https://doi.org/10.1051/e3sconf/202337601010

Features of cutting processing of disperse-filled of aluminum-matrix composite materials

Y. Kurganova[1*], *D.* Vinogradov[1], and *Y.* Ivanova[1]

[1]Bauman Moscow State Technical University, 2nd Baumanskaya street, 105005, Moscow, Russia

Abstracts. The results of studies of machinability by cutting of experimental samples of promising aluminum-matrix disperse-filled composition materials are presented. The axial force and cutting torque during drilling were measured, the surface roughness of the obtained holes was studied, and the shape of the chips was analyzed. Analysis of the obtained data allowed to determine the composition of aluminum-matrix material, which provides lower cutting forces, roughness of the machined surface and better chip formation. The influence of the filler composition on the machinability by cutting of aluminum-matrix composites is shown.

1 Introduction

Aluminum-matrix disperse-filled composite materials with their unique set of properties are in demand in modern high-tech industries [1-6]. Despite their clear attractiveness, their use is limited predominantly due to difficulty of cutting processing. The hetero-phase structure of the viscous aluminum-matrix with inclusions of disperse fillers prevents ensuring the preset roughness level [7-12]. Identification of specific features of blade processing allows us to identify key behaviors of the material and select the rational regimes. The most widespread material procession operation is drilling. It is this operation that causes special problems due to material bouncing as the drill comes in and out of the hole. The issues of significant drilling forces and quality assurance of the formed surfaces arise [13-18].

2 Experimental procedure

2.1 Materials and Experimental Equipment

Experimental samples of the promising composition [19-27] have been obtained using the liquid phase mechanical mixing method (invention patent No. 2755353) [28]. For the compositions of the samples, please see Table 1. The sample taken from 1160 (D16) has been studied as a control one.

[*] Corresponding author: kurganova_ya@mail.ru

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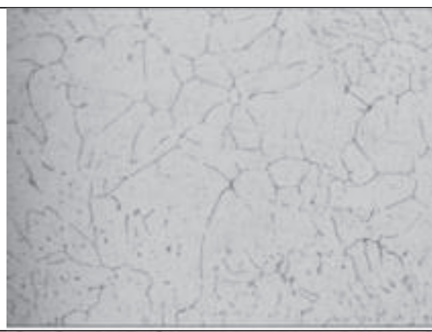
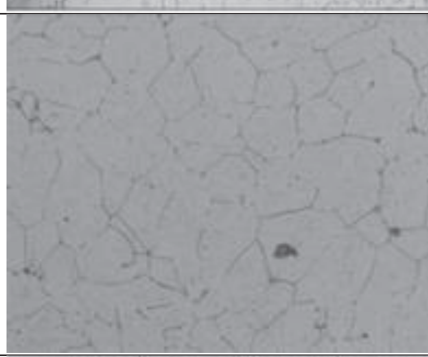
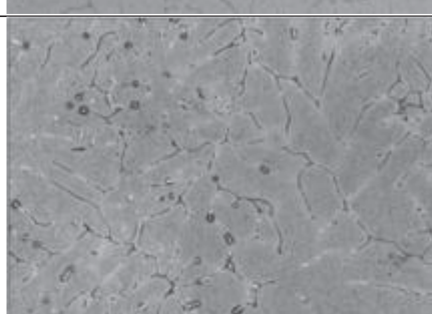
Table 1. Sample Composition of Aluminum-Matrix Composite Materials.

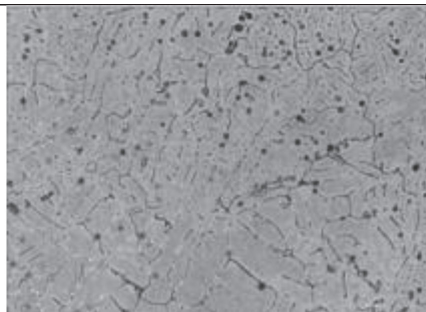
Sample Designation	Matrix	Filler			
		Cu_{20}	Cu_{200}	Al_2O_3	SiC
1011 (AD0)	1011	-	-	-	-
1011+1%SiC	1011	-	-	-	1%
1011+1%Cu_{20}3	1011	1%	-	-	-
1011+1%Al_20_3+1%Cu_{20}	1011	1%	-	1%	-
1011+2%Cu_{200}+1%SiC	1011	-	2%	-	1%

For the microstructure and micro hardness of experimental samples, please see Table 2.

Table 2. Sample Features.

