

MECHANICAL TESTING OF COMPOSITE SPECIMENS MADE BY RFI TECHNOLOGY

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Abstract. The present paper provides a description of the RFI (Resin Film Infusion) method and influence of the polymer epoxy systems and their reinforcements on the mechanical properties of the whole composite specimen.

Typically, the RFI element consists of a thermoset resin film placed between one side of a metal tool and a dry textile fiber preform. Then, a bag connected to a vacuum pump and processed under a selected thermal curing cycle closes the whole system. RFI technology has gone through some changes since it was discovered. One of the RFI varieties is LF-Technology (Letoxit Foil) provided by local Czech producer 5M Ltd. LF Technology, developed and patented by 5M Ltd., is a very efficient technique for producing sophisticated and relatively cheap composite structures.

Part A: The composite specimens were prepared from various types of reinforcements and matrices, as noted below. The basic experimental part of the research program was focused on the property verification of two polymer epoxy matrix systems applicable to RFI technology. Glass (plain and twill weave), carbon (plain and twill weave), hybrid - Carbon/Kevlar (plain weave) and basalt (plain weave), reinforcements were used. In the experimental part of this work, tests on the mechanical properties were made. These properties (Flexural strength, interlaminar shear strength [ILSS] and impact toughness) were chosen because of their fast orientation in material properties and the state of the finished composite part. Test specimens were prepared by 5M Ltd. Borsice u Buchlovic, Czech Republic, Europe.

Part B: Other samples of hybrids (Basalt/Kevlar) and UD (unidirectional) composites were fabricated and tested at the IAE (Institute of Aerospace Engineering), Brno University of Technology. The epoxy resin foils LFX023, LFX032 and LFX035 were applied.

Part C: In this part unidirectional (UD) materials were tested. Thanks to the resin properties it was easy to get clear material after selecting the right curing cycle.

LF Technology gives freedom to designers, helps push down prices of composite products and increases properties and reliability, which is supported by favorable responses from customers and quick and relatively easy development of new products. All these advantages promise a very good future for LF Technology [9].

Keywords: RFI technology, mechanical testing, LF-Technology.

Introduction

In recent years, the resin film infusion has gained popularity for the manufacture of structural polymer-based composites for aerospace, automotive, and military applications. RFI (Resin Film Infusion) has been identified as an alternative cost-effective manufacturing technology to RTM and the conventional autoclave prepreg technique. The production cycle is usually performed in the autoclave under increased temperature

and pressure, where the fiber infiltration and the composite consolidation occur in a single step process. Typically, the RFI element consists of a thermoset resin film placed between one side of a metal tool and a dry textile fiber preform. Problems with conventional RFI appear if sandwich structures are manufactured; honeycombs are filled with resin and foam which prevents impregnation of the sandwich skin on the opposite site of the resin layer.

Concerning these disadvantages of conventional processes and a need for universal low cost technology,

5M Ltd. developed and patented a very efficient technique for production of sophisticated and relatively cheap composite structures, which is called Letoxit Foil Technology (LF Technology). LF Technology is based on laying dry reinforcement and core material in the mould with layers of foil polymer material – commercial name Letoxit Foil. The entire composition is vacuum-bagged and cured at an elevated temperature. The scheme can be seen in figure 1. The finished part is released from the mould as a ready to use product with an excellent surface. The variability of LF Technology gives freedom to design composite parts at a very competitive price. Autoclave can be employed but is not necessary, as vacuum assistance is usually enough for reinforcement impregnation [9].

The basic component for LF Technology is Letoxit Foil, which is usually a thermoset flexible film. The basic type is Letoxit Foil LFX 023, which is a composition of special epoxy resin hardeners that are latent at room temperature. The film color is originally light yellow but can be set according to the customer desire. The thickness of Letoxit Foil varies between 0.1 and 0.7mm and is described by the area weight, which is usually between 100g/m² and 700g/m².

Alongside LFX 023, there are several other types of Letoxit Foils available. Some of them are listed in the table below (Tab. 1) [9].

