World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

(Research Article)

Impact of granular material size and curing conditions on the properties of a building material with melted plastic waste as the only binder

M. Thiam *

Ecole Normale d'Enseignement Technique et Professional (ENETP) du Mali.

World Journal of Advanced Research and Reviews, 2026, 29(01), 096-110

Publication history: Received on 18 November 2025; revised on 24 December 2025; accepted on 26 December 2025

Article DOI: https://doi.org/10.30574/wjarr.2026.29.1.4272

Abstract

In recent years, environmental protection has drawn considerable attention across the world and new initiatives are being adopted to develop eco-friendly or cementless concrete or building material as an alternative to Portland cement based concrete or construction materials. Among these works, there are the use of plastic wastes as a binder or substitute/replacement for granular materials in the concrete. This paper aims to investigate the effect of curing conditions and granular material size on the physical and mechanical properties of a cemented construction material, PlasticWasteCrete (PWC), using melted plastic wastes (HDPE and LDPE) as the only binder. Two curing conditions, namely, air dry at ambient temperature and thermal shock in water were used for this research. Moreover, the dimension the size of the granular materials (sand and gravel) was varied in order to test its impact on the physical and mechanical properties of the corresponding PWC sample formulations with given plastic content and HDPE/LDPE (H/L) ratio. Independent of the plastic content and H/L ratio, the reinforcement of granular material skeleton by adding coarser grains was found to increase both compressive and splitting tensile strengths of the corresponding PWC samples. However, subjecting the hot PWC to thermal shock in water shortly after casting was found to decrease its strengths (UCS and tensile) in comparison to the PWC samples cured at ambient temperature. These changes in the material strength, which are linked to the porosity and pores interconnectivity of the tested samples, are in good correlation with the permeability/absorption results. The samples with lower strength were observed to have higher rate of absorption. Linear relationship with high correlation coefficient was established between the UCS and splitting tensile strength of the PWC subjected to thermal shock in water.

Keywords: Granular material size; Curing conditions; Building material; Plastic waste; Binder

1. Introduction

Concrete with its durability and ability to take different forms is one of the most widely used materials in the modern societies (Shi et al. 2012). From its invention to date, several improvements have been made to enhance the properties of this ubiquitous product used in various sectors of the construction industry. The conventional concrete comprises of water, sand, gravel, cement and additives depending on the final use of the product. The cement paste is an essential component in the concrete, which binds other constituent elements together in order to meet the final requirements for which the concrete is designed.

The concrete industry is known to have an enormous environmental footprint because of sheer volume of raw materials needed in its production process. The production of cement alone is believed to be responsible for 7% of the global CO_2 emissions (Meyer, 2009). Also, the cost of cement in vis-a-vis other constituent elements of the concrete is considerable, and the cement production industry is one of the major contributors of greenhouse gases in the atmosphere with impact on human and the environment (Meyer, 2009). Thus, with key attention being given to the protection of the

* Corresponding author: M. Thiam

environment, various initiatives have emerged towards developing environmentally friendly materials as an alternative to help reduce the rate of pollution and enhance diversification in the construction industry.

Several researchers have studied different parameters of concrete containing different materials as additives or binder, among which there is plastic, a product that can be found everywhere in today lifestyle from rural to urban areas around the world. With its long life and its very affordable cost, plastic is often discarded after a limited number of uses, ending up in rivers, oceans or at landfills with huge consequences (Zuberi and Ali, 2015; Boucher and Damien, 2017; Barboza et al. 2018; Schwarz et al. 2019). Numerous studies have been conducted on the engineering properties of conventional concretes, in which plastic waste was used as aggregates to partially replace natural aggregates or as additives in the concrete material (e.g., Vaverka, 1991; Reibeiz, 1996; Al-Manaseer and Dalaal 1997; Sam and Tam 2002; Kumar and Bhattacharjee, 2003; Choi et al. 2005; Ismail and Al-Hasmi 2008; Kou et al. 2009; Zhang and Li 2011; Zarnaghi et al. 2018). Tremendous progress has been made by these studies in understanding the impact of plastic waste aggregates or additives on the mechanical (e.g., strength, deformation behaviour), physical (density, sorptivity) of conventional concrete. However, none of the aforementioned studies assessed the engineering properties of concrete material made by using plastic wastes as the only binding material.

Thiam and Fall (2020) performed studies on the mechanical, physical and microscopic properties of PWC containing molten plastic wastes (HDPE and LDPE) as the only binder and cured at room temperature. They found that the compressive strength of the tested PWC material is higher than 10 MPa, regardless of age and plastic content. Furthermore, its splitting is approximately 20% to 25% of its compressive strength. They also observed that the PWC material exhibits interesting interesting post peak strength capable of supporting loads and its deformation is more ductile than that of conventional concretes. They also concluded that the PlasticWasteCrete could meet certain construction requirements due to its lightweight and can eventually help reduce the unit weight of the structure when used in construction. However, despite the promising results obtained by Thiam and Fall (2020), the PWC samples considered in their study were only cured at ambient room temperature (~20°C). Moreover, the inorganic granular materials (sand, gravel) used to prepare the PWC had a fixed particle size distribution. In other words, the impact of various curing conditions and the variability of the grain size distribution of sand and gravel on key performance or engineering properties (strength, deformation behaviour, density, sorptivity) is not known. There is a need to address this knowledge gap. Indeed, curing conditions and grain size distribution of the granular materials could play an important role on strength development and durability of the proposed PWC material. Moreover, elucidating the behaviour of the PWC under different (practical) operating conditions (curing conditions, variability of the grain size of the granular materials available in a region or site) will contribute to its optimization as well as enhance its practical engineering application. The objective of the study is, therefore, to investigate the effect of curing conditions and granular material size on the physical and mechanical properties of the PWC using melted plastic wastes (HDPE and LDPE) as the only binder.

2. Experimental Program

2.1. Materials and methods

2.1.1. Materials

Plastic wastes (HDPE and LDPE) collected from Bamako's waste collection streams were washed and shredded to the corresponding sizes for the experiment purposes. Figure 1 shows samples of plastic used for the PWC preparation.

a) b)

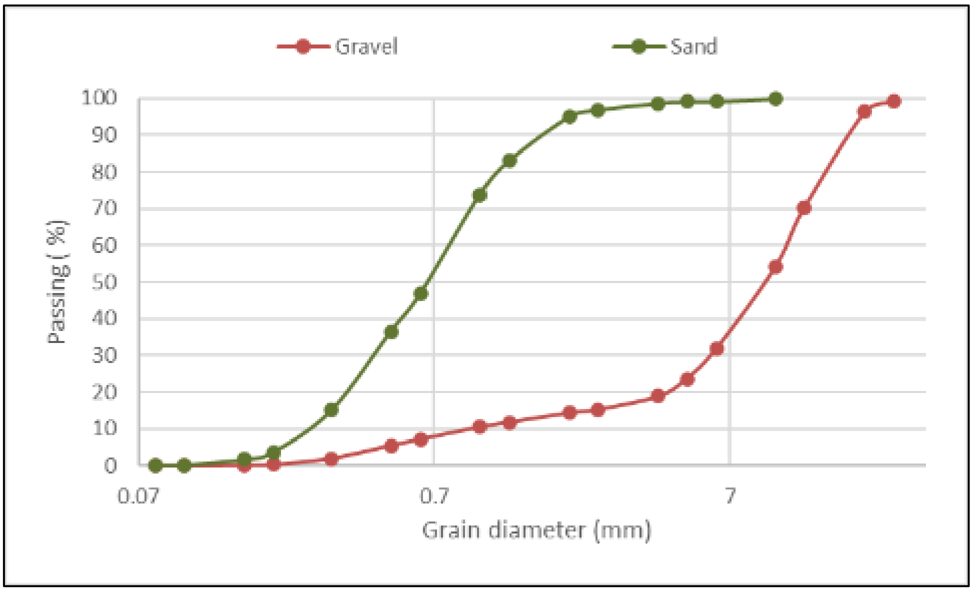
Figure 1 Samples of (a) LDPE and (b) HDPE plastic materials used in this study

