

# The investigation of drilling an aluminium matrix composite reinforced with iron hollow spheres

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**Abstract.** Since composites have numerous advantages, they have a prominent role in manufacturing. That is the reason why they might substitute conventionally used materials. Nowadays cutting processes are among the most commonly used finishing technologies. In the case of composites the cutting tools have to meet particular requirements. This paper represents the machinability examinations of a special type of composites – iron hollow sphere-filled aluminium alloy matrix (AlSi12) – during drilling. The input cutting parameters, the feed ( $f$ , mm) and the cutting speed ( $v_c$ , m/min), were varied at a wide range according to a design of experiment (a full factorial design was used). Drilling studies were carried out under dry conditions and with internal cooling lubrication as well. The axial (feed) force ( $F_f$ , N) was measured. Based on the experimental results, the different drilling conditions were compared. In addition, a proposal is made for cutting this kind of material. The joint properties of the aluminium matrix and the iron hollow spheres during cutting were examined by scanning electron microscopy.

## 1. Introduction

Syntactic metal foams possess both the characteristics of known metal foams and the advantageous properties of composites. These materials have been researched more and more recently. They have excellent mechanical properties. Their energy absorption, compressive strength and damage localization capability are outstanding, while their density is low, thanks to the light metal matrix and the hollow spheres.

In an aluminium matrix the reinforcing material can be basically divided into two groups: metal and ceramic hollow spheres [6]. For example, Hollomet GmbH. [2] sells ceramic hollow spheres (Globocer, GC), and iron hollow spheres (Globomet, GM).

The material properties of such materials are much researched [7]. The upsettability of these materials is very good. Orbulov and Ginsztler [10] examined the upsettability of three different metal matrix syntactic foams (the matrix was Al99.5 and reinforcement was three different types of ceramic hollow spheres). The three kinds of spheres mostly differed from each other in diameter (100  $\mu\text{m}$ ; 150  $\mu\text{m}$ ; 1450  $\mu\text{m}$ ). The results showed that the size of the spheres and the temperature of testing had a considerable effect on compressive strength. Smaller thin-walled hollow spheres produced higher compressive strength. The tests were carried out at room temperature and at 220 °C. The higher temperature reduced compressive strength by about 30%. Kiser et al. [4] investigated the upsettability of composites of aluminium matrix and ceramic hollow sphere reinforcement. They used a composite



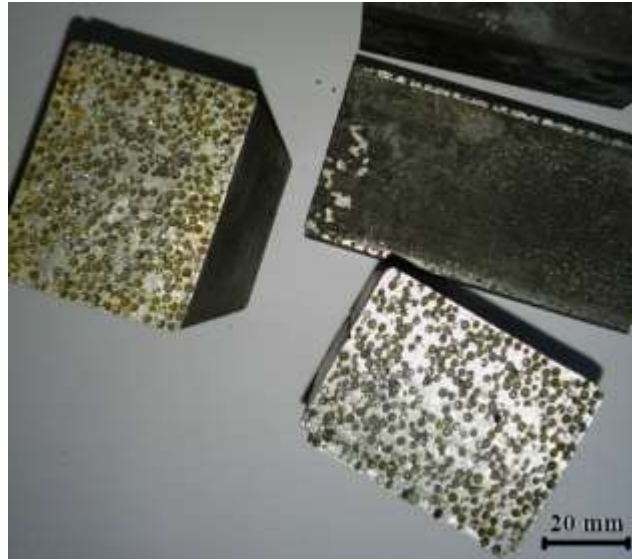
of A201 aluminium alloy and 55%  $\text{Al}_2\text{O}_3$  ceramic hollow spheres, and a composite of A360 aluminium matrix and 60% ceramic hollow spheres. Their results showed that the energy absorption capability of the tested composites largely depend on the parameters and conditions of loading. Such materials can be very effectively used against local penetration, such as bullets. Szlancsik et al. [12] examined the upsettability of composites of different matrix materials (Al99.5, AlSi12, AlMgSi1 and AlCu5) and Globomet reinforcement. The obtained upsetting curves (gentle slopes) indicate that the composite has high energy absorption capability. They also found that the matrix material and heat treatment has a considerable effect on the mechanical properties of the composite, therefore with the proper choice of matrix and heat treatment, mechanical properties can be varied in a wide range according to requirements. Orbulov and Ginsztler [11] examined the upsettability of composites of four matrix materials (Al99.5, AlSi12, AlMgSi1 and AlCu5) and ceramic hollow sphere reinforcements of two diameters (100  $\mu\text{m}$ , 150  $\mu\text{m}$ ). They also found that smaller spheres lend higher compression strength and stiffness to the composite than larger spheres.

