Chapter 6

Drilling of composite

6.1 The drilling operation

The drill manufacturing is one of the most important operations about chip machining, as it results frequently the most used about the carrying out of mechanical components.

Since the one simple drilling could require similar situation as a rough-shaping, with quite poor tolerance about the diameter, circularity and surface finishing, each hole requires a complex sequence of operations in accordance with the geometry, its quality and role for that it has realized.

In except the case where some operations are carried out by lathe, the characteristic machining motions by that it's possible to realize are the following:

- cutting motion: rotary e continuous, every time regarding the tool;
- feed motion: rectilinear, it can regard the tool or the workpiece, in conformity with the particular used equipment
- position motion: regarding generally the workpiece and it is used in order that the tool axis coincides with the hole axis, so to bring the same tool near the workpiece.

The typical tool for a drill machining is the classical helical drill, of that the geometry and fundamental parameters are showed in the following Fig.1.

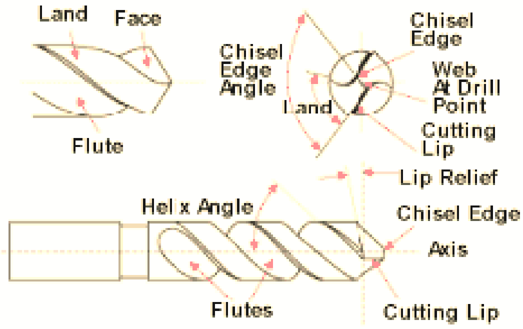

Fig.1 Characteristic identifiable parameters for a helical drill

About this case, during drilling the tool must win two type of force:

- the torque that opposes to tool rotation
- the thrust (along axial direction) that opposes to tool feed

An approximated description about this forces can be considered dividing the cutting strain for each edge in a component F_G (caused by penetration strain) and in that F_T (generating drill torque della coppia di foratura), both of them applied on the middle of the same cutting edge. In particular the first can be divided in an axial component (coinciding with the aforesaid thrust force) F_z and in that $F_{R,}$ perpendicular to the same axis.

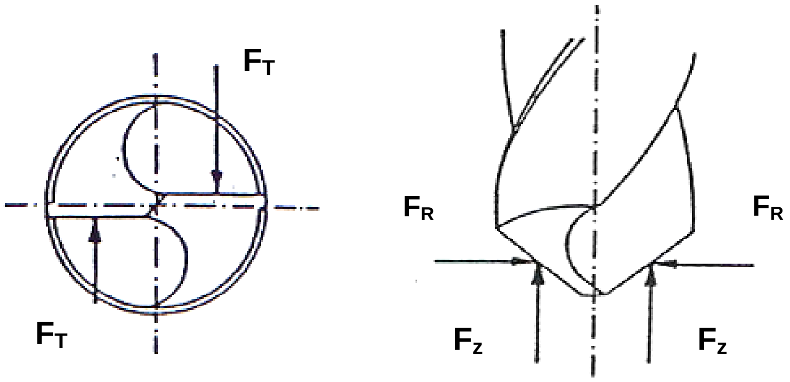

Fig.2 Application point (in the middle) of the components F_T, F_R and F_Z

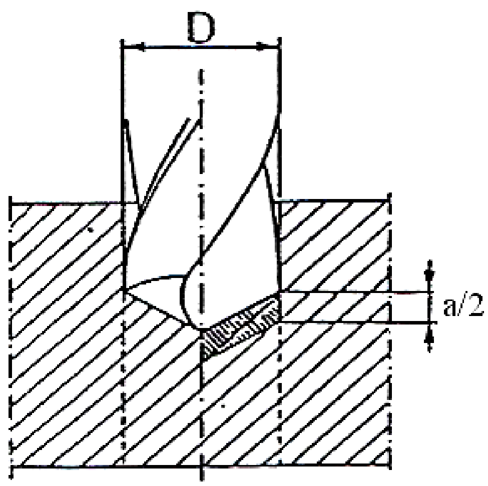

Fig.3 Sketch of the thickness for the removed chip

Chip section S removed by each cutting edge is calculable by the relation (Fig.3):

$$S = D \cdot \frac{a}{4}$$

where D is the drill diameter and a is the feed (mm/rev).

