MANUFACTURING PROCESS AND APPLICATIONS OF COMPOSITE MATERIALS

POP P. Adrian[1], BEJINARU MIHOC Gheorghe[2]
[1]University of Oradea, e-mail: adippop@yahoo.com
[2]"Transilvania" University of Brasov, e-mail: bejinaru_georghe@yahoo.com

KEYWORDS: composite, lightweight, matrix, reinforcement

ABSTRACT: This paper is presented some manufacturing processes of composites, as laminating, filament winding, pultrusion, resin transfer molding, and them large applications in aeronautics, automotive, maritime, etc. Also, a FEA of slide bearing form PA6 reinforced with glass fibers that change the slide bearing from bimetallic used of machine tools is analyzed.

1. INTRODUCTION

The composite materials have got a widely applications in all cutting-edge ranges of advanced materials as aeronautics, automotives, boats, sports parts and medical devices.
As a general definition, the composite material has more versions, and ones of them can be as a material composed by the combination of two or more materials: a reinforcing element and a compatible resin binder (matrix) to obtain specific characteristics and properties [1-3, 6-8].
The roles of matrix in composite materials are to give shape to the composite part, protect the reinforcements to the environment, transfer loads to reinforcements and toughness of material, together with reinforcements.
The aims of reinforcements in composites are to get strength, stiffness and other mechanical properties, dominate other properties as coefficient of thermal extension, conductivity and thermal transport.
As a comparison between composites and metals, the composites materials are some advantages as:

- Lightweight,
- High specific stiffness and strength,
- Easy moldable to complex forms,
- Easy bondable,
- Good dumping,
- Low electrical conductivity and thermal expansion,
- Good fatigue resistance,
- Part consolidation due to lower overall system costs,
- Low radar visibility,
- Internal energy storage and release.

Such as disadvantages of composites are the followings:

- Cost of materials,
- Long development time,
- Difficulty manufacturing,
- Fasteners,
- Low ductility,
- Temperature limits,
- Solvent or moister attack
- Hidden damages and damage susceptibility

All of these have made those composites to change more and more the metals, in specials in aircrafts, automotives, marines, constructions, etc.

The most common type of composite material is fiberglass, which is very strong, fracture readily if notched, and at compression, it buckles easily. It can be protected from damage by encapsulating the fiberglass in a resin matrix, which transfers applied loads in the unified fibers, due to used it both for tension and compression. A most influences about the composite strength are get by the arrangement of fiberglass, presented in Fig.1.

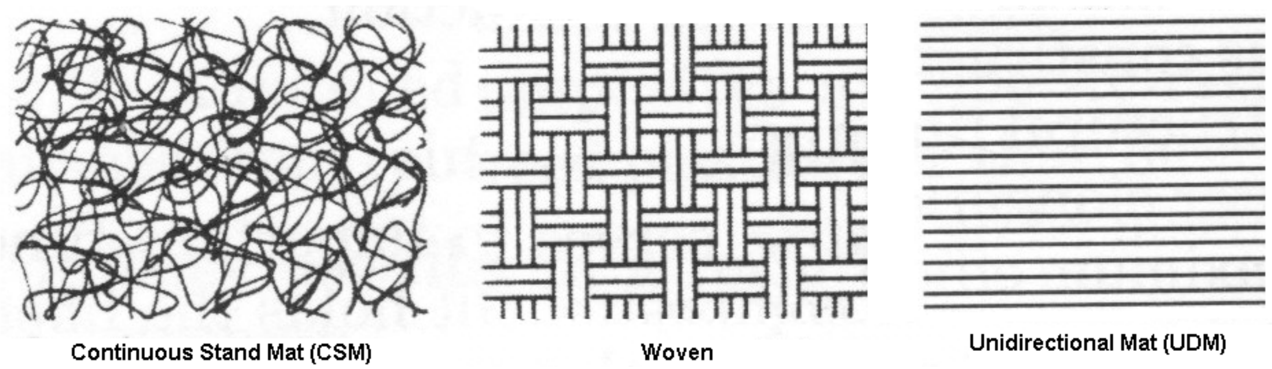


Fig.1. Common forms of fiberglass [6]

After the nature of its matrix, the composites are classified in:

- Composite materials with organic matrix,
- Composite materials with metallic matrix, and
- Composite materials with ceramics matrix.

In generally, the more advanced structural composites use fiberglass, carbon/graphite, boron, Kevlar (aramid) and other organic materials, which emphasized the main properties as lightweight, higher strong and stiffness. These strengthening effects of fiber reinforcements in composites are get by the percentage of fibers (fiber-resin ratio), type of fibers and fiber orientation with respect to the direction of loads.

