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Composite Load–Bearing Element Based on the Perforated Steel Wastes

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A question of industrial wastes application is of high importance at the present moment. Repeated using of industrial wastes or recycling is a possible way to increase the effectiveness of structural materials application. In this case perforated steel tape is considered as a raw material for producing of load-bearing units. A composite materials based on polymer matrix combined with perforated steel material is proposed. Example of load-bearing element based on perforated steel band reinforced polymer (PSBRP) composite is proposed. A manufacturing approach for PSBRP production is outlined.

Keywords: *composite, load-bearing element, perforated steel band, industrial wastes, polymer matrix.*

1. Introduction

Construction is an area for which fast development, unstoppable searching of new solutions and investigating of new technologies are characteristic. Increase of effectiveness of structural materials application is one of a tendencies and a question of high level of importance at the present moment. Repeated using of industrial wastes or recycling is one of the probable ways to fix the problem (Hargreaves *et al.* 2013).

Latvia also has a number of factories, whose production waste can be re-used for different aims. Perforated steel band as a waste material after punching in Latvia is produced at JSC "Ditton Driving Chain Factory" (Products 2014). There have been attempts to make polymeric materials reinforcement with metallic fibers (SPI 1995, Seidel *et al.* 2013) and non-perforated metallic sheets (Sherman *et al.* 1991), thus increasing the design modulus of elasticity and rigidity. However, a major problem is the provision of adhesion between the polymer and the metal sheet. As a result, the structure breaks down - perforated sheet detached from the polymer matrix. Meanwhile, use of perforated sheets makes it possible to influx polymer matrix inside through-channels, cross-linking polymer layers. Thus, obtained composite material leads to joint operation of composite components.

The aim of current study is to find out the possible use of perforated steel band made of wasted material designing a composite material in combination with polystyrene polymer, and its efficiency. There is also a significant advantage in that the perforated steel wastes can be considered as an inexpensive raw material for design and manufacturing of new composites for civil engineering applications.

2. Materials and Methods

The developed composite material consists of two components: polymer matrix and perforated steel band. Materials were selected with following considerations:

- composite dimensions must be such as to be able to use a perforated steel band without the need for geometry changes to increase the efficiency of waste material usage;
- total composite tensile load-bearing capacity up to 25 kN (equal to the capacity of the testing equipment);
- polymer material must be thermoplastic (Крижановский 2004) with melting point up to 350°C (not exceeding maximum allowable temperature of hot press equipment).
- polymer materials and perforated metallic material must be available in sufficient quantities to produce 5 samples of PSBRP for testing;

Therefore, for polymer-perforated metal composite manufacturing the following components were used:

1) Polymer component:

Technical thermoplastic polypropylene Polystone® P gray homopolymer, produced by German company Rochling. Technical properties of Polystone® according to manufacturer’s specification are given in table 1.

Table 1. *Polypropylene Polystone® P grey properties*

Property	Value
Density, g/cm^3	0.91
Modulus of elasticity, MPa	1300
Tensile strength, MPa	32,00
Breaking extension, %	>50
Melting point, °C	162 - 167
Linear expansion coefficient, $10^{-6}K^{-1}$	120 - 190

2) Metal component:

Perforated steel bands LPM-4 (steel grade 08пс-ОМ-Т-2-К) is a chain parts stamping waste material (Fig. 1) produced by company JSC "Ditton Driving Chain Factory" (Daugavpils, Latvia). Main geometrical characteristics of LPM-4 band are given in table 2.

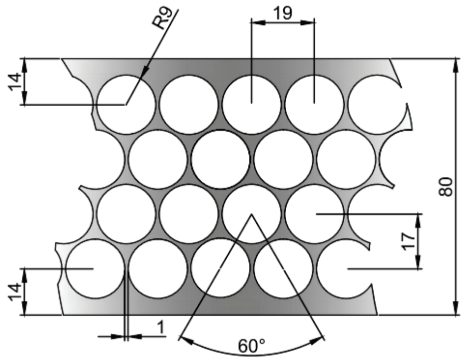

Fig. 1. Perforated steel band as a component for polymer-metal composite material

Table 2. Geometrical characteristics of perforated steel band waste material LPM-4

Parameter	Value
Thickness, mm	1.50
Complete cross-sectional area, mm^2 (Brutto)	120.00
Effective cross-sectional area, mm^2 (Netto)	25.13
Density of perforation, %	69.10

Mechanical properties of LPM-4 are summarized in table 3. (ГОСТ 503-81).

