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Mechanical properties of composite material reinforced with textile waste from the process of tyres recycling

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Abstract

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The paper deals with the polymeric fibre composite with the reinforcement on the basis of the waste from the process of the tyres recycling. The aim of the research was the use of the material of cleaned textile waste from the process of the tyres recycling. The secondary waste raw material was used as filler in the composite. The subject of performed experiments was the polymeric composite, whose continuous phase was in a form of a two-component epoxy adhesive (GlueEpox Rapid) and a discontinuous phase in a form of microfibers from the process of tyres recycling. The experiments results proved that the composite materials based on the textile waste from the process of the tyres recycling reached an increase of an impact strength, a tensile lap-shear strength and an elongation of the adhesive bond (to 2.5% vol.). The textile microfiller has a negative influence on the tensile strength and elongation of adhesives.

Keywords: epoxy resin; quality testing; microfiber; testing

A general aim in re-utilization of polymeric waste is to contribute to an environmental decontamination (Gaggino et al. 2014).

The paper deals with a testing of polymeric composite materials reinforced with fabrics, which were obtained after a recycling process of used tyres. Tyres which cannot be already used in road traffic become the waste. A priority is their material recycling. The tyres are on the first place from the point of view of production of the rubber waste (Fang et al. 2000).

The European legislation established the following preferential order of the environment- friendly management with respect to the waste material: reduction, reuse, recycling and energy production (Acevedo et al. 2015). The waste reduction (or prevention) is the preferred approach to the waste management because waste that is not created forestalls the waste management costs. Moreover, the waste reduction also helps to conserve resources for future generations and contributes to a cleaner environment.

Technologies dealing with recycling of products from the ecological liquidation of tyres have been constantly developing. A principle of the ecological liquidation of tyres is a separation of their parts (a material separation) (Fang et al. 2000; Dadfar, Ghadami 2013; Ferreira et al. 2013). Rubber granulate, metal waste and textile waste are products of

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the mechanical process of the waste tyres recycling (Knapčíková et al. 2014; Acevedo et al. 2015).

The rubber granulate is used in the area of the tyres recycling at present. The rubber granulate is effectively used in various products. However, we cannot forget other parts of the tyre, e.g. the textile fibres (Taranu et al. 2013).

Fibres are used for a large variety of applications. Textiles, nonwovens as well as composite materials reinforced with fibres are commonly used in daily life and in technical applications (Bartl at et. 2005). At present, there are only minimum works available dealing with the utilization of this waste in this area (Bartl at et. 2005).

The results of the thermal analysis of the waste fibres show that the fibres are of polyamide (Parres et al. 2009). After the process of tyres shredding two main types of fibres can be identified: fibre and microfibre. Fibres maintain their original form (cord) while the microfibres are consequence of different stages in the shredding process (Parres et al. 2009).

Morphology of microfibers is important for the production of the composite material (Parres et al. 2009). The morphology is very different in case of utilization of the fibres from the tyres shredding process. The aim of the research was to determine a possible utilization of cleaned textile waste from the process of the tyres recycling in the area of the polymeric fibre composite systems. The basic assumption for an optimum choice of materials is the knowledge of the applied material behaviour.

MATERIAL AND METHODS

Utilization of the textile waste is problematic because of the contamination with the rubber granulate. The textile waste contains a certain amount of rubber that can be separated with difficulties (Acevedo et al. 2015).

A great part of impurities in form of the rubber granulate were removed from the textile waste used for experiments. This material was used as the filler for a production of the polymeric composite material. The cleaning of the textile microfibers from the rubber particles was performed by a fluid cleaning.

The subject of performed experiments was the polymeric composite, whose continuous phase was in form of a two-component epoxy adhesive (Glue-Epox Rapid; DCH Sincolor, a.s., Plzeň, Czech Republic) and a discontinuous phase (reinforcing particles) in a form of Polyamide PA microfibers (Fig. 1a).

The epoxy resins are typical reactoplastics. The epoxy resins properties can be changed by adding appropriate types of fillers (Kejval, Müller 2013; Xu et al. 2013; Valášek 2014). Reactoplastics are used for the material recycling of various types of the waste (Valášek, Müller 2014).

The experiment tries to describe the change of the mechanical qualities with changeable amount of the filler (textile waste – fibres of Polyamide PA).