Natural sand and gravel from Niger river in Bamako were used in this study to prepare the PWC and conventional concrete (Figure 2). Before their uses, sand and gravel were sampled and sieved to determine their grain size distributions according to ASTM C136 / C136M procedures. Figure 3 (a) displays the obtained grain size distributions granular materials sampled and Figure 3 (b) shows the ones used for the preparation of various PWC samples.

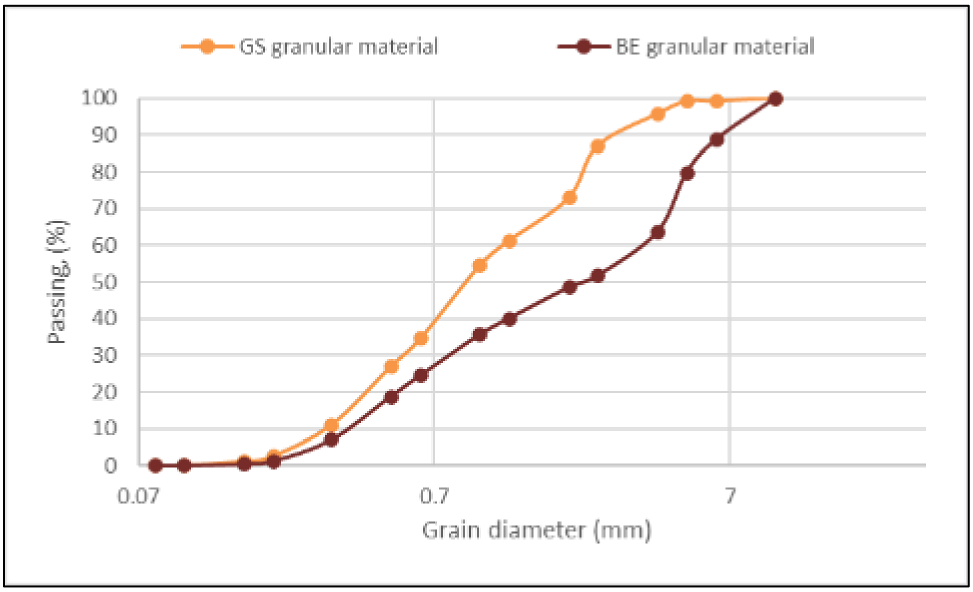
Ordinary Portland cement type I and tap water were employed in the preparation of the conventional concrete used as a reference material in the study. It should be stressed that the purpose of preparing conventional concrete samples is not to compare the performance of the PWC and conventional concrete, but rather to acquire a better comprehension of the properties of the PWC, since conventional concrete is one of the most widely used construction material in the world.

a) b)

Figure 2 (a) Natural gravel from Niger River in Bamako, Mali and (b) image of the sand sample used in the experiment



a) Sampled granular materials (Sand and gravel)



b) Granular materials used for the preparation of various PWC samples.

Figure 3 Particle size distribution of the sand and gravel materials sampled and used in this study

2.2. Sample preparation and curing

Conventional concrete with water to cement ratio (W/C) of 0.5 and granular material (gravel + sand) to cement ratio, (G+S / C) of 3 were prepared and used as reference in this study. Portland cement (type I) and tap water were used to prepare the samples. The ingredients were mixed in a concrete mixer for about 7 minutes, and then poured into metallic cylinders of 5 cm in diameter and 10 cm in height. The cylinders were then sealed (to avoid evaporation) and cured at room temperature for 1, 3, 7, and 28 days before being tested.

A preliminary explorative study was performed by Thiam and Fall (2020) to establish the optimum mix proportion conditions and melting temperature of the plastic waste for the preparation of PWC. Optimized parameters obtained from the aforementioned study were adopted for the preparation of PlasticWasteCrete samples in the present study. Accordingly, PWC samples with the composition described in Table 1 were prepared. The plastic contents of the PWC samples are 50% and 60% and the HDPE/LDPE (H/L) ratio is 50/50. Moreover, the melting and casting temperature of the plastic waste is about 250°C. To assess the effect of the grain size distribution or coarseness of the granular material (sand + gravel) on the properties of PWC, two mixes of granular materials (sand, gravel) were used to prepared the PWC samples. The coarser granular material, called BE, contains 50% of finer sand (< 2 mm), 30% of sand and gravel (2 mm < size < 4.75 mm) and 20% of gravel (4.75 mm < size < 10 mm), whereas the finer granular material (GS) consists of 70% of finer sand (< 2 mm) and 30% of sand and gravel (2 mm < size < 4.75 mm) (Table 1, Figure 3(b)). Sampled gravel and sand were first oven dried at 105°C and passed through the corresponding sieves in order to achieve in the total mass of aggregates.

For each mixture, the required amount of granular materials was added to the melted plastic waste, and then well mixed at a temperature of about 100°C until obtaining a homogeneous mixture. Then, the fresh PWC was poured into the molds in a molten state and compacted using a manual hand press. After cooling down, the PWC specimens were then cured under different conditions for periods of 1, 3, 7 and 28 days before testing. Two curing conditions were applied on the PWC samples: (i) at ambient temperature with free air contact and (ii) others subjected to the thermal shock in water few times (5 min) after casting them in the molds. The samples introduced in water will have the letter (w) at the end of their names (Table 1).

Table 1 Mix proportion and curing time of the PlasticWasteCrete containing melted HDPE and LDPE plastics as the only binder

PlasticWasteCrete sample	**Plastic binder type**	**Plastic binder content (%)**	**HDPE / LDPE**	**Granular materials**	**Curing time (days)**
BE50% P – H/L 50/50	HDPE - LDPE	50	50/50	Gravel-Sand	1, 3, 7, 28
BE60% P – H/L 50/50	HDPE - LDPE	60	50/50	Gravel-Sand	1, 3, 7, 28
GS60% P – H/L 50/50	HDPE - LDPE	60	50/50	Gravel-Sand	1, 3, 7, 28
GS50% P – H/L 50/50	HDPE - LDPE	50	50/50	Gravel-Sand	1, 3, 7, 28

P: plastic content in in (wt %) by reference to the dry mass of sand, H/L ratio of HDPE to LDPE.

