Investigation of mechanical properties and crack propagation behaviour of hybrid composites with epoxy resin matrix

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Abstract. Mechanical properties, micro structure and crack propagation behaviour of different fabric reinforced mono and hybrid composites for materials of wind turbines have been investigated. Mechanical properties of different fabrics (glass, basalt and carbon) reinforced mono and hybrid composites with epoxy resin matrix have been compared. For characterization of materials tensile, three-point bending and single-edge notched tensile (SEN-T) tests with acoustic emission study were used and scanning electron microscope (SEM) pictures have been taken of the fracture surfaces of composite specimens. Similar behaviour of glass and basalt fibre reinforced composites was revealed by tensile and three-point bending tests. The satisfactory adhesion between fibre and matrix was shown by scanning electron microscope. The fibre-break was proven by the taken pictures to be the main failure mechanism. Results of mechanical tests were also confirmed by acoustic emission study. The crack propagation method of glass and basalt fabric reinforced composites is similar.

Introduction

Over the last decades the usage of fibre reinforced composites have become widely spread as simple structures like machines covering and also complex parts of wind turbines and airplanes [1]. By using the hybrid composites the beneficial properties of the different reinforcements can be merged. Commonly used combination is the carbon and the glass fibre, because the addition of glass fibre to carbon fibre reinforced composites decreases price and increases toughness [2, 3]. In some cases, however, glass fibre cannot resist the environmental damages (alkaline resistance, salt water ageing).

Basalt fibre is a novel reinforcement for composites. Considering its mechanical properties and chemical composition it is similar to the glass fibre, but it can be used in the temperature range between -200 and 600ºC without significant loss of the mechanical properties [4]. Basalt fibres are biologically inert as well as environmentally friendly and can be used in aggressive environments [5, 6].

Acoustic emission (AE) study can be used parallel to mechanical tests to assess crack propagation and study failure analysis [7-10]. Advantages of the AE method are the real-time monitoring of the structure, observation of crack propagation and analysis of the failure mechanism. Different damage modes can be concluded by amplitude range of the recorded signals. 0-40 dB amplitude range predicts matrix deformation 40-45 dB range suggests fibre-matrix debond, the main failure mechanism, fibre pull-out, is in the range of 45-60 dB and fibre break is indicated by the above 60 dB range.

The aim of this study was the investigation of mechanical properties and crack propagation behaviour of mono and hybrid composites. Tensile, flexural and single edge notched tensile test

(SEN-T) were carried out for the characterization of mechanical properties. Acoustic emission measurements were executed parallel to the SEN-T tests.

Materials and methods

FM-20 epoxy laminating resin was used (ipox chemicals GmbH, Germany) with T-16 curing agent (ipox chemicals GmbH, Germany) as matrix material. The mixing weight ratio was 100:20. Glass (Saint-Gobain Vetrotex, Germany), basalt (Basaltex, Belgium) and carbon fabrics (SGL Group, Germany) a surface density of 220g/m^2, plain knitting and silane sizing were used as reinforcement. The composite sheets have been prepared by hand layup at room temperature. Every sheet was built up by 6 layers and an alternate layer order (Fig. 1.). The fibre content was 55 wt% in every case.

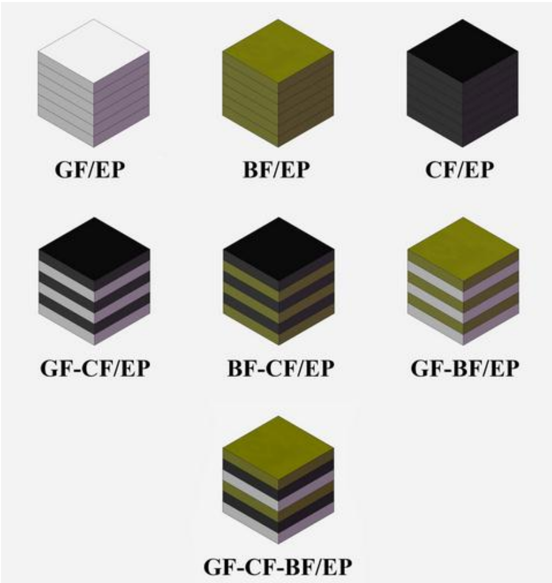


Fig. 1 The different layer ordering of mono and hybrid composites

Specimens have been cured in a Heraeus UT20 drying oven at 70°C for 2 hours after moulding. After curing the specimens have been cut by a Mutronic Diadisc 4200 cutting machine.

