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USE OF POST CONSUMER WASTE IN CONCRETE & CONCRETE BLOCK – LITERATURE REVIEW

S.N. Mihaljevic [1] and S.E. Chidiac [2]

[1] M.A.Sc. Candidate, Department of Civil Engineering, McMaster University, Hamilton, ON, L8S 4L7, Canada, mihaljsn@mcmaster.ca

[2] Professor, Center for Effective Design of Structures, Department of Civil Engineering, McMaster University, chidiac@mcmaster.ca

ABSTRACT

Concrete is the most widely used construction material, therefore reducing the environmental impact of concrete would greatly benefit the construction industry. The production of concrete, concrete blocks are no exception, requires the use of large quantities of natural resources, namely limestone, granite, shale and clay, and contributes to the production of carbon dioxide, in the manufacturing of Portland cement. Environmental benefits may be achieved by replacing a portion of the aggregate and cement with waste materials, such as glass and polymers, from post-consumer sources. It has been shown that glass can be used to replace a portion of the natural aggregate. Glass also is also being used as a supplementary cementing material. Furthermore, post-consumer polymer products, referred to as plastics, have been used as aggregate replacement in concrete. This paper provides a review of the research reported in the literature on the effects of using post consumer waste glass and plastics in concrete and concrete block production.

KEYWORDS: aggregate, cement, concrete, glass, plastic, pozzolan.

INTRODUCTION

Concerns about human impact on the environment and the threat of global warming are forcing industries to consider more sustainable and environmentally friendly methods of production. For the construction industry, concrete is a major consumer of natural resources, in the form of aggregates and cement, and a major contributor to the emission of carbon dioxide, in the production of Portland cement. One ton of carbon dioxide is released into the atmosphere for every ton of cement produced [1]. Replacing a portion of the aggregate and/or cement used in concrete with recycled post-consumer products will reduce the environmental impact of this industry. Possible substitutes for aggregates include crushed waste glass and plastic waste, while a portion of the cement may be replaced with materials having pozzolanic properties such as fly ash, blast furnace slag and finely ground waste glass.

For industry, glass is an attractive material since it can be recycled, by melting, many times without changing its chemical composition [2]. However, a significant portion of the waste glass collected still ends up in landfills. Some glass is not recycled because the glass colours are mixed, the glass is contaminated or it is too expensive to recycle [3]. The low cost, low weight and ability to be shaped into any form has lead to an ever increasing use of plastic. It is estimated that plastic makes up 7 to 8% of Ontario household residual waste, 81% of which comes from packaging. Of households with access to recycling, only about 33% of their plastic packaging waste was recovered through recycling as of 2000 [4]. There are two categories of plastics: thermoplastics and thermosetting plastics. Thermoplastics can be recycled by melting and remoulding. Examples include polyethylene and polyethylene terephthalate (PET). Thermosetting plastics, such as phenolic and melamine, cannot be recycled by melting [5].

Waste glass has the potential to be used as an aggregate in concrete and concrete blocks because of its hardness and its negligible water absorption. While glass is expected to produce concrete with good mechanical properties, the possibility of the alkali-silica reaction (ASR) needs to be addressed since it adversely affects the durability of concrete [6]. ASR is a reaction that takes place in concrete between the alkalis in the cement paste and silica. The reaction produces a gel, which absorbs water and expands. The expansion of the gel causes pressure in the concrete leading to damage. For ASR to occur there must be alkalis, free silica and water [7].

There is also evidence that glass may be used as a supplementary cementing material. Glass has the potential to be used as a pozzolanic material since it has high silica content and is amorphous; however it needs to be ground into a very fine powder to achieve a large surface area so that it reacts in the cement paste [8].

Another option for recycling waste material is to use plastic within concrete or mortar to replace a portion of the aggregate. Since plastics have a lower density than regular aggregate, there is great potential for them to be used in concrete as lightweight aggregate to reduce the dead weight of concrete, as long as their adverse effects on the mechanical properties of the concrete can be mitigated [5].

This report summarizes the findings of research reported in the literature on the use of glass and plastics in concrete and concrete blocks. The effects of replacing aggregate and cement with waste glass or plastic on the mechanical properties and durability of concrete are examined to determine their viability as replacement materials.

