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EFFECTIVENESS OF MOLTEN PLASTICS AS AN ALTERNATIVE BUILDING CONSTRUCTION MATERIAL

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ABSTRACT

This paper presents the research findings on use of molten plastics as a binder in making building blocks. Laboratory experimental analysis method was adopted for the research study. Sample blocks were made from molten plastics and quarry dust in different proportions. The mixture was subjected to pressure so as to achieve reasonable compaction. The mix proportions were 15:85, 20:80, 30:70, 40:60 50:50, 60:40, and 70:30 of plastic to quarry dust. Laboratory tests carried out included compressive strength, density and water absorption. Results showed an increase in strength as the proportion of the molten plastics increased to an optimum value of 10.47N/mm^2 at 40% of molten plastic contents, which is higher than the cement-quarry dust. The strengths were comparable to that of designed block strength made from quarry dust and cement in the ratio of 1:6 and 2:4 with water-cement ratio of 0.5, which gave 4.00N/mm^2 and 1.72N/mm^2. The water absorption decreased with increase in plastic content. Values of water absorption capacities obtained from of all the blocks were between 0.22% -7.60% which are below the standard maximum value of 12%. This implies that the volume of fine content is appropriate and the desired strength of the block can be achieved. From the forgoing, it can be concluded that molten plastics is an effective alternative binder in the construction industry, thus managing solid waste.

Keywords: Molten plastics; Binder; Building blocks; Construction industry; Compressive strength.

1.0 INTRODUCTION

Plastics are indispensable materials in the modern world. Plastic manufacturing is a multi-million industry providing employment and job opportunities to many people globally. However, disposal of plastics has resulted into high environmental hazard to man. On the other hand, construction industry is in acute need of sustainable and affordable materials with required strength to meet the ever increasing demand for modern infrastructure.

It is a common sight in both urban and rural areas to find empty plastic bags and type of plastic packing material littering the environment (Chand and Hashmi, 2003; Varzinskas Visvadas *et al.*, 2009; Gawande *et al.*, 2012). Due to its non-biodegradability it creates stagnation in flow of water and associated hygiene problems. Studies have been carried out to determine the suitability of waste plastics to be reused productively in construction such as construction of roads (Kolo,

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2013). These have shown that plastics, when added to hot aggregate will form a fine coat of plastic over the aggregate thus improving conditions of bonding (Rajasekaren *et al*., 2013). The aggregates are found to give higher strength, higher resistance to water absorption and better performance over a period of time (Neville and Brook, 2003; Taylor, 2013). Density, water absorption and compressive strength are the three properties for which building materials are designed (Neville and Brook, 2003)

The construction industry is fast growing due to increased demand of structural facilities, especially due to urbanization. The demand for construction materials is thus high and there is an encroaching danger of depletion of materials. In addition, development in construction techniques has triggered the need for materials with superior quality and outstanding properties. Various researchers have tried to develop alternative building materials using waste ash in order to lower the cost of materials (Isaac *et al*., 2013; Yamusa *et al.*, 2013).On the other hand, the plastic industry is enormous and there is a wide variety of plastic products for use in the society (McCrum *et al.*, 1988). Consequently, there is an increasing trend of environmental pollution with plastic wastes, which are mostly non-biodegradable, thus posing hazard to environmental health (Central Pollution Control Board, 2014). Generally, it is a good development to explore the usage of plastic waste in construction (Plastic Waste Management Institute, 2009). Plastics have been in use in the construction industry although little effort has been made to utilize waste plastics in the same industry. The large volumes of plastic wastes disposed in the environment are unmanageable and should be recycled. The prominent properties of plastics will cause tremendous improvement in construction in terms of strength, light-weight, flexibility and insulating properties (William, 2006; Matoke *et al.*, 2012). The main objective of this research is to determine the three properties for which building materials are designed density, water absorption and compressive strength of blocks made using different mix proportions of quarry dust and molten plastic (NIS 87, 2007; Neville and Brook, 2003)..

