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Comparative Analysis of Recycled Waste Plastic Tiles and Alumina Ceramic Tiles with ANSYS 15

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Abstract

This research illustrates and compares the analytical and behaviour of recycled waste plastic tiles and a conventional alumina ceramic tile. The melting point adopted for all waste plastic material was 60^{o}C with a controlled cooling temperature method. The flexural strength and compression strength of the various plastic type used were conducted with a universal testing machine and these laboratory results were then used to simulate the recycled plastic tiles which were compared with those of alumina ceramic tile. A recycled waste plastic tile of 300 x 300 x 10mm was analysed with a central load for all recycled waste plastic types and were compared with those of alumina ceramic tile. The stresses, strain, deformations and force reactions were observed for all recycled waste plastic types and the alumina ceramic tile analysed. The results obtained from the analysis of the plates (tiles) specimen made of various recycled waste plastic was seen to have maximum deformations of 1.7499, 1.7445, 1.7242, 1.7499 and 1.556mm for water sachets, water bags, water bottles, polythene bags and alumina ceramic tile respectively and other parameters were also obtained. Also, the maximum use temperature for the various recycled waste plastic types were compared with that of the alumina ceramic tile.

Keywords:
Universal Testing Machine (UTM), Solid Waste Management (SWM), Polythene bags (PB), Water Sachets (WS), Water bags (Wb), Water Bottles (WB), Alumina Ceramic Tile (ACT)

1. Introduction

Waste is defined as any material that is not useful and does not represent any economic value to its owner, the owner being the waste generator (Maria et. al., 2011). Depending on the physical state of waste, wastes are categorized into solid, liquid and gaseous. Solid Wastes are categorized into municipal wastes, hazardous wastes, medical wastes and radioactive wastes, liquid waste can be defined as such fluids as wastewater, fats, oil or grease, used oil and hazardous household liquid to name a few while gaseous wastes are gas products that results from various human activities such as manufacturing, processing, material consumption or biological processes. Note that, gaseous waste that is held in a close container falls into the category of solid waste for disposal purposes. However, this study will be focused on solid waste and to be specific thermoplastics. Managing solid waste generally involves planning, financing, construction and operation of facilities for the collection, transportation, recycling and final disposition of the waste (Maria et. al., 2011).

A solid waste management (SWM) system includes the generation of waste, storage, collection, transportation, processing and final disposal. Agricultural and manufactured products of no more value are discarded as wastes. Once items are discarded as waste, they need to be collected. Waste collection in most parts of the world is centralized and all kinds of waste generated by a household or institution are collected together as mixed wastes.

Solid waste management (SWM) is a basic public necessity and this service is provided by respective urban local bodies. SWM starts with the collection of solid wastes and ends with their disposal and/or beneficial use. Proper SWM requires separate collection of different wastes, called source separated waste collection. Source separated collection is common in high income regions of the world like Europe, North America and Japan where the infrastructure to transport separate waste streams exists. Most centralized municipal systems in low income countries like Nigeria, Cameroon etc collect solid wastes in a mixed form because source separate collection systems are non-existent. Source separated collection of waste is limited by infrastructure, personnel and public awareness. A significant amount of paper is collected in a source separated form, but informally. In this report, unmixed waste will be specially referred to as source separated waste, in all other cases municipal solid waste (MSW) or solid waste would refer to mixed wastes. The effect of plastic on landfills is problematic, as it takes a long time to disintegrate. It is important to note that despite it being a man made, chemical product it takes just as long to decompose as any food or paper wastes. Given this, the recycling of plastic is still vital, as the carrying capacity of landfills is limited. Even though earlier studies stated that plastic wastes do not create difficulties in landfill operations and do not add to the toxicity of leachate from the landfills (Eniromental protection agency (EPA), 1990), over time these have been discredited. The new concepts of biodegradation (where starch additives are incorporated to plastic) and photo degradation (where photo sensitive additives are integrated in the manufacturing of plastic products) have been controversial towards commercial applications. Light and air must be available in order for the biodegradable and photodegradable materials to decompose, along with sufficient moisture and nutrients to sustain microbial action (Alter, 1993). Thus, the deeper these plastics are buried in the landfill, the less likely they are to decompose. “Moreover, making plastics degradable would lower the quality and performance of the material and therefore would mitigate some of its major desirable features in various applications” (Siddique et. al., 2008). Therefore, it is reasonable to say that the market for plastic recycling is not threatened by biodegradable and photo degradable plastic products. Due to the higher manufacturing costs of these products compared to regular plastics, and the lack of environmental benefits, firms will not replace conventional plastic products. However, the aim of this research is to recycle waste plastic materials for use as construction materials in buildings.

