Preparation of Hybrid Tapes for Fabrication of Composites

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Abstract
Among many other materials for the reinforcement of composites, technical fabrics are increasingly being used, especially from glass tows, which have good mechanical properties. In this paper glass fibre based tapes containing special types of resins in pre-condensate form for use in technology of composites preparation by precise winding is prepared. The tensile properties of the tapes made from glass were investigated. Measurements were focused on the breaking force, deformation at break and initial modulus. It was found that the durability of the tapes was sufficient for long term storing. The main benefit was avoiding of resin penetration into winded structure which is due to tight arrangements of fibrous phase which is very complicated. Also, the selected suitable resin was loaded by suitable types of nanoparticles for enhancing mechanical properties. The results showed a significant difference between the samples.

Key words: hybrid tapes, tensile properties, precise winding, composites, epoxy resin

1. Introduction

Glass fibres are commonly used due to their nonflammability, strength, abrasion resistance, cost effective processing and reasonable price in textile industry application. Multifilament yarns are used for the production of glass fabrics, where filaments are glued together (roving yarn) into tape shapes (tows) to ensure compactness and improved properties (strength, evenness) [1, 2]. The starting material for composites is multifilaments (wires), i.e., the strands that are formed by a combination of filaments (filaments) of low fineness (diameter below 10 μm) required to ensure low bending stiffness. The number of cross-sectional fibers ranges from 1k to 24k (number of filaments in roving in thousands).
Twisted yarns, i.e. yarns, have an approximately circular cross-section and the density of the arrangement increases with increasing twist. However, the curl affects the initial modulus and yarn strength. Also, penetration of the resin or its components is not easy.
Rovings (tow) are with slight (protective) twist (less than 50 curbs / m) and are suitable for the manufacture of prepregs. They usually have an oval cross section and their porosity decreases toward the center of the body. Spread Tow Tape (STT) is characterized by the fact that their width is multiplied by more than 3 times the diameter of the original multifilament (Fig 1).

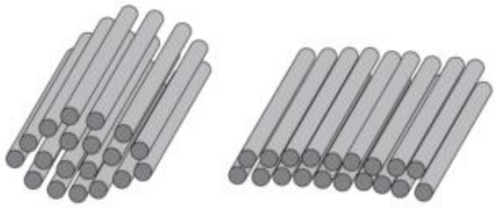

Fig 1. Original cable and spread tape

The individual filaments are much more closely arranged and behave like a bunch of identical long parallel threads. This leads to a better utilization of the strength of individual filaments and to a reduction in the thickness (by 20 to 30%) and hence the density of the composites [3-6]. The problem is to ensure cohesion and then resin saturation. The resin must ensure the storage life of the tapes. To improve mechanical properties of resins, it is preferred to use suitable fillers (particulate systems). The resulting stabilized hybrid composite tapes (SHCT) comprising an optimally arranged resin-bonded fibrous phase and a surface nanoparticles with functional particles will allow the production of composites in particular by the technique of precision robotic winding. Among the end-use properties of glass fabrics, one should note generally high strength along with a relatively low density, high thermal resistance and nonflammability, good insulative characteristics, resistance to microorganisms, as well as good chemical resistance to oils, fats and organic solvents, acids and alkalis in the pH-range from 3 to 9. Major disadvantages are sensitivity to strong alkalis, surface corrosion, fragility and relatively hard processability [7 - 13]. This paper deals with the preparation and mechanical properties (breaking force, deformation at break, initial modulus) of stabilized hybrid composite tapes (SHCT).

2. Materials and Method

The stabilized hybrid composite tape SHCT (Fig 1) consists of the following components:
An expanded tape of a glass uncoated multifilament cable (E-glass 1310 fibers) parallelized to the direction of the belt axis.

- average fiber fineness 3.16 (95% IS IS *) 2.60-3.72) dtex,
- average fiber strength 30.64 (95% IS 26.29-35.00) cN,
- average fiber deformation at break 6.72 (95% IS 6.07-7.35)%,
- average fiber initial modulus 26.12 (95% IS IS 17.30-34.95) GPa.

