Research of plastic and wood raw wastes recovery

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Abstract

The main aim of this paper is to present the research findings regarding the recovery possibilities of plastic and wood raw wastes. One of the recovery possibilities for mentioned raw materials is production of waste raw materials based wood-plastic composites (WPC). Lonely production process is influenced by technological and raw material parameters (type of raw material and particle size) and thus the final quality and mechanical properties of WPCs have to be determine. This paper also presents the results of realized experimental research which dealt with the determination of relationship between material parameters and mechanical properties during production of WPCs. The main goal of presented paper is to determine the mutual interaction between mechanical properties, type of the plastic matrix used in WPC, wood/plastic concentration ratio and particle size of wood sawdust used in WPC. In this paper the authors also comparing mechanical properties of WPCs based on recycled and original plastics. As a plastic matrix 100 % original HDPE and recycled HDPE originating from lids of PET bottles was used. Obtained research findings can be very helpful at WPCs production and shown the possibility of using also waste raw materials for WPC products, and thus increase the environmental responsibility with the environment protection.

Keywords: Material recovery, WPC, waste, mechanical properties, HDPE, particle size.

Introduction

There is an estimated hundreds million tons of wood and plastic waste produced each year **[1, 2]**. The construction waste is one of the largest waste streams in the EU. The EC Waste Directive 2008/98 targets a more sustainable construction industry, recovering a 70% (by weight) of its non-hazardous construction waste by 2020**[3]**: to meet that objective, new solutions must be found to achieve an efficient material recovery. One of the solution should be the wood-plastic composites (WPCs) production process **[4]** which is very well known. The rising concern towards environmental issues and, on the other hand, the need for more polymer-based materials has led to increasing interest about polymer composites based waste materials **[5]**.The wood-plastic composites (WPCs) production process is very well known. Also, various research studies with material and technological variables impacts on the production are dealing with **[5, 6]**. WPCs are produced by thoroughly mixing ground wood particles (sawdust) and heated thermoplastic resin **[6]**. The most common method of production is to extrude the material into the desired shape using injection molding **[7]**. WPCs may be produced from various virgin thermoplastics but polyethylene based WPCs are by far the most common **[8]**. Also, the additives such as colorants, coupling agents, UV stabilizers, blowing agents or foaming agents are included **[7, 8]**. The usual composition of WPCs based virgin material is 60 - 65% of high-density polyethylene (HDPE) **[6]**, 30 % of wood sawdust without defined granulometry, but the particle sizes up to 2 mm and the additives according to the final application, which helps tailor the end product to the target area of application **[4]**. Other hand on the base of amounts of wastes and environment protection is using of waste or recycled materials for WPCs production a big issue for nowadays **[6]**. The general purpose of this paper is to gain the research findings about waste recovery possibility that can show the possibility and application for rapid prototyping using WPCs based waste raw materials. Obtained research findings can be very helpful at WPCs production and shown the possibility of using also waste raw materials for WPC products and using of such a composites for rapid prototyping which is very interesting issue and recovery possibility for nowadays. Taking in mind these sources of wastes which opens such opportunities and challenges with application of recycling and recovery methods can be increase the environmental responsibility with the environment protection.

Experimental

The main aim of our experiment is to determine the impact of material variables on mechanical properties of WPCs based waste raw materials. According to our previous basic research (screening experiment), analyses **[9-14]** and knowledge an important input variables were chosen. Raw material variable´s impact, especially (type of raw material and wood sawdust particle size) can be recognized during the production of WPCs **[9, 10]**. Their impact can be seen through the quality indicators; especially mentioned parameters significantly influence the mechanical properties of WPCs (ultimate strength, maximal force, elongation, impact strength, modulus of elasticity, water absorption, etc.) **[11-13]**.The best way is to choose such variables which have during the production process continuous characteristics and where the impact on outputs are expected. In our case, determination of the mutual interaction between mechanical properties, type of the plastic matrix used in WPCs, wood/plastic concentration ratio and particle size of wood sawdust used in WPCs were chosen. In the following **Table 1** the chosen levels for each variable can be seen.

