Chapter 7

Material and experimental

7.1 Introduction

About the study of drilling of composite, experimental tests have been developed on more typology of material, all regarding that composite having matrix oh aluminium alloy.

To obtained results as much possible general, the drilling operations has been carried out by more different cutting parameters, in terms of feed speed, round number, diameter of the drill, temperature of the workpiece. After that the cutting forces Fz and M_z have been analyzed about each combination, the surface finishing of the hole has been observed, too.

7.2 Material

The materials used for the experimentation are composites with aluminium metal matrix, with reinforcement in the form of SiC whiskers or alumina Al_2O_3. In particular, about the whiskers reinforcement the aluminium alloys of 2000 series (Al2009) and 6000 (Al6061) series have been used. About the Al_2O_3 reinforcement only the Al6061 alloy has been adopted.

About the Al2009 alloy, this has the main element in copper in concentrations ranging from 1 to 6% by weight, which are sometimes added small amounts of magnesium and manganese. Generally these types of alloys developed mechanical properties comparable with those of carbon steel. But they have a corrosion resistance lower than that of other aluminum alloys, therefore, in critical applications they require appropriate protection systems. They have a maximum work temperature of 200 ° C and an excellent machinability by machine tools.

In the case of Al6000 alloy, the main elements of the alloy, in addition to obviously aluminium, are silicon and magnesium (usually remain below 1 .5% by weight, wiith the silicon that in addition increases the fluidity and reduces the coefficient of thermal expansion). The material hardening succeeds predominantly by the Mg_2Si precipitation, but these are characterized by lower mechanical properties than the 2000 series alloys. Alloys of this type have generally good formability, machinability, and weldability. Especially noted by the insensitivity to problems SCC (Stress Corrosion Cracking).

	Al2000	Al6000
Density	2.8 g/cc	2.7 g/cc
Hardness, Brinnell (HB)	120	50 -70
Tensile Strength, Ultimate	480 MPa	310 MPa
Tensile Strength, Yield	350 MPa	260 MPa
Elongation at Break	18 %	10 %
Shear Strength	280 MPa	126 MPa
Modulus of elasticity E	70 - 80 GPa	60 – 70 GPa
Thermal Conductivity	120 W/mK	170 W/mK

Tab.1 Principal thermal and mechanical properties about the considered matrices

Notably in Tab.3 are shown and compared the most important and the usual mechanical and thermal properties about the two leagues, to take in the view of different behaviours for the two composites during the probes.

It is useful also describe in more detail the type of reinforcement constituent.

The whiskers are monocrystalline short filaments produced by growth in controlled conditions. The characteristic structure is highly ordered and it allows not only high resistance, but changes in the optical, magnetic, conductive and superconductive properties, too. Especially about the tensile strength, the values of the whiskers is much higher than the typical large volume reinforcements (Fig.1).

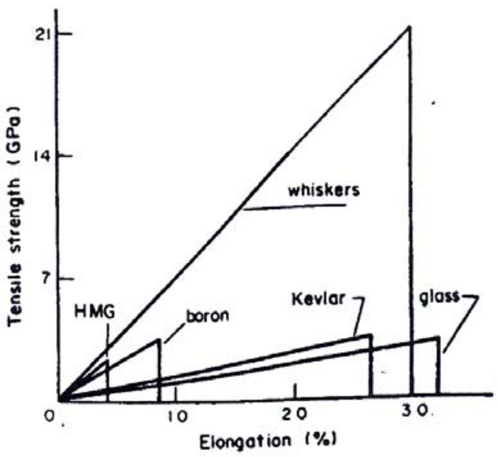


Fig.1 Comparison between various reinforcement type for composites

Therefore whiskers are a class of materials that have mechanical strength equivalent to the atomic bond forces. For example, those in SiC (relative to our experiments) have a tensile strength greater than 27 GPa and a Young modulus of 500 GPa (with a melting temperature of about 2300 ° C). In particular thanks to the structural perfection, their resistance is not limited by any superficial defects. This condition usually ensures high resilience and handling friability, especially if compared to glass or polycrystalline fiber. Furthermore, these type of reinforcement exhibits less resistance degradation with temperature increasing, because in the absence of imperfections the sliding are favourite. Numerous studies showed that there is no significant effect about the fatigue phenomenon. All this allows to handle roughly, grind, chop, and generally work without damaging the property.

