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Scientific paper
ISSN 0351-9465, E-ISSN 2466-2585
https://doi.org/10.5937/zasmat2204493S

Zastita Materijala 63 (4)
493 – 501 (2022)

Experimental investigations on the workability of sustainable composite by recycling waste plastics and agro-waste

ABSTRACT

Widespread applications of raw materials in building construction with population generation have steadily increased the demand for fresh raw materials and provoked environmental pollution. Development of sustainable building materials by recycling various solid waste could be a viable approach to reduce the problems arising from generating solid waste besides providing an alternative raw material for building construction. The present study demonstrates the development of polymeric composite materials as floor tile using different waste plastics, includes low- density polyethylene, high-density polyethylene, polyethylene terephthalate, and polypropylene as matrices with incorporation rice husk ash and sand as fillers. The workability of the developed materials was verified through experimental evaluations of physical, mechanical, and tribological properties. The minimum values of water absorption and abrasive wear were found to be 0.0397 % and 0.03267 (cm^3) for the composites LDPE50PET20S30 and LD50S50, respectively. However, the composites HD50S50 resulted in an optimum mechanical strength with compressive strength and flexural strength of 46.2 and 6.24 (N/mm^2), respectively. It was observed that the workability of the composites improves with the incorporation of sand particles. The scope of the present study relies on the development of methods and techniques for developing sustainable building materials through recycling of solid waste along with its characterization which provides an easy reference for solid waste processing towards sustainability.

Keywords: *Characterizations, Green manufacturing, Sustainable composites, Recycling, Waste management*

1. INTRODUCTION

Like other developing countries, India is grappling with strained waste management systems that harm the environment and human health. The problem of solid waste generation is permanently harming the environment. One of the biggest issues is achieving sustainable recycling and effective solid waste management. In addition, there is a great requirement for the building materials to accommodate the rising population's need for shelter. Recycling solid waste for the development of alternatives materials for building applications has been highlighted as a possible solution to tackle these issues. Plastics that have a low bio-degradability are causing environmental problems. In India, both the informal and formal sectors contribute to a plastic generation rate of 6.5-8.5 million tonnes per year. Plastic thrash accounts for 8-10% of municipal waste, with 190 million tonnes produced annually [1,2]. Because many plastics are discarded, and only a small portion is recycled, management of plastic waste remains a global concern [3].

The waste generated due to the different agricultural activities are termed as agro waste. Rice husk is an agro-industrial waste produced during rice milling and it occupies a high dry volume due to its low bulk density (90-150 kg/m^3). Each kg of rice on milling yields around 0.28 kg of rice husk resulting in a massive amount of rice husk. A portion of the rice husk is burned to produce rice husk ash used as a fertilizing agent while the remainder is deposited in landfills resulting in a significant amount of rice husk ash in the environment [4]. The growing problem of rice

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Paper received: 15. 06. 2022.
Paper accepted: 07. 07. 2022.
Paper is available on the website: www.idk.org.rs/journal

husk disposal, environmental concerns and the need to conserve natural resources have drawn researchers' attention to the effective treatment of rice husk ash [5,6]. The rice husk is being used as a fuel in the boiler to generate steam for generator turbine to provide electricity leaving RHA as a bye product due to burning of rice husk in a boiler. The work provide an innovative way to reduce the problem RHA by recycling it for the development of sustainable building material. Here, the generated RHA is recycled directly with a little input energy for the development of composites without releasing any toxic material in the environment therefore, it is economical, effective and environmental friendly.

