The effect of basalt knitted fabric on the properties of green epoxy resin

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Abstract: The influence of basalt fabric on the tensile mechanical properties and the impact resistance of green epoxy resin was investigated. Composites with parallel arrangement of insert yarns had better properties than in the case of their perpendicular arrangement. The properties were also influenced by the number of layers of the fabric. The tensile strength and impact resistance of the composites were better than the commercially available side mirror covers due to the superior properties of the basalt fiber.

Keywords: green composites, tensile properties, impact strength.

Wpływ tkaniny bazaltowej na właściwości „zielonej" żywicy epoksydowej

Streszczenie: Zbadano wpływ tkaniny bazaltowej na właściwości mechaniczne przy rozciąganiu i odporność na uderzenie „zielonej" żywicy epoksydowej. Kompozyty o równoległym ułożeniu przędzy charakteryzowały się lepszymi właściwościami niż te o prostopadłym ułożeniu. Na właściwości miała również wpływ liczba warstw tkaniny. Wytrzymałość na rozciąganie i odporność na uderzenie kompozytów były lepsze niż dostępnych na rynku osłon lusterek bocznych ze względu na dobre właściwości włókna bazaltowego.

Słowa kluczowe: „zielone" kompozyty, właściwości mechaniczne przy rozciąganiu, udarność.

Automotive sector is one of the fastest growing segments of the industry and is one of the major industrial and economic force worldwide. The market research shows that the global use of composites in automotive applications will grow from \$5.4 billion in 2020 to \$9.3 billion in 2025 [1]. The materials used in manufacturing of car parts consist of cast iron, steel, copper, aluminum, magnesium, and plastic. There is an increasing demand of light weight automobile and air craft made with polymer-based composites and plastic materials as they improve the fuel efficiency by reducing inertia force and consequently cause lower carbon emission. Research showed that the polymer composites are used substantially to develop the light weight components [2–3]. The acceptance of these material is due to lower cost and the better mechanical performance characteristics [4–5]. It was investigated that in order to achieve light weight, environment friendliness and better functional properties, the composite materials are preferred as raw material for parts or component applications [6]. The components may be used in aeronautic wings of air craft, luggage weather strips (seals for lift gate), radiator lining in automotive sector, and in civil engineering for smart building applications [7]. Basing on the research, it was found that the composite materials have a significant role in automotive parts with respect to specific application. The composite and plastic materials have up to 50% share in manufacturing of automotive subassemblies [6]. In automotive manufacturing, the composite materials are used to develop various functional parts such as pistons, high friction brakes, door handles, door panels, rear and front bumpers [8–10]. Balaji *et al*. stated that automotive structures such as lift gate, front end module and bonnet are developed by glass and carbon fiber reinforced thermoplastic polymer composites [11].

Reinforcement plays a very important function in composite structures providing the stiffness and strength of the composite material, while matrix material gives the surface appearance and the shape of the composite [12]. This fact shows that the mechanical properties of com-

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posite materials are directly related to the mechanical properties of reinforcement material. Synthetic fibers/polymer composites have a non-degradability issue. Synthetic materials synthesis and their manufacturing processes have also negative impact on the environment. In a world with limited resources but increasing consumption, there is a significant focus on the composites field to use renewable resources and to be more environmentally friendly.

Basalt fiber, one of high-performance inorganic fibers, is an alternative which usage reduces the negative impact of synthetic fibers. It is made of single material *i.e.* crushed basalt. Its mechanical characteristics is in between of glass and carbon fibers, having no toxic reaction with air or water and being non-combustible and explosion proof [13–14]. The industry's main requirements are high mechanical properties and outstanding recyclability. Basalt fibers are basically made by crushing of basalt rock and due to their low cost as well as good mechanical properties, they are used in automotive, civil engineering, reparation of buildings, boat manufacturing, turbine blades, oil and sports tools applications [15–16]. Previous research showed that composites of basalt reinforced epoxy matrix used in automobile applications have better tribological and mechanical properties. Apart from these properties it is also cost efficient and environmentally friendly [16–17]. Saleem *et al*. investigated that the basalt fibers hybridization with bast fiber gives better mechanical and thermal properties [18]. From the available research, it was observed that basalt fiber with epoxy has better thermal and mechanical properties and is cost efficient, renewable, and sustainable [19].