The concentration of the components was expressed by means of ratios in mass percentage. A diameter and length of recycled fibre were evaluated on a basis of a picture analysis. The evaluation was performed using a microscope Jenavert PA HD (Zeiss, Oberkochen, Germany) with a camera ARTCAM 300 MI (Artray, Tokyo, Japan). Textile microfibers and rubber particles are presented in the Fig. 1b.

The composite systems were tested from two points of view. The first one was the material testing. The reason is an application in form of production of self-contained products. The second point of view

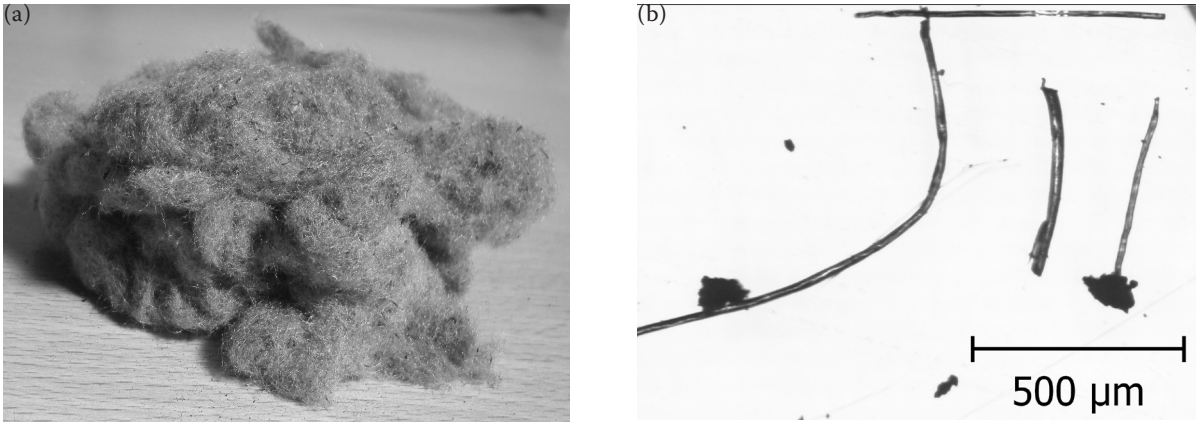

Fig. 1. Microfibre after the shredding process (a) and textile microfibres and rubber particles (b)

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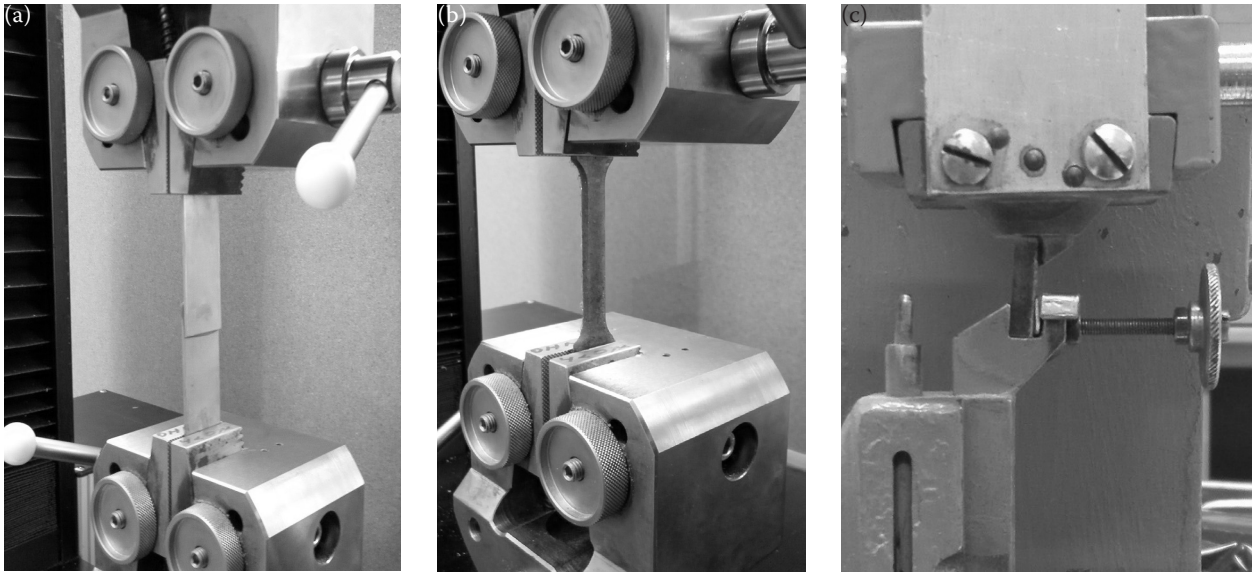

Fig. 2. Testing according to (a) CSN EN 1465:2009 – adhesive bond, (b) CSN EN ISO 527-1:1997 – cast of test specimen, and (c) CSN 64 0611:1968

is in the interaction with the adherent, that means the adhesive bond. The reason is a hypothetical utilization as the filled adhesive.