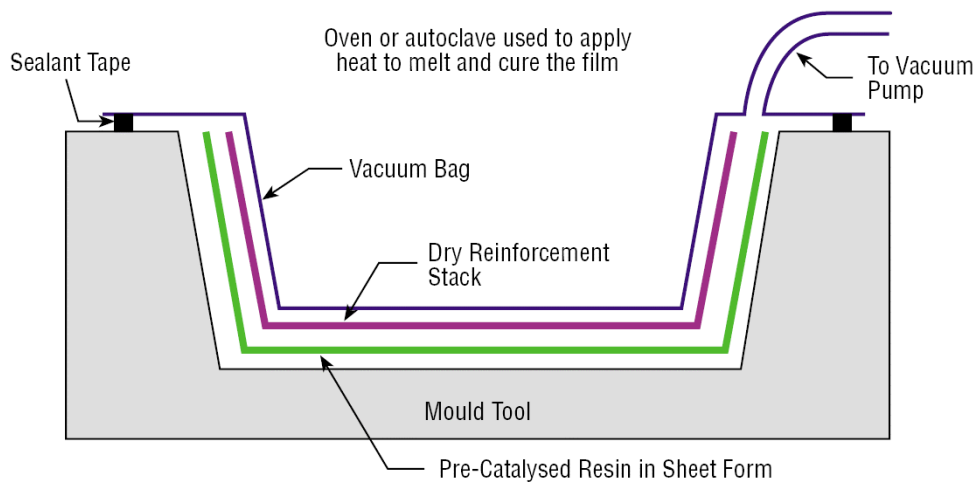


Fig 1. Scheme of RFI technology

Table 1. Commonly used Letoxit Foil types

Name	Resin type	Advantage
LFX023	EPOXY	Basic type
LFX033	EPOXY	Fast curing
LFX036	EPOXY	T _g above 150°C
LFX037	Modified EPOXY	High impact strength
LFX038	Halogenated EPOXY	Fire retardant
LFX040	Modified CYANOESTER	T _g up to 250°C
LFX035	EPOXY	Viscous & tacky - ideal for UD reinf.

The main advantage of LF Technology is the variability of reinforcement due to very simple impregnation. Also, a combination of different reinforcement types is possible. The most common reinforcements are fabrics, where glass, carbon, aramid and basalt are usually used. Also hybrids of these materials are possible. The most important parameters of fabrics for LF Technology are area, weight, thickness and size.

The main difference between LF Technology and standard RFI consists in the sandwich structure production, as in the case of prepregs. Almost all types of core material used for sandwich structures of thermoset

composites can be chosen. The most popular are honeycombs, foams and special core materials such as SORIC, COREMAT etc. Core materials can be applied locally in the composite if an increase in stiffness of a certain area of the composite part is required. This approach easily excludes ribbon necessity. LF Technology also gives the possibility of one-shot application of local reinforcements. Typical examples are metal ribbons or pulled profiles and inserts for screw and rivet fastenings made from steel, aluminum or composite [8].

Testing conditions

The 3-point flexure test was performed according to international testing standard – ISO 178. This scheme can be seen in figure 2.

- Test specimen's size:
h x b x l = 3 x 15 x 65 [mm]
- Support width: $l_v = 50$ mm
- Support radius: $R_p = 2$ mm
- Loading pike radius: $R_t = 5$ mm
- Testing machine INSTRON, loading velocity 2 mm/min

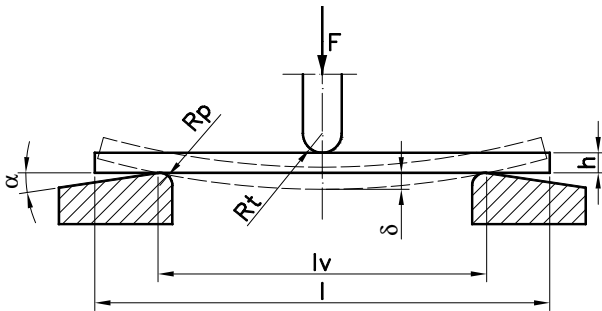


Fig 2. 3-point flexure test scheme

Interlaminar shear strength was conducted in accordance with ASTM, designated D2344-84.

- Test specimen's size:
h x b x l = 3 x 15 x 20 [mm]
- Support width: $l_v = 13$ mm
- Support radius: $R_p = 2$ mm
- Loading pike radius: $R_t = 2$ mm
- Testing machine INSTRON, loading velocity 1 mm/min.

The impact strength was tested according to the Charpy impact test, designated ISO 179, non-instrumented part. Specimens were 80 x 10mm thick. The specimens were un-notched.

Each test series had 10 testing specimens.

Part A: Common classic fabrics

Various classic fabrics along with 2 epoxy systems (Letoxit Foil LFX023 and Letoxit Foil LFX032 - toughened epoxy resin films) were tested and compared. In figures 3 and 4 similar standard curing cycles are shown. The testing specimens were composed of 12 layers of fabric and 8 layers of epoxy resin film.

Figures 5 and 6 show the flexural modulus and strength of composite samples made by Resin Film Infusion technology (Letoxit Foil technology by 5M Inc.).

Table 2. Used materials

Reinforcing materials:
Carbon (plain and twill weave) fabric 200 g/m²
Glass (plain and twill weave) fabric 211 g/m², 200 g/m²
Basalt (plain weave) fabric 210 g/m²
Hybrid carbon/Kevlar® fabric (plain w.) fabric 160 g/m²
Matrix materials:
EPOXY pre-catalyzed resins in foil form
Letoxit Foil LFX023
Letoxit Foil LFX032

