

Research on Wear Resistance of Polymeric Composite Materials Based on Microparticles from Tyre Recycling Process

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A huge amount of waste comes into being from tyres which cannot already be used for their purpose. There are many ways how to utilize this waste but material recycling is a priority. Waste tyre rubbers can be processed into a form of granulate which can be used into polymeric composite materials. This research deals with possibilities of tyre waste composite material utilization in areas distinguished for wear. The aim of the research was an assessment of a usage possibility of rubber powder (RP) coming into being from tyre recycling process as a filler into a thermosetting matrix from firm Havel Composite applied into composite boards made by a vacuum infusion. The research focused on an evaluation of wear by friction against loosely fixed abrasive particles according to GOST 23.208-79, hardness and interaction of the matrix and the reinforcement by means of SEM analysis of the polymeric composite materials reinforced with waste microparticles arisen from tyre recycling process. Research results proved a positive influence of the filler on the improvement of the wear resistance depending on the size of active rubber powder.

Keywords: Hardness, Mass Loss, Wear Track, Loosely Fixed Abrasive Particles, SEM

1 Introduction

The global consumer problem is the emergence of waste that needs to be handled and used as efficiently as possible [1]. A biological waste is treated relatively simply [2, 3]. Worse situation comes with synthetic waste. Large amount of tyre waste comes from e.g. traffic transport, construction and agriculture vehicles, where the tyres cannot fulfil their function [4, 5]. The lifetime of tyres is relatively low, and it is given by intensive operation or by degradation process, which cause the wear and other defects. This fact leads to a significant global production of tyre waste [6, 7, 8]. The most leading recycling process of the waste tyre is milling and crushing, which produce granulate for next use [7, 8]. This granulate cannot be repeatedly vulcanized, therefore the granulate is used in composite production [1, 7]. In general, composite materials are used in various products. Composite materials contain a matrix and a reinforced phase (filler) which improves mechanical properties and possibly decreases costs of the matrix. The mechanical properties of the matrix are usually improved by reinforced phase in a fibre form as fabric [9, 10, 11, 12]. The use of a reinforcing phase (filler) in a form of particles is rather a price reduction, tribological properties improvement or hardness improvement against the matrix [13, 14,

15, 16, 17, 18]. However, it is always important to examine an interaction between filler and matrix which is necessary for right function of the composite material.

The aim of the research was an assessment of usage possibility of the active rubber powder (ARP) coming into being from tyre recycle process as the filler into the thermosetting matrix from firm Havel Composite applied into composite boards made by a vacuum infusion. The research focused on an evaluation of wear by friction against loosely fixed abrasive particles according to GOST 23.208-79, hardness and interaction of the matrix and the reinforcement by means of SEM analysis of the polymeric composite materials reinforced with waste microparticles arisen from tyre recycle process.

2 Materials and methods

The research evaluated the polymeric composite material based on microparticles from tyre recycling process. The rubber particles were provided by Czech leading producer of tyre recycling. For the research two fraction types of the rubber powder marked as (RP) in sizes 0.0–0.4 mm and 0.4–0.8 mm were used (Fig. 1 C – below). This rubber powder was produced by fine milling of waste tyre.

For production of a polymeric composite material with microparticles RP the matrix by Havel Composite LH 388 with the hardener H 282 was used.

Test samples for evaluation of the wear resistance were produced in dimensions 25 x 25 x 5 mm by vacuum infusion according to GOST 23.208-79 (Ensuring of wear resistance of products. Wear resistance. Testing of materials by friction against loosely fixed abrasive particles). The filler RP was added in 30 vol.%. This concentration was proved as limited from previous researches [1].

The research of the wear resistance was performed according to standard GOST 23.208-79 on testing device with rubber wheel and abrasive particles (float sand Otava with fraction dimensions from 0.2 to 0.3 mm) by loading of the test sample from 700 to 1600 g. The wear testing process is evident from fig. 1 A. The wear evaluation was based on a wear track and a mass loss measured on analytical scale Kern. The wear track was determined on a basis of the rubber wheel speed i.e. after 1000 rpm. The test samples after wear process are evident from fig. 1 B and C.

The hardness of test samples was measured according to CSN EN ISO 2039-1 by a ball of a diameter 5 mm, loading force 358 N on device DuraJet G5 Rockwell Hardness tester. A size and a shape of the filler RP, the wear process and the interaction between the matrix and the filler RP were evaluated by SEM analysis.