By mixing of the specified matrix – filler phases ratio the composite was made, which was used for the preparation of test specimens according to the specified standards.

Following composite systems containing 0.5, 1, 2, 3, 4 and 5 g of the filler were tested within the research. The epoxy resin was the comparing standard. The composite mixture was left for the time stated by the producer of the adhesive for the total hardening.

An influence of a tensile strength of adhesives, an elongation of adhesives, an adhesive bond tensile lap-shear strength, an elongation of the adhesive bond and an impact strength were experimentally tested.

Tensile test. The test specimens for the tensile properties determination according to the standard CSN EN ISO 527-1:1997 (Plastics – Determination of tensile properties – Part 1: General principles) were prepared according to the standard CSN EN ISO 3167:2015 (Plastics – Multipurpose test specimens). By the destructive testing, the tensile strength and the elongation were determined.

The moulds for casting of the test specimens were made from the material Lukapren N (Lučební závody, Kolín, Czech Republic) using the prepared models. The shape and sizes of moulds meet the corresponding standards.

The mould consisted of two parts in order to reach an even surface on both sides of the test specimens.

Adhesive bonds. The basis of adhesive bonds laboratory testing was the determination of the tensile lap-shear strength of rigid-to-rigid bonded assemblies according to the standard CSN EN 1465:2009 (equivalent is BS 1465:2009).

Specimens of all the tested materials were obtained identically – cutting from the semi-products in the hydraulic guillotine sheet metal machine. Laboratory tests of the adhesive bonds were performed using the standard test specimens made according to the standard CSN EN 1465:2009 (dimensions 100 ± 0.25 × 25 ± 0.25 × 1.6 ± 0.1 mm and lapped length of 12.5 ± 0.25 mm) from the constructional plain carbon steel S235J0 (Ferona, Prague, Czech Republic).

The surfaces of 1.5 mm thick steel sheets were at first blasted using the synthetic corundum of a fraction F80 under the angle of 90°. Using the profilograph Surftest 301 (Mitutoyo, Michigan, USA) the following values were determined: the arithmetic mean of the departures of the profile from the mean line (*R*a) 1.25 ± 0.15 μm, the average of the maximum peak-to-valley length of five consecutive sampling lengths (*R*z) 6.4 ± 0.73 μm.

Then the surface was cleaned and degreased using acetone and prepared to the application. The surface preparation is important and should guarantee good strength on the boundary adherent/adhesive/

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adherent (Novák 2011; Čierna, Ťavodová 2013; Ťavodová 2013; Hricová 2014). An even thickness of the adhesive layer was reached by a constant pressure 0.5 MPa. The lapping was according to the standard 12.5 ± 0.25 mm.

The failure type according to ISO 10365:1995 was determined at the adhesives bonds. The tensile strength and the elongation test (the adhesive bond (Fig. 2a), the cast of the test specimens (Fig. 2b)) were performed using the universal tensile strength testing machine LABTest 5.50ST (a sensing unit AST type KAF 50 kN, an evaluating software Test&Motion (all from Labortech s.r.o, Opava, Czech Republic)). A speed of the deformation corresponded to 6 mm/min.

Impact strength. The impact strength was set in an apparatus Dynstat determined for the testing of plastics. The test specimen preparation and impact tests were performed according to the standard CSN 64 0611:1968 (Determination of the impact resistance of rigid plastics by means of Dynstat apparatus (Koegel, Leipzig, Germany)). By the destructive testing the impact strength was determined (Fig. 2c).

For the correct evaluation it is also important to determine the determination index R^2. It is the problem of the correlation analysis. The values of the determination index can be from 0 to 1. So far, as R^2 equals to 1, there is a perfect correlation in this sample (so there is no difference between a calculation and real values).

The tested sets were mutually compared using *F*-test from the point of view of the influence of various filler concentrations of cast test specimens on the tensile strength of adhesives, the elongation of adhesives, the adhesive bond tensile lap-shear strength, the elongation of the adhesive bond and the impact strength.