The term of advanced composites includes a special technology, where resin-matrix composites can include hybrids, which are mixtures of fibers in various forms in the resin matrix. These advanced composites denotes a resin-matrix material reinforced with high-strength, high modulus fibers of carbon/graphite, aramid, or boron, fabricated in layers to form an engineering components. It's used for combination of epoxy-resin matrix materials reinforced with oriented, continuous fibers of carbon and fabricated in a multilayer form, assured a higher rigidity and strong structure.

An important distinguishing between composites from reinforced plastics is the fiber to resin ratio, usually this ratio is greater than 50% fiber per weight.

This paper has the goal to presents certain manufacturing process' techniques of composite materials and them applications.

2. MANUFACTURING PROCESS OF COMPOSITE MATERIALS

In function of composite constructions, those can be divided in two categories [3,7]:

- **Laminates**, which have layers bonded together,
- **Sandwiches**, which are multiple-layer structural materials containing a low-density core between thin faces (skins) of composite materials.

As an observation, can be mention that in some application of advanced composite materials, the individual layer may themselves be composites, usually of fiber-matrix type.

Composites fabrication have many processes, some of the most important processes are:

- Hand and automated tape lay-up,
- Resin injection,
- Compression molding,
- Pultrusion,
- Filament winding.

Other classification of composites process can be after the process volume, which due to of two categories: high and low volume.

Low-volume processes are manual and low-pressure spray lay-up in low-cost molds with a high working cost. High-volume processes, such as lamination, filament-winding, pultrusion and resin transfer molding, have an initial high cost for tooling and installation, which are compensated by low-intensity of working. In addition, lamination processes can be found in both of them, lamination as a hand lay-up process, or as the automated using sheet-molding compounds.

Lamination, filament winding, pultrution and resin transfer molding are relevance in production of continuous fiber composites with closely controlled properties, being used for obtained of comparative flat parts.

A potential and high-speed process in fabrication of tubs and other cylindrical parts represents the filament-winding process, in which time the pultrusion process is applied for fabrication of parts with constant cross-sectional shapes, and resin transfer molding shares some similarities with injection molding.

2.1. Laminating Process

The laminating process is large used at fabrication of advanced materials. To improve the process it can be used a prepreg material, which is a preimpregnated reinforced material with high composite's property by fibers aligned parallel to each other. A sample of product's form is cut off by variety proceedings and the prepreg material is fixed into desired laminate geometry. The final workpiece is achieved by curing the stacked plies under pressure and heat in an autoclave. For examples, the graphite-epoxy composite is cured at aprox.180^{0}C and at pressure of 0.7MPa, and for high-temperature composite such as bismaleimides the cured temperature is of 320^{0}C. The tooling is requested a mold following a part through the lay-up and autoclaving process. As material tooling for fabrication of composites are aluminum, steel, electroplated nickel, a high-temperature epoxy-resin system casting, etc [1-3,5-8].

The productivity of manual lay-up can be improved by used an automated process by CNC machines, with large applications in aerospace and automotive industry.

Fig.2. Robot system lays thermoset, thermoplastic or dry fiber [2].

2.2. Filament-winding Process

Filament-winding process is a relative slowly with possibility to control the fiber direction and the diameter of parts can be varied along the part. During the process, roving or tape is drawn through a resin bath and wind in a rotational mandrel. Filament-winding mandrels may be metallic or non-metallic and assured the possibility of easy part removal or be dissolvable after curing. The fiber bundle has various dimensions, from several thousand of carbon fibers to several centimeters. The finished part is cured in an autoclave and later is removed from mandrel (Fig.3).

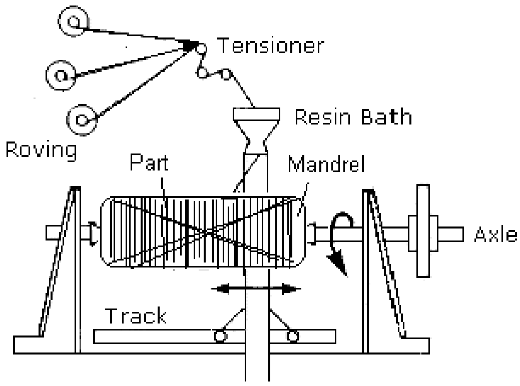


Fig.3. Filament-winding process [6]

When the mandrel is removed, a hollow shape is the result. With this process can be realized variety parts as pipe, tubing, pressure vessels, tanks and items of similar shape. For enhance the structure of parts, the carbon fibers are wound with epoxy-resin systems.

