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A CONCISE ANALISYS ON COMPOSITES MACHINING TECHNOLOGIES

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Abstract: *Composite materials offer the benefits of part integration and thus minimize the requirement for machining operations. However, machining operations cannot be completely avoided and most of the components have some degree of machining. Machining operations are extensively used in the aerospace industry. Machining of metals is very common but machining of composites poses some very specific difficult. In the paper is presented a concise analyze on composites machining. Conventional and non-conventional machining is presented with their technical requirements, advantages and disadvantages.*

Keywords: *composites, conventional machining, turning, milling, drilling, non-conventional machining, abrasive water jet, laser machining, ultrasonic machining*

1. INTRODUCTION

There is no universal definition of composites. In general, a composite material is a heterogeneous material system consisting of two or more physically distinct materials. It is made by combining two or more materials to give a unique combination of properties. The above definition is more general and can include metals alloys, plastic co-polymers, minerals, and wood. Fiber-reinforced composite materials differ from the above materials in that the constituent materials are different at the molecular level and are mechanically separable. In bulk form, the constituent materials work together but remain in their original forms. The final properties of composite materials are better than constituent material properties.

The main concept of a composite is that it contains matrix materials. Typically, composite material for aircraft parts is formed by reinforcing fibers in a matrix resin. The reinforcements can be fibers, particulates, or whiskers, and the matrix materials can be metals, plastics, or ceramics. The reinforcements can be made from polymers, ceramics, and metals. The fibers can be continuous, long, or short [3].

Composites are made with a polymer matrix which can be thermoset or thermoplastic resins.

Composites have been designed and manufactured for applications in which high performance and light weight are needed. They offer several advantages [2, 3, 4]:

- design flexibility, complex parts, which are sometimes not possible with metals, can be fabricated without welding or riveting the separate pieces or can be replaced by a single composite component;
- high specific stiffness;
- very high specific strength;
- the fatigue strength (endurance limit) is much higher than steel and aluminum alloys;
- high corrosion resistance.

During the process in the raising of a composite parts, there are four main steps which are **forming**, **machining**, **joining–assembly** and **finishing**.

In figure 1 is presented a very concise schema of composites manufacturing.

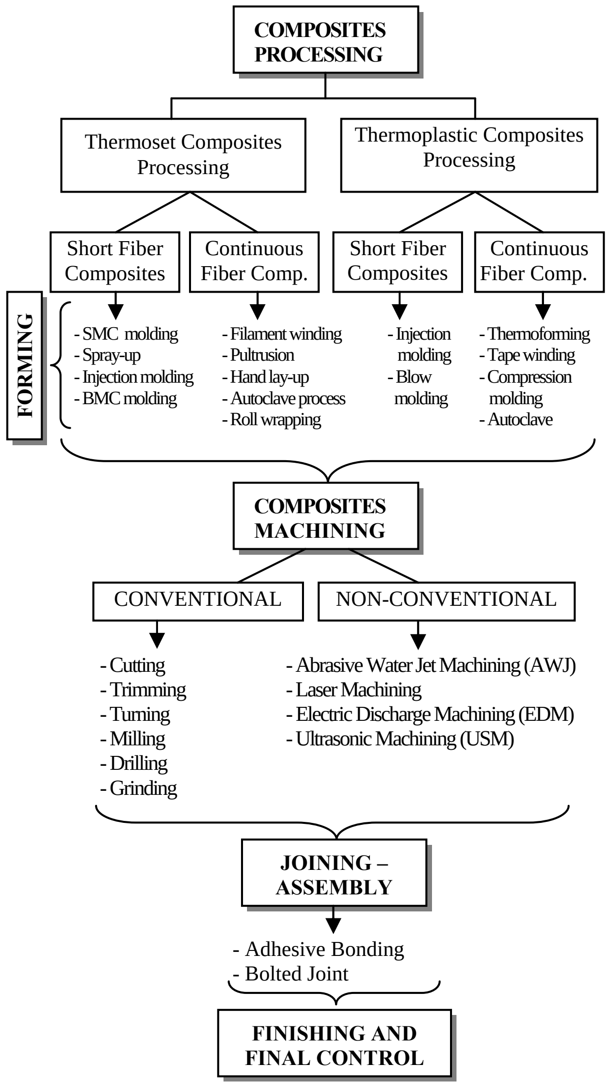

Fig.1 Composites Manufacturing Schema

2. CONVENTIONAL MACHINING

Composite materials offer the benefits of part integration and thus minimize the requirement for machining operations. However, machining operations cannot be completely avoided and most of the components have some degree of machining. Machining operations are extensively used in the aerospace industry.