Curing cycles

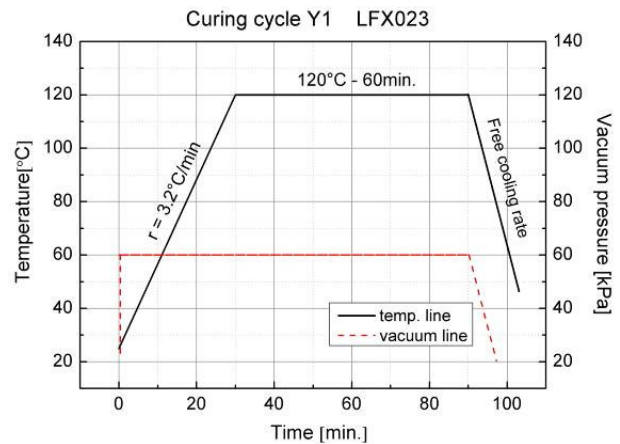


Fig 3. Curing cycle Y1 for LFX023

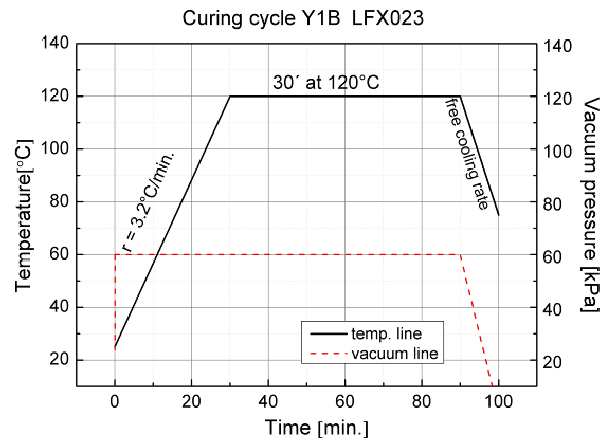


Fig 4. Curing cycle YB1 for LFX023

The typical curing conditions are 120°C for 1 hour but LFX 023 can be cured at any temperature between 90°C and 130°C.

Mechanical properties

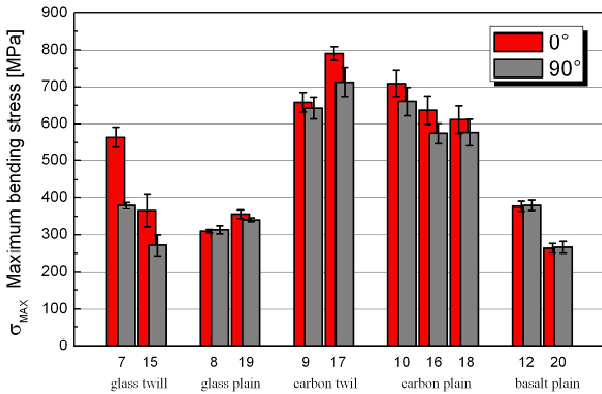


Fig 5. Maximum flexural stress

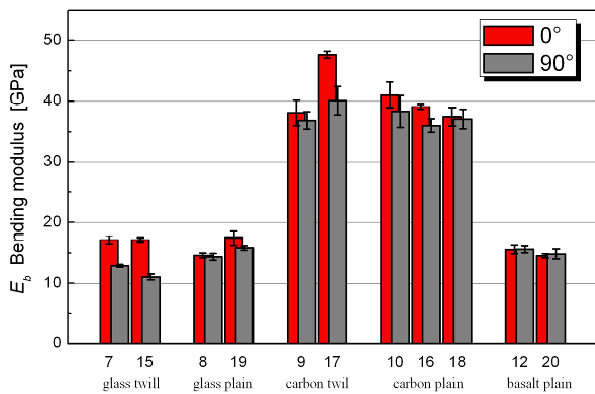


Fig 6. Flexural modulus

The bending modulus along the fiber (0°): was highest with plain carbon reinforcement contra, the lowest value of plain glass reinforcement.

The bending modulus across the fiber (90°): good flexural strength of *carbon plain reinforcement* and low properties were registered with *twill glass reinforcement*. The highest flexural modulus had *twill carbon weave*.

It is interesting to compare the plain glass weave and basalt plain weave on the grounds of eventual replacement of glass behind the basalt (from a cost-effective and mechanical standpoint). In figure 5 we can see the difference. Basalt along the fiber and across the fiber had better results than glass reinforcement.

The interlaminar shear strength is largely dependent on matrix properties. In figure 7 we can see the highest values for *carbon plain weave* (60.31 ± 2.46MPa) and the lowest for *glass plain weave* (44.88 ± 2.91MPa). The standard epoxy matrix LFX 023 with LFX 032 epoxy system were compared. In figure 7 we can see results of ILSS testing of both epoxy resin systems where LFX 023 shown higher values of mechanical properties.

Plain weave glass vs. basalt (with LFX023) was comparable. Twill weave carbon vs. glass (with LFX023) was also comparable [3].

The ILS strength of the composites made of the epoxy film resin LFX 023 is higher than that of the composite made from the epoxy film resin LFX 032, respectively. Overall, it is possible to say that the matrix

system with LFX023 is, at result level, more reproducible and it is preferable to manufacture composites using the RFI process with this type of resin. Optimal mechanical properties (flexural and interlaminar - ILSS) are guaranteed by low void content and defects, etc. [4].