Table 3. Technical properties of perforated steel band LPM-4

Parameter	Value
Steel density, kg/m^3	7850
Tensile strength, N/mm^2	217.18
Specific strength, kNm/kg	27.67
Bearing capacity, t	0.55

Composite material was made by means of hot pressing process. Initially, metal parts made of sanded and degreased perforated steel LMP-4 band with dimensions 1.5x80x300 mm were prepared.

Polypropylene sheets with overall dimensions 3.0x90x310 mm were prepared providing an overlapping of 5 mm behind the edges of LPM-4 band samples, thus ensuring a strong contact of melting polypropylene with perforated steel band. As polypropylene melting temperature range is within 162-167°C, therefore a hot-press equipment was set to heat up to 210°C, heating press plates up to 180°C and ensuring complete polypropylene fusing.

Prior to compression, component materials were stacked together providing a multi-layer "polypropylene-perforated tape-polypropylene" sandwich (Fig. 2).

Prepared sandwich was wrapped into a heat-resistant paper sheet (temperature resistance up to 200°C). Wrapping is important for two reasons:

- to limit a diffluence of liquid polypropylene,
- to protect hot press sintering plates of liquid polypropylene.

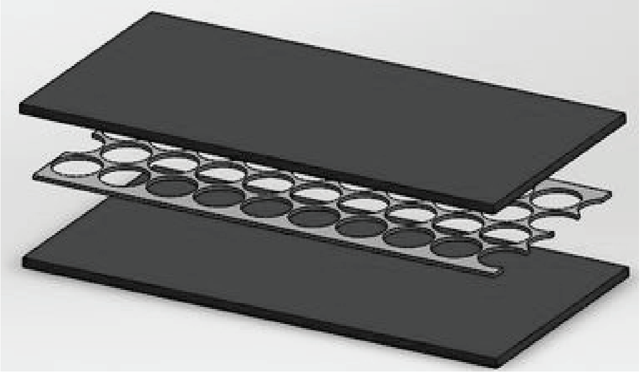

Fig. 2. "Polypropylene - perforated tape – polypropylene" sandwich design

The samples were wrapped in such manner to leave 5 mm indent between edges, ensuring a space for expanding of melting polypropylene.

For pressing and complete sintering of all components the following methodology has been developed:

1) Sandwich structure is compacted up to 9.5 kN load (5 bar) and maintained until the pressure begins to fall polypropylene melting;
2) repeatedly increase the load up to 9.5 kN and further control its release (pressure fall);
3) raise pressure up to 19 kN (10 bar) and leave the sample until complete compression for 2 minutes;
4) a sample is withdrawn from the press.

For the tensile strength experimental trials, edges of samples were trimmed to dimensions: 310x90x6.30 mm.

Similarly to tests of perforated steel bands LPM-4 and polypropylene samples, obtained composite materials tensile strength tests were conducted on INSTRON 8802 machine. Composite tensile strength was conducted in 5 test series with loading rate 5.00 mm/min. A sample of obtained composite material used for testing is shown in Fig. 3.

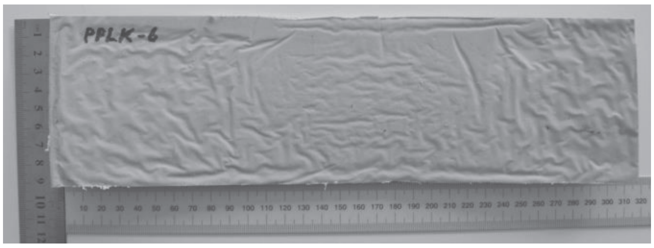

Fig. 3. Obtained composite material sample for tensile strength testing

3. Results

Experimental trials have revealed a simultaneous loss of load-bearing capacity of obtained polymer-metal composite. It was noticed that perforated steel band LPM-4 and polypropylene component are losing its load-bearing capacity simultaneously. Such materials behavior was characteristic for all polymer-metal composite samples. Example of of polymer-metal composite sample crack is shown in Fig. 4.