WASTE GLASS AS AGGREGATE REPLACEMENT

Compressive Strength

Topcu and Canbaz used green waste soda glass, with a particle size between 4 and 16 mm, to replace 15, 30, 45 and 60% of the coarse aggregate, a crushed calcareous stone, at a water to cement ratio (w/c) of 0.54. Increasing the replacement of natural aggregate with waste glass (WG) resulted in a linear decrease in the compressive strength, as shown in Figure 1. When 15%, 30% and 60% of the aggregate was replaced by WG, the compressive strength was lower than that of the control by 8%, 15% and 49%, respectively. The reduction in compressive strength is attributed to the poor geometry of the glass aggregate which prevents a homogeneous mix from being obtained, the brittleness of the glass aggregate which allows for cracks to form within the aggregate, and the poor adhesion between the cement paste and the glass particles [9].

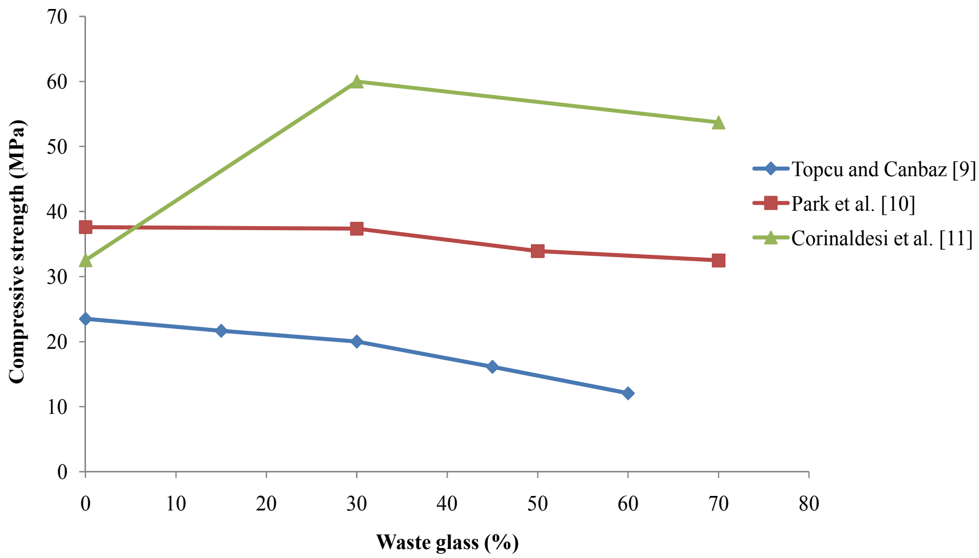

Figure 1: Effect of using waste glass as aggregate replacement on compressive strength.

Park et al. investigated the effect of using different colours of WG, as fine aggregate, on the compressive strength of concrete. The WG was separated by colour (amber, emerald green and flint) then crushed to particle sizes less than 5 mm. The concrete mixes used a w/c of 0.5. The fine aggregate was replaced by 30, 50 and 70% WG. It was determined that regardless of colour, the concrete compressive strength containing WG had a similar reduction in strength for the same replacement levels. Figure 1 shows the compressive strength of the emerald green glass a 28 days. When 30% fine aggregate was replaced by WG the compressive strength was 99% of the control, while for 50% and 70% replacement the strength was 90% and 86% of the control, respectively. Poor compaction and the lower adhesion between cement and WG were identified as possible reasons for this loss in compressive strength [10].

Corinaldesi et al. looked at the effect of replacing fine aggregate with WG on the compressive strength of mortar. They replaced either 30% or 70% of the sand with one of three glass particle sizes, less than 36 µm, greater than 36 and less than 50 µm, and greater than 50 and less than 100 µm. The water content of all the mortars was determined to give a consistent workability. The results show that the compressive strength increased along with the increase in WG content. The 180 day compressive strength is shown in Figure 1 for the mortar with glass particles less than 36 µm. They reported a positive effect on the mortar strength when replacing fine aggregate with WG. The mechanical properties were found to improve due to the denser microstructure obtained when fine aggregate was replaced with ground WG [11]. The WG particles used in this study were fine enough to undergo a pozzolanic reaction [2] [8], which would result in a higher compressive strength at 180 days than that of the control. This also explains the denser microstructure than the control since pozzolans improve the microstructure of concrete.

Jin et al. attempted to use WG to produce concrete masonry blocks. They replaced either 10% of the aggregate, 10% of the cement or both 10% of the cement and 10% of the sand with WG. The WG was size NO. 30 particles. The highest strength decrease observed was 9% and was attributed to statistical variation. They conclude that the strength of masonry with WG is adequate. However, the greatest benefit from using WG in masonry is that the concrete blocks have the ability to absorb high contents of glass waste products [12].