Given the shortage of land in metropolitan areas, the traditional strategy of managing garbage as a landfill is unsustainable. Furthermore, dumping solid trash in landfills locks up precious resources and necessitates the use of fresh materials and energy as well as the release of hazardous pollutants into the environment [7]. To manage the created plastic wastes in an efficient and environmentally friendly manner, an effective waste management strategy is required. Plastic waste has recently been used to manufacture composite floor tiles due to its availability in various forms, including low-density polyethylene (LDPE), high- density polyethylene (HDPE), polyethylene terephthalate (PET), Polypropylene (PP), polystyrene polyvinylchloride, etc. with remarkable properties such as lightweight, non-corrosive, toughness, and durability making it a useful raw material for the development of sustainable building materials [8,9]. The workability of the polymeric composites was found to improve with the addition of fillers [10,11]. The wear resistance of grewia optiva fiber-packed with rice husk composites was found to be improved [12]. The tensile strength and flexural strength were found to improve with the addition of 5% and 15% of rice husk, respectively [13,14]. The earlier work has been demonstrated on fibers derived from PET bottle waste to improve the flexural strength of concrete [15]. The damping properties of concrete tile containing 10% and 15 % plastic fiber were found to be superior to normal concrete. Seghiri et al. 2017; conducted research to build eco-friendly tiles using waste plastics and sand and revealed that the addition of sand increases the strength of the material, making it more durable to endure temperature changes, and investigated its feasibility for usage in a terrace. Furthermore, the tile's compressive strength and water absorption were comparable to that of the standard tiles [16]. Ilkeret et al. 2007, researched the manufacturing of ceramics tile by combining blast furnace slag and clay and analyzed the mixture to find the best mix and temperature [17]. Li et al., 2019, conducted an absorption test, weathering with rapid xenon arc lighting, and freeze-thaw cycling to determine the durability of wood-plastic composite [18]. Siddiqi et al., 2008, discuss waste management solutions for plastic recycling in concrete [19]. A study was conducted on the environmental repercussions of plastic trash [20,21]. William (2006) demonstrated the utilization of plastic waste for sustainable development by incrementally substituting waste plastics and determining physical attributes [22]. The successful recycling of solid wastes for developing new materials could significantly improve the environmental condition besides reducing the demand for virgin quarry materials. The recycling of fly ash and waste plastics for developing building materials is important from different points of view. It helps to save energy, sustain natural resources, decrease environmental pollution and reduce the requirement for fresh raw materials in the production of building materials. The present study demonstrates the development of eco-friendly building materials such as pavement using rice husk ash (RHA), waste plastics and sand as raw materials which can obtain good workability. The structure of the study is organized as follows: (i) Research background (ii) Description of materials and procedure for preparation of the samples (iii) Development of composites (iv) Investigations of the physical, mechanical, and tribological properties (v) Inference of study.

2. EXPERIMENTAL

2.1. Materials

The study uses matrices and fillers as the raw materials to develop polymeric composites. Low-density polyethylene, high-density polyethylene (HDPE), polyethylene terephthalate (PET), and polpropylene (PP) are taken as matrices. The characteristics of the plastics are listed in Table 1. Rice Husk Ash (RHA) and natural silica sand are taken as the fillers. The RHA is having a particle size of 100 μm and specific gravity of 2.1 g/cm^3. Moreover, the specific surface area of the RHA were found to be 2.33 m^2/g. The chemical and mineralogical composition compositions of RHA are given in Table 2. The particle size of the silica sand is 600 μm. The silica sand has a specific density of 1730 kg/m^3 and a specific gravity of 2.65 respectively. The raw materials used to prepare samples are shown in Figure 1 (a-f).

Table 1. Properties of waste plastics

Tabela 1. Svojstva otpadne plastike

S. No.	Material	Coefficient of linear thermal expansion (in/ºF×10^{-5})	Tensile strength (Psi)	Specific gravity	Tensile Elongation (%)	Hardness Durometer Shore D	Flexural Modulus of Elasticity,(Psi)	Heat Deflection Temperature, (ºF)
1	LDPE	-	1400	0.92	500	55	30,000	122-
2	HDPE	9.0	4000	0.96	600	69	200,000	172-
3	PP	5.0	5400	0.94	-	75	225000	210-
4	PET	3.9	11,500	1.38	70	87	400,000	175-