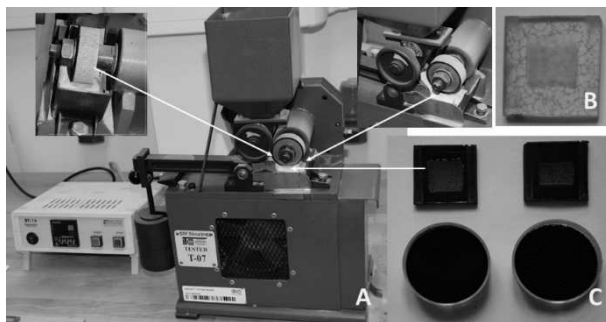


Fig. 1 Wear testing process: A: Device Tester T-07, ITC PIB Institution of Technology Radom and control device BT – 16 Controller with detailed view on wear process, B: Test sample after wear process – matrix, C: Test sample after wear process – composite RP0.0-0.4 (upper left), RP0.4-0.8 (upper right) and filler RP0.0-0.4 (below left), RP0.4-0.8 (below right)

3 Results and discussion

The filler was analysed by Gwyddion program from SEM images. The results are listed on fig. 2 which records a size representation on the reference sample of the filler marked as RP0.0-0.4 and RP0.4-0.8. The filler RP0.0-0.4 had average dimensions $99.38 \pm 81.40 \mu\text{m}$ and the filler RP0.4-0.8 had average dimensions $571.80 \pm 171.83 \mu\text{m}$. From fig. 2 it is evident that the filler RP0.0-0.4 represents a significant ratio

of microparticles smaller than $100 \mu\text{m}$.

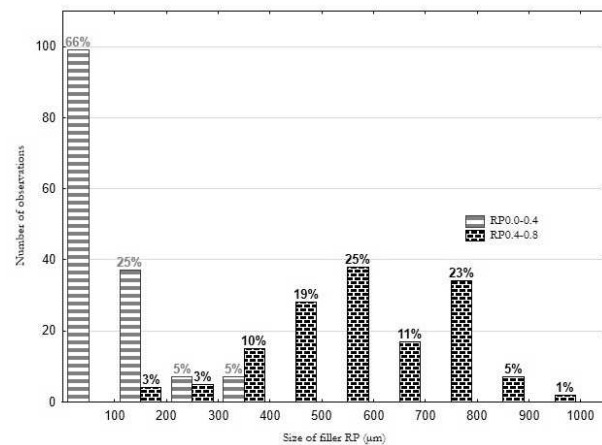


Fig. 2 Frequency histogram with microparticles of filler RP from tyre recycle process

By more detailed SEM analysis a shape of the filler RP was determined which is evident from fig. 3. Especially the filler RP0.0-0.4 shows an irregular surface, which is evident from fig. 3 A and B. Other authors came to similar conclusions [1, 8]. The filler RP0.4-0.8 shows a regular surface, which is visible from fig. 3 C and D.

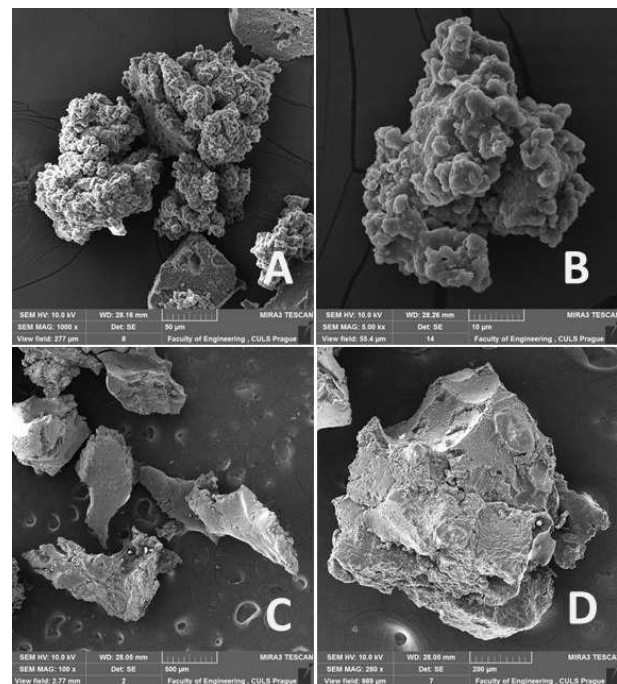


Fig. 3 SEM images of filler RP: A: Filler RP0.0-0.4 (MAG 1000x), B: Detailed view on irregular surface of filler RP0.0-0.4 (MAG 5.00kx), C: Filler RP0.4-0.8 (MAG 100x), D: Detailed view on surface of filler RP0.4-0.8 (MAG 280x)

