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Harnessing earthquake generated glass and plastic waste for sustainable construction

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Abstract

On February 6, 2023 Türkiye witnessed two massive earthquakes of magnitudes 7.6 and 7.8 centred near Gaziantep Province. The aftermaths of the earthquakes were devastating. Thousands of people were dead under the rubble of collapsed buildings and millions displaced. The challenge was the disposal of tons of debris generated due to the destruction of structures and roads, and the construction of new buildings for relocation of displaced people. Not only being uneconomical, the disposal and new construction also became a major environmental concern. A solution to this problem lies in the constructive disposal of earthquake wastes i.e., the utilization of waste materials from debris generated after an earthquake in order to ensure its proper and beneficial disposition. The article provides a two problems one solution technique in this regard. Research techniques and outcomes of modification of glass and plastic waste in the industries for the manufacture of good quality construction materials and the subsequent use of these materials in construction are reviewed. Further analysis is carried out to determine whether the application of this knowledge in practical field ensures that both environmental and economical requirements are met.

1. Introduction

Natural disasters are the naturally occurring, mostly unpredictable and highly uncontrollable events that cause huge loss to life and property. High magnitude destruction and economic disruption are due after such disasters. Cyclones, Tsunamis, Landslide, floods, earthquakes etc come under the category of natural disasters. Earthquakes are the most unpredictable of all. The intensity of earthquakes determines the magnitude of destruction which mostly is quite high. As a result of it many buildings collapse or get affected severely enough to be demolished for safety purposes. Huge number of casualties are reported in such cases. The earthquakes result in huge destruction of cities and towns, deaths of people on large scale and loss of livelihood. After a high intensity earthquake, huge amounts of debris are generated due to the collapse and sometimes subsequent demolition of buildings and other structures. Considering the material point of view the debris comprises mostly of fly ash, broken concrete, steel pieces, plastic, glass, ceramics, wood, brick etc. The quantity of each of these materials varies from one structure to another. Most of this waste is disposed of into land fillings or water bodies, ignoring the environmental concerns and health hazards. With loss of localities, people are rendered homeless. Another civil engineering aspect is the construction of new residencies for the accommodation of these people and their wellbeing. A huge scale construction of cities and towns should be initiated which requires raw material worth a lot of money. This is the economic aspect of the earthquake which needs to be dealt with. For third world nations, this situation is quite grave and might result in the economic collapse of the whole country. A solution is thus proposed in order to ensure the proper disposal of earthquake waste which is the re construction of buildings using material made from some modified components of the debris of collapsed structures. The materials that would be used for the manufacture of these materials are otherwise harmful for the environment if disposed of directly and take centuries to decompose. Also, the need for new raw material is minimized resulting in the economic safety of the country in the aftermath of a disaster.

1.1. Türkiye Earthquake

Türkiye is a country of 84.78 million inhabitants located on the west of Asia with some parts in the

European continent. A major portion of Türkiye lies on a microplate called Anatolian plate. Anatolian plate itself is located on the line of tension of the two plates – Arabian and Eurasian plate. Another plate bordering the Anatolian plate is the African plate. Therefore, the microplate on which Türkiye sits is located at the interaction point of three tectonic plates. As a result, high seismic activity is observed in the country. Major and densely populated cities of Türkiye lie on fault lines of these tectonic plates posing great threat to the lives of people living there. As per the Turkish disaster and Emergency Management Authority, in the first half of the year 2023 more than 60 thousand tremors were registered. For the year 2022, the recorded tremors were lesser, about 20 thousand.

Table 1 shows the data of the number of earthquakes corresponding to the years of occurrence for the last 25 years.

Table 1. Record of earthquakes in Türkiye for the last 25 years [1].

Year	Number of earthquakes
2023	60,546
2022	20,277
2021	23,763
2020	33,824
2019	23,481
2018	22,899
2017	38,287
2016	20,541
2015	22,290
2014	24,132
2013	23,607
2012	26,973
2011	29,831
2010	19,023
2009	15,211
2008	11,754
2007	7820
2006	5,038
2005	9,481
2004	7,682
2003	1,914
2002	1,078
2001	599
2000	745
1999	2,101

Türkiye has a history of major earthquakes dating back to 17 CE. earthquakes are therefore much expected in Türkiye; however, their occurrence time and magnitudes are unpredictable.