2.3. Experimental tests

2.3.1. Uniaxial compression strength and splitting tensile strength tests

Compressive and splitting tensile strengths were determined for various PWC specimens following ASTM C39 / C39M – 18 and ASTM C496 / C496M – 17 specifications respectively. The load was applied at slow rate (1 mm/min) using a computer-controlled press and the axial deformations were recorded using the data acquisition system. Each test was repeated at least 3 times to ensure the repeatability of the results.

2.3.2. Hardened density test

The density of various PWC samples was determined using ASTM C 138 / C138M - 17a procedures. Each density value for various formulations was determined as an average of at least three measurements from different samples to ensure the repeatability of the results.

2.3.3. Absorption test

The immersion absorption test was conducted in accordance with ASTM C97 / C97M – 18. After drying the cylindrical specimens (5 cm in diameter, 10 cm in height) in a ventilated oven at 60°C for 2 days, they were placed in a temperature-controlled room (23 ± 2°C) for about 30 min to cool down. Later the samples were weighted and placed in distilled water at 23 ± 2°C for 48 hours. The surface water on the samples was removed using dry cloth before taking their weights again. The immersion water absorption is then calculated as the difference in mass before and after immersion divided by the initial mass. The average value of at least two specimens with the same plastic content and H/L ratio was taken as the absorption of each sample. The main purpose of the absorption test was to gain a deeper insight into the porosity and pore structure of the tested PWC samples. Porosity, which is also an indicative to pore volume and structure, is reflected by the amount and speed of water suction by means of capillary action (Fall and Pokharel, 2011).

3. Results and discussions

3.1. Impact of granular material size and amount on the compressive strength of the PWC

The amount and size of granular materials have previously been observed to influence the mechanical strength of cementitious materials by controlling the porosity and pore structure of the materials (Fall and Samb 2008, Azhdarpour et al. 2016, Kurad et al. 2017). Figure 4 presents the strength development of PWC samples made with BE or GS, and cured at room temperature. This figure shows that the grain size distribution of the granular material (sand, gravel) in the PWC materials has a significant influence on its strength gain regardless of the plastic content. The strength values of the BE samples are higher than the ones obtained for GS specimens. The main reason can be related to the difference in packing density between the PWC samples made with BE and those with GS, in other words, the difference in porosity or void ratio. Lower packing density means higher porosity and volume of void spaces between the granular particles that need to be cemented with the melted plastic. Larger porosity will result in a less dense and less resistant material (Wu and al. 2001, Marzouk and al. 2007; Abukhettala and Fall 2020, Fang and Fall 2020, Li et al. 2020).

The BE contains only 50% of finer sand, whereas the GS consists of 70% finer sands. This high proportion of finer sand is detrimental to the packing density of the PWC, i.e. it increases the overall porosity. Consequently, for a given plastic waste content, the volume of void spaces between the granular particles to be filled by the melted plastic binder is smaller in the PWC specimens made with BE (lower porosity) than those made with GS. This is supported by the experimental results of absorption testes presented in Figure 5. From this figure, it can be noted that independent of the curing time, the water absorption was found to be generally higher for the GS samples than for the BE specimens. The immersion absorption reflects the ease of water penetration in a given composite material (Marzouk et al. 2007). In the BE samples, the 50% of finer sand particles fill the voids left by the larger particles, which leads to higher initial packing density, i.e. lower porosity. Moreover, the force applied during compaction brings the granular particles closer resulting in a denser configuration with less porosity thereby reducing the absorption (Uysal et al. 2012). In opposite, the high amount of finer grains (70%) in the GS samples means lower packing and not all the voids between the coarser granular materials will be occupied by the fine grains. Thus, the porosity and pores interconnectivity will be higher in the GS samples, leading to higher rate of absorption and thus lower strength than the BE samples (Uysal et al. 2012).

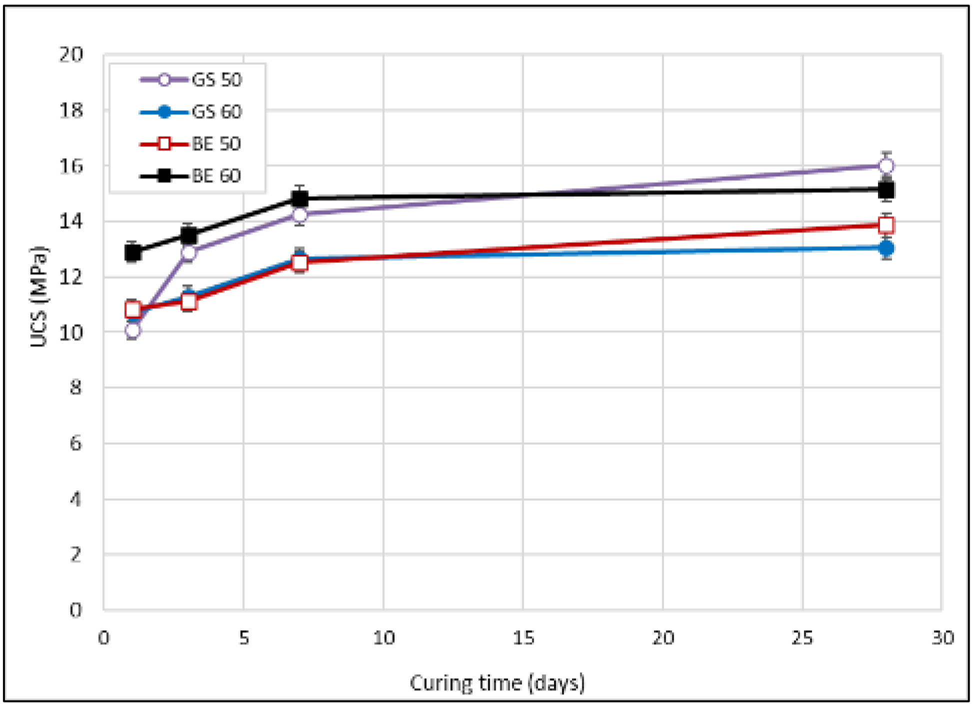


Figure 4 Effect of granular material size and amount on the compressive strength of PWCs for different plastic contents and constant H/L ratio of 50/50 (PWC samples cured at room temperature)

