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Utilization of plastic and glass waste mixed with sand as an alternative brick materials

ABSTRACT

Nowadays, the research for innovative approaches to and practices for plastic waste in a circular economy has acquired a big attention. Plastic waste causes a serious environmental pollution concern. Meantime, the cement industry is one of the biggest sources of carbon monoxide and carbon dioxide emissions, which is considered as another environmental challenge to change of climate. All those and others side effects of plastic waste, make the plastic sand glass bricks an attractive alternative material to construction. In this paper, the plastic and glass waste were used at different percentage for replacing cement as a binder to produce non-traditional concretes. The literature review reveals that there is a deficiency of studies that manage the plastic sand glass as a construction material from economic perspective. Plastic sand glass bricks prepared could be a workable solution for combating issues related to solid waste. The results showed that the compressive strength decreased with increasing ratios of plastic to sand. On another hand, it is increased with increasing of sand ratio. Plastic brick prepared poses a density less than the conventional bricks, and acceptable hardness. Low water absorption also reflected that the plastic brick could be used in the construction. TGA and DSC analysis showed that the plastic brick prepared has a good thermal stability and the decomposition is in the limited and acceptable range. Optimization of the two effective variables (plastic/sand and galas ratios) has been made and correlating the results obtained using Box–Wilson statistical method to create a model for describing the predictable properties of a new product.

***Keywords**: material waste, brick industry, compressive strength, hardness*

1. INTRODUCTION

There are millions of tons of plastic and glass waste, which cause environmental pollution. The problem of waste, due to the growing global population, consumerism, and the linear approach to industrialization, has become an increasingly severe issue in the 21st century. Manufacturing of plastic brick from plastic and glass wastes is one of important industrial recycling would be developed in the world. Plastic brick has been contributing to economy and environment solution and will increase its role in the coming years. The compressive and flexural strength, hardness and water absorption of the brick made are the main tests to nominee the product to be one for contributing in some constructions. This type of work before 7 years was not available elsewhere, but in the recent years it got some attention the researchers have developed in the construction area but does not take the serious attention around the world.

Using plastic sand as a construction material toward a circular economy has been searched by [1]. They proved that the compressive strength decreased with increasing ratios of plastic to sand as well plastic sand bricks weighed less than the conventional bricks [2,3] studied the utilization of plastic waste material in masonry bricks production towards strength, durability, and environmental sustainability. Waste plastic bricks produced from blending scrap polyethylene terephthalate plastics and foundry sand. It was observed that the blend of 70% sand and 30% foundry sand of plastic bricks resulted in 42 MPa with approximately 60.31% increase in strength compared to fired clay bricks. Worked on developing plastic sand bricks used in construction. It is found that when the plastic/sand ratio increased, the compressive strength decrease, as well the plastic sand brick was lighter

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in weight and contained no alkali. Moreover, the thermal conductivity of the plastics brick fell down.

Development of sand-plastic composites as floor tiles using silica sand and recycled thermoplastics has been investigated by [4]. The research explored the potential of waste plastics and silica sand for developing thermoplastic composite as floor tiles. The maximum compressive and flexural strength were found to be 46.20 N/mm^2 and 6.24 N/mm^2 , respectively, with the minimum water absorption and sliding wear rate of 0.039 % and 0.143 $\times 10^{-8}$ kg/m, respectively. Recycling waste plastic bags as a replacement for cement in production of building bricks and concrete blocks has been studied by [5]. The results obtained from the flexure test showed that the bending moment and thus the bending stress increased with increasing the plastic content in both the bricks and concrete blocks. The results also showed that the thermal conductivity fell with increases in the plastic content of both the bricks and concrete blocks. Recent trends in utilization of plastics waste composites as construction materials has been reviewed by [6]. Their paper gathered many researchers who have tried to developed a new brick using plastics waste in concrete along with sand, clay, sawdust, rice husk, and other fillers are detailed.

S. David and all. [7] conducted an experimental study to examine the mechanical behavior of rubberized concrete with waste clay brick powder under different conditions of curing including water and sea water. The findings showed that the conventional and modified concrete mixtures which were cured in sea water illustrated reduced compressive and split tensile strengths compared with corresponding mixes cured in water. Various studies [8-11] confirmed that plastic sand bricks with certain plastic to sand ratios provide a good nonbearing alternative to conventional bricks and concrete blocks, especially in terms of compressive strength, maximum load crushing, water absorption, and efflorescence testing. The recycling plastic waste to reduce pollution, researches have been conducted on using plastic and sand to produce alternative bricks and blocks [12-14].