(*) confidence interval

Since the strength of the epoxy-free tape (sample 1) was 285.6 N, and the strength of the fibers were 30.65 cN fiber, the number of fibers in the tape were estimated as 922 fibers. According to the manufacturer, the fibers in the tape are 1310 fibers. This difference indicates the measurement uncertainty.
Epoxy type resins with a special catalyst ensuring durability (in the order of months) under storage conditions and subsequent heat curing.
Grinding activated fumed F-type fly ash at a concentration of 3% found as a compromise to improve most of the mechanical properties of the matrix. Selection of a suitable filler to improve the properties of the epoxy matrix The ash from SILO, Pilsen was selected. Mechanical activation of fly ash was carried out on a Fritsch pulverisette 7 planetary ball mill. As a textile reinforcement, glass fabrics of filaments of 600 Tex, thickness of 2.15 mm and of a fiber content of 0.34 were used. LH 288 epoxy resins and hardener HY 951 were purchased from Havel Composites Czech Republic. The calculated amount of fly ash particles at 1, 3, 5 and 10% by weight was mechanically mixed with the epoxy resin at room temperature until a homogeneous mixture was obtained. The composite was cured in an oven at 120 ° C and 50 kPa for 30 minutes.

Table 1 Sample description

Sample no.	Sample description
Sample 1	E-glass without epoxy marked glass without modification
Sample 2	E-glass 1310/1 epoxy coated
Sample 3	E-glass 1310/1 epoxy dissolved in acetone (fast), washed in water and air-dried.

2.1. Preparation of Tapes

Preparation of prepregs was carried out on pilot plant, which was built by company Večerník s.r.o. The pilot plant is a model which however fulfilled the purpose of producing a reproducible prepreg made of glass roving in the form of thin endless tapes. At present, the development of a drive unit is being carried out at the department of textile and single-purpose machines.

The aim of this device is to automatically control the speed of initial unwinding of roving and final winding of finished prepreg. The drive unit will also include an element that will provide a constant strain of roving. The current form of a semi-operating device for preparing a prepreg is shown in Fig 1. The overall path of roving before the wrap of the prepreg is about 15m.

Fig 2. Semi-operating device for preparing a prepreg

In the first part roving passes through the smooth steel rod system. In this part, the effort is to mechanically separate the individual fibres and pull on the roving to ensure a constant disconnection of the individual fibres. For industrial glass roving, the major problem is due to very high speeds in the production itself and the subsequent spinning of the cross-winding fibres, uneven disconnection of the individual fibres occurs. If composite material from such a roving is prepared, optimal mechanical properties cannot be achieved. It is due to the reason that when the composite is loaded, only the percentage of fibres can be completely turned off during the preparation of the prepreg. The roving is made from a mixture of acrylate polymers and epoxysilane, suitable for epoxy matrices. In Czech Republic, glass roving prepared in the industries are unsuitable for epoxy mats due to starch sizing fibre blending. The possibility of modifying the sizing, which would be compatible with the epoxy matrix, but at the same time would not cause the fibres to be interconnected. It would be possible to achieve a homogenous shutdown of the individual fibres to ensure their perfectly parallel arrangement which would at least ensure the approximation of the theoretical value of the glass fibre strength. This is the main objective of the study that will have a major impact on improving the mechanical properties of composites made from these prepregs.

In order to ensure sufficient epoxy matrix content, three epoxy dispersion-based coating stations are used in the line and at each of the stations the impregnated roving is dried at elevated temperatures. In terms of sifting the fibrous structure, the first deposit is most important, further deposits are mainly due to the fact that the layers are interconnected with each other in the formation of the composite. After the last coating of the epoxy dispersion with the catalyst, a cross-winding is performed on a paper roll, which is currently performed manually and awaits completion of the drive unit development. The cross section and SEM image of hybrid tapes shown in Fig 3 and 4.

