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# Mechanical and Thermal Properties of Interlocking Bricks Utilizing Wasted Polyethylene Terephthalate

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## Abstract

Plastic bottles are non-biodegradable material made up of Polyethylene Terephthalate (PET) and takes around 450 years to get decomposed. In Malaysia, near 13.2% of plastics contribute to municipal solid waste, where 2.5% is PET. To reduce the waste, interlocking bricks manufacture by waste plastic bottles are used to replace the conventional bricks that use cement and clay. The purpose of this research is to reuse plastic bottles comprised of Polyethylene Terephthalate and Polyurethane binder, by manufacturing interlocking brick that helps to reduce the waste on landfills and the pollution. The plastic bottles were shredded and grinded to a size of 0.75 mm and mixed with the Polyurethane (PU) and the Polymer. The mixed later casted and compacted in the interlocking brick machine mould. The tests performed on the interlocking bricks were compressive strength, impact, flexural strength and thermal conductivity for obtaining the mechanical and thermal properties. The tests values were then keyed into the Response Surface Methodology (RSM) to obtain the optimal PET and PU to verify reliability. Based on the results it is concluded that PET/PU of 60/40 ratio is suitable as non-load bearing masonry brick and recommended to be used as partition walls.

**Keywords:** polyethylene terephthalate, polyurethane, mechanical and thermal properties, RSM

## 1 Introduction

Plastic bottles are made up of thermoplastic polymer known as Polyethylene Terephthalate (PET). It is one of the largest and most problematic sources of waste as it is affordable, lightweight and sturdy material, which can be moulded into a wide range of products. As a result, the generation of plastic waste has expanded significantly in the recent years. Dumping plastic wastes in the landfills is not encouraged due to its bulk and slow degradation rate (Hopewell et al. 2009). However, other than the land-filling and stockpiling, incineration processes can be conducted to break down plastic to generate energy, but the high temperature can produce high-calorie energy, where its combustion generates harmful gases which affect both

human health and the environment. In addition, the vast amount of plastic produced yearly is used for packaging disposable items or other fleeting items which are discarded within a year of manufacture. This scenario causes accumulation of discarded plastic as debris in landfills and oceans. These two perceptions alone demonstrate that our present utilization of plastic is not economical (Saikia et al. 2014). Recycling the plastic is one of the most prominent method to diminish these effects by constructing various useable objects (Hopewell et al. 2009).

The generation of Polyethylene Terephthalate (PET) is higher than recovery and due to this large gap, an innovative approach to encourage high recycling of the material is recommended. PET has a property of low modulus synthetic fibres along with other fibres sharing the similarity such as polyethylene, nylon, and polyester. However, PET bottles are being experimented to produce a non-load bearing product and partition walls in many

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parts of the world (Chowdhury et al. 2013). The possibility of PET plastic bottles to be used as building material exist and it is also significant for sound insulation (Joravia and Parikh 2015). Many researchers have included plastic in their research in the aim of reducing PET plastic waste, which causes a reduction in shrinkage cracking but not so effective in increasing tensile strength (Foti 2011). However, there is a lack of research related to the incorporation of polyethylene terephthalate and polyurethane binder moulded together to form an interlocking bricks (Chowdhury et al. 2013).

As part of sustainable development, flourish technologies and researchers lead to the alternative construction materials to the cement which cannot be de-emphasized (Mousavi 2016). Polystyrene is used in various fields mainly packaging of industrial and food products. Expanded polystyrene beads are stiff cell plastic material, produced from moulding of tiny pearls, showing a closed structure and made up of thermoplastic with trapped air in a 96–98% proportion of the volume of pearls (Sayanthan et al. 2013a; Aciu et al. 2015).

Plastic bottles infilled with sand, soil, fly ash or any other material gives higher compressive strength as compared to the traditional bricks but requires binding material, mainly cement to form a structure (Sharma 2017; Shoubi et al. 2013). Due to the low cost and effectiveness, masonry infill has been extensively utilized as construction material (Vincent Sam Jebadurai et al. 2019). Whereas the engagement of interlocking brick is developing notoriously around the world due to the mortarless brick construction concept, where mortarless methods demonstrate the accompanying points of interest such as increased construction productivity, labour intensive, reduction in construction duration and reduced overall construction cost. In view of its innovative coherence and considering the local source dependence, the mortarless-brick development progressively fits into the local communities easier than conventional mortar-brick techniques (Kintingu 2009). The interlock between bricks provides a very accurate assembly and a neat finishing during construction of buildings. The installation is continued similar to an ordinary clay brick but does not use mortar because these bricks are shaped with projected parts, which fit exactly into depressions in the bricks placed above and automatically aligned vertically and horizontally (Malahayati et al. 2018). Except for mortarless formation and a better visual effect of interlocking brick, it is also convenient for those places where the availability of natural quarry is low, making it more suitable to be used as compared to the infilled plastic bottles which mainly requires sand or soil and also binding material.