The aim of this research is to carry out a comparative analysis of recycled plastic tiles and a conventional tile such as alumina ceramic tile and the main objective here is to validate the results of a waste recycled plastic tile with that of a conventional (alumina ceramic) tile using ansys15.

2. Materials and Methodology

2.1 Materials

The materials used in this paper are as follows: three waste plastic types (i.e plastic bottles, water sachets and water bags), an electric furnace with up to 1000^{o}C, a pot made of stainless steel material, a ladle, moulds (forms).

2.2 Method

The various plastic waste types were processed in five steps as follows:

(i) Plastic collection: the plastics wastes for recycling were collected around the Ilorin metropolis.
(ii) Manual sorting: each plastic waste type were separated from each other and unwanted materials were removed from the waste, like in waste plastic bottles, the plastics normally attached on the skin of bottles and the bottle caps were removed.
(iii) Chipping: the various plastic waste sorted were then chopped into smaller pieces.
(iv) Washing: The chips were then washed to remove glue, paper labels, dirt and any remnants of the product they once contained.
(v) Melting: this was done by dissolving the chopped plastic which was placed in a pot and inserted in the furnace. The furnace was then connected to the electricity and the melting point and time of melting were recorded. Initially, the plastic wastes were melted at 170^{o}C, 155^{o}C, 120^{o}C and 60^{o}C; this was to select a suitable melting temperature.

However, when pouring the molten plastic into the forms, two cooling methods were carried out. They are described as follows:

a) Uncontrolled cooling method: In this method, the molten plastic was poured into the forms and it was allowed to cool at room temperature.
b) Controlled cooling method: In this method, the molten plastic was poured into the forms and it was then pressed and covered with a thick metal sheet so as to delay the thermal equilibrium between the molten plastic and the surrounding.

2.2.1 Laboratory tests conducted on the specimens produced

Physical properties: (i) Water Absorption: The water absorption test was carried out in accordance with ASTM D570. The test specimens for moulded plastics were in the form of a disk 50.8 mm (2 in.) in diameter and 3.2 mm (1⁄8 inch.) thickness in accordance with ASTM D570. The specimens were dried in an oven with temperature of 105^{o}C to 110^{o}C for duration of 24 hours and placed in a desiccator to cool. Immediately upon cooling, the specimens were weighed. The specimens were then emerged in water with 23^{o}C for 24 hours and specimens were then removed, patted dry with a lint free cloth and weighted._Water absorption is expressed as increase in weight per cent._Per cent (%) of water absorption = (wet weight – dry weight)/ dry weight X100, and (ii) Density and Specific gravity: The density and specific gravity of these waste plastics were carried out according to ASTM D792. The specimen was first weighted in air, then weight when immersed in distilled water at 23^{o}C using a sinker and wire to hold the specimen completely submerged as required. Hence the density and specific gravity were calculated._Any convenient specimen size can be used for the test.

Computation: Specific gravity = a/ [(a + w) – b] (1)

Where_a = mass of specimen in air,_b = mass of specimen and sinker in water,_w = mass of totally immersed sinker if used and partially immersed wire, Density (kg/m^3) = (specific gravity) X 997.6 (density of water).

Mechanical properties

Tensile Strength: This test was carried out in accordance to ASTM D638. The rate at which a sample was pulled apart in the test was ranged to be from 0.5 inches per minute (0.212mm/sec). Five specimens were tested for all the various recycled plastic waste. Figure 1.

