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INTEGRATED PRODUCTION TECHNOLOGY AND PROCESS DEVELOPMENT FOR AUTOMATED COMPOSITES PRODUCTION

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Abstract: *Within the defining integrated technology strategy a critical issue is integration of production technology and process development. Often production technology development does not include process development with the assumption being that process technology can be easily developed by the company introducing automated composite production. We have established a long term development and research policy which includes integrated production technology and process development for automated composites production. This article will present two technologies and development efforts: Filament Winding with different degree of complexity and automation and Automated Fiber Placement Machine (AFPM) with complex machine software for programming and control (MikroPlace, MikroAutomate). Parallel efforts have been focused on new process development and process improvement, particularly in terms of technological, economical and ecological aspects.*

Keywords: *Composites production, Filament Winding, Automated Fiber Placement Machine.*

1. INTRODUCTION

In composite materials the word "composite" signifies two or more materials combined on a macroscopic scale to form a useful material. Composites are a very important class of engineering materials named as "materials of the future". Generally, they are made of matrix and reinforcements, mostly in the form of fiber, so that the matrix is unable to deform freely because it is surrounded by stiff and strong fibers. The advantage of the composites is that they usually have the best qualities of their constituents and often some qualities that neither their constituents exhibits. The properties that can be improved by forming composite materials are: strength, stiffness, corrosion resistance, attractiveness, weight, fatigue life, temperature-dependent behavior, thermal insulation/conductivity, dielectric and acoustical properties.

Polymer resins are mostly used as matrix material, and they can be *thermosets or thermoplastics*. There are few types of fibers usually used in composite production as reinforcements such as: carbon, glass and aramid fibers. The fibers can be arranged in a unidirectional way/tape, a woven fabric, or random chopped fiber sheets. The main property of the composite materials is their anisotropy that is determined by the orientation of the fibers within the composite (direction of the fiber placement in the final product).

A preimpregnated fiber reinforced material where the matrix is partially cured or thickened is called *prepreg*. Advantages of using prepregs are: high fiber volume fraction, uniform fiber distribution and simplified manufacturing. Disadvantages can be time and labor consuming, more expensive curing equipment and additional cost of prepreg manufacturing. In most of the prepreg system the polymer matrix is epoxy (thermoset) resin. On the other hand thermoplast prepregs become very attractive nowadays due to their high performances, recycling and reusing opportunities. Processing of thermoplasts differs from the processing of thermoset resins. The temperature and pressure used for thermoplasts are usually higher than those used for thermosets due to the fact that thermoplasts in general have high melting points and consequently high viscosities [1-3].

High-performance polymer composites usually consist of layers or *laminae* stacked in a pre-determined arrangement. Each lamina may be regarded as homogeneous in the sense that the fiber arrangement and volume fraction are uniform throughout. This is very important for the prediction of elastic properties of the composite as a whole. The fibers in the laminae may be continuous or in short lengths and can be aligned in one or more directions or randomly distributed in two or three dimensions. *A unidirectional lamina is often called a ply and a stack of laminae is called a laminate*. The flat laminate, as a composite configuration, is typical for materials used high-stiffness panels in aircrafts. On the other hand, the curved laminate is a part of the wall of a cylindrical vessels, pressure pipes and torsion tubes.

Manufacturing of composite materials is very important from the aspect of achieving desired properties for the composites. But, sometimes materials' defects may occur and they decrease composite's performance such as weaken the mechanical properties, poor fiber-matrix adhesion and consequently poor interface communication. Some of the common defects that must be controlled and should be avoided during composites' manufacturing are: interlaminar voids due to the air entrapment, delamination, lack of resin, etc.; then incomplete curing of resin, excess resin between layers, excess matrix voids and porosity, incorrect orientation of laminae, damaged fibers, wrinkles or ridges caused by improper compaction, winding or layer alignment, inclusion of foreign matter, unacceptable joints in layers and variation in thickness. That's why the fabrication and processing parameters are very important for the composite manufacture in order to achieve the desired properties of the composite [4-9].

