EXPERIMENTAL STUDY OF THERMOPLASTICS MATERIAL REINFORCED BY VARIOUS TYPES OF HIGH-STRENGTH FIBRES

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This paper aims to study the application of various types of high-strength fibres in the recycled polyvinyl butyral matrix, esp. effects of sizing on properties of differently sized. For the verification of tensile test according to standard DIN EN 527-1 we used numerical results. The reinforced material was moulded and the fibres are inserted at a distance of 3 mm and 5 mm at the middle of the matrix and subsequently again at 150 °C by 10MPa and by the pressing time, 2 minutes pressed.

KEYWORDS

polyvinyl butyral, high-strength fibres, matrix

1 INTRODUCTION

Ralph Laessig (2015) say "In key sectors of industry, like automotives, aeronautics and wind energy, we are already seeing the use of large quantities of continuous fibre-reinforced components.“ [Laessig 2012] According to Shackelford (2001) [Sathishkumar 2014] is in Tab. 1 presented a listing of commonly used fibre materials. Commonly utilized fibres include Kevlar as a polymer fabric (with very low density), E-Glass (with low-cost) and Carbon (with high strength, high modulus). High-strength fibres with a thermoplastics matrix make an excellent material with some special properties [Shaw 2010, Vasiliev 2001]. Johannes Ganster and Hans-Peter Fink (2006) described Cordenka as a rayon tyre cord yarn provided by Cordenka Gmb Obernburg Germany and is produced by a special variant of the viscose process. Enka viscose is atypical viscose fibre for textile applications produced by Enka GmbH and Co. KG, Oberbruch,Germany. Viscose sliver was kindly provided by Kelheim Faser GmbH, Germany, and taken from the staple fibre production line (non-wovens applications) by separating a sliver of approximately 2 ktex. Mueller (2015) deals in his study field with hybrid composite materials on basis of reactoplastic matrix reinforced with textile fibres from process of tyres recyclation. Authors El-Bashir, Binhussain, Al-Thumairi et al.(2014) preparated and characterizated of PMMA stone waste nanocomposites for marmoreal artificial stone industry. Auhors Sathishkumar and Naveen Satheeshkumar (2014) tested hybrid fiber reinforced polymer composites [El-Bashir 2014, Ganster 2006, Mueller 2015, sathiskumar 2014, Shackelford 2001, Taranu 2014].

According to literature review we can say, high-strength fibres represented a cutting edge material used in various types of matrix. By our research work was used a thermoplastics matrix, esp. recycled polyvinyl butyral.

Thermoplastics (or rather some thermoplastics) show favourable processing and properties for use as a matrix system, including such a very high elongation at break, compared with thermosets have a very good temperature resistance. Thermoplastics have a high environmental resistance and fundamental possibility of reusability (recycling). In the Table 1 are presented some characterization of selected fibre-reinforcing materials. Recycled polyvinyl butyral is a part of car glass [Shaw 2010, Vasiliev 2001]. Recycling process of car glass is provided by device for separating glass from film windscreens of cars consists of several pairs of cylinders, surface-treated and pivoted around its longitudinal axis. [Knapcikova 2011] One is mounted in the support structure and the other is immobilized slid ably adjusted. The pair of rollers are pivoted to a support structure and a vertically disposed in a row at a given distance and the distance pivoted in each pair of rolls is optionally adjustable. With distance between the rolls following pairs is less than the distance between the rolls of the preceding pair. The roll surface is specially treated and with the roll pressure can be separated completely from the film [Vable 2015, Vasiliev 2001].

The first phase of recycling windshields is based on the perfect milling, driving instructors, using input line which is equipped with highly functional shredder. Crusher is able to grind windscreens passenger and freight cars, buses and trucks. Then comes the series of conveyors and separators to sort out metals and remained inert matter contained in a windscreen. PVB chips are further conveyed to a set of optical sensors, which are excellent from the pulp to remove soil residues foils, the stripper rubber. The temperature of recycled PVB is Tg of 68 °C, the temperature Tm is 123 °C. The use of PVB is in the granules, flocks, sheets and powder form [Vable 2015, Vasiliev 2001, Zatko 2013].

The use of recycled PVB is in the manufacture of composite materials, as electrostatic coatings, as a discussion paper, as a coatings resistant grease, as a metal finishing and a binder too.