Figure 8 shows the impact test result for plain fabrics. The basalt and glass reinforcements showed the highest impact strength.

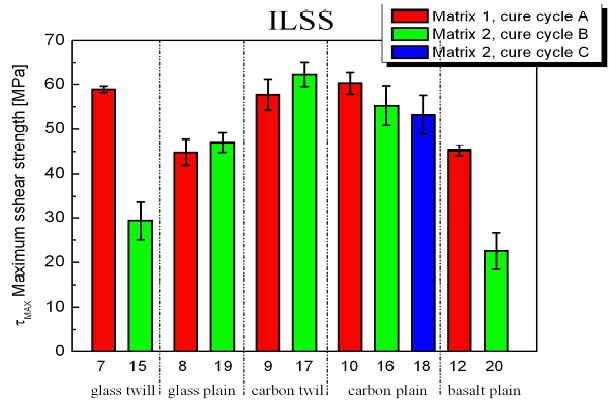


Fig 7. Interlaminar shear strength

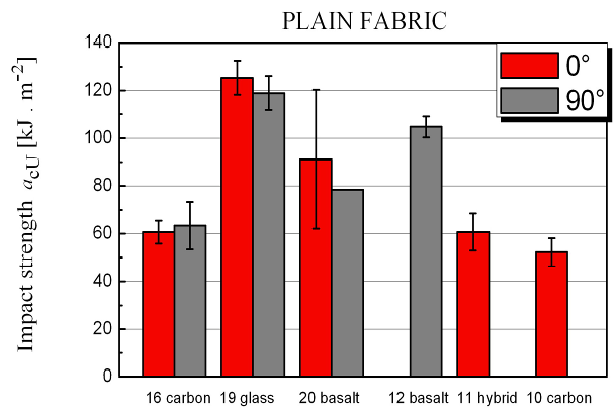


Fig 8. Impact strength

Part B: Hybrid fabrics

Recently in terms of non-availability of carbon reinforcements, it was the aim of this part of the research to investigate the mechanical properties of hybrid basalt/Kevlar fabrics as an alternative to use basalt instead of carbon in hybrid fabrics. In terms of price and design, basalt appeared to be an acceptable material (Tab. 3). The testing specimens were composed of 16 layers of fabric and 8 layers of epoxy resin film (this set-up is used for hybrid samples only!).

Table 3. Used materials

Reinforcing materials:
Carbon/Kevlar® (plain and weave) fabric 160 g/m²
Basalt/Kevlar® (plain weave) fabric 220 g/m²
Matrix materials:
EPOXY pre-catalyzed resin in foil form - Letoxit Foil LFX023

Composite samples were composed of 12 layers of fabrics (glass, carbon and basalt), 16 layers of hybrid fabrics and 8 layers of epoxy resin LFX023.

Curing cycle

For preparation of hybrid composite testing specimens the standard curing cycle was selected.

Mechanical properties

The flexural properties data below, gives information about each single type of reinforcement used in hybrid fabrics. They were taken from part A and compared to the hybrid (basalt/Kevlar and carbon/Kevlar) samples (Fig 9 and 10).

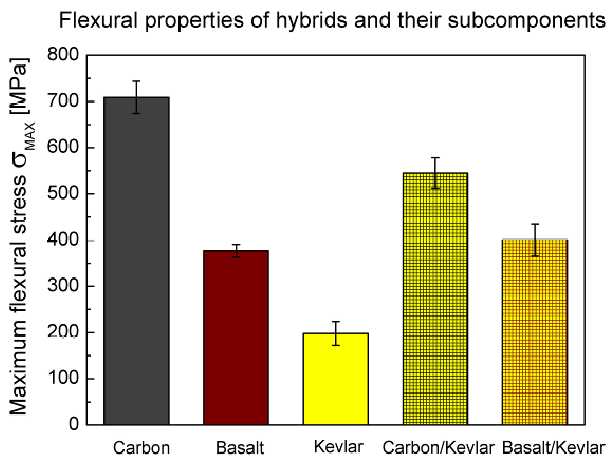


Fig 9. Maximum flexural stress

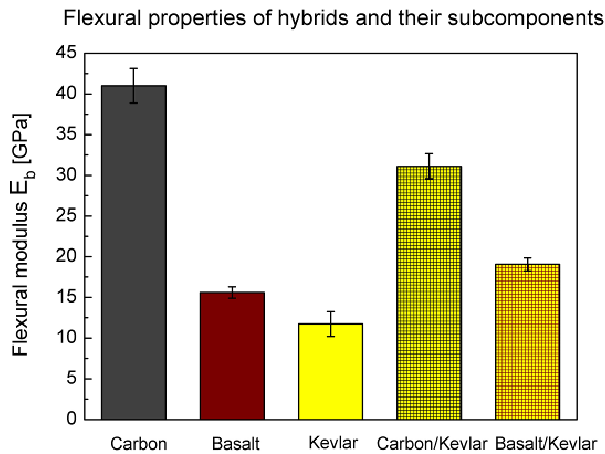


Fig 10. Flexural modulus

From the obtained flexural data we can see the highest flexural modulus of the carbon sample in contrast to the lowest of the Kevlar sample. Interlaminar shear strength is similar to measured flexural data (as shown in figure 11). Basalt samples and hybrid (Basalt/Kevlar) showed the best impact strength properties, over 100kJ/m², (Fig 12) [7].

