STATIC AND DYNAMIC MECHANICAL PROPERTIES OF COMPOSITE FROM TYRE WASTE MICROPARTICLES/EPOXY RESIN

Martin TICHÝ[1], Viktor KOLÁŘ[1], Miroslav MÜLLER[1]

[1]*Department of Material Science and Manufacturing Technology, Czech University of Life Sciences Prague, Kamýcká 129, 165 00 Praha 6 – Suchdol, Czech Republic*

Abstract
The world-wide year production of tyres is over 1.5 billion and 6 % of scrap is used as a recycle product for engineering. The research finding an use of tyre waste in the engineering field. This research deals with the recycle product from tyre waste as rubber powder (RP) in microparticles form. To ensure an application of composite material in production engineering, it is necessary to meet appropriate mechanical properties to be able to compete with conventional materials. The aim of this research was specification of an absorption effect of tyre waste microparticles/epoxy resin composite by the impact strength and determination the fracture process by SEM analyses. The research finds a dependency between the impact strength and static mechanical properties i.e. tensile strength, elongation and hardness. Results of the research proved that the filler in rubber powder form has absorbing effect in matrix. The composite is suitable for application where are stiffness and ductility needed.

Key words: *impact strength; tensile strength; elongation at break; hardness; rubber powder; SEM.*

INTRODUCTION

A waste from worn out tyres from road transportation are serious environmental problem. The world-wide year production of tyres is over 1.5 billion and scrap of the tyre production is over 300 million only for the United States. An use of this tyre wastes is dived into 40 % as fuel for power station, 26 % ground into granulate rubber, 13 % landfills and 6 % as recycle product for engineering *(Karakurt, 2015; Sienkiewicz et al. 2017).*

For these reasons are necessary to develop new materials to find a use of tyre waste and increase the number of products in engineering field.

However, the recycling methods can reach several products from a tyre waste which is steel wires, textile fibres and rubber *(Fang et al., 2001)*. All these products can be used in a composite. In general, a composite is based form matrix and reinforcing phase *(Pihtili & Tosun, 2002)*. According to phase is composite marked as fibre *(Singh & Garg, 2000)* or particle composite *(Fu et al. 2008)*. The filler reinforce a matrix which is a thermosetting polymer or a thermoplastic.

This research deals with recycle product from tyre waste as the rubber powder (RP) in microparticles form. There are many researches about interaction of rubber particles on total characteristic of composite *(Müller et al. 2018; Krmela & Tomanova, 2010; Sienkiewicz et al. 2017; Valášek, 2015)*. The problem of rubber powder from tyre waste is that the vulcanisation process cannot be applicable repeatedly, for this reason it is good filler in composite *(Sienkiewicz et al. 2017)*. The most common characteristic of rubber powder is an absorbing "toughening" effect which leads to significant influence on mechanical properties *(Ahmed et al. 2015)*. Another useful feature of rubber powder is, that the particles can be added into various matrix *(Sienkiewicz et al. 2017)*.

To ensure an application of composite material in production engineering, it is necessary to meet appropriate mechanical properties to be able to compete with conventional materials. Each composite needs different mechanical properties according to application field i.e. high strength and brittleness or otherwise stiffness and ductility *(Yang et al., 2011)*. Tests of composite materials must be as close as possible to real condition, for these reasons it´s necessary to measure static and dynamic mechanical properties.

In this research the tensile strength, elongation and hardness were measured as the static mechanical properties. The impact strength was measured for the dynamic mechanical properties, which is very important factor especially for determination of fracture process. Good impact strength is needed for application where is absorbing effect required e.g. automotive components *(Yang et al., 2011)*.

The aim of research was specification of absorption effect of tyre waste microparticles/epoxy resin composite by the impact strength and determination of the fracture process by SEM analyses. The research finds dependency between the impact strength and mechanical properties i.e. the tensile strength, elongation and hardness.