Since the fact that composites are anisotropic materials the orientation of the fibers is very important for achieving desired composite's properties. The application angle of the fiber is controlled by the motion controller. If the surface of fiber application is symmetrical correctly direction can be achieve on a symmetrical or unsymmetrical rotation of shapes. For this requirement Mikrosam company manufactures *filament winding machines with six axis of control*. If the surface of the fiber application is convex, than *automated fiber placement machine or automated tape placement machine with eight or more than eight axis can be used.*

Customer requirements for composite's manufacturing can vary from general to very specific ones. Depending on the need for the composite's process specification, Filament Winding (FW), Automated Fiber Placement (AFP) or Automated Tape Placement (ATP) as automated manufacturing processes can be applied (Fig. 1).

2. AUTOMATED TECHNOLOGY FOR ADVANCED COMPOSITES PRODUCTION

Filament winding (FW) process (see Fig.2) is used for production of simple hollow shapes and is particularly suitable for pressure vessels and pipes manufacturing. Materials used for FW can be thermoset or thermoplasts as polymer matrix and different types of fibers as reinforcements. Usually, continuous fiber strands are fed through the resin bath from fixed position alongside the machine. The fibers emerge from the bath via nip rollers (to remove excess resin) and then pass through a vertical comb before being wrapped around the rotating former. By changing the relative speeds of mandrel and traverse the winding angle can be controlled. The fiber orientation and thickness can therefore be varied to give optimum performance. The tension applied to the reinforcement can also be controlled to achieve optimum fiber content and good consolidation of the laminate [8,10,11].

Automated Fiber Placement (AFP) and Automated Tape Placement (ATP) (Fig.3) are used on very complex surfaces and smaller structures and utilize single or multiple narrow, slit tapes or tows to make up a given total pre-preg band width. In both thermoset and thermoplastic processing, incoming tape is electrically heated using nitrogen. Pre-preg material application and consolidation or debulk is always achieved through a compaction roller medium that may be heated or cooled. Information about pre-preg diameter and pre-preg thickness are very important. Other information that are important as well are: fiber placement head- temperature and pressure under which the pre-preg would be placed, temperature under which the placed pre-preg would be cooled, placement pre-preg angle. The process of fiber or tape placement is controlled by in-house designed software (MikroPlace or MikroAutomate) (Fig.4 and 5) [12-14].

Fiber placement process should be automated, with the ability to customize the feature set and machine design. This includes: fiber placement head, offline programming and analysis- MikroPlace, online control and data acquisition- MikroAutomate, customized machine kinematics and advanced fiber creel.

The fiber placement head is the heart of the process. It allows on-the-fly cutting, clamping and restarting of every single tow, while maintaining proper temperature difference between the deposition surface and inside the head. Transport of the tow is possible by keeping the tow cold, through the temperature difference and makes them stick on the surface by using controlled heating just before placement. Placement on the surface is done with a help of a special roller to place every single tow precisely next to each other while allowing each one to be placed at a different radius- fiber steering. High compaction force being applied over the fibers to ensure that all the layers can be properly homogenized to their ideal structure is the final and crucial process.

The core of offline programming and analysis- MikroPlace (Fig. 4) is build around a robust, industry standard geometric kernel, providing full NURBS support and easy import/export from the leading CAD packages such as CATIA, Pro/ENGINEER, Autodesk Inventor, SolidWorks and others.

Online control and data acquisition- MikroAutomate software (Fig. 5) provide an intuitive interface over the complete production process. The operator can run a production program, override set of parameters while running, and provide complete tracking of important data points during the production process. The functionalities of a modern CNC system, SCADA and Real-Time control are integrated into a single, easy-to-use interface thanks to MikroAutomate. Based on the PC platform, MikroAutomate provides a complete data tracking method to acquire, store and easily retrieve data on a variety of aspects of the production process and the machine itself. The collected data can be used to generate reports and inspect history production runs.

