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Szalóki, I.; Sipos, S.; Viharos, Zs. J.: Aluminum-Based MMC Machining with Carbide Cutting Tool, *Proceedings of the 8th International Congress on Precision Machining - ICPM 2015*,
Novi Sad, 1 - 3 October 2015, pp. 151-156.,
ISBN 978-86-7892-742-3

PROCEEDINGS

ICPM 2015 Congress

8th International Congress on Precision Machining

01 - 03 October 2015, Novi Sad, Serbia

Original Paper

ICPM 2015 Congress
8th International Congress on Precision Machining
01-03 October 2015, Novi Sad, Serbia

ALUMINUM-BASED MMC MACHINING WITH CARBIDE CUTTING TOOL

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Keywords: Metal Matrix Composites (MMCs), face milling, built-up edge (BUE), surface roughness

Abstract. Cutting of metal matrix composites (MMCs) has been considerably difficult due to the extremely abrasive nature of the reinforcements causing rapid tool wear and high machining cost. In this experimental study, three aluminium-based metal matrix composites (MMCs) were produced using a high pressure infiltration. Machining tests were carried out by face milling on the MMCs using coated carbide (HM) cutting tool at various values of feed rate, width of cut and depth of cut, under a constant cutting speed. The effect of the varied parameters on the surface roughness was investigated. The obtained results indicate that the Rz and Rp parameters are more capable to describe the influence of the milling parameters on the surface quality.

Introduction of Aluminium Matrix Composites

A composite is a multiphase material consisting of the basic material (an embedding and integrating so-called matrix) and a second phase (intended for reinforcement, with high strength and high elastic modulus). Therefore, the component to provide the basic properties of the composite is the basic material of lower strength, and the load-bearing and load-mediating component is a continuous or granular material, the role of which is made effective by applying a variety of production technologies and establishing a bond with the matrix material. So, the basic material (matrix) keeps together the particles of the second phase and is responsible for an even distribution of external loads, while the second phase is destined for bearing mechanical stress as described above. Even in case of high levels of mechanical stress, there is a permanent and strong (adhesion) link between the two components. In general, it can be stated that composite properties are determined by the quality and structure of the two components mentioned (the matrix and the second phase), the morphology (shape) of the second phase, and the boundary surface between the constituents [1].

Aluminium matrix composites (AMCs) are the basic of this paper. In AMCs one of the constituent is aluminium/aluminium alloy, which is a matrix phase. The other constituent is embedded in this aluminium alloy (AlSi12, AlCu5 etc.) matrix and serves as reinforcement, which is usually non-metallic and commonly ceramic such as SiC and Al_2O_3. Properties of AMCs can be tailored by varying the nature of constituents and their volume fraction.

The objectives of producing AMC materials are manifold: to increase mechanical strength; to influence friction and wear; to affect thermal dilatation / stability; to decrease weight by light-structured materials and by preserving low-level density; to ensure excellent processibility and workability [2].

Having regard to the fact that component loads are scarcely identical in all spatial directions, it is obviously reasonable to reinforce homogeneous structural materials with reinforcement materials of higher strength in the distinctive direction of load [2].

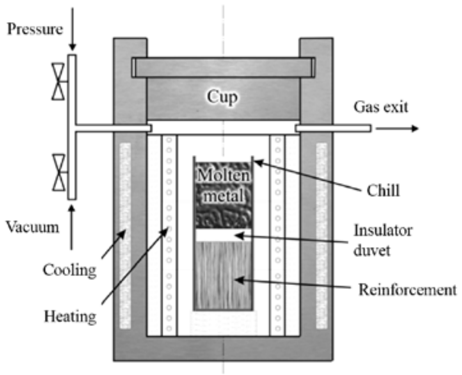
The machined surface quality of composites is one of the most important concerns affecting the actual application of the composites [3]. The structure of wire/fibre reinforced composites is composed of a soft matrix and hard reinforcing strands. It means that under the cutting force the Al matrix and the wire or fibre do not deform uniformly.

Planning for Face Milling Experimentation

Experimental AMC materials

The face milling tests were conducted on fiber reinforced AMCs. The materials with dimensions of 85×85×50 mm were produced using a high pressure infiltration at Budapest University of Technology and Economics, Faculty of Mechanical Engineering, Department of Materials Science and Engineering.

The high-pressure metal infiltration (Fig. 1.) procedure essentially means that the melted metal is introduced to the porous preform at high pressure.



Schematic diagram of batch pressure infiltration unit [4]

WRAMC
(Wire reinforced AMC)

FRAMC
(Fiber reinforced AMC)

Fig. 1 Infiltration process and produced materials

The metal melt is forced into the porous reinforcement material, into the spaces between its granules by pressure. This procedure requires a minimum use of materials and energy, and is also suitable for the production of both particulate and fibrous composites [4]. The produced materials have a relative high volume fraction (~55 vol.%).