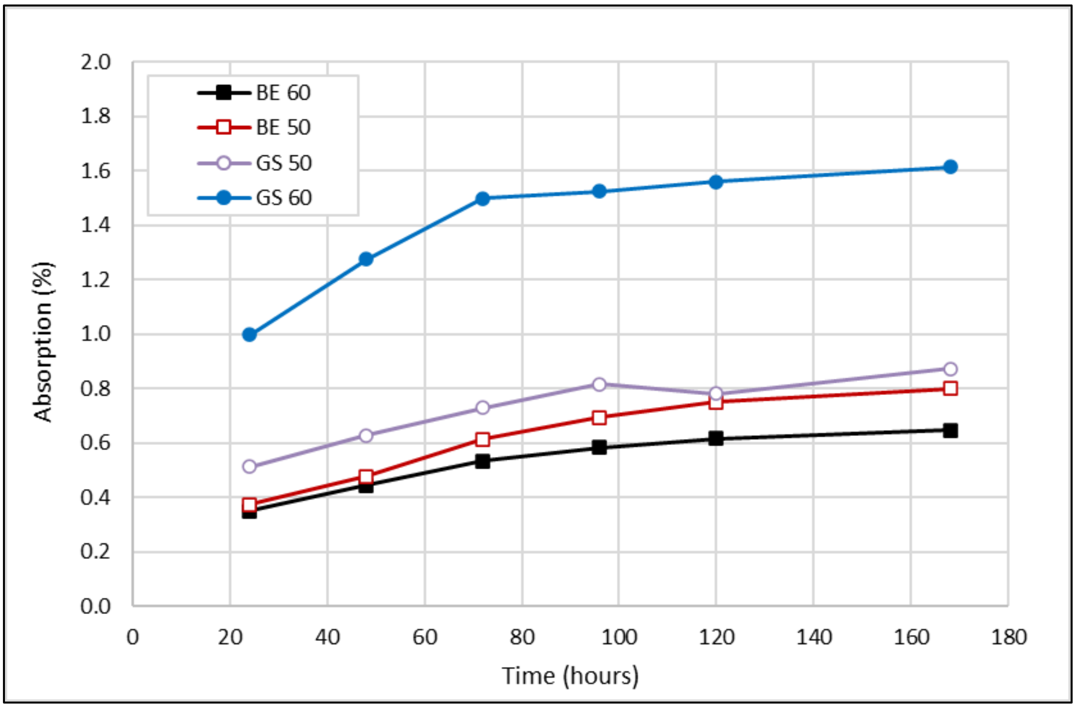


Figure 5 Effect of granular material size and amount on the immersion absorption of PWCs for different plastic contents and constant H/L ratio of 50/50 (PWC samples cured at room temperature for 28 days)

3.2. Influence of curing conditions on the density and mechanical properties of PWC

Typical results of the effect the two adopted curing conditions density and mechanical properties of PWC are presented and discussed in this section. To recall, the applied curing conditions included: (i) curing at ambient temperature; (ii) thermal shock curing: PWC samples were submerged in water for about 5 min. after being casted in the molds (samples with the letter W at the end of their name).

3.3. Impact of curing regime on the density of PWC

Figure 6 presents the obtained results of the density vs time for different BE samples under two different regimes. In general, no significant difference can be observed between the densities of the BE specimens cured at ambient temperature and those subjected to thermal shock in water. The average density under both curing conditions was found to be close to 2 g/cm^3, considered by RILEM classification as lightweight construction material (RILEM, 1978). Since the density values are similar under the two curing regimes, it can be said that the sudden cooling has minor impact on the density of PlasticWasteCrete containing melted HDPE and LDPE as the only binder.

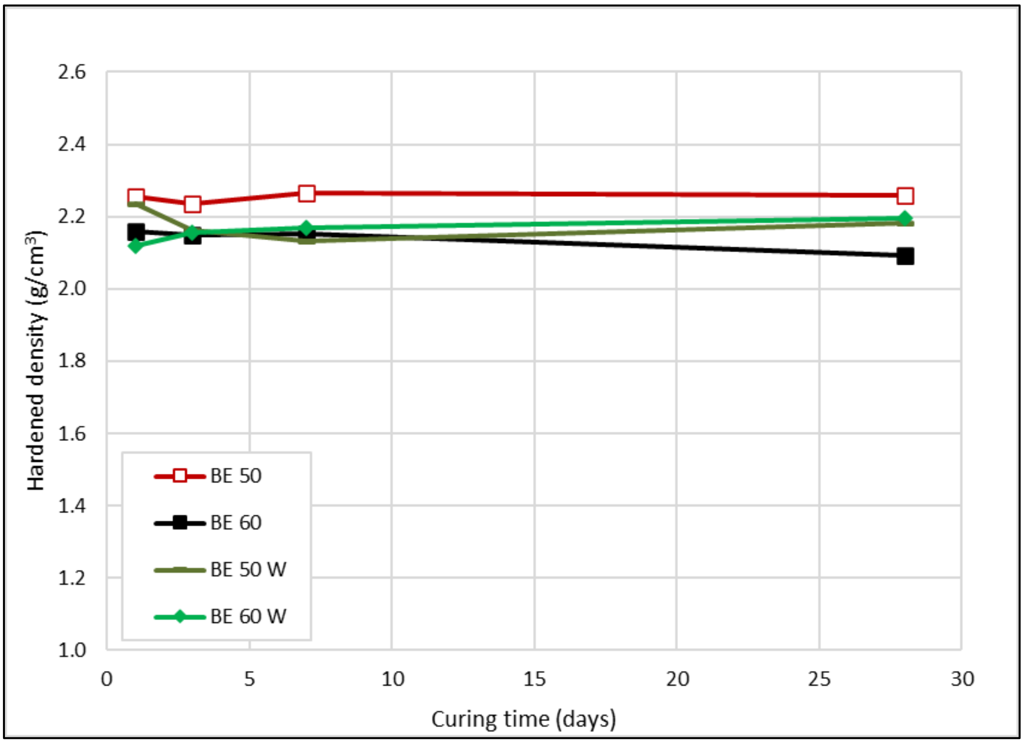


Figure 6 Density vs time for various BE 50 and BE 60 samples cured under two different regimes (ambient temperature and thermal shock in water (w))

3.4. Impact of curing conditions on the compressive strength and splitting tensile strength of the PWC

Figures 7 and 8 show the compressive and splitting tensile strengths vs time for different mixtures of PWC cured under two different regimes. A decrease of both splitting tensile and compressive strengths was observed in the BE samples subjected to the thermal shock in water. Over the whole curing period, the drop in compressive strength of BE samples subjected to thermal shock was found to be in the range of 0.46 to 3.82 MPa (corresponding to the relative values between 4.4 to 40.6%) in reference to the BE samples cured at ambient temperature. Several factors may be responsible for this drop in strengths. Since the BE is poured at hot temperature (> 100° C), time is required for it to solidify and achieve strong interfacial transition zone (ITZ) between the plastic paste and the matrix, which is not observed for the case of thermal shock curing method. This could result in poor contact at the ITZ, which will affect the porosity of the corresponding samples, subsequently leading to the drop of both tensile and compressive strengths (Comby-Peyrot et al. 2006; Fall et al.2010; Hannawi et al. 2010; Silva et al. 2013).

On the other hand, the BE sample does not take its final shape several hours after casting because the transition from liquid to solid state happens slowly. This has a strong impact on the physical and mechanical properties of the BE samples such as the strengths (Volk et al. 2015; Inai et al. 2018). Moreover, the thermal shock will also have some impacts on the physico-chemical transmissions of the BE properties as a result of the aggressive reaction of water with the material at hot temperature. The shock will influence the solidification of the plastic paste binder with apparition of thermal induce stresses affecting the pores structures. Thus, contributing to the creation of weak points, and subsequently to the decrease of the strength. Moreover, the strength is polymer dependent, meaning that the accelerated solidification for the semi crystalline HDPE and LDPE melted paste in contact with water at lower temperature will affect the crystallization and other properties of the BE (Braun, 2002; Volk and Magniez, 2015; da Silva and Wiebeck, 2017; Ragaert and Van Geem, 2017). These thermally induced micro cracks and weak compaction points, contribute to the increase of the porosity of the materials, and cause the decrease in strength (Henkensiefken et al. 2009). Independent of the curing conditions, all the UCS values were higher than 9 MPa, which is an encouraging finding with respect to the practical application of this new construction material (Marzouk et al. 2007).