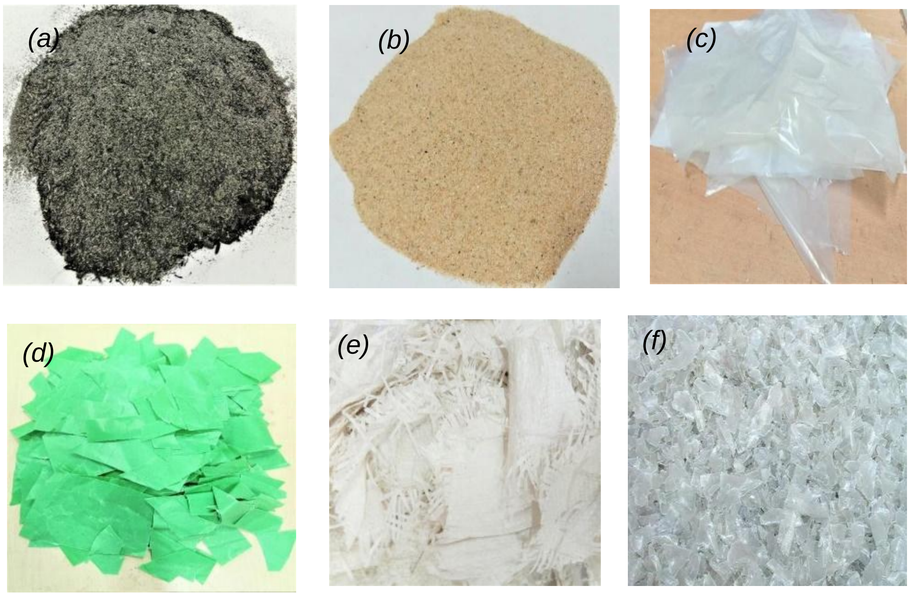

Figure 1. Images of the prepared samples a) Rice husk ash b) Sand c) LDPE d) HDPE e) PP f) PET

Slika 1. Slike pripremljenih uzoraka a) Pepeo od pirinčane ljuske b) Pesak c) LDPE, d) HDPE e) PP f) PET

Table 2. Chemical compositions of RHA

Tabela 2. Hemijski sastavi RHA

Chemical constituents	Sample 1	Sample 2	Sample 3	Mean value
SiO_2	81.04	86.51	78.87	82.14
Al_2O_3	1.80	0.61	1.61	1.34
Fe_2O_3	1.01	0.06	2.20	1.27
CaO	1.60	0.71	1.33	1.21
MgO	2.25	1.53	2.11	1.96
SO_3	0.45	0.02	0.03	0.17
Na_2O	0.16	0.05	0.03	0.17
K_2O	2.35	1.89	2.03	2.09
P_2O_5	5.26	4.20	9.87	6.44
SiO_2+ Al_2O_3 + Fe_2O_3	83.85	87.72	82.68	84.75

2.2. Development of composite

The process flow chart for the specimen development is shown in Figure 2. The raw materials were initially collected from various waste collection stations. The collected thrash plastics were thoroughly cleaned and dried. After that, the processed plastic waste was sorted and shredded into small pieces.

Figure 2. Process flow chart for Specimens preparation

Slika 2. Dijagram toka procesa za pripremu uzoraka

The compositions were prepared by following *Table 3.* The mixture was melted to a semi-solid state. The sand and plastic trash mixture are continuously mixed until a homogenous blend forms. The static compaction process was used to cast the composites. The optical images showed that the fillers are entirely encapsulated and mechanically bound into the polymer matrix. A high concentration of fillers was observed for the samples with 50 % of the matrix as shown in Figure 3 (a & b). Furthermore, observations for the samples with a 70 % matrix show lesser fillers in Figure 3 (c & e) and decreases further with 90 % matrix as seen in Figure 3 (d & f). The polymer segregation became more severe with a higher filler fraction. Moreover, the matrix fills the surface cavities and hold the fillers together by generating a significant interfacial bond strength. Furthermore, because no holes are visible on the surfaces, the entire encapsulation of the filler particles with the matrix is evident ensures the optimal strength at suitable compositions [23]. Figures 4 (a -i) gives the images of the specimens prepared by following the composition as proposed.