The zero hypothesis H_0 presents the state when there is no statistically significant difference ($P > 0.05$) among the tested sets of data from their mean values point of view.

RESULT AND DISCUSSION

The cleaning of the textile microfibers from the rubber particles was performed by means of the fluid cleaning. The mixture contained 63.91 ± 2.25% of the textile microfibers and 36.09 ± 2.27% of the rubber particles before cleaning. The average size of separated particles was 311.08 ± 162.91 μm. The size of the rubber particles contained in the product supplied by the producer (the mixture of the rubber particles and the textile microfiber) is visible from a histogram (Fig. 3a). The average size of the rubber particles after cleaning of the textile microfibers was 6.02 ± 3.77 μm. It is obvious from the histogram that it came to removing of particles higher than 24 μm (Fig. 3b).

A width of the microfibre was 27.65 ± 9.41 μm. Similar width of the microfibres 29.67 ± 2.3 μm was ascertained also by Parres et al (2009). They also state a very variable length.

The length was very different in their research and it ranged in the interval 2,000 to 8,000 μm (Parres et al. 2009).

The length of measured microfibers was 2,205.80 ± 1,722.80 μm. It is obvious from the results of the tested microfibers that the length was smaller. There was 43.35 % of the microfibers longer than 2,000 μm (200 microfibers were tested). It was as-

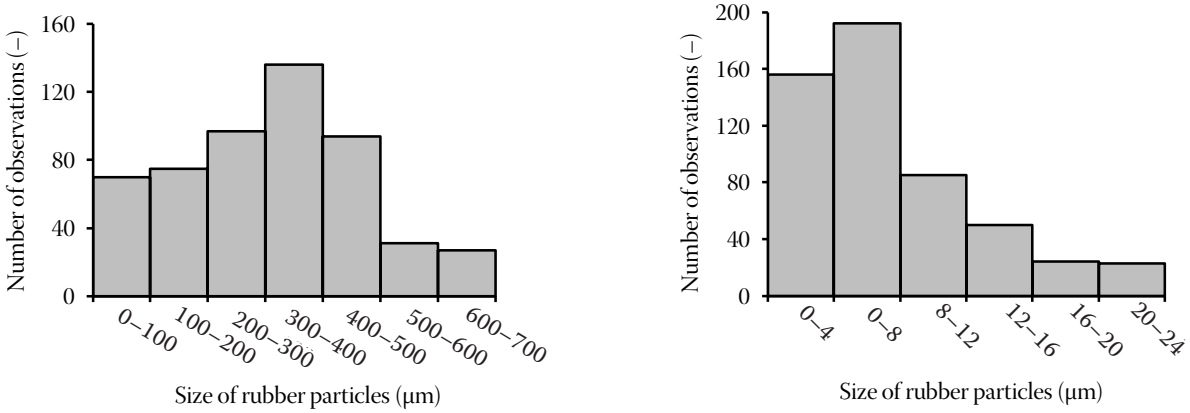

Fig. 3. Size of rubber particles (a) before and (b) after fluid cleaning of textile microfibres

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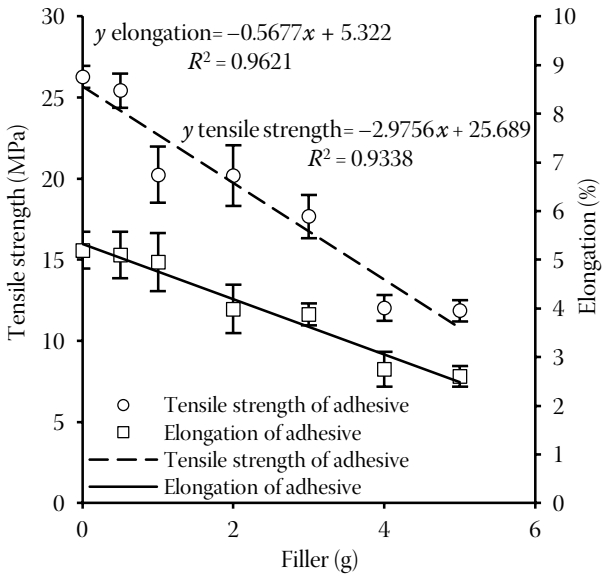

Fig. 4. Tensile test (tensile strength, elongation of adhesives) – CSN EN ISO 527-1:1997