MATERIALS AND METHODS

In the research static and dynamic mechanical properties of tyre waste microparticles/epoxy resin composite were measured. The composite is divided in two phases i.e. a matrix and a filler. The matrix of the composite presents thermosetting epoxy resin by Havel Composite LH 288 with Hardener H 282. The filler of the composite presents rubber powder (RP) with two sizes of microparticles fracture i.e. sizes 0.0 – 0.4 mm and 0.4 – 0.8 mm. This rubber powder (RP) is product from tyre waste recycle process. The rubber powder AGP4 (0.0 – 0.4) and AGP8 (0.4 – 0.8) was add in concentration 30 wt.%.

The test samples were created by the vacuum infusion method with flow 16 $m^3.h^{-1}$ and vacuum pressure 2 mbar. The composite plate from vacuum infusion was cut into test samples by abrasive water jet (AWJ) on the machine AWAC CT 0806. The test samples meet the standard ČSN EN ISO 3167.

The composite was tested on static mechanical properties i.e. the tensile strength, elongation at break and hardness. The tensile strength and the elongation at break were measured on universal testing machine LABTest 5.50ST with measure hardware AST KAF 50 kN and software Test & Motion with loading speed 2 $mm.min^{-1}$. The hardness was measured according to ČSN EN ISO 2039-1 (Plastic – determination of hardness – Part 1: Ball indentation method) on device DuraJet G5 Rockwell Hardness tester with diameter of ball 5 mm and loading force 358 N.

The dynamic mechanical properties of composite were tested on the impact strength by Dynstat. The impact strength test was measured according to ČSN 64 0611.

Determination of fracture process and interactions between filler and matrix were evaluated by SEM analyses on electron microscope TESCAN MIRA 3. The shape and dimension of rubber powder (RP) were examined by SEM images with Gwyddion program, where the test group was 100 values. The samples for SEM analyses were prepared by gold-plating on Quarum Q150R ES.

The measured values were evaluated by statistical analyses ANOVA (Analysis of Variance) F-test with established p-values. The difference between p-values of F-test was analyse be hypothesis. Hypothesis H_0 establish no statistically significant difference between measured value: $p > 0.05$.

RESULTS AND DISCUSSION

The first part of results presents measured values of static mechanical properties i.e. the tensile strength, elongation at break and hardness. Measured values of tensile strength (Fig. 1) confirmed statistically significant difference between matrix and composite with filler AGP4 and AGP8 i.e. the hypothesis H_0 was rejected: $p = 0.00001$. The average tensile strength was 30.31 ± 1.21 MPa for matrix (concentration 0 wt.%), 32.83 ± 3.78 MPa for composite with filler AGP4 (concentration 30 wt.%) and 25.94 ± 1.40 MPa for composite with filler AGP8 (concentration 30 wt.%). The Fig. 1 presents increase of the tensile strength on composite with filler AGP4 with dimension 0.0 – 0.4 mm.