Lam et al. used crushed WG consisting of 30% colourless glass, 40% green glass and 30% brown glass from beverage bottles to replace fine aggregate to make precast concrete paving blocks. The glass was graded to match the grading requirements for fine aggregate. The fine aggregate was 100% replaced with waste materials, consisting of WG and recycled fine aggregate (RFA) obtained by crushing concrete from demolition sites. The mixes used 75% WG with 25% RFA, 50% WG with 50% RFA and 25% WG with 75% RFA, each of which incorporated pulverized fly ash (PFA) at 0%, 5%, 10% and 15%, by weight of the aggregate, to prevent ASR, for a total of 12 different mixes. The blocks were dry-cast to achieve a zero slump. The results showed that PFA is very effective in reducing ASR expansion. The compressive strength of the concrete paving blocks was shown to increase as the WG aggregate content increased, provided PFA was added to the mixture. This was attributed to the improved packing achieved with the WG particles. Lam et al. concluded that good quality paving blocks, which achieved a 90 day compressive strength of 82 MPa, could be created with 50% RFA and 50% WG aggregate along with 10% PFA [7]. These results suggest that the WG aggregate would perform well in other precast, dry-cast applications such as structural concrete masonry blocks.

Tensile Strength and Flexural Strength

Park et al. tested the tensile strength of concrete specimens made with WG of various colours replacing the fine aggregate at substitution rates of 0, 30, 50 and 70%. The three colours tested all preformed similarly. As the substitution of WG increased, the tensile strength decreased. At 28 days, concrete containing 30% WG had a tensile strength 97% of the control while the concrete containing 50 and 70% WG had tensile strength of 91% and 85% of the control, respectively. The flexural strength also decreased with the addition of WG. The concrete with 30%, 50% and 70% WG attained a flexural strength of 97%, 89% and 82% of the control, respectively. The lower adhesion between the aggregate and the cement paste was identified as the main factor for the reduced strength of concrete when WG was added [10].

Water Absorption

Lam et al., who used WG and RFA to replace 100% of the fine aggregate in paving blocks, also measured the water absorption of the concrete paving blocks. They determined that by increasing the WG content, the water absorption of the blocks was reduced. This was attributed to WG absorbing significantly less water than RFA [7].

WASTE GLASS AS POZZOLAN

Compressive Strength

Shao et al. tested the pozzolanic activity of concrete made with finely ground WG particles. The glass was obtained from waste soda-lime fluorescent lamps. All the mixes in this study replaced

30% of the cement with ground WG, silica fume or fly ash. The glass sizes used were 150 µm, 75 µm and 38 µm. All the mixes with WG achieved lower compressive strength than the control mix with 100% Portland cement at all ages, except the mix with 38 µm WG, at 90 days, which achieved a compressive strength 8% greater than the control. In all cases, the smaller the particle size the higher the compressive strength attained since the smaller particles exhibit greater pozzolanic activity. It should be noted that the compressive strength of concrete mixes containing 30% 38 µm WG as cement replacement was greater, in all cases, than the ones containing 30% fly ash and much lower than the mixes containing 30% silica fume. ASTM C 618 [13] requires a strength activity index of 75% for a pozzolan to be beneficial to concrete. The 75 µm and 38 µm WG satisfied this requirement and their corresponding mixes achieved results similar to fly ash. Moreover, the mixes containing 38 µm WG were found effective in reducing the expansion of the mortar bars tested for ASR to half that of the reference sample [8].

Shayan and Xu used WG as coarse aggregate (4.75-12 mm), fine aggregate (0.15-4.75 mm), and powder (WGP) (<10 µm) to act as a pozzolan. WGP was used to replace 10, 20, 30 and 40% of the cement. For these mixes, the aggregate to cement ratio was 2.25 and the w/c 0.47. When WGP was used for cement replacement, the 28 day compressive strength was lower than that of the control. This was attributed to the slow pozzolanic reaction of the WGP. Samples with WGP increased in strength up to 270 days, indicating an on-going pozzolanic reaction. Investigation of the microstructure revealed that the structure of mortar with 30% WGP is denser than that of the plain mortar and that the WGP particles were consumed by the pozzolanic reaction. Furthermore, the pozzolanic nature of the WGP was found to suppress the ASR expansion when WG aggregate was used. Cement replacement by 30% WGP was suggested to be optimal [2].

