A REVIEW OF THE DRILLING PROCESSES OF COMPOSITE MATERIALS

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Abstract: Drilling operation has a significant share in the machining of composite materials. In essence, the principle is known from the processing of metallic materials. Processing elements, however, presents characteristics which are determined by the nature and characteristics of the fiber material, the interface fiber / matrix geometry / etc configuration tool edges.
These features, which determine the defect in the delamination noted. The paper makes a systematic analysis of the drilling process from the technological system, machine tool, tool, device and material processing. References are made on the mechanism generating the phenomenon of delamination.

1. INTRODUCTION

The composite materials are defined, in [25], [39], as being the solid and deformable bodies, which are obtained through the assembly, with the specific technological methods [27], [23], of two or more distinct materials, from chemical point of view.

Generally, the composite materials can be classified in function of the matrix nature, of the reinforced material, etc., [25], [39], [27]. In function of the second criteria there are the following types of composite materials:

- the composite materials with particles;
- the composite materials armed with fibers (polymer matrix composite, metallic matrix composite, ceramic matrix composite and “carbon – carbon” composite);
- the ply laminated composite.

Composite polymeric materials reinforced with fibers (FRP_s) are grouped, in function of the fiber type, in three main categories [4], [25], [40]: 1. glass fiber - glass fiber reinforced plastic (GFRP); 2. carbon fiber - carbon fiber reinforced plastic (CFRP); 3. aramid fiber – aramid fiber reinforced plastic (AFRP).

These composite materials are characterized [4], [31], of the high resistance and stiffness, the inhomogeneous structure, the low weight, the insulator properties etc.

In global considering, the composite materials, especially the fiber armed composites create the specific problems of cutting processing (turning, drilling, milling operations) etc.

Basically, the mechanism of processing of the composite turning, and particularly, of the FRP composites is different of the mechanism of the metals processing. [33]

This review is determined by the fact that some mechanical, chemical, thermal composites characteristics etc. [25], [39] influence [4], [5], [6], [9], [17], [18], in different mechanisms, the machine process of drilling. There are some examples, as [37]: the way of chip forming, different of the one of metal processing, the wear of the cutting tool (the abrasive wear, high in the case of carbon fibers); difficulties in spreading of the heat generated by the cutting process, the influence of the composite fibers orientation under the value of the turning force etc.

This is very important, to maintain a certain temperature during the cutting process, related to the polymerization temperature of the composite resin, thermoplastic or thermorigid [23]. By the way, if the cutting temperature reaches to the melting temperature

of the thermoplastic composite, it is possible that the drill to lock [23]. It can be shown some examples of GFRP composite characteristics [4], [5], [34]:

- higher anisotropy of the properties;
- fiber abrasive action;
- low thermal resistance;
- low conductivity etc.

As any cutting process, the process of composite drilling includes the following main components [38]:

- machine tool;
- materials;
- workers;
- methods;

The technological operation of composite material drilling is made in the technological couple machine - tool M, device D, work P and drill D_r entitled technological system $MDWD_r$ of the composite material drilling. This system is defined by technological and constructive characteristics. These are presented in figure 1.