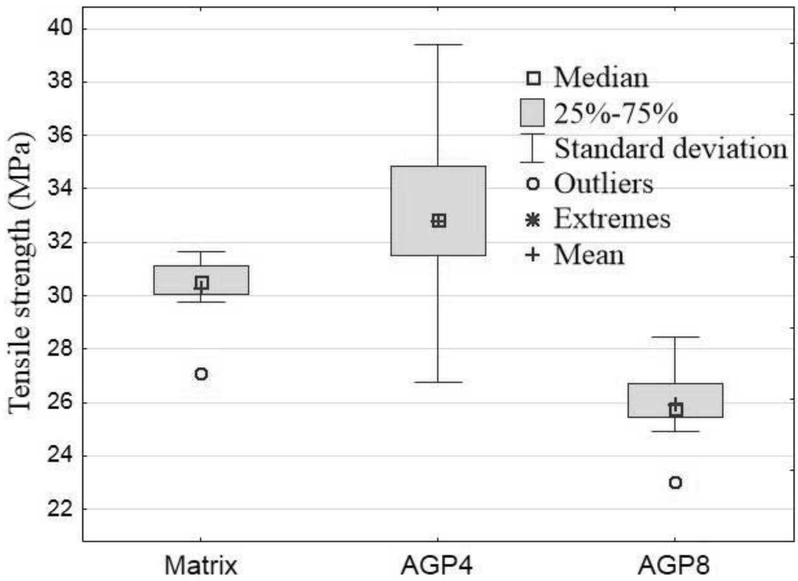

Fig. 1 Influence of the AGP4 and AGP8 filler on tensile strength

Measured values of elongation at break (Fig. 2) confirmed statistically significant difference between matrix and composite with filler AGP4 and AGP8 i.e. the hypothesis H_0 was rejected: $p = 0.00000$. The average elongation at break was 1.51 ± 0.45 % for matrix (concentration 0 wt.%), 2.00 ± 0.12 % for composite with filler AGP4 (concentration 30 wt.%) and 2.46 ± 0.27 % for composite with filler AGP8 (concentration 30 wt.%). The Fig. 2 presents biggest increase of the elongation at break at composite with filler AGP8 with dimension 0.4 – 0.8 mm. This fact is given by larger dimension of filler which also influence elasticity.

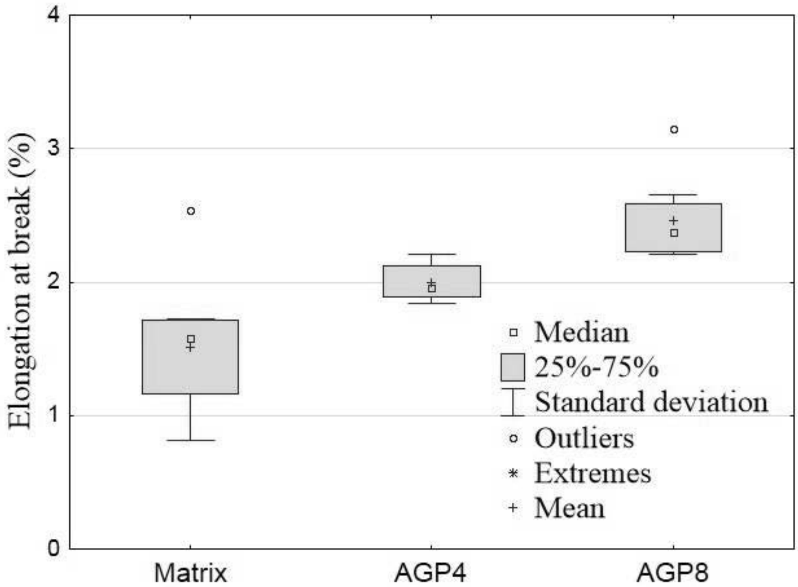

Fig. 2 Influence of the AGP4 and AGP8 filler on elongation at break

Measured values of hardness (Fig. 3) confirmed statistically significant difference between matrix and composite with filler AGP4 and AGP8 i.e. the hypothesis H_0 was rejected: $p = 0.00000$. The average hardness was 205.98 ± 7.15 HB for matrix (concentration 0 wt.%), 22.93 ± 4.64 HB for composite with filler AGP4 (concentration 30 wt.%) and 30.31 ± 3.08 HB for composite with filler AGP8 (concentration 30 wt.%). The Fig. 3 present decrease of the hardness at composite with filler AGP4 and AGP8 which is caused by adding elastic elements in rubber powder form into the matrix.