2.3. Pultrusion Process

The pultrusion process represents a continuous transportation of fiber bandles through a resin matrix bath, following by a dropping of them into a preheated die or a set of dies. After curing process, where the part is changed from wet saturated reinforcement to a solid par the pultrusion is saw-cut to desired length. A flow diagram of process is showed in Fig.4.

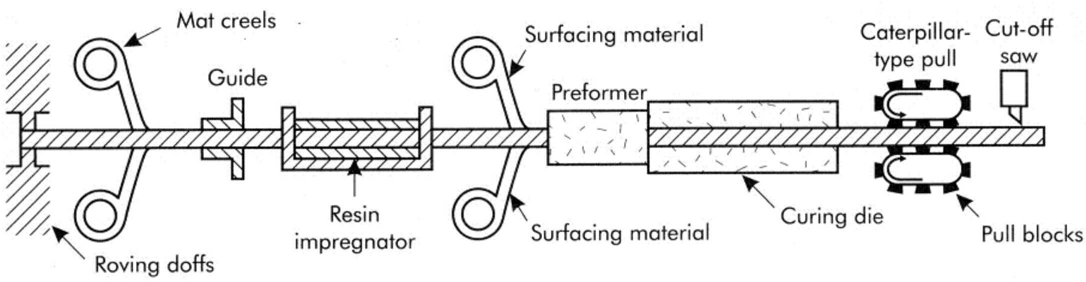


Fig.4. Flow diagram of pultrusion process [6]

With this process results parts with complex shapes, such as tubing, channels, I-beams, Z-sections and flat bars.

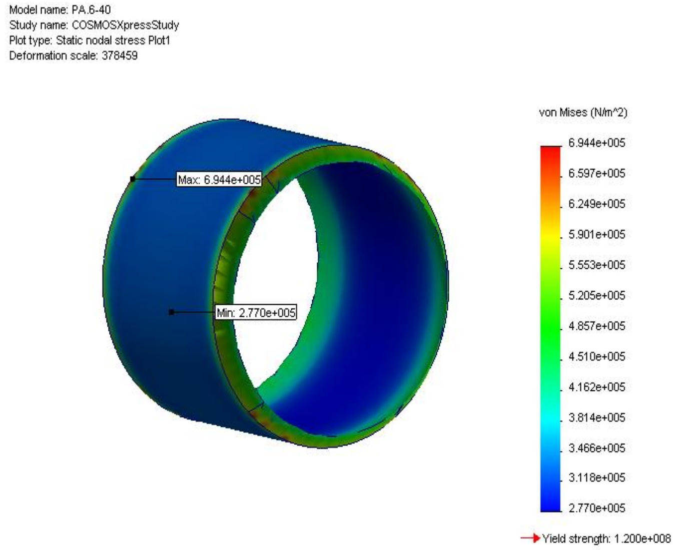
For the composites, the pultrusion process is equivalent of metals extrusions, with difference that at pultrution the part is pulled from the exit end of die.

2.4. Resin Transfer Molding Process

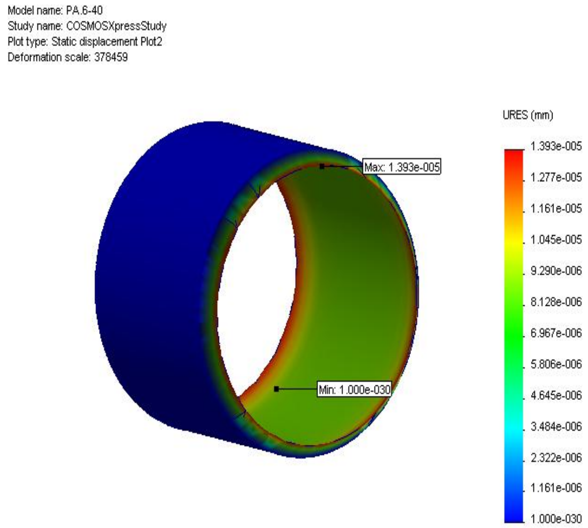
This process represents a completion between hand manufacturing lay-up or spray-up of parts and compression molding in matched metal molds [2,3,6,7].
In resin transfer molding (RTM) process, a set of mold halves are loaded with reinforcement material then clamped together. Resin is then pumped, or gravity fed into the mold infusing the reinforcement material. Once the mold is filled with resin, it is plugged and allowed to cure. After curing, the mold halves are separated and the part removed for final trimming and finishing.
The RTM permits faster cycle times and required less work as spray-up method. The cycle times of RMS are longer than for compression molding, but low tooling cost get compensation, in special for a low production. Resin transfer molding produces large, complex items such as bath and shower enclosures, cabinets, aircraft parts, and automotive components.
As processing of composite materials are used the injection molding that is widely automated and vacuum bagging, autoclave cure process, which is a hand lay-up or an automated tape lay-up that must be cured by a combination of heat, pressure, vacuum, and inert atmosphere.
The selection of adequate process of composites is made by some rules, such as type of composites, applications, quality parts, size of production, costs, etc.