The roughness was measured before the wear process. The roughness of the matrix was $R_a 0.60 \pm 0.18 \mu\text{m}$, $R_z 3.10 \pm 0.33 \mu\text{m}$, the roughness of the composite RP0.0-0.4 was $R_a 0.38 \pm 0.06 \mu\text{m}$, $R_z 2.24 \pm 0.29$

μm and of the composite RP0.4-0.8 was $R_a 0.20 \pm 0.06 \mu\text{m}$, $R_z 0.92 \pm 0.19 \mu\text{m}$. From the results it is evident that the surface of composite materials reports lower value of tested roughness parameters.

The matrix and composite materials wear progression at various loadings is evident on fig. 4 and 5 i.e. various loading forces on the test sample to the rubber wheel. The wear progression shows a same linear trend at various loading forces on test sample to rubber wheel. The results show a linear increase of the

mass loss at test samples. The composite reported best results at both loadings 1600 g and 700 g at filler RP0.4-0.8, i.e. the composite reinforced with micro-particles RP with fraction size $571.80 \pm 171.83 \mu\text{m}$. Lower wear resistance was reported by the composite material with the filler RP of the fraction size $99.38 \pm 81.40 \mu\text{m}$. This composite material reported lower wear resistance than the matrix.

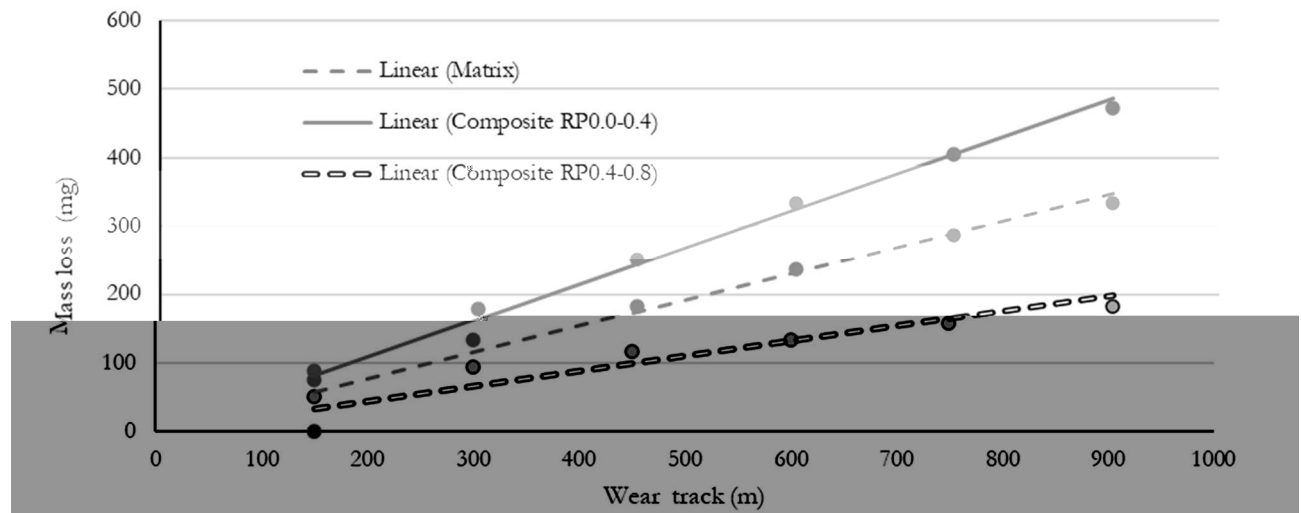


Fig. 4 Wear progression at loading 1600 g

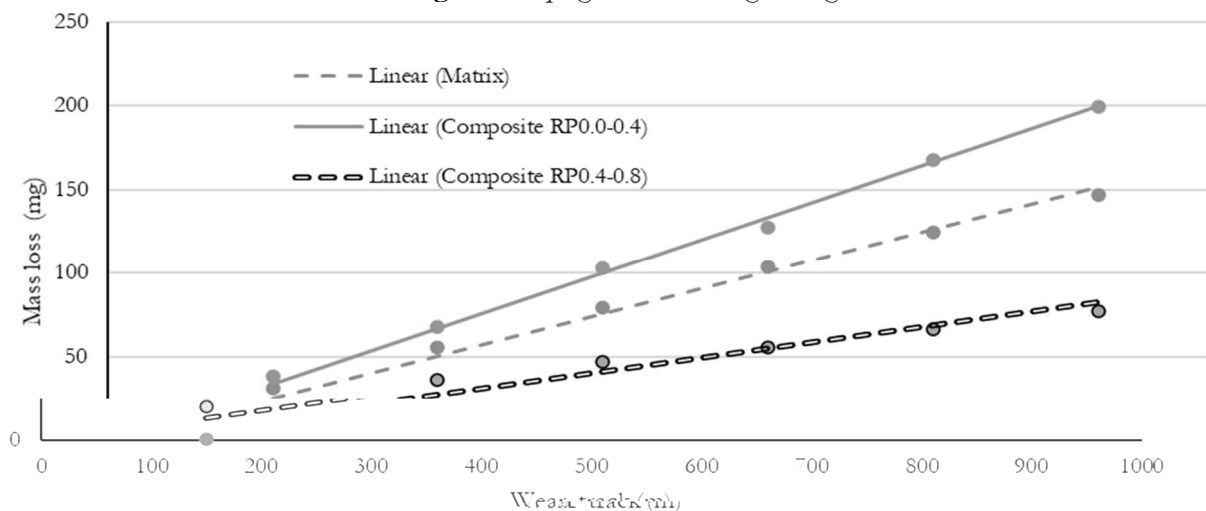