Due to the scarcity of the research in this field, this work is considered to have a great economic value as it deals with solid waste management to produce alternative materials in the world of traditional building materials.

2. MATERIALS & METHODS

2.1. Materials

The materials used in this work are plastic waste, glass waste, and fine sand. The plastic waste was collected from area around Taiz city, cleaned, dried and cutting to desired small size using grinding machine (model PTL5100) is available at Engineering Faculty, Taiz University. Table 1 shows the types of the plastic waste used in this study, all types were mixed with the sand and glass with different percentages. The glass waste was also collected from Taiz city and was crashed into particle size of 600 to 700 µm using crushing machine. The sand was taken from around the university where it is clean and different sizes not more than 1800 µm. The chemical composition of the sand (wt%) are depicted in Table 2. The typical sample prepared is shown in Fig.1.

Table 1. Types, physical and thermal properties of plastic waste used

Tabela 1. Vrste, fizička i termička svojstva korišćenog plastičnog otpada

Material	HDPE	LDPE	PET
Type	Thermoplastic	Thermoplastic	Amorphous thermoplastic
Density (kg/m^3)	945	923	1380
Melting point (^oC)	136	115	255
Thermal conductivity (W/M.K)	0.46	0.37	0.22

Table 2. Chemical composition of the sand (wt%)

Tabela 2. Hemijski sastav peska (tež.%)

SiO_2	CaO	MgO	Al_2O_3	Fe_2O_3	K_2O	Na_2O	Impurities
75.45	5.36	0.978	3.50	6.81	4.69	2.56	0.65

2.2. Compressive strength

The compressive strength test was determined according to ASTM C39/C39M guidelines. A number of 9 casting cylinders with size 50 × 50 mm were casted with the mixture following by pressure to remove any void and left at a dry place for 4 days until test. The compressive strength of all samples was evaluated by a compression testing machine of 100 kN capacity.

Figure 1. The samples prepared

Slika 1. Pripremljeni uzorci

2.3. Hardness test

The Brinell hardness tests was performed according to ASTM E10, where a hard, and spherical indenter is subjected into the surface of the material to be examined. The diameter of the hardened steel indenter is 12 mm. Standard loads range between 20 and 100 kg in 10 kg increments; during a test, the load is maintained constant for a period between 10 and 30 s. According to Eq.(1), the hardness can be assigned.

$$HB = \frac{2F}{\pi D\left(D-\sqrt{D^2-d^2}\right)} \quad (1)$$

Where *F* (N) is the force applied to the specimens, *D* id the diameter of the indenter, and *d* is the diameter of the hole penetrated by the indenter (indentation). We have found that the measuring of the hardness of the plastic brick prepared using Brinell is more better than the Durometer (Shore durometer) because it is not pure plastic that the Shore durometer is suitable technique for hardness test.

2.4. Water Absorption and resistance to abrasive

Water absorption test was performed according to ASTM D570. The specimens with dimension of 60×60×5 mm were prepared for the test. The specimens were dried in an oven at 70^{o}C for 6 hours then placed in an desiccator to cool. Instantly, the specimens were weighed. The specimens were then immersed in a distilled water at agreed 23°C for 72 hours or until equilibrium. Specimens are removed, patted dry with a lint free cloth, and weighed again. Eq.(2) is used to obtain the water absorption:

$$WA\,\% = \frac{(W_2-W_1)}{W_1} \times 100 \quad (2)$$

Where *WA* % is the water absorption percentage, W_1 is the mass of dry brick and W_2 is the mass of wet brick.

Standard test method for abrasion resistance of plastic brick carried out according to ASTM C418 by sandblasting over 60×60×5 mm. The abrasion resistance characteristics of material by subjecting it to the impingement of air-driven silica sand was determined. A specimen is placed with the surface to be tested at a distance of 3 in from the nozzle. The specimen is then clamped, and a shield is attached. Sand is blasted on the test surface for a period of 1 minute. Finally, the specimen is weighed, and the difference between the initial and final weigh is the mass loss due to the abrasion.