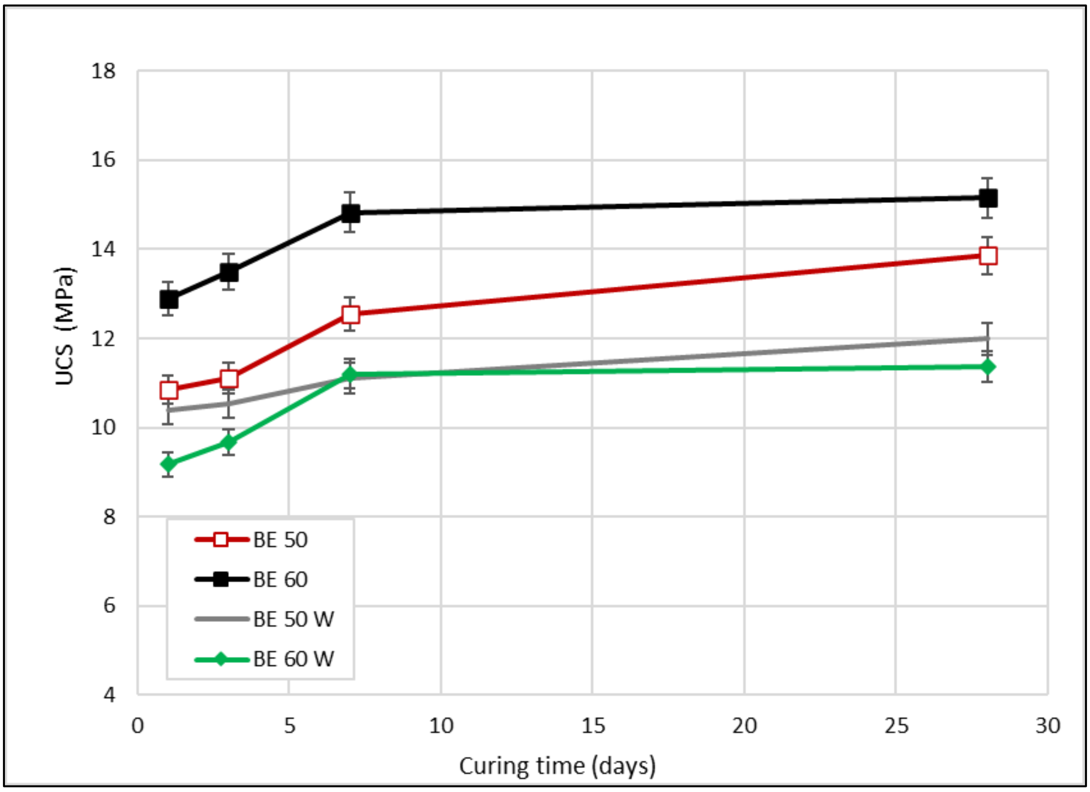


Figure 7 Compressive strength development vs time of the PlasticWasteCrete with different percentages of plastic waste under two different regimes

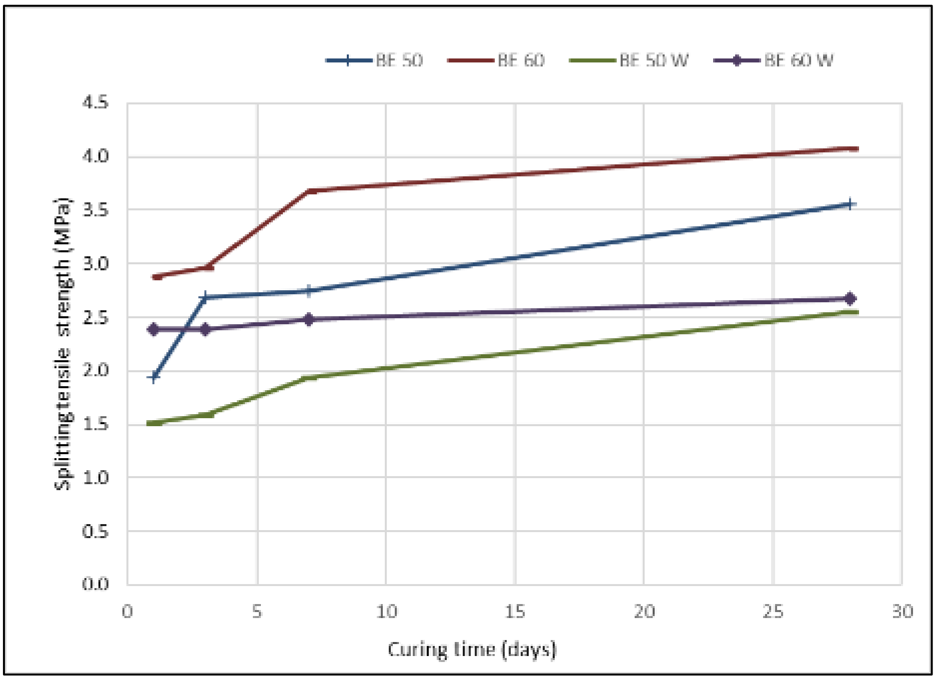


Figure 8 Splitting tensile strength development vs time of the PlasticWasteCrete with different percentages of plastic waste under two different regimes

Figure 9 presents the relationship between the splitting tensile strength and compressive strength for the hot BE placed in water and subjected to the thermal shock. Using the regression analysis, a linear relationship expressed below with higher determination factor was found between the splitting tensile strength (f_t) and the compressive strength (fc). This correlation will facilitate a better understanding of the PWC behaviour under extreme external conditions in practice for regions where there is winter and summer, and strong raining seasons within the year, and also for the Sahel regions with extreme temperature difference from night to day.