Tensile tests were carried out according to EN ISO 527-4:1999 by a Zwick Z050 universal testing machine with 5 mm/min crosshead speed. Three point bending tests were performed according to EN ISO 14125:1999 by a Zwick Z005 universal testing machine. For the flexural test 5 mm/min crosshead speed was applied. The SEM micrographs were taken by a JEOL JSM-6380LA scanning electron microscope. The specimens were gold coated prior to tests. Fracture tests were carried out by a Zwick Z050 universal testing machine. For the measurements SEN-T type specimens were used and the crack propagation was followed by a Sensophone AED-64 acoustic emission equipment. For the crack propagation four Micro30s microphones were applied with 41 dB threshold level. Every measurement was arranged at room temperature.

Results and discussion

According to the tensile test results, the carbon fabric reinforced composite had the highest tensile strength and Young's modulus among the monocomposites (Fig. 2.) as it was expected. Among the hybrid composites the basalt-carbon fabrics reinforced composites were the strongest; the tensile strength was higher than the monocomposite with carbon fabric reinforcement. The Young’s modulus of the glass-carbon and the basalt-carbon fabrics reinforced composites were similar. Among the hybrid composites the common failure mechanism was delamination. It occurred due to the different elongation of the reinforcements.

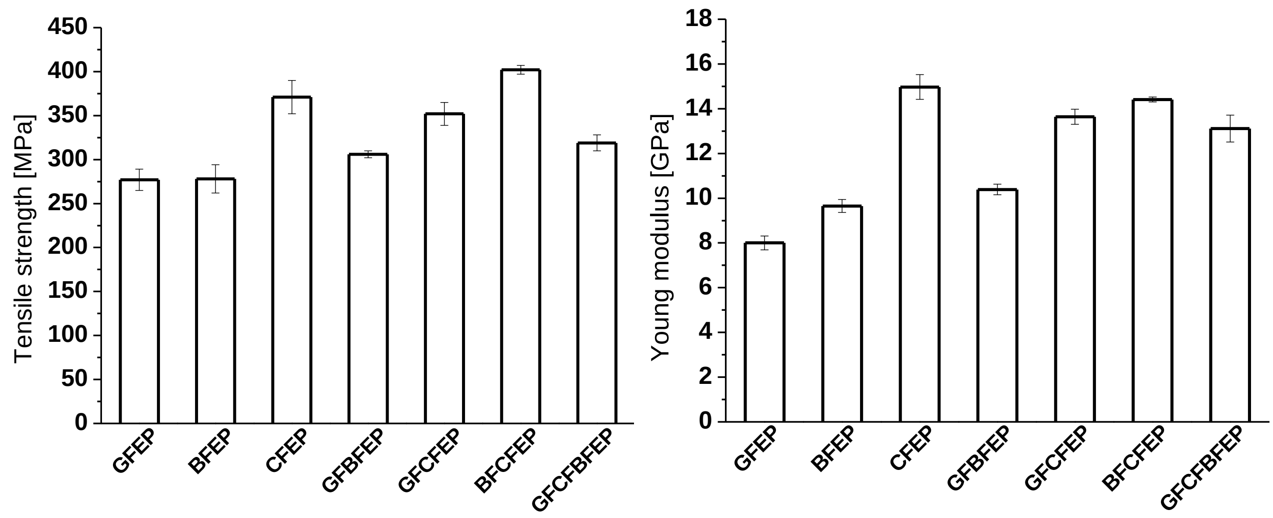


Fig. 2. Results of tensile tests

On the basis of the flexural tests, it can be declared that the flexural stress and flexural modulus of the carbon fabric reinforced composite were the highest out of the investigated mono and hybrid composites (Fig. 3.). The composite with carbon fabrics reinforcement is two times stronger than the glass or basalt reinforced mono composites and glass-basalt fabrics reinforced hybrid composite. The glass-carbon and basalt-carbon fabrics reinforced composites behaved in the same way.