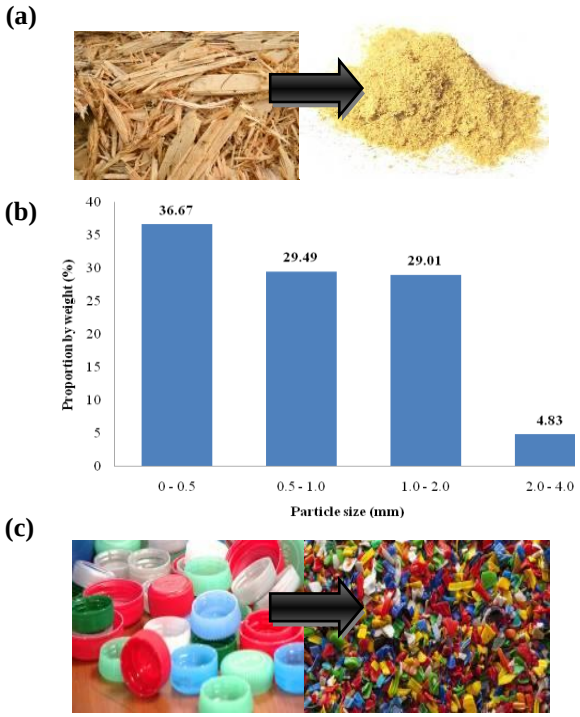

Fig. 1. (a) Disintegration of wood waste to sawdust, (b) sawdust particle size distribution, and (c) disintegration of PET bottle lids.

Other important issue of our research was also comparing mechanical properties of WPCs based on recycled and original plastics. As a polymer matrix 100% virgin high-density polyethylene (HDPE v) and recycled HDPE originating from lids of PET bottles (HDPE r) was used. As a wood component spruce sawdust with 0.5 mm and 1.0 mm particle size was used. Spruce sawdust originating from Western Slovakia was obtained from wood processing company with 8 % of moisture content and without bark. Experimental research was done according to the designed experimental plan where the full factorial experiment was used. Experimental research consisted of 3 influencing parameters, specifically type of polymer matrix - on a 2 levels, particle size - on a 2 levels and concentration ratio of plastic/wood where the 90:10, 80:20, 70:30 ratios were used (see **Table 1**).

Table1. Input controllable variables of the experiment.

	Variables		
	Wood/Plastic ratio	**Sawdust particle size**	**Polymer matrix type**
Levels	**(%)**	**(mm)**	**(-)**
1	0 / 100	0.5	HDPE v
2	10 / 90	1.0	HDPE r
3	20 / 80		
4	30 / 70		

Because the experimental research with raw waste materials was dealt and according to given experimental plan raw material for experiment had been treated**[12, 14]**. For obtaining the given wood sawdust particle sizes the disintegration and separation processes were used (see **Fig. 1 (a)**). For raw wood waste disintegration hammer mill Stoza ŠV 5 was used and initially the particle size distribution (see **Fig. 1 (b)**) was analyzed by using an AS 200 Vibrating Sieve Shaker. For disintegration of PET bottle lids (see **Fig. 1 (c)**) cutting mill Retsch SM 300 was used. 100 % Virgin HDPE was obtained from the biggest refinery company in Slovakia.

The experimental samples production process can be seen on the **Fig. 2**. Given wood/plastic ratios had to be prepared by mixing with using an usual electric mixer (see **Fig.2 (a)**), weight by using MR 120 balance was controlled. Final samples by Brabander twin-screw granulator (see **Fig. 2 (b)**) and DEMAG ErgoTech 50-200 injection molding machine were produced. Samples dimensions related the Standard STN EN ISO 527-3 were produced**[15]**.