Interlaminar shear strength of hybrids and their subcomponents

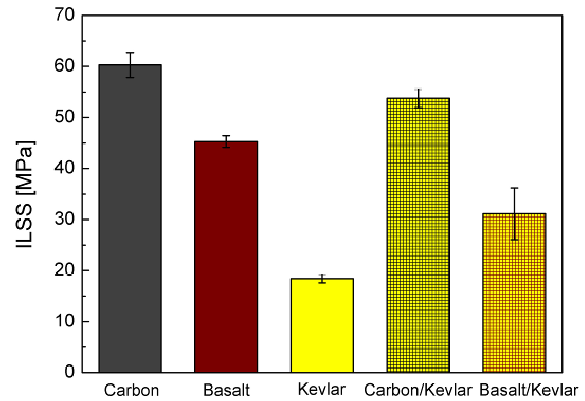


Fig 11. Interlaminar shear strength

Impact strength of hybrids and their subcomponents

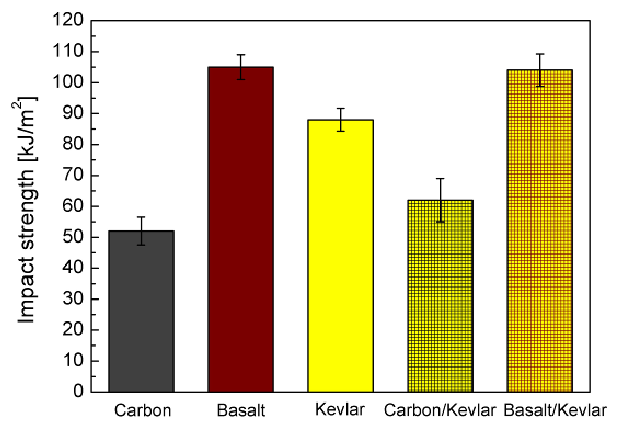


Fig 12. Impact strength

Part C: Unidirectional Fabrics

The unidirectional fabrics were tested with new LFX035 RFI epoxy film resin which is more liquid hence more suitable for the RFI infusion process where UD textiles do not wet out well (LFX035 was compared to LFX023) (Tab. 4). Curing cycles are described below and shown in figure 13. The test specimens were composed of five layers of fabric and six layers of epoxy resin film.

Table 4. Used materials

Reinforcing materials:
Glass unidirectional fabric Interglas 92145 220g/m²
Carbon unidirectional fabric 140g/m²
Matrix materials:
EPOXY pre-catalyzed resin in foil form
Letoxit Foil LFX023
Letoxit Foil LFX035

Curing cycles

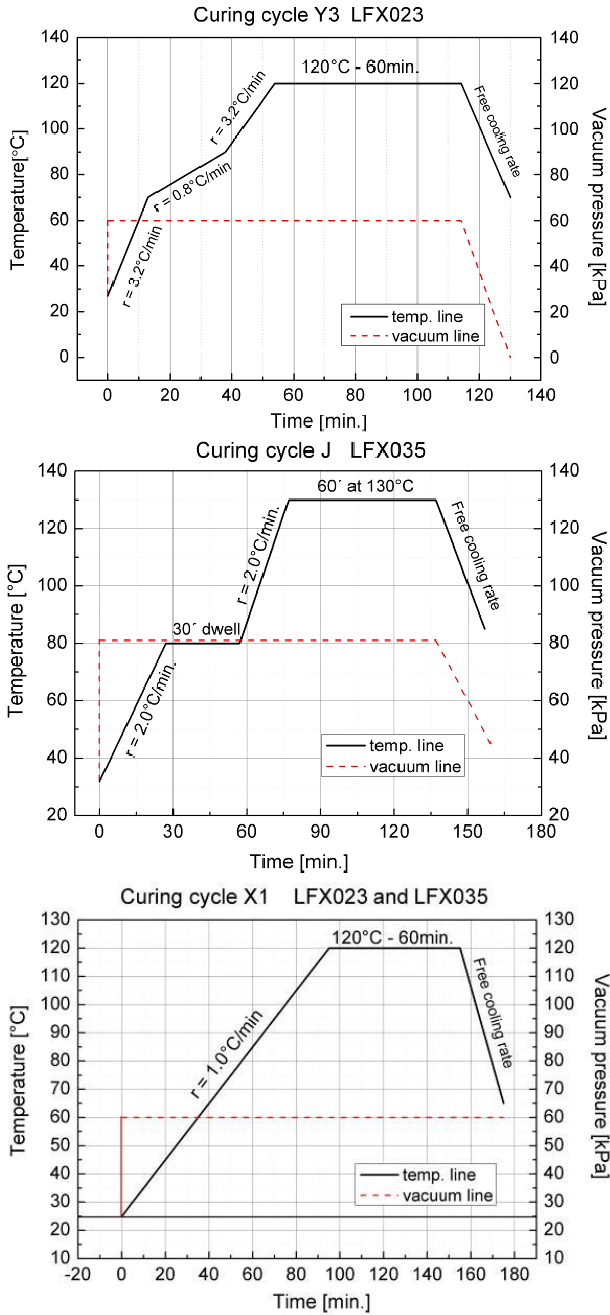


Fig 13. Curing cycles Y3, J and X1 for LFX023 and LFX035

The ramp of curing cycle J was 2°C/min with a 30 min dwell at 80°C. Cycle X1 ramp was 1°C/min.