Figure 1 Tensile strength test

Compressive Strength: This test was carried out according to ASTM D695. The speed of the movable load was 0.05inch per minute (0.0212mm/s). From ASTM D695 the dimension of the specimen is 12.7 X 12.7X 25.4mm. Five specimens were tested for all the various plastic waste.

Flexural Strength: This test was carried out in accordance with ASTM D790. The specimen of 3.2 X 12.7 X 127mm was placed on two supports and a load was applied at the centre. Five specimens were tested for all the various plastic waste.

Chemical Properties

Resistance to Chemical Reagents: This test was carried out according to ASTM D543. In this research, the various recycled plastics were immersed in hydrochloric acid with concentration of 5%, 15% and 60% concentration of the acid. These plastics were also immersed in sodium hydroxide with concentrations of 5%, 15% and 60% respectively. However, the recycled waste plastics were also immersed in a common salt called sodium chloride. After 24 hours, the specimens were removed and evaluated for desired properties such as change in weight, appearance.

3. Laboratory Results

The table below shows the mechanical and physical properties of various plastic types and those of the alumina ceramic tile gotten from CBP Engineering Corp 185 Plumpton Avenue- Washington. These results are presented as follows:

Table 1: Mechanical and Physical properties of waste plastics and alumina ceramic tile

Property	SI units	Alumina tile	Water sachets	Water bags	Water bottles	Polyethene bags
Density	g/cm^3	3.52	1.10152	1.10382	1.11664	1.06277
Young's Modulus	MPa	270	137.8	140.6	152.4	131.2
Flexural Strength	MPa	275	6.286	6.112	4.720	5.113
Compressive Strength	MPa	1.77GPa	3.805	5.100	3.349	5.055
Specific Gravity	__	Nil	1.104	1.106	1.119	1.065
Water Absorption	%	None	3	2.67	2.81	2.62
Maximum Use Temperature	^oC	1250	300	300	300	300

3.2 Chemical Properties

The performances of each of the recycled waste plastic resistance to chemical attack are tabulated below.

Table 2: Resistance to chemical attack of various recycled waste plastic

S/N	Plastic type	Hydrochloric acid (HcL) with concentrations			Sodium hydroxide (NaOH)			Sodium chloride (NacL)
		5%	15%	60%	5%	15%	60%	
1	Water sachets	E	E	G	E	E	E	E
2	Water bags	E	E	G	E	E	E	E
3	Water bottles	E	E	G	E	E	E	E
4	Polyethene bags	E	E	G	E	E	E	E

Where; E stands for excellent and it means the plastic totally resisted that particular substance and G stands for good, which means that, the influence of that substance for a longer period of time causes little or no defects to the specimen in it.

4. Analysis

From the laboratory results obtained, a computer analysis using ANSYS15 was carried out to see how the material fails under flexural load and compressions load and also to investigate the behaviour of the various recycled plastic waste materials. The stresses, strain, total and directional deformations and strain energy were determined from the analysis and their results were tabulated and graphs were plotted. The analyses carried out are as follows:

4.1 Analysis of flexural specimen

Analysis of flexural Specimen for water sachets, polythene bags and ceramics tiles are shown in Figures 2 to 11.