The processes used to manufacture composite structures generally require that trimming and other machining operations be performed prior to assembly. Machining processes are required to produce accurate surfaces and holes to allow precision fitting of components into an assembly. Due to shrinkage during the curing stage of the composite structure it is not practicable to place holes in the part during the molding stage, therefore milling, cutting, drilling etc. are considered a post cure operation.

The tool used for the composite machining are generally the same whit the tool used in metal machining. A large database of machining information for various high speed steel and carbide cutting tool materials exists for machining metal, wood and some thermoplastics. But much of this data cannot be applied to machining modern composites. Each modern composites have their own machining characteristics. Composites are not homogeneous or isotropic, therefore the machining characteristics are dependent on the tool path in relation to the direction of the reinforcing fibers. Metals or metal alloys have nearly homogeneous properties throughout the workpiece, but each material in a composite retains its individual properties.

Machining of metals is very common and is easily performed but the machining of composites poses some difficult very specific:

- Machining of composite creates discontinuity in the fiber and thus affects the performance of the part.
- The temperature during cutting should not exceed the cure temperature of the resin for thermoset composites to avoid material disintegration. Glass and Kevlar fibers have poor thermal conductivity and such high temperature may lead to localized heating and degradation.
- Machining exposes fibers to chemicals and moisture.

2.1 Conventional turning. The turning of composites is utilized to produce round surfaces that need to mate with either metal or composite parts. Depth of cut will vary depending on the thickness of the part and the amount of material to be removed.

Advantages: Computer numerical controlled lathes (CNC) can be used to machine simple to very complex rotational parts. CNC machining produces accurate parts at a high production rate.

Disadvantages: Delamination (Fig.2) can also occur on a lathe, therefore the part may require a finish cut moving from the largest diameter to the smaller diameter.

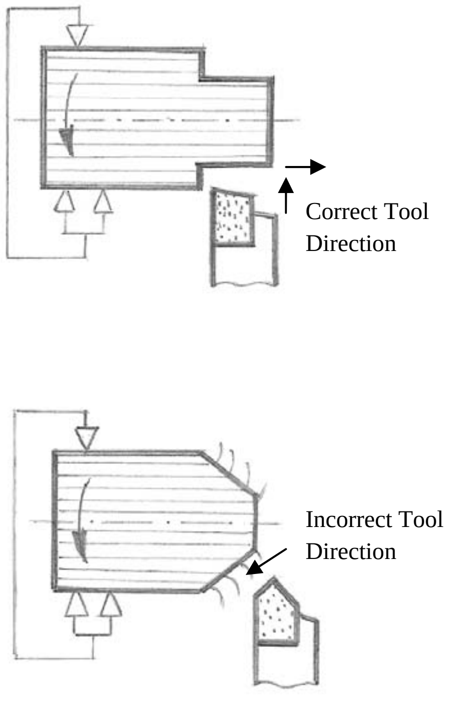

Fig.1 Turning composite parts on a lathe

Machining parameters:
- Rotational speed
- Direction of rotation
- Angle
- Traverse rate
- Initial diameter
- Final diameter
- Depth of cut.

Machining requirements (dependent variables):
- Turned diameter
- Surface finish
- Machining time.

Recommended milling parameter is [4]:
-cutting speeds range can be over 300 m/min.

2.2 Mechanical Drilling. Drilling holes in composites can cause failures that are different from those encountered when drilling metals. Delamination, fracture, break-out and separation are some of the most common failures. Delamination (surface and internal) is the major concern during drilling composite laminates as it reduces the structural integrity, results in poor assembly tolerance, adds a potential for long term performance deterioration and may occur at both the entrance and exit plane. Delamination can be overcome by finding optimal thrust force (minimum force above which delamination is initiated). Figure 2, a) shows delamination at exit because at a certain point loading exceeds the interlaminar bond strength. Figure 2, b) shows peel-up delaminating at entrance because the drill first abraded the laminate and then abraded material away along causing the material to spiral up before being machined completely. This type of delamination decreases as drilling proceeds since the thickness resisting the lamina bending becomes greater. Among the variables to be considered for tool selection include the thickness of material, diameter of hole, tolerance requirements, hole finish requirements and the composite material being drilled.