Mechanical properties

For epoxy resin LFX023 was optimized curing cycle signed as Y3. After resin strips application results were significantly better Y3 curing cycle was optimized for LFX023 epoxy resin film (Fig 14-15). Better mechanical results can be achieved after application of resin strips in combination with dry UD reinforcement.

Maximum flexural stress for glass reinforcement Interglass 92145 220g/m² was 794, 4 ± 63, 8 MPa and for flexural modulus was 26, 7 ± 1, 6 GPa, which is in

comparison to commercial technologies almost equivalent (Maximum flexural stress 810 MPa, R&G) (Fig 22).

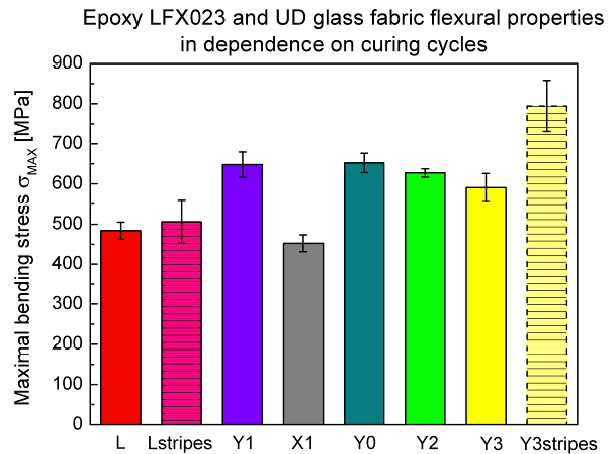


Fig 14. Maximum flexural stress - LFX023+glass UD

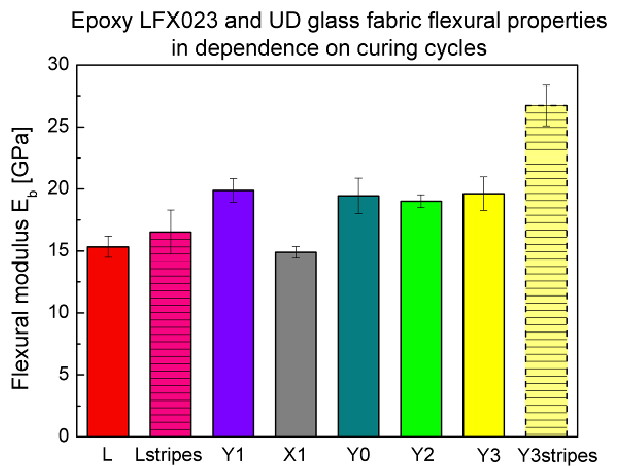


Fig 15. Flexural modulus - LFX035+glass UD

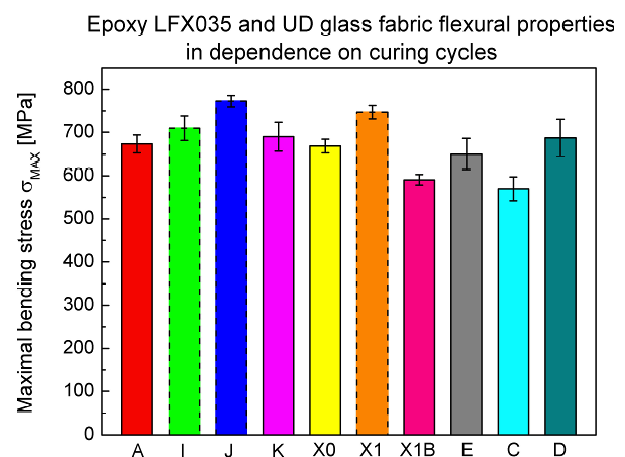


Fig 16. Maximum flexural stress - LFX035+glassUD

Maximum flexural stress for glass reinforcement Interglass 92145 220g/m² was 772, 6 ± 13, 1 MPa and flexural modulus was 24, 4 ± 0, 9 GPa (curing cycle J), which is in comparison to commercial technologies

almost equivalent (Maximum flexural stress 810 MPa, R&G), shown in figures 16 and 17.

region where resin has the highest viscosity = 80°C) (Fig 18-19).