In Carrasco et al. (2013) study the performance of walls constructed with interlocking bricks were evaluated. The interlocking bricks were made in a mixture of iron ore tailings, cement and water and put through a simple compressive loading. Compressive strength tests are conducted to determine the capability of a material or structure to withstand vertically projected stress. Test specimens were crushed and the results from the study concluded that mixing iron-ore tailings enhanced the compressive strength. The iron tailing infused mix design met a high compressive strength of 14.57 MPa for bricks, 9.8 MPa for prisms and 25.3 MPa of the mortar. The wall demonstrated a good mechanical strength of 2.05 MPa, which portrays 14% of the brick strength. However, the deformation was higher than the usual axial deformation modulus of 420 MPa, indicates the flexural behaviour of the wall. Watile et al. (2014) used various mixed designs that incorporate varying percentages of fly ash, stone dust and sand with a man-made fire, Glass Reinforced Polymer (GFRP) as a reinforcing material to produce interlocking bricks.

Al-Fakih et al. (2018a) studied the crumb rubber used in geopolymer interlocking bricks. Crumb rubber is obtained from the disposal of scrap tyres and discarded scrap tires pose critical environmental concerns worldwide due to major drawbacks (Mui et al. 2004; Al-Fakih et al. 2020). Therefore, utilizing crumb rubber as a replacement of fine aggregate in geopolymer interlocking bricks is a novel approach to solve the burdening scrap tyres problem worldwide. The rubberized geopolymer interlocking brick comprises sodium hydroxide, crumb rubber, alkaline solution, and sodium silicate. Response Surface Methodology (RSM) and Face Centered Central Composite Design (FCCCD) were used to develop the mathematical models for 28 days' compressive strength. The trial mixes were tested for compressive strength, water absorption, modulus of rupture and efflorescence test. It was concluded that the average compressive strength was 3.98 MPa, and the interlocking brick was classified as a non-load bearing brick according to BS 3921. Where the modulus of rupture was comparatively low (Al-Fakih et al. 2018a, b). However, the study did not discuss the flexural properties and other major parameters.

Therefore, this study aims to determine the mechanical and thermal properties of interlocking bricks incorporating PET and polyurethane binder by using the RSM, as PET plastic bottles take a longer time to decompose. In the study, ground plastic is been used in making the interlocking brick which won't change its properties.

## 2 Methodology

### 2.1 Materials

To formulate the mix proportions for the interlocking bricks, the materials used were:

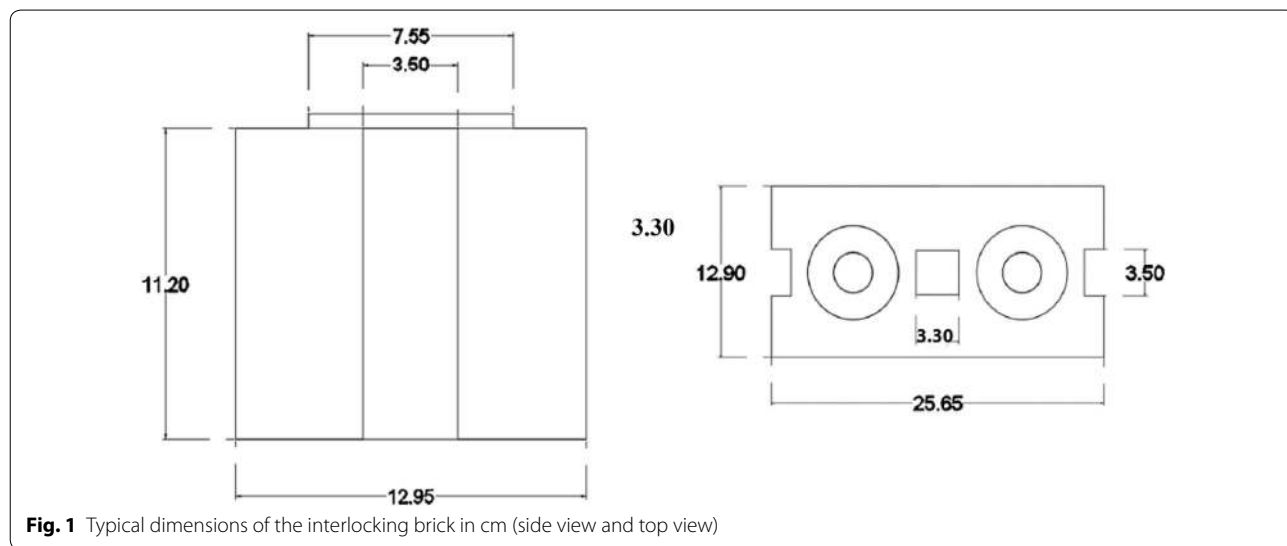
- i. Ground polyethylene terephthalate (20%, 40%, 60%, 80%).
- ii. Polyurethane binder (20%, 40%, 60%, 80%).