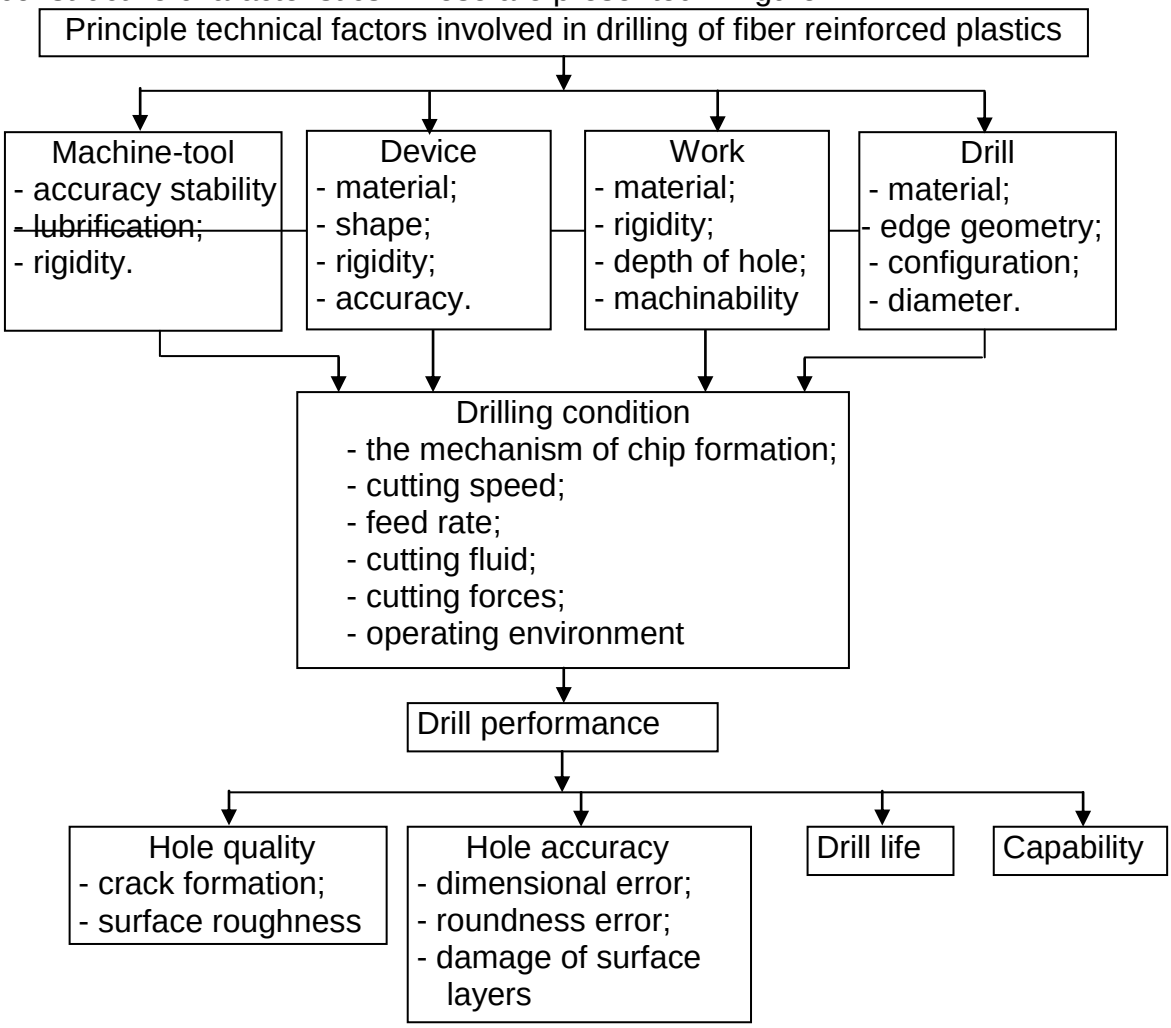


Fig. 1 The Representation of the MDWD system characteristics, in drilling of fiber reinforced plastics

This is notable that the technical factors of MDWD system and the technological conditions of the drilling process are in good correlation with the composite material characteristics.

Every factor influences the performances of the drilling process, such as the hole's quality (a very special criteria in the case of the composite process), the hole's accuracy, drill life etc. Vandervelde [38] presents in systematic way, helping of fishbone diagram effects, which the materials, machines and methods have it on the composite drilling process.