The detaching of this section generates a force that provides a torque M_z (with axis z coinciding with the drill rotation and with the direction of feed motion), that is convenient to consider how to:

$$M_z = F_T \cdot \frac{D}{2}$$

Also it consider that F_T can be expressed as directly proportional to S by the term "specific cutting " K_s (that depends on material and it’s obtainable by literature), usually used to quantify the real strain operating on the cutting edge during the drilling:

$$F_T = K_s S$$

This parameter depends on the characteristics of the material and is clearly variable with the section *S*. Because of the front rake angle is variable along the cutting edge profile, we must distinguish between a pressure of cutting average K_s and a local K_{so}, depending on the ratio *d/D* as shown in Fig. 4.

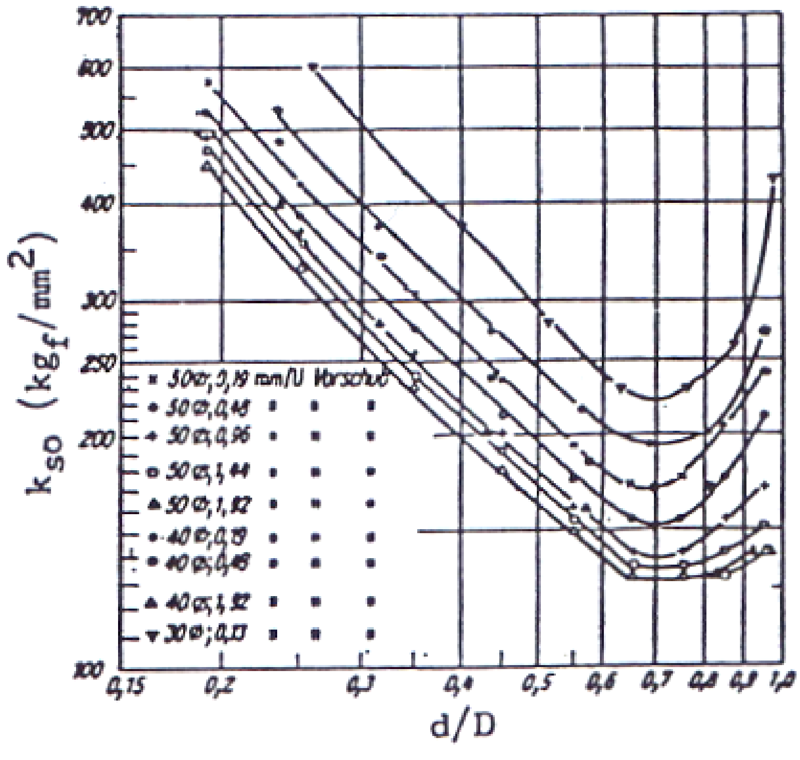

Fig.4 Trend K_{so} vs. (d/D)

K_s is usually used about practical aim: about that by the research of various authors diagrams have been constructed, as in Fig. 5, that show the K_s trend as function of feed and worked material.