Table 3. Composition of the prepared samples

Tabela 3. Sastav pripremljenih uzoraka

S. No.	Sample designation	Material (wt. %)					
		LDPE	HDPE	PET	PP	RHA	Sand
1	LD50S50	50					50
2	HD50S50		50				50
3	LD50PET20S30	50		20			30
4	LD90R5S5	90				5	5
5	HD70R15S15		70			15	15
6	PP90R5S5				90	5	5

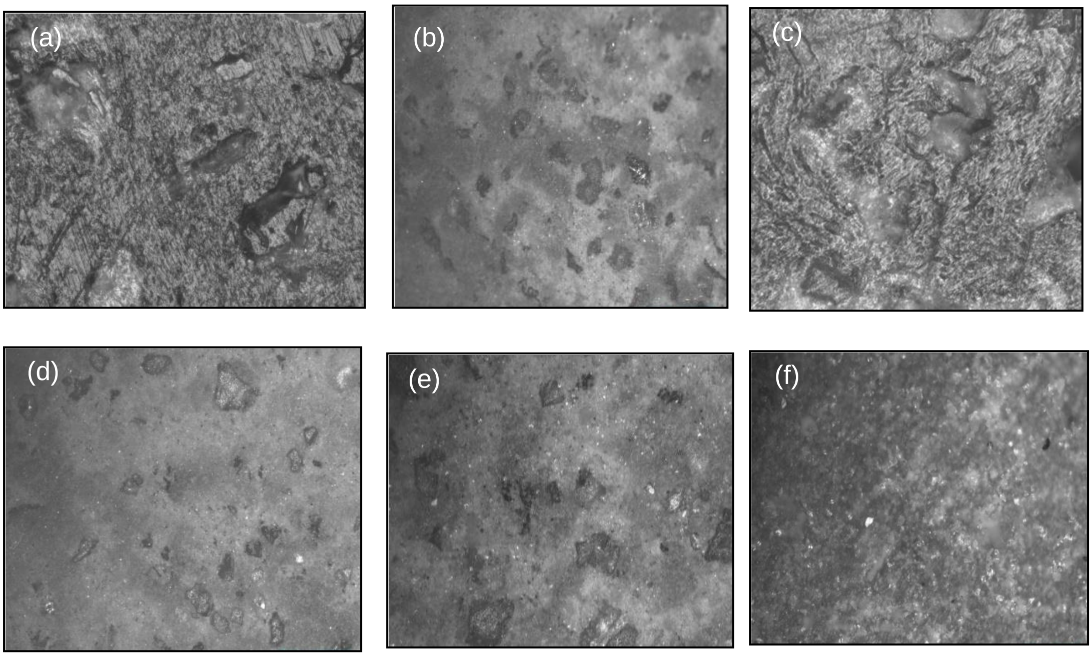

Figure 3. Optical micrographs composites surfaces a) LD50S50, b) HD50S50 c) LD50PET20S30 d) LD90R5S5, e) HD70R15S15, f) PP90R5S5

Slika 3. Optički mikrosnimci kompozitnih površina a) LD50S50, b) HD50S50, c) LD50PET20S30 d) LD90R5S5, e) HD70R15S15, f) PP90R5S5