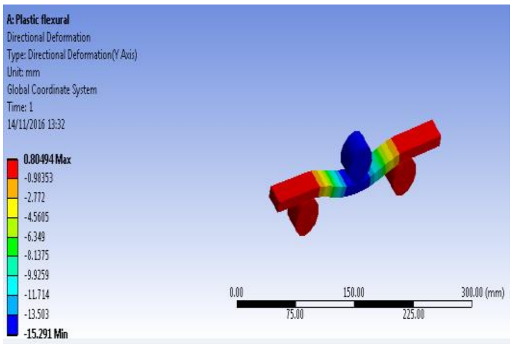

Figure 2 Directional deformation in y-axis for water sachet

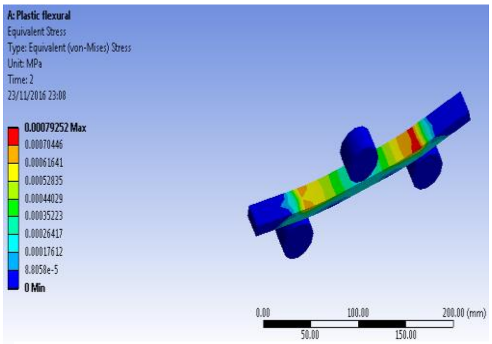

Figure 3 Equivalent (von mises) stress in flexural specimen for water sachet

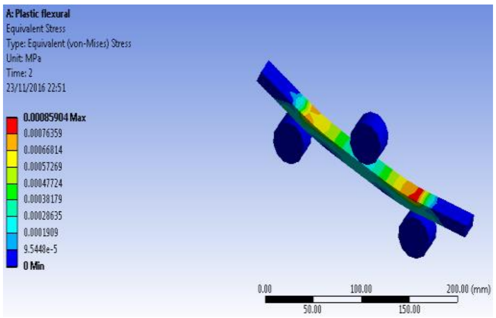

Figure 4 Equivalent stress in flexural specimen for water table

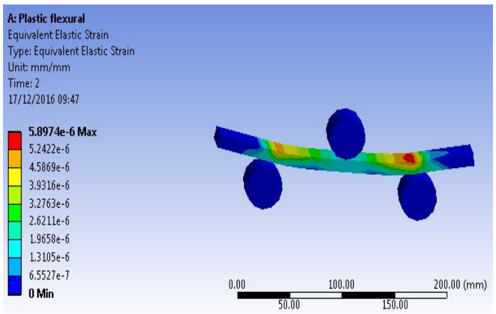

Figure 5 Equivalent stress in flexural specimen for water table for polythene bags