Sample	Sample Microstructure Olympus GX 51 Microscope	HV_{cp} Micro hardness meter DURASCAN 70	Incremental HV_{cp}
1011		26.6	-
1011+1%SiC		27.8	4.5 %
1011+1%Cu_{20}		30.2	13.5 %

 https://doi.org/10.1051/e3sconf/202337601010

1011+1%Al_20_3 +1%Cu_{20}		31.5	15.6 %
1011+2%Cu_{200} +1%SiC		27	1.5 %

Cast samples were pre-machined on a CTX 310 ecoline lathe on the face and outer diameters "as clean". Views of the original and the processed samples are shown in Fig. 1a and 1b.

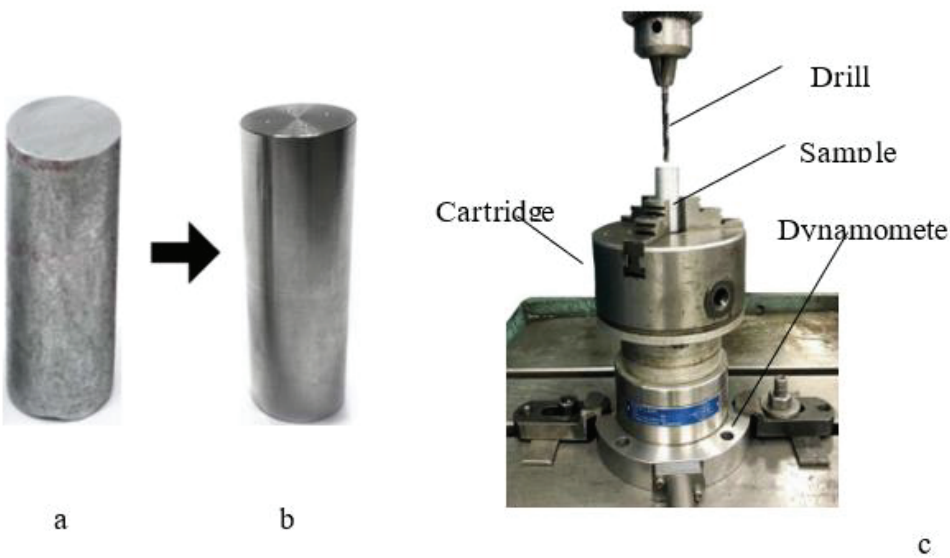


Fig. 1. Cast Sample (a), Machined Sample (b) and Dynamometric Drilling Device (c).

The study examined the axial cutting force and torque in the course of drilling, roughness of surfaces of drilled openings and compared the type of the chips formed.

The axial cutting force (P_0) and torque (M) were measured on a cutting force estimation apparatus [29, 30] with a KISTLER dynamometer, on which a three-jaw chuck with a fixed experimental sample was mounted as shown in Fig. 1.c. The technique of measuring the forces and torques of cutting is described in [31-33]. Given the study conditions, we have

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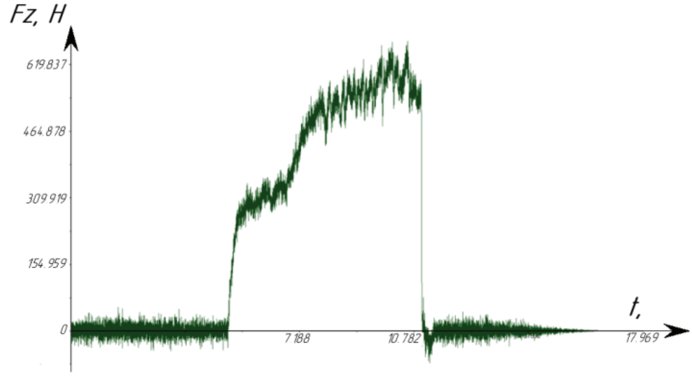
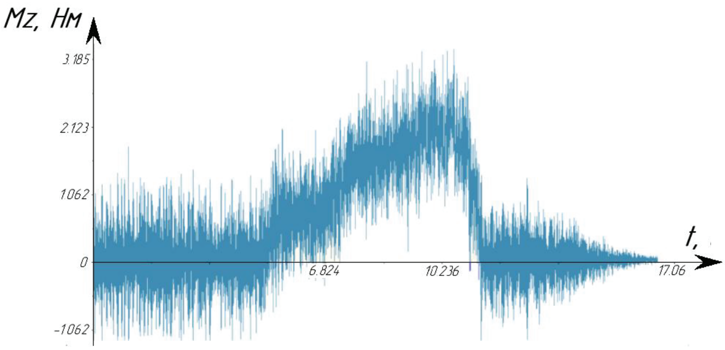
selected a Sandvik CoroDrill drill 460-XM 460.1-0500-025A0-XM GC34 Ø5 mm made of hard alloy was used.