2.0 MATERIALS AND METHODS

2.1 Materials

2.1.1 Molten plastics. Plastics were randomly collected from the Masinde Muliro University of Science and Technology Kakamega,, Kenya dustbin bits and clean with water, and thereafter open fire was used to heat and melt the plastics in the steel basin. Molten plastic was thoroughly stirred to make it consistent.

According to Noel *et al*. (2015) plastic melts at a temperature range of between 130-140˚C. The melting point for linear polyethylene obtained is 138˚C, which is within the range. The plastics were thermoplastics and it was noted that most of them were Polyethylene of either Light Density or High Density. The specific gravity and average density of Polyethylene (ρ) were taken as 1.10 and 925.5 kg/m³ respectively (Jackson and Dhir, 1991)

2.1.2. Quarry dust. Quarry dust was obtained from stock piles at the Masinde Muliro University of Science and Technology Kakamega, Kenya construction site. The quarry

dust used was pulverized to loosen it into individual particles after drying in the sun.
Quarry dust was graded through seize analysis in accordance with recommendation of BS 812: Part 103.1 (1985) to determine the particle size distribution, and was found to conform to the specification as contained in BS 882, (1992). According to Jackson and Dhir, (1991) the range of density for crushed stone is 1900-2200 kg/m³, and the lowest value was adopted given the condition of the quarry dust as stated in BS 882 (1992). The specific gravity of quarry dust used was 2.45
Portland Pozzolana Cement used in making samples for comparison conform to the quality of Ordinary Portland Cement as described by BS 12 (1996), and specific gravity and unit weight of cement are 3.15 and 1440 kg/m³ respectively. The cement initial and final setting times were also taken to be 40 minutes and 215 minutes, since BS 12 (1996) and ASTM C 150 (2000) specified that initial setting time of Ordinary Portland Cement should not be less than 30 minutes and not more than 45 minutes, and its final setting time should not exceed 600 minutes. These values are within the stipulated values which indicates that the.blocks made from the cement can be mixed properly, transported, placed and compacted before stiffening process.
The water used for the mix was also in conformity with recommendation of BS 5184, (1980) having the density and pH value of 1000kg/m^3 and 6.9 respectively Other materials used include: firewood; kerosene and lubricating oil. Most of the equipments and tools were available in the laboratory, for instance; scoop, trowel, tamping rod, mug, beakers, electronic balance and oven. Others were purchased or hired such as Jua-kali steel basin and the protective gear.

2.2. Methods

2.2.1. Mix proportion of materials (Molten plastic-quarry dust). Molten plastic and quarry dust in measured proportions were mixed and stirred to achieve a workable mix. The mix proportions percentage weight of molten plastic to quarry dust were in the ratio of 15:85, 20:80, 30:70, 40:60 50:50, 60:40, and 70:30 by volume respectively. The mixture was stirred well for about 10-15 minutes to obtain the proper bond between the molten plastic and quarry dust.
Specimen were made by casting of the molten plastic-quarry dust mix using cylindrical moulds of 150 mm height and 105 mm diameter steel tubes (Plate 1).

Plate 1: Cylindrical moulds

It is important to note that quarry dust that has not been preheated significantly lowered the temperature of the molten plastic causing it to set. Therefore, the temperature had to be increased gradually during the mixing process to maintain the temperature of the plastic within the melting range as stated by Noel, *et al*, (2015).
A cylindrical paste specimen size of 105 mm x 150 mm in diameter and height was used and its fixed volume (V) in m^3 computed from equation 1.

$$V = \pi r^2 h \quad \ldots \quad (1)$$

Where: r is the radius, and h is the height of the sample specimen.

It is important to note that water was not involved in the mixing of molten plastic-quarry dust specimen. Using the fixed volume, the density of the specimens and the predetermined proportions by volume, the corresponding quantities in mass were determined as the product of percentage content, volume and unit weight of sample (W = 925.5 kg/m^3).

For each proportion, three specimen sample contents were produced to increase the accuracy of the results. Two cement-quarry dust mix proportion samples A*and B* with water cement ratio of 0.5 were used to produce block for the purpose of design strength comparism with that of molten plastic-quarry dust. There was a 0.02 kg increment in the measured quantities to cover the losses.