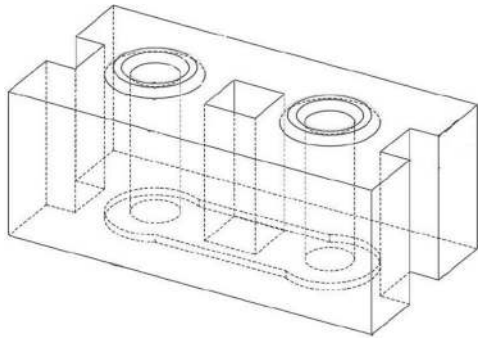
The post-consumer plastic material can either be used directly, physically processed, such as grinding, melting and reforming, or undergo chemical treatment after the components are isolated and reprocessed for manufacturing. Prior to grinding, the PET is washed thoroughly to remove contaminants (Jankauskaite et al. 2008). The dimensions of the interlocking brick are provided in Fig. 1, whereas the actual interlocking brick images in Figs. 2 and 3.

### 2.2 Response Surface Methodology (RSM)

In this study, RSM was used to obtain a mix design of interlocking bricks incorporating PET and PU, where both the materials are variables. After inputting the information in the RSM, 12 mix designs were obtained with different percentages for PET and PU as discussed in Table 1.

After obtaining the experimental results, the values were incorporated into the RSM to obtain a model for the optimum amount of PET and PU. RSM's functionality includes modelling and analysis using an assembly of statistical and mathematical methods for developing the empirical model building, improving and optimizing process parameters. It can also be used to find the interaction of several factors. The response surface models are the variation of simple linear regression, which incorporates the second order effect of non-linear relationships, and is a prominent enhancement procedure to decide the most ideal mixes of factors and the phenomenon (minimum/maximum/saddle point) (Anjum et al. 1997).





**Fig. 3** Interlocking brick 3D view

**Table 1** Mix designs obtained from RSM

Run	Mix	PET (%)	PU (%)
1	M1	20	80
	M2	20	80
	M3	20	80
2	M4	40	60
	M5	40	60
	M6	40	60
3	M7	60	40
	M8	60	40
	M9	60	40
4	M10	80	20
	M11	80	20
	M12	80	20

### 2.3 Mixing Procedure

The mixing of the samples was done after the materials weighed and added to the mixing tray in a conventional manner. The process was carried out until a consistent and homogeneous mix was made and poured into specified moulds. In addition, the mix was vibrated to bring entrapped air bubbles to the surface where they escape. Later, the samples were air cured for 3 days after getting demoulded to get the required strength parameters.

### 2.4 Compressive Strength Test

Compressive strength test was carried out by using the standard test method of ASTM C67 (Standard 2014b). This test was conducted to obtain the maximum compressive strength of the specimen. In this experiment, a 50 mm × 50 mm × 50 mm cube was obtained which was weighed to determine the density. The cube was then placed into the compressive testing machine where the amount of load was taken. Figure 4 shows the sample after testing.



**Fig. 4** Compressive strength samples after testing

### 2.5 Direct Tensile Test

The direct tensile test was carried by using the standard test method of ASTM D638 (Standard 2014a) to measure the force required to elongate the specimen to breaking point. Like the compressive strength test, all the 3 samples were tested to obtain an average to further solidify the outcomes in terms of accuracy. The specimen was casted in the dog bone mould associated by its shape having dimensions of 500 mm × 100 mm × 25 mm and were tested by Universal Testing Machine (UTM). The aim of performing this test is to discover the ultimate tensile strain, tensile strength and tensile yield strength of the sample. Once the sample is dried and weighed, it was loaded into the tensile grips, where an extensometer was attached. The test was begun by separating the tensile grips at a constant rate of speed. Speed depends on specimen shape and can range from 0.05 to 20 mm/min. The target time from the start of the test to break should be between 30 sec. to 5 min. The failure of the sample marks the end of the test. The tested samples are shown in Fig. 5.



**Fig. 5** Tensile strength samples after testing

**2.6 Impact Strength Test**

Impact test was done by using the standard test method of Izod Impact Testing with ASTM D256 (Standard, A 2002), where a 64 × 13 mm × 3.2 mm of specimen in a batch of 3 was prepared. This test was conducted to determine the amount of energy absorbed by a material during fracture. The pendulum is raised to the left until it indicates the maximum energy range on the upper indicator unit. The samples were placed horizontally across the supports, with the notch away from the pendulum and released to check the impact resistance, where the value from the indicator unit was recorded. The procedure was repeated for the other samples as well to check their impact resistance.

**2.7 Thermal Conductivity Test**

Thermal conductivity test is defined as the ability of the material to transmit heat. Thermal conductivity test was carried out to determine the thermal conductivity of the specimen by using the standard test method of ASTM C177 (Standard 2010). The equipment used in this test is the guarded hot plate. The specimen is placed on the hot plate and the values of the thermal conductivity of K are determined. To obtain a more accurate value of the

thermal conductivity, 10 values were taken, and the average value was calculated.