On morning of 6 February 2023, at 4:17 am a massive earthquake occurred in the south of Türkiye. The magnitude of this earthquake was 7.8 and it was observed on the northern border of Syria with epicentre in Pazarcik, Kahramanmaras at 8.6 km depth from ground. After approximately 10 hours another earthquake measuring 7.5 magnitude, struck a region just 95 kilometres from the first earthquake zone with epicentre at Elbistan, Kahramanmaras at a depth 7 km from ground. Within 24 hours of the earthquakes, more than 570 aftershocks were recorded [1]. Aftershocks continued for months after the earthquakes. More than 14 million people were affected and large-scale destruction of property and livelihood was experienced. Level-4 emergency was declared for three months in 10 provinces of Türkiye and international assistance demanded. The death toll in the regions was estimated about 46 thousand [1]. Millions of people were left homeless and had to move to other cities. The aftermath of the earthquakes was even worse. The economic loss as a result of the earthquake was estimated with 35 percent probability to be between US$ 10 billion to US$ 100 billion. And with 34% probability, it was estimated to exceed US$ 100 billion.

Direct collapse of about 6000 buildings was observed. Tons of debris was generated from the structures destroyed by the earthquake. After survey, many buildings were deemed unsafe and thus had to be demolished.

Table 2 is a rough estimate of the number of buildings that collapsed directly due the earthquake or had to be demolished immediately after.

Table 2. Rough estimate of number of collapsed and demolished buildings in 2023 Türkiye earthquake [1].

Place	Collapsed and demolished buildings
Kahramanmaras	10,800
Adana	1,333
Malatya	36,046
Gaziantep	16,211
Islahiye	200
Hatay	21,643
Kirikhan	1886
Defne	943
Reyhanli	2042
Arsuz	381
Kumlu	215
Payas	727
Adiyaman	76,600
Diyarbakir	8086
Sanliurfa	201
Osmaniye	1739
Kilis	119
Batman	234

1.2. Debris generated

Near about 364 $million^2$ of structures were demolished or damaged. Between 520 to 840 million tons of debris was generated as a result of direct collapse of buildings in Türkiye earthquake. Furthermore, the demolition waste was accounted to be between 450-920 million tons [2]. This data gives us the insight that about 250,000 buildings had been damaged overall. As per UGSC assessment the amount of debris to be cleared from Türkiye was estimated to be around 116-210 million tons. A volume of $100m^3$ was estimated to have been generated [3].

The debris generated was reported to be able to cover two Manhattans. In other words, the debris could make a three feet high stack when spread on an area equal to 14,000 soccer fields [4].

Xiao et al. [2] estimated the amount of debris generated in the Türkiye earthquake. He represented the data through a pie chart. The contents of the debris were analysed as shown in Figure 1.

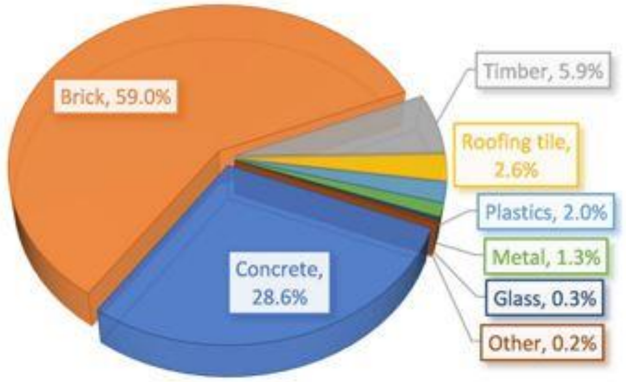


Figure 1. Pie chart representation of the percentage of different components of debris generated from Türkiye Earthquake 2023

With 685 million tons as the approximate total waste generated, 404 million tons of brick waste and 191 million tons of concrete waste was generated. Timbre constituted about 5.9% of the total waste. 2.6% of the total waste comprised of roofing tile and metal waste was about 1.3% of total waste. Glass waste generated was found to be 0.3% of the total waste of 685 million tons which is 2.055 million tons. Plastic waste concentration was found to be reasonably high i.e., 2% of 685 million tons which accounts to 13.7 million tons. This amount of plastic is clearly not suitable for dumping due the health and environmental hazards.

2. Usage of debris

The focus of this article is on the proper disposal or utilization glass and plastic waste. It provides an insight as to how the glass and plastic waste from earthquake can be used in the manufacture of bricks, concrete and other materials which can in turn be used for the construction of buildings or pavements. A review has been done on the work of scientists and the data has been analysed. This article provides suggestions as to how the wellbeing of citizens can be achieved and the economy of a country saved. All this being done while making no compromise with the safety and sustainability of the environment.

2.1. Use of glass waste

The earthquake and subsequent demolition of buildings produces tons of glass waste. In Türkiye the earthquake generated about 2.055 million tons of glass waste. This glass waste could be put to use in the construction of bricks or concrete. Following research has been done by scientists in the same regard. Research done by Demir [5] is in line with the technique of converting glass waste to bricks.