2.5. Bulk density

This test was examined according to the ASTM C138. The bulk density was determined by dividing the total mass of fabricated plastic brick on the volume of the specimen itself, Eq.(3):

$$\boldsymbol{\rho} = \frac{\boldsymbol{m}}{\boldsymbol{V}} \quad (3)$$

2.6. TGA and DSC Analysis

To evaluate the thermal characteristics of plastic brick due to the existence of the plastic as a binder for the sand and glass powder, the thermo gravimetric analysis (TGA) and differential scanning calorimetry (DSC) analysis were used using a Mettler Toledo instrument. Under nitrogen atmosphere with a flow rate of 20 mL/min, the optimized plastic brick and the reference of plastic waste were heated at a rate of 10°C/min to 600°C. The DSC was carried out using samples of 6 mg where they were placed in the aluminum pan and heated between 22°C and 200°C at a rate of 10 °C/min under nitrogen atmosphere maintained with volumetric flow rate of 20 mL/min. The plastic brick samples were then heated to 200°C for the first scan, and then cooled to 22°C at the same pace. The crystallization temperature and the melting temperature were calculated from the DSC thermograms.

2.7. Box-Wilson statistical method for the experimental results of compressive test

In general, the purpose of an experimental design is to find useful relationships between independent (plastic/sand and glass weight percentage) and observed response (Compressive strength). A second order polynomial mathematical model is employed to the present work using the following equation:

$$\sigma = b_\circ + \sum_{i=1}^{p} b_i X_i + \sum_{i=1}^{p} b_{ii} X_i^2 + \sum_{i,j}^{p} b_{ij} X_i X_j \qquad (4)$$

where

b_o, b_i, b_{ii} and b_{ij} are constant as coefficient for independent variables. The relationships between the coded variables and the corresponding real variables are as follows:

$$x_{Coded} = \frac{(X_{Actual} - X_{Centre})}{(X_{Centre} - X_{Minimum})} \times \sqrt{p} \qquad (5)$$

where

X_{Actual} is X_1 (Plastic Sand ration by mass), X_2 (percentage of the glass waste by mass), the center values, $X_{center} = \frac{(X_{Min} + X_{Max})}{2}$ for the given ranges, and p is the number of variables (in this statistical work, it is 2, which are PSR and G). The number of experiments (N) was estimated as follows:

$$N = 2^p + 2p + 1 \rightarrow N = 2^2 + 2 \times 2 + 1 = 9 \qquad (6)$$

3. RESULTS AND DISCUSSION

3.1. Compressive strength

Compressive strength test for the plastic sand glass brick at different ratio of waste plastic/sand/waste glass has been investigated. Nine tests were examined in order to emphasize the quality of the new bricks as shown in **Table 3**. **Fig.2** obviously states that the compressive strength significantly is dependent on the existence of the sand. Moreover, the effect of glass is slight and limited. It seems that the plastic acts as a binder and its effect on compressive strength is also remarkable. It is found that the best percentage of mixture is 3:4:1 plastic to sand to glass which gives a compressive strength of 7.45 MPa.

Table 3. Compressive strength and bulk density test varied with different plastic-sand- glass ratio

Tabela 3. Test čvrstoće na pritisak i zapreminsku gustinu varirao sa različitim odnosom plastika-pesak-staklo

Sample No	Plastic: Sand: Glass	Compressive Strength (MPa)	Bulk density Kg/m^3
1	2:2:1	5.22	1208
2	2:3:1	6.08	1285
3	3:2:1	5.55	1140
4	3:3:1	5.78	1210
5	4:3:1	5.16	1158
6	4:4:1	6.54	1208
7	3:4:1	7.45	1262
8	3:5:1	6.90	1305
9	3:4:2	6.93	1267