**2.8 Verification Mix**

Once the results have been successfully obtained from the initial mixing based on the 12 various mix designs conjured by the preliminary RSM mix design, they were inputted again into the RSM to validate the finalized model. The verification mix designs were obtained via multi-response optimization technique as indicated in Table 2.

**3 Results and Discussion**

**3.1 Compressive Strength**

Upon the completion of the 48-h curing, the cubes of dimensions 50 mm × 50 mm × 50 mm were put through a compressive strength test as per BS1881: Part 116: 1983 to determine the load resistance. Table 3 shows the compressive strength test results for the 12 mix designs.

In Table 3, the highest compressive strength belongs to Run 3 having a PET/PU of 60/40 Ratio which is 84.54% less than the control sample. The lowest compressive

**Table 3** Compressive strength test results

Run	Mix	Compressive Strength (MPa)
0	Control	33
1	M1	2.1
	M2	1.8
	M3	1.8
2	M4	3.2
	M5	3.6
	M6	3.5
3	M7	5.3
	M8	4.9
	M9	5.1
4	M10	2.9
	M11	3.1
	M12	3.0

**Table 2** Verification mix design

Mix ID	PET (%)	PU (%)	Model based expected Compressive Strength (Mpa)	Model based expected Tensile Strength (Mpa)	Model based expected Impact Strength (Mpa)	Model based expected Thermal Conductivity (W/m K)
Verification Mix 1	60	40	5.2	1.321	24.3	0.179
Verification Mix 2	60	40	5.2	1.321	24.3	0.179
Verification Mix 3	80	20	3.0	0.432	22.1	0.163

strength is displayed by Run 1 which has a PET/PU of 20/80 Ratio.

In comparison to a research conducted by Sayanthan et al. (2013b), the compressive cube strength obtained for interlocking lightweight cement blocks was 4.9 N/mm<sup>2</sup> which is required to construct walls up to 5 stories high with the mortar designation. Based on the current study results, the highest obtained compressive strength value was 5.3, which fulfils the non-bearing masonry wall requirement in accordance as per ASTM, where the minimum acceptable strength is 4.14 MPa (ASTM 2011).

The other mix designs, however, did not surpass the benchmark value of 4.9 N/mm<sup>2</sup>. Since Run 1 had excess polyurethane binder, it caused the sample to be more elastic, thus leading to higher flexibility. The sample remained in elastic limit even after the critical load was applied. Unlike these samples, Run 3 and Run 4 had successfully transcended from elastic region to the plastic region up to the point of failure and showed an optimum result. Another possible reason for the reduction of compressive strength is the escalated volumes of air entrapment due to higher amount of polyurethane (PU).

Table 4 shows the Adjusted R-Squared value of 0.9981 and Predicted R-Squared value of 0.9970. This indicates an acceptable difference of 0.0011 which is less than 0.2. Looking at the adequate precision of the model, which is 114.2233, is a positive result. The adequate precision value can further be used to navigate the design.

Therefore, an equation in terms of actual factors can be obtained as:

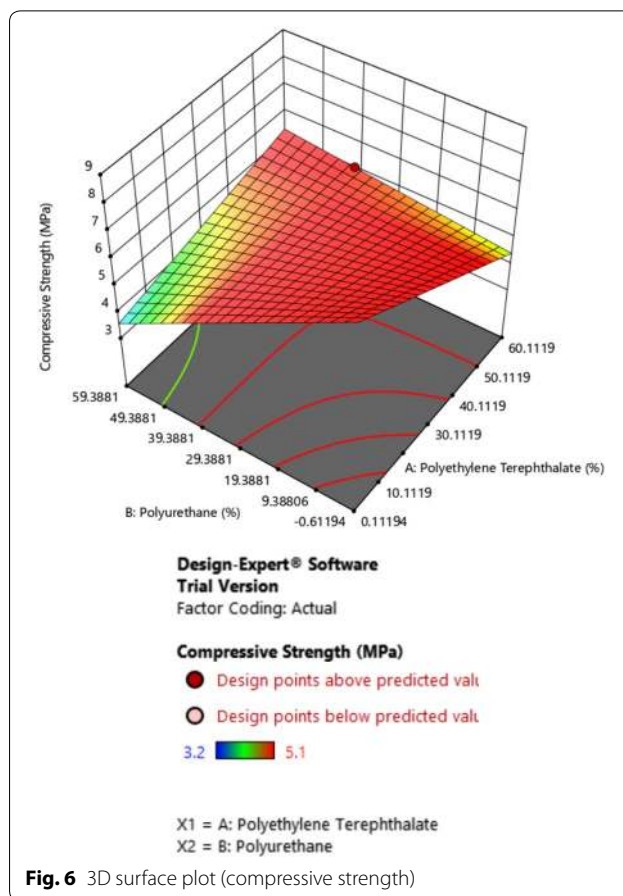
$$\text{Compressive strength} = 5.08 + 0.4670A + 1.39(A)(B). \tag{1}$$

Equation 1 shows the model which the RSM has come up with and can be used to make reliable predictions about the model to obtain several values of compressive strengths in order to obtain satisfactory results. Where A is Polyethylene Terephthalate and B is Polyurethane.