Fig. 5 Wear progression at loading 700 g

The dependence tightness is measured by a determination index and takes values from 0 to 1. The closer values approach 1, the stronger dependence is. The determination index R^2 gives the percentage influence of the wear track on the mass loss. The dependence tightness, the functional equations of the wear (mass loss) and the wear track are listed in tab. 1.

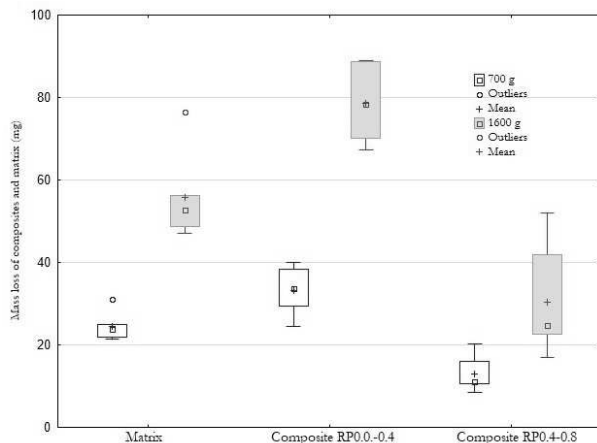
The matrix and the composite materials were tested between themselves according to ANOVA F-test in significant level 0.05. The results are evident from fig. 6. The null hypothesis H_0 was referred when there is no statistically significant difference between indivi-

dual data: $p > 0.05$. The hypothesis H_0 was not confirmed for any loading of test samples i.e. various intensity of loading force on test samples to rubber wheel (700 g, $p = 0.001$ and 1600 g, $p = 0.001$), there is a significant difference in the significant level 0.05 between tested materials (matrix, composite RP0.0-0.4 and RP0.4-0.8).

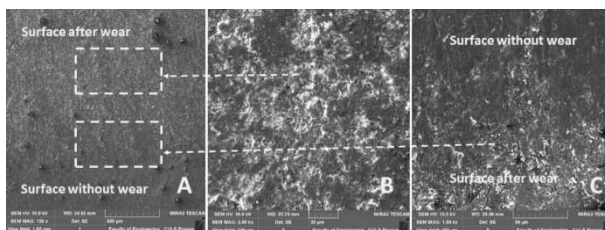
On fig. 6 there are total results of the wear where it is evident that the highest wear resistance is at the composite material with the filler RP0.4-0.8 at loading 700 g. There was a significant dispersion of the results at higher loads.