The Al_2O_3 reinforcement is instead in small particles and it is the most commonly used in these fields, because of its high dissemination for use in powder metallurgy. In Tab.4 the most important properties are indicated,

Reinfocement	**Particle Al_2O_3**	**Whiskers SiC**
Density	3,9 g/cc	3,1 g/cc
Modulus of elasticity E	370 GPa	500 GPa

Tab.2 Mechanical properties about the reinforcements considered about the experimentation

The materials at our disposal are the final result of the mixture of aforesaid components. Therefore about the hot drilling process the results about the composites Al2009/SiC_w, Al6061/SiC_w and Al6061/Al_2O_3 have been studied and compared. In the first two cases the reinforcement part interests the 20% on the total volume of the composite, in the second case the 10%.

7.3 Sample properties

About the Al/SiC_w composite, the samples have been made by two extruded bars (one for each composite typology), having a length of about 50 cm. Then these bars have been cut on the perpendicular direction extrusion axis, in order to obtain samples with size of 3.8 cm x 0.5 cm x 7.5 cm.

About the Al6061/Al_2O_3 composite, the samples have been obtained by the cut of a circular extrusion bar, having a radius of 40 mm. Successively changes to the sample shape have been performed to increase the clamp area, making it by a semi-rectangular shape (Fig.2).

Regards the sample thickness, it has been chosen basing on the fact that a too little thickness would result in harmful vibrations during the drilling process. So the final choice has been regarded the thickness of 10 mm for the samples.

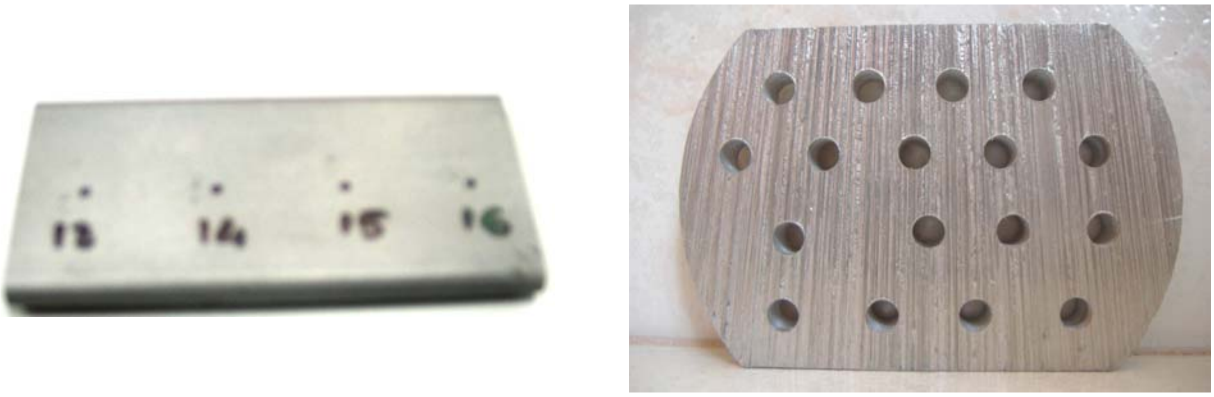


Fig.2 Samples subjected to the hot drilling experimentation

Once executed drilling operations, the samples have been cut along the perpendicular planes to the drill surface direction (Fig.3). By this way we could have uncovered sections of the holes, so the surface roughness and the hardness (in the immediate vicinity of hole) have been evaluated

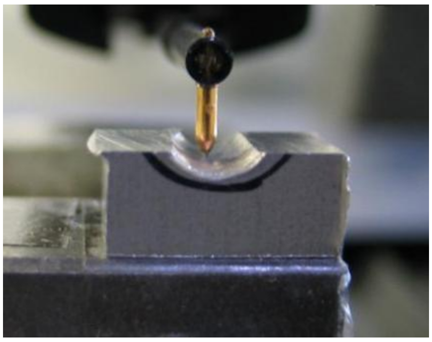


Fig.3 Cut sample to the surface survey

7.4 Equipment and instrumentation

The drilling operations for this experimental study have been carried out using a traditional tool of high quality but as the steel auto-centring helical drill "HSS" (DIN 338) Cobalt (Co 8%), with a sharpening of 135°. The carried operations has been a dry drilling, while the aforesaid type of drill tool has been chosen because resistant to high temperatures by the percentage of present cobalt .