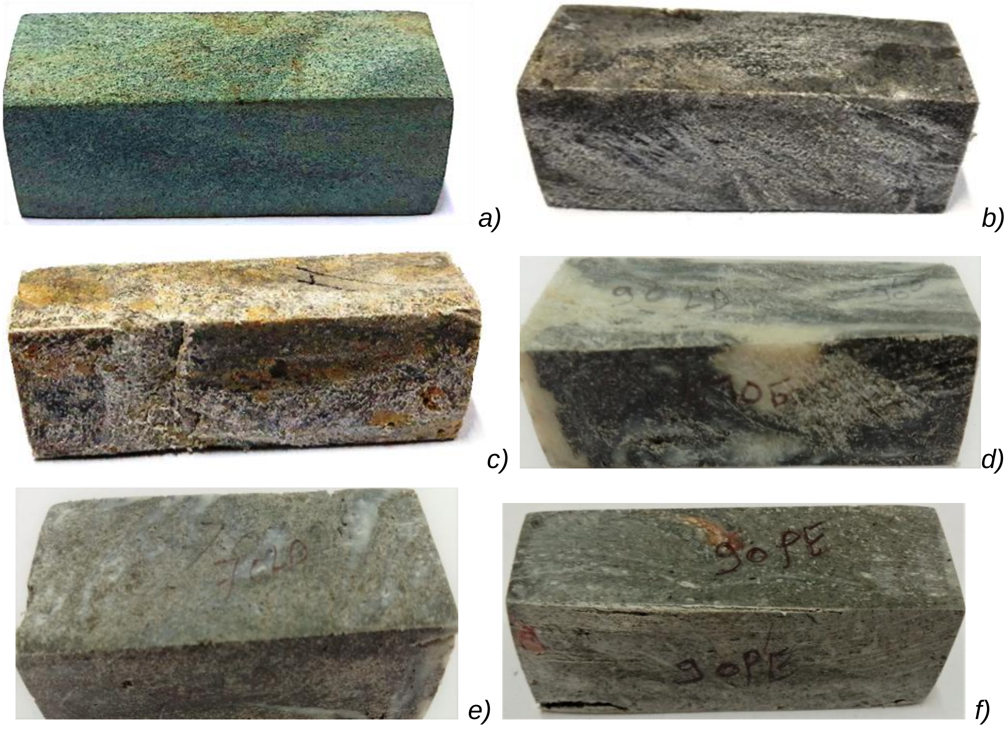

Figure 4. Images of the prepared samples: a) LD50S50, b) HD50S50, c) LDPE50PET20S30, d) LD90R5S5, e) HD70R15S15, f) PP90R5S

Slika 4. Slike pripremljenih uzoraka: a) LD50S50, b) HD50S50, c) LDPE50PET20S30, d) LD90R5S5, e) HD70R15S15, f) PP90R5S

2.3. Characterization of composites

The workability of the composites can be investigated by performing the different characterizations. This sections discusses the mechanical and tribological characterizations performed in the present study.

2.3.1. Compression and flexural strength

To investigate the response of the developed composites against external load, the compressive strength and flexural strength of the composites were evaluated according to ASTM D638 utilizing a compression testing machine. The test specimens are gradually loaded until the fracture point is reached and the maximum load is recorded which gives compressive strength to the specimens. The flexural strength of the composites is evaluated using the hydraulic universal testing machine (model HL59020) with 600 KN capacity by applying a three-point bending load.

2.3.2. Three-body abrasive wear

The abrasive wear test is performed using a Dry Abrasion Tester TR-50 built by DUCOM instrument Pvt. Ltd. The abrasive tests were carried out according to the ASTM G65 standard [24]. The abrasive wear is measured in volume loss (cm^3) under the given set of conditions. The abrasion test was carried out at an applied load of 90.745 N with a sliding speed of 0.3592 m/s. The AFS 60 grade silica sand (density 2.6 g/cm^3 and knop hardness 875) with an angular shape and sharp edges was used as abrasive.