Karabulut and Karakoç [3] examined the machinability (milling) of open-cell aluminium alloy-based SiC foam composite with an uncoated carbide tool. The tests were conducted with the use of a Taguchi  $L_{27}$  full-factor orthogonal array and milling parameters were optimized for surface roughness. The results showed that the feed rate was the milling parameter that affected surface roughness most significantly. Krajewski & Nowacki [5] examined the geometric structure of an AlSi-SiC composite after EDM cutting, waterjet cutting (with and without abrasive blasting), laser and air plasma cutting, and cutting with a band saw and circular saw. They characterized the surfaces with numerous 2D and 3D roughness parameters and based on the results, they determined optimal cutting conditions. Fakhri et al. [1] examined the relationship between porosity and cutting force. They found that the resultant cutting force has high correlation with porosity (ratio of solid material). They also examined the behaviour of aluminium foam with unconventional cutting technology. B.S. Yilbas et al. examined the size of cut surfaces in the case of laser cutting with triangles [13] and circular holes [14].

This paper presents the drilling tests of a eutectic aluminium matrix metal hollow sphere-reinforced composite (in dry conditions, and with internal cooling and lubrication).

## 2. Materials and tools used

We used a eutectic Aluminium-Silicon alloy (AlSi12) as matrix and Globomet of 100% Fe as reinforcement. The aluminium alloy consisted of Al = 87.1 vol%, Si = 12.8 vol% and Fe = 0.1 vol%. The iron hollow spheres were Globomets [2] sold by Hollomet GmbH, and had a characteristic diameter of 1.4–1.8 mm and a wall thickness of 0.2 mm. Manufacturing was done with infiltration [8]. The finished specimens (Figure 1) had outer sizes of  $35 \times 45 \times 85$  mm.



**Figure 1.** Specimens prepared for the drilling test

The cutting tests were performed with a MAZAK VCN 410A-II vertical machining centre ( $n_{max} = 12000$  1/min;  $P_{max} = 11$  kW).

The drilling test were executed with Dream Drills D5433100 5XD uncoated carbide tools [9] ( $\varnothing 10$  mm), which have cooling holes.

Forces in the feed direction were measured with a Kistler 9257b multicomponent dynamometer and a KISTLER 5019 multichannel charge amplifier. The measured forces were processed with the DynoWare program.

The cutting parameters (both the cutting parameters of drilling and cutting speed –  $v_c$ , m/min, and feed –  $f$ , mm were varied at four levels:  $v_c = 80, 120, 160, 200$  m/min;  $f = 0.1, 0.2, 0.3, 0.4$  mm. The 16 measurement points obtained this way can be seen in Table 1. The cutting tests were performed both dry and with internal cooling and lubrication.

**Table 1.** The measurement points of drilling experiments and their cutting parameters

Experimental runs	$v_c$ (m/min)	$f$ (mm)
1.	80	0.1
2.	80	0.2
3.	80	0.3
4.	80	0.4
5.	120	0.1
6.	120	0.2
7.	120	0.3
8.	120	0.4
9.	160	0.1
10.	160	0.2
11.	160	0.3
12.	160	0.4
13.	200	0.1
14.	200	0.2
15.	200	0.3
16.	200	0.4

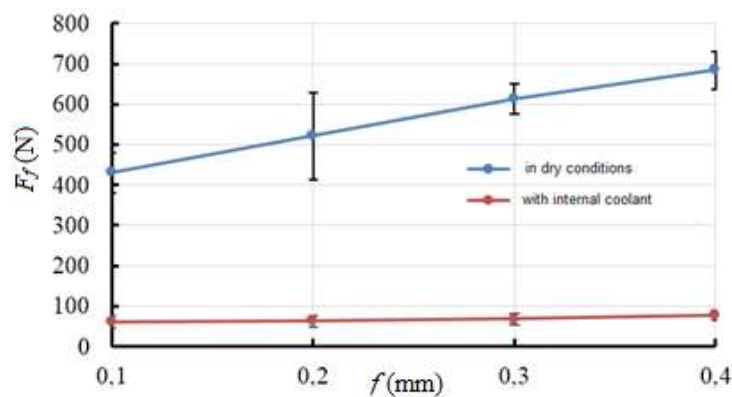
A 4 vol% oil emulsion (AGIP AQUAMET 4 HS-BAF) was used as coolant and lubricant.