Schwarz et al. attempted to find the optimum amount of cement in concrete to be replaced with WG or fly ash at a water to binder ratio (w/b) of 0.42. The glass used in the study was obtained from the waste powder created by the manufacture of glass beads from old window panes. The WGP had 72% of the particles smaller than 45 µm. High levels of cement replacement with WGP resulted in a lower compressive strength than the control, while using 20% fly ash resulted in a cement paste with compressive strength very close to the control. From this analysis, the optimum amount of cement to be replaced with WGP was determined to be 10%. WGP was shown to facilitate cement hydration at early ages because of the negligible water absorption of the glass. The concrete paste having 10% replacement of cement with glass had a higher compressive strength than the concrete modified with fly ash at 28 days, however at 90 days the fly ash mix had higher strength. This was attributed to the greater pozzolanic activity of fly ash [14].

THERMOPLASTICS AS AGGREGATE REPLACEMENT

Compressive Strength

Babu and Babu used two commercially available expanded polystyrene (EPS) beads to make concrete with densities between 1440 and 1850 kg/m^3 and compressive strengths greater than 17 MPa. The EPS beads had diameters of mainly 6.3 mm (type A) and 4.75 mm (type B). The mixes were made with silica fume at 3, 5 and 9%, by weight, of the total cemetitious material. Although the authors noted the possibility of problems with segregation due to the hydrophobic nature of EPS plastic, they decided not to use any additives to improve bond. However, a naphthalene based superplasticizer was used to improve workability. The resulting mixes showed no problems with segregation. The compressive strength of the concrete decreased as the EPS content increased, but increased with a decrease in the size of the EPS beads. The concrete made with type B beads showed the highest strength. The reduction in compressive strength was attributed to the negligible compressive strength of the EPS aggregate. The failure mode of the specimens was not brittle, in comparison to samples made of ordinary concrete, and the specimens maintained the load at failure without total degradation [15]. Babu et al. [16] continued the study by substituting fly ash for silica fume, and obtained similar trends for the compressive strength. Babu et al. [17] compared the use of unexpanded polystyrene (UEPS) and EPS as aggregates in concrete. Concrete with UEPS showed higher strength that the concrete with EPS aggregate, but was more brittle.

Ghaly and Gill investigated the effect of using plastic aggregate in concrete to replace coarse aggregate at 5, 10, and 15% replacement levels, each at w/c of 0.42, 0.54 and 0.69. Various post-consumer plastics were chopped up for use as aggregate resulting in different particle shapes. The plastic aggregate particles were found to be poorly graded since most were of the same size. Compressive strength greatly decreased with the addition of plastic aggregate, compared to the control mix, and the reduction in strength was almost linear. The concretes with 5% plastic had strengths 6 to 15% lower than the control. The concretes with 10% and 20% plastic had compressive strengths 18 to 20% and 29 to 35% lower, respectively, than the control concrete at 28 days. Although their strength was much lower, the plastic aggregate specimens were able to undergo significant displacement and failed in a ductile manner. The compressive strength was much lower when plastic aggregate was used because the plastic aggregate was poorly graded and had a lower strength than that of the natural coarse aggregate [18].

A study by Gavela et al. attempted to replace natural sand and gravel with polypropylene (PP) or PET waste plastic. They made mixes with 20 and 30% of the total aggregate replaced by volume and w/c of 0.5. Only 20% replacement was used for mixes with a w/c of 0.6. A sieve analysis showed that the plastic aggregate was poorly graded and consisted mainly of one size. For workability, a superplasticizer was employed at 1% by weight of the cement. The 28 day compressive strength showed a decrease with the addition of plastic for both types of plastic. The mix with 20% PP and w/c of 0.5 achieved a strength of 33 MPa, which is 83% of the control strength. The mix with 20% PET and w/c of 0.5 achieved a strength of 35 MPa, a 12% reduction in strength. The values reported are reproduced in Table 1 [19].