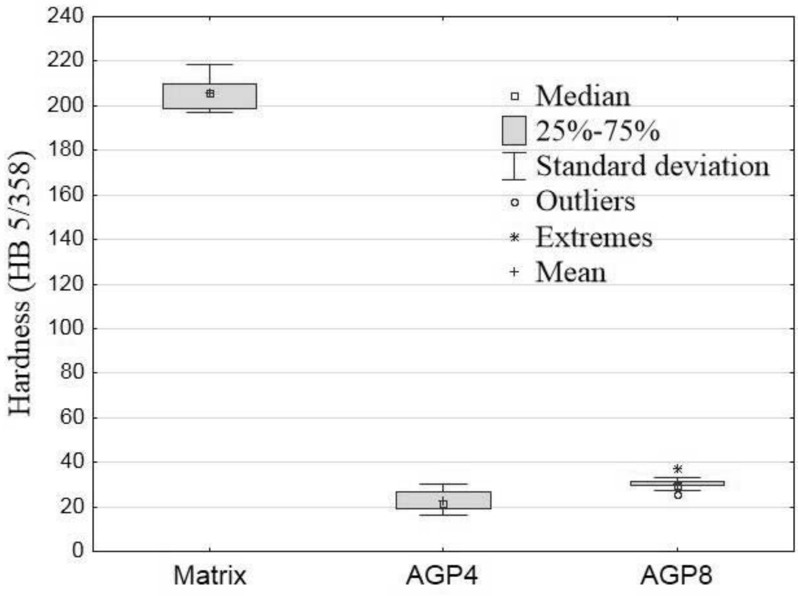

Fig. 3 Influence of the AGP4 and AGP8 filler on hardness

The Fig. 4 presents values of impact strength from test on the dynamic mechanical properties. Measured values confirmed statistically significant difference between matrix and composite with filler AGP4 and AGP8 i.e. the hypothesis H_0 was rejected: $p = 0.0347$. The average impact strength was 2.87 ± 0.29 kJ.m^{-2} for matrix (concentration 0 wt.%), 3.55 ± 0.84 kJ.m^{-2} for composite with filler AGP4 (concentration 30 wt.%) and 4.12 ± 0.49 kJ.m^{-2} for composite with filler AGP8 (concentration 30 wt.%). The Fig. 4 presents increase of the impact strength at composite with the filler AGP4 and AGP8. This fact confirmed the absorbing effect of rubber powder (RP) *(Ahmed et al. 2015)*.

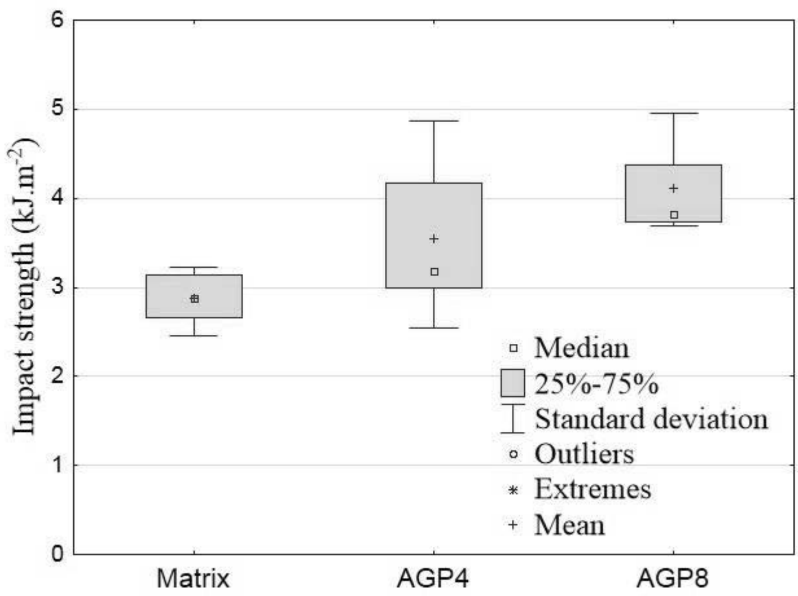

Fig. 4 Influence of the AGP4 and AGP8 filler on impact strength

Comparation of another composite is shown in Tab. 1, where are main factor a different matrix, ratio of RP and RP size. Tensile strength and elongation at break of composite types decrease with increasing amount of RP particles, which is different from this study. Hardness in the table decrease with increasing amount of RP particles, which was also proved in this study.