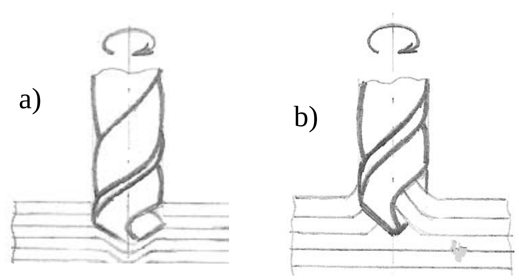

Fig. 2 Delamination during drilling composite
a) push-out at exit
b) peel-up at entrance

Machining parameters:
- Angle
- Traverse rate
- Standoff distance
- Dwell time
- Pressure profile
- Material thickness.

Machining requirements (dependent variables):
- Diameter
- Drilling time
- Hole shape.

Recommended drill cutting parameters are [4]:
-feedrates range from 0.025 mm/rev to 0.063 mm/rev;
-cutting speeds range from 30 m/min to 460 m/min;

2.3 Conventional milling. The surface roughness is a function of fiber orientation, cutting direction and the angle between cutting direction and fiber direction. When taking heavy milling cuts there is a greater tendency to break comers as the tool exits the material so it is advisable to first machine a step on the edge perpendicular to the final pass. A four fluted end mill will reduce cutting pressure on the laminate and keep it cooler. Climb milling helps prevent the fibers separating from the matrix bond material.

Advantages: improved surface finish unless part surface was directly in contact with the mold surface, machined surfaces provide accurate surfaces for parts to be assembled.

Disadvantages: controlling the dust particles, confining them to a small area and having an adequate collection system and controlling the outer layers of the composite so that the fibers will shear instead of lifting up under the force of the cutting action and leaving extended fibers beyond the cut surface (when cutting perpendicular to the lay of composite fibers, edge break-out can occur).

Machining parameters:

- Traverse rate
- Number of passes
- Number of sweeps.

Machining requirements (dependent variables):

- Volume removal rate
- Depth control.

Recommended milling parameter is [4]:

-cutting speeds range from 250 m/min to 760 m/min.

2.4 Grinding of composites. The grinding process has been used extensively for finishing composite parts. The grinding of polymer matrix composites has a number of problems. For example in the case of thermoplastic matrix, the surface of grinder becomes covered with melted thermoplastic. In the case of aramid fiber it is hard to get a clean cut surface because the grains cannot abrade the aramid fibers cleanly. Abrasive belts have been used on aramids with some success but dust collection has been a major problem.

Recommended grinding parameter is [4]:

-surface speeds range from 1200 m/min to 1800 m/min.

For all conventional machining, high cutting speeds can burn the matrix material and reduce bond strength between the composite material and the matrix material. So, a water soluble coolant forced through a cold air blast unit is recommended when machining most composite materials. If the composite is hydrophilic, a cold air blast unit in combination with dust or vacuum collection system should be used.

3. NON-CONVENTIONAL MACHINING

3.1 Abrasive water jet (AWJ) machining - is used for linear profile cutting, turning, milling and drilling operations in composite materials.

Conventional tool machining is affected by fiber or particle reinforcements rather than the matrix material while AWJ machining is not.

Water jets without abrasive are also used for cutting soft composites.

Advantages offered by AWJ are:

- suitable for wide range of composites;
- can perform many operations like turning, drilling and milling;
- no thermal stresses;
- omnidirectional machining;
- process can be automated;
- optimal range of parameters available to prevent delamination, loading and splintering;
- it can be drilled fine holes (0.5 mm).

Disadvantages:

- dimensional accuracy is low;
- temperature rise in cutting region may be observed;
- not suitable for hydrophilic materials.

AWJ machining parameters are [4]:

- Pressure
- Water jet diameter
- Mixing tube length
- Mixing tube diameter
- Abrasive material
- Abrasive size
- Abrasive flow rate.