$$\text{ft} = 0.2697 * fc + 1.3413 \qquad \text{(in MPa)} \qquad (1)$$

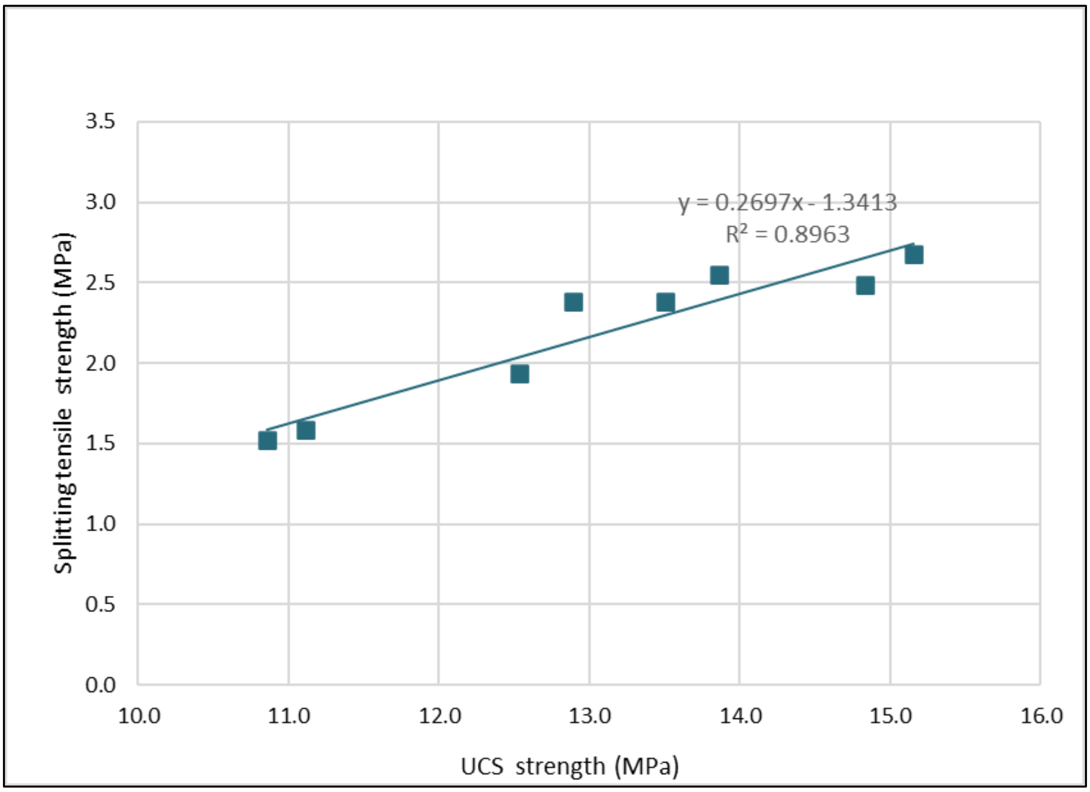
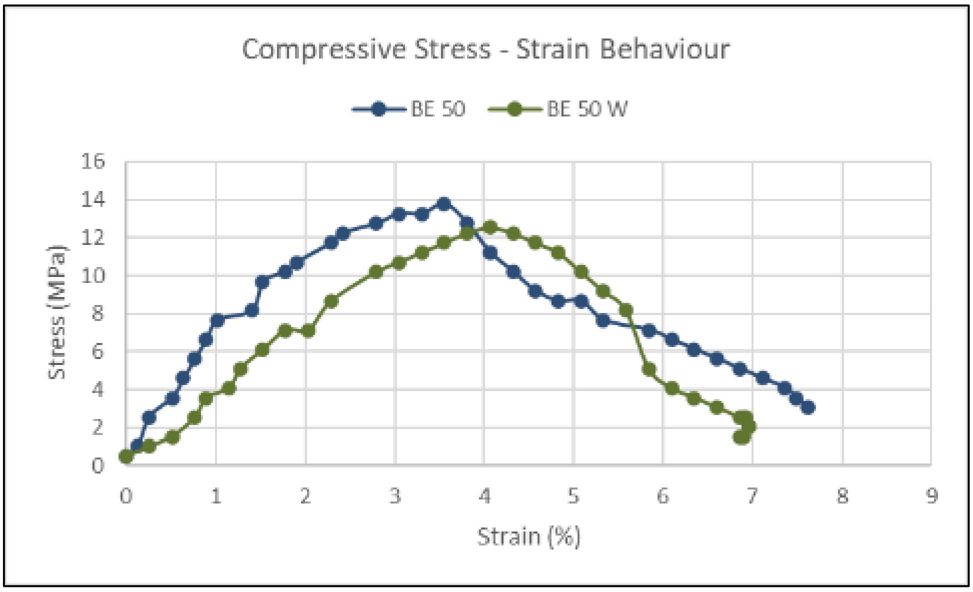


Figure 9 Splitting tensile strength vs UCS of the PlasticWasteCrete with 50% and 60% of plastic content and H/L 50/50 subjected to the thermal shock in water

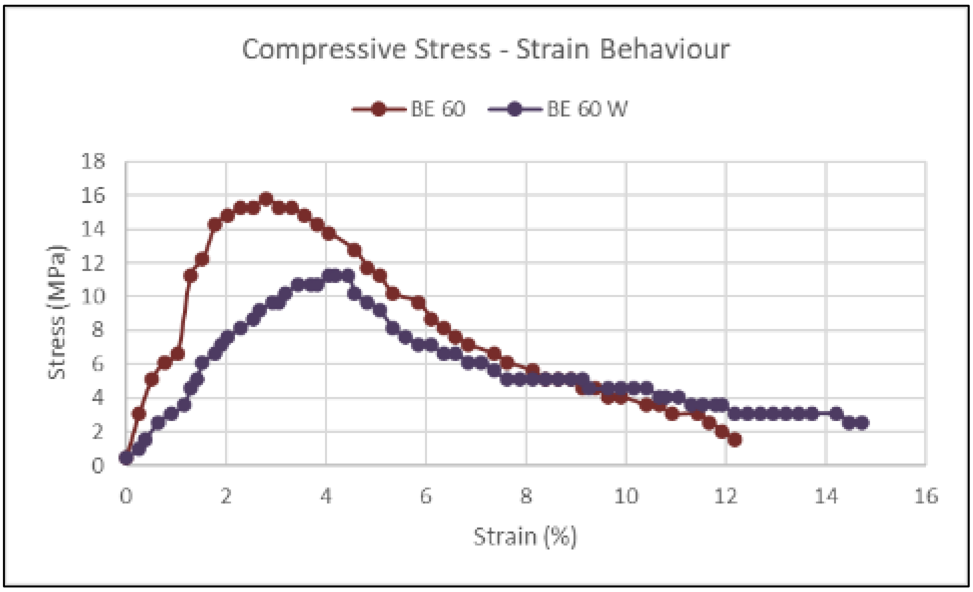
3.5. Impact of curing conditions on the compressive and splitting tensile stress – strain behaviour of the PWC

Figures 10 and 11 present the stress strain behaviour of BE under compressive and splitting tensile forces. Independent of the curing regime, the BE samples showed ductile behaviour that is similar to the concrete containing plastic wastes as aggregates or binder, due to the ability of plastic material to undergo a larger interval of cracks propagation before full disintegration (Wang and al. 2000, Song and Hwang 2004, Hannawi et al. 2010, Thiam and Fall 2020).

Similar to the samples cured at ambient temperature, after the peak stress, the PWC samples that were subjected to thermal shock undergo more plastic deformation, whereas the conventional concrete is more brittle with sudden failure (Hannawi et al. 2010; Thiam and Fall 2020). The ductile characteristic of the BE is very important for long-term fatigue behaviour of the structure using the ecological concrete, especially when subjected to dynamic loadings.