Tab. 1 Comparation of another composite in view of matrix and RP composition, components ratio, RP size and mechanical properties from other studies *(Sienkiewicz et al. 2017, Müller et al., 2017)*.

Composition of matrix and RP	Components ratio [%]	RP size [μm]	Results on mechanical properties	Reference
Linear low-density polyethylene/rubber powder/ethylene-1-octene copolymers	50/0/50 – 50/50/0	425 – 500	Tensile strength increase with amount of RG decrease Elongation at break decrease with amount of RP increase	(Rocha et al., 2014)
Polyvinyl chloride/rubber powder	100/0 – 30/70	200 200 – 500 >500	Reducing in tensile strength, toughness and stiffness with amount of RP increasing	(Orrit et al., 2011)
Epoxy resin/ rubber powder	100/0 – 70/30	0 – 400	The tensile strength was reduced with increasing concentration of RP. The material hardness reduction was increased with increasing concentration of RP.	(Müller et al., 2018)

On Fig. 5 is shown SEM analyse of used filler. There is evident iregular geometric shape (Fig. 5 A, B, C, D, E, F). From Fig. 5 is evidetn that the particle is composed by groupe of aggregates.

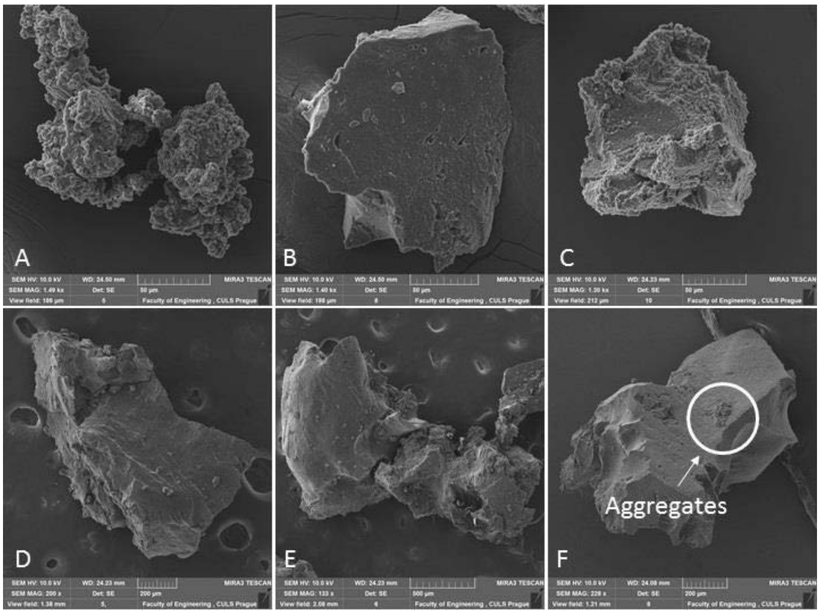

Fig. 5 SEM analyses of filler: A – microparticle of filler AGP4 composed by aggregates (MAG 1.49 kx), B – microparticle of filler AGP4 without aggregates (MAG 1.40 kx), C – microparticle of filler AGP4 with aggregate surface (MAG 1.30 kx), D – microparticle of filler AGP8 (MAG 200 x), E – microparticle of filler AGP8 with fracture (MAG 133 x), F – microparticle of filler AGP8 with small aggragates on surface (MAG 229 x)

SEM analyse proved good interaction between the matrix and the filler i.e. good wettablity (Fig. 6 A, F). From Fig. 6 C is evdent fragile fracture of the matrix. On Fig. 6 D is evident pulled-out particle of filler from the matrix and aggregates in the fracture area. On Fig. 6 E is evident that microparticles are not completely separated. The small agregates and incomplete separation of microparticles decrease adhesion to the matrix and negatively influence mechanical properties, which is evident on tensile stregth on Fig. 1 at filler AGP8. This fact was also confirmed by other authors *(Aoudia et al., 2017; Müller et al. 2018)*.