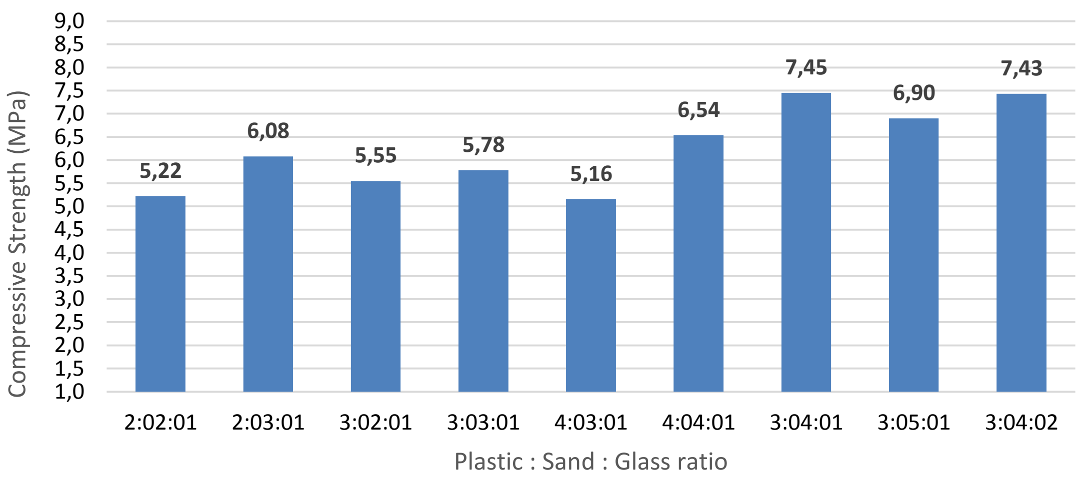

Figure 2. Compressive strength as a function of plastic : sand : glass ratio

Slika 2. Čvrstoća na pritisak u funkciji odnosa plastika : pesak : staklo

3.2. Water absorption and abrasive resistance

Water absorption tests as a function of plastic to sand and glass ratio according to ASTM -D570 are presented in **Fig.3**. It is shown that the positive affect on the water absorption comes from the plastic material because it acts as a binder to prevent the water penetration. Remarkably we can see that adding the glass has a little bit improvement in water absorption, and economical applications no value added by adding the glass comparing to the optimized sample of 7.45 MPa. The optimized sample of 18.79 HB hardness only has been examined for abrasive resistance. The percentage weight loss was found as 0.011 g/(cm^2 .min) for abrasion process period of 1 minute on the surface area of 36 cm^2 (60 × 60 mm). It is found that the abrasive resistance of the sample prepared is reasonable comparing to the concrete brick. The results give us impression that the more difficult the material deforms in contact with a particular abrasive, the better the abrasion resistance.

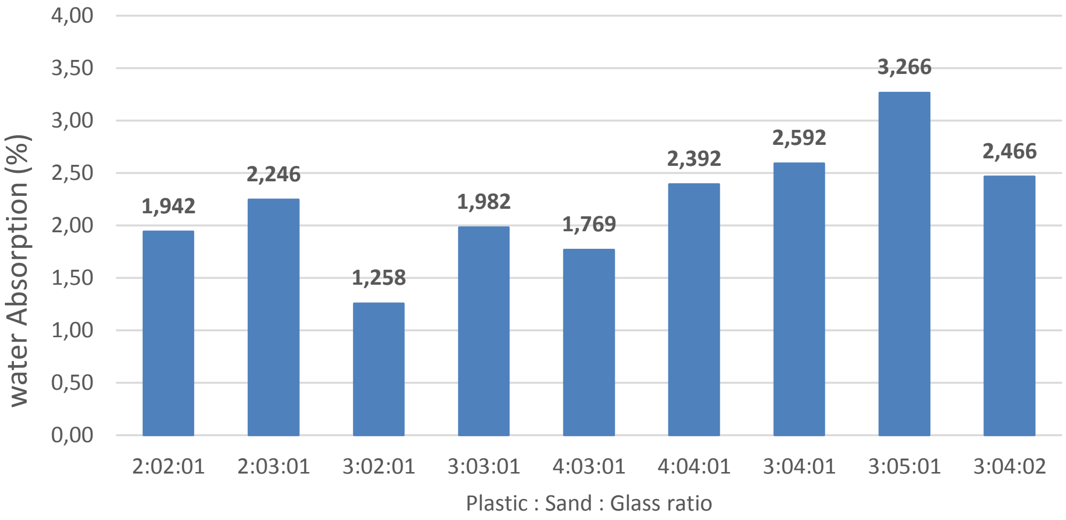

Figure 3. Water absorption test as a function of plastic: sand : glass ratio

Slika 3. Test upijanja vode u funkciji odnosa plastika : pesak : staklo

According to the Table 4, it is found that plastic brick prepared in this work has a good resistance to water absorption than fly ash brick and burnt brick.

Table 4. Water absorption of plastic brick comparing with standard bricks

Tabela 4. Upijanje vode plastične cigle u poređenju sa standardnim ciglama

Type of Brick	Water Absorption (%)
Fly ash brick	8.012 [100]
Burnt brick	9.086 [200]
Plastic sand glass brick	2.592*

Optimized plastic brick prepared due to the compressive strength*

3.3. Hardness

The hardness of the produced samples has been investigated and the results are depicted in Fig. 4. It is remarkable that the hardness increased as the sand increases for all sample. Due to the sand poses a good toughness, the plastic brick acquires a good hardness. Meanwhile. It is observed that the highest hardness, in the presence of the same ratio of plastic and sand, is caused by glass powder. Moreover, the well mixing has a significant result in the term of hardness and little deformation of the sample in the applications life. There is a limitation of the ratio of the sand since beyond this limitation, the hardness decreased because the matrix becomes out of the suitable volume and gets over bed. On the other hand, the ratio of 3:5:1 has the lowest hardness as shown the Fig. 5.