Tab. 1 Functional equations of mass loss dependence on wear track of composite material with its determination index

Designation	Wear test – Mass (g)	Functional equation	Determination index
Matrix	1600	$y = 0.3862x$	0.981
Composite RP0.0-0.4	1600	$y = 0.5415x$	0.994
Composite RP0.4-0.8	1600	$y = 0.8413x$	0.841
Matrix	700	$y = 0.1685x$	0.989
Composite RP0.0-0.4	700	$y = 0.2222x$	0.996
Composite RP0.4-0.8	700	$y = 0.0919x$	0.916

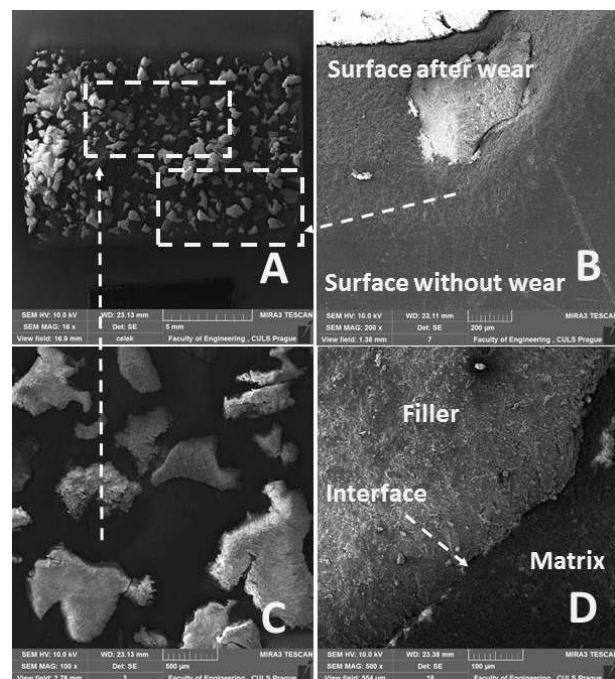
**Fig. 6** Statistical comparison of total wear results

The SEM analysis proved a different behaviour of tested materials at the wear process. The surface of the wear matrix is on fig. 7. From fig. 7 A the surface without the wear and the surface after the wear are evident. From fig. 7 C the detailed view on a transition area i.e. the surface without the wear and the surface after the wear is evident. The wear surface shows craters created by abrasive grains of floated sand. Fig. 7 B shows the wear surface in the middle part of the wear track which is evident on fig. 1 C.

**Fig. 7** SEM images of tested matrix surface – loading 1600 g: A: Transition surface area before and after wear (MAG 150x), B: Wear surface (MAG 2.00 kx), C: Detailed view on transition area before and after wear (MAG 1.50 kx)

The wear surface of the composite material RP0.4-0.8 is on fig. 8. From fig. 8 A the wear track is evident. From fig. 8 B the surface without wear and the surface after wear are evident. From fig. 8 C the detailed view on the wear surface is evident. The wear surface did

not show craters created by abrasive grains of floated sand. The abrasive grains wore the matrix and the RP fillers stayed on the surface until they were broken up from the matrix (fig. 8 A, B and C).

**Fig. 8** SEM images of tested composite surface RP0.4-0.8 – loading 1600 g: A: Total view on wear surface (MAG 16x), B: Transition area before and after wear process (MAG 200x), C: Wear surface (MAG 100x), D: Detailed view on matrix and filler interaction (MAG 500x)

This fact significantly increases the wear resistance. The microparticle filler RP showed good adhesion strength to the matrix even there is evident lower interaction between the matrix and the filler (fig. 8 D). The interaction between the filler and the matrix is influenced by the wettability which interfaces the cohesion strength i.e. inside strength of the composite layer [15, 16, 17, 19]. This lower interaction on interface of the matrix and the filler (fig. 8 B and D) is not evident on total circuit of microparticle RP (fig. 8 B). It is possible to conclude from this that it is not lower wettability of microparticle RP. It is probably by influencing microparticle RP deformation and its delamination from the matrix. Same conclusions were made in

other studies dealing with usage of tyre recycle [1, 8, 20, 21, 22, 23].