2. THE PARTICULARITIES OF THE DRILLING OF COMPOSITE POLYMERIC MATERIALS REINFORCED WITH FIBERS

Compared with the milling, turning, etc., the drilling process is largely used in composite materials processing. This review is met in aeronautic area, at the realizing of the assemblies with screws, rivets, and bolt technique [41], [2]. In this meaning, Faraz et. al. [8] mention a number of 55000 holes realized at the manufacturing of the Airbus A 350 aircraft. There are a good percent which shows the drilling importance in the mentioned area. Although, the technological process of composite materials drilling is the same with the one met, at the metal drilling, this one has some particularities about the tool

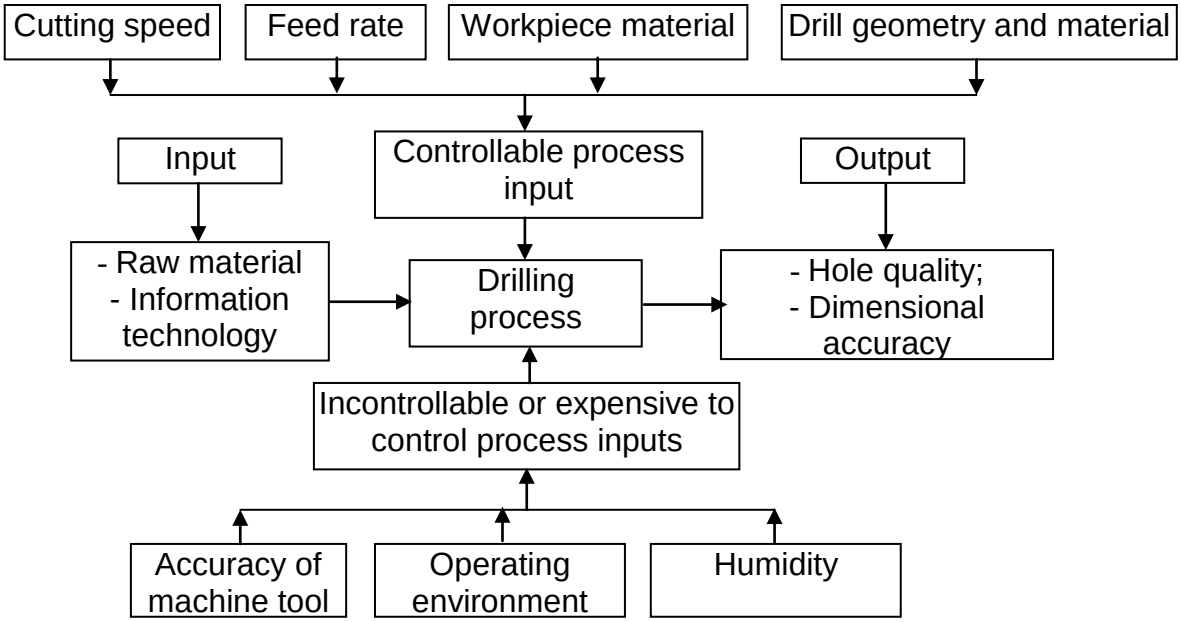


Fig. 2 The Systematic Representation of the technological drilling operation.
About Pop [27], Ariffin [2] and Madiwal [21]

construction, of the installing conditions of work on the tool - machine and of the characteristics of precision and the quality of the realized hole (Fig. 1). The technological drilling process can be systematic approached as in figure 2.

There are two categories of input variables:

- the controllable variables represented by cutting speed; feed rate, workpiece material and drill geometry and material;
- the incontrollable or expensive variable to control process inputs represented by: accuracy of machine tool, operating environment and humidity.

Regarding to the controllable variables, drill geometry and material has a major role to obtain the desired performances in composite materials drilling. Thus, Ariffin et al. [2] appreciate that the delaminating can be controlled with the help of the geometry and material of the drill.