Based on the 3D response surface plot in Fig. 6, it is inferred that the highest compressive strength of 5.05 MPa can be achieved by using PET/PU of 60/40 Ratio. This can be observed at the reddish zone in the contour plot.

**Table 4 Key results from ANOVA (Compressive)**

Std. dev.	0.0326	R <sup>2</sup>	0.9984
Mean	4.30	Adjusted R <sup>2</sup>	0.9981
C.V. %	0.7576	Predicted R <sup>2</sup>	0.9970
		Adeq precision	114.2233



**Fig. 6** 3D surface plot (compressive strength)

### 3.2 Tensile Strength

Upon the completion of 48-h curing, the dog bone mould of dimensions 500 mm × 100 mm × 25 mm was

**Table 5 Tensile strength test result**

Run	Mix ID	Tensile strength (MPa)
0	Control	1.28
1	M1	0.396
	M2	0.416
	M3	0.410
2	M4	0.696
	M5	0.652
	M6	0.691
3	M7	1.233
	M8	1.241
	M9	1.301
4	M10	0.420
	M11	0.426
	M12	0.417

put through a tensile strength test as per ASTM D638 (Standard 2014a). The measure of the force required to elongate a specimen to breaking point is calculated and discussed in Table 5.

From Table 5, it can be observed that the highest tensile strength was recorded for the control sample as 1.28 MPa. Whereas, from the mixes, the optimum mix design was for Run 3 having a PET/PU of 60/40 ratio, as it has the highest tensile strength. This is due to the strong bond formed between the polyethylene terephthalate powder and the polyurethane binder. The total curing time of 3 days was provided for all samples to ensure the wet mixes; Run 1 and Run 2 were completely dried and ready for testing, yet the overall results obtained for the tensile strength were unsatisfactory.

As for concrete, the tensile strength is enhanced by introducing reinforcement bars into the concrete. This further improves the bond in the concrete matrix and its overall performance (Pillai et al. 1999). The unreinforced concrete tensile strength falls in the range of 2.2–4.2 MPa. In contrast, the results obtained from the experiment falls in the range of 0.4–1.3 MPa.

The tensile strength values were much lower for Run 1 and Run 2 is due to its wet mix. In nature, PET and PU both have elastic properties. The concurrence of both materials mixed in a wet proportion caused the samples for Run 1 and Run 2 to become more elastic and spongier which significantly reduced the individual strength and making it brittle. However, Run 3 and Run 4 took a longer time to reach the breaking point from the elastic limit. Thus, it can be concluded that the material specimen was ductile in nature. In conclusion the overall performance of the interlocking brick as a tensile member is unsatisfactory and therefore not suitable to be used as a tensile member in a structure.

Table 6 shows the Adjusted R-Squared value of 0.9960 and Predicted R-Squared value of 0.9934. This indicates an acceptable difference of 0.0026 which is less than 0.2. Looking at the adequate precision of the model, which is 64.5141, is a positive result. The adequate precision value can further be used to navigate the design space.

Therefore, an equation in terms of actual factors can be obtained as:

$$Tensile = 1.04 + 0.9756A + 0.6242AB + 0.9688A^2B \tag{2}$$

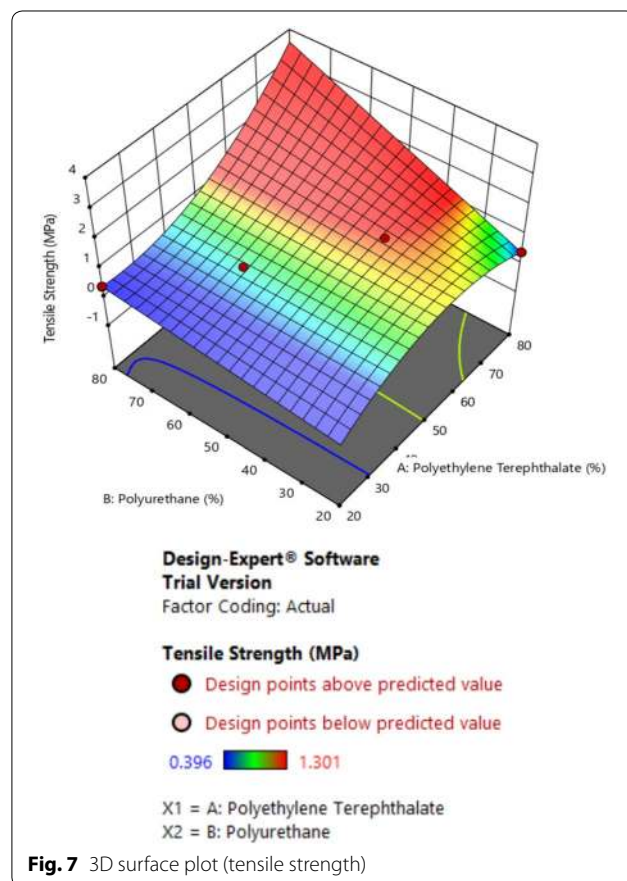
Equation 2 shows the model which the RSM has come up with and can be used to make reliable predictions about the model to obtain several values of tensile strength in order to obtain satisfactory results. Where A is Polyethylene Terephthalate and B is Polyurethane.