Table 1. Characterization of Selected Fiber-Reinforcing Materials [DuPont 2011]

Fiber	Dispersed Phase	Tensile modulus [MPa]	Elongation at break [%]
	C- Glass	69.103	4.5
Glass Fiber	E- Glass	$72,4.10^3$	4.8
	S- Glass	$85,5.10^3$	5.6
Ceramic Fiber	C (Graphite)	$340\text{-}380,10^3$	-
Polymer Fiber	Kevlar	131.103	2.8

Matrix materials bind the fibres and transmit loads to the fibres through chemical or mechanical bonds; they also generally have low strength and modulus values as compared to the fibres that they bind [DuPont 2011 ,Mueller 2015, Taranu 2013, Zaťko 2013]. Tab. 2 presents comparative properties for fibre reinforcements for plastics.

Table 2. Common Properties of fiber reinforcements for plastics [DuPont 2011]

Property	Glass (E)	Carbon (High Tenacity)	Aramid (Kevlar 49)
Tensile strength [MPa]	3100	3450	3600
Tensile modulus [MPa]	76	228	131
Elongation at break [%]	4.5	1.6	2.8
Density [g.cm^{-3}]	2.54	1.8	1.44

2 EXPERIMENTAL PROCEDURE

Material Using polyvinyl butyral (PVB) as a matrix (Fig.1) comes from automotive and architectural laminated glass, from different backgrounds. [Barry 2000, Din 1997, Karsli 2015, Ji-nian 2015] It is used in glass recycling plants recovered. After recycling process of car glass we obtained the remaining PVB film – flakes. It is also necessary use different separation methods and cleaning steps. These ensure that therein and foreign contaminants such as glass, rubber, wood, metal and PVC are removed. At the end of the recycling process is a colour separation of the PVB film flakes in process [Karsli 2015].

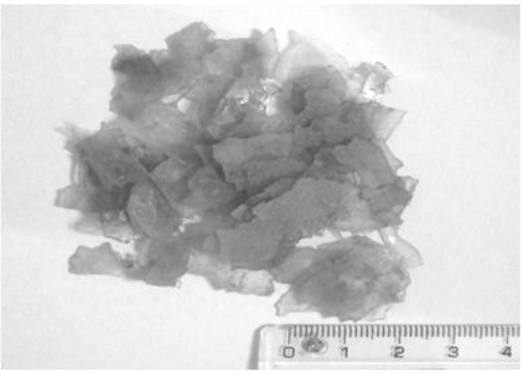

Figure 1. Polyvinyl butyral after windscreen recycling

Properties of thermoplastics PVB Matrix using by our testing:
- High elongation,
- By thermosets comparison high temperature stability,
- In general very good life stability,
- Recycling possibility,
- Higher viscosity as by thermosets [Vable 2015, Vasiliev 2001]

In the next table (Table 3) are presented characteristics of test specimens by pressing technology.

Table 3. Characteristics of the test specimens [Knapcikova 2012]

Equipment Type	Servitec Polysat 400 S
Pressing Temperature	150 ° C
Pressure	10 MPa
Pressing Time	5 min(PVB-resin) 15 min (with filler)

The homogenization of PVB was realized by kneading equipment (BRABENDER, Germany). Homogenization of mixtures was conducted at 150 °C, during 30 min, torsion moment is 18 1/min, and the machine temperature is 200 °C.

Pressing process takes place in three cycles:
- Pre-heating - 20 min
- Pressing - a period of 15 min
- Cooling - 20 min.

After homogenization of thermoplastic PVB, was pressed test specimens with prescribed dimensions necessary according to standards DIN EN 527-1 [Corny 2014, DuPont 2011, Zaťko 2013]. The specimens were tested to detect the tensile characteristics (E-module, σm and εm) by tensile test (show in Tab. 4) [DuPont 2011, Vasiliev 2001].

Synthetic Fibres as a Filler to reinforce plastic materials

By the research was used Glass-, Carbon-, Aramid- Fibres and also Cordenka a synthetic fabric with excellent properties using in the tyre industry.

Table 4. Characteristics of the tensile test [Knapcikova 2012]

Equipment	Universalpruefungsmaschine (D)
Type	Zwick Z020
Max. Force	20 kN
Test Speed	100 mm/ min
E-Module Speed	10 mm/min
Standard	DIN EN ISO 527-1

The next Table (Table 5) describes mechanical properties of tested fabrics. [Barry 2000, Shackelford 2001]

Table 5. Mechanical properties of tested fabric

Fabric	Tensile modulus [MPa]	Tensile strength [MPa]	Elongation at break [%]	Density [g.cm^{-3}]
Glass Fabric (GF)	50000	1500	3.5	2.5
Carbon Fabric (CF)	150000	2500	1.5	1.8
Aramid Fabric (AF)	100000	2000	2	1.45
CordEnka	833000	20000	13	1.5