It was found that during an experiment before the collapse of the cracks microfractures of polypropylene layer is formed. Polypropylene microfractures repeat contour lines of LPM-4 band perforation. With elongation, these microfractures do not break but continue to deform.

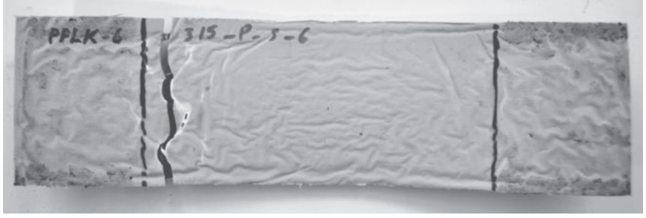

Fig.4. *Obtained composite material sample breakage during the tensile strength testing*

Relationship between tensile elongation of polymer-metal composite components (polypropylene, perforated steel band LPM-4) and obtained composite sample and axial tensile load is shows in Fig. 5.

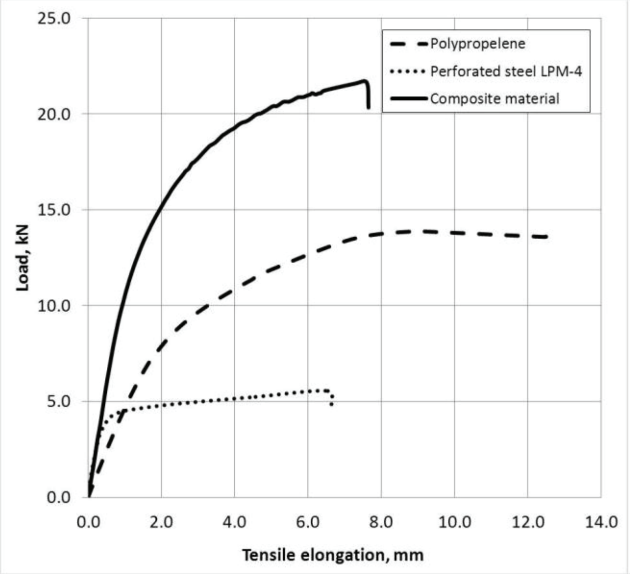

Fig.5. *Tensile elongation of components and obtained composite material vs. axial tensile load*

Relative deformation curves in relation to applied tension are given in Fig. 6.

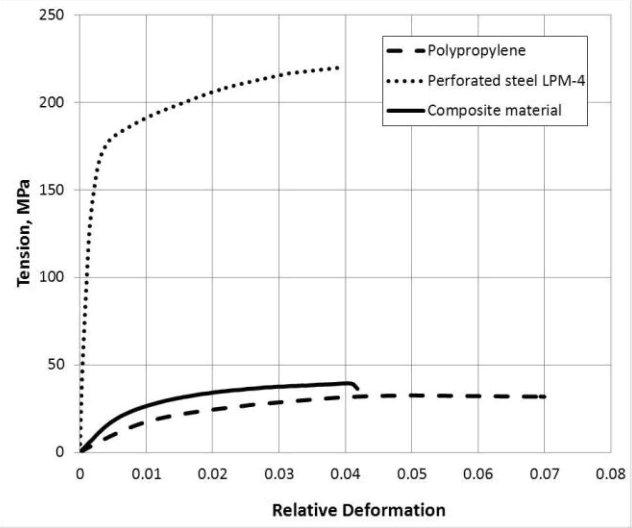

Fig.6. *Relative deformation of components and obtained composite material vs. applied tension*

It was also found that bonding between metal and polymer component is weak due to insufficient adhesion between components. Meanwhile, polypropylene is filling up all steel band perforations, thus polymer layers are tightly bounded to each other. Mechanical characteristics of polymer-metal composite samples (table 4.) were identified by means of tensile strength trials.