### 3. Results And Discussion

In the drilling tests we recorded  $F_f$  forces in direction  $z$ . We performed a significance test to see which cutting parameters have a significant effect on the measured  $F_f$  force component. The test showed that only feed had a significant effect on the  $F_f$  force component. For this reason, this paper presents the analysis of the effect of feed.

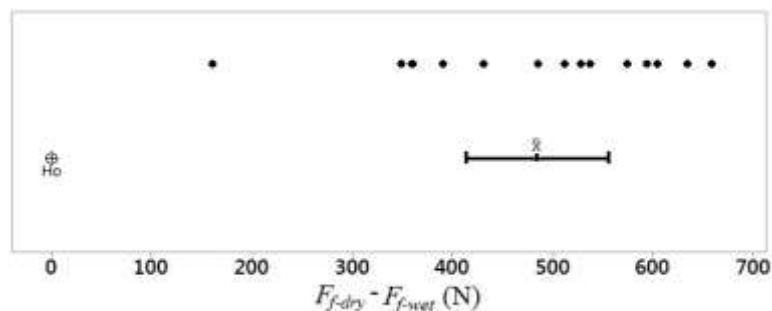
#### 3.1 The effect of feed on forces in the feed direction

Figure 2 shows the average of the measured forces when lubricant-coolant was used and in dry conditions. It can be clearly seen that the forces are much higher in dry cutting than when lubricant-coolant was used.



**Figure 2.** Average  $F_f$  force values as a function of  $f$  feed

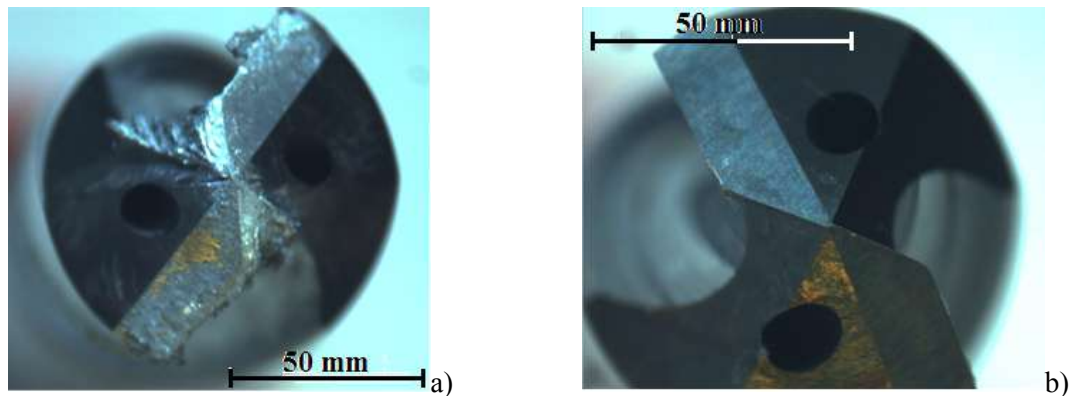
A paired t-test was performed on the data obtained, which showed that on average the force requirement of feed is 484.8 N higher in the case of dry cutting (Figure 3).