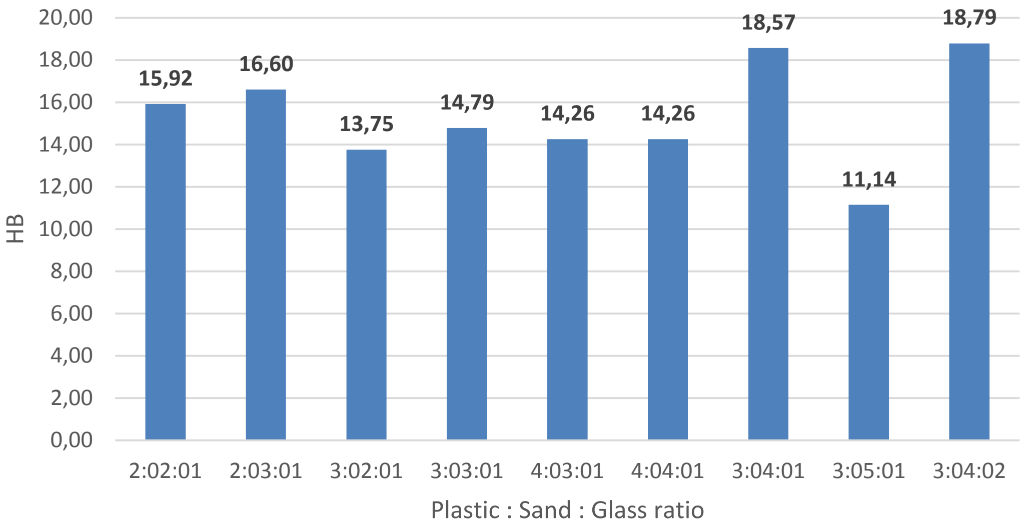

Figure 4. Hardness of the plastic brick prepared in the load of 500 N (50.97 kg)

Slika 4. Tvrdoća plastične cigle pripremljene pri opterećenju od 500 N (50,97 kg)

3.4. Bulk density

The densities of the plastic brick at various ratio of plastic, sand, and glass powder are figured out in Table 1, and represented in Fig.5. Obviously, the density increased with increasing the sand, this attributed to the heaviest weight of the sand among the other components. It can be noticed that a little pit effect in the presence of glass powder. The density has a significant role in the economics of the construction, hence this work try to manufacture a lighter product than the conventional brick used in the road pavement.

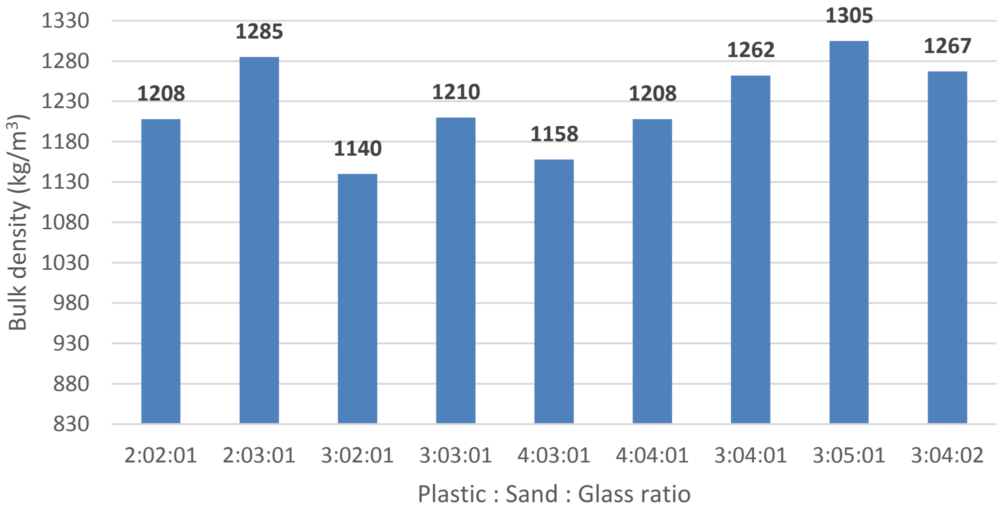

Figure 5. Bulk density of the plastic brick prepared at different ratio of plastic, sand, and glass powder

Slika 5. Zapreminska gustina plastične cigle pripremljene u različitim odnosima plastike, peska i staklenog praha

3.5. TGA

TGA analysis is used to evaluate the thermal stability of weight loss of the materials against temperature. Fig. 6 shows the weight loss of the plastic free sand and plastic brick prepared with temperature. The plastic waste incorporated with sand and glass is significant stability more than that of plastic waste free of sand. At the temperature of 80 ^{o}C, the stability behavior for both samples is the same. The sand and glass powder increase the resistance to endo energy between the molecules of new sample which leads to higher thermal stability.