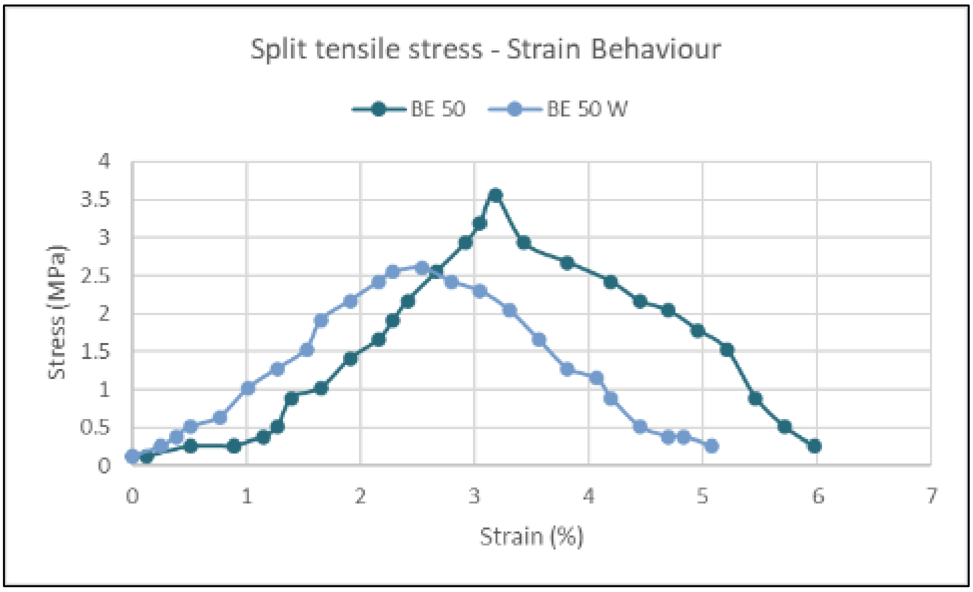


a) BE 50

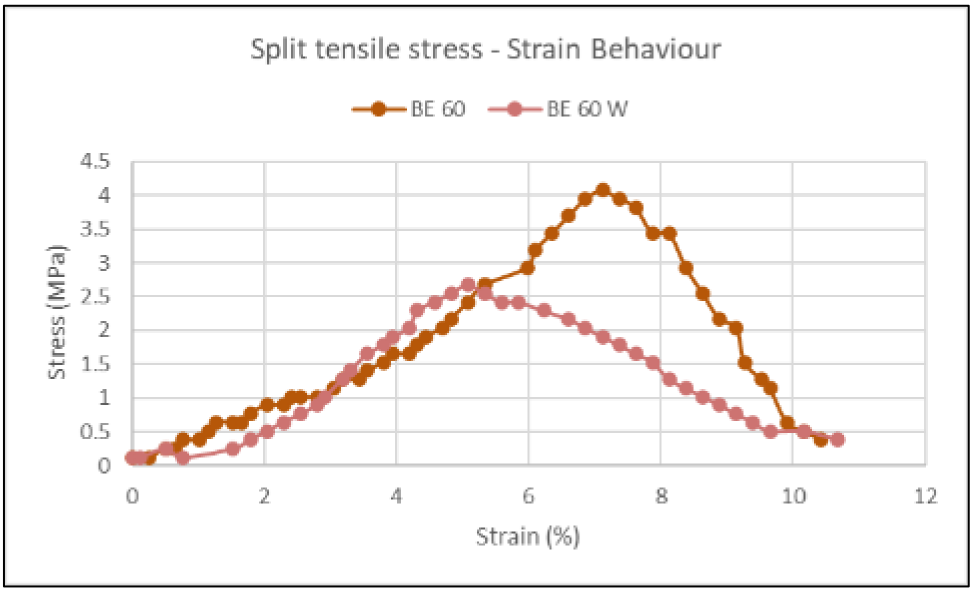


b) BE 60

Figure 10 Compressive stress-strain curve of the PlasticWasteCrete under two different curing regimes after 28 days with 50% and 60% of plastic contents and H/L of 50/50



a) BE 50



b) BE 60

Figure 11 Splitting tensile stress-strain curve of the PlasticWasteCrete under two different curing regimes after 28 days with 50% and 60% of plastic contents and H/L of 50/50.

4. Conclusion

In this study, physical and mechanical properties of various cylindrical PWC samples of different sizes were studied under two curing regimes and different sizes of granular materials (sand and gravel). The following conclusions were drawn:

The density of the PWC is similar for both samples cure at ambient temperature and samples subjected to thermal shock. It can be said that the sudden cooling has little impact on the density of PlasticWasteCrete made from plastic waste.

Solidification, which allows soft materials to take shape and gain strength is accelerated when the hot PWC sample is introduced in water. However, the sudden solidification eliminates some crucial development phases, thereby impacting the strength development negatively. This is due to the development of weak points in the samples leading to an increase in the voids and weaker ITZ, which reduces the PWC ability to uniformly support load during strength test, and contribute to drop the corresponding strength values.

When the percentage of fine sand was changed from 70% to 50%, the PWC strength under both compression and tensile forces was found to be improved

With large molds, the density and UCS values of PWC cast in larger molds are lower than the PWC made with small molds due to less compaction achieved during preparation and higher volumetric amount of plastic in the given molds.

Independent of the curing ages, plastic content and H/L ratio, the thermal shock in water was found to decrease both UCS and splitting tensile strengths. However, no considerable change has been observed for density vs time graphs of the PWC between the curing regimes.

Ductile deformations with great capacity of supporting loads after peak values was observed for PWC while brittle fractures with full disintegration was observed for commercial cement pavers from Malian Market

Linear relation was deducted between UCS and splitting tensile strengths for PWC subjected to thermal shock. This, allows the determination of one parameter if the other is known for future practical applications

More research is needed to fully understand all the properties of the large-scale PWC pavers and substantial consumers' surveys is needed, especially interviews for high school students and youth to get their opinions in order to incorporate their thoughts to have future PWC products which will be more inclusive. Thus, we can improve the PWC products qualities with amazing aesthetic and great technical properties for the benefit of saving our planet from plastic related problems and provide alternatives for future businesses.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Abukhettala, M., & Fall, M., (2020). Geotechnical characterization of plastic waste materials in pavement subgrade applications. Transportation Geotechnics, 100472.

[2] Al-Manaseer, A. A., & Dalal, T. R. (1997). Concrete containing plastic aggregates. Concrete International, 19(8), 47-52.

[3] Azhdarpour, A. M., Nikoudel, M. R., & Taheri, M. (2016). The effect of using polyethylene terephthalate particles on physical and strength-related properties of concrete; a laboratory evaluation. Construction and building Materials, 109, 55-62.

[4] Bachir redjel, la mesure de la resistance du beton a la traction

[5] Barboza, L. G. A., Vethaak, A. D., Lavorante, B. R., Lundebye, A. K., & Guilhermino, L. (2018). Marine microplastic debris: An emerging issue for food security, food safety and human health. Marine pollution bulletin, 133, 336-348.

[6] Boucher Julien, B., Damien, F. (2017). Primary Microplastics in the Oceans: a Global Evaluation of Sources.

[7] Braun, D. (2002). Recycling of PVC. Progress in polymer science, 27(10), 2171-2195.

[8] Choi, Y. W., Moon, D. J., Chung, J. S., & Cho, S. K. (2005). Effects of waste PET bottles aggregate on the properties of concrete. Cement and concrete research, 35(4), 776-781.

[9] da Silva, D. J., & Wiebeck, H. (2017). Using PLS, iPLS and siPLS linear regressions to determine the composition of LDPE/HDPE blends: a comparison between confocal Raman and ATR-FTIR spectroscopies. Vibrational Spectroscopy, 92, 259-266.