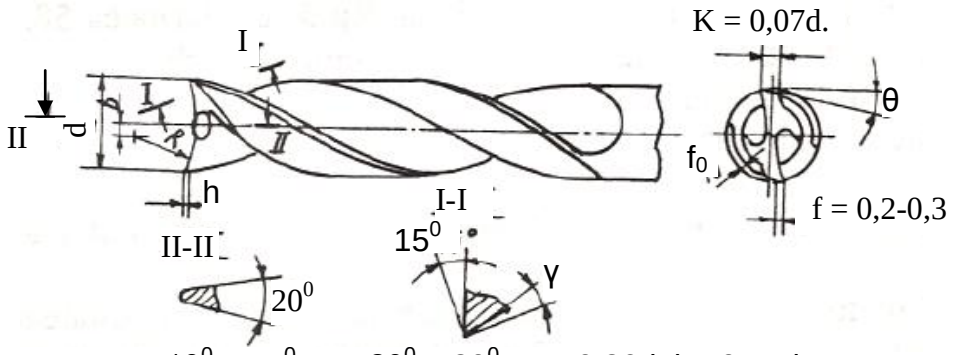
Furthermore, at the processing by turning at a piece by composite material, the problem of the choosing the tool material (particularly, of the drill material), have to be made in function of the main criteria [26], [23]:

- the coefficient of thermal expansion CTE;
- the estimation of the duration of the tool's use in the process of the production of the composite material pieces, in desired numbers;
- the level of precision of the composite piece, produced with the fabricated or achieved tool;
- the materials and the equipments disposable for the tool construction and/or the sharpening;
- the cost for the tool fabrication and/or the sharpening.

Generally, for the execution of the hole in FRP composite materials one use the drills met at the metal processing or at the wood species. and the drill rectified and chromed (the sharpening is made of the pitch surfaces and of the flats) or the drills with special construction [29], [24] [16] (Fig. 3 - 4).

The drills are executed by the following materials [16], [33], [24], [29], [18], [13]: high-speed steel (HSS); high-speed steel covered with hard coats, ex. with titanium nitride etc.; tungsten carbide; cubical boron nitride (CBN) and polycrystalline diamond (PCD). In function of the composite type, one chooses the material which has a high resistance at the abrasive wear [12], [16].

The drills realized only of the rapid steel is used just to the execution of a reduced number of holes.



$\gamma = 10^0 - 15^0$; $\alpha = 20^0 - 30^0$; R = 0,36d; b= 0,17d;
h = (0,12-0,16)d; f_0 = 0,15-0,6 la d = 5-20 mm

Fig. 3 Drill for the drilling with GFPR mechanical advance;. *from Minciu. Reference [24]*

3. THE CHARACTERISTICS OF THE HOLE QUALITY

At the composite materials drilling, an important aspect is the hole quality expressed by some parameters as [21], [11], [13], [17]: surface finish, roundness, hole diameter etc. Therewith, the FRP composite material drilling is accompanied by the apparition of some particular defects. These appear at the entrance of the hole, at the surface of the hole and at the hole issue.

The failures for drilling composite FRP_s can be classified as [3], [8] [10-11], [37], [38] fiber break-out, interlaminate cracking, delamination, spalling, fiber/matrix de bonding and thermal damage.

In the specific literature [5], [6], [12], [16] there are presented these categories of defects and the factors which determine his appearance, are analyzed.

A major defect [26] of the CF composites drilling is the delamination. This phase is represented by the exfoliating of the adjacent plies of the composite in length fiber. The delamination is developed in two phases [30]: the chisel edge action phase and the cutting edge action phase, and in two areas of the hole: at the drill entrance (Fig. 5. a) and respectively, at the drill issue (Fig. 5. b). In the second area, in the moment when the drill is near of the issue of the hole, the number of the composite plies, which is against of the drill advance, is reduced and it is produced the reduction of the rigidity of their fixing in composite structure In this way, one produces the delamination (the exfoliating) of the last plies and the fracture of the last fibers of the composite.