The literature review shows that the limited work is available regarding utilization of basalt fiber with green epoxy. For the development of reinforcement, knitting technique is used as the fastest method of fabric production. Knitted fabric possesses an excellent interlaminar fracture toughness, damage tolerance, and impact resistance [20]. Knitting of high-performance yarn is very difficult due to its brittle nature. In this paper development of shield of car side view mirror using basalt knitted fabric instead of synthetic materials is described. This protective cover is efficient and protects the car side mirror against various damages caused by stones or sudden impacts [21]. These composites can be used in different parts of cars due to their safe manufacturing process and sustainable source.

EXPERIMENTAL PART

Materials

Basalt yarn was purchased from China. It had linear density 54,000 denier. Green epoxy resin CHS-G530 (new commercial name EnviPOXY®530) was purchased from company SPOLCHEMIE in Ústí nad Labem, Czech Republic. It has low molecular weight and low crude oil content as well as high renewable content [22].

Methods

Sample preparation and composites fabrication

Samples were knitted using Shima Seiki (Japan) double bed electronic flat knitting machine of E = 7 and 8 feeder. Inlay structure was used for knitting as shown in Figure 1. Hand lay method was used for composite manufacturing. According to the composite manufacturing plan, single-ply and double-ply samples were laid in mold with 0° orientations for better mechanical properties [23–24].

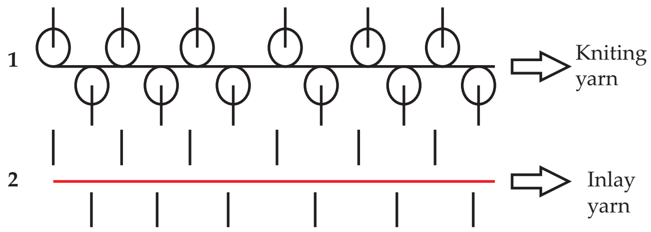

Fig. 1. Inlay structure

A mixture of epoxy and hardener (CHS-HARDENER P11) with ratio of 100:32 was prepared according to the manufacturer guidelines. All the samples were cured at 120°C for 1 h in mechanical convection oven. Illustration of fabrication of composite sample and market sample is given in Figure 2. Vernier caliper was used before testing to measure the thickness of each specimen. The thick-

Fig. 2. Composite and market samples: a) knitted sample, b) basalt knitted composite, c) market sample