Table 4. *Mechanical properties of obtained composite material samples.*

Composite material sample # (PSBRP)	Maximum load, kN	Tensile stress, N/mm^2	Relative deformation, %	Elastic modulus, GPa
PSBRP-1	19.93	37.96	3.43	3.27
PSBRP-3	22.82	40.98	4.17	3.38
PSBRP-4	22.82	39.89	4.78	2.79
PSBRP-5	21.52	37.37	4.23	3.74
PSBRP-6	21.10	40.18	4.07	3.71
Mean value:	**21.64**	**39.28**	**4.14**	**3.38**

On the basis of methodological approach (Lisicins 2014) the theoretical properties of obtained metal-polymer composite and its components were calculated. In order to provide an objective evaluation of experimental results calculated values were compared to experimental results obtained from average values. The comparison of the theoretical and experimental values is given in table 5.

Table 5. *Comparison of polypropylene, perforated steel band and composite materials calculated and measured properties*

Results	Maximum load F_t, kN	Tensile stresses (average scatter) σ_t, N/mm^2	Relative deformation ε_{Fmax} %	Elastic modulus *E*, GPa
Perforated steel band (LPM-4)				
Calculated	5.53	220.00	3.50	136.01
Experimental	5.54	220.65	3.93	130.05
Difference, %	0.18	0.29	10.94	4.38
Polypropylene				
Calculated	13.66	32.00	-	1.30
Experimental	13.89	32.64	4.95	2.11
Difference, %	1.66	1.96	-	38.39
Obtained composite material				
Calculated	19.18	34.81	-	1.57
Experimental	21.64	39.28	4.14	3.38
Difference, %	11.36	11.38	-	53.55

4. Discussion

A significant result of presented work is that the bearing capacity of obtained composite material is better, than polypropylene and perforated tape bearing capacities, but tensile elongation at maximum load is between polypropylene and perforated steel tensile elongation (Figure 5.). Both results demonstrate that properties of composite structure are governed by two main parameters:

- load-bearing capacity,
- elastic modulus.

It can be concluded that performance of a whole structure does not impair the physical-mechanical properties of a single component.

According to graphics illustration given in Figure 6, it can be concluded that tensile strength of composite material element is greater than the strength value for polypropylene, but much lower than the strength of perforated steel band. At the same time, composite material relative deformation slightly exceeds relative deformation of perforated steel band. Thanks to relative deformation of polypropylene component we observe an increased deformation of composite material. At the same time, an increased tensile strength of composite material is defined by strength of perforated steel band, which is much higher than for polypropylene component.

From illustrations (Fig. 5 and Fig. 6) follows that elastic modulus of obtained composite material is lower comparing to elastic modulus of perforated steel band component, so that observed deformation of the composite material structure increases (relatively to perforated steel band).

Hence, the theoretical assumptions and analytical calculations have been confirmed by graphical correlations. Obtained composite material is characterized by its elastic modulus of individual component, which can be expressed as a weighted average in accordance to percentage of each component in composite material. Elastic modulus is determined by composite tensile strength and its relative deformation, which is lower than for perforated steel band, but higher than for polypropylene component. Composite material's load carrying capacity can be approximately expressed as a sum of bearing capacity of individual components.

From analytically calculated and experimental data comparison (table 5) follows that by means of analytical calculation it is possible to predict physical-mechanical characteristics of obtained composite material with high precision, which is necessary for real design applications. That confirms a feasibility of experimental composite material parts and its components.

The most significant difference (10.94%) between experimental and calculated relative deformation results is observed for perforated steel band. Regarding other parameters, the difference between analytical and experimental values does not exceed 5%. Taking into account possible anisotropy due to perforation asymmetry and material defects that could occur during the stamping, obtained results can be considered as very accurate. For the polypropylene component the largest difference (38.39%) observed for elastic modulus. Therefore, it can be concluded that the actual elastic modulus of material is greater than one specified by the manufacturer. The difference in other characteristics does not exceed 5%.

In case of composite material, the most notable difference in the results is for elastic modulus 53.55% (similarly to polypropylene). Modulus value could be affected by stress repartition between perforated steel tape and polypropylene. In addition, an experimentally determined elastic modulus is higher than theoretical, that influences on materials mechanical properties (strength increase).

In a whole, a comparison of results demonstrates that experimentally determined values are greater than those analytically calculated. It is evident that bearing strength capacity and overall performance of obtained composite is much better than a sum of individual components. So polypropylene and perforated steel band in a composite material structure mutually enhance each other's properties.
A visual comparison of mechanical properties (elastic modulus, tensile strain, tensile strength, and load-bearing capacity) of obtained composite material and its individual components (polypropylene and perforated steel band) is illustrated in plots (Fig. 7- Fig. 10).

