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Grindability assessment of metal matrix composites

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Abstract

In this paper, an experimental study on the grindability evaluation of Metal Matrix Composites is reported. To this purpose, experimental data obtained from tests carried out on a horizontal surface grinder have been employed. Investigations deal with the grinding forces and the degradation of the grinding wheel surface, acquired during the machining process and surface roughness of the workpiece material. The effects of grinding wheel abrasives, both conventional and superabrasives as well as the material characteristics, such as shape, orientation and content of the reinforcement and type of matrix, on the grinding wheel degradation and ground surface quality is analyzed by means of grindability indices.

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Keywords: Grinding, Metal matrix composite; Grindability; Modelling.

Nomenclature

a	depth of cut (mm)
v_w	feed speed (mm)
v_s	wheel peripheral speed (m/s)
V'_w	specific material removal rate (mm^2/s)
F_t, F_n	tangential and normal forces, respectively, per unit width of grinding wheel (N/mm)
A	flat area percentage on the active surface of the grinding wheel (%)
I(x)	grindability indices, where, according to the cases, x stands for F_t, F_n and A
TGI	Total Grindability Index
Ra	Roughness Average (μm)
HRB	Brinell hardness

1. Introduction

In recent years Metal Matrix Composites (MMCs) have attracted much attention due to their excellent mechanical properties such as high specific strength and wear resistance. Some of the typical applications are bearings, automobile pistons, cylinder liners, piston rings, connecting rods, sliding electrical contacts, turbo charger impellers, space structures. MMCs components need to be formed into the desiderate shapes and finished to the required dimensions and tolerances. Metal Matrix Composites are given their required shape by bonding, brazing, powder metallurgy techniques, casting, metal spraying and by forming operations such as bending, swaging, drawing and extrusion [1]. Although components made of these materials, can be produced by near-net shape manufacturing, they usually require subsequent machining operations to achieve dimensional tolerances as well as good finish.

Machining of these new materials requires tool materials possessing very high wear resistance because the

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reinforcement is extremely abrasive [2]. Among traditional machining processes, grinding operation is important for MMCs, since it could be applied also in heavy-duty machining, in addition than that to obtain desired dimensional tolerances and surface quality. In literature, a considerable work has been carried out to understand the mechanisms of grinding conventional materials by regarding the grinding process as an interaction system between the surface of the wheel and the workpiece [3]. On the contrary, information about the grindability of MMCs are not yet sufficient [4,5]. A study on grinding with resin bonded and plated diamond abrasive wheels has been carried out to evaluate the significance of bond on wheel performance [6]. Grinding is a complex manufacturing process with many parameters which influence each other, therefore, modelling can be an useful tool to the comprehension and the simulation of the process itself [7,8]. Tönshoff et al. have described the state of the art in the modelling and simulation of grinding processes of traditional materials [9]. The aim of this study is to propose grindability indices for investigating how the grinding wheel and the workpiece material affect the grinding forces, the flat area percentage on the active grains of the wheel and the surface roughness.

2. Experimental tests

Experimental tests have been carried out utilizing for tests a horizontal surface grinder, employing grinding wheels based on both conventional abrasives and superabrasives. Grinding wheels, based on four different abrasive types, i.e. alumina (Al_2O_3), silicon carbide (SiC), Cubic Boron Nitride (CBN) and diamond (ASD), Table 1, have been used in the tests. Hereafter, the above four types of abrasive wheels are referred to as A46, C60, CBN and ASD, respectively. The MMCs employed as workpiece in the tests are Aluminium alloys reinforced with powders/whiskers made of silicon carbide. Two types of MMCs have been initially investigated, one, referred to 15P-p (see Table 2) with a reinforcement in form of powder, the latter, referred to 15W-n, with a reinforcement in form of whiskers. Specimens with dimensions 13x23x23 mm have been cut from extruded bars.

Table 1. Abrasive grinding wheels employed in the tests.

Grinding wheel	Diameter (mm)	Abrasive type	Grit size	Bond type
32A 46-IV	200	Al_2O_3	46	vitrified
39C 60-KVS	200	SiC	60	vitrified
CBN 126QB99	200	CBN (75% concentration)	126	resinoid
ASD126R75B99	200	Diamond (75% concentration)	126	resinoid

MMC samples reinforced with powders have been ground in direction parallel to the extrusion one, while MMC specimens reinforced with whiskers have been ground in the direction perpendicular, i.e. perpendicularly to direction to which the fibres are preferentially oriented. Thereafter, in order to compare the behaviour of the different kind of MMCs, tests using the same grinding wheel (alumina) have been carried out. Alumina is softer that silicon carbide, i.e. the reinforcement material of the MMCs under test. However, it has been found in our previous investigations as well as in the present one that the main form of wheel degradation is the clogging due to the soft aluminium matrix, with a negligible wear of the alumina grains. This behaviour can be attributed to the small relative motion occurring between the silicon carbide particles and the grains of the wheel due to the fact that the SiC particles are very small and not held strongly by the soft matrix.

Table 2. MMCs employed for the grinding tests.

Workpiece material	ID code	Hardness (HRB)
Al-2009 / SiC-15P, parallel	15P-p	83.4 ± 1.0
Al-2009 / SiC-20P, parallel	20P-p	62.4 ± 1.7
Al-2009 / SiC-20P, normal	20P-n	67.6 ± 1.5
Al-2009 / SiC-25P, parallel	25P-p	72.6 ± 1.0
Al-2009 / SiC-15W, parallel	15W-p	62.1 ± 1.4
Al-2009 / SiC-15W, normal	15W-n	70.5 ± 1.1
Al-2009 / SiC-20W, normal	20W-n	95.9 ± 0.7
Al-6061 / SiC-25P, normal	6061-25P	52.4 ± 0.6
Al-7075 (not reinforced), normal	7075	47.4 ± 0.6

Dry conditions and constant cutting parameters have been adopted for all tests, as reported in Table 3. Each test, consisted of 100 plunge cut grinding passes with 0.01 mm depth. Force components per unit width of grinding wheel (F_n and F_t), flat area percentage on grinding wheel surface (A) and workpiece surface roughness (Ra) have been measured every 5 single grinding passes. The images have been recorded by means of a CCD camera, with an illuminating system perpendicular the wheel surface [10].

Table 3. Grinding parameters adopted in the tests.

Depth of cut, a (mm)	0.01
Feed speed, v_W (mm/s)	300
Wheel peripheral speed, v_S (m/s)	22

3. Modelling

In order to establish easy to handle relationships to correlate the output parameters to the process parameters, empirical relationships, have been formulated for each quantity recorded during tests. However, such empirical models can be employed for the description of one machining characteristic at a time. On the other hand, material grindability cannot be defined on a specific technological property, but it is a function of a set of different behaviour which cannot be correlated each other. In order to compare the behaviour of the different MMCs under test, the weighted average values of the measured quantities, i.e. normal and tangential components of grinding forces, flat area, and roughness, have been calculated through defining the following grindability indices: