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Investigation of Ultrasonic Assisted Milling of Aluminum Alloy AlMg4.5Mn

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Abstract

Rotary ultrasonic machining is a machining process designed for machining hard and brittle materials, utilising a tool of undefined geometry. Soft and tough materials, such as aluminum alloys, are not suitable for this type of machining using a tool of undefined geometry. However, the milling of tough alloys is also possible with the assistance of ultrasound, using a tool of a defined geometry, which is called ultrasound assisted milling. This contribution investigates the surface quality parameters achieved by the ultrasound assisted milling of EN AW 5083 non-hardenable aluminum alloy.

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Keywords: Milling assisted by ultrasound; Non-hardenable aluminum alloy; Quality of surface

1. Introduction

Ultrasound assisted machining processes have many advantages. Application of ultrasound decreases cutting forces (enables machining thin-walled workpieces), decreases generation of process heat (enables machining heat sensitive materials) and increases tool life. Also, it enables machining hard and brittle materials, such as glass and ceramics. These effects also influence surface roughness. Rotary ultrasonic machining (RUM) can reach arithmetic roughness Ra 0.3 μm. However, RUM is usually used for the machining of brittle materials, and it utilises a tool of undefined geometry with diamond abrasive particles. Such tool, however, is not suitable for machining soft and tough materials, such as aluminum alloys. Therefore the mill of defined geometry made of high speed steel (HSS)

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and coated with TiCN is recommended for this kind of materials. Combination of the tool of defined geometry with ultrasonic vibration should positively affect the quality of surface [1,2,3,4,5].

Nomenclature

Ra	arithmetic roughness
Rz	maximum height roughness
Tp	material proportion profile

2. Workpiece material and machining equipment

2.1. Workpiece material

The current interest in the materials of low mass and high strength, such as aluminum alloys, keeps growing. Such materials are being increasingly used for their low weight and relative high strength, as well as for their good corrosion resistance. Their main applications are in automotive industry, aerospace and in other kinds of industry. Aluminum alloys could be divided to hardenable and non-hardenable. One of the most utilised Al alloy is AW 5083 (AlMg4.5Mn). It is a non-hardenable alloy of series 5 (alloyed by Mg). AW 5083 is the most wide-spread non-hardenable Al alloy. Its chemical composition is shown in Table 1. Its main mechanical properties are shown in Table 2. Table 3 shows its physical properties [6,7].

Table 1. Chemical composition of AW 5083.

Element	**Al**	**Mg**	**Mn**
wt. %	94.84	4.53	0.63

Table 2. Mechanical properties of AW 5083.

Hardness [HRC]	**Elongation** [%]	**Yield strength** [MPa]	**Tensile strength** [MPa]
35,6	16	228	317

Table 3. Physical properties of AW 5083.

Melting point [°C]	**Density** [$kg.m^{-3}$]	**Young´s modulus** [GPa]	**Thermal conductivity** [$W.m^{-1}.K^{-1}$]
638	2660	71	1.15

2.2. Machining equipment

Ultrasonic 20 linear, the machine tool made by DMG Mori Seiki was used in this experiment. It is a five-axis rotary ultrasonic and high speed cutting machine tool. Ultrasonic oscillation is provided by an ultrasonic generator with a piezo-ceramic convertor. High speed cutting is ensured by spindle, which can reach 42 000 rpm. Feed acceleration is over 2g. It has a 5-axis gantry construction with an integrated NC swivel rotary table. It has very high precision of positioning. The cooling system can supply the process liquid by four outer nozzles and by the core of the tool. During the experiments, only outer nozzles were used. Presence of liquid with proper attributes is necessary for RUM [8,9,10,11,12].

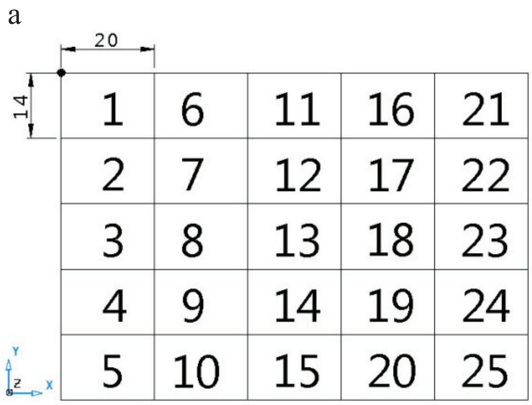
As a tool, a face mill with two cutting edges was used. The tool is made of carbide by SECO Company under the trade name 905XL020-MEGA-T. The main dimensions of the tool are presented in Table 4. Tool-holder bears a label HSK 32S-ER11 [13].

Table 4. Dimensions of tool.

Diameter [mm]	Length of active part [mm]	Whole length [mm]	Rake angle [°]	Flank angle [°]
2	2.2	60	10	25

3. Description of the experiment

A plate by the dimensions 100 x 70 x 10 mm made of the above mentioned EN AW 5083 Al alloy was used for the experiment. On the biggest surface (100 x 70 mm) rectangular areas by the dimensions 20 x 14 mm were milled (25 areas at all), as shown Fig. 1a. Scheme of clamping and placement of workpiece in workplace of the machine tool is shown in Fig. 1b.



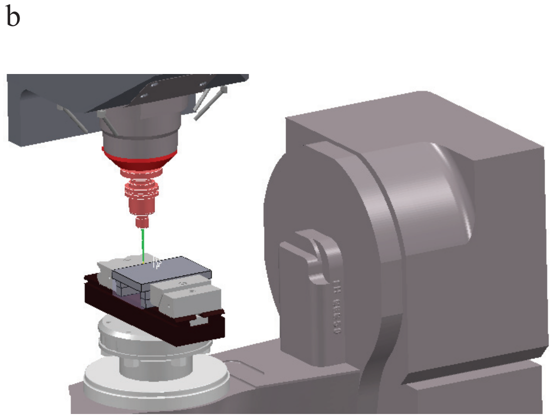


Fig. 1 Scheme of experiment (a) milled areas on workpiece, (b) workpiece in workplace of machine tool.

During the experiment, the speed of spindle changed in the horizontal direction (axis X in Fig. 1a) and the feed rate in vertical direction (axis Y in Fig. 1a). The frequency of the spindle rotation reached the values 5000 rpm (first column), 5500 rpm (second column), 6000 rpm (third column), 6500 rpm (fourth column) and 7000 rpm (fifth column). The feed rate reached the values 100 (first line), 200 (second line), 300 (third line), 400 (fourth line) and 500 $mm.min^{-1}$ (last line). Depth of the cut was constant 0.1 mm. The workpiece was milled by ultrasound with frequency 21 467 Hz (harmonic frequency of tool – determined by FEM analysis) and amplitude 6 µm.

Measurement was performed on Surtronic 3+, the measuring device made by Taylor Hobson Company [14]. Measured were the surface parameters, such as arithmetic roughness Ra, maximum height roughness Rz and material proportion profile Tp. Each measurement was repeated three times. The measurement was performed in the cross as well as longitudinal directions. It gives 600 results, including average values. Therefore, in this article, only the average values of Ra, Rz and Tp in cross direction will be presented. Generally, surface parameters in cross direction are much more important than surface parameters in longitudinal direction. Longitudinal roughness is usually much lower and therefore less significant, than cross roughness.

4. Results of the experiment

The resultant surface roughness for ultrasound assisted milling is shown in Table 5. Average values of arithmetic roughness, maximum height roughness and material proportion profile in cross direction are presented. Owing to the assistance of ultrasound, surface roughness is lower than the roughness measured in conventional milling. The difference is significant especially during milling at the slower spindle speed, as well as at the higher feed rate.

However, conventional milling can achieve a slightly better material proportional profile. Feed rate was not expected to have significant influence on surface roughness as in conventional milling, however, this influence is similar to that in conventional milling [15].

Table 5. Surface quality of machined workpiece by milling assisted by ultrasound.