Table 1: 28 day compressive strength of concrete containing varying percentages of PP and PET as aggregate replacement [19]

Mix constituents	Strength (MPa)
Control mix, w/c=0.5	40
Control mix, w/c=0.5	41
20% PP, w/c=0.5	33
20% PP, w/c=0.6	24
30% PP, w/c=0.5	26
20% PET, w/c=0.5	35
30% PET, w/c=0.6	24

Marzouk et al. used PET waste from plastic bottles as aggregate to replace sand by 2, 5, 10, 15, 20, 30, 50, 70 and 100% by volume. The plastic waste was shredded after washing and the plastic aggregate was separated into three categories based on maximum aggregate size. Type A had a maximum size of 0.5 cm, type C had a maximum size of 0.2 cm, and type D had a maximum size of 0.1 cm. All three types were graded coarser than sand. The reference mortar was made with a sand to cement ratio of 2.8 and a w/c of 0.5, while the mortars tested with PET aggregate had a higher w/c ratio in order to achieve workability. The compressive strength of the reference mortar was 56 MPa. It was found that as the amount of PET was increased from 0% to 50%, the 28 day compressive strength decreased by up to 16% with respect to the reference mortar. When the substitution was greater than 50%, the compressive strength dropped dramatically. Type A aggregate mortars performed differently than the other two mortars with plastic and produced the best results, achieving high strength even at high PET replacement levels. At 70% PET, the compressive strength only diminished by 12% of the control. It was concluded that both the size of the plastic aggregate and the amount of sand substituted affect the mechanical properties of the mortar. The microstructure of the mortars was studied using a scanning electron microscope. The microstructure of the mortar below 50% PET substitution was very dense while, above 50% replacement, the structure was more porous, which was likely related to the significant loss of strength. While this study showed that it would be feasible to use PET plastic as a fine aggregate below 50% sand replacement for mortar, it failed to account for the varying w/c, which significantly affects the compressive strength [20].

Ismail and Al-Hashmi used plastics, which consisted of 80% polyethylene and 20% polystyrene, collected from a plastic manufacturing plant, in concrete. Sand was replaced by plastics at the following replacement ratios: 10, 15 and 20% at a w/c of 0.53. The compressive strength was found to be lower for all the mixes containing plastics, in comparison to the control at all curing ages. The concrete containing plastics had similar values of compressive strength, all of which were greater than the minimum required for structural concrete (17 MPa). The decrease in strength was attributed to the lower bond strength between the plastics and cement paste when compared to that between sand and cement, and to the elongated particle size of the plastic aggregate. Furthermore, the hydrophobic nature of the plastic may have impeded the entry and distribution of the water into the mix to hydrate the cement, resulting in decreased strength [21].

Tensile Strength and Flexural Strength

Gavela et al. tested the flexural strength of concrete made with either polypropylene (PP) or PET plastic replacing 20 or 30% of the natural aggregate. Although there was only a minimal difference between the flexural strength of concrete made with PP and that made with PET, there was a noticeable decrease in the strength of the concrete with plastic compared to the reference concrete when 30% of the aggregate was substituted. The 20% substitution did not significantly affect the flexural strength. The mix with 20% PP and w/c of 0.5 achieved a 28 day strength of 5.0 MPa in flexure, which was approximately 94% of the control, while the mix with 20% PET and w/c of 0.5 achieved a 28 day strength of 4.8 MPa, which was about 90% of the control concrete strength [19].

Marzouk et al. also tested the flexural strength of mortar made with PET. They determined that the flexural strength of the reference mortar was 9.5 MPa and that the 28 day flexural strength decreased at a regular rate with the addition of PET aggregate. At 50% replacement, the flexural strength was 33% less than the control, which shows that strength loss was greater for flexural than compressive strength when plastic aggregates were used. Similar to the results measured for compression tests, the mortar with type A aggregate performed better than those with type C and D PET [20].

Modulus of Elasticity

The effect of mixed plastic waste aggregate on the elastic modulus of concrete was studied by Ghaly and Gill. The concrete was made by substituting 5, 10, and 15% of the coarse aggregate with waste plastic at various w/c ratios. It was found that the modulus of elasticity was greater than the control for all the substitution levels when the w/c is 0.42, with the highest value occurring at 5% plastic, as shown in Figure 2. These results are not, however, consistent with past experience that an increase in w/c yields a decrease in strength and stiffness. At the other w/c, 0.54 and 0.69, the elastic modulus was lower than the control at the same w/c. The elastic modulus was 15% lower than the control when 15% of the coarse aggregate was replaced by plastic at w/c equal to 0.54 and 38% lower than the control when 15% of the coarse aggregate was replaced by plastic at w/c equal to 0.69 [18].