**Figure 3.** Results of the paired t-test of the axial force differences between the wet and dry drilling

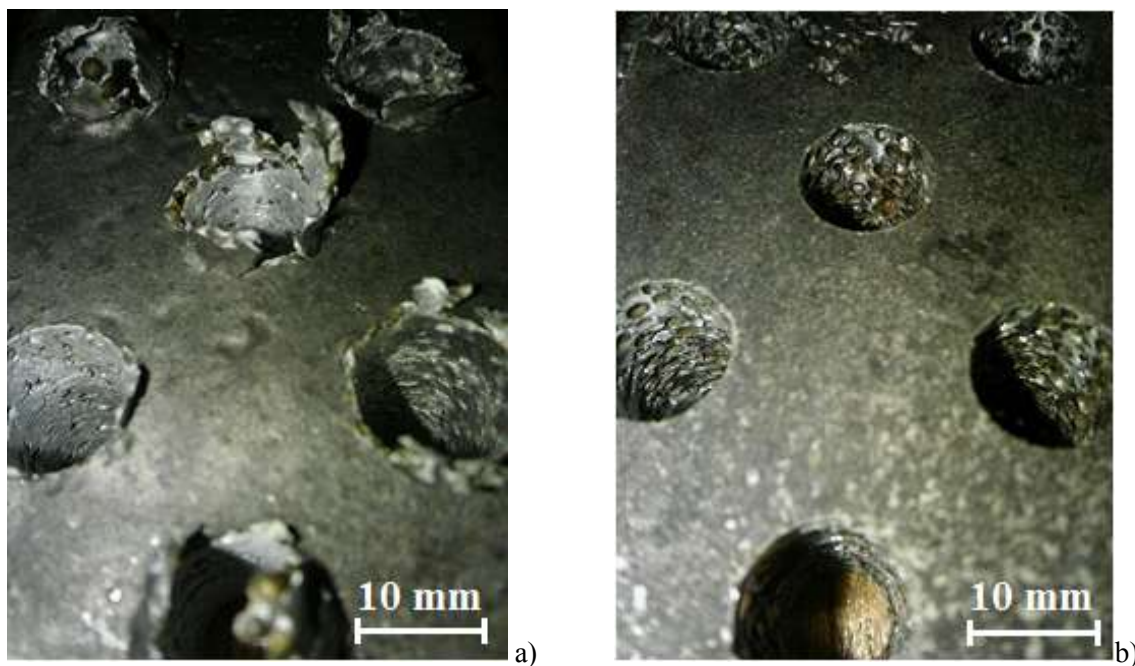
#### 3.2 Built Up Edge (BUE) and burr formation analysis

After finishing the holes, the tool was checked and it was found that during dry cutting a BUE was always found, while when the tool was lubricated, BUE wasn't formed. Figure 4 shows the tool with the BUE and the lubricated tool without a BUE.



**Figure 4.** Built Up-Edge: a) on the tool with BUE after the dry drilling process and b) the tool without it after lubricated drilling

After this the holes and the burrs were inspected on the side the tool exited the sample. During dry cutting, burr was formed at this side in every case, but with a coolant-lubricant this did not happen (Figure 5).