2.1.1. Method

Glass waste crushed in jaw crusher and ground in a ball mill was sieved through 0.5mm sieve. Brick clay was crushed and sieved through a sieve of size 1mm. The clay particles were very fine and the only coarse particles were the calcium carbonate. Four different classes were formed for comparative analysis- A, B, C and D. Class A was the standard brick, class B had 2.5% by weight of fine glass, Class C contained 5% by weight of fine glass and Class D comprised 10% by weight of fine glass mixed with the brick clay. The samples were 75mm x 40mm x 100mm in size and dried under laboratory conditions for 24 hours and further dried to constant weight at 110 degrees in oven. The changes in plasticity and drying shrinkage were observed with respect to the change in glass content. Then the samples were fired in an electrically heated kiln with 3 degree Celsius/ min heating rate at three different temperatures of 850, 950 and 1050 degree Celsius for 2 hours. The samples were then allowed to cool naturally. Then the tests were done on at least 12 samples and the results were produced.

2.1.2. Tests

For determination of compressive strength of materials, a testing machine of testing capacity 25k N was used with 1 and 0.45 k N/s loading rates. Properties such as bulk and apparent density, porosity and water absorption were established on the basis of Archimedes Principle. Loss of ignition and total shrinkage was observed. Electron microscopy was done to understand the effect of addition of glass and firing temperature on microstructure of bricks. Table 3-6 illustrate the results:

Table 3. Variation in shrinkage and loss of ignition at different temperatures and glass contents of glass induced bricks.

Waste glass content (%)	Shrinkage (%)				LoI(%)		
	Dry	850 °C	950 °C	1050 °C	850 °C	950 °C	1050 °C
0	3.95	5.35	5.67	6.12	8.17	9.19	9.69
2.5	3.72	5.15	5.21	5.28	7.79	8.64	9.22
5	3.64	4.65	4.69	4.82	7.84	8.19	9.10
10	3.53	4.35	4.48	4.57	7.27	8.24	8.61

Table 4. Variation in bulk density and loss of apparent density at different temperatures and glass contents of glass induced bricks.

Water glass content (%)	Bulk Density (g/cm^3)			Apparent Density (g/cm^3)		
	850 °C	950 °C	1050 °C	850 °C	950 °C	1050 °C
0	1.66	1.60	1.69	2.58	2.31	2.34
2.5	1.62	1.55	1.66	2.55	2.23	2.25
5	1.67	1.56	1.64	2.56	2.22	2.24
10	1.68	1.59	1.65	2.56	2.25	2.25

Table 5. Variation in apparent porosity and water absorption at different temperatures and glass contents of glass induced bricks.

Water glass content (%)	Apparent Porosity (%)			Water Absorption (wt. %)		
	850 °C	950 °C	1050 °C	850 °C	950 °C	1050 °C
0	35.71	30.9	27.7	19.45	15.48	13.94
2.5	35.02	28.43	26.4	19.06	14.72	12.86
5	33.27	29.58	26.77	18.35	13.52	11.67
10	34.17	29.21	26.16	17.73	12.82	10.89

Table 6. Variation in compressive strength at different temperatures and glass contents of glass induced bricks.

Waste glass content (%)	850 °C	950 °C	1050 °C
0	16.45	19.50	20.37
2.5	18.75	22.65	24.50
5	20.15	25.13	27.15
10	20.62	27.56	29.35

Strength of brick was observed to increase with glass content and firing temperature. The lowest compressive strength was observed in clay bricks due to high porosity. The pores in glass bricks are filled with glass in glassy phase at firing temperature of 95 degree and 1050 degree. As a result, densification occurs and brick strength increases. Also, the risk of strength due to quartz transformation is reduced making a positive contribution to the overall strength. Except for the bricks made in kiln of firing temperature 850 degree, the compressive strength of all the samples of bricks with glass was found to be more than 18MPa which is considerably higher that compressible strength of brick prescribed in TS EN-771-1 code.

2.1.3. Results

All the bricks with additional glass content were found out to be crack free after being taken out of kiln. Decrease in Loss in ignition is observed with increase in glass content. Higher weight loss and drying shrinkage was observed in clay brick during firing than in the glass-additive brick. As a result, any chance internal shrinkage is minimized in glass additive brick. Apparent density was found to be more in the bricks heated at 850 degrees due to low glassy phase at this temperature than at 950 and 1050 degree Celsius. Another positive aspect was water content which was showing significant decrease with increase in temperature and glass content. Thus, it can be established that bricks with 10% crushed clay content made at a firing temperature of 950-1050 degree Celsius are suitable for construction and have higher compressive strength than clay bricks. These bricks also have low change of damage during production.