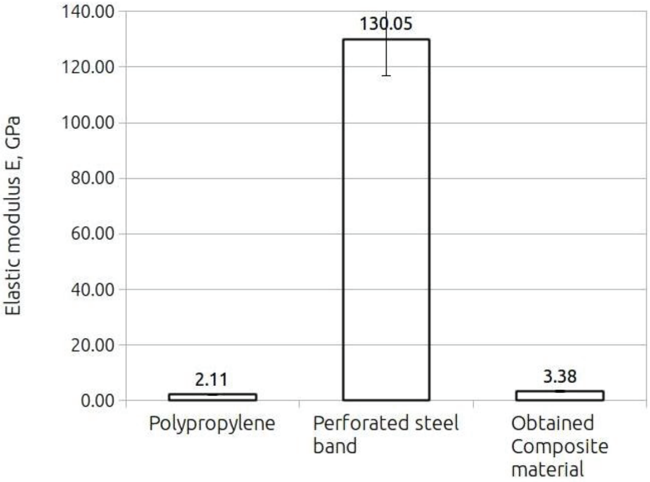

Fig.7. *Comparison of modulus of elasticity in tension for samples of polypropylene, perforated steel band, and obtained composite material.*

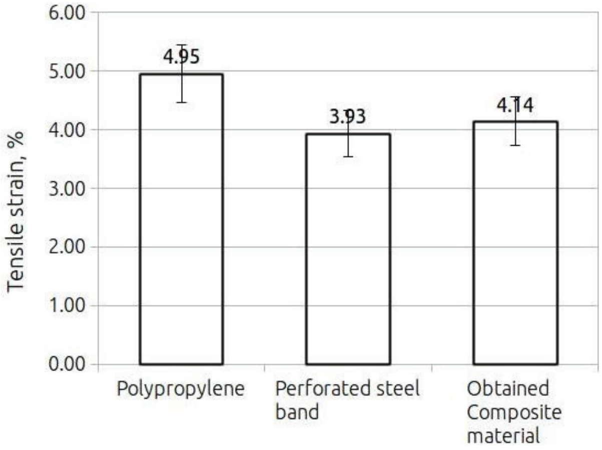

Fig.8. *Comparison of tensile strain for samples of polypropylene, perforated steel band, and obtained composite material.*

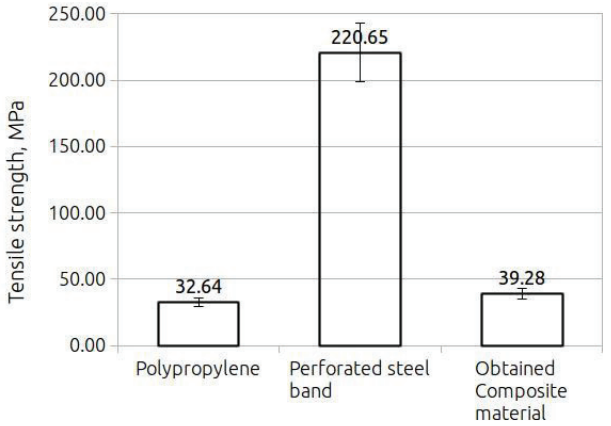

Fig.9. *Comparison of tensile strength for samples of polypropylene, perforated steel band, and obtained composite material.*

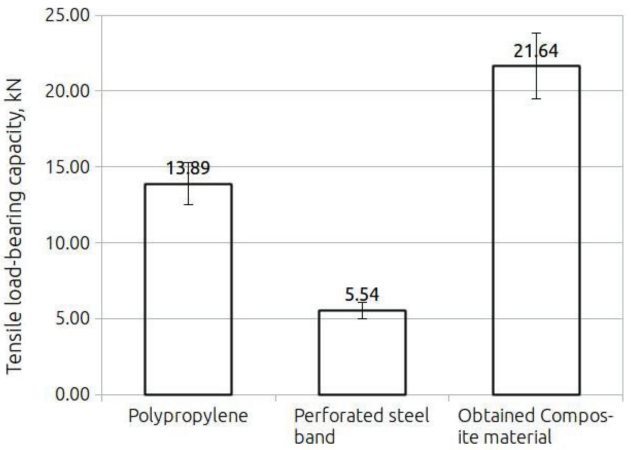

Fig.10. *Comparison of tensile load – bearing capacity for samples of polypropylene, perforated steel band, and obtained composite material.*

5. Conclusions

In present paper development and manufacturing procedure of load-bearing element based on perforated steel band reinforced polymer (PSBRP) composite are described.