3.2 Laser machining of composites. Lasers are used in various industrial applications such as drilling, cutting, welding and heat treatment of metals, etc. In composites, polymer matrix materials are most suited for laser cutting. Laser cutting is a non-contact ablation process in which efficiency is determined by thermal properties of the workpiece material. Two types of laser have been used in industry [1]: Nd-YAG solid state laser and CO, gas laser. The Nd-YAG laser operates in the near infrared (IR) region of the spectrum while CO, gas laser operates in the far infrared region. The Nd-YAG (IR region) wavelength is not absorbed by glass and many plastics, while the CO (far IR region) wavelength is. It has been determined that the Nd-YAG laser is very effective in cutting composite materials. The high power short pulses achieved with this laser vaporizes both the fibers and matrix before the epoxy resin can be overheated.

Advantages:

- superior quality edges due to high temperatures;
- vaporization of the material in cut zone;

Disadvantages:

- beam divergence after its focal point;
- material thickness of 10 mm is the maximum that can be cut with 1500W;
- Varying dimensions of heat affected zone.

3.3 Electric Discharge Machining (EDM) - Advanced composites can be cut by EDM as there is no physical contact between the electrodes or workpiece and the tool. In order to EDM a composite, it should have an electrical resistivity of less than 1-3 ohm/m. Polymer matrix composite manufacturers can add a small amount of copper in the matrix of the product to allow shaping by EDM.

EDM can be used with conductive silicides, borides, carbides etc. The EDM process is more accurate than AWJ machining. Small holes of 0.25 mm diameter can be drilled in composites. The EDM process is found to be slow for many production applications [4].

3.4 Ultrasonic machining (USM). This technique incorporates a tool vibrating at 20 kHz and abrasive in a slurry to perform impact grinding of brittle materials. This technique is particularly useful for machining of ceramic matrix composites that are difficult to process by conventional methods. USM is a mechanical material removal process best suited for machining brittle materials like glass, ceramics, graphite and ceramic matrix composites. The process is limited to workpieces of size below 100 mm because of the limitation on the size of the tool [4]. Some of the variables that influence USM for close tolerances are follows: abrasive type and size, sonotrode (tool) material, ultrasonic vibrations, surface area.

USM is used in applications like drilling aerospace cooling holes in ceramic matrix composite turbine blades, slotting, irregular configurations in ceramics and composites, machining of radar components, superconductors, wire draw and extrusion dies.

Advantages:

- conductive and nonconductive materials can be machined;
- material hardness is not important;
- there are no chemical or electrical alterations in the workpiece;
- 3D and complex shapes can be machined easily and quickly;
- no heat affected zone.

Disadvantages:

- amplitude of ultrasonic vibrations are very important for proper machining;
- limited sizes can be machined.

4. CONCLUSIONS

In today's highly competitive global economy, the need for new materials with high properties to meet the demands of design, environment, durability and economics is growing. Composite materials, with their high strength and stiffness-to-weight ratios, have many advantages and are a desirable engineering material.

In a composite material system, the individual materials exhibit their unique properties and the composite as a whole shows properties that are different from its constituents. The properties of composites depend on the form and structural arrangements of the constituents and the interaction between the constituents. Composites consist of two components, a matrix and reinforcement. The matrix functions as the body constituent, serving to bind the reinforcement together and giving the composite its bulk form. The reinforcements are the structural constituents, providing high strength to the internal structure of the composite.

The composite parts manufacturing consist in four main steps which are forming, machining, joining–assembly and finishing. In the paper it is considered some aspects about composites conventional and non-conventional machining.

If composites are not homogeneous or isotropic, therefore the machining characteristics are dependent on the tool path in relation to the direction of the reinforcing fibers.

There is no accurate method of determining the operating modes, only general recommendations, most experimentally determined. Each modern composites have their own machining characteristics.

Composites machining have some difficult very specific such as creating discontinuities in the fibers arrangements and exposes fibers to chemicals and moisture (the performance of the parts are affected).

In the same time, the temperature during cutting can burn the matrix material and reduce bond strength between the composite material and the matrix material

REFERENCES

1. Amza, Gh.,. *Materials Technology Treated*. Bucharest: Romanian Academy Publishing House (2002).
2. Harper, A., Charles, Petrie, M., Edward *"Plastics materials and Processes. A Concise Encyclopedia"*, John Wiley & Sons, U.S.A., 2003.
3. Mazumdar, K., Sanjay, *"Composites Manufacturing – Materials, Product and Process Engineering"* CRC Press LLC, U.S.A., 2002.
4. Peters, S.T. *Handbook of Composites*. London, Chapman & Hall, 1998.
5. http://www.e-composites.com.