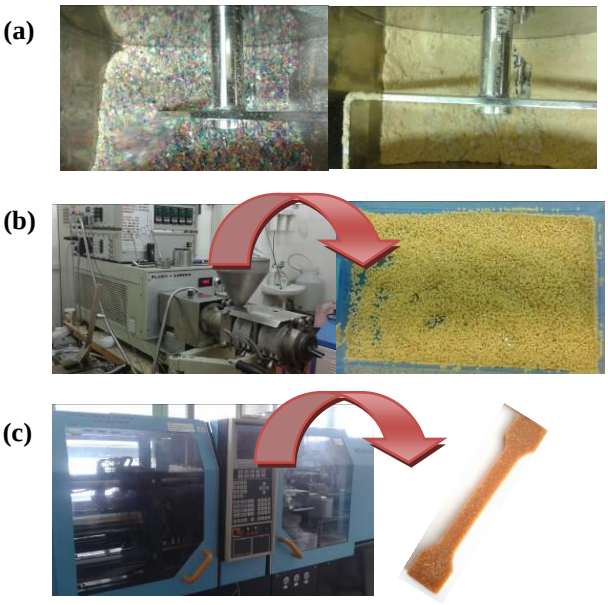

Fig. 2. (a) Polymer granules and wood sawdust mixing, (b) granules extruding, and (c) WPC samples producing.

In the final, the outputs variables (see **Table 2**) were measured on the base of tensile testing by automatic testing equipment INSPEKT desk 5 with force range up to 5 kN.

Table 2. Outputs (monitored) variables of the experiment

Label	Outputs	Unit
Fmax	Maximal force	(N)
Rm	Ultimate strength	(MPa)
A	Elongation	(%)
E	Modulus of elasticity	(MPa)
T	Hardness	(-)
WA	Water absorption	(g)

Monitored variables (outputs) according to the technical standards and WPCs application were chosen. Tensile test speed was 35 mm/min and for each of 14 experimental settings (see **Fig. 3**) 6 measurements were done. Displayed outputs are representing quality indicators and these variables have also a function of comparative criterions.

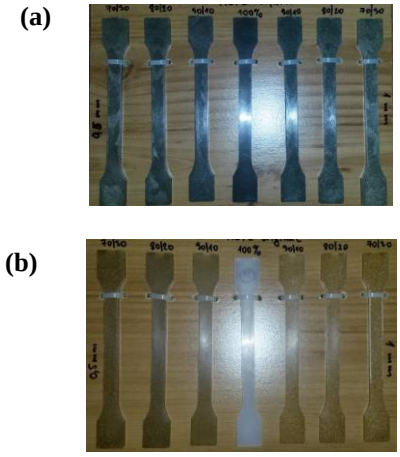

Fig. 3. (a) Obtained WPC´s samples based on recycled HDPE, and (b) obtained WPC´s samples based on virgin HDPE.

Results and discussion

In this research paper authors would like to present research findings of the preliminary phase of presented experimental research. This preliminary phase relates to the impact of material variables determination on mechanical properties of WPCs, effect of type of the plastic matrix used in WPCs, wood/plastic concentration ratio and particle size of wood sawdust on maximal force, ultimate strength and elongation was determined. Impact of input variables on modulus of elasticity, hardness and water absorption is not included.

According to the main aim of our experiment which was the impact of material variables determination on mechanical properties of WPCs, effect of type of the plastic matrix used in WPCs, wood/plastic concentration ratio and particle size of wood sawdust on maximal force, ultimate strength and elongation was determined. On the following **Fig.4**, **Fig.5** and **Fig.6** can be seen impact of investigating variables (plastic/wood ratio, particle size and type of polymeric matrix) during WPC´s production and thus on final mechanical properties.

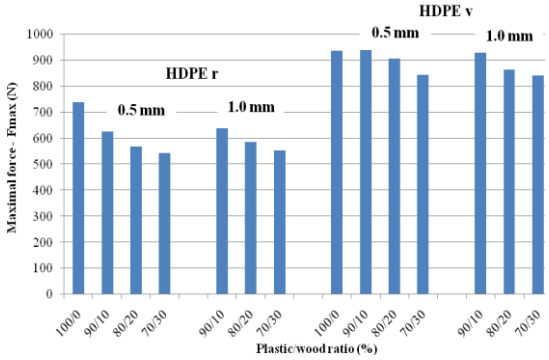

Fig. 4. Comparison of maximal force obtained at various plastic/wood ratios, particle sizes and different type of polymeric matrix.