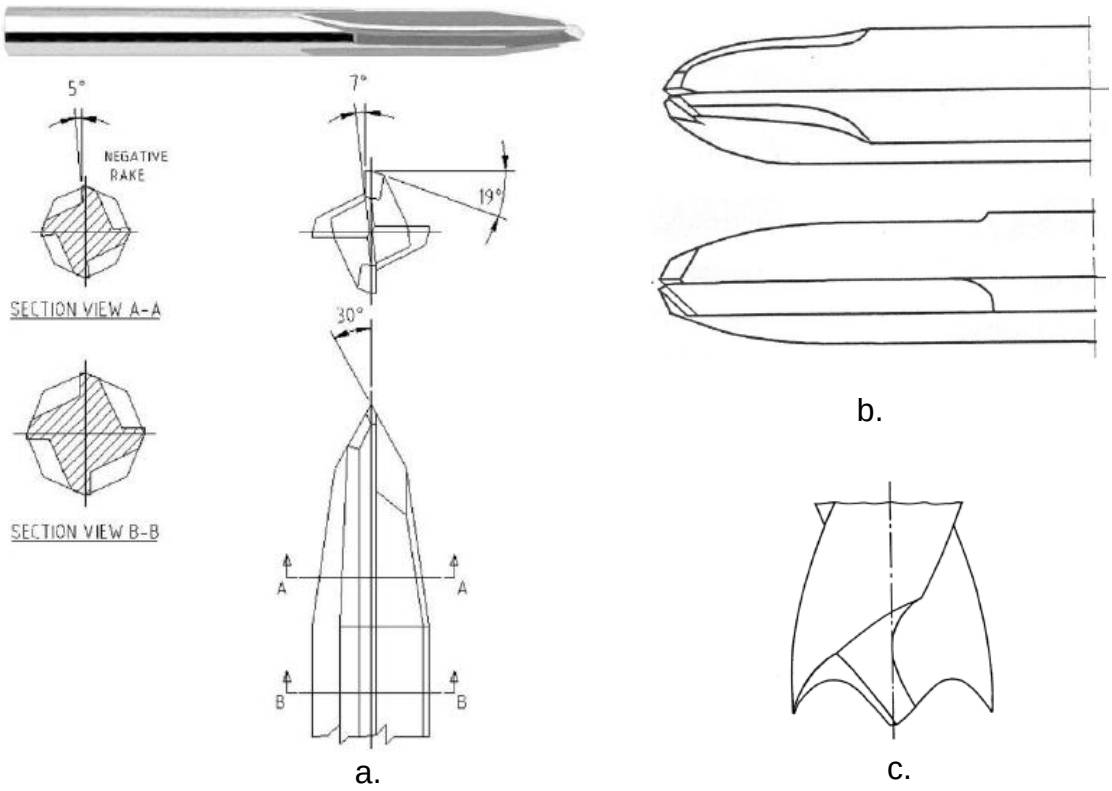


Fig. 4. The drills with specific geometry for the composite materials drilling. A-b.for composite carbon/epoxy. *From Iliescu, reference [16]; c. for aramid. From Durao, reference [10]*

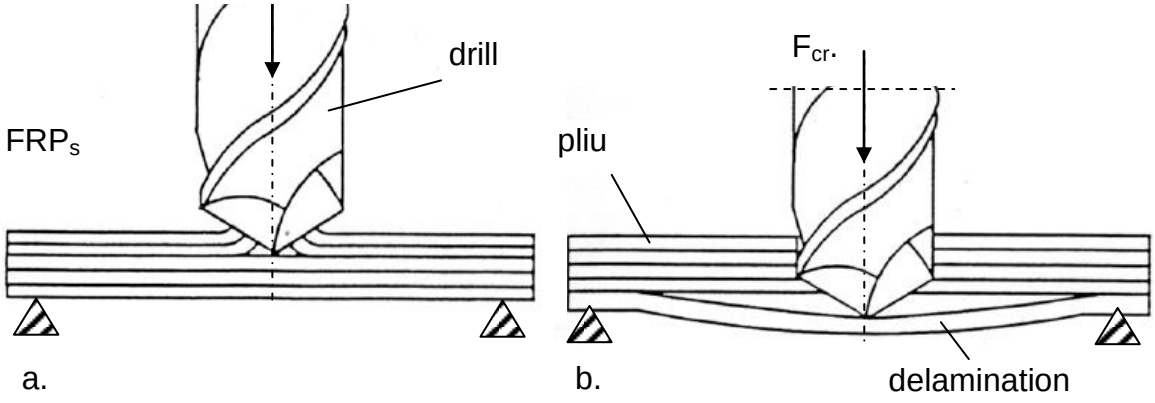


Fig. 5. The drilling of the FRP composite material: a. peel-up delamination at entrance; b.; push-out delamination at exit the axial critical force, F_{cr}

Many studies analyzed the delamination and the mechanism of his appearance: P. M. L. Durão, [10], [11], D. Iliescu, [16], H. Hocheng [14], C. C. Tsao, [34], [35], A.