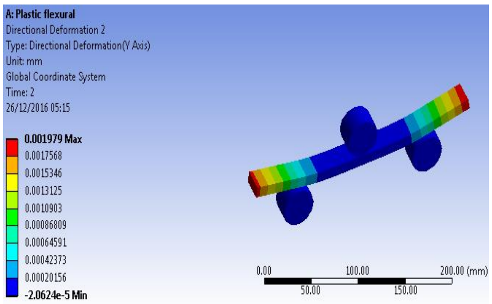

Figure 6 Directional deformation in flexural specimen for alumina ceramic tiles

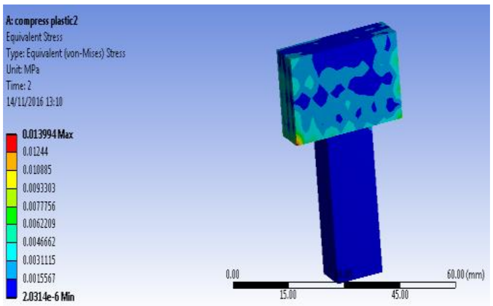

Figure 7 Directional deformation in flexural specimen for water sachet

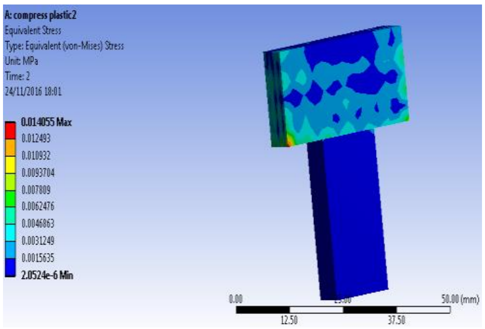

Figure 8 Equivalent stress in compression specimen for water bottle

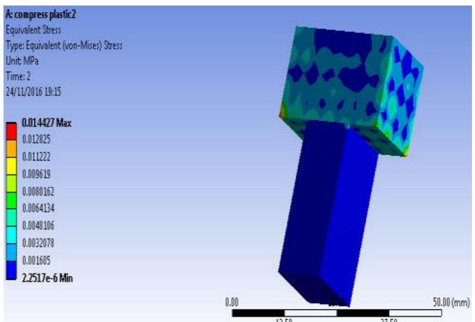

Figure 9 Equivalent stress in compression specimen for polythene

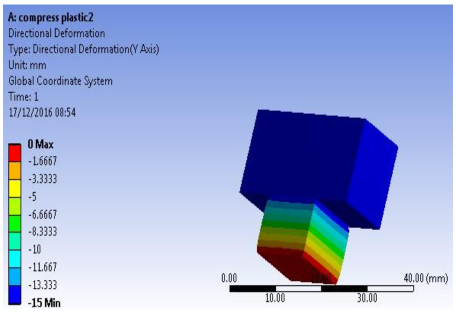

Figure 10 Directional deformation of alumina ceramic tile

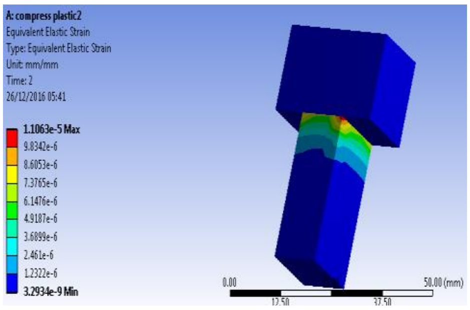

Figure 11 Equivalent elastic strain for compression specimen ceramic tile

4.3 Analysis of Recycled Plastic Plate (Tile)

Plates (tiles) made of various recycled plastic material were also analysed with a point load at the centre of the plate. However, the dimension of the plate was (300 x 300 x 10) mm and the base of the plate was assumed to be of an elastic support with a unit weight of $18N/mm^3$. Furthermore, the stress, strain, deformations and energy were determined as shown in the models below. Analysis of plate sheet for water sachets, water bags, water bottle and polythene bags as well as alumina ceramics bags are shown in Figures 12 to 16