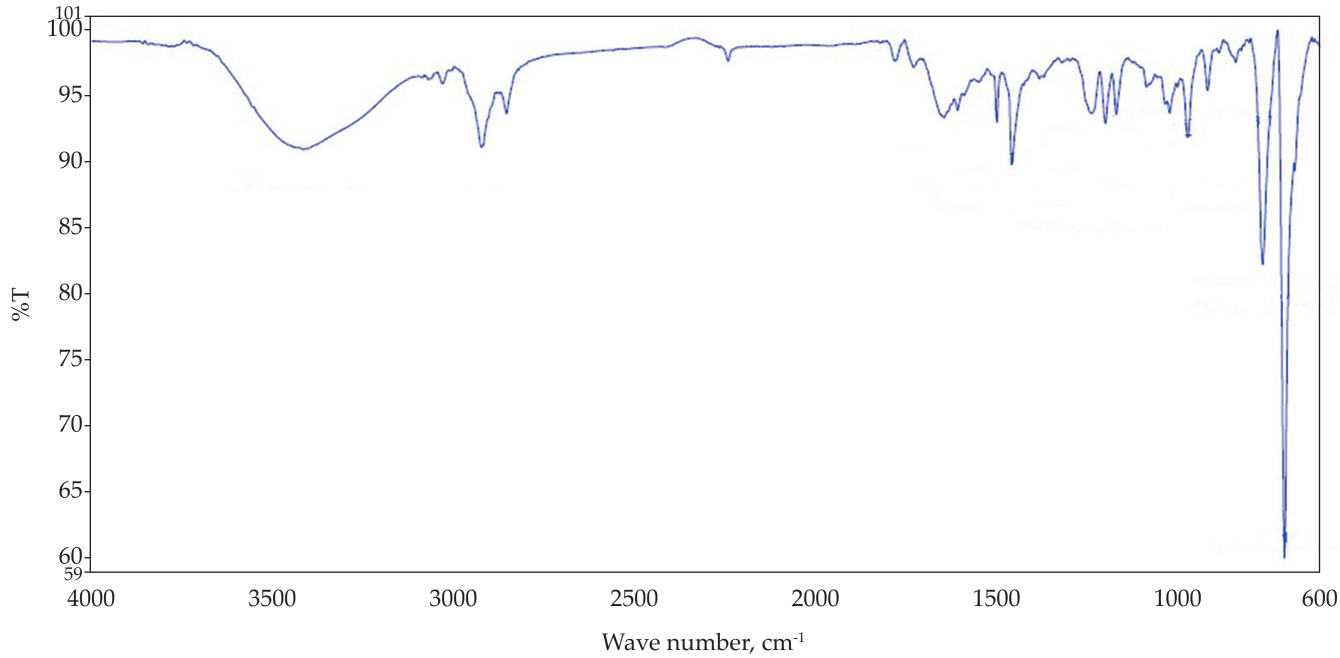

Fig. 3. FTIR spectra of car side mirror cover

ness of single-ply samples was 2.33 mm and double-ply samples was 4.65 mm while market cover sample's thickness was 3.83 mm.

FTIR analysis

Fourier Transform Infra-Red spectroscopy (FTIR) was used to characterize the material of market available car side mirror cover with Spectrum Two FTIR spectrometer (Perker Elmer).

It can be seen from Fig. 3 that the car mirror cover available on the market contains approx. 70% of acrylonitrile-butadiene-styrene copolymer (ABS) and 30% of polycarbonate (PC). ABS is a common thermoplastic polymer. Its demerit is a poor UV resistance. To improve its property PC is used as it is famous for applications requiring high impact resistance and UV filter. ABS is considered as carcinogenic [25].

Tensile test

Tensile strength characterizes in plane mechanical behavior of the composite materials. The tensile strength and modulus of all the composite specimens were determined according to the standard procedure of ASTM D-3039 using Universal Testing Machine Z100-100 KN (Zwick/Roell Germany). Maximum load of a specimen was noted before fracture or failure. In textile reinforced composites, structure of reinforcement and properties of composites were characterized by direction of fiber or yarn in it. As textile materials and structure were isotropic, they had different properties in different directions. That's why samples were checked in both directions, parallel and cross to inlay yarn direction, as given in Table 1.

T a b l e 1. Sample description

Sample code	Sample description
P1C	Single-ply, cross to inlay yarn
P1U	Single-ply, parallel/direction of inlay yarn
P2C	Double-ply, cross to inlay yarn
P2U	Double-ply, parallel to inlay yarn
P	Market sample

Drop weight impact test

A drop weight impact test typically determines a material's resistance to a sudden external force. Since the primary concern is potential damage of the composite structure induced by low-velocity impact, like a tool drop on an aircraft wing skin either an automobile component bumping a stationary object or during crashing cars, striking a flat plate with a falling weight was adopted as the impact test method of choice. The impact test was performed to characterize the out of plane direction force according to standard ASTM D7136 using the Zwick/Roll drop impact tester.

RESULTS AND DISCUSSION

Tensile properties

The results of tensile tests are shown in Figures 4–5. It can be seen that all the samples made of basalt had better tensile properties than market sample due to better properties of basalt fiber. Figure 4 shows that the tensile properties like tensile strength and elastic modulus increased with the increasing the number of plies as more force was required to break reinforcement [23].

