grinding energy increases along with the temperature of the test specimen. This gets compensated with the superior surface finish and accordingly closer tolerances can be achieved.

Experimental Work: Preparation of nano alumina powder: Alum [$Al_2(SO_4)_3K_2SO_4 24.H_2O$], hydrochloric acid [HCl], buffer solution [ammonium sulphate + ammonium chloride] and distilled water are used as a raw materials to prepare nano alumina powder. Alum is crushed into mortar to get fine powder. The alum powder is mixed with hydrochloric acid [HCl] and distilled water. The solution is heated to boil till alum is completely mixed into solution. The solution is filtered in another beaker and clear solution is obtained.

Al(s) + HCl → $AlCl_3$ + H_2 + Silica and ferrous impurities.

Distilled water is added slowly in above solution which settles down the impurities $AlCl_3$ + silica and ferrous impurities + H_2O → SiO_2+ Fe_2O_3+ $AlCl_3$

Above solution is filtered.

The clear solution is heated till boiling and then buffer solution [ammonium sulphate + ammonium chloride] is added. Figure-1 shows the process. A buffer is solutions that can maintain a nearly constant pH if relatively small amounts of strong acids or bases are added. Buffer solutions resist pH changes. Addition of buffer into this hot clear solution gives very fine and white precipitate.

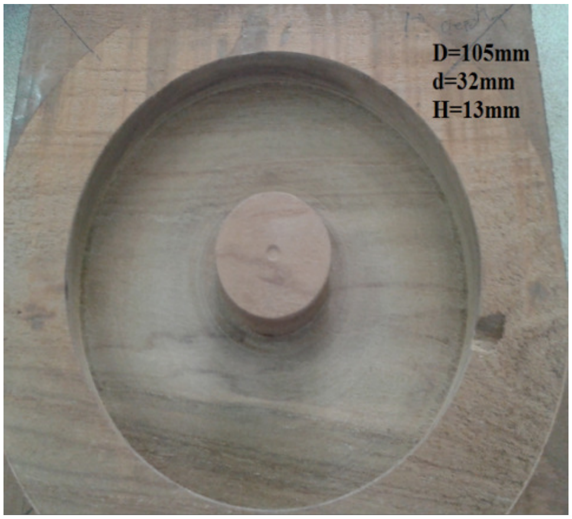
This white precipitate (consisting of …..) and solution is heated and filtered to obtain very fine and light precipitate. This precipitate is to be heated in furnace up to 5 hours at 600°C to obtain very fine powder.

To develop a grinding wheel: A commercial grinding wheel (100×31.75×13 mm^3) is fixed inside a mould with 2.5 mm outside gap. The alumina nano powder and resin as a binding material is poured into the gap of the mould and slowly dried to form grinding wheel coating. The wheel with the coating is taken out from the mould and the diamond wheel dressing is done on the wheel coating of 2.5 mm for the roundness of the disc. The coating thickness reduces to around 1 mm.

Figure 1(a) Al_2O_3ppt

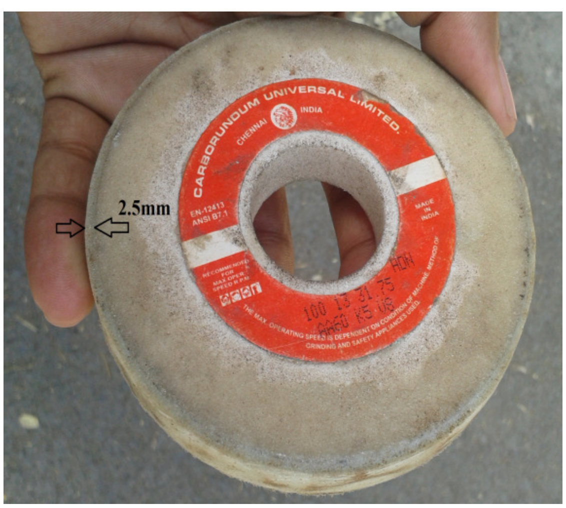
Figure-1(b) precipitates after heating

Figure 1(c) Alumina nano powder
Figure-1
Preparation of abrasive nano particles



(a) Wheel mould

(b) Nano coating



(c) Wheel after dressing
Figure-2
Grinding wheel

Grinding on SS-304 plate: Figure-3 shows the test specimen machined with new grinding wheel on surface grinding machine. The surface shows the grinding passage with and without coolant.