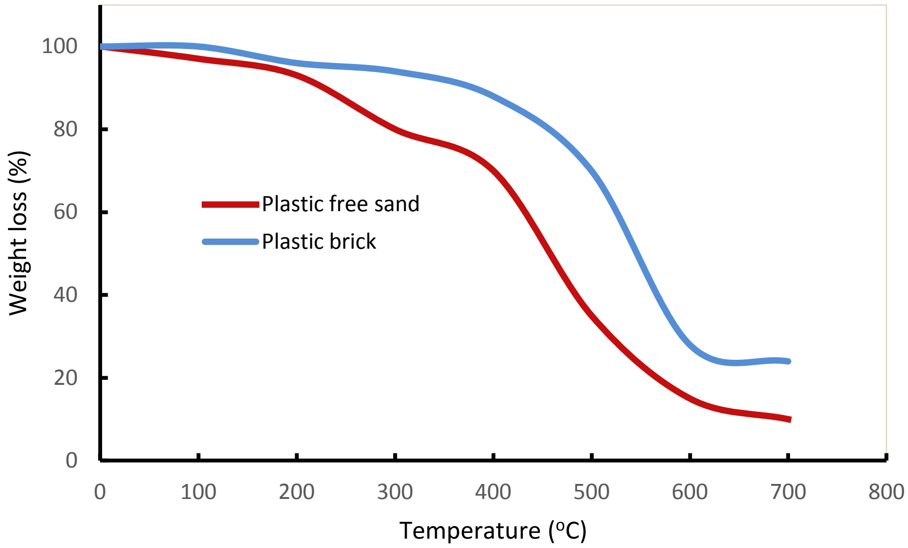

Figure 6. TGA for plastic free sand and Plastic brick sample- Weight loss percentage as a function of temperature

Slika 6. TGA za pesak bez plastike i uzorak plastične cigle – procenat gubitka težine u funkciji temperature

3.6. DSC

The DSC curves of the Plastic waste free sand and the optimized plastic brick prepared are shown in Fig. 7. Obviously, it is shown that the melting temperature in matrix of plastic waste with sand and glass powder are higher than that of plastic waste free of sand. The peaks of melting temperature for the plastic brick and plastic free sand are 200 °C and 160 °C, respectively, indicating the stability of the plastic brick prepared.

The enhancement in thermal stability may be attributed to the presence of the sand and glass powder that led to improve the adhesion between the plastic waste molecules meanwhile makes the mobility of plastic chains hard. All this can act as a resistance of absorbed energy. On the anther hand the energies absorbed in the plastic brick and plastic waste free of sand are 190 mW and 230 mW, respectively, indicating that the decomposition for the plastic brick is not readily.

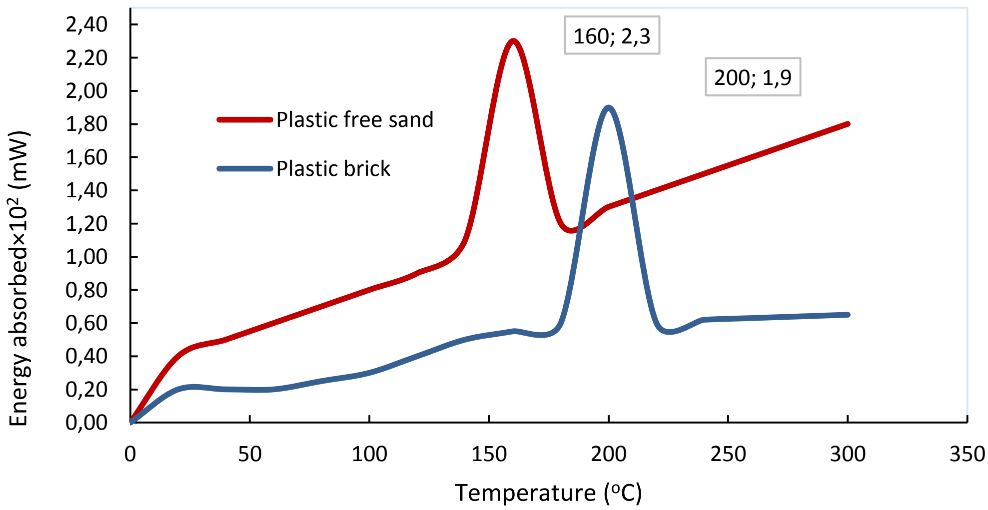

Figure 7. DSC for plastic free sand and Plastic brick sample- Energy absorbed as a function of temperature