Fig.4 Used helical drill

Nevertheless, it usually is used for advanced application (for example by the diamond tool) and so it allows an more immediate study of the wear effects.

The tests have been conducted by an universal milling machine available at the laboratories of the Department of Mechanical Engineering at the University of Rome "TorVergata" (Fig.5).

Fig.5 Universal milling used for the drilling operations

This machine has a spindle at high speeds (up to 20,000 rpm) and a motorized table equipped for vertical motion and for the movement along the two orthogonal directions of the horizontal plane. The choice of this machine has been motivated by the need to have precise control about drill rotation speed V_r (rpm) and about feed speed V_a (mm/min).

The sample clamping during the drilling has been carried out by a vice support directly coupled to a load cell (model Kistler 9273) with four channels: it has been used to detect and to acquire the corresponding data to thrust and torque during the drilling performance (Fig. 6).

Cause to the particular type of considered tests, it was necessary to heat the samples. To do that, the same samples are heated and maintained in temperature through irradiation by the halogen lamp LineIR5194 (Fig.6), having a power radiating governor (up to 2000 W) and a air cooling system. This is mounted on the machine and its position is adjustable through a system of arms and hinges.

Moreover, to not heating also the dynamometer (penalty the unreliability of the results), a very simple ceramic material has been placed between the lamp and the vice: it has been punched in the centre of the ceramic plate to permit that the irradiation reaches the workpiece in the vice.

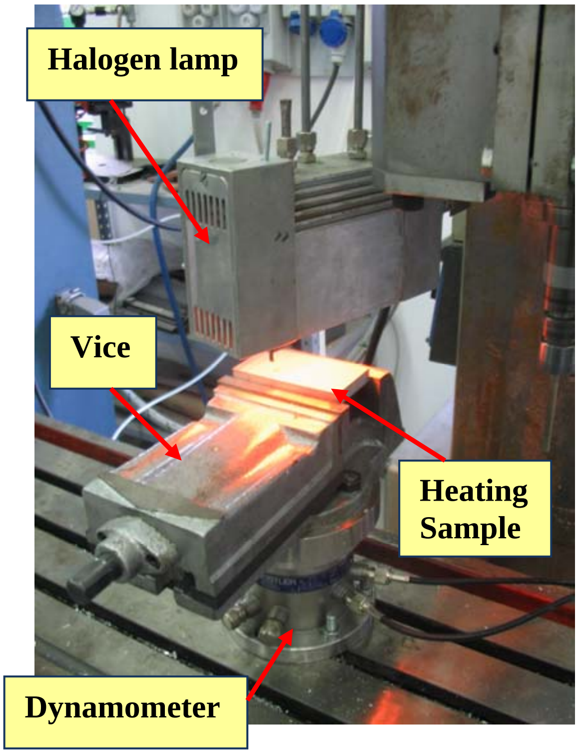


Fig.6 Assembled system on the milling machine for the drilling operations

The sample temperature is constantly monitored by the use of a thermocouple inserted into a small hole made on the lateral surface of the sample.