Another study titled 'Bricks Made from Glass Residues: A Sustainable Alternative for Construction and Architecture' by Cecilia I et al. [6] gives almost the same results. However, the researchers let the bricks to dry naturally without a kiln. The bricks were found to be suitably good in dimension, warpage, absorption and compression.

2.1.4. Method

The bricks were made of commercially obtained cement and sand and crushed glass waste which was obtained by subjecting 240 clear and dark glass bottles to cleaning, drying and crushing. The total weight of crushed glass used for making bricks was 252 kg.

The ratio of cement/sand/crushed glass was taken as 1:3:2 and water were steadily added until the mixture became plastic enough to be moulded and free of lumps. Further, the mixture was placed in a mould and compacted. The bricks were demoulded and left to dry for one day, to be subjected to curing with potable water for next 7 days. Lastly, the bricks were left to dry over a period of 28 days and then testing was done.

Tests: Following physical and mechanical tests were done on the bricks:

Physical Tests

1. 10 samples were tested for dimensional variation in mm
2. 5 samples were tested for absorption (%)
3. 10 samples were tested for warpage in mm

Mechanical Tests

1. 5 samples were tested for compression test in masonry unit in kg/cm^2
2. 15 samples were tested for compression in masonry piles in kg/cm^2

2.1.5. Results

For the composition ratio of cement: coarse aggregate: crushed glass of 1:3:2 the performance of the brick was remarkable under pile compression test surpassing the minimum value 35kg/cm^2. The best results for the mechanical properties were obtained only after 28 days of life. The values suggest that the bricks apart from being suitable for partition walls can be used for load bearing walls. Also, over the days, resistance of the brick was found to have increased between 58.96-98.16kg/cm^2. Brick V and brick IV classification has been given to bricks for 28 and 14 days of life in case of warping. With regard to absorption, minimum value of 7.2% was obtained in line with the specifications of NTP-E.070.

2.1.6. Discussion

Both the methods are quite efficient, however the technique used by Ismail Demer of brick production using kiln resulted in higher compressive strength of bricks. All the samples had Compressive strength greater that 18 MPa which is more than the clay bricks.

Waste glass can also be used in in concrete or mortar in place of aggregates. Research has been done by various scientists in this regard. Research has been done by various scientists in this regard.