4. RESULTS AND DISCUSSIONS

Table 4 shows the results of the physical, mechanical and tribological properties. The test results of water absorption revealed that the water absorption of the prepared composites samples is less than 5% as shown in Figure 5 indicates that it meets ASTM C140 requirements. The water absorption ranges between 0.1 % and 0.5 %. The ratio of open to closed porosity and the interconnectivity between the surface and inner pores plays an important role in water absorption [25]. The composite LD90R5S5 has the maximum water absorption of 0.5 % due to the low fraction of fillers. Furthermore, when PET with a different granulometry replaces part of the natural sand provides a correct and distinct porosity than the sand since it is the planner and elongated and results in minimum water absorption of 0.0397 % [26,27]. Figure 6 shows the mechanical strength values as compressive and flexural strength. The composition of composites impacts the compressive strength of the composites. The compressive strength was found to improve with the addition of fillers and is agreeable to as reported in earlier studies [28,29]. The minimum and maximum compressive strength values were 5.416 and 46.2 (N/mm^2) for LD90R5S5 and HD50S50, respectively. The poor interfacial transition zone strength between the matrix and fillers increases the air content while insufficient strength due to low fillers content lowers the compressive strength of LD90R5S5 [30,31]. An improvement in compressive strength with matrix replacement could be attributed to the strength of adhesion between the matrix and surfaces of neighboring fillers. This subsequent increase in the surface area improves compressive strength [32]. Therefore, replacing LDPE with HDPE and increasing the fraction of fillers increases the compressive strength, thus resulting in optimum compressive strength for HD50S50. Furthermore, the compressive strength of the generated HDPE composites reduces slightly as the fraction of fillers is reduced from 50% to 30%. The low fillers content is responsible for reducing compressive strength and the behavior is consistent with previous research [33]. The decrease in compressive strength with matrices is attributed due to the weaker strength of the matrices compared to fillers and poor bonding between the matrices and fillers [34,35]. The flexural strength values for the developed composites are LD50S50, HD50S50, LD50PET20S30, LD90R5S5, HD70R15S15 and PP90R5S5 were found to be 5.13, 6.24, 5.96, 3.68, 4.79 and 7.98 (N/mm^2). In the investigation, the flexural strength improves with the replacement of the matrices due to the improved elasticity of the specimen with plastic content and flexural strength improves with HDPE under the same loading of fillers. The findings are consistent with the study that revealed that the addition of RHA to concrete significantly improves flexural strength [36]. Thus, the developed composites have adequate mechanical strength making them appropriate for use as floor tiles. The resulted values of the abrasive wear is given in Figure 7 shows that specimen LDPE50S50 has minimum wear of 0.03267 cm^3. Moreover, the wear resistance of the composites is improved by adding sand particles fillers. The sufficient elasticity of LDPE favors the condition for minimum wear. The hard sand particles are considered to play a significant role in the sliding wear between the rubbing pairs. According to the earlier studies, the wear of the solid materials during abrasion is a complex behavior due to the interdependency of the encountering forces [37,38].

Table 4. Results of the properties

Tabela 4.Rezultati ispitivanja

S No.	Sample designation	Water absorption (%)	Compressive strength (N/mm^2)	Flexural strength (N/mm^2)	Abrasive wear (cm^3)
1	LD50S50	0.3	44.50	5.13	0.03267
2	HD50S50	0.2	46.20	6.24	0.14991
3	LD50PET20S30	0.1	20.81	5.96	0.09287
4	LD90R5S5	0.5	5.416	3.68	0.15625
5	HD70R15S15	0.3	7.501	4.79	0.35793
6	PP90R5S5	0.1	24.39	7.98	0.16771