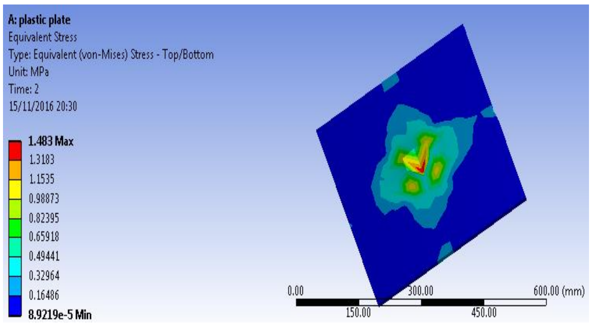

Figure 12 Equivalent stress of tile made of recycled plastic

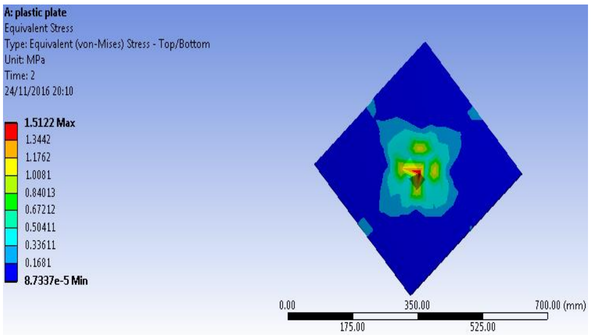

Figure 13 Equivalent stress of tile made of recycled plastic

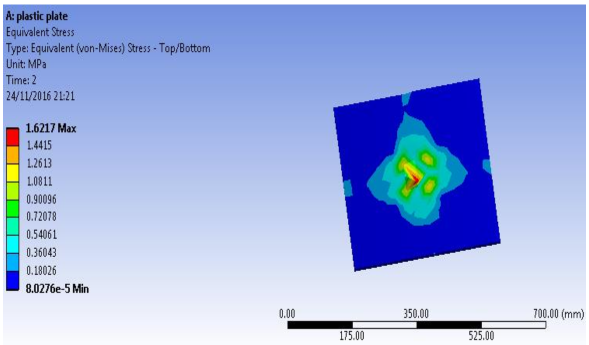

Figure 14 Equivalent stress of tile made of recycled plastic

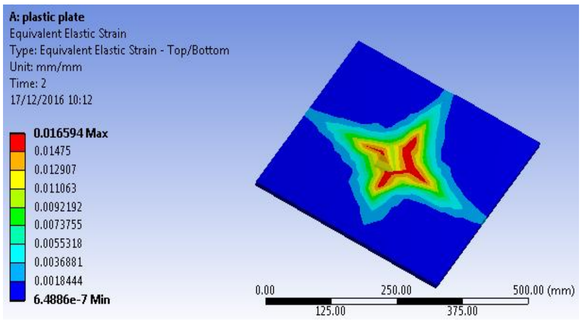

Figure 15 Equivalent elastic strain

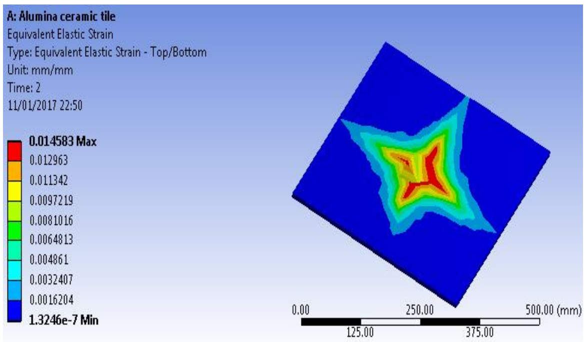

Figure 16 Equivalent elastic strain

5. Discussion of Results

From the results obtained, the analysis of the flexural specimen made of various recycled waste plastics and the alumina ceramic tile were seen to have maximum reaction forces as follows 1427N, 1463N, 1585.8N, 1466.6N and 2809.5N in y-axis for water sachets, water bags, water bottles, polythene bags and alumina ceramic tile respectively as shown in the chart below, while the reaction forces in the x and z-axis were found to have no effect on the specimen since they had negative values. (Figures 17).

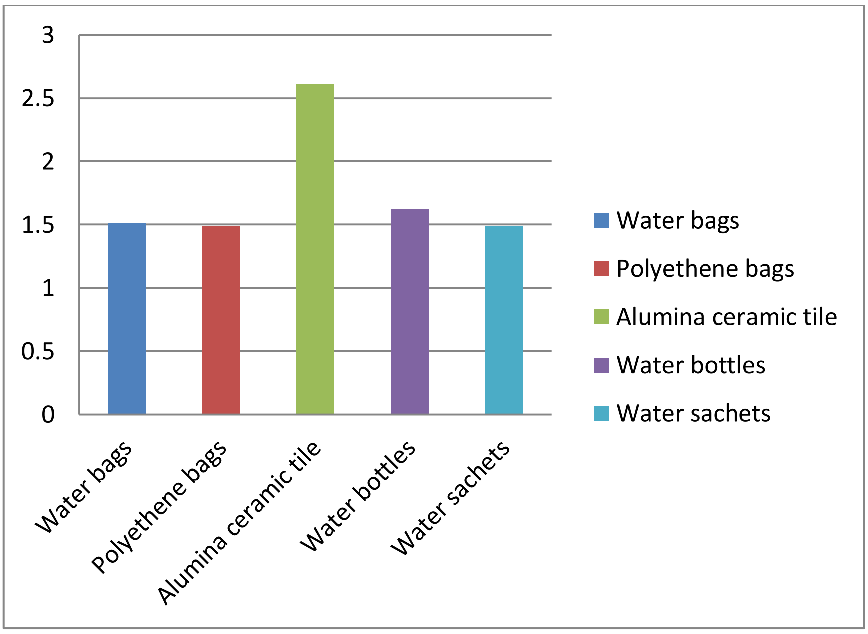

Figure 17 Force reaction (N) of various recycled waste plastics and alumina ceramic tile in flexure.

The total deformations and the directional deformations of the various specimens before failur were seen to be 15.291mm and 0.80494mm respectively for all recycled waste plastic type and alumina ceramic tile. Also, the equivalent stress hits a maximum of 10.603MPa, 10.87MPa, 11.783MPa, 11.054MPa and 20.875MPa for water sachets, water bags, water bottles, polythene bags and alumina ceramic tile respectively and an equivalent strain of 0.0872mm/mm for all the recycled waste plastic types and the alumina ceramic tile. However, other relevant information such as the strain energy was also found to be 219.42mJ, 224.95mJ, 243.83mJ, 227.07mJ and 431.99mJ for water sachets, water bags, water bottles, polythene bags and alumina ceramic tile respectively and can be presented as follows.(Figure 18).