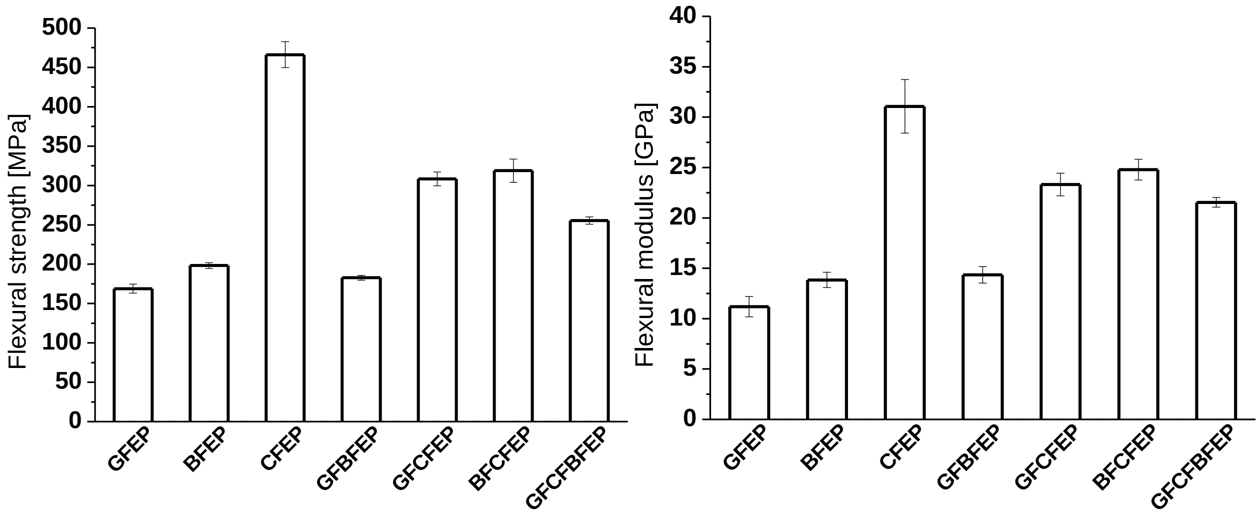
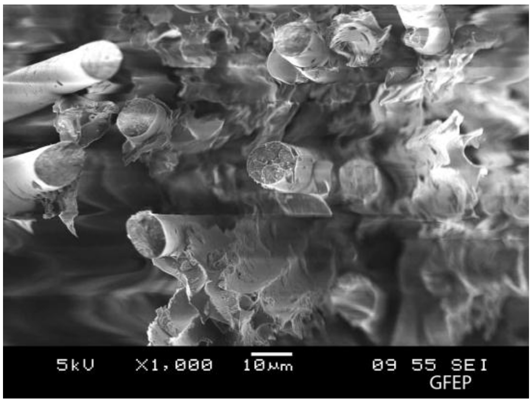
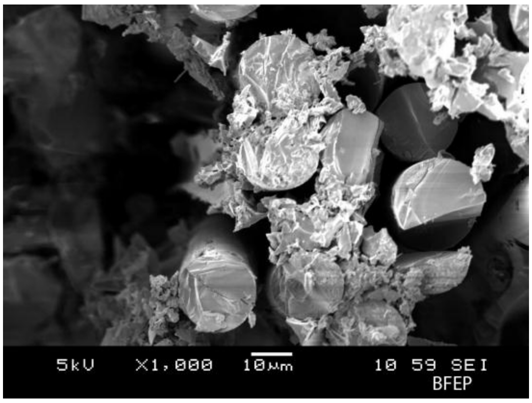


Fig. 3. Results of three-point bending tests

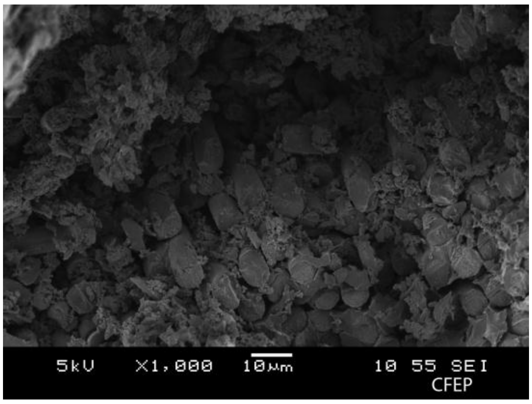
The SEM pictures of the mono composites showed that the adhesion between the glass or basalt fibres and epoxy matrix was satisfactory (Fig. 4.). The common failure mechanism was the fibre-break; however we could see evidences for fibre-pull-out. In the pictures a bound layer between the different fibres were seen. The different fibres could be identified by the differences in fibre diameter in some cases. The fracture surfaces of the glass and basalt fabrics reinforced composites were similar (Fig. 4.a, 4.b). On the basis of these pictures it can be declared the composites were rigid. In Fig.4 g) the carbon fibre (smaller diameter) and the glass or basalt fibre (bigger diameter) could be identified.