Slika 7: DSC za pesak bez plastike i uzorak plastične cigle - Apsorbovana energija kao funkcija temperature

3.7. Correlation with statistical analysis

Rewriting Eq. (4) for the two variables (compressive strength and ration of sand to glass) in the present work as follows:

$$\sigma = b_\circ + b_1x_1 + b_2x_2 + b_3x_1x_2 + b_4x_1^2 + b_5x_2^2 \qquad (7)$$

The design of the coded data has the properties that $\sum x_i/N = \sum x_i x_j/N = 0$ and $\sum x_i^2/N = 0.889$, then eq. (7) can be rearranged as follows:

$$B_\circ = b_\circ + 0.889 \times b_4 + 0.889 \times b_5,$$

By substituting $b_\circ$ into eq. (7) one obtains,

$$\sigma = B_\circ + b_1x_1 + b_2x_2 + b_4(x_1^2 - 0.889) + b_5(x_2^2 - 0.889) \qquad (8)$$

$$\sigma = B_\circ + b_1x_1 + b_2x_2 + b_4r_1^2 + b_5r_2^2$$

$$: r_1^2 = x_1^2 - 0.889$$

$$b_i = \sum x_i \times \sigma_i / \sum x_i^2 \qquad (9)$$

The σ can be calculated from Eq. (5) after substituting B_o and b_i. Table 5 shows coded and real variables, σ calculated and error which were conducted according to Box-Wilson method and the experimental response was represented by the measured σ. The analysis of variance F-value was used for testing the significance of each effect in eq.(10). The values of degree of freedom ($\gamma = N - 6, N = 9$) then γ is 3 and the experimental error variance ($S_r^2 = \sum_i^N e_i^2/\gamma$) is 0.97, respectively. The estimated variance of coefficients, ($S_b^2 = S_r^2/\sum X_i^2$) was determined. The values are presented in Table 6. By using confidence level of 0.95 ($F_{0.95}$), after substituting the values of B_o and b_i in eq. (7):

$$\sigma = 5.66 + 0.801x_1 - 0.085x_2 - 0.271x_1x_2 + 0.245r_1^2 - 0.011r_2^2 \qquad (10)$$

$$: r_i^2 = x_i^2 - 0.889$$

Table 5. Conducting the real variable PSR, G and measured Compressive Strength by experiment and calculated Compressive Strength by the model.

Tabela 5. Sprovođenje realne promenljive PSR, G i izmerena pritisna čvrstoća eksperimentom i izračunata čvrstoća na pritisak po modelu

Run No.	Coded variables		Real variables to run the experiment		[a] σ_m (Mpa)	[b] σ_{cal} (MPa)	e_i (MPa)
	x_1	x_2	PSR (by mass)	G % (by mass)			
1	-1	-1	1.000	1	5.22	4.55	0.67
2	1	-1	0.667	1	6.08	5.81	0.27
3	-1	1	1.500	1	5.55	4.94	0.61
4	1	1	1.000	1	5.78	6.28	-0.5
5	-1.41	0	1.333	1	5.16	4.05	1.11
6	1.41	0	1.000	1	6.54	6.24	0.3
7	0	-1.41	0.750	1	7.45	7.75	-0.3
8	0	1.41	0.600	1	6.90	7.02	-0.12
9	0	0	0.750	2	7.43	6.84	0.59
							$\sum e_i^2 = 2.92$

[a]compressive strength measured, [b]compressive strength calculated from equation

Table 6. Analysis of variance of variable effects

Tabela 6. Analiza promenljivih varijabilnih efekata

Effect	$\sum X_i^2$	$\sum \sigma_m \times x_i$	$b_i = \sum x_i \sigma_m / \sum x_i^2$		$S_b^2 = S_r^2/\sum x_i^2$	F-value (b_i^2/S_b^2)	$F_{0.95}$ =0.101
x_0	9.0	56.11	$B_\circ$	6.23	–	–	–
x_1	8.0	3.04	b_1	0.38	0.12	1.19	S
x_2	8.0	-0.75	b_2	-0.09	0.12	0.07	US
x_1x_2	4.0	-0.63	b_3	-0.16	0.24	0.11	S
[a] r_1^2	4.889	-3.99	b_4	-0.82	0.20	3.36	S
[a] r_2^2	4.889	1.28	b_5	0.26	0.20	0.34	S