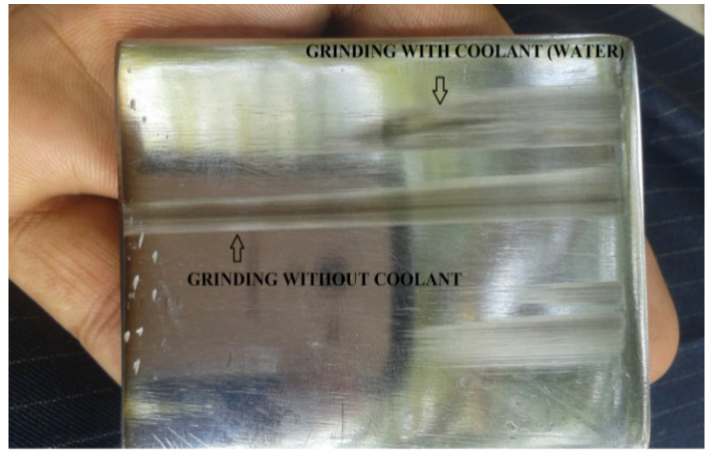


Figure-3
Test specimen after grinding

Figure-4 shows the variations in surface scratches on the test specimen. Before using the new grinding wheel the grinding was done with conventional grinding wheel. The use of new wheel shows the remarkable improvement on the surface finish as observed by microscope as shown in Figure-4.

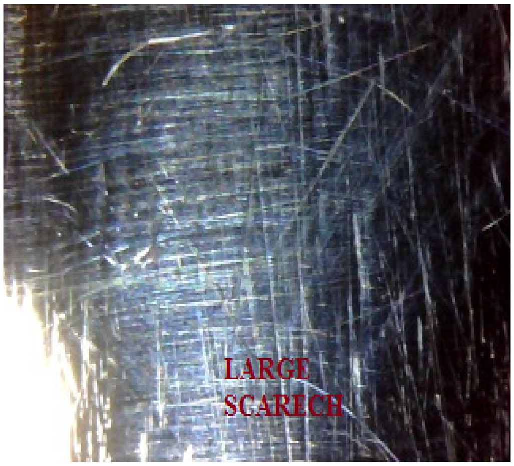
Surface cleaning of test specimen: In absence of a regular production facility of a grinding wheel the process of making the wheel was done by coating of nano abrasive particles with available resin in a mould. The resin could not withstand the grinding temperature howsoever the process of grinding was carefully done. The burnt deposit of resin had to be cleaned before any conclusion. The buffing and ultrasonic cleaning was done thereafter. The comparison of the surface was done with the same setting of machine and the adjacent passages of new and conventional wheels.

Results and Discussion

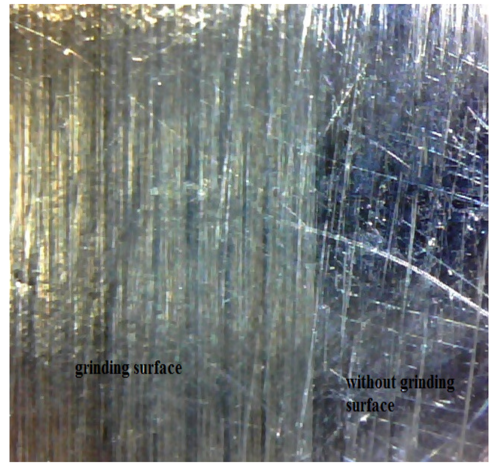
X-Ray diffractometer (XRD) test: For the alumina nano powder, the XRD measurements were carried out using Bruker D8 Advance X-ray diffractometer. The x-rays were produced using a sealed tube and the wavelength of x-ray was 0.154 nm (Cu K-alpha) $2\Theta = 10^o - 80^o$.