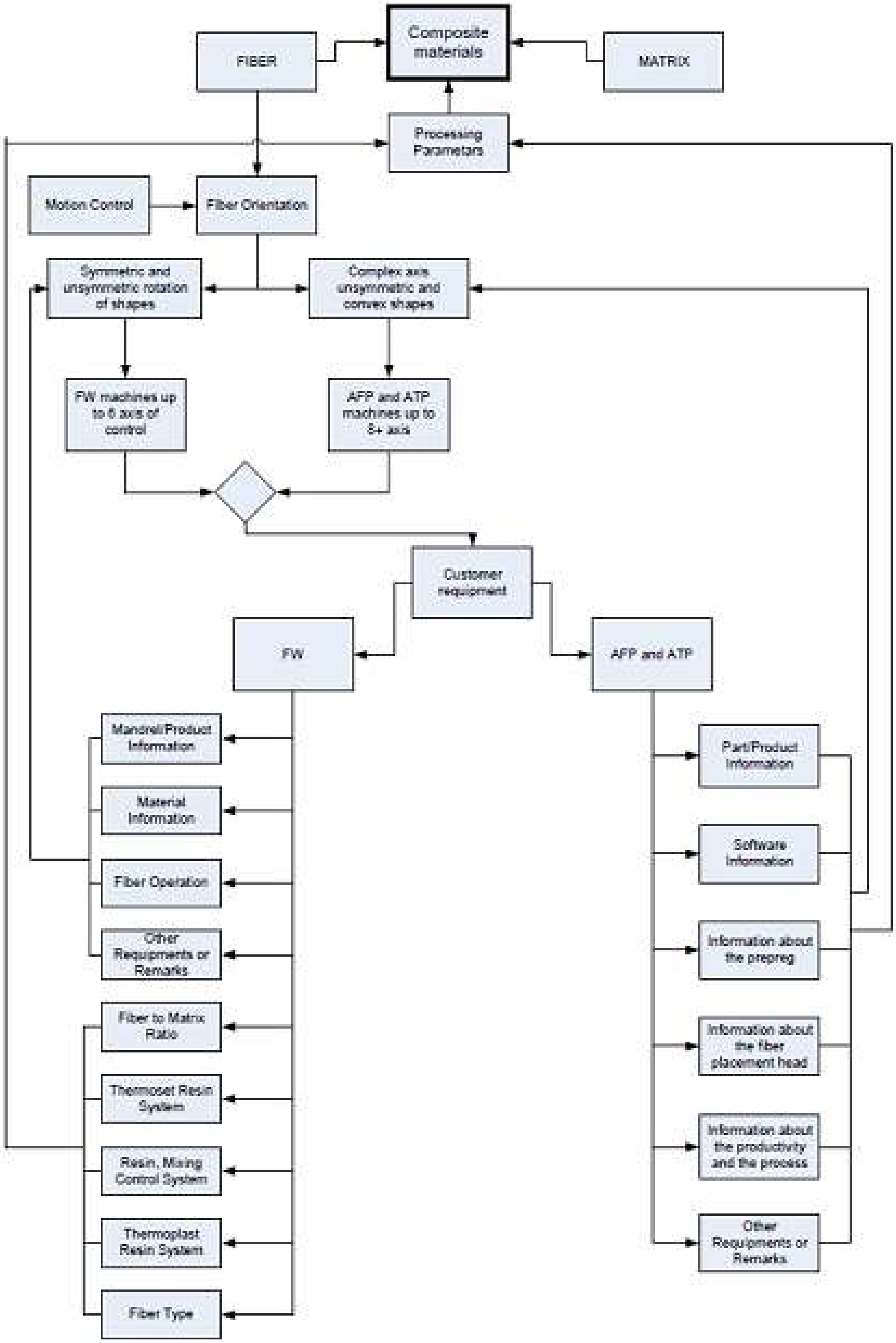

Figure 1: Connection between the composite and the customer requirements

Figure 2: Filament Winding Machine / Detail of placement of roving over the mandrel