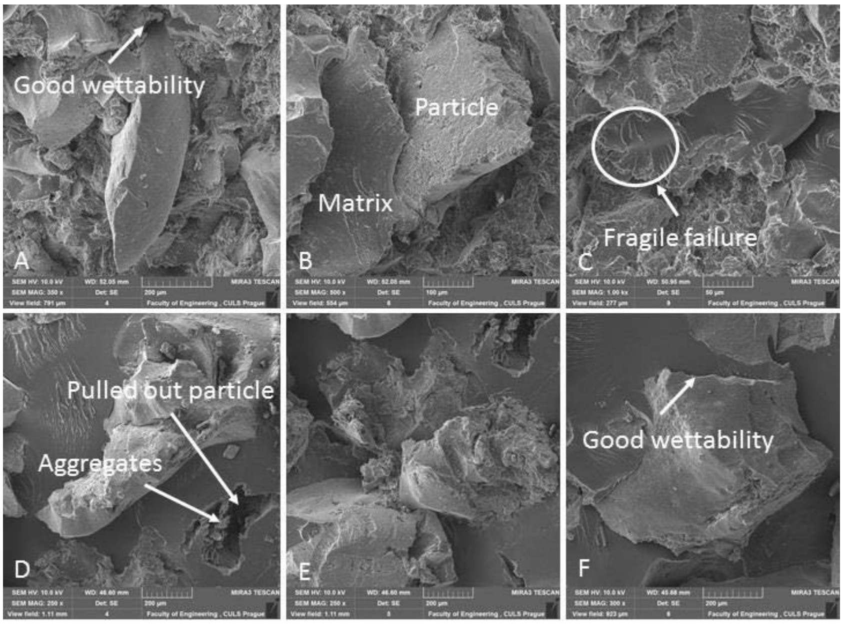

Fig. 6 SEM analyses of fracture surface: A – good wettability of the matrix and the filler (MAG 350 x), B – the matrix and the filler (MAG 500 x), C – fragile fracture of matrix (MAG 1 kx), D – the pulled-out particle and aggregates (MAG 250 x), E – exposition of not completely separated microparticles of filler (MAG 250 x) F – good wettability of the matrix and the filler (MAG 300 x).

The SEM analyse of rubber powder dimensions report average dimension of individual microparticles. Results of analyse present average dimension 174 ± 77.8 μm on the filler AGP4 and 995 ± 178.8 on the filler AGP8. This result show that filler AGP8 has larger dimension than stated by the manufacturer.

CONCLUSION

The results of impact strength proved significant increase with rubber powder AGP4 and AGP8 i.e. the main aim has been met. The result of SEM analyses confirmed good wettability of filler which positively influenced the impact strength and elongation. The tensile strength was positively increased only with filler AGP4 i.e. filler is resistant only with particle dimension to 0.4 mm. On the other hand, filler AGP8 positively increased at the elongation at break, which is given by larger base for elasticity than the filler AGP4. From the results is evident dependence of the impact strength and elongation at break of the composite. The hardness rapidly decreased with the filer AGP4 and AGP8 which is given by the elasticity of rubber particles. The results of the research proved that the filler in rubber powder form has absorbing effect in the matrix. The composite is suitable for application where are stiffness and ductility required.

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Corresponding author:
Ing. Martin Tichý, Department of Material Science and Manufacturing Technology, Czech University of Life Sciences Prague, Kamýcká 129, 165 00 Praha 6 – Suchdol, Czech Republic, e-mail: martintichy@tf.czu.cz