3. COMPOSITES APPLICATIONS

The advanced composite materials can be used for applications demand high strength, high stiffness, or low thermal conductivity, which substituted many aerospace parts by metal with these composites [1-3, 6-8].
Advanced composites contained materials such as carbon/graphite, boron or aramid fibers in an organic resin matrix used by aerospace's industries. The special properties of these materials, examples lightweight, stiffness and strong materials are used from aircraft structures to automotive and trucks parts, from spacecraft to printed circuit boards, sports equipment, such as: the gamut for boat hulls and hokey shine guards, advanced composite hinge for retractable arm of space shuttle.
Carbon/graphite-reinforced composites are used in many applications, which required thermal stability, high temperature strength, good ablation characteristics and insulating capability.
Graphite fibers are used in place where required greater strength and higher thermal conductivity, have six times the tensile strength of carbon fibers.
Carbon fibers are used in rocket nozzle thoughts and ablation chambers, because of them physically stability and elevated temperature.
In generally, the composite materials can change with success the metal parts in diverse application, for example will be analysis the altering of slide bearing of bimetallic material from machine tools with bearing of composites [4,5], by used the finite element analysis (FEA).
The behavior at stress and deformation of bearing is made with COSMOS from SolidWorks Simulation Xpress Program. The bearings from PA6 reinforced with glass fibers have inner diameter=40mm, outside diameter=45mm, and length=30mm are loaded with a pressure stress of 0.6MPa and a restrain of inner diameter of bearing is applied. The result of this simulation of bearing in Fig.5 is presented.



Static Stress



Static displacement

Fig.5. FEA of PA.6 reinforced bearing with d=40mm, and p=0.6 MPa

The parameters of FEA for PA.6 reinforced bearing are: nr. of elements=10432, nr. of nodes=17844, von Misses stress=0.69MPa, displacement=$1.4 \cdot 10^{-5}$ mm, which confirms the good parameter of reinforced PA6 slide bearing used at machine-tools.

4. CONCLUSIONS

This paper has presented certain fabrication techniques of composite materials and some applications of advances materials. The selection of adequate technique is given by type of composites, applications, quality parts, size of production, costs, etc.

The high property of composites and large applications of them led to chance the metal parts with composites in cutting-edge ranges of economy.

5. REFERENCES

[1] Bullen, N.G.: “Unified Composite Structures”, Manufacturing Engineering Magazine, SME Editor, Vol.144, No.3, March 2010, pp.47-55, Dearborn, MI, USA, 2010

[2] MOREY, B.: “Innovation Drives Composite Production” Manufacturing Engineering Magazine, Society of Manufacturing Engineer Editor, Vol. 142, No.3, March 2009, pp.49-60, Dearborn, MI, USA, 2009.

[3] MOREY, B.: “Composites Challenge Cutting Tools” Manufacturing Engineering Magazine, Society of Manufacturing Engineer Editor, Vol. 138, No.4, April 2007, Advanced Technology Supplement 2007, pp.AT6—AT11, Dearborn, MI, USA, 2007

[4] POP, P.A., UNGUR, P., LOPEZ-MARTINEZ, J., BEJINARU-MIHOC, G.: “Theoretical and Practical Estimations Regarding of Borderline Conditions Imposed for Qualitative Achievement of Sliding Bimetallic Bearings from Steel-Bronze”, Proceedings of the 2009 ASME Conference MSEC2009, October 4-7, 2009, West Lafayette, IN, USA,, pp.1-8, 2009

[5] POP, P.A., UNGUR, P., VERES, M., GORDAN, C.:”Rheological Aspects to Horizontal Rotational Forming of Thermoplastic Materials”, ASME Conference MSEC & ICMP2008, October 7-10, 2008, Evanston, IL, USA, Proceedings of MSEC2008/ICMP2008, pp.1-7, 2008

[6] RUFE, P.D.: “Fundamentals of Manufacturing”, Second Edition, Society of Manufacturing Engineer Editor, Dearborn, MI, USA, 2002

[7] STRONG, A.B.: “Fundamentals of Composite Manufacturing. Materials, Methods and Applications”, Second Edition, SME Editor, Dearborn, MI, USA, 2008

[8] TOLINSKI, M.: “Composites Challenge Cutting Tools”, Manufacturing Engineering Magazine, SME Editor, Vol. 138, No.4, April 2007, Advanced Technology Supplement 2007, pp.AT1—AT5, Dearborn, MI, USA, 2007.