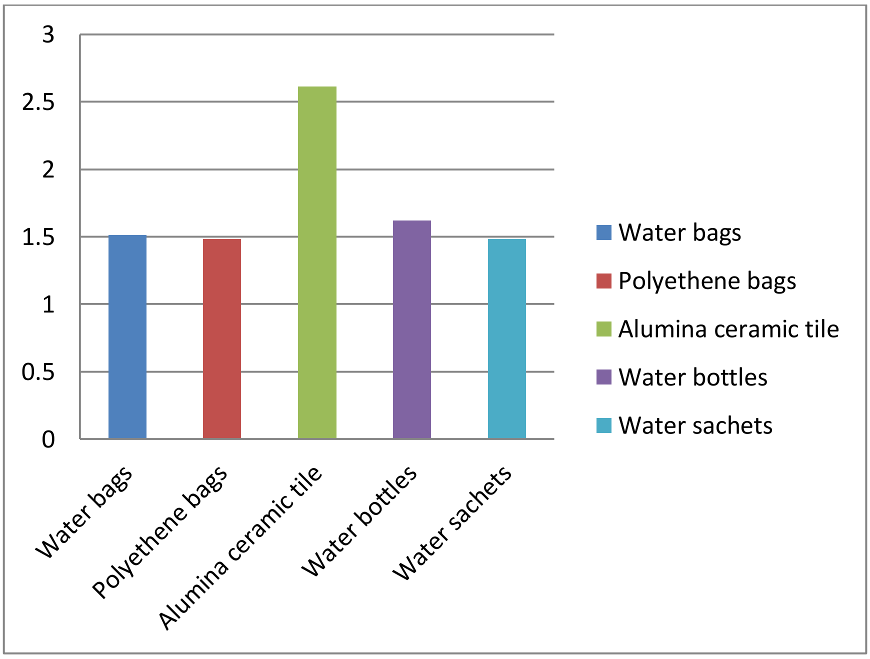

Figure 18 Strain energy (mJ) of various recycled waste plastics and alumina ceramic tile in flexure.

These values obtained from the analysis however, shows some dissimilarities from the values obtained in the laboratory between different recycled waste plastic types. The graph in Figure 19 shows the variation of each of these properties with time. Also, the stress/strain graphs were found to be linear for recycled waste plastic types. Again, from the results obtained, the analysis of the compression specimen made of various recycled waste plastic, it can be seen to have maximum reaction force of 13076, 13405, 14530, 13405 and 25736N in the y-axis for water sachets, water bags, water bottles, polythene bags and alumina ceramic tile respectively, while the reaction forces in the x and z-axis were found to have no effect on the specimen since they had negative values. The total deformations and the directional deformations of the various specimens before failure were seen to be 15mm and 0mm respectively for all recycled waste plastic type and alumina ceramic tile. Also, the equivalent stress hits a maximum of 85.26, 87.412, 94.75, 87.412 and 167.9MPa for water sachets, water bags, water bottles, polythene bags and alumina ceramic tile respectively and an equivalent strain of 0.6217, 0.62171, 0.62172, 0.62171 and 0.62185mm/mm which is same for recycled waste plastic type and the alumina ceramic tile. However, other relevant information such as the strain energy was also found to be 1843.3, 1889.7, 2048.2, 1889.7, and 3626.8mJ for water sachets, water bags, water bottles, polythene bags and alumina ceramic tile respectively. Finally, these values obtained shows some difference from the values obtained in the laboratory between various plastic types. The graphs below show the variation of each of these properties with time. Also, the stress/strain graphs were found to be linear for recycled waste plastic types. From the results obtained, the analysis of the plates (tiles) specimen made of various recycled waste plastic can be seen to have maximum total deformations of 1.7499, 1.7445, 1.7242, 1.7499 and 1.556mm for water sachets, water bags, water bottles, polythene bags and alumina ceramic tile respectively. Also, the equivalent stress hits a maximum of 1.483, 1.5122, 1.6217, 1.483 and 2.6123MPa for water sachets, water bags, water bottles, polythene bags and alumina ceramic tile respectively as shown in the chart below and an equivalent strain was found to be 0.0166, 0.0165, 0.0163, 0.0166 and 0.0146mm/mm for all the recycled waste plastic types and alumina ceramic tile respectively.