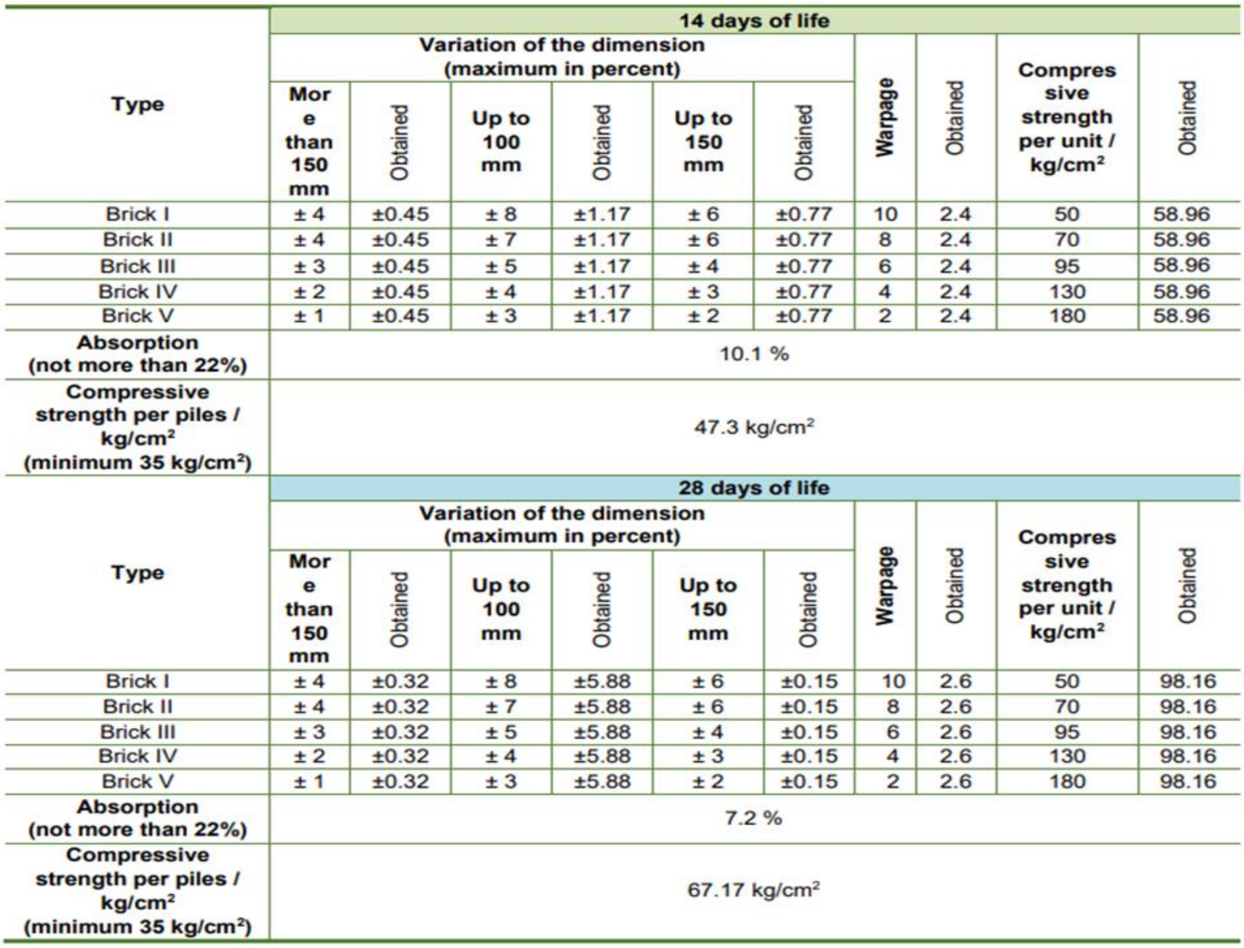
2.1.7. Other studies

Penacho et al. [7] replaced fine aggregate in a concrete mass with glass in varying percentages of 20%, 50% and 100%. The aim was to enhance the compressive and the flexural strength of the concrete. It was observed that the replacement of sand with waste glass powder increased the strength of the concrete between 28 to 90 days. As for 100% replacement, the strength was found to be more than the reference sample at 90 days. The reason for the increase in strength was mainly due to the pozzolanic reactions that occur in glass.

Corinaldesi et al [8] conducted a study in 2004 where he made the analysis after 180 days for the compressive and the flexural strength of concrete made using glass. The size of glass particles varied between 36 micro metre, 35-50 micro metre and 50-100micro metre. The observations suggested that at 70% replacement of aggregate with glass powder of size 36-50 micro metre, the compressive strength was maximum. The 180 days strength showed slight variation. An increase in the compressive strength was noted for 50-100micro metre aggregate sample in comparison to the reference.

Le et al [9] in similar research observed that the compressive strength of concrete increased after 28 days in samples which had glass powder of particle size less than 600 micro metre.

A study done by Batayneh [10] showed that the waste glass if incorporated with fine aggregates resulted in the increase in the compressive strength of material while the splitting strength remained same (Figure 2).



Type	14 days of life									
	Variation of the dimension (maximum in percent)						Warpage	Obtained	Compressive strength per unit / kg/cm^2	Obtained
	More than 150 mm	Obtained	Up to 100 mm	Obtained	Up to 150 mm	Obtained				
Brick I	± 4	±0.45	± 8	±1.17	± 6	±0.77	10	2.4	50	58.96
Brick II	± 4	±0.45	± 7	±1.17	± 6	±0.77	8	2.4	70	58.96
Brick III	± 3	±0.45	± 5	±1.17	± 4	±0.77	6	2.4	95	58.96
Brick IV	± 2	±0.45	± 4	±1.17	± 3	±0.77	4	2.4	130	58.96
Brick V	± 1	±0.45	± 3	±1.17	± 2	±0.77	2	2.4	180	58.96
Absorption (not more than 22%)	10.1 %									
Compressive strength per piles / kg/cm^2 (minimum 35 kg/cm^2)	47.3 kg/cm^2									
Type	28 days of life									
	Variation of the dimension (maximum in percent)						Warpage	Obtained	Compressive strength per unit / kg/cm^2	Obtained
	More than 150 mm	Obtained	Up to 100 mm	Obtained	Up to 150 mm	Obtained				
Brick I	± 4	±0.32	± 8	±5.88	± 6	±0.15	10	2.6	50	98.16
Brick II	± 4	±0.32	± 7	±5.88	± 6	±0.15	8	2.6	70	98.16
Brick III	± 3	±0.32	± 5	±5.88	± 4	±0.15	6	2.6	95	98.16
Brick IV	± 2	±0.32	± 4	±5.88	± 3	±0.15	4	2.6	130	98.16
Brick V	± 1	±0.32	± 3	±5.88	± 2	±0.15	2	2.6	180	98.16
Absorption (not more than 22%)	7.2 %									
Compressive strength per piles / kg/cm^2 (minimum 35 kg/cm^2)	67.17 kg/cm^2									

Figure 2. Variation in dimension, warpage and compressive strength of bricks made with glass powder after 14 and 28 days of life.