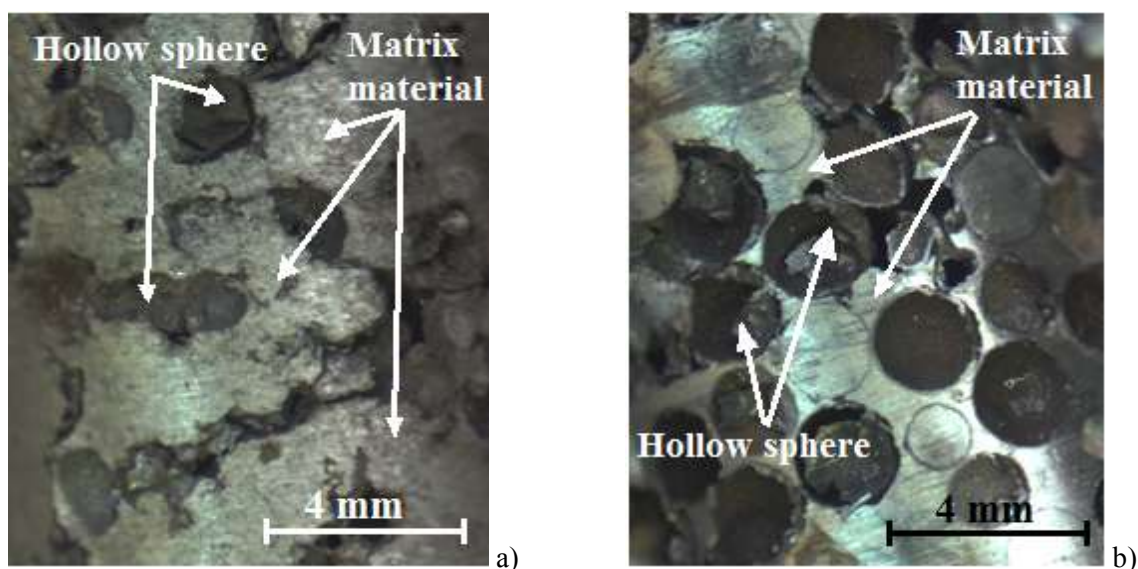


**Figure 5.** Burr on the exit sides of the holes: a) during dry conditions and b) during lubricated cutting

### 3.3 Examining the drilled surfaces

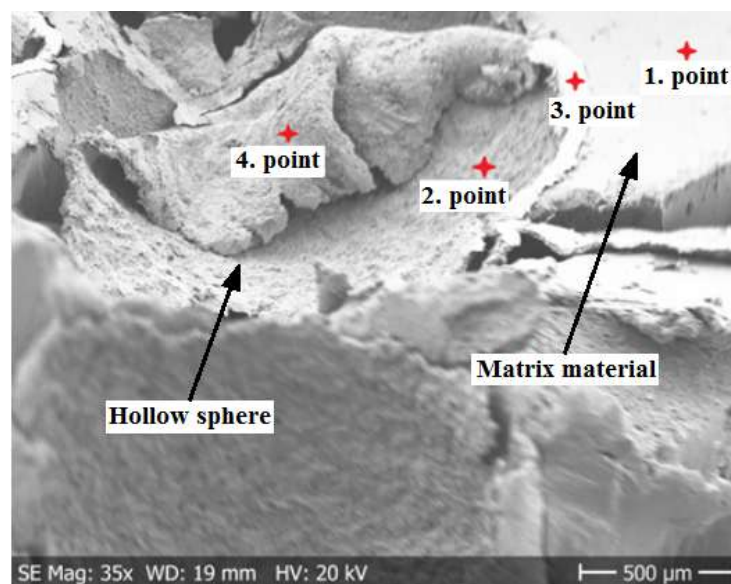
Examining the holes, we found that in the case of dry cutting the matrix material was always smeared and the Globomets were torn out. On the other hand, with internal cooling and lubrication, cutting conditions were better, the matrix was cut cleanly and the Globomets were cut through. In the case of internal cooling and lubrication, far fewer Globomets were displaced. Figure 6 shows the microscope images of the walls of the holes.





**Figure 6.** Inner surfaces of the holes: a) made without lubricant and b) made with internal cooling-lubrication

The drilled surface of the holes was tested at several points by scanning electron microscopy. The volume percentage of the Fe, Al and Si atoms was analyzed on the drilled surface (Figure 7). The chemical composition of the measurement points in Figure 7 can be seen in Table 2.



**Figure 7.** SEM image of the inner surface of the drilled hole (internal cooling-lubrication)

**Table 2.** The measured chemical composition (by EDS method) of the material on the drilled surface according to Figure 7.

Measurement points	Al (vol%)	Si (vol%)	Fe (vol%)
1.	83.55	14.65	1.80
2.	2.84	0.51	96.65
3.	14.00	1.46	84.54
4.	26.17	0.64	73.2

At the first measurement point only matrix material was found, as expected.

At the second measurement point the inner surface of a cut sphere was analyzed, where almost only iron was found.

The third measurement point shows the outer surface of the cut sphere. In this case, mostly iron was found, as in the previous point, but the spectroscopy showed a small amount of aluminium, as well. The reason for this, that the iron hollow sphere bended on the matrix material where the measurement was performed.

Point 4 analyzes the outer surface of a reinforcing sphere, which was bent during drilling. A significant amount of aluminium was found here. Fig. 7 shows that the two sides of the sphere were affected differently by the tool; the upper side of the sphere was bent because of the feed but the exit side is cut through. This phenomenon can be explained with the fact that when the sphere was bent, the tool was in contact with the outer surface of the sphere, but when the tool exited the sphere, it was in contact with the inner surface of the sphere.

#### 4. Conclusion

We performed drilling experiments on a metal matrix syntactic foam under dry drilling conditions and with internal cooling in the tool. The parameters of feed and cutting speed were varied in a wide range. The following conclusions can be drawn from the tests:

Of the cutting parameters, only feed has a significant effect on the feed direction forces ( $F_f$ ) both under the conditions of dry cutting and with internal cooling-lubrication. The effect of cutting speed on feed direction forces is negligible.

In the case of dry cutting, feed direction (axial) forces could be 8-10 times more (the average difference is 484 N between the dry and wet cutting process).

In dry cutting a built-up edge was formed on the tool edges in every test run, and burr was found on the exit sides of the holes, while with the use of coolant-lubricant, these effects were not experienced.

Dry cutting of these kinds of materials is not recommended because of the increased forces, the burr on the exit side of the hole, and the built-up edge. The uncut spheres reduce surface quality, the quality of the hole and tool life.

Under the conditions of internal cooling both the matrix and the reinforcing spheres were cut but some of the hollow spheres were cut through and some were deformed depending on the orientation. This was proved with electron microscopy and spectroscopy analysis.

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