Vijayaraghavan [39] etc. At the modelling of this mechanism the main role is the one of the total advance force F_A. His direction is perpendicular of the composite plate.

The size of the advance force F_A depends [7], [29], [24] of the mechanical characteristics of the composite material, of the material, the geometry and the wear of the drill and of the advance speed size.

The value of the total advance force consists of the following components [7]:

$$F_A = 2\ F_{x\,t} + F_{ce} + F_{ss} + F_{hg} \quad (1)$$

where $F_{x\,t}$ is the advance force which acts on every point at the drill;

F_{ce} – the penetration force, generated of the chisel edge in the fiber length;

F_{ss} – the friction force generated (in the longitudinal axis of the drill) by the friction between the side surface of the tool and the generated hole's surface;

F_{hg} – the friction force (in the longitudinal axis of the drill) between the chip flow along the helical grooves.

During the drilling, the size of the force F_A is floating as is showed in figure 5.

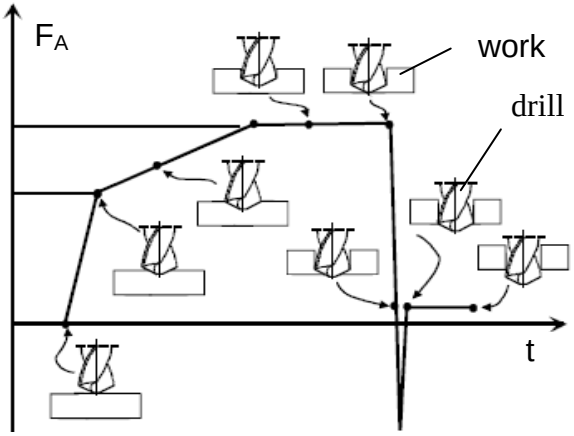


Fig. 5 The floating of the total advance force F_A as a function of drilling time t. *From reference [7]*

Capello et al. [7] shows that the level of action of the components under the advance force size F_A is different, by the expression:

$$2\ F_{x\,t} > F_{ce} >> F_{ss};>> F_{hg} \quad (2)$$

By this reason, at the modeling of the advance force F_A the action of the components F_{ss} and F_{hg} are neglect.

By this mean, the delamination is produced at a critical value F_{Acr} of the advance force F_A [29], [34], [35]. For to establish of this value, one elaborates some computing models [16], [10], where is observed the model proposed by H. Hocheng and C. C. Tsao [14], [35].

4. CONCLUSIONS

This paper has presented the reviews specific for the FRP composite materials drilling. By this mean, these consist of the following:

- The mechanism of the processing by turning of the composites and particularly, at the FRP composites, which is different by the mechanism of the metals processing. This review is determined by the structure and by the mechanical, thermal, etc. characteristics of the composite material.

- The systematic representation of the technological couple of drilling $MDWD_r$ which allows the highlight of the input and output variables for the technological operation of the FRP composite material drilling and the highlight of the parameters of the drilling regime.

Reporting of the controllable variables, drill geometry and material have a major role to obtain the desired quality performances at the composite material drilling;

- The choosing of the drill material has to assure the resistance of the abrasive wear;
- For reasons of the assuring of hole quality and the productivity, at the FRP composite materials processing it is used many constructive shapes of the tool geometry;
- The main problem of the defects met after the fabrication consists of the delamination of the hole. By this reason, in specific literature are elaborated some physical models for analyzing this defect.

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