Table 1. Molten plastic and quarry dust predetermined proportions

Sample notation	Molten plastic		Quarry dust	
	Percentage Content, (%)	Mass 10^{-3}, (kg)	Percentage Content, (%)	Mass 10^{-3}, (kg)
A	15	0.18	85	2.10
B	20	0.24	80	1.97
C	30	0.36	70	1.73
D	40	0.48	60	1.48
E	50	0.60	50	1.23
F	60	0.72	40	0.99
G	70	0.84	30	0.74

Mix proportion of cement-quarry dust sample for design strength comparison - Sample A* constituted 1:6 parts of cement and quarry dust. Using absolute volume method, the mix proportion of this sample was very close to that of the experimental sample A (15% plastic and 85% quarry dust by volume). Using unit weight and specific gravity of cement (P_{cement}) as 1440 kg/m³ and 3.15, specific gravity of quarry dust 2.65, unit weight of water as 1000kg/m^3 and water-cement ratio of 0.5. Mass of cement and quarry dust were determined to be 0.27 kg and 2.12 kg respectively.

Sample B*****contained 20% of cement and 80% of quarry dust by volume. It corresponds to a mix proportion 1:4 of cement to quarry dust respectively. Consequently, mass of cement and quarry dust were determined to be 0.374 kg and 1.97 kg.

2.2.2 Setting time of molten plastics-quarry dust. Having the cylindrical moulds of 105x150mm in diameter and height lubricated and well positioned on a flat metallic plate, the hot mix was poured in layers using a scoop. Compaction was done for each layer using an improvised tamping rod, and the setting time of the specimen was determined in accordance to IS 8142, 1997 recommendations. The setting time was divided into two namely, initial and final setting times. Initial time is time at which the specimen paste loses its plasticity, and time taken to reach the stage when the paste becomes a hard mass is known as final setting time.

2.2.3. Density and compressive strength test. The density of the concrete or block as a construction material is mainly governed by the particle density of the aggregate mixture. Density test was conducted in accordance with BS 1881: Part: 114, (1983) and crushing strength tests for the compressive strength in accordance with BS 1881: Part 116, (1983) recommendations. Specification of the compressive strength test machine used conformed to BS 1881: Part: 115, (1983). The mix proportions in percentage, 15:85, 20:80, 30:70, 40:60 50:50, 60:40, and 70:30 of molten plastic-quarry dust were used to cast the block sample. The samples were cured in curing tank containing water for 28 days and crushed at room temperature of 25-30˚C. The compressive strength was computed through equation (2)

$$\text{Compressive strength} = \frac{N,(N)}{A(mm^2)} \quad \dots \quad (2)$$

Where: N is the crushing load and A is the surface area

2.2.4 Water absorption test. Water absorption test of the specimen was conducted in accordance with BS 812: Part 107: (1995). Water absorption as the ratio of decrease in the mass between a saturated sample and a surface dried aggregate after oven drying for 24 hours to the mass of the oven dried sample expressed as a percentage was computed from equation 4.

$$\text{Water absorption} = \frac{W_2 - W_1}{W_1} x100,(\%) \quad \dots \quad (4)$$

Where: W_1 is the weight of oven dried sample; W_2 is the weight of saturated sample.

3.0 RESULTS AND DISCUSSIONS

3.1. Results

3.1.1 Setting Time: The sieve analysis conducted on the quarry dust is presented in form of grading curve on Figure 1. The uniformity coefficient, U was used to analyze the grading curve through equation 5:

$$U = \frac{D_{60}}{D_{10}} \quad .. \quad (5)$$

Where: D_{10} and D_{60} represent effective/normal maximum grain size in microns that correspond to 10% and 60% fine passing the respective sieve sizes which are related to permeability and capillarity values (BS 812: Part 103, 1985).

From Figure 1 the diameters that correspond to 10% and 60% passing are 0.159 and 1.5 respectively, consequently the uniformity coefficient, U was determined to be 9,43.