2.1.8. Economic aspect

The need of raw material for the manufacture of bricks is minimized with the usage of crushed used glass. Good quality yet cheap bricks can be manufactured which would save billions when done on large scale. An approximate 50% of money is saved on one project by using these bricks. A household generally costing 30 million made with standard brick can be completed at about 10 million only using the brick incorporated with crushed glass [11]. In times of natural calamities, this initiative can prove to be economical for the common public.

2.2. Plastic waste

Huge amount of plastic waste can be put to use in construction by manufacturing bricks, blocks by using it directly or its components.

In research done by Aneke et al. [12] bricks were manufactured by using scrap plastic waste (SPW) and Foundry sand (FS) and tested against good quality standard brick to draw comparison and determine the suitability for construction.

2.2.1. Method

SPW was collected from landfill sites and washed and sanitized in laboratory to eliminate any virus present. Then the sample was dried for three days and later shredded using a shredder for the purpose of undergoing chemical compositional test in X Ray fluorescence machine. With a melting rate of 2 degree Celsius/min, the SPW was heated in a furnace to a controlled temperature of 220 degree Celsius. At the attainment of proper consistency of SPW, Foundry sand was added and the mixture was steered for smooth blending until a homogenous mixture was attained. The mixture was then put in silicon coated moulds of dimensions 220x106x73mm and compressed with a pressure jack of compressive strength 5MPa to reduce voids. The samples were then cooled at room temperature of 24 degree Celsius. Three compositions of SPW and foundry sand were used with varying ratios. For brick named SPW-1, the ratio for FS:SPW was 80:20, 70:30 for brick named SPW-2 and 60:40 for SPW-3 brick.

2.2.2. Testing

After undergoing chemical compositional test, the samples were subjected to various tests for the determination of their strength, durability and other properties. 18 SPW bricks are produced and cooled in open air for 2 days. For each test 3 SPW bricks were used on average and for the final test result, mean value of each was used.

1. Unconfined Compressive Strength Test (UCS):

According to ASTM D2116, UCS was carried out on the SPW bricks after series of wetting and drying. Bricks were placed between two clean plates of testing chamber and stress and deformation was recorded with electronic data logger. Maximum load was recorded in Newtons and the UCS was calculated.

2. Splitting Tensile Strength Test (STS):

The test was done in accordance to ASTM C496 with dimensions of bricks being same as the UCS test. After cycles of wetting and dryings the bricks were placed between the bearing blocks of tensile testing machine. In order to ensure that the pressure if uniformly applied, mild steel piece of 190x90x4 mm is placed horizontally along upper length of the brick and the lower length as well. Maximum tensile load rate of 0.5mm/min was recorded and split tensile strength was calculated.

3. Durability test:

Conducted as per ASTM D559/559-M procedures, weight of bricks was taken two times, once in dry stage and then after being soaked for 24 hours. The bricks were then dried for 48 hours and soaked again to complete one cycle of wetting and drying. The bricks were completely saturated and then subjected to the tests of compressive and tensile tests to determine the durability and effects of soaking on the brick. Furthermore, the bricks were soaked in varying molarities of acidic solutions and the effect of acidic environment on bricks was determined by observing the response of the bricks. The bricks were again dried for 24 hours before being tested for compressive and tensile strengths.

2.2.3. Results

For compressive strength test, the SPW-2 brick with composition ratio FS:SPW = 70:30 showed the highest compressive strength, independent of the number of wetting and drying cycles. The optimum strengths recorded by SPW1, SPW2 and SPW3 bricks were 29.45MPa, 38.14MPa and 33.25MPa respectively. All the data was higher than the Standard clay brick which recorded an optimum Compressive strength of 14.25MPa. Low water absorption and no loss of particles during wetting and drying was recorded for SPW bricks. However, for fire clay bricks a loss of 4.3g of initial weight of bricks and 2.4% loss of strength was recorded. SPW bricks were recorded to have high compressive strength, density and resistance to failure than the ordinary clay brick.

Tensile strength of SPW bricks was observed to be higher than the tensile strength of clay bricks because of the presence of melted plastic and low pore space. It was noted that compressive strength of SPW bricks was 4 times higher than tensile strength, however for clay bricks, compressive strength was 8 times higher than the tensile strength. The tensile strength of SPW bricks was independent of the number of wetting and drying cycles unlike the clay brick.

For durability test, again SPW bricks showed remarkable performance with more survival time in acidic medium and no loss in strength, therefore showing more resistance to the acidic medium. Higher absorption of energy on application of load was noted for SPW bricks indicating higher toughness.