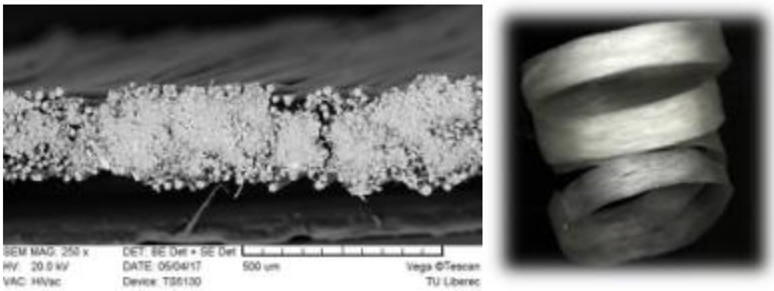

Fig 3 Cross-section and view of a stabilized hybrid nano composite tape

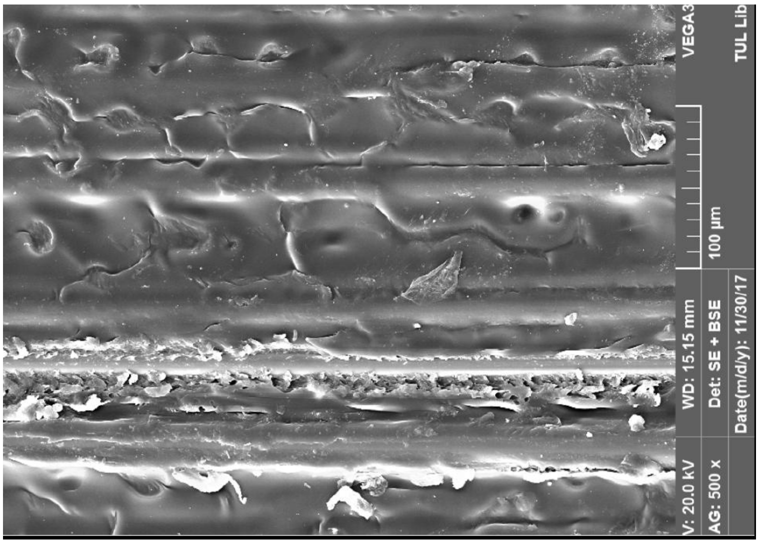

Fig 4 SEM image of composite tape with visible glass fiber in the center

The tensile properties were measured by 1000N (Instron instrument) head with pneumatic jaws and rubber, a clamping length of 200mm, a jaw velocity of 50mm / min, i.e. a strain rate of 0.25 / min, a tape thickness of 0.16mm (differences without epoxy) and a width of 4mm. Fiber properties were measured in Vibrodyn 400 instrument.

3. Results and Discussion

The basic mechanical characteristics of the glass tape without modification (black), SHCT (red) and SHCT after removal of resin in acetone (blue) are shown in Fig 5, 6,7 and 8. The initial modulus in MPa applies to all samples on a constant surface of 4x0.16 = 0.64mm^2. The highest values of strength, deformation at break and initial modulus are achieved with epoxy glass, the smallest epoxy without glass. The values of these properties for glass with epoxy dissolved in acetone between the epoxy and non-epoxy glass values increase the variability of the values and indicate the imperfect removal of the epoxy. The results showed a significant difference between the samples. Values in brackets are 95% confidence intervals of mean values of breaking force, deformation at break and initial modulus.