Figure 3: Fiber Placement Machine / Fiber Placement Detail

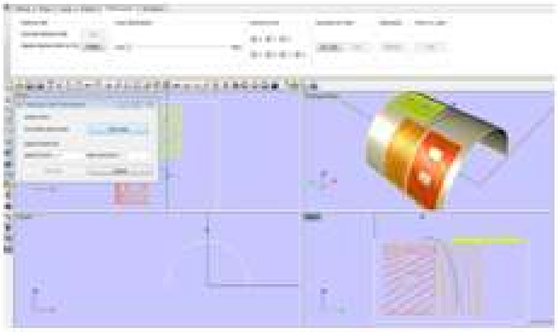

Figure 4: MikroPlace Software

Figure 5: MikroAutomate Software

3. PROCESS INVESTIGATION

Parallel efforts have been focused on process development and process improvement for composite manufacturing during the years. Namely, Mikrosam company and the Institute for Advanced Composites and Robotics (IACR) developed and still develops own machines for automated composite manufacturing and know-how technologies. Figure 6 presents processes for composite’s manufacturing where Mikrosam and IACR have a competency and own experience in process investigation, development and machine offers for that purpose.

Not only the machines but the processes are improved during time-being of the company in terms of their technological, economical and ecological aspects. The technology was improved by proper selection of composite material constituents such as suitable polymer matrices and reinforcements-fibers. Initially, solvent-based processes were used. Later they were improved towards use of less dangerous chemicals (solvents) and consequently less VOCs in the environment. The process changed from wet to dry process or in other words solvent- based polymer resins were replaced by the hot melt ones in the cases where it was possible or where customer requirements allowed that.

Nowadays the tight collaboration between Mikrosam company and IACR as well as the collaboration with external partners from the country and abroad leads to innovative improved processes by investigating and using novel hybrid nanocomposites. It means that by use of nano-doped polymer matrix and fiber reinforcements in the composite final product variety of enhanced properties can be achieved. Preliminary investigations showed that

novel hybrids have improved reinforcing effects as well as improved barrier and mechanical properties. These experiments are still under investigation within the company and the Institute [15-21].
Some examples of the ongoing work are presented in Fig. 7. Namely, Fig. 7 shows SEM images of the consolidation process for a certain roving (resin impregnated fibers): before (Fig. 7a), during (Fig. 7b) and after the treatment (Fig.7c). For example, Fig. 7d) shows a cross section of a pipe (tank) with the idea of our team- FW hybrid composite material over a mandrel with a protective layer on the top [21].