Figure 2 shows samples of resulting force and torque oscillograms (the dynamometer sampling frequency of 1 kHz).



(a)

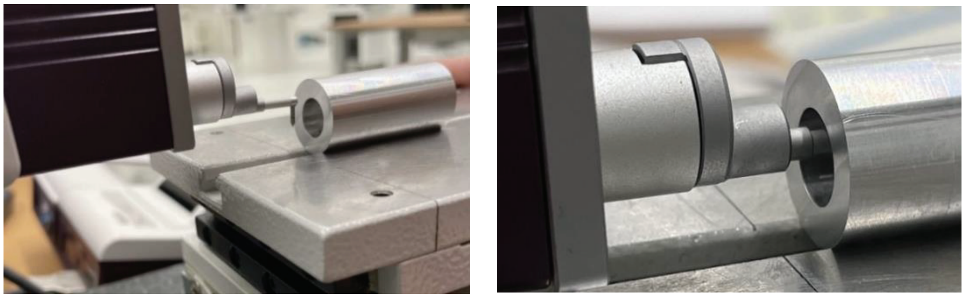


(b)

Fig. 2. Axial Force F_z (a) and Torque M_z(б) Oscillograms.

To improve the measurement, each sample had 4 openings drilled in it. Preliminary experimentation shows that both the cutting force and the torque increase as the drilling bit penetrates deeper into the workpiece. Therefore, the force and torque have been identified at two areas with relatively constant values - at the beginning and at the end of drilling.

We have measured the roughness using the Mitutoyo SJ-410 profile meter at three section of the surfaces of the openings drilled in experimental samples with the Ø10 drill Sandvik CoroDrill® 860.1-1000-080A1-NM H10F (Figure 3). For the cutting conditions, please see Table 3.



(a) (b)

Fig. 3. Sensor Input (a) and Surface Roughness Measurement of Openings (b).

The type of chips has been examined visually.

The drilling modes for the studies presented in Table 3 were selected on the basis of preliminary studies and expert evaluation.

Table 3. Cutting modes during experiments.

Experiment	Supply S mm/rev.	Rotation Speed, rpm	Opening Diameter, mm	Opening Depth, mm
Force Measurement	0.1	1,400	5	15
Roughness Measurement	0.1	4,500	10	10

3 Results and discussion

3.1 Cutting Force Measurement

The experiments have provided the values of the axial cutting force (F_z) and torque (M_z) in the course drilling of samples of various aluminum-matrix composite materials. For the study results, please see Figures 4 and 5.

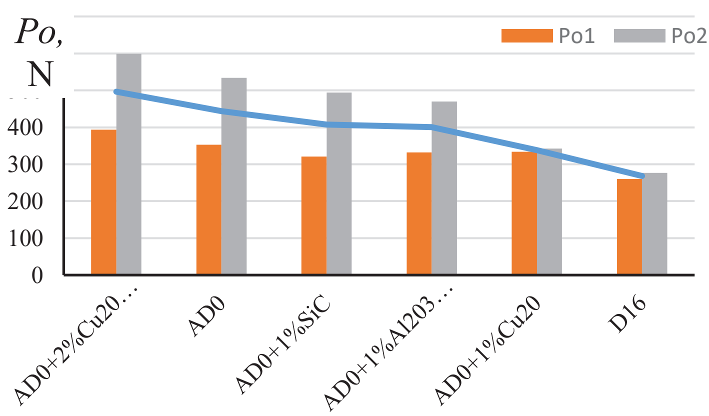


Fig. 4. Mean axial cutting force P_o for drilling of openings 5 mm in diameter in samples of various aluminum-matrix composite materials at the beginning (P_{o1}) and end (P_{o2}) of drilling as well as the mean value of P_{ocp}.

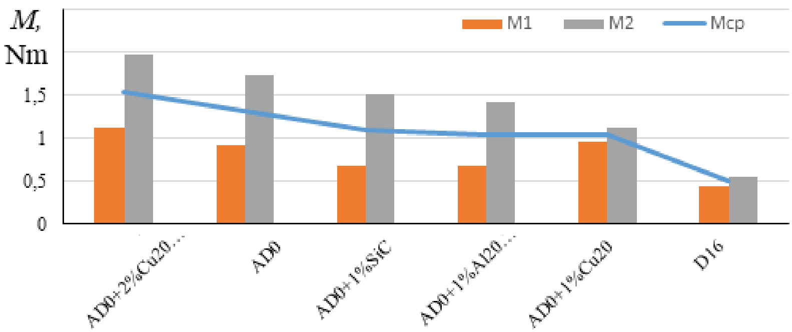


Fig. 5. Mean cutting torque M for drilling of openings 5 mm in diameter in samples of various aluminum-matrix composite materials at the beginning (M_1) and end (M_2) of drilling as well as the mean value of M_{cp}.