Specimen Preparation

In the next figure (Figure 2) are the schemes of specimen preparation for the tensile test according to standard DIN EN 527. [Knapcikova 2011, Knapcikova 2012] The samples are clamped such that the protective carton with the edge of the lower jaw closes, so that the fibre is not damaged by the jaw. The matrix of the sample is clamped accordingly so that the zone in which the fibre is buried is exposed. [Knapcikova 2011, Sathishkumar 2014, Shackelford 2001] End of the sample are glued with epoxy resin on carton. In the next steps are describes main characteristics for our test specimen preparation:

- PVB sheet pressing at 125 ° C, 2 min
- Sample cut on the size 20x40 mm
- Sample pieces cut on the narrow side
- Size 3 or 5 mm from the edge of the sample check
- Insert the fibre -bundle to the mark, place specimen with fibre so that the fibres put in the grooves
- Sample press for 2 min

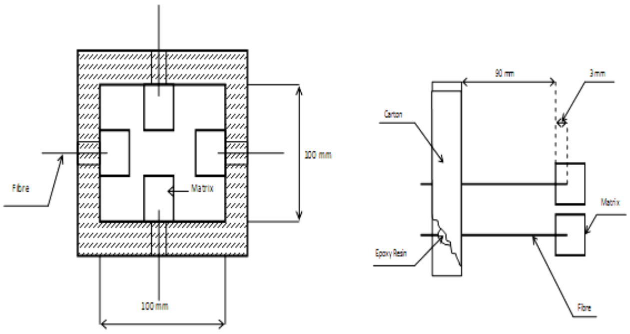

Figure 2. Scheme of specimen preparation

In the Fig. 3 is shown specimen prepared for a tensile test according to DIN EN 527. [DIN 1997]

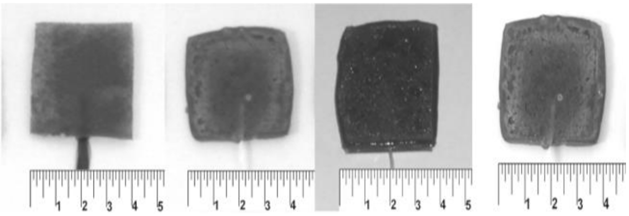

Figure 3. Specimen for a tensile test (from left side: carbon fibre, glass fibre, aramid fibre, Cordenka in thermoplastics PVB matrix)

3 RESULT AND DISCUSSION

These experiments showed that the path for the fibre out of the matrix is relatively wide. Therefore it was decided to experiment with samples in which the fibres were inserted just 3 mm deep into the matrix, to be repeated. These experiments yielded the following results.

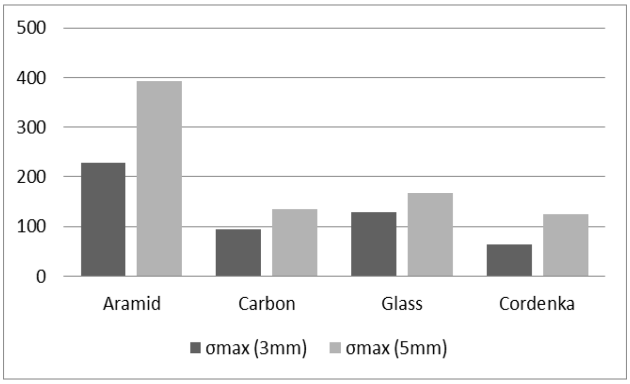

Figure 4. Results comparison after tensile test according to DIN EN 527 for the σmax

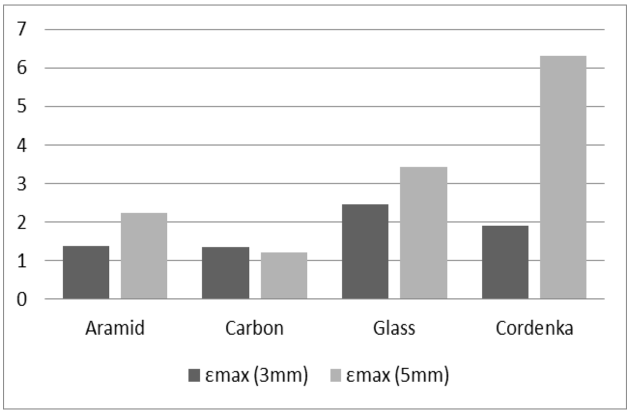

Figure 5. Results comparison after tensile test according to DIN EN 527 for the elongation of material