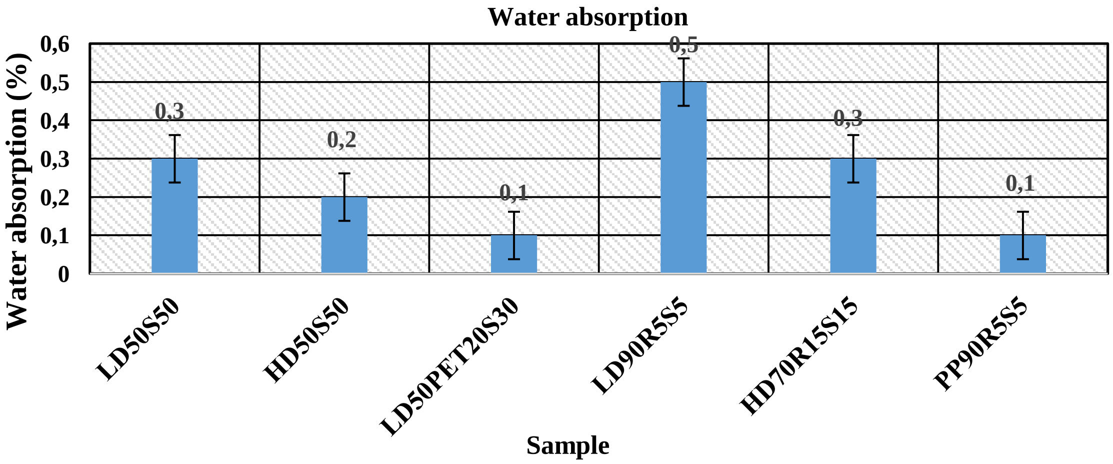

Figure 5. Water absorption of the sample

Slika 5. Upijanje vode uzoraka

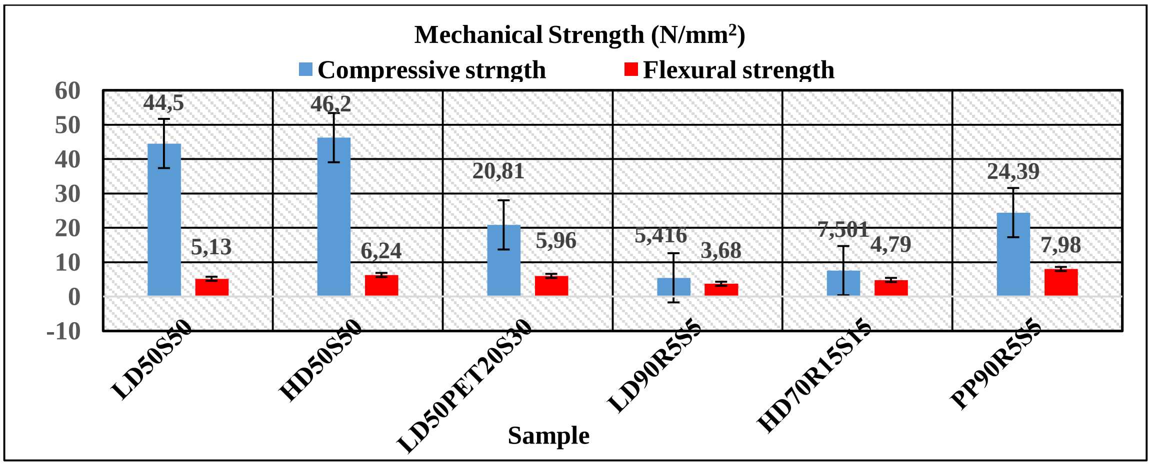

Figure 6. Mechanical strength of the samples

Slika 6. Mehanička čvrstoća uzoraka

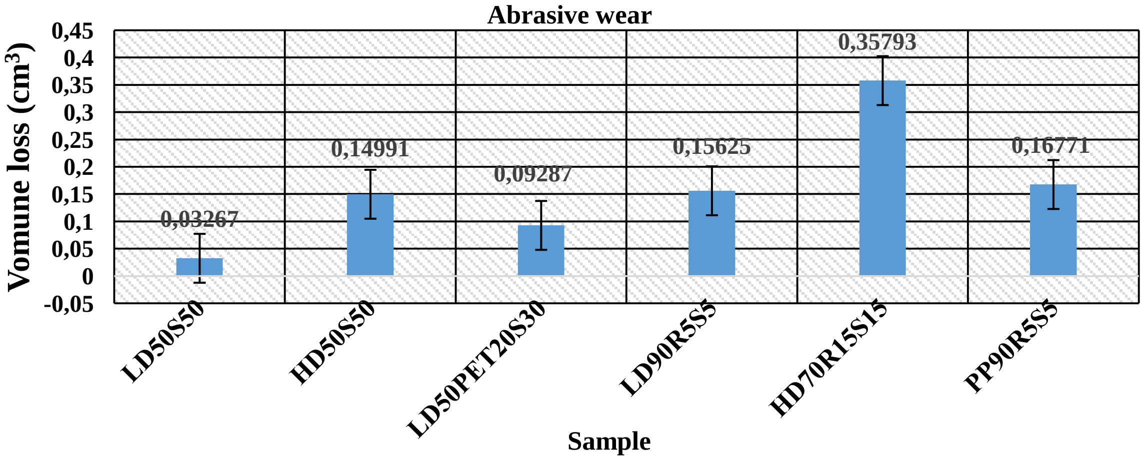

Figure 7. Abrasive wear of the samples

Slika 7. Abrazivno habanje uzoraka

5. CONCLUSIONS

The study successfully demonstrates the development of thermoplastic-based sustainable composites by using plastics waste, which is having applications in building construction materials such as floor tiles. The study increases the economic viability of the waste products by developing value-added products through recycling waste materials. The study shows the perspective for improving environmental health besides providing alternative raw materials for building construction. The microscopic examination verifies the homogeneity of the composites compositions and compactness of the composites structures. The workability of the composites is found to improve with the incorporation of filler. However, the invariability was found due to the interaction of complex forces with the characteristic of composites composition. The water absorption of the developed composites was found satisfactory to use under different ambient conditions. The composite HDPE50S50 results in an optimum compressive and flexural strength of 46.20 N/mm^2 and 6.24 N/mm^2, respectively. The tribological characteristics of abrasive wear were found to be 0.03267 to 0.35793 (cm^3). The results of the tested properties shows the suitability of the developed composites for usage as floor tile. This study will provide a reference for futures research on the development of sustainable polymer-based composites. The study will assist the researchers and scientists working on sustainability. The research will mitigate the problems due to solid waste besides providing a novel alternative building material with reduced cost and weight, therefore contributing to the socio-eco-environmental development of nations. The result of sustainable composites materials with different compositions and investigations remains a future scope of the study.