[a] $r_i^2 = x_i^2 - 0.889$, S: Significant; NS: Not Significant

This equation represents the best form of mathematical model which correlates the σ with three variables in terms of the coded variables. The real values were determined using eq.(5). An equivalent in terms of actual variables will be more useful in the estimation of compressive strength (σ) of fabricated plastic brick at any desired conditions. The optimum condition of variables was found by taking the first derivative for eq.(11 or 12) for the dependent variables which are taken with respect to x_1 and x_2 ,

$$\frac{\partial\sigma}{\partial x_1} = 0 \quad \textit{and} \quad \frac{\partial\sigma}{\partial x_2} = 0 \qquad (11)$$

The two equations obtained with two unknowns can be solved by using MATLAB software. The real values were obtained by substituting eq. (5) in eq.(10) to obtain general mathematical model represents the compressive strength at the :

$$\sigma_{cal} = 6.23 + 0.25PSR + 0.427\,G -$$

$$-0.085(PSR)(G) + 0.1695(PSR)^2 \qquad (12)$$

where PSR is the plastic to sand ratio and G is glass powder weight percentage.

4. CONCLUSIONS

The management of solid waste is global challenge. Recycling the plastic waste to plastic brick using sand and glass powder materials is one of the solutions for those challenge. In this work, the possibility making a new brick consists of plastic waste as a binder incorporated with sand and glass powder was investigated. The compressive strength, hardness, abrasive resistance, water absorption, TGA, and DSC for the new brick have been examined. The compressive strength of the plastic brick prepared increased with increasing the sand to the limit value, beyond this value no further improvement. The density of the plastic brick found better at the ration of 3:2:1 for plastic waste, sand, and glass powder, respectively. The optimized water absorption for the sample was 1.258%, indicating that the plastic brick could be used for construction in rainy environment. The optimized plastic brick possesses a good thermal stability to be sustainable in the hot conditions. The experimental results obtained were well correlated using Box-Wilson statistical method.

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IZVOD

KORIŠĆENJE PLASTIČNOG I STAKLENOG OTPADA POMEŠANOG SA PESKOM KAO ALTERNATIVNI MATERIJALI OD CIGLE

U današnje vreme, istraživanje inovativnih pristupa i praksa za plastični otpad u cirkularnoj ekonomiji dobija veliku pažnju. Plastični otpad izaziva ozbiljnu zabrinutost zbog zagađenja životne sredine. U međuvremenu, industrija cementa je jedan od najvećih izvora emisije ugljen-monoksida i ugljen-dioksida, što se smatra još jednim ekološkim izazovom promene klime. Sve te i druge nuspojave plastičnog otpada čine plastične peščane staklene cigle atraktivnim alternativnim materijalom za izgradnju. U ovom radu plastični i stakleni otpad korišćeni su u različitim procentima za zamenu cementa kao veziva za proizvodnju netradicionalnih betona. Pregled literature otkriva da postoji nedostatak studija koje upravljaju plastičnim peščanim staklom kao građevinskim materijalom iz ekonomske perspektive. Pripremljene plastične staklene opeke od peska mogu biti izvodljivo rešenje za borbu protiv problema u vezi sa čvrstim otpadom. Rezultati su pokazali da se čvrstoća na pritisak smanjuje sa povećanjem odnosa plastike i peska. S druge strane, povećava se sa povećanjem odnosa peska. Pripremljena plastična cigla ima gustinu manju od konvencionalne cigle i prihvatljivu tvrdoću. Niska apsorpcija vode je, takođe, pokazala da se plastična cigla može koristiti u konstrukciji. TGA i DSC analize su pokazale da pripremljena plastična cigla ima dobru termičku stabilnost i da je razlaganje u ograničenom i prihvatljivom opsegu. Urađena je optimizacija dve efektivne varijable (odnos plastika/pesak i galas) i korelacija rezultata dobijenih primenom Bok-Vilson statističke metode za kreiranje modela za opisivanje predvidljivih osobina novog proizvoda.

Ključne reči: *materijalni otpad; Industrija opeke; jačina pritiska; tvrdoća*

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