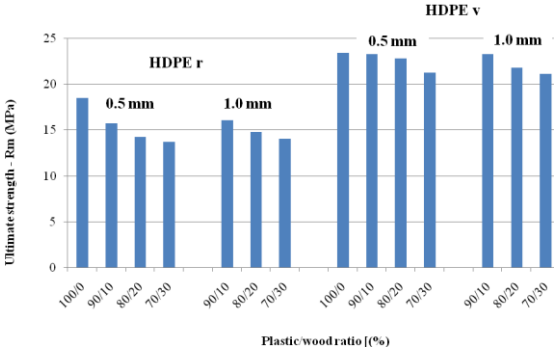

Fig. 5. Comparison of ultimate strength obtained at various plastic/wood ratios, particle sizes and different type of polymeric matrix.

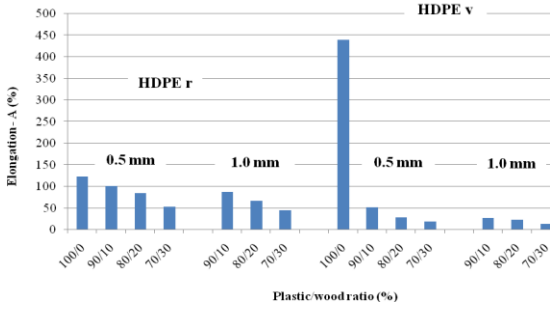

Fig. 6. Comparison of elongation obtained at various plastic/wood ratios, particle sizes and different type of polymeric matrix.

As we expected recycled HDPE based WPC´s have lower values from mechanical characteristic point of view **[11, 13]**. Different results were obtained from a elongation point of view. Higher elongation, up to 40 %, was achieved with recycled HDPE, when comparing the WPCs. Mutual interaction of plastic/wood ratio, particle size and type of polymeric matrix has interesting impact on final samples elongation**[16, 17]**. But in general we can say that recycled HDPE originating from lids of PET bottles can be used for WPC´s production. Difference between WPC´s based on recycled HDPE with comparing WPC´s originating from virgin HDPE is acceptable, up to 30 % from maximal force and ultimate strength point of view. During the samples production any problems were

reported. Plastic/wood ratio impact on maximal force can be seen on **Fig. 4**, on ultimate strength can be seen on **Fig. 5** and on elongation can be seen on **Fig. 6**. As the polymeric matrix ratio in basic volume decreases so too does the mechanical properties. Wood sawdust amount negatively influences the mechanical properties of WPCs. This result was obtained also with recycled HDPE and also with virgin HDPE.

Wood sawdust particle size impact on maximal force can be seen on **Fig. 4**, on ultimate strength can be seen on **Fig. 5** and on elongation can be seen on **Fig. 6**. Change of sawdust particle size has only small effect on maximal force and on ultimate strength. But impact of the particle size can be mainly seen at elongation**[14]**. As the particle size increases elongation is decreasing. Higher particle size negatively influences the bounding between particles in WPC. This result was obtained also with recycled HDPE and with virgin HDPE.

Wood sawdust particle size impact will be much more seen through the remaining outputs, especially modulus of elasticity and water absorption**[16, 17]**. From these outputs point of view could have particle size higher importance as was listed.

Conclusion

Research of plastic and wood raw waste materials recovery was investigated in this research. Presented results of preliminary phase relates to the impact of material variables determination on mechanical properties of WPCs, effect of type of the plastic matrix used in WPCs, wood/plastic concentration ratio and particle size of wood sawdust on maximal force, ultimate strength and elongation.

The main conclusions that can be drawn from this study are as follows:

- All of the investigated input variables have an effect on monitored outputs.
- Recycled HDPE originating from PET bottle lids can be used for WPC production.
- Wood sawdust particle size and plastic/wood ratio impact was proven.
- WPCs based on recycled HDPE has around 30 % lower mechanical properties - maximal force, ultimate strength.
- WPCs based on recycled HDPE has around 40 % higher elongation.

Additional phase of this experimental research will concern to research of plastic and wood raw waste materials recovery with using a rapid prototyping technology. Research of basic material composition suitable for 3D printing and development of WPC´s composition based on waste materials which can be used for 3D printing is very ambitious and interesting issue.

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Author's contributions

Conception/experimental design: PK, JB; Performed the experiments: PK, MM, ĽK; Data analysis and interpretation: MM, JB, PK; Wrote the paper: PK; Paper editing/reviewing and conceptual advice: ĽK, ĽŠ. Authors have no competing financial interests.

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