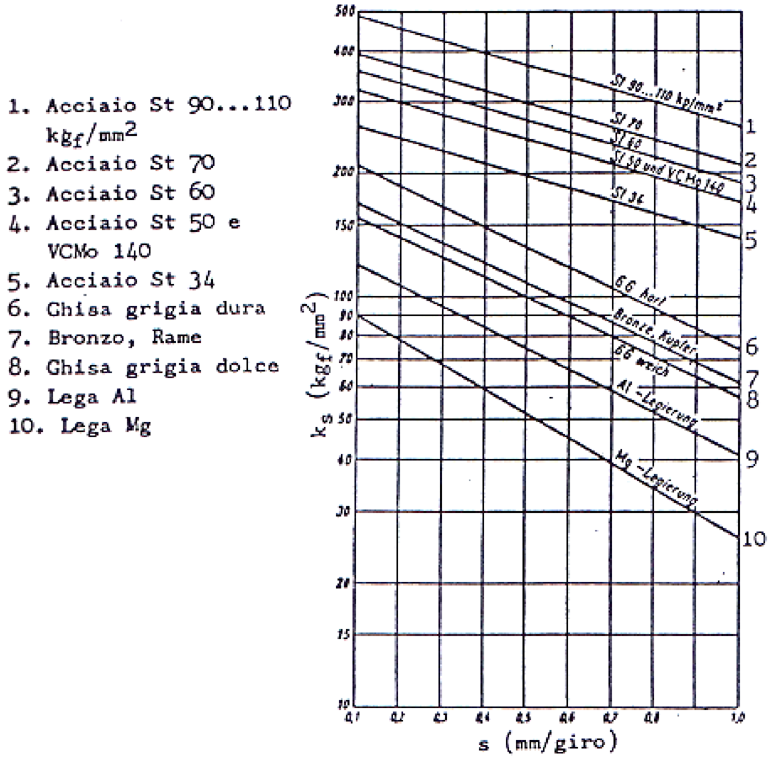

Fig.5 Valore di K_s in funzione del materiale e dell'avanzamento

Therefore, expressing M_z as function only in terms D and a by simple substitution in the aforesaid formulas, it is clear that, for conventional materials, the torque is directly proportional to feed and dependent quadratic on the drill diameter in quadratic form.

About the thrust force, experimetal results obtained by different researchers show a good correlation less than that seen for torque. This is mainly due to the great influence of the length of the connection between the cutting edges, variable for each drill, that can grow to 2 or 3 order of magnitude the feed resistance . The values of this component force (which, according to M_z, we call F_z) are usually calculated using an expression like this:

$$F_z = C_1 \cdot D^f \cdot a^g$$

Some indicative values are reported in Tab.2.

Drilled material	***C*₁**	***f***	***g***
Steel (vary hardness)	570 ÷1000	1	0,78
Cast iron (middle hardness)	380	1	0,6
Aluminium	200	1,2	1,1

Tab.2 Coefficient values to calculated the F_z thrust

Then it is possibile to note as about the drilling steel the thrust grows in proportion way with the driil diameter, less than proportionally respect to feed. Drilling by high feed is generally good generally convenient (for steel and cast iron), as the drilling time is reduced considerably while the feed resistance in way less than proportional (the limit is the maximum axial thrust that the spindle of the machine may support and also by eventual peak load during the work).

Finally a fundamental parameter about the drilling operation results the cutting speed v_t, defined as:

$$v_t(m/\min) = \frac{\pi \cdot D \cdot n}{1000}$$

in which *D* is the driil diameter (in mm) and *n* is the r.p.m. of the spindle.

A high-speed cutting involves considerable amount of energy concentrated on a very small area, causing the material on that point and therefore a local cutting instantly more "efficient". About that, so the evaluation of tool wear acquires special importance: tool wear is characterized by a progressive increase about cutting forces, as a function of time and number of the holes realized by the same drill (Fig.6)

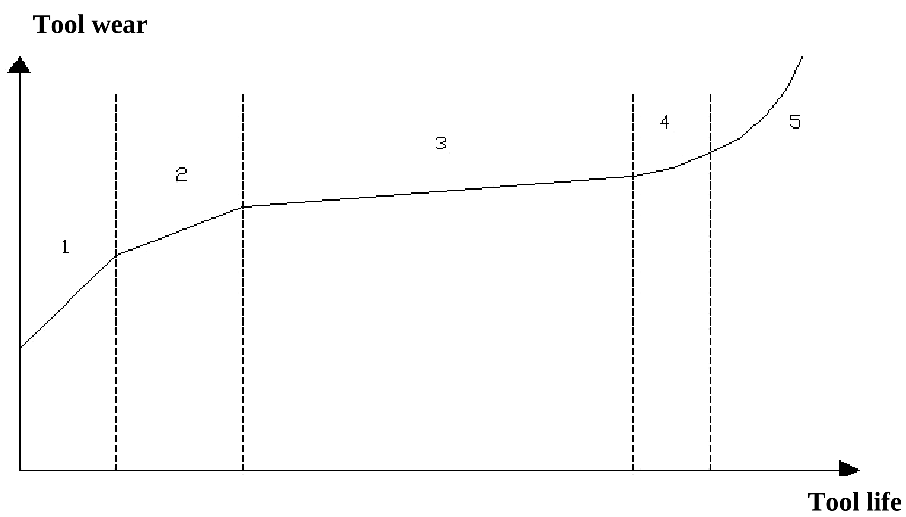

Fig.6 Tool wear vs. tool life (1: initial wear, 2: surface wear, 3: moderate wear, 4: quick wear, 5: deteriorated tool)

About the drill the tool wear is concentrated especially:

- on the external points of cutting edges, i.e. the cutting speed has the maximum.
- on the points near the rotation axis, cause to the particular operation to that is subjected the central edge zone.