Table 6. Results of fibres in PVB matrix after tensile test

Fibre	3 mm in PVB			5 mm inPVB		
	σ max [MPa]	ε max [%]	E-module [MPa]	σ max [MPa]	ε max [%]	E-module [MPa]
Aramid	228.7	1.39	7457	393.6	2.25	15026
Carbon	95.4	1.35	5437	134.3	1.22	8452
Glass	128.7	2.45	4907	166.8	3.42	4430
Cordenka	63.0	1.9	2936	124.0	6.3	2117

As expected, the tensile strength for the types of fibres in the thermoplastic PVB matrix- lower for a material that is at a distance of 3 mm at the middle of the matrix, as the reinforced fibre and inserted at a distance of 5 mm at the middle of the matrix .The value of σmax for each fibres range from 63 MPa to 228.7 MPa for the 3 mm in PVB, values for reinforced material with 5 mm in the PVB is from 124.0 MPa to 393.6 MPa. The value of elongation for each filament ranges from 1.35 % to 2.45% of a 3 mm fibres in the matrix. Results for the distance 5 mm into the matrix are from 1.22% to 6.30 % (Fig. 4-7).

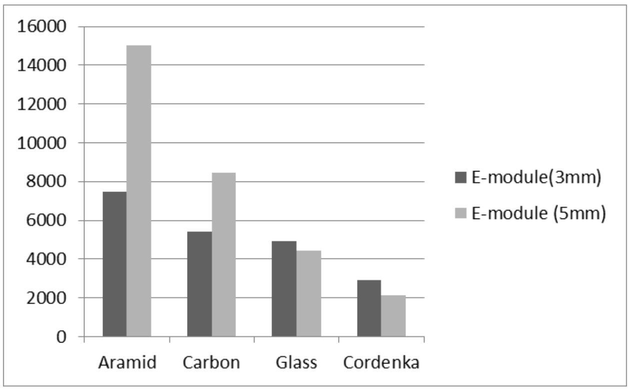

Figure 6. Results comparison after tensile test according to DIN EN 527 for the E-module

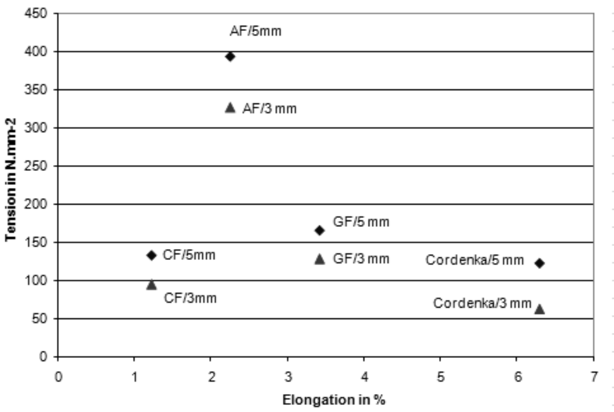

Figure 7. Results after tensile test according to DIN EN 527, comparison for 3 and 5 mm fibres into the matrix

Generally, the mechanical behaviour of fibre is considered to be the result of gradual debonding of an interface surrounding the fibre followed by frictional slip and pullout of fibre. Regarding the debonding phenomena, some micro-hardness tests made on the matrix around the fibre. [Shaw 2010, Vasiliev 2001] At the first stage of pullout loading, induced shear stresses along fibre do not exceed the bond strength between fibre and matrix. Fibres and matrix deforms elastically. [Vasiliev 2001] The stiffness of the fibre - matrix system depends on such parameters as Young's modulus of the fibre and matrix respectively, the fibre - matrix volume ratio, the shear modulus of the matrix and the porous layer as well as the loading conditions.

4 CONCLUSION AND FUTURE DIRECTION OF RESEARCH

The contribution shall be devoted to testing the mechanical properties of the thermoplastic matrix material and various types of fibres. The material was moulded and the fibre is inserted at a distance of 3 mm and 5 mm at the middle of the matrix and subsequently again at 150 °C, 10MPa and the pressing time 2 minutes pressed. Results for individual fibre types are as follows:

• The value σmax of aramid fibre embedded at 3 mm and 5 mm in the middle of the matrix is higher in comparison with carbon and glass fibre (228.7 MPa and 393.6 MPa for aramid fibre and 95.4 MPa and 134.3 MPa for carbon fibre)

• The value of εmax of the glass fibre embedded at 3 mm and 5 mm at the middle of the thermoplastic matrix it is higher than a carbon fibre (2.45% and 3.42% glass fibre and 1.35% and 1.22% of carbon fibre and Cordenka with 6.30%)

The above results show that use of aramid fibre is suitable for use in which the need for increased impact resistance. Glass fibre reinforced materials provide electrical insulation and electromagnetic transparency. Conversely, carbon fibres provide electrical conductivity of the material.

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