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Time dependent behavior of alumina grains manufactured by two different routes while grinding of AISI 52100 steels

Umamaheswari Madopothula [*], *Vijayaraghavan Lakshmanan*, *Ramesh Babu Nimmagadda*

Manufacturing Engineering Section, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600036, India

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ABSTRACT

Grinding is a finishing process in which material is removed from workpiece by hard abrasives with random shape and orientation. The sharpness of abrasive grains tends to vary with grinding time which has a direct impact on material removal mechanisms and hence, the ground surface quality. This urges the researchers to continuously monitor the behavior of abrasive grains online to improve the grinding efficiency. In this paper, two different types of wheels are used: one wheel consists of 100% conventional fused alumina grains and the other wheel is made of 30% sol–gel alumina grains and remaining 70% by fused alumina grains. In case of the wheel containing sol–gel grains, attritious wear of grain occurs as the grinding proceeds which increases the contact area between abrasive grains and workpiece leading to change in dominant material removal mechanism from shearing to plowing and rubbing. The generated wear flats increase the grinding force and temperature in the grinding zone. In case of grinding wheel with 100% fused alumina grains, grit fracture occurs when the grinding force exceeds a critical value leading to self-sharpening and thus maintains the dominant mechanism to be shearing. Post-grinding microstructural characterization is also done to evaluate the materials surface integrity from the aspects of wheel grain behavior.

1. Introduction

Grinding is one of the most commonly used finishing process in manufacturing industries, especially for hard and brittle materials. It is the most complex metal removal process due to the random size and orientation of the abrasive grains [1]. In production industries, the primary needs are high MRR, better grinding ratio, good surface finish and high surface integrity. However, in grinding there is always a trade–off between the quality of the machined product (surface finish and integrity) and the productivity (MRR and operational cost) [2]. Selection of proper grinding wheel–workpiece combination along with other process parameters such as feed rate, cutting speed, depth of cut, etc., plays a key role in producing quality product with higher productivity. Grinding ratio is an important parameter considered in selecting a proper grinding wheel–workpiece combination [3].

* *Corresponding author.*
E-mail address: umapapa@gmail.com (U. Madopothula).

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Nomenclature

v_w	feed rate (m/min)
v_s	cutting speed (m/s)
a	depth of cut (μm)
F_t	tangential component (N)
F_n	normal component (N)
Δw_{sample}	difference in sample weight before and after grinding (kg)
Δw_{wheel}	difference in grinding wheel weight before and after grinding (kg)
ρ_{sample}	density of the sample (kg/m^3)
ρ_{wheel}	density of the grinding wheel (kg/m^3)
U	specific grinding energy (J/mm^3)
b_s	width of the sample (mm)
MRR	material removal rate (mm^3/s)
CCD	charge coupled device
WA	grinding wheel with 100% fused alumina abrasive grains (WA60J8VS3)
SG	grinding wheel with 30% sol–gel and 70% fused alumina abrasive grains (SG60-30J8VS3)
EDM	electrical discharge machining

In grinding wheel, the hard phase components are the abrasive grains, which have more influence on the microscopic interactions of the process (such as cutting, plowing and rubbing) and surface integrity of the samples [4]. Since the removal rates (grinding efficiency) and surface integrity of the ground surface depend upon the performance of the abrasives, any advancement in abrasive grain leads to better grinding process.

Diamond cannot be used to grind ferrous materials due to the chemical affinity between them. Grinding of ferrous material with diamond leads to the formation of Fe_3C degrading the surface integrity and also tends to cause diamond pull out from the grinding wheels [5] leading to poor grinding wheel performance. Grinding of ferrous materials with silicon carbide (SiC) grains leads to similar phenomenon [3]. Hence, alumina grains and cubic boron nitride grains (cBN) are mostly used to grind hardened steel work materials [6]. Conventional fused alumina grains have self–sharpening features, hence it has more friability. This high friability attributes more wheel wear in conventional alumina grains. Alumina grains are also fabricated using a novel method called sol–gel process. In this process, the alumina grains have more toughness compared to the conventional alumina grains [3].

In this paper, the performance of grinding wheels with two different types of alumina grains is evaluated in terms of wheel wear, grinding temperature, tangential and normal grinding forces, grinding ratio and specific energy. Also, the surface integrity of the material ground by both the wheels is also investigated using the grinding parameters as mentioned before.

2. Experimental procedure

Commercially available AISI 52100 steel is procured and through–hardened using standard heat treatment procedure to attain an average hardness of 62 HRC. The chemical composition of the material is validated by optical emissive spectroscopy, which is shown in Table 1.

Samples of dimension 50 mm × 13 mm × 20 mm for grinding experiments are cut using wire cut EDM. The process parameters used for wire cut EDM (make: Elektra Ecocut) are presented in Table 2. After cutting, the samples are finished using mild grinding with flood coolant to minimize the thermal damage. Two grinding wheels, with alumina grains processed by different routes, are used in this study. In the first grinding wheel, all the alumina grains (100%) are processed by conventional fusion route (WA60J8VS3). In the second type of grinding wheel, 30% of the grains used are processed by sol–gel technique and rest of the grains (70%) is fusion processed (SG6030J8VS3). The specifications of the wheels are presented in Fig. 1. Both the wheels have the same grain size, hardness and porosity. The wheels have an outer diameter of 200 mm, inner diameter of 31.75 mm and a width of 13 mm. The run–out of the wheel spindle of the grinding machine is measured using dial indicator and is found to be within 2 μm.

Plunge grinding experiments are conducted with feed rate (v_w) of 7.2 m/min, cutting speed (v_s) of 25 m/s and depth of cut (a) of 10 μm. In order to maintain constant surface speed, the spindle speed (rpm) is varied to compensate for changes in wheel diameter due to wheel wear. Prior to each test, the workpiece is ground to ensure its flatness. To evaluate the time dependent behavior of the grinding wheels, two different types of grinding experiments are conducted. The first sets of experiments (discrete experiments, hereafter) are conducted on 25 samples without wheel dressing in between. Each sample is ground by removing a total depth of 200 μm with 10 μm depth of cut per pass using SG wheel and the various samples are marked as S1, S2, S3, . . ., S25 accordingly. Similar

Table 1 – Chemical composition of AISI 52100 steel.

Element	C	Si	Mn	P	Cr	Ni	Fe	Others
% comp	0.948	0.292	0.43	0.168	1.38	0.123	96.4	0.28

Table 2 – Process parameters for wire cut EDM.

Wire used	Gap voltage (V)	Wire feed rate (mm/min)	Pulse on time (μs)	Pulse off time (μs)	Peak current (A)	Dielectric fluid
Brass wire of diameter 0.25 mm	40	4	6	6	2	Deionized water