Table 1 shows the chemical composition and properties of reinforcements of AMCs used for this purpose.

Equipment setup and procedure

The test were executed in the workshop of Óbuda University Donát Bánki Faculty of Mechanical and Safety Engineering, on a vertical machining center (type: MAZAK Nexus 410A, control: Mazatrol™), which is installed to carry out tool test experiments and equipped with a device for blowing cold, compressed air. Cold Air Gun^{TM} (air temperature: -10 °C) device was used to cool the cutting zone and to support the chip transport.

When machining composite materials, emission of airborne dust is usually formed, so we need to protect ourself from the dust. Vacuum system (type: Einhell RT-VE 550A) combined with Cold Air Gun^{TM} were used to avoid dust entering our bodies and the machine's components.

The face milling cutter – with one cemented coated (TiCN) carbide (HM) insert – (type: 50A05RS90SD12D, insert: SDET1204PDSRGB), having a diameter of ø50 mm, nose radius (r_ε) of

0,8 mm, clearance angle of 5°, rake angle of 6°, major cutting edge of 89.25° and minor cutting edge of 0.75° was provided by Kennametal.

The milling operations were performed at constant ~250 m/min cutting speed, various values of feed rate (f_z – feed per tooth, values: 0.08 ; 0.125 ; 0.16 mm), width of cut (a_e, values: 10 ; 20 ; 40 mm) and depth of cut (a_p, values: 1 and 1.4 mm). Figure 2/a. shows the different sets of experiment.

Aluminium alloy (AlSi12) was also used for milling tests as reference material (marking: **MM**) without any reinforcements. However, the matrix material of AMCs was the same aluminium alloy.

Table 1. Composition of Aluminium Matrix Composites used for experiment

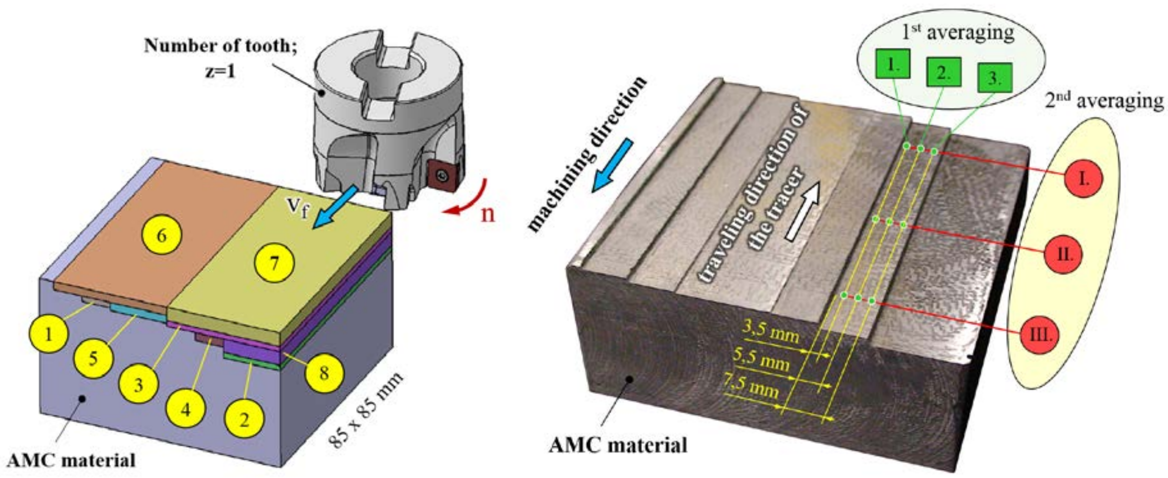
Type of AMC	Wire reinforced AMC	Fiber reinforced AMC
Abbreviation	**WRAMC**	**FRAMC**
Type of reinforcement	Nextel™ 440	Nextel™ 550
Chemical composition of reinforcement	wt.% 70 Al_2O_3 wt.% 28 SiO_2 wt.% 2 B_2O_3	wt.% 73 Al_2O_3 wt.% 27 SiO_2
Orientation of reinforcement	The composite wires are randomly located	The strands are perpendicular to each other
Length of reinforcement	~ 20 mm	It can't be measured because the tool edge cuts across the fibers
Thickness of reinforcement	dia. ~1.5 mm	□ 0.8 x 0.8 mm
Average density of AMC, g/cm^3	2.53	2.51

Table 2. Chemical composition of AlSi12 aluminium alloy (nearly eutectic)

Material	Si	Mg	Cu	Fe	Mn	Zn	Aluminium
(%)	12.8	0.01	0.002	0.13	0.005	0.007	remaining

Method for measuring surfaces

Microgeometric measurements on milling surfaces were performed using the Mahr-Perthen Perthometer PRK Concept-2D, 3D surface tester equipment available at Óbuda University. By fixing an FRW-750 type tracer of 4-5 µm peak radius in the tracing head of the measuring system, measurements were carried out with the following settings: applied traction length (Lt) = 5.60 mm; cut-off filtering wavelength Lc = 0.8 mm; length of assessment (Lm) = 4.00 mm; traction speed set = 0.50 mm/s. The published measuring results of surfaces machined by the different sets of experiments are averaged from nine measurements (it is well to see on Figure 2/b.).



a.) b.)