6.2 Hot drilling concepts

The hot-drilling is an experimental process about that numerous studies have been developed in recent years. In particular the interest of researchers has been to try the work conditions by it’s possible to reduce the cutting forces, so that to enlarge life tool.

The use of refrigerant lubrication fluid permits to limit the drill heating, however putting a question about environmental impact with regard to the its disposal. The trend therefore is to reduce this use and to work to dry as much possible, but this situation requires cutting forces always lower in order to reduce tool wear, or more generally excessive stress that can damage it.

The experimental idea is based on the change of thermal conductivity of the studied material, which decreases with increasing temperature. So in these conditions, during drilling operation, the grown heat is disposed by more difficulties locally, and in the hole point it is possible to reach more easily the conditions of "softening" of material, through the consequent reduction in associated cutting forces F_z and M_z.

. The temperature increase, however, should not be too large or characterized by long exposure time, otherwise the transition from a simple heating to a real heat treatment. In fact the change of the mechanical properties needs to be local about the drilling area and not global, otherwise would invalidate all the reasons for the application of that material.

The reduction of cutting forces implies not indifferent benefits including wear, not only about the quantitative reduction of the aforesaid forces values: in fact many searches are being developed about the possible decrease of the slope on the characteristic wear trend seen in Fig.6.

6.3 State of the art

The metal matrix composite by aluminium alloy usually have been studied with high interest, thanks to their versatility about use and processing, in addition to the fact that the manufacturing processes may relate to the more common processes for the metal industry. In particular here we will consider the development and achievements in the field of machining, especially with regard to drilling.

Many studies have been primarily developed about a reinforcement as the Al_2O_3. First the influence of the material tool was confirmed about the operating cutting forces, about the tool integrity and the hole quality [40]. It was possible to observe as diamond tool is stressed by force less than a HSS tool, which suffers much the reinforcement high abrasiveness.

The analysis about the cutting forces is important also about the quality of the drilling carried out: in fact it was noted that the rise of the forces (in particular the thrust force) induced at the hole exit a burr formation increasingly growing. The tool wear and therefore the stress grows with the number of operated holes, so the burr dimension are a function of the hole numbers (and of the tool material, too) [40]. In addition there are also consequences about the surface roughness, which suffers the progressive rounding if the cutting edge, confirming its dependence by feed a_z and therefore the parameters n [rpm] and v [mm/min]. The cited rounding grows significantly in the HSS drill, so that the drilling operation becomes by friction, pushing and extruding the material in contact [40].

Since the Al_2O_3 particulate was then passed to the SiC reinforcement, making a more careful microstructural analysis and also considering the possible influence of the sharp angles of the drill [41]. This decreases with increasing of the feed. Moreover it was decided to verify the matrix influence about the considered operation: to realized that the material was subjected to heat treatment of various types [41] (for different heating time and fast cooling type), which may be typical in any manufacturing process of composite. The heat treatment can change the matrix mechanical properties, especially in terms of hardness, changing the cutting conditions and consequent applied stress.

In particular it was seen as hole surface roughness is an important indication about the influence of these parameters. In fact it decreases with the increasing of feed $a_{z,}$ with the increasing of the angle between the principal cutting edges but especially with the “softening” of the matrix material following to a heat treatment that can achieve it (it was particularly for HSS drill) [42].

Looking more closely the heat treatment effects (that usual concern about a heating of 500 °C for 2h, followed by rapid water cooling or by aging for temperatures about 190 ° C and 12-20h [43]) was confirmed as the eventual hardening of the matrix caused by them will lead to an increase of applied stress and of tool wear. The situation can be explained in these terms: about the softer material, the force reduction and so the wear reduction is due to the matrix relaxation that minimizes the physical contact between the abrasive particle and the tool [43]. In the case where the heat treated material, and so with higher hardness, is drilled, many authors [44] suggest as the fragments of reinforcing particles are not “captured” by the matrix , coming directly into contact with the cutting edge and becoming particularly abrasive [43] .