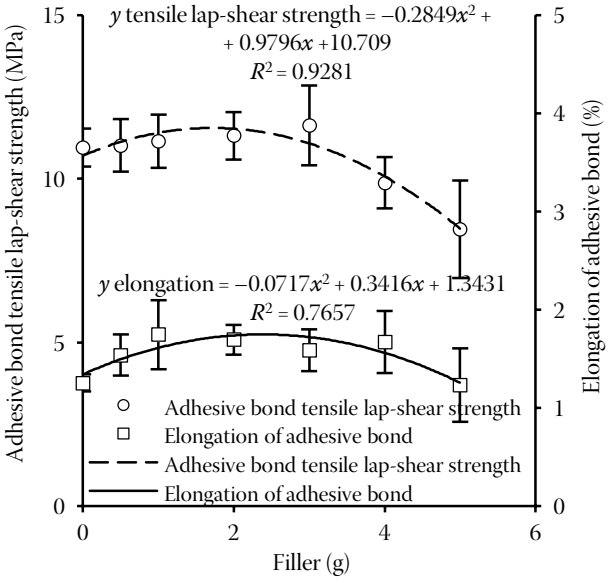

Fig. 5. Adhesive bond tensile lap-shear strength and elongation CSN EN 1465:2009

certained by measuring that dispersion variance of the results of the microfibers length was 78%.

The tensile strength of composites showed lower values compared with the matrix (the epoxy adhesive, Fig. 4)

Fig. 4 shows the results of the tests focused on the evaluation of the elongation of the matrix and composite systems. It is obvious from the results that higher ratio of the filler decreases the elongation values. The fall of the tensile strength and the elongation of the adhesive showed a linear trend. The functions presented in Fig. 4 are determined by equations and a strong dependence is obvious from the values R^2.

The tensile strength (P = 0.0000) and the elongation (P = 0.0000) did not certify the hypothesis H_0, so there is the difference among particular tested filler concentrations in relation to the adhesive strength and to the elongation in the reliability level 0.05.

It is obvious from the results of the adhesive bonds that the adhesive bond tensile lap-shear strength increases when adding the filler (to 3 g) (Fig. 5). After adding 3 g of the filler the fall of the adhesive bond tensile lap-shear strength follows. The similar trend is at the elongation of the adhesive (Fig. 4). The dependence course is of a polynomial trend.

The functions presented in Fig. 5 are determined by equations and high to strong dependence is obvious from the values R^2.

The adhesive bond tensile lap-shear strength (P = 0.0001) and the elongation of the adhesive bond (P = 0.0148) did not certify the hypothesis H_0, so there is the difference among particular tested filler concentrations in relation to the adhesive bond tensile lap-shear strength and the elongation in the reliability level 0.05.

The adhesive layer thickness was 167.38 ± 15.55 μm. The thickness of the composite systems layer was 137.76 ± 5.07 μm (Fig. 6).

A type of a failure area changed after adding of the filler. The failure area of the matrix (the adhesive) was of the adhesive type (Fig. 7a). At the adhesive bonds (adhesive bonded with the composite system) the failure area was of the adhesive – cohe-