The average crystallite size of 25 nm obtained powders was estimated by Scherer's equation from the XRD pattern. The x-rays were detected using a fast counting detector based on Silicon strip technology (Bruker LynxEye detector).

Surface roughness: With the conventional grinding wheel the R_a value obtained on the test specimen was 0.15 micron and with the new grinding wheel the value obtained was 0.09 micron.



(a) Before grinding at 40x



(b) After grinding at 40x

(c) After buffing at 40x

(d) After ultrasonic cleaning

Figure-4
The surfaces using new grinding wheel

(a) Buffing the surface

(b) Ultrasonic cleaning of surface

Figure-5
Surface cleaning

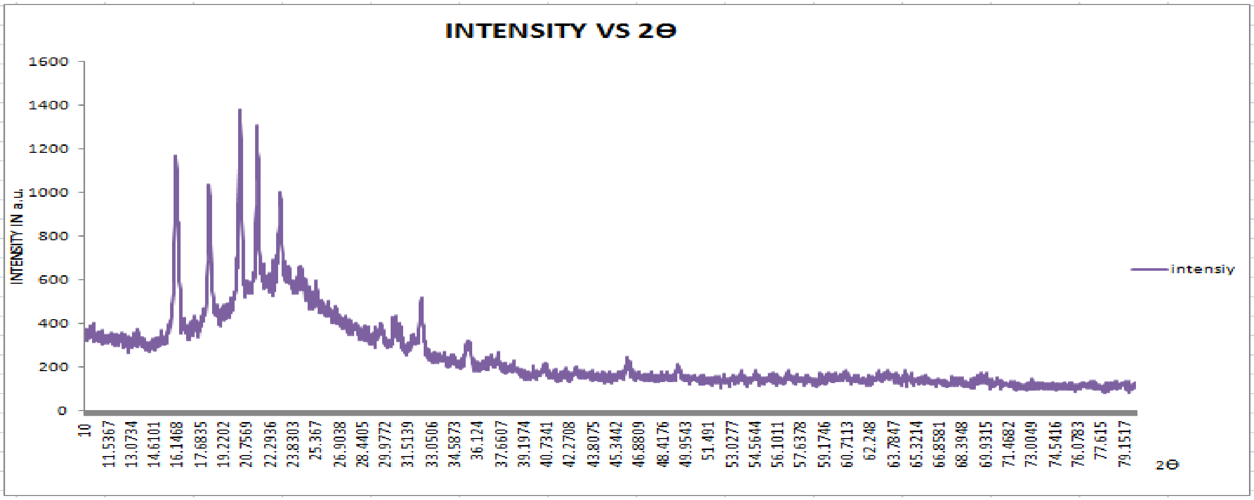


Figure-6
X RD Graph

Conclusion

The nano particle of alumina or nano α-Al_2O_3, by alum as a base material can be made very conveniently. X-Ray diffractometer (XRD) test of the nano alumina powder to determine the crystal size of average particle gives the value as small as 25 nm. The surface finish of the steel is improved by using grinding wheel which is formed by nano size alumina or α-Al_2O_3abrasive. There is a remarkable improvement in surface roughness value of R_a from 0.15 microns to 0.08 micron as indicated by the profilometer.

The current work reports the sequential process and comparative evaluation of α-Al_2O_3embraced grinding wheel for achieving metallic surface roughness at nano level. It demonstrates a cost efficient process to achieve super fine surface finish for a wide range of metallic surfaces. The grinding wheel so developed shows significant improvement of over 46 percent for the values of R_a,. Subsequently, it also scores high on factors like, effective use of specific energy and ease of fabrication to name a few.

It can thus be concluded that α-Al_2O_3 embraced grinding wheel provides efficient alternative over existing and conventional grinding wheels. Such a development is of high industrial significance as it provides an improvised alternative to existing surface grinding processes.

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