No.	Feed rate [mm.min^{-1}]	Spindle speed [rpm]	Ra [µm]	Rz [µm]	Tp [%]
1	100	5000	0.68	5.00	53.10
2	200	5000	0.86	6.37	56.07
3	300	5000	0.87	6.43	54.27
4	400	5000	1.14	8.53	53.53
5	500	5000	1.52	11.13	54.53
6	100	5500	0.67	5.97	53.13
7	200	5500	0.96	7.63	56.50
8	300	5500	1.14	8.17	53.53
9	400	5500	1.26	9.77	54.43
10	500	5500	1.30	9.23	56.50
11	100	6000	0.59	4.80	51.63
12	200	6000	0.66	5.03	52.70
13	300	6000	0.61	4.17	52.00
14	400	6000	0.69	5.67	52.07
15	500	6000	0.79	6.73	50.70
16	100	6500	0.66	6.43	52.70
17	200	6500	0.68	5.67	51.33
18	300	6500	0.71	6.50	52.93
19	400	6500	0.81	7.43	52.03
20	500	6500	0.92	7.13	52.77
21	100	7000	0.65	5.63	51.00
22	200	7000	0.70	6.17	54.83
23	300	7000	1.41	16.07	52.57
24	400	7000	1.54	17.23	51.97
25	500	7000	1.13	8.87	51.27

During ultrasound assisted milling, an unexpected decrease of value of the machined surface roughness was observed at the spindle speed 6000 rpm. The rapid decrease of surface roughness was measured several times. Fig. 2 shows the above mentioned dependence for ultrasound assisted milling.

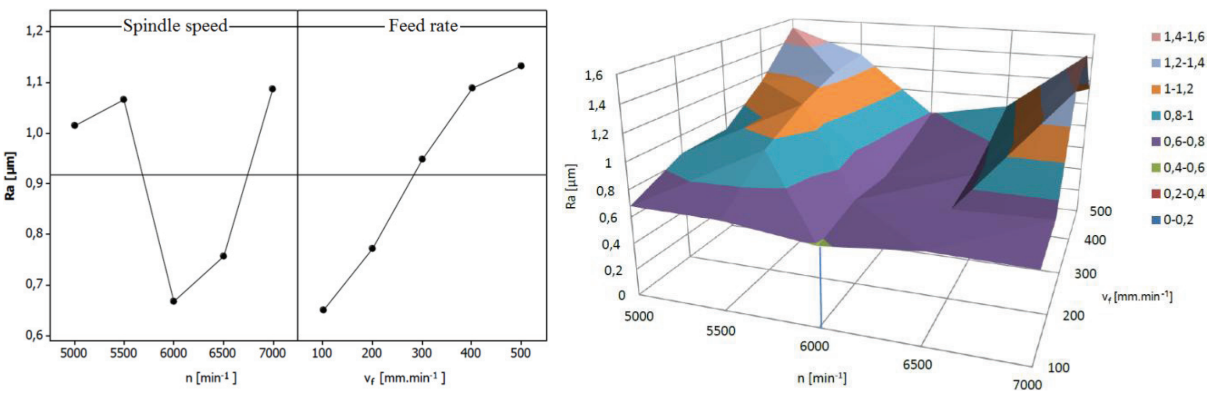


Fig. 2. Dependence of Ra on spindle speed and feed rate during milling assisted by ultrasound.

5. Conclusion

Ultrasonic machining by a common tool for ultrasonic milling, i.e. of undefined geometry is not proper for soft materials. Aluminum should seal active part of the tool, and therefore the tool is not able to cut, only to push material ahead. This is due to fine cutting teeth. However, the tool of defined geometry could have much larger teeth, and therefore active part of the tool could not be sealed by the soft material of workpiece. The experiment confirms the premise, that even soft and tough materials such as Al alloys can be machined with assistance of ultrasound, when using a tool of defined geometry. The best parameters of machined surface were achieved at the spindle speed 6000 rpm. At these conditions, the resultant roughness as well as material proportion profile almost does not depend on feed rate. This unexpected fact could be probably caused by the interference of rotation frequency of the tool and vibration frequency. Anyway, this fact could significantly decrease the production time and also improve the quality of machined surface. Therefore, in further research, this issue will be elaborated in detail, and it will be complemented by other materials (such as titanium and magnesia alloys). Also explained will be the decrease of surface roughness and its independence on feed rate.

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