The composite material RP0.0-0.4 worn surface is on fig. 9. From fig. 9 A the wear track is evident, which created the irregular surface. From fig. 9 B the surface without wear and the surface with the wear is evident. On the wear surface the microparticles RP are evident. From fig. 9 C the detailed view on the wear surface is evident, which has irregular crater surface. There was considerable mass loss at the wear process, which is evident from fig. 9 C. This fact significantly decreases the wear resistance. An interaction between the matrix and the filler is evident on fig. 9 D.

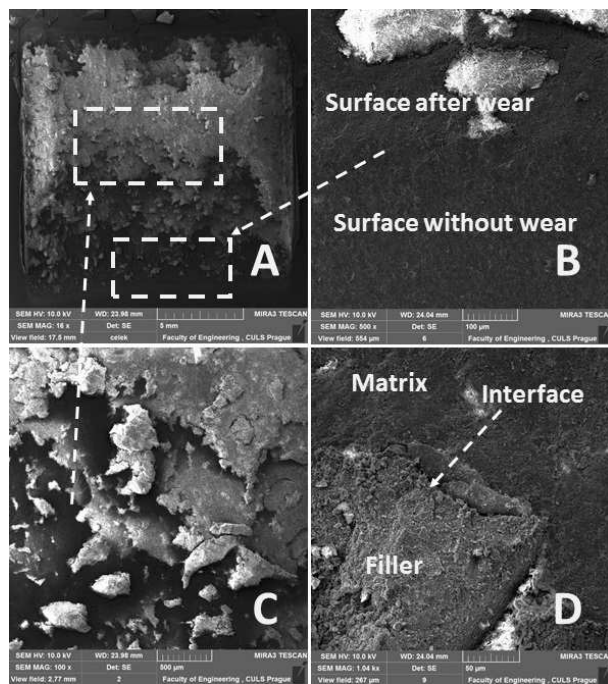


Fig. 9 SEM images of tested composite surface RP0.0-0.4 – loading 1600 g: A: Total view on wear process (MAG 16x), B: Transmission area of surface before and after wear process (MAG 500x), C: Wear surface (MAG 100x), D: Detailed view on matrix and filler RP interaction (MAG 1.04kx)

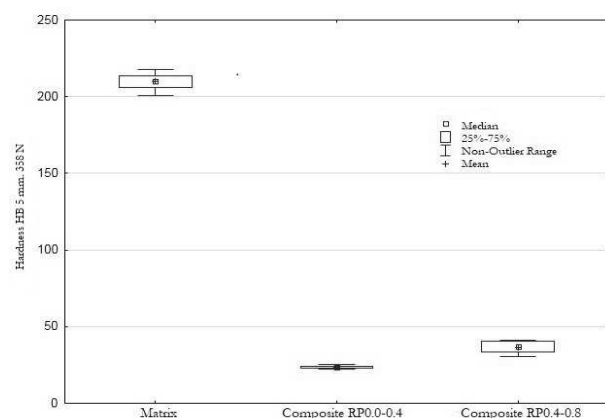


Fig. 10 Hardness of tested material by HB method

The results of composite materials and matrix hardness are evident from fig. 10. The matrix shows a

significant difference of the hardness against the composite materials. The filler RP in matrix significantly decreases the hardness of tested materials. The hardness decrease of the composite material is caused by use of the filler based on elastomeric particles. From the results it is evident that there is no direct proportion between the hardness and the wear resistance as at steel. Therefore, it cannot be said that the hardness is directly proportional to the wear resistance. In terms of the statistical testing it is possible to state that it is statistically inhomogeneous groups i.e. there is the significant difference between the composite material and the matrix in the significant level 0.05 ($p = 0.000$).

Results of the research proved that the elastomeric product from tyre waste recycle process can be used in the material field [7]. One of the possibilities is the composite material production based on thermosetting matrix.

4 Conclusion

The research deals with usage possibility of the filler RP from waste tyre recycle process into polymeric composite materials with thermosetting resin matrix. In the research two fractions of the filler in the interval from 0 to 400 μm and from 400 μm to 800 μm (significant representation of this fraction) were used. The results of the research confirmed that the composite material RP0.4-0.8 showed good wear resistance by method of use the rubber wheel and the abrasive according to GOST 23.208-79. The elastic rubber microparticles RP can absorb internal stress on the interface of the matrix and the filler.

Acknowledgement

Supported by Internal grant agency of Faculty of Engineering, Czech University of Life Sciences Prague (no. 31140/1312/313108)

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