Since U is between 5 and 10 the quarry dust is in medium uniformity.

From Figure 1 the values obtained from sieve analysis of the quarry dust particles size are between 0.075 – 4.75mm, which are within the range of 0.15-5mm of the particles size of ag-

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gregate (fine) normally used as recommended by BS 812: Part 103, 1985.

3.1.2 Density and Compressive Strength: The thermoplastic (polyethylene) used in this study had a density range of 910-941 kg/m³. This value is below the density of water, 1000 kg/m³ indicating the weight reduction effect as the proportion of molten plastic used is increased. The variation of density with percentage of molten plastics are presented in Table 2 and Figure 2.

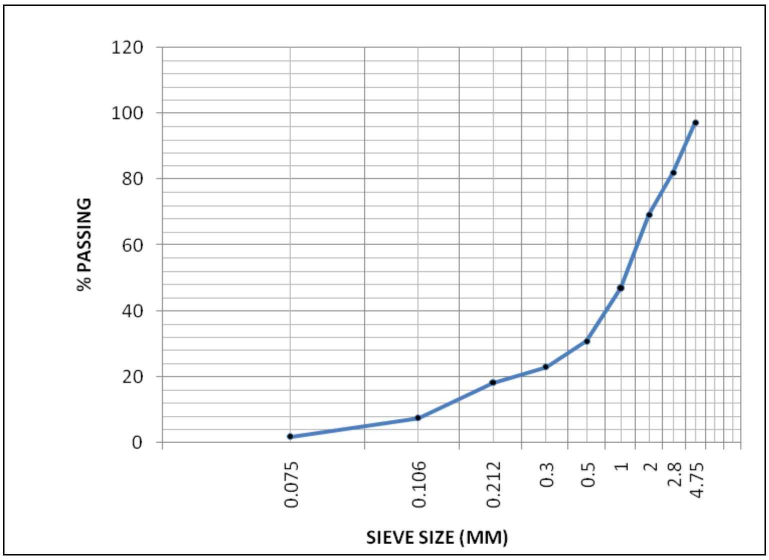

Figure 1. A plot of particles size against percent passing

Table 2: Density results

Block Sample notation	Material Content, (%)				Diameter, (m)	Height, (m)	Volume 10^{-3}, (m^3)	Mass , (kg)	Density, (kg/m^3)
	Molten Plastic	Quarry dust	Cement	Quarry dust					
A	15	85			0.105	0.15	1.299	2.230	1. 68
B	20	80			0. 105	0.15	1.299	2.161	1.66
C	30	70			0.105	0.15	1.299	2.034	1.63
D	40	60			0.105	0.15	1.299	1.723	1.59
E	50	50			0.10.	0.15	1.299	1.813	1.47
F	60	40			0.105	0.15	1.299	1.561	1.43
G	70	30			0.105	0.15	1.299	1.337	1.24
A*			15	85	0.105	0.15	1.299	2.387	1.86
B*			20	80	0.105	0.15	1.299	2.348	1.82
(A* +B*)/2									1.84

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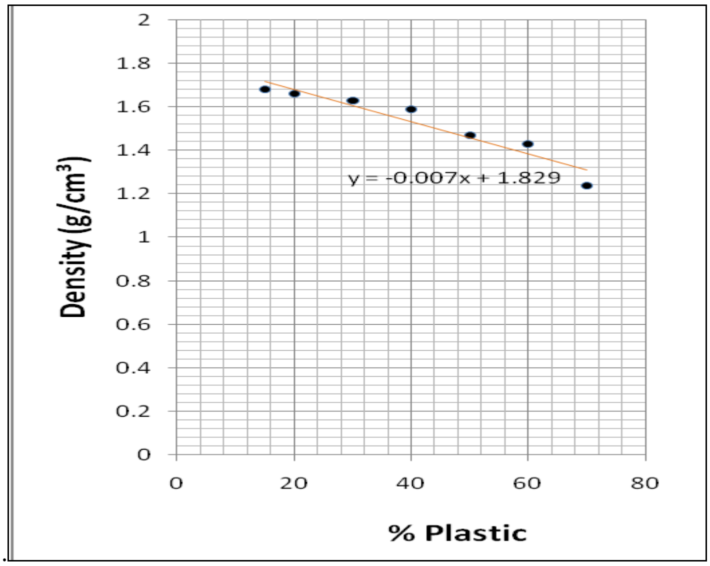