Based on the 3D response surface plot in Fig. 7, it is inferred that the highest tensile strength of 1.3 MPa can be achieved by using PET/PU of 60/40 Ratio This can be observed at the reddish zone in the contour plot.

### 3.3 Impact Strength

The samples for impact strength test were put for testing to obtain the impact of interlocking bricks incorporating PET and PU. This test was conducted by the Izod impact test machine adhering to the ASTM D256 (Standard, A 2002) as shown in Table 7.

From Table 7, it can be observed that the highest impact strength was 43.08 J/m for the control sample. Whereas, within the mixes, the highest impact strength was of Run 3 having a PET/PU of 60/40 Ratio. The lowest recorded impact strength was for Run 1 having a PET/



**Table 6** Key results from ANOVA (Tensile)

Std. dev.	0.0228	R <sup>2</sup>	0.9971
Mean	0.6916	Adjusted R <sup>2</sup>	0.9960
C.V. %	3.30	Predicted R <sup>2</sup>	0.9934
		Adeq precision	64.5141

**Table 7 Impact strength results**

Run	Mix ID	Impact strength (J/m)
0	Control	43.08
1	M1	19.552
	M2	19.536
	M3	19.601
2	M4	21.633
	M5	21.741
	M6	21.620
3	M7	23.169
	M8	23.334
	M9	23.343
4	M10	21.231
	M11	21.221
	M12	20.921

PU of 80/20 Ratio. The two most common methods in assessing the impact strength of a material are through Izod and Charpy impact test. However, the Izod impact test is more suitable to be used for plastic materials whereas the Charpy impact test is useful for testing common metals. The energy required to break a test specimen is obtained when the sample is struck in the center by pendulum weight.

The results obtained were excellent as it can withstand high impact. Plastic is a sturdy material where higher percentage of PET increases strength but consequently reduces the toughness. This scenario can be related to samples for Run 3. Plastic has poor impact strength properties but it dramatically improved due to the addition of polyurethane binder; an elastomer which encouraged molecular weight build up and resulted in improved impact strength. High molecular weight and narrow molecular weight distribution improves impact strength.

However, wet mixes of Run 1 and Run 2 produced unsatisfactory results. This is because both the materials were mixed in a wet proportion, caused the samples to become more elastic and spongier which significantly reduced the individual strength of the material itself and making it brittle.

Moreover, the impact strength reduces in Run 4 after the addition of PET to the blend. This is because the dry mix has inadequate bonding between the polyethylene terephthalate (PET) and the polyurethane binder. Adequate bonding between the two materials is essential for the satisfactory performance of the interlocking brick. (Abu-Isa et al. 1996) The impact strength increased after blending polyethylene terephthalate pellets with polyester to the mix design, where the impact obtained was

70/30 PET/copolyester 20.5 J/m. In comparison with this research the impact strength obtained for this project raised by a 23.3 J/m with 60/40 PET/PU Ratio. Therefore, it can be concluded that the impact strength is adequate to be used as a construction material.

Table 8 shows the Adjusted R-Squared value of 0.9921 and Predicted R-Squared value of 0.9852. This indicates an acceptable difference of 0.0069 which is less than 0.2. Looking at the adequate precision of the model, which is 51.7616, is a positive result. The adequate precision value can further be used to navigate the design.

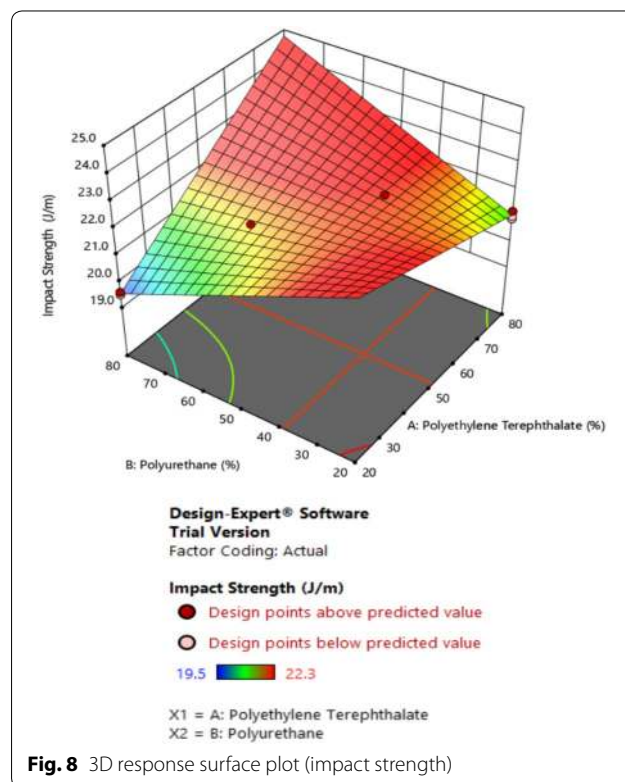
Therefore, an equation in terms of actual factors can be obtained as:

$$\text{Impact strength} = 22.16 + 0.7550A + 1.86AB \quad (3)$$

Equation 3 shows the model which the RSM has come up with and can be used to make reliable predictions about the model to obtain several values of impact

**Table 8 Key results from ANOVA (Impact)**

Std. dev.	0.1027	R <sup>2</sup>	0.9921
Mean	21.13	Adjusted R <sup>2</sup>	0.9904
C.V. %	0.4859	Predicted R <sup>2</sup>	0.9852
		Adeq Precision	51.7616



**Fig. 8** 3D response surface plot (impact strength)



strengths in order to obtain satisfactory results. Where A is Polyethylene Terephthalate and B is Polyurethane.

Based on the 3D response surface plot in Fig. 8, it is inferred that the highest compressive strength of around 23.3 MPa can be achieved by using PET/PU of 60/40 Ratio. This can be observed at the reddish zone in the contour plot.

### 3.4 Thermal Conductivity

The thermal conductivity test samples were put for testing to obtain the values as shown in Table 9, incorporating PET and PU. The thermal conductivity test is to measure the thermal insulation capability. This test was conducted by the thermal conductivity meter adhering to the ASTM C177 (Standard 2010).

From Table 9, it can be observed that the thermal conductivity is decreasing as the percentage of PET is increasing. The thermal conductivity for post-consumer PET is 0.19 W/m °C and the literature value for virgin PET is 0.0375 W/m °C, both at 25 °C. Based on the results obtained from the experiment, the thermal conductivity is within the range of 0.15–0.3 W/m K. In comparison with other waste materials such as the use of crumb rubber in concrete panels, crumb rubber has a thermal conductivity in the range of 0.303–0.476 W/m K, which is higher than the results obtained from PET and PU (Sukontasukkul 2009).

Higher thermal conductivity signifies that the material can transfer more heat per unit time. In addition (Sukontasukkul 2009) the thermal conductivity is inversely proportional to the density of the material. Since, plastic interlocking brick has a lower density, it is expected to exhibit a lower thermal conductivity, k value. When this experimental result is compared to plain concrete, the

average k value was 0.531 W/m K, which is still higher than the plastic interlocking brick.

Since the thermal conductivity of Polyethylene Terephthalate and Polyurethane binder is low as a raw material, the k value of the both materials moulded together reduced. Therefore, the rate of heat transfer is directly proportional to the k value. The temperature gradient along the sample is high and according to Fourier’s Law of thermodynamics, temperature gradient is inversely proportional to the thermal conductivity. Since the thermal conductivity is less, it is obvious that the heat transfer rate along the material will reduce.

In conclusion, thermal control is one of the important aspects in buildings. The basic understanding regarding heat transfer and temperature distribution thought building materials can be used for analysing the energy use, and thermal comfort in the buildings. Good thermal insulation provides thermal comfort without excess air conditioning which is one of the primary requirements of a building. Therefore, this plastic interlocking brick can be categorized as a good thermal insulator.

Table 10 shows the Adjusted R-Squared value of 0.9883 and Predicted R-Squared value of 0.9820. This indicates an acceptable difference of 0.0063 which is less than 0.2. Looking at the adequate precision of the model, which is 47.1109, is a positive result. The adequate precision value can further be used to navigate the design.

Therefore, an equation in terms of actual factors can be obtained as:

$$Thermal\ conductivity = 0.1806 - 0.0310A - 0.0051AB \tag{4}$$

The above Eq. 4 shows the model which the RSM has come up with and can be used to make reliable predictions about the model to obtain several values of thermal conductivity in order to obtain satisfactory results. Where A is Polyethylene Terephthalate and B is Polyurethane.

Based on the verification made by RSM, it was observed that all the models are proven to be significant and having 4% difference from the original model-based value.

Based on the 3D response surface plot in Fig. 9, it is inferred that the lowest thermal conductivity of around 0.155 MPa can be achieved by using PET/PU of 80/20

**Table 9 Thermal conductivity results**

Run	Mix ID	Thermal Conductivity (W/mK)
0	Control	0.41
1	M1	0.221
	M2	0.214
	M3	0.215
2	M4	0.192
	M5	0.188
	M6	0.194
3	M7	0.172
	M8	0.169
	M9	0.172
4	M10	0.154
	M11	0.157
	M12	0.153

**Table 10 Key results from ANOVA (Thermal)**

Std. dev.	0.0026	R <sup>2</sup>	0.9905
Mean	0.1834	Adjusted R <sup>2</sup>	0.9883
C.V. %	1.43	Predicted R <sup>2</sup>	0.9820
		Adeq precision	47.1109

Ratio. This can be observed at the blue zone in the contour plot.