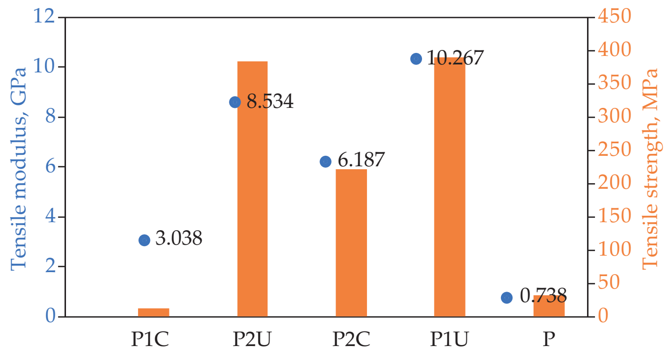

Fig. 4. Tensile properties of the samples

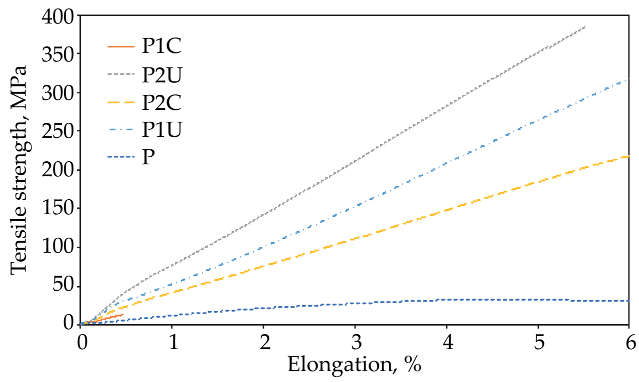

Fig. 5. Stress-strain curves of the samples

T a b l e 2. Comparison of sample impact properties

Sample code	F_{max}, N	S_m, mm	W_m, J	l_p, mm	F_p, N	E_p, J
P1U	894.3	26.4	12.6	40.2	447.1	20.9
P2U	1979.5	10.8	13.0	15.7	989.8	21.6
P	853.2	25.5	15.1	31.3	426.6	19.4

where: F_{max} – maximum force, S_m – deflection at F_{max}, W_m – energy at F_{max}, l_p – puncture deformation, F_p – puncture force, E_p – puncture energy.

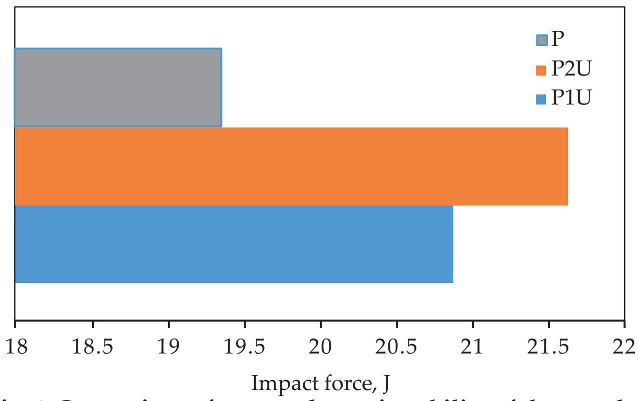

Fig. 6. Comparison of energy absorption ability of the samples

Additionally, stress beard by composites increased with the increase in plies' number (Figure 5). So it can be established that the strength of composites is a function of number of plies.

A great difference in modulus was observed when composite specimens were tested in parallel and cross directions. Samples with inlay yarn in parallel direction had significantly higher properties during loading as inlay yarn running in parallel is virtually straight. They are entirely aligned with the loading direction and tend to carry a considerably larger share of the applied load [19, 26–27].

Drop weight impact properties

In drop weight impact test, the weight and heights were predetermined *i.e.* 1.04 kg weight accordingly for 10 J impact energy was allowed to strike on composites. The absorbed energy can be calculated from the force-displacement curve.

All the samples were cracked. The results of the impact properties' tests are shown in Table 2. Data depicted in Figure 6 show that basalt specimens exhibited better energy absorption behavior than market specimens due to their high tensile properties. The graph shows that P2U samples had the largest impact energy. P2U achieved a high primary peak value of 1979.5 N and a secondary peak value of 989.7 N corresponding to the puncture force (the value at which force had fallen to the half of value of its primary force). Due to the high force area under the curve increase, the amount of absorbed energy was increased.

CONCLUSIONS

In this research, composites of basalt knitted reinforcement and green epoxy matrix were fabricated successfully. Characterization of basalt knitted fabric for composites application as car side mirror cover was performed by mechanical testing. Samples showed better tensile properties in comparison with market sample. Composites with parallel direction of inlay yarn had better properties. Also number of plies influenced the properties. Developed composites also had high impact energy in comparison with market sample. From the study, it is evident that basalt-based composites have better performance in comparison with market cover while being the most environmentally friendly option.

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