Fig. 2 a.) Schematic illustration of the different sets of milling process
b.) measuring points of surface roughness [5]

Results and Discussions

Fractured and pulled out particles are practically unavoidable in MMC machining, and the subsurface damage is more substantial in whisker or fibre reinforced MMC than in particle reinforced MMC materials [6].

Surface integrity is affected by particle fracture, interfacial delamination, particle pull out and matrix work-hardening [7]. All of these factors deteriorate the surface roughness and influence the measured values.

The following subsections describe the values of the filtered and unfiltered registered profiles, furthermore, the comparison of the Ra, Rz, Rt, Rp, RSm, resp. Pa, Pz, Pt, Pp, PSm parameters. These values are to carry out a versatile characterization of the surface roughness of the machined surfaces.

Table 3 illustrates the general roughness values of the machined surfaces in case of the selected materials. The given values are averaged from 54 measurements.

Table 3. Comparison of the measured roughness values

Material mark	Ra	Pa	Rz	Pz	Rz/Ra	Pa/Ra	Pz/Rz	PSm/RSm
MM	1,39	2,02	8,08	11,64	5,82	1,45	1,44	1,64
FRAMC	0,72	1,04	5,41	8,13	7,52	1,45	1,50	1,96
WRAMC	0,65	1,09	4,91	8,67	7,54	1,67	1,77	2,97

Analysing the data of the table shows us the following statements:

- common surface quality can be achieved with the hard metal insert by milling AMCs;
- built-up edge (BUE) were observed by each runs, which has a significant effect on the surface roughness parameters;
- the accompanying built-up edge damaged mostly the surface of Matrix Material (MM);
- the surface roughness depth (Rz) is 5…8 times higher than the average roughness (Ra) parameter - as we recommended to use in practice the much more informative parameter Rz;
- the results also indicate that the index number Pa of the unfiltered profile is only 1.4 to 1.7 times larger than the filtered parameter (Ra), while in case of roughness height (Rz) the value of the parameter Pz is also 1.4 to 1.8 times higher when comparing filtered and unfiltered parameters. This proves that there is no considerable different between the P and R-profile by face milling of AMCs. In case of both parameters analyzing the unfiltered profile is demonstrable the slight waviness of the surface.
- PSm/RSm ratio clearly shows that the surface of WRAMC is loaded with higher waviness. Its main reason is that under the cutting forces the Al matrix and the wire do not deform uniformly.

Average surface roughness (Ra) and surface roughness depth (Rz)

Figure 3 shows the average roughness (Ra) and maximum height of the profile (Rz) of the workpiece surface vs. feed when the material was machined at one cutting speed (~250 m/min) with three different values of feed per tooth. The obtained surface finish has significantly changed when varying feed rate within the experimental range.

It results in a better surface roughness (by 30-40% lower) when increasing the feed rate from 0.08 to 0.16 mm during machining of FRAMC material. The 4th experimental set is unequivocally the best. Furthermore, the 3rd set is favourable in case of machining composites and it is also productive.

Generally the surface finish has not expectedly deteriorated when increasing the feed rate, but at higher feed rates, there is a little difference.

The increased feed rate influences negatively the surface roughness of the matrix material (MM) because there is strong built-up edge on the tool edge and it changes the micro geometry of the surface.