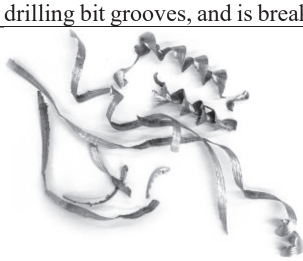
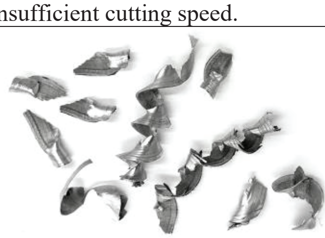
The data provided shows that both the cutting axial force and torque are greater at maximum penetration of the drilling bit into the opening than at the beginning of drilling. This is due to the effect of converging chips, which adhere to the cutting edge, rubbing against the surface of the hole and the chip groove of the drill bit. This requires additional force.

The minimum axial force and torque are observed when drilling samples made of composite materials alloyed with copper - AD0+1%Al_20_3+1%Cu_{20} and AD0+1%Cu_{20}. Therefore, one may declare that adding copper to the aluminum matrix reduces the material friction ratio with Cu particles acting as lubricants

The results of roughness measurement and the type of chips obtained are presented in Table 4.

Table 4. Opening surface roughness and type of the chips formed

Item No.	Sample	Outlook and description of chips	Section No.	Ra, mcm	Ra_{cp}., mcm
4	1011+1%Al_20_3+1%Cu_{20}	 Long comma shaped bouncing chips The material is quite plastic, the chips are rigid and sparkle specifically. The material is easily removed from the drilling bit grooves and is breakable.	1	0.889	0.869
			2	0.885	
			3	0.833	
1	1011		1	0.837	0.830
			2	0.787	

		 Continuous chip, tape and screw type. The material is sufficiently elastic with the homogenous structure making the chips uniform and homogenous with the specific shine.	3	0.865	
2	1011+1%SiC	 Long comma shaped bouncing chips The material is sufficiently elastic, the chips are rigid and sparkle the material is easily removed from the drilling bit grooves, and is breakable.	1	0.620	0.746
			2	0.729	
			3	0.890	
3	1011+1%Cu_{20}	 Continuous chip, tape and screw type. The material is sufficiently elastic, the chips do not sparkle, the surface is matted, and there are torn edges. It may result from the insufficient cutting speed.	1	0.562	0.571
			2	0.590	
			3	0.560	
7	1011+2%Cu_{200}+1%SiC	 Long comma shaped bouncing chips The material is quite plastic, the chips are rigid and sparkle specifically. The material is easily removed from the drilling bit grooves and is breakable.	1	0.574	0.498
			2	0.448	
			3	0.472	

8	1160	 Continuous chips, screw-type The machinability of the material is good, the chips are easily evacuated from the shaving grooves and do not adhere to the drilling bit	1	0.379	0.355
			2	0.365	
			3	0.322	

The analysis of the chips shows that particles of reinforcing phases of Al_2O_3 and SiC disrupt the continuity of the metal and contribute to the crushing of chips. The best cutting chips are comma-shaped bouncing chips. This type of chip has materials 1011+1%SiC, 1011+1%Al_20_3+1%Cu_{20} and 1011+2%Cu_{200}+1%SiC.

The lesser surface roughness of openings is ensured when drilling the following materials 1011+2%Cu_{200}+1%SiC and 1011+1%Cu_{20}.

When comparing the results of the study of cutting forces, roughness of the machined surface and chip type, it is clear that the compositions of aluminum-matrix composites that provide the best machinability by drilling are different. This can be explained by the different influence of microadditives on the physical mechanisms of cutting forces, chip formation and roughness of the machined surface. Additional studies are required to clarify these effects.

4 Conclusions

The comparative analysis of drilling machinability of samples of disperse-filled aluminum-matrix composite materials of various compositions shows that reinforcement of aluminum with small additions of copper, aluminum oxide and silicon carbide affects the structure and properties of the material. The reinforcing effect of various additives is accompanied by a not so unambiguous behavior in blade machining. The effect of additives is ambiguous and may result both into improved machinability and decreased machinability versus materials of other compositions. However, it can be argued that the introduction of the copper microadditive reduces the axial force and torque during drilling, as well as achieving better chip removal from the hole.

Acknowledgements

The reported study was funded by RFBR and NSFC according to the research project №20-53-53022.

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