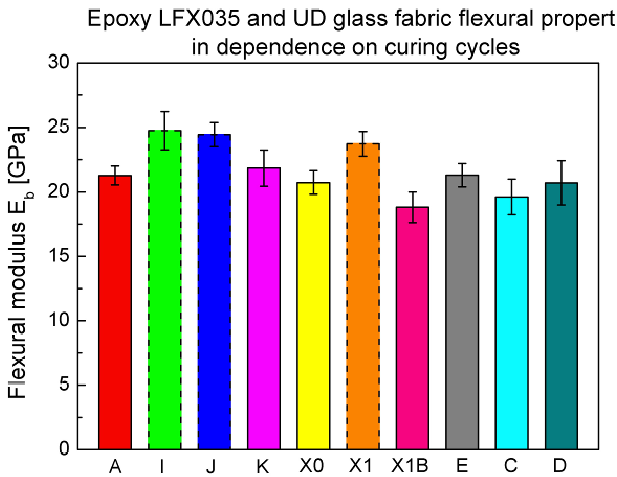


Fig 17. Flexural modulus - LFX035+glassUD

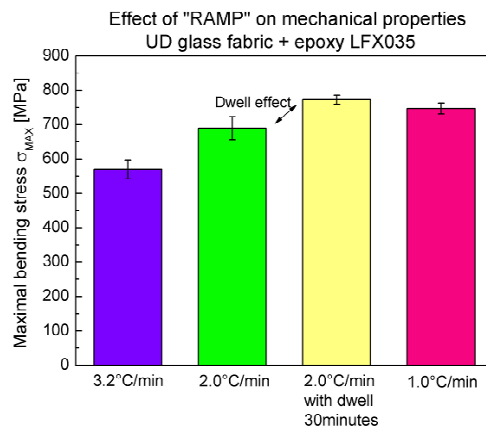


Fig 20. Maximum flexural stress – effect of RAMP

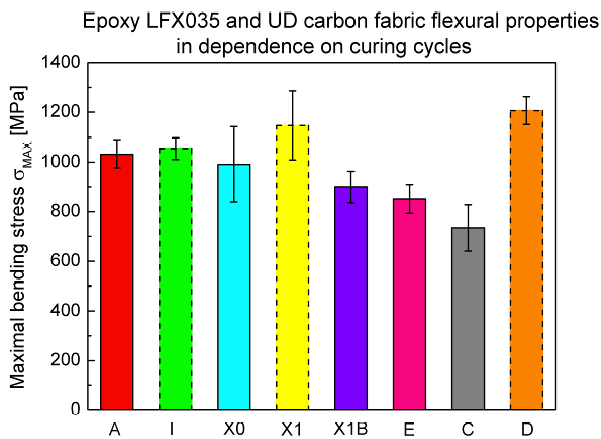


Fig 18. Maximum flexural stress - LFX035+carbon UD

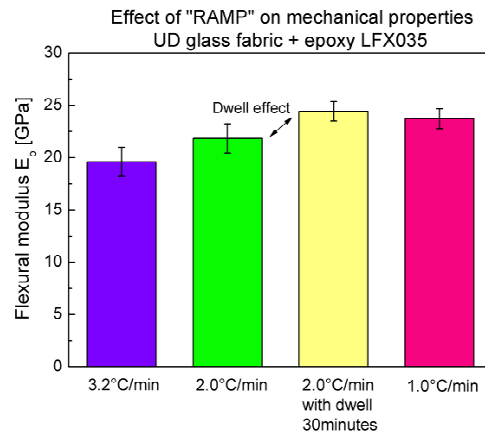


Fig 21. Flexural modulus – effect of RAMP

Ramp analysis: application of slower ramp into the curing cycle when using UD reinforcements along with epoxy film resins was effective (Fig 20-21).

Curing cycle Y3 has an average heat-up speed (ramp) of 2.4°C/min, and other tested curing cycles 3.2°C/min., a decrease in speed to 1°C/min is recommended to soak resin through all layers of unidirectional fabric (to get a clear effect).

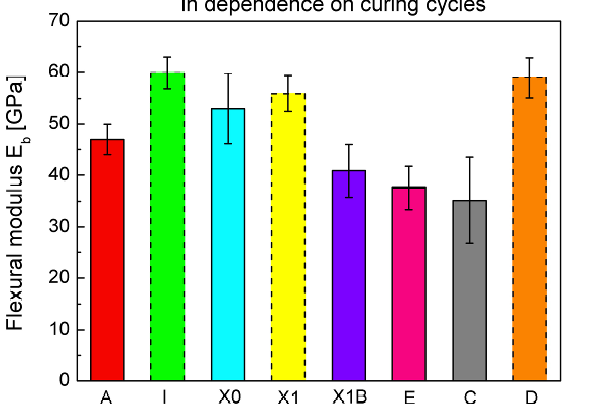


Fig 19. Flexural modulus - LFX035+carbon UD

Results for carbon UD reinforcement are shown for information purposes only. Carbon UD reinforcement Maximum flexural stress was 1054, 3 ± 43, 7 MPa and flexural modulus 59, 9 ± 3 GPa (cycle I, which is different from cycle J only by vacuum level change in the