Fig.7 Amplifiers type PCB 443 B102 and acquisition schedale type N. I. SC-2345 N

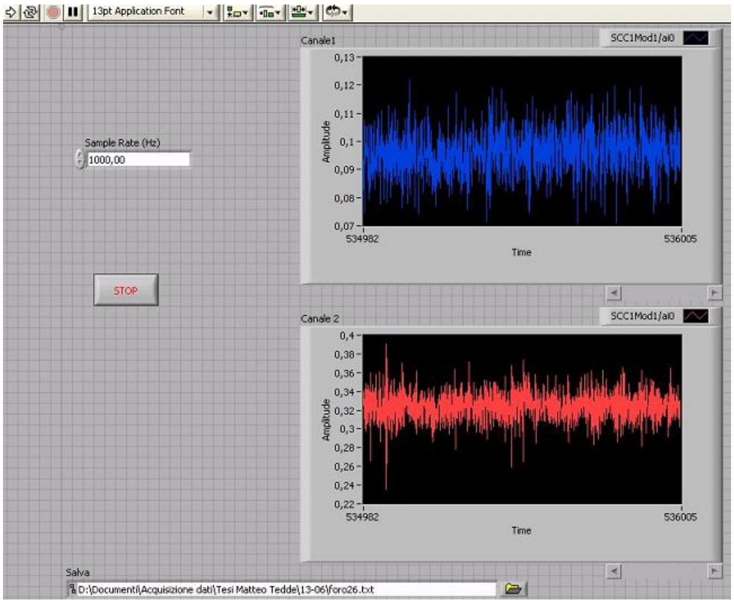


Fig.8 N.I. LabVIEW software frame for the data acquisition

By the dynamometer the signal is sent to a data acquisition system through two amplifiers type PCB 443B102 (one for each solicitation analyzed, F_z and M_z) adopted to the signal conversion, an acquisition schedule type National Instruments SC-2345 N (Fig.7) and a portable computer to provide to the data processing software National Instruments LabVIEW 7.0 (Fig.8).

The development of the experimental part has also involved a more detailed study of the mechanical properties of the considered materials, in particular it has been interesting to identify the yield strength σ_S [MPa] and stiffness [N/mm].

About that FIMEC indentation tests have been carried out. In this case, the samples have been subjected by indentation with a punch of 2 mm diameter.

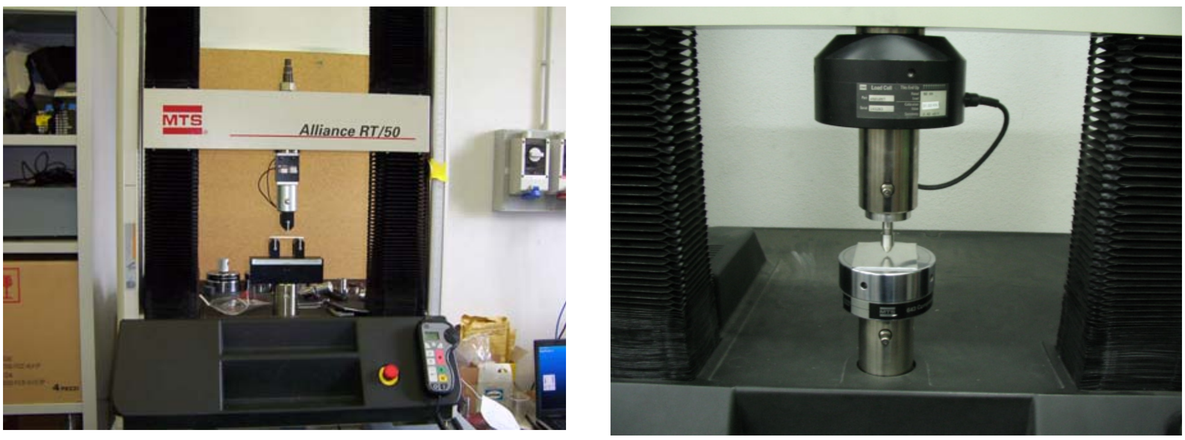


Fig.9 FIMEC instrumentation

Then data and trends are processed through appropriate spreadsheets used for that purpose.

The performed tests include roughness measurement conducted on the hole surfaces: the instrumentation used is a produced by Taylor Hobson Precision machine, model Talysurf CLI2000. It is equipped with a diamond tip of a mobile faceplate plan .