Production of metal-polymer PSBRP can be realised by means of hot-pressing method. In order to improve the accuracy of the final composite structure (obtaining of the smooth shape) use of templates (formwork) are recommended.

The wrinkling process of polypropylene during PSBRP cooling was observed (Figure 3. and Figure 4.). This phenomenon is caused by different thermal properties of steel and polypropylene materials. However, the results show that wrinkling did not affect the mechanical properties of obtained composite PSBRP. Use polypropylene casting or extrusion methods in future research to avoid heating of steel are recommended.

After the collapse of the PSBRP structure a detachment of polypropylene and steel were observed as a result of axial tensile load the as a result of poor adhesion between materials. Additional measures to make a composite structure was envisaged during a development by providing melting polypropylene inflow into perforations of steel band ensuring its mutual bonding.

Obtained composite PSBRP elastic modulus, affects the tensile strength and deformability of construction. This can be expressed as a sum of components, taking into account their percentage in PSBRP composition;

A tensile load-bearing capacity of obtained composite PSBRP is higher by 11.37% than total load carrying capacity of its individual components (perforated steel band and polypropylene) due to filling up the perforations with liquid polypropylene. Providing a complete adhesion between polypropylene and steel, ensures better and more uniform stress redistribution and increase load-bearing capacity;

Knowing physical-mechanical and geometrical characteristics of composite PSBRP components facilitate calculation of composite design and predict actual performance of designed structure. In current case, the difference between calculated and experimental results for obtained composite structure did not exceed 15%, which can be considered as feasible design result. The actual modulus of elasticity of the material turned out about by 38.39%. A mismatch in results for PSBRP elastic modulus can be explained by variance between real values of elastic modulus and values given in manufacturer’s specifications.

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References

Hargreaves, J. S. J., Pulford, I. D., Balakrishnan, M., Batra, V. S. 2013. Conversion of Large Scale Wastes into Value-added Products. CRC Press, 23 – 68.

Lisicins, M. 2014. Lentveida perforētu tērauda atlikuma materiālu izmantošanas iespējas būvniecības tehnoloģijās (in Latvian) [The Usage Possibilities of Perforated Steel Band Waste Materials in Construction Technologies]. Master Thesis of Civil Engineering Faculty of Riga Technical University, Riga, Latvia. 2014, 107 – 112.

Products of JSC "DITTON Driving Chain Factory". Available at: http://www.dpr.lv/index.php?lang=en&id=produkt (accessed 18 May 2014).

Seidel, Ch., Zosch, A., Seidel, M., Sover, A., Frormann, L. 2013. Non-destructive characterization of fibre-filled plastics using eddy current technique. Zwickau, Germany. 1 – 4. Available at: http://www.xn--werkstoffe-prfen-vzb.de/app/download/5785232937/Non-destructive....pdf (accessed 10 July 2014).

Sherman, E., Winkle, Sr., Cockerham L. E., Meyers F. A. 1991. Process for coating on metal strip with plastic powder. European patent application EP19910102095.

Society of the Plastics Industry (SPI) Composites Institute. 1995. Introduction to Composites. Third Edition. Washington, DC: Society of the Plastics Industry, Inc.

Крижановский, В. К., Кербер, М. Л., Бурлов, В. В., Паниматченко, А. Д. 2004. Производство изделий из полимерных материалов (in Russian) [Proizvodstvo izdyeliy iz polimyernih matyerialov]. Publishing House Профессия [Professiya], Sankt-Peterburg, Russian Federation. 2004, p. 456.

ГОСТ 503-81. Лента холоднокатаная из низкоуглеродистой стали. Технические Условия [GOST 503-81. Tapes made of low carbon steel. Technical specifications]. National Standard of Soviet Union and Russian Federation.

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