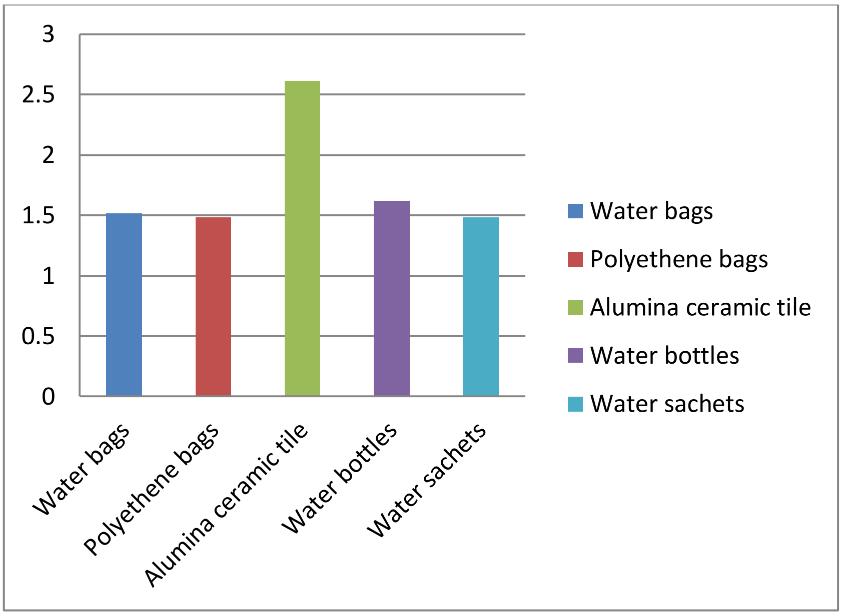

Figure 19: Stresses of various recycled waste plastic tiles and alumina ceramic tile.

However, other relevant information such as the strain energy was also found to be 202.11, 204.84, 214.75, 202.11 and 283.59mJ respectively. The graphs below show the variation of each of these properties with time. Also, the stress/strain graphs were found to be linear for recycled waste plastic types. Also, when applying these recycled plastics as tiles, a suitable adhesive should be properly tested from the wide range of structural adhesives so as to interconnect the joints between the recycled plastic tiles for it to be tight and water proof from the surface.

6. Conclusion

Based on the findings of this research, the following conclusion can be drawn:

(i) Any other thermoplastic that is recycled to form any of the specimens above, its properties will be the same since the plastics recycled in this research showed very little or no difference. Also, when a thermoplastic is recycled or melted, it has little or no tensile strength due to it great shrinkage.
(ii) There is really no difference between the plastics types studied in this research because, they all have similar properties and can all be applicable in all areas such as construction tiles just as alumina ceramic tile.
(iii) When cooling these recycled plastics, the controlled cooling method should be adopted because this method minimises the chances of shrinkage in the final product.
(iv) The maximum used temperature of these recycled waste plastic tiles was found to be 300^{o}C compared to that of alumina ceramic tile which is 1250^{o}C and the suitable melting point for all the waste plastics studied in this research was found to be 60^{o}C.
(v) From the computer analysis carried out, the alumina ceramic tile shows less deformations compared to recycled plastic product and also, the stresses in the recycled plastic product were found to be less compared to that of alumina ceramic tile when the was applied at the centre of the plate. Furthermore, the equivalent strain for all recycled plastic types were equal but less than that of alumina ceramic tile and also the strain energy of alumina ceramic tile hits a value higher than strain energy of all the recycled plastic types.

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