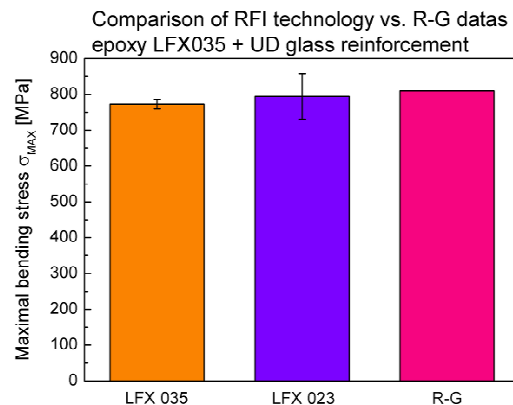


Fig 22. Maximum flexural stress – comparison of RFI technology and R&G data

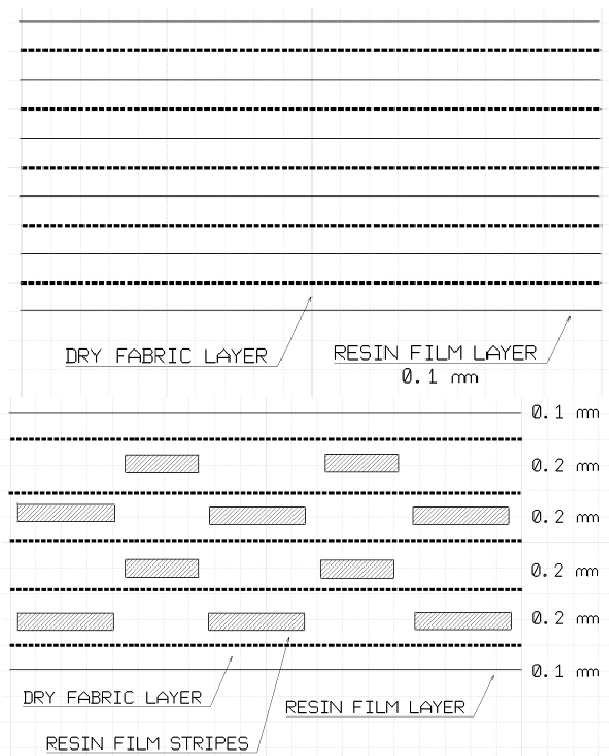


Fig 23. Typical RFI sample layout

At the start of unidirectional glass fabrics testing, preliminary wet out samples were made. With LFX023 epoxy resin it was hard to wet out the glass fabric well. That's why another epoxy resin (LFX035) was examined. To get a clearer effect, stripes of LFX023 epoxy resin were laid on UD glass fabric (see Fig 23 for lay-out system). The system contained less resin and low void content thanks to the free space among the stripes.

This formation is similar to ZPREG technology where surface ply consists of a lightweight (usually glass) fabric laminated to a dry, medium weight carbon or glass fabric using stripes of resin. The resin impregnates the lightweight fabric sufficiently to provide light tack, whilst the heavier inner ply retains a dry surface. This format ensures that air is channeled away from the tool face before the resin stripes close [1].

Conclusion and discussion

There are many potential applications for the technology in automotive and transportation (bodies, covers, side panels, and doors), aerospace (covers, doors and all type of panels) and building (tables). The main field of RFI technology is in aerospace technology where this method can lower the cost of the finished composite.

Part A: From obtained data of mechanical properties we can assume, matrix system No 1 (LFX023) has more reproducible results, with a relatively low error load. Epoxy resin system LFX023 is standard epoxy resin and is recommended for use with classic fabrics [3].

Part B: Basalt plain reinforcement seems to be acceptable instead of glass plain reinforcements. Flexural properties of Basalt hybrid fabrics are not good compared to Carbon hybrid.

This is thanks to the Basalt fabric structural components, which do not have the same mechanical properties as Carbon fiber. On the other hand, basalt hybrid composite withstands the impact test much better.

Part C: The unidirectional fabrics with new LFX035 RFI resin were tested (LFX035 was compared to LFX023). LFX035 is more liquid and therefore acceptable for the RFI infusion process where UD textiles are hard to wet-out. On mechanical testing results conclusion was made out. The most suitable curing cycles for epoxy resin LFX035 are cycles J and X1. They have different ramp parameters. Between them, we can choose one acceptable for us.

After evaluation of work and time effectiveness it was assumed that curing cycle J is more desirable for UD composites processing. The time needed to reach a curing temperature is shorter (1hr. and 15 min.) than in cycle X1 (1hr. and 40 min.).

Future work

During 2006/2007, spinner and spinner backplate will be fabricated by RFI technology [4]. For future application of external pressure during the curing process it is planned to obtain higher mechanical properties. The relationship between compaction pressure and fiber volume fraction is very important in the RFI process since fiber volume fraction has a large influence on the mechanical properties of the composite part.

A computer simulation model of the RFI process can be used to predict resin infiltration into the preform and cure of the resin saturated preform for a given processing cycle [6, 5].

Acknowledgments

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