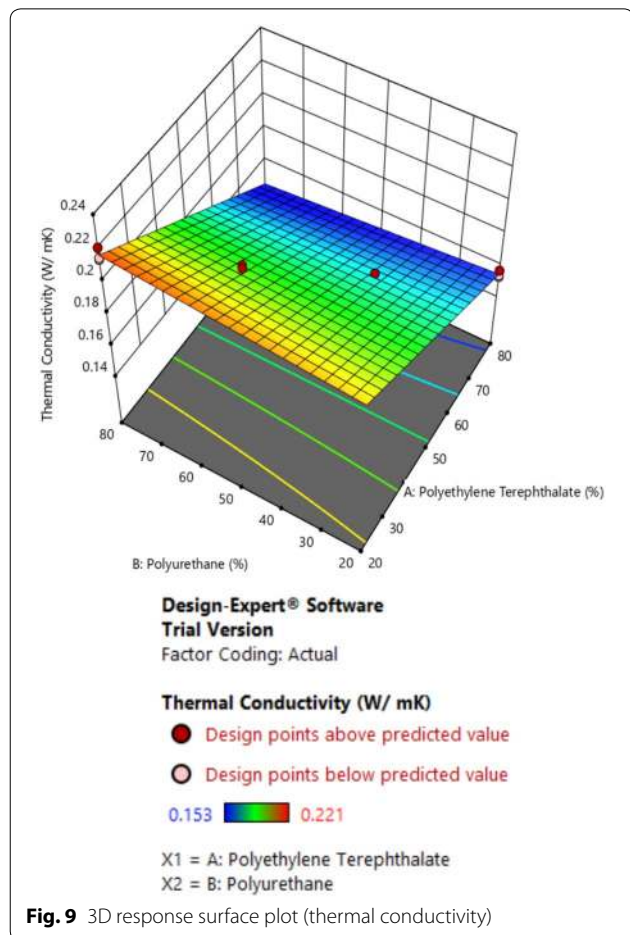
### 3.5 Verification by RSM

The verification mix designs were obtained via multi-response optimization technique. Table 11 shows the percentage difference of the attained results with the model.

From Table 11, it is observed that all the models are proven to be significant and have less than 4% difference from the original model-based value.

## 4 Conclusion

1. A good compressive strength of 5.3 was obtained for a PET/PU of 60/40 ratio which is suitable to be used as non-load bearing masonry brick wall. Thus, it can also be used as partition wall.
2. The interlocking brick utilizing PET and PU did not obtain an ideal tensile strength requirement of a structure and therefore unideal to be used as a ten-



**Table 11** Percentage difference with model

Verification mix ID	Mix 1	Mix 2	Mix 3
Experiment based compressive strength	4.9	5.1	2.89
Percentage difference with model-based	3.9%	1.92%	3.6%
Experiment based tensile strength	1.28	1.31	0.418
Percentage difference with model-based	3.10%	0.83%	3.24%
Experiment based impact strength	23.165	23.231	21.114
Percentage difference with model-based	4.6%	4.39%	4.46%
Experiment based thermal conductivity	0.177	0.176	0.156
Percentage difference with model	1.12	2.22	4.29

sile member. This is due to the polyurethane’s elastic properties which weakens the material strength causing it to be brittle. The highest tensile strength obtained was 1.3 MPa for a PET/PU of 60/40 ratio.

3. PET and PU incorporation in an interlocking brick have demonstrated good impact strength which was higher than other research project utilizing waste material. The highest impact strength obtained was for the PET/PU of 60/40 ratio with a value of 23.3 J/m. Due to a high impact strength, the interlocking brick is suitable to be used as highway crash barriers or column crash barriers.
4. The overall thermal conductivity test results were satisfactory as it falls within a range of 0.15 to 0.2 W/mK. Low thermal conductivity signifies a good thermal insulating material. The lowest thermal conductivity of 0.153 W/mK was obtained for PET/PU of 80/20 ratio which is low compared to other construction materials.
5. Successful research surface models were created by considering the statistical values and verified accordingly to prove its physical reliability as statistical significance of model has been proved.

## 5 Recommendation

1. Mechanical cutting and injection moulding can help to obtain more accurate results.
2. Advanced usage of RSM provides the best and more accurate results for scientific purposes and industrial application.
3. Further validation of the results can be made through field testing.

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**Authors' contributions**

All authors equally contributed for this study. All authors read and approved the final manuscript.

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**Competing interests**

The authors declare that they have no competing interests.

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