Acknowledgements

The authors would like to thank Universiti Teknologi PETRONAS, Malaysia for providing resources in conducting this research.

Conflict of interest

The authors declare that there is no conflict of interest to declare.

Data availability statement

All data generated or analysed during this study are included in this published article.

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IZVOD

EKSPERIMENTALNA ISTRAŽIVANJA OBRADIVOSTI ODRŽIVOG KOMPOZITA RECIKLAŽOM OTPADNE PLASTIKE I POLJOPRIVREDNOG OTPADA

Široka primena sirovina u građevinarstvu sa generisanjem stanovništva stalno je povećavala potražnju za svežim sirovinama i izazivala zagađenje životne sredine. Razvoj održivih građevinskih materijala reciklažom različitog čvrstog otpada mogao bi biti održiv pristup za smanjenje problema koji proizilaze iz generisanja čvrstog otpada, pored obezbeđivanja alternativne sirovine za izgradnju zgrada. Ova studija pokazuje razvoj polimernih kompozitnih materijala, kao podne pločice koristeći različite otpadne plastike, uključujući polietilen niske gustine, polietilen visoke gustine, polietilen tereftalat i polipropilen kao matrice sa ugradnjom pepela od pirinčane ljuske i peska kao punila. Obradivost razvijenih materijala je verifikovana eksperimentalnim procenama fizičkih, mehaničkih i triboloških svojstava. Utvrđene su minimalne vrednosti upijanja vode i abrazivnog habanja od 0,0397 % i 0,03267 (cm^3) za kompozite LDPE50PET20S30 i LD50S50, respektivno. Međutim, kompoziti HD50S50 su rezultirali optimalnom mehaničkom čvrstoćom – čvrstoćom na pritisak i čvrstoćom na savijanje od 46,2 i 6,24 (N/mm^2), respektivno. Primećeno je da se obradivost kompozita poboljšava ugradnjom čestica peska. Obim ove studije oslanja se na razvoj metoda i tehnika za dobijanje održivih građevinskih materijala kroz reciklažu čvrstog otpada zajedno sa njegovom karakterizacijom koja pruža laku referencu za preradu čvrstog otpada ka održivosti.

Ključne reči: *karakteristike, zelena proizvodnja, održivi kompoziti, reciklaža, upravljanje otpadom.*

Naučni rad
Rad primljen: 15. 06. 2022.
Rad prihvaćen: 07. 07. 2022.
Rad je dostupan na sajtu: www.idk.org.rs/casopis