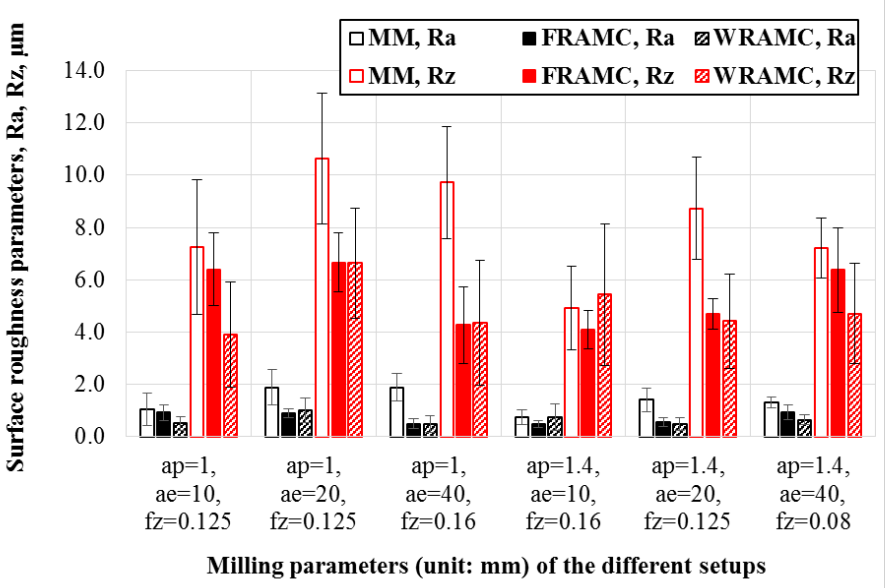


Fig. 3 Values and deviations of surface roughness depth by different sets

Significance of the parameter to describe the maximum peak height of the profile

The maximum peak height (Rp) of the profile corresponds to the distance of the centre line and the tallest profile peak measured along the length of assessment (5x0.8 mm) [9]. The content of the parameter Rp is questionable in certain cases as measurement evaluation can be easily altered by a lofty profile deviation, therefore a detailed check was performed on our tests with carbide insert.

The great number of measurements (exactly 54 pieces) performed by us, is definitely enough for characterizing the significance of parameter Rp.

Smaller peak height values indicate a surface divided by strong, robust, lean valleys, while larger Rp values refer to profiles ”scantier in substance”, with pointed peaks wearing much more intensively and divided by thick valleys. If the ratio Rp/Rz is higher than 0.5, then the peak zone will be ”pin-like”; if it is smaller than 0.5, then the characteristic material profile will be more favourable and rounded off [10].

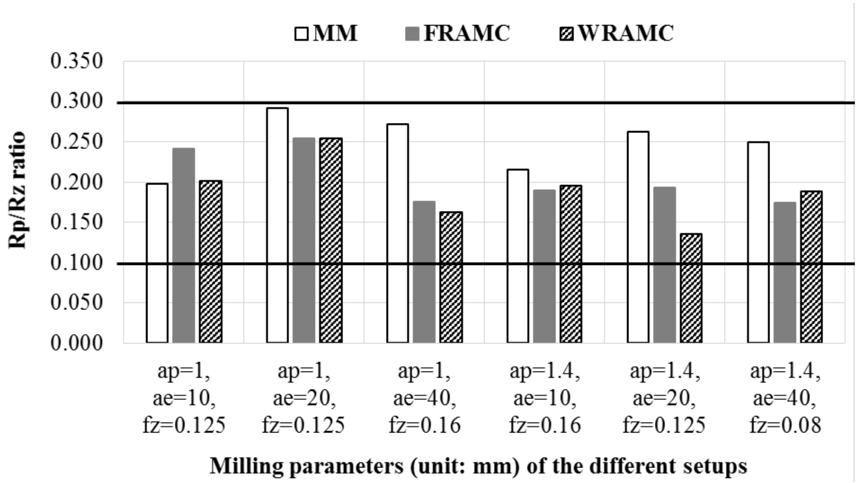


Fig. 4 Rp/Rz ratio in a function of the experimental runs

The average Rp/Rz ratio (Fig. 4.) of milled surfaces of the tested matrix material is 0.38. The same parameter for the FRAMC material is 0.33 and for WRAMC 0.34. It is really favourable because the wear properties of such a surface is highly strong and the pointed peaks of the matrix material have an improved lubricant retention capacity. These results can be achieved using the 3rd and 4th experimental sets.

Summary

Face milling is preferred by us when studying machinability of AMCs since face milling requires much less material for machining.

Based on the results described in this study, the following conclusions can be drawn:

- generally, the surface finish is improved when increasing feed rate value at the same cutting speed;
- it is important to note that the best surface finish of machined AMCs is obtained with an axial depth of cut of 1.4 mm and a feed rate of 0.125 and 0.16 mm, so it can be concluded that the higher feed rate improves the surface roughness;
- the real P profile (unfiltered and containing waviness as well) shows a significant (the P-profile is 1.4 … 1.7 times higher than the R-profile) deviation from the R profile and their R-parameters in case of machining the produced FRAMC and WRAMC materials;
- the Rp/Rz ratio of milled surfaces of the tested materials varies between 0.1 and 0.3. It is really favourable because the wear properties of such a surface is highly strong and the pointed peaks of the matrix material have an improved lubricant retention capacity.

All of these machine-induced effects and considerations of the surface might be a concern when the AMCs are used in a critical application.

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ISBN 978-86-7892-742-3