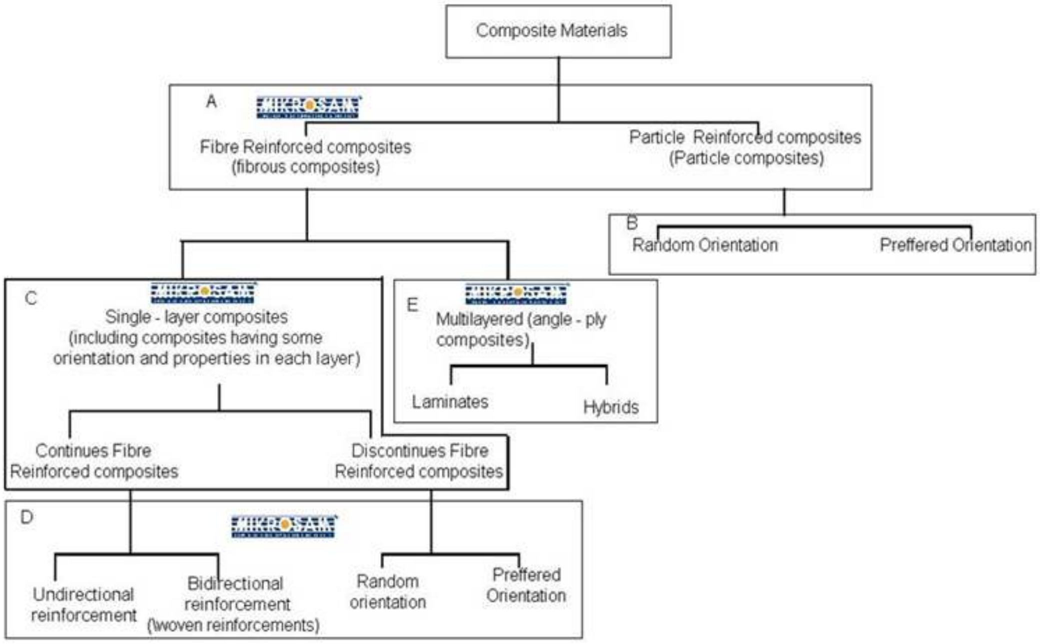

Figure 6: Variety of constiuents' arrangements in composite's manufacturing (Mikrosam's logo in boxes denotes processes where this company has a competency of doing and own experience.

4. CONCLUSION

Mikrosam AD and the Institute of Advanced Composites and Robotics are innovative, future- and customer-oriented institutions that apply continuously R&D in the area of composite materials and their manufacturing. Both institutions make a good connection between fundamental research and industrial application with a mutual goal –customer satisfaction.
Mikrosam is an expert for design, development and realization of machines and equipment for manufacturing of innovative, high tech and lightweight composite systems. Its strong competitiveness in research, development and manufacturing made this company to be unique and world- recognizable company with activities that are not easy reachable by other competitors in the field. Its tight collaboration with IACR and other R&D Institutions from the country and abroad leads to gain new applicable knowledge in the area of automated composite processing and nanocomposite manufacturing. Together they can offer support at all stages of composite manufacturing from design towards selection of the materials to automated production of the composites.
The processes like, FW, AFP and ATP are improved during the last several years and became very recognizable for most of the clients and new customers in the region and wider in the world.
In the meantime, extensive efforts have been made on new process development and improvement, particularly in terms of technological, economical and ecological aspects. Depending on the customer requirements both institutions with their own team members and collaborators investigate and develop process and machines for suitable and automated composite manufacturing according to specific customer requirements.

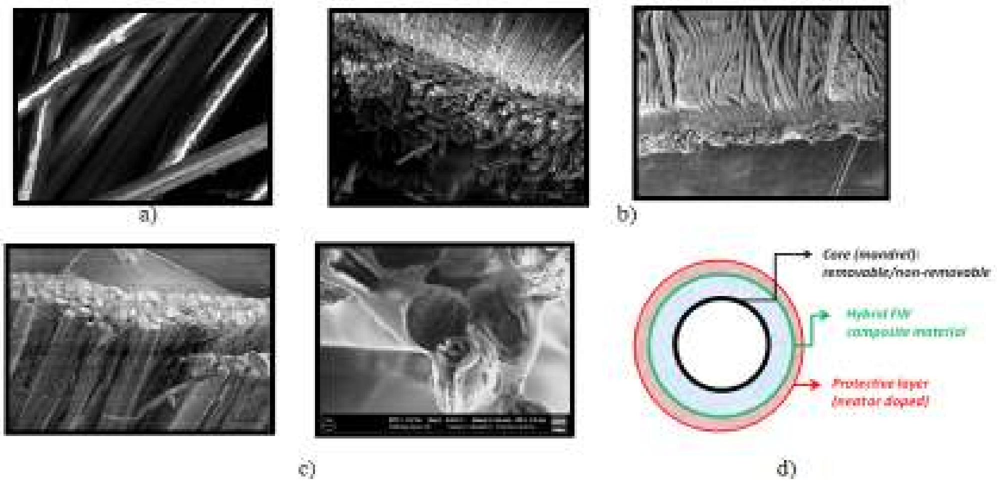

Figure 7: SEM micrographs illustrating commingled roving (polypropylene and glass fibers): a) before, b) during, c) after consolidation process. d) Scheme of the idea of the cross section of a pipe made of hybrid composite material.

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