All this suggests that especially about the tool wear, matrix mechanical properties of the composite are not a marginal factor, but essential. This last point is very important for the testing that we was undertaken here.

As far as the “hot drilling” (see Chapter), the composite research is still in a primitive state. In fact a search of this type has been mainly developed about the non-ferrous metals such as aluminium alloys. But the material submitted to our research is a composite with matrix in aluminium, therefore it is fair to mention the results of such research, especially since they will serve as a useful comparison for our experiment.

To the typical study about the drilling parameters influence, it is then added an experimentation to determine the effect of workpiece temperature T on the F_z and M_z solicitations. The results (obtained for a common Al6082) not only confirmed the force proportionality with the feed $a_z\ [mm/rev] = v_{feed}/n$, but also a minimum temperature of the various conditions has been identified [45]. The drill diameter becomes essential not only with regard to the torque amount, but for the easiness with that the chip is ejected. Indeed, the situation that the force to be again growing after a certain T appears due to the difficulties of the workpiece to evacuate regularly the chip, because the filling cutting forms of cutting, hard to detach [46]. The difficulties logically increases with decreasing diameter, so that there may be real drill sudden break [46].

If about the Al6082 a T minimum has found, this case has not happened for a alloy as Al2024, by the highest mechanical properties. Here the F_z decrease remains uneven but on average constant [46]: cause to the high material properties, the aforesaid material “softening” is significantly delayed.

About these results, it is possible to added as they are confirmed by wear tests, that is seen as the trend passes to down or to up depending on the temperature [46].

The surface roughness obtained by the experimental drilling indicates not anything particular changes with the workpiece temperature, if not a little more probability for the Al6082 to find pieces of filling cutting attached to the surface hole.

It is right to consider the evolution of the results about evidence FIMEC indentation at hot conditions obtained in [46], where it is confirmed the influence of the heating adopted about the properties of aluminium alloys. The gradual reduction of tension yield, that increases with the workpiece temperature T , can clear about to what is due the increasing or decreasing trend for the tool stresses.

By the good results about hot drilling, the research of models and methods for the prevision of cutting forces as function of the vary cutting parameters (including workpiece temperature) has been developed. In particular a neural network was implemented to predict the cutting force in hot drilling machining and to evaluate the effects of the process parameters on thrust force. The network was trained and tested by experimental data containing thrust force, torque, workpiece temperature, drill diameter, feed and number of revolutions. Details about neutral network system are in [48].

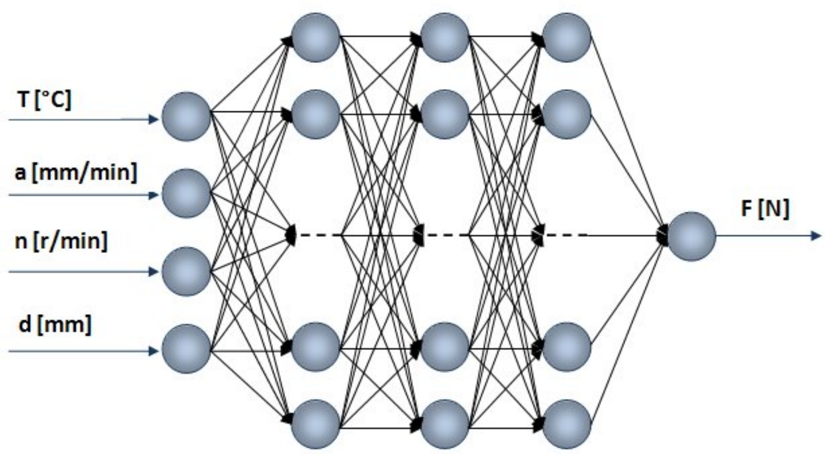

Fig.6 Architecture of the neural network mode developed for drilling

In fact it has been observed as the neural network is able to effectively learn the pattern of wear, and is thus applicable to the prediction of drill wear.

About this case the aim of future research is that to develop the carried out system about the composite, also implementing the factors regarding the specific material component.