2.2.4. Other studies

A study was done by Akinwumi et al. [13]. In this study Polyethylene Terephthalate (PET) and Clayey sand were used in the manufacture of Compacted earth blocks (CEB). PET waste was first shredded into fines pieces. These were then mixed with clayey sand in varying percentages of 0%, 1%,3% and 7%. In order to determine the properties of soil, the mixture was tested for Atterberg's limits, explicit gravity, molecule size dispersion etc. The compressive strength for the blocks was determined with different percentages of PET and the results were recorded. For 0% of PET, the compressive strength was very low having value 0.45MPa. However, 244.4% increment of strength was recorded with addition of 1% plastic waste of size 6.3mm to the mixture. Also, at this percentage the disintegration rate was minimum. Finally in order to attain high compressive strength for these blocks, cement, lime or any other cementitious binder was used.

A study was done to replace tradition bricks with construction and demolition waste materials and plastic bottles by Paihte et al. [14]. The study was based on the reuse of waste materials. Waste aggregate was recycled first and then compressed. Used plastic bottles were treated as containers and were filled with these aggregates at varying water contents of 0, 2.5, 5, 7.5 and 10%. The bottles were then tested for compressive strengths. At 5% water content the compressive strength was comparable to the compressive strength of conventional brick which is 17N/mm^2 and fly ash brick of compressive strength 12N/mm^2. The results suggested that the bottles with compressed aggregate of size less than 425micro metre showed the highest compressive strength of 15.25N/mm^2. For Recycled aggregate of size between 425 and 4.75 micro metre the compressive strength was relatively lower i.e., 9.84N/mm^2.

In a study done by Safinia and Alkanbani [15] concrete blocks were made from the waste plastic bottles. The tradition concrete blocks were compared to the plastic filled concrete blocks having same dimensions of 200x200x400mm. Both the weight and compressive strength were compared. It was observed that the plastic filled concrete blocks has weight and compressive strength 24.85kg and 10.03Mpa while as for the conventional block the values were 20.08kh and 6.38MPa. Thus, the addition of plastic bottles enhanced the compressive strength and increased the weight of hollow blocks.

In similar research done by Mukhtar et al. [16], plastic bottles were treated as containers filled with sand to replace traditional clay bricks. Waste plastic bottles are recycled into bricks by filling the with sand and compressing the sand with tamping rod for analysis. While the normal clay brick has a compressive strength of 8.58N/mm^2, the plastic brick was found to have a compressive strength of about 38.34N/mm^2 which is about 3-4 times higher. The highest outdoor temperature for plastic brick was recorded to have been 36degree Celsius and the lowest outdoor humidity and wind velocity were found to be 78% and 0.8m/s.

Research was done by Alaloul et al. [17] to produce interlocking bricks by replacing clay and cement by Polyethylene Terephthalate (PET) and polyurethane (PU) binder. Waste plastic bottles were considered for the experiment. The bottles were first chopped and grated to a fine size of 0.75mm. Then the grated plastic was mixed with polyurethane. The mixture was then condensed using interlocking brick machine. Different ratios for PET/PU were considered and the results were recorded. It was observed that for the PET/PU ratio of 60:40 the highest compressive strength achieved was lower than that of controlled group by 84.54%. The tensile strength and the maximum impact value were found to be 1.3MPa and 23.343J/m and thermal conductivity in the range 0.15-0.3 was observed. The bricks were thus found to be suitable for construction of curtain wall and non-load bearing masonry walls.

Hameed and Ahmed [18] conducted a study to make concrete using flake aggregates of PET. The range of percentage by weight of Portland cement in which PET was used was 1, 3, 5, 7 and 10%. On addition 1% PET, a reasonable increase in compressive strength of the concrete was observed with value of 20.720MPa. The flexural strength also showed an increase of 23.11% and 25.59% when compared to normal concrete. An increase in splitting tensile strength was observed with the increase in PET content particularly at 1% and 7%. The splitting tensile strength for 1 and 7% PET was 130% and 102% more than the normal concrete, respectively. However, a decline in density from 2.27-2.15g/cm^3 was observed with the increase in PET content.

A similar study was done in which concrete was made with waste PET as its content. The waste PET was taken in different percentages of 5,10 and 20 for analysis. A comparison was made between normal concrete and plastic concrete by recording the strength values for both in compression, tension and flexure and shrinkage values as per the codes ASTM C39, ASTM C469, ASTM C78, and IS:1199-1959. With 10% of added plastic, the compressive strength and Elastic modulus was noted to be the maximum in comparison to other percentages. A decline in density and flexural strength was observed with increase in the plastic percentage. It was observed that for PET 20% the water absorption was maximum [19].