Fig.10 Instrumentation used to roughness measurements on the hole surface

7.5 Experimental method

To test homogeneity of the reinforcement distribution about the materials, initially FIMEC indentation have been carried along the greater length direction of extruded bars (Fig.11) for the Al/SiC$_w$ composites. Below the basic parameters are shown:

Punch diameter [mm]	Test speed [mm/min]	Penetration depth [mm]	Pre-load [N]	Maximum load [N]
2	0,1	1	5	8000

Tab.3 Realized FIMEC indentation parameters

Fig.11 Direction along the composite extruded bar of the carried out FIMEC tests

About the $Al6061/Al_2O_3$ instead it has been possible to value the FIMEC tests at different probe speed, due to the large area of the circular section of the bar. In particular the speed of v=1 mm/min and 0,1 mm/min are adopted, on different radial line (Fig.12).

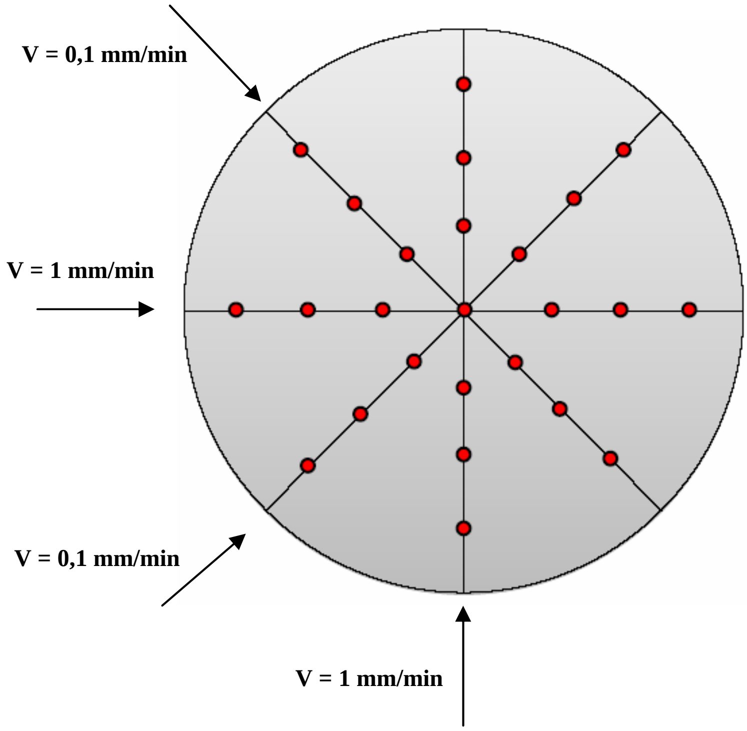


Fig.12 Direction along the Al/Al_2O_3 composite extruded bar of the carried out FIMEC tests

About the experimental steps adopted in the present work, drilling operations have been carried out by certain temperature values of the workpiece, in order to assess the trends of thrust and torque with the temperature change for that particular material. For each material, at any temperature, set cutting speed, feed rate and drill diameter, three replicates of drilling have been performed in order to reduce as much possible the error about the collected quantities.

In the specific case the following combinations about process drill parameters (by a drill of 5mm diameter) have been developed.

Feed rate [mm/min]	Rev. number [giri/min]
77,5	5000
210	15000

Tab.4 Cutting parameters about the carried drilling operation (with drill of 5 mm diameter)

Temperature [°C]
Amb ≡ 25
60
80
100
120
140
160

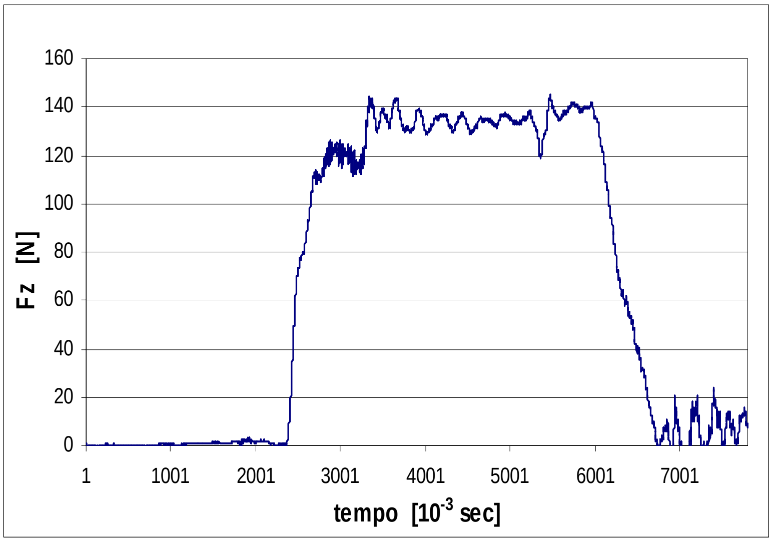
Tab.5 Adopted temperature about the present experimentation