Figure 2. Density of block sample against molten plastic content

It was observed that the samples varied in height and also in diameter. The variation in height was by a margin of about 25mm, between the maximum and minimum height while that of diameter was by a margin of 2.3mm between the maximum and minimum diameter. The expected dimensions of the sample were 105 mm in diameter and 105 mm in height. There were slight variations in these measurements.

From Table 2 the average diameter is beyond 105 mm with the largest diameter being 106.7 mm for block A (15% molten plastic by volume). The diameter decreases non- uniformly towards the expected value (105 mm) as the percentage of molten plastic content increases. In addition to the variations explained above, samples with 15%, 20% and 30% molten plastic content were found having minor cracks on the surface thus the trend of increment in diameter. The variation of diameter in control sample was comparatively minimal with the largest size value being 105.5 mm. Thus the variation can be attributed to bond strength which further implies the strength of the block. The bond associated with cement is chemical in nature while that of plastic is physical. The sample height decreases as percent plastic increase. The smallest and largest heights were 123.0 mm and 148.0 mm respectively, thus the expected sample heights were hardly achieved. This variation can be attributed to thermal properties of the plastic matrix, and use of non-uniform compacting effort. Three samples were made for each mix proportion of molten plastic to quarry dust. This was done for both plastic and cement samples. Figure 2 shows a linear relationship between density and percent molten plastic content. The graph shows an inverse relationship thus slopes in the negative direction. As the percent molten plastic content increases, the density decreases proportionally.

Figure 3 shows that the strength increase gradually with increase in molten plastic content of up to a value of 10.47 N/mm² at 40% molten plastic content, the strength then decreases with further increase in molten plastic proportion. There was no stripping and this shows that the coated molten

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plastic stick well with the surface area of the aggregate. Further increase in proportion of molten plastic and increases in quarry dust cause decrease in strength, as a result of splitting. This shows that the binding strength of the molten plastic at this content is bad. However, this is limited to a particular value of 40%, beyond which strength starts to decrease. The results of experimental investigation on compressive strength are presented in Table 3.

Table 3: Compressive strength

Block sample notation	Material Content, (%)				Max load, (N)	Surface area, (mm^2)	Compressive strength, (N/mm^2)
	Molten plastic	Quarry dust	Cement	Quarry dust			
A	15	85			30000	8942.83	3.35
B	20	80			45000	8909.33	5.05
C	30	70			70000	8842.54	7.92
D	40	60			90000	8594.28	10.45
E	50	50			65000	8742.81	7.43
F	60	40			40000	8726.25	4.58
G	70	30			20000	8759.39	2.28
A^*			15	85	35000	8742.81	4.00
B^*			20	80	15000	8726.25	1.72
$(A^* + B^*)/2$							2.86