In a study done by Khan et al. [20] the bitumen properties were modified by addition of LDPE, HDPE and crumb rubber in varying percentages of 2,4,8 and 10% by weight of bitumen. Data was recorded at varying temperatures and frequencies for the viscosity and elasticity of binders. An improvement in the elastic behaviour of binder was observed with the addition of Low density polyethene (LDPE), High density polyethene (HDPE) and crumb rubber thus ensuring increase in the service life of binder by the reduction of chances of rutting and cracking.

In yet another research cum review carried out by Zhenhua Duan et al in the year 2023, Plastic fiber was put under recycle and then used in the reinforced cement concrete. The review of all the mechanical, micro and early age properties and the methods of improvement of recycled plastic fiber suggested an enhancement of the mechanical properties, durability and tensile strength of concrete and an improvement in the crack resistance. In addition, increase in corrosion resistance of the reinforcement was observed [21].

3. Dust mitigation

The processing of debris and the recycle of materials results in the release of dust into the atmosphere. This leads to environmental degradation, dropping of air quality index, reduction in visibility and health hazards. Thus, a thorough mitigation is required to reduce these impacts. The most feasible method is the method of water suppression [22]. Other methods that can be accounted for the reduction in the dust production are the exhaust ventilation, the use of dust screens, chemical agents and electric sweepers and the application of water before cutting, grinding or processing [23].

4. Conclusion

The work done by various scientists can be used to understand that the waste generated from earthquakes has efficient disposal capacity. The two constituents of the waste under study, glass and plastic, can be put to use for the manufacture of other construction materials such as bricks or can be used in concrete as well.

1. Powdered glass can be mixed with brick clay to produce high compressive and tensile strength bricks. This would decrease the demand for high amount of raw material and would also reduce the amount of carbon emission in the atmosphere, which normally occurs during the manufacture of traditional brick.
2. Glass can also be used to substitute fine sand in concrete. The pozzolanic reaction occurring in glass results in high compressive strength of concrete. Within 28-90 days the concrete gains good strength with the addition of suitable size powdered glass to the mixture.
3. Scrap plastic waste (SPW) and foundry sand (FS) can be used in the ratio of 30:70 in the manufacture of bricks which can be used as an alternative to clay bricks. The strength in compression is observed to exceed the strength of traditional brick by multitudes and other properties as in durability and water absorption are more enhanced.
4. Scrap Plastic waste (SPW) and Manufacturing sand M sand in the ratio 1:2 can also be used in the manufacture of bricks exhibiting compressive strength higher than traditional bricks.
5. Glass can also be used to substitute fine sand in concrete. The pozzolanic reaction occurring in glass results in high compressive strength of concrete. Within 28-90 days the concrete gains good strength with the addition of suitable size powdered glass to the mixture.
6. Scrap plastic waste (SPW) and foundry sand (FS) can be used in the ratio of 30:70 in the manufacture of bricks which can be used as an alternative to clay bricks. The strength in compression is observed to exceed the strength of traditional brick by multitudes and other properties as in durability and water absorption are more enhanced.
7. Scrap Plastic waste (SPW) and Manufacturing sand M sand in the ratio 1:2 can also be used in the manufacture of bricks exhibiting compressive strength higher than traditional bricks.
8. Bricks for curtain walls and non-load bearing walls could be produced by using polyethylene terephthalate (PET) and polyurethane (PU) binder in place of clay and cement.
9. Compacted earth blocks can be manufactured from polyethylene terephthalate (PET) (1%) and Clayey sand with some cementitious additives to increase the compressive strength.
10. Direct use of recycled plastic bottles filled with sand, or coarse aggregate and binders exhibits higher strength than the clayey bricks and can be substituted for the same.
11. 1% or 7% of Flake aggregates of PET by weight of Portland cement can be used in making high strength concrete. However, with the increase in PET percentage a decrease in density and flexural strength was observed.
12. Even for the construction of pavements, Plastic scrap can be used. LDPE, HDPE and crumb rubber from waste can be used to enhance the elastic behaviour and increase the service life of binder.
13. Further research can be initiated to look for the disposal of other earthquake wastes in an economical and constructive way.
14. The filtration of glass and plastic material from tons to debris is a time consuming and tiresome process which needs to be simplified through proper research.
15. The quality of the building materials generated need to be thoroughly examined under different conditions of loading, temperature and environment.

Thus, in an event of a massive earthquake, the debris generated can be filtered and waste materials such as plastic and glass extracted. Instead of disposing these wastes directly into the environment, processing can be done and manufacture of new building materials can be attained. This would ensure that harmful effect on the environment due to direct disposal of waste is minimized. At the same time, the demand for new raw material is cut short and the economic benefit is attained. Reconstruction is thus cheaper, faster and more sustainable.

Author contributions

Fazilah Khurshid: Conceptualization, Methodology, Software, Writing-Original draft preparation **Ayse Yeter Gunal:** Data curation, Software, Validation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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