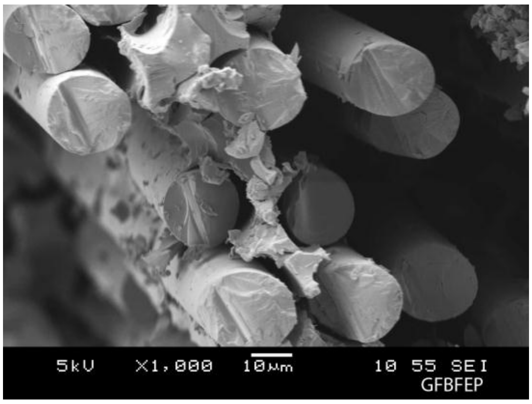
a)



b)



c)



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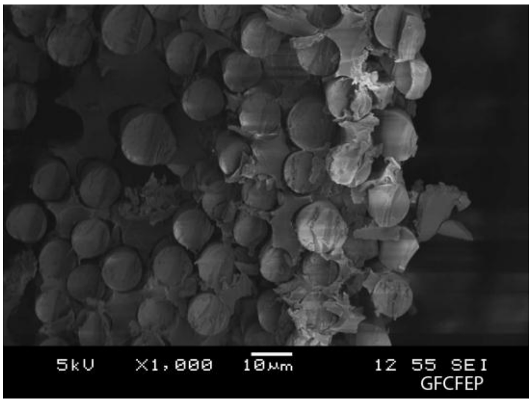

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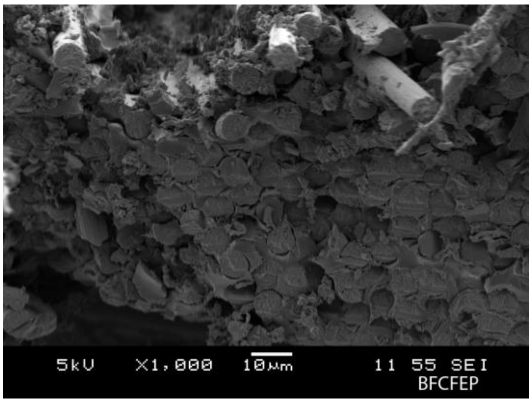

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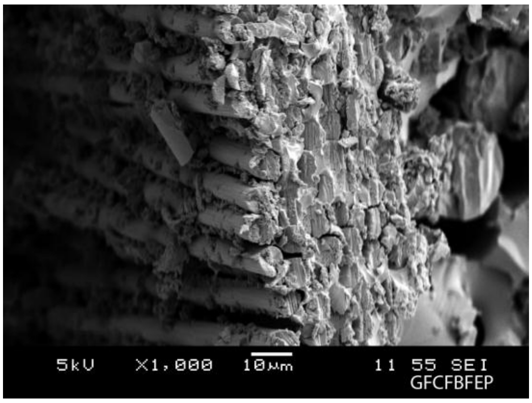

g)

Fig. 4. SEM pictures of the fracture surfaces of tensile specimens
a) GFEP b) BFEP c) CFEP d) GFBFEP e) GFCFEP f) BFCFEP g) GFCFBFEP

Critical stress intensity factors were calculated based on the SEN-T tests (Table 1.). Results showed that among the mono composites the carbon fabric reinforced composites had the highest stress intensity factor. The carbon fabric improved the critical stress intensity factor of the composites with glass and basalt fabric reinforcement.

Results of the acoustic emission measurements (Table 1.) showed that the behaviour of the glass and basalt fabric reinforced composites was similar; the crack propagation was continuous. During the measurement the sum of events was recorded. The fewest event was emitted by carbon fabric reinforced composite what proved the rigid behaviour of this material. The rigidity of the carbon fibre reinforced composites was decreased by the addition of glass or basalt fabrics. The positive effect of glass and basalt fibre was shown by the sum of acoustic events.

Material	Critical stress intensity factor [$MPam^{1/2}$]	Typical amplitude range [dB]	Average cumulative events [pieces]
GFEP	30,3±2,1	60-65	65536±11495
BFEP	29,3±2,3	65-70	209363±36534
CFEP	49,5±4,3	45-50	11650±1978
GFBFEP	32,5±2,9	55-60	302845±54524
GFCFEP	42,3±4,2	45-50	109802±19633
BFCFEP	41,9±3,7	45-50	119019±20364
GFCFBFEP	39,9±4,0	55-60	75602±14017

Table. 1. Results of the SEN-T and the acoustic emission study

Summary

According to the mechanical and acoustic emission tests could be declared that among the investigated monocomposites the carbon fabric reinforced one has the highest tensile and flexural strength and modulus. Critical stress intensity factor of the composite with carbon fabric reinforcement was higher with 60% than of glass and basalt fabric reinforced composites. Among the hybrid composites the basalt-carbon fabric reinforcement offered the highest resistance against the tensile and flexural load. Critical stress intensity factor of glass-carbon or basalt-carbon reinforced composites were increased by addition of carbon fabric. The similar behaviour of glass and basalt fabric was proven by conformity to typical amplitude range and piece of average cumulative events.

The behaviour of the basalt fabric reinforced composites is similar to the glass fibre reinforced composites; therefore it can be concluded that the basalt fibre could be a good alternative of the glass fibre as a reinforcement of wind turbine blades.

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