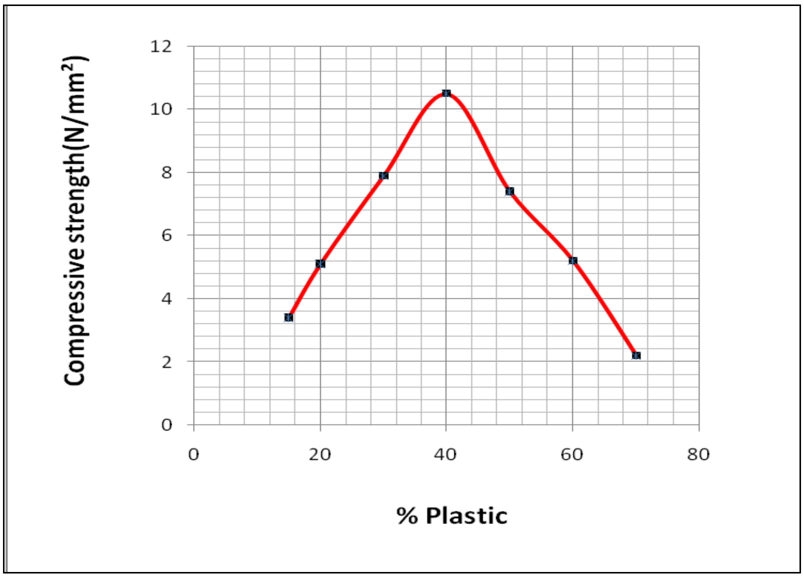

Figure 3: Compressive strength against percentage molten plastic content

3.1.3 Water Absorption:

Table 4 and Figure 4 presents the results of the water absorption of the blocks. From Figure 4, it can be observed that the water absorption increasing non- linearly, and decreases as the percentage of molten plastic contents increases. The decrease of water absorption with increase in plastic matrix may be attributed to the water repelling properties associated with molten plastics. More also it is observed that the water absorption had decreased with the increase in the percentage coating of molten plastic over the quarry dust as fine aggregate. This shows that coating of molten plastic reduces the voids.

Table 4: Water absorption results

Block sample notation	Material Content, (%)				Average mass - sook sample, x, (kg)	Average mass - unsoak sample, y, (kg)	Percentage absorption (x-y)/100, %
	Molten plastic	Quarry dust	Cement	Quarry dust			
A	15	85			24000	2230	7.60
B	20	80			2310	2161	6.90
C	30	70			2080	2034	2.30
D	40	60			1750	1723	1.57
E	50	50			1830	1813	0.94
F	60	40			1565	1561	0.26
G	70	30			1340	1337	0.22
A^*			15	85	2580	2387	8.09
B^*			20	80	2450	2348	4.31
$(A^* + B^*)/2$							6.22

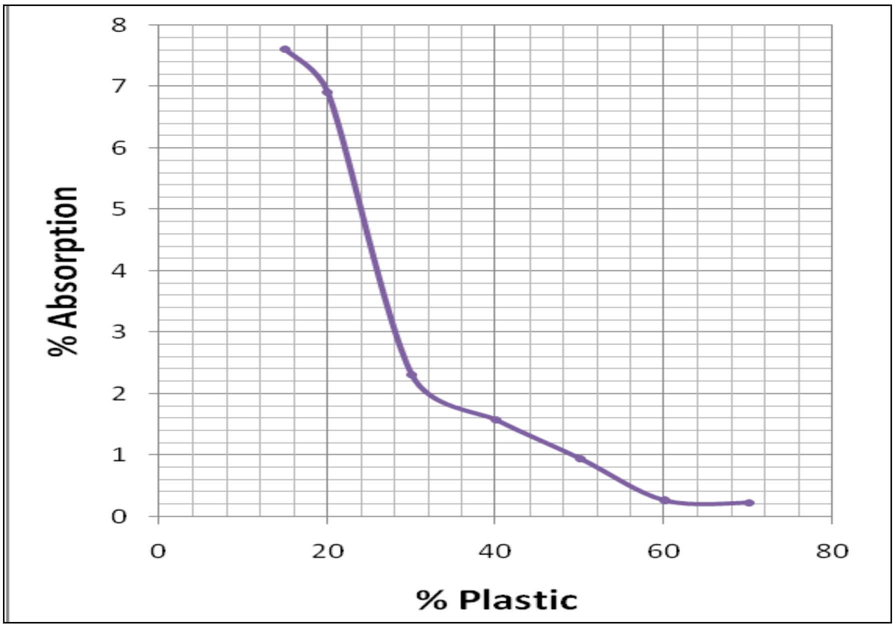

Figure 4. Water absorption against molten plastic content

3.2 Discussion of Results

The setting time of molten plastic can be explained in terms of change of state into the hardened state. The molten plastic as polyethylene gets softened easily without any gas evolution of gas around 130-140^{o}C (IS 8142, 1997). The initial and final setting times were found to be 45 minutes and 50 minutes. These values are within the stipulated value in IS 8142 (1997), which signify that the block made from these materials can be mixed properly, placed and compacted before stiffing process begins. There is no chemical reaction involved as in the case of cement (hydration process). The setting time of molten plastic depends on room temperature and that of the mixing constituents (quarry dust).