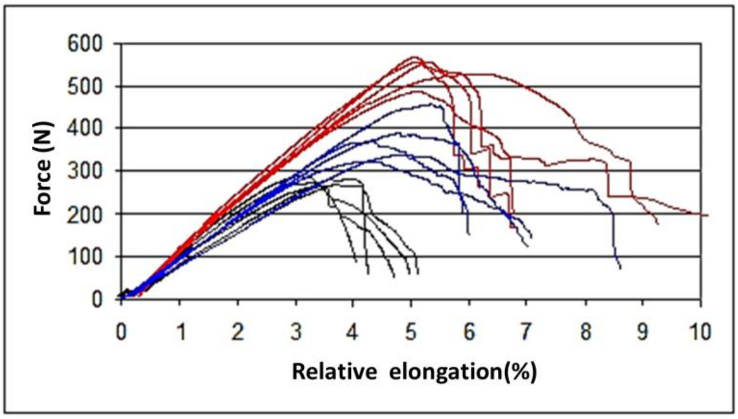

Fig 5 Relative elongation, red – SHCT (sample 2), blue- glass tape after resin removed with acetone (sample 3), black – glass tape without modification (sample 1)

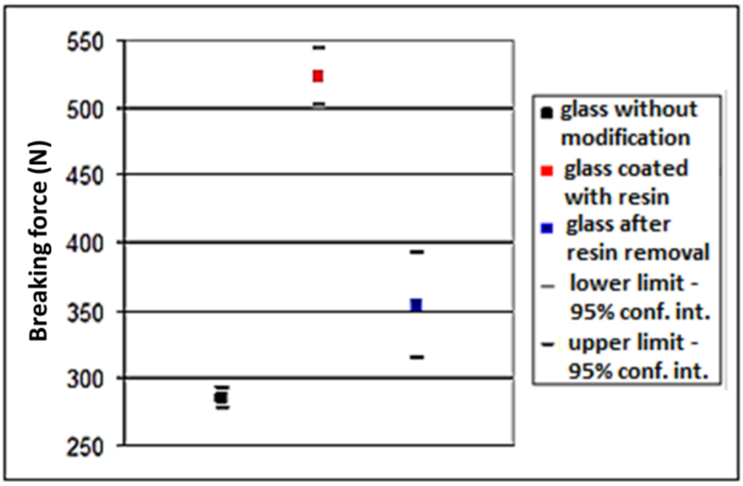

Fig 6 Breaking force of glass tape without modification (black), SHCT (red) and SHCT removed by acetone (blue).

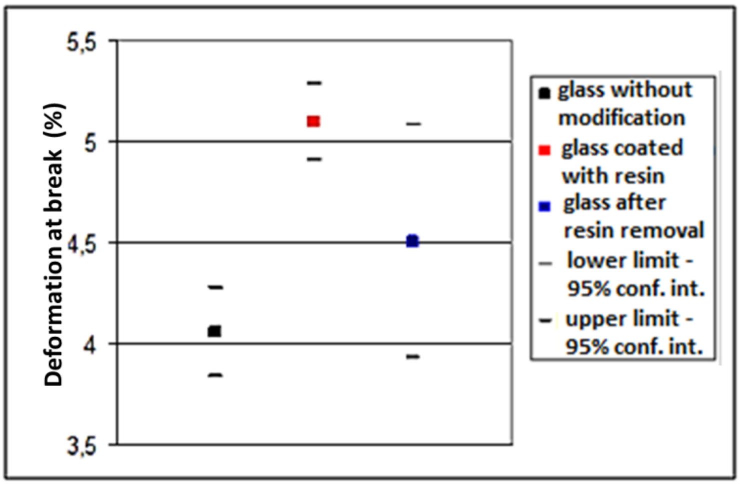

Fig 7 Deformation at break of glass tape without modification (black), SHCT (red) and SHCT removed by acetone (blue).