The preparation and execution process of the single probe provides the following same steps:

1) The sample is climbed on the faceplate table and on the load cell;
2) On the sample the thermocouple for monitoring temperature is placed;
3) Above the sample-vice system, the ceramic material is placed as described, in order to be heated only the sample on that te drilling must be carried out;
4) The lamp is placed above everything and it turned on at full power until the sample material do not reach the desired temperature;
5) By the aforesaid software is created the file, to the description and the acquisition data coming from load cell;
6) To achieve the desired temperature, the lamp and the protective ceramic material are removed;
7) The faceplate table is moved first hand horizontally to position the sample under the tool, then vertically and automatically so as to realize finally a single drilling test.

At this point the data is transferred to Excel spreadsheets to be developed; by the acquisition during the drilling operation the values of thrust F_z and torque M_z is acquired at intervals of millisecond with the form of electrical signal (in millVolt). Then the signal is converted in the units [N] and [N*m], using the conversion factors determined by the calibration of the amplifiers (Fig.14).

a)



b)

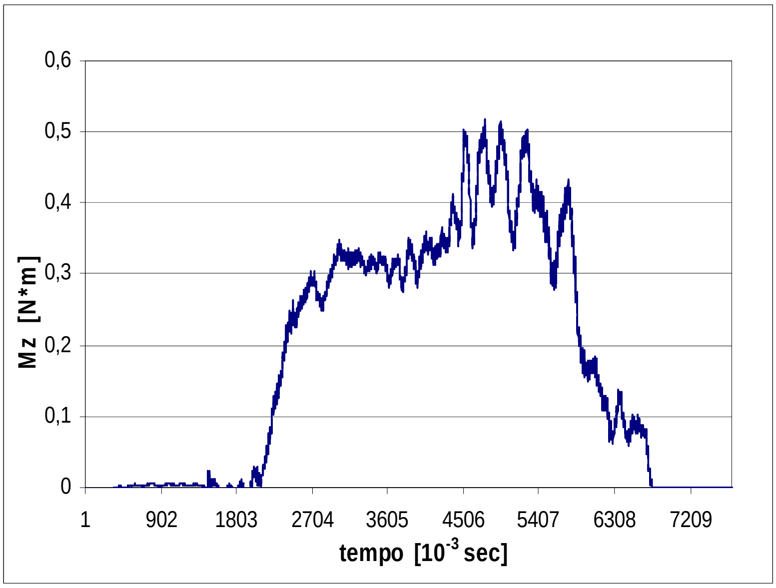


Fig.13 Typical output signal elaborated and converted in appropriate measure units

Below the setting parameters are listed for roughness the tests.

Lenght	X = 4 mm	Y = 1 mm
Resolution	4000 points	100 traces
Spacing	1 µm	10 µm
$V_{measure}$	1 mm/s	

Tab.6 Parameters for the roughness tests

About the micro-hardness tests performed near the surface of the holes, they are Vickers (HV) type, carried out by pyramidal penetrator (having 148° for the opposite edge angle) with square base, whose rhombic imprint on the material, as function of the diagonals, indicate the analyzed hardness. In particular, in our case micro-hardness tests have been performed with a applied load of 300 g_f and for a loading time of 15 sec., parallel to the surface drilling (step 1.5 mm) than in the perpendicular direction to it (step 1.5 mm). By the same characteristics of the applied load, before the drilling an extensive campaign of 20-30 micro-hardness also carried out for each materials in order to determine in a statistical and thus secure way the real hardness value at the pre-worked state .