For the molten plastic samples, it was clear that setting and hardening of the mix was temperature dependent as evidenced in the setting of molten plastic upon temperature drop. However, the process of crystallization of molten plastic takes place in two stages, where molecules lose energy to conform and then pack together. This process probably depends on other factors apart from temperature and thus curing would take more time even if the sample was cooled to room temperature.

It was observed that samples with smaller proportions of plastic binder were hard to remove and there was stripping. These were samples A, B and C containing 15%, 20% and 30% of plastic by proportion respectively. On the other hand, samples D, E, F and G which had 50%, 40%, 60% and 70% of plastic were removed from the moulds with ease. There was no stripping and this shows that the coated molten plastic stick well with the surface area of the aggregate.

Hence, the coating of plastic over aggregate helps to improve the quality of the aggregate. The water absorption decreased with increase in molten plastic content indicating that molten plastics is an effective alternative binder in the building construction. The water absorption capacities values obtained were between 0.22 -7.60% which are below the maximum value of 12% by NIS: 87 (2007). This implies that the volume of fine content is appropriate and the desired strength of the block can be achieved.

4. CONCLUSIONS

Based on the experimental investigation of the effectiveness of molten plastic as alternative building construction material, the following conclusions are deduced:

Setting time of molten plastic depends on room temperature and that of the mixing constituents The molten plastic as polyethylene gets softened easily without any gas evolution of gas around 130-140^{o}C (IS 8142, 1997). The initial and final setting times were found to be 45 minutes and 50 minutes respectively. IS 8142, (1997) specified that initial setting time should not be more than 60 minutes and not less than 45 minutes, and it's final setting time should not exceed 180.minutes These values are within the stipulated value for initial and final setting times, which signify that the block made from these material can be mixed properly, placed and compacted before stiffing process begins. There is no chemical reaction involved as in the case of cement.

The maximum value of 12% by NIS:87, (2007). This implies that the volume of fine content is appropriate and the desired strength of the block can be achieved. The coating of molten-plastic over the aggregate reduces water absorption. This shows that the voids at the surface were reduced, and the lesser the voids, the better the quality of the aggregate.

The water absorption value increases non- linearly and begin to decrease as the percentage of molten plastic contents increases. Decrease of water absorption with increase in plastic matrix may be attributed to the water repelling properties associated with molten plastics. The water absorption decreased with increase in molten plastic content indicating that molten plastics is an effective alternative binder in the building construction. The water absorption capacities values obtained from of all the blocks were between 0.22% -7.60%, which are below the standard maximum value of 12% as recommended by NIS:87 (2007). This implies that the volume of fine content is appropriate and the desired strength of the block can be achieved. The coating of molten-plastic over the aggregate reduces water absorption. This shows that the voids at the surface were reduced, and the lesser the voids, the better the quality of the aggregate.

However, the outcome of experimental investigations with regard to the effectiveness of molten plastic as alternative building construction material, call for some important considerations. For example, the mixture should be stirred well for about 10-15 minutes to obtain the proper bond between the molten plastic and quarry dust. The quarry dust that has not been preheated significantly lowered the temperature of the molten plastic causing it to set. Therefore, the temperature should be increased gradually during the mixing process to maintain the temperature of the plastic within the melting range as required.

Good mix proportion of molten plastic as binder and quarry dust as aggregate should be employed to achieve strength requirement of blocks either for non-load or load bearing walling material. The mix proportion should be between 15% - 60% molten plastic to between 40-85% quary dust, since this proportion yielded minimum recommended for blocks to be used for building construction.

The water absorption capacities values of the building construction material containing molten plastic as binder should be below 12% to achieve the desired strength of the block to make it non-load or load bearing walling material..

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