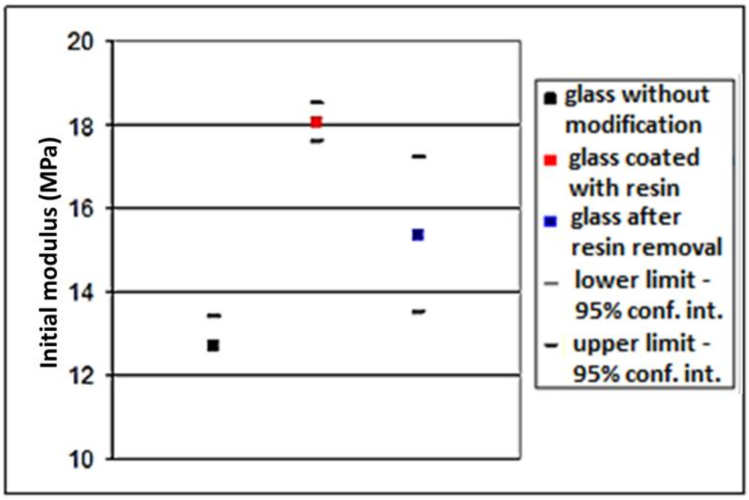

Fig 8 Initial modulus of glass tape without modification (black), SHCT (red) SHCT removed by acetone (blue).

A. Composite specimens containing activated fly ash particles containing 1% by weight exhibited the greatest improvement in bending properties (the bending modulus increased from 87.55 to GPa of 124.35 GPa and the bending strength increased from 621.63 MPa to 634.20 MPa.) The addition of activated fly ash in 3, 5 and 10% by weight, the bending modulus changed by 0.71%, 42.50% and 58.93% and bending strengths of 12.05%, 33.58% and 47.35% relative to ash-free samples. The agglomeration of fly ash particles is likely to increase at its higher concentrations in the composites.
B. For composite samples containing activated fly ash particles, an improvement in tensile characteristics up to 3% by weight of fly ashes was found. In particular, there is a significant increase in the initial modulus and a slight increase in tensile strength compared to ash-free composites. A maximum increase of the initial modulus from 27.32 GPa (ashless composite) to 48.22 GPa (a composite containing 3% by weight of ground fly ash) was achieved.
C. Composite samples filled with 1, 3, 5 and 10% by weight of ground fly ash had an impact strength increase of 17.20%, 60.71%, 31.18% and 18.86%. However, the composite filled with original fly ash exhibited only 5.64% 10.27%, 13.54% and 1.57% increase in impact strength compared to ash-free samples.
D. The dynamic elastic modulus of ash-filled composites improves over the entire temperature range compared to the uncompleted composite. A significant effect of the ash refinement by grinding on the dynamic elastic module is demonstrated. The maximum improvement was observed for a 10% concentration of softened ash where the dynamic elastic modulus was increased from 18.1 to 34.8 GPa at 40 ° C. For composites filled with refined ash at concentrations of 1, 3, 5 and 10% to 30.38%, 33.70%, 48.61% and 92.26% of module growth. In the case of a composite with unblended ash content, the dynamic elastic modulus increased by 50.27%, 22.65%, 45.85% and 29.83% at 40 ° C, depending on its concentration.
Mechanical tests and dynamic mechanical analysis were used to select a suitable filler and its concentration. Based on these tests, 3% by weight of fly ash particles was chosen as optimal with respect to the combination of improvement of mechanical properties, ease of preparation and possible health aspects, which is not the best in terms of the dynamic elastic modulus but with the inclusion of static mechanical characteristics and impact characteristics as a suitable compromise.

4. Acknowledgement

This work was supported by the project "Sophisticated hybrid tapes for fabrication of composites by precise winding" [Project no: TJ01000292, 14014/136].

5. Conclusion

Advanced glass fibre based tapes containing special types of resins in pre-condensate form for use in technology of composites preparation by precise winding was prepared. Main benefit is avoiding of resin penetration into winded structure, optimization of tape geometry and composition according to the requirement of precise winding, maximum use of tow filaments strength and enhanced durability for long term storage of tapes. Mechanical properties (breaking force, deformation at break and initial modulus) were enhanced by adding suitable type of nano particles in the resin which showed a significant different between the samples. The resin containing ground fly ash particles increased the strength and SHCT modulus significantly over the spread of the glass tape. Based on durability tests, it has been shown that SHCT can be stored and used after a longer period of time.

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