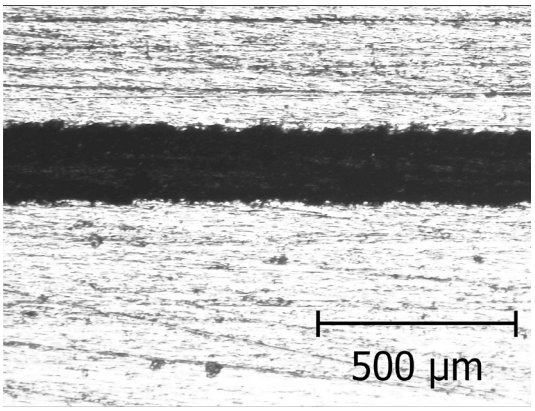

Fig. 6. Adhesive bond cut – adhesive bond filled with 4 g of textile microfibres

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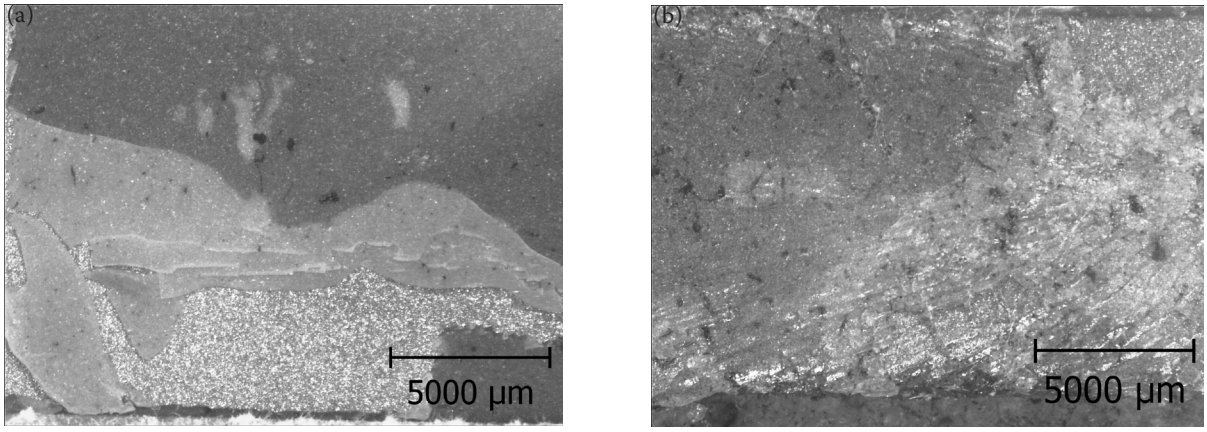

Fig. 7. Adhesive failure area – adhesive (matrix) (a) and adhesive – cohesive failure area (b) – adhesive bond filled with 5 g of textile microfibers

sive type (Fig. 7b). This change decreasing the cohesive strength of the adhesive is probably caused by the rubber particles. According to Parres et al. (2009) the rubber microparticles decrease the adhesion to the matrix (epoxy adhesive).

Fig. 8 shows the results of the impact strength. The positive influence of the filler on the impact strength of the composite system is visible from the results. The impact strength increase showed the linear trend.

The functions presented in Fig. 8 are determined by equations and a strong dependence is obvious from the values R^2.

The impact strength (P = 0.0000) did not certify the hypothesis H_0, so there is the difference among particular tested filler concentrations in relation to the impact strength in the reliability level 0.05.

Many authors dealt with the research of the polymeric particle composites on the basis of the waste.

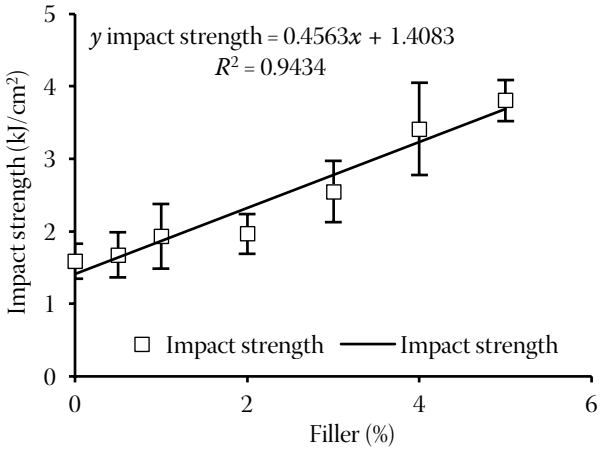

Fig. 8. Impact strength – CSN 64 0611:1968

The mechanical properties showed a negative trend (Ferreira et al. 2013; Valášek 2014; Valášek, Müller 2014).

On the basis of laboratory results it is possible to agree with the statement of that epoxy adhesives are of low impact strength and that they are brittle (Weizhou et al. 2009).

The polyamide fibres from the process of the tyres recycling are recommended to remove the brittleness of the materials (Parres et al. 2009). This assumption was certified within the research. The impact strength significantly increased when adding the filler.

Adhesive bonds with max. 15% vol. of the filler do not show the statistically significant fall of the tensile lap-shear strength (Valášek et al. 2014). The composite systems with the filler of the volume 0.4 to 4% were used within the research. The experiment results proved the increase of the adhesive bond strength. These conclusions were confirmed by the results of the research.

CONCLUSION

The research results confirmed possible application of the waste textile fibres in the composite systems on the basis of the reactoplastics.

Following statements can be concluded in the end:

– The tensile strength and the elongation of adhesive were decreasing. The fall of the tensile strength was 54.81% at the application of the filler. The fall of the elongation was 49.84% at the application of the filler.

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– The tensile lap-shear strength and the elongation of adhesive bond increased with up to 3 g of the filler. Subsequently, it shows a decreasing trend at increasing concentration. The failure area changed at adding the filler. The impact strength of adhesive was increasing. The increase of the impact strength was 140.1% at the application of the filler.

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