[10] Duan, S., Liao, H., Cheng, F., & Tao, M. (2020). Effect of curing condition and carbonization enhancement on mechanical properties of fly ash-desulfurization gypsum-steel slag blocks. Journal of CO2 Utilization, 38, 282-290.

[11] Fang, K., & Fall, M., (2020). Shear Behaviour of Rock–Tailings Backfill Interface: Effect of Cementation, Rock Type, and Rock Surface Roughness. Geotechnical and Geological Engineering, 1-18.

[12] Fall, M. & Pokharel, M., (2011). Strength development and sorptivity tailings shotcrete under various thermal and chemical loads. Canadian Journal of Civil Engineering 38 (7), 772-784.

[13] Fall, M., Célestin, J.C., Pokharel, M. & Touré, M. (2010). A contribution to understanding the effects of temperature on the mechanical properties of cemented mine backfill. Engineering Geology 14 (3-4), 397-413.

[14] Fall, M., & Samb, S. (2008). Effect of high temperature on strength and microstructural properties of cemented paste backfill. Journal of Fire Safety 44 (44), 642-651

[15] Guerrin, A., & Lavaur, R. C. (1976). Traite du beton arme-murs de soutenement et murs de quai (Vol. 7).

[16] Hannawi, K., Kamali-Bernard, S., & Prince, W. (2010). Physical and mechanical properties of mortars containing PET and PC waste aggregates. Waste management, 30(11), 2312-2320.

[17] Hannawi, K., Kamali-Bernard, S., & Prince, W. (2010). Physical and mechanical properties of mortars containing PET and PC waste aggregates. Waste management, 30(11), 2312-2320.

[18] Henkensiefken, R., Castro, J., Bentz, D., Nantung, T., & Weiss, J. (2009). Water absorption in internally cured mortar made with water-filled lightweight aggregate. Cement and Concrete Research, 39(10), 883-892.

[19] Inai, N. H., Lewandowska, A. E., Ghita, O. R., & Eichhorn, S. J. (2018). Interfaces in polyethylene oxide modified cellulose nanocrystal-polyethylene matrix composites. Composites Science and Technology, 154, 128-135.

[20] Ismail, Z. Z., & Al-Hashmi, E. A. (2008). Use of waste plastic in concrete mixture as aggregate replacement. Waste management, 28(11), 2041-2047.

[21] Kou, S. C., Lee, G., Poon, C. S., & Lai, W. L. (2009). Properties of lightweight aggregate concrete prepared with PVC granules derived from scraped PVC pipes. Waste Management, 29(2), 621-628.

[22] Kou, S. C., Lee, G., Poon, C. S., & Lai, W. L. (2009). Properties of lightweight aggregate concrete prepared with PVC granules derived from scraped PVC pipes. Waste Management, 29(2), 621-628.

[23] Kumar, R., & Bhattacharjee, B. (2003). Porosity, pore size distribution and in situ strength of concrete. Cement and concrete research, 33(1), 155-164.

[24] Kurad, R., Silvestre, J. D., de Brito, J., & Ahmed, H. (2017). Effect of incorporation of high volume of recycled concrete aggregates and fly ash on the strength and global warming potential of concrete. Journal of cleaner production, 166, 485-502.

[25] Li, L., Fall, M., & Fang, K., (2020). Shear behavior at interface between compacted clay liner–geomembrane under freeze-thaw cycles. Cold Regions Science and Technology 172, 103006

[26] Marzouk, O. Y., Dheilly, R. M., & Queneudec, M. (2007). Valorization of post-consumer waste plastic in cementitious concrete composites. Waste management, 27(2), 310-318.

[27] Meyer, C. (2009). The greening of the concrete industry. Cement and concrete composites, 31(8), 601-605.

[28] Ragaert, K., Delva, L., & Van Geem, K. (2017). Mechanical and chemical recycling of solid plastic waste. Waste Management, 69, 24-58.

[29] Rebeiz, K. S. (1996). Precast use of polymer concrete using unsaturated polyester resin based on recycled PET waste. Construction and Building Materials, 10(3), 215-220.

[30] Saikia, N., & De Brito, J. (2012). Use of plastic waste as aggregate in cement mortar and concrete preparation: A review. Construction and Building Materials, 34, 385-401.

[31] Sam TD, Tam MN. (2002). Polymer concrete based on recycled polyethylene terephthalate (PET). NOCMAT/3. In: Vietnam international conference on non-conventional material and technologies. Pp. 226-228.

[32] Schwarz, A. E., Ligthart, T. N., Boukris, E., & van Harmelen, T. (2019). Sources, transport, and accumulation of different types of plastic litter in aquatic environments: A review study. Marine Pollution Bulletin, 143, 92-100.

[33] Shi, X., Xie, N., Fortune, K., & Gong, J. (2012). Durability of steel reinforced concrete in chloride environments: An overview. Construction and Building Materials, 30, 125-138.

[34] Silva, R. V., de Brito, J., & Saikia, N. (2013). Influence of curing conditions on the durability-related performance of concrete made with selected plastic waste aggregates. Cement and Concrete Composites, 35(1), 23-31.

[35] Silva, R. V., & de Brito, J. (2018). University of Lisbon, Lisbon, Portugal. Waste and Supplementary Cementitious Materials in Concrete: Characterisation, Properties and Applications, 199.

[36] Song, P. S., & Hwang, S. (2004). Mechanical properties of high-strength steel fiber-reinforced concrete. Construction and Building Materials, 18(9), 669-673.

[37] Uysal, M., Yilmaz, K., & Ipek, M. (2012). The effect of mineral admixtures on mechanical properties, chloride ion permeability and impermeability of self-compacting concrete. Construction and Building Materials, 27(1), 263-270.

[38] Vaverka, J. V. (1991). An analysis of reinforced concrete composites utilizing recycled polyethylene terephthalate thermoplastic.

[39] Volk, N., He, R., & Magniez, K. (2015). Enhanced homogeneity and interfacial compatibility in melt-extruded cellulose nano-fibers reinforced polyethylene via surface adsorption of poly (ethylene glycol)-block-poly (ethylene) amphiphiles. European Polymer Journal, 72, 270-281.

[40] Wang, Y., Wu, H. C., & Li, V. C. (2000). Concrete reinforcement with recycled fibers. Journal of materials in civil engineering, 12(4), 314-319.

[41] Wu, K., Chen, B., & Yao, W. (2001). Study of the influence of aggregate size distribution on mechanical properties of concrete by acoustic emission technique. Cement and Concrete Research, 31(6), 919-923.

[42] Zarnaghi, V. N., Fouroghi-Asl, A., Nourani, V., & Ma, H. (2018). On the pore structures of lightweight self-compacting concrete containing silica fume. Construction and Building Materials, 193, 557-564.

[43] Zhang, M. H., & Li, H. (2011). Pore structure and chloride permeability of concrete containing nano-particles for pavement. Construction and Building Materials, 25(2), 608-616.

[44] Zuberi, M. J. S., & Ali, S. F. (2015). Greenhouse effect reduction by recovering energy from waste landfills in Pakistan. Renewable and Sustainable Energy Reviews, 44, 117-131 City of Kathmandu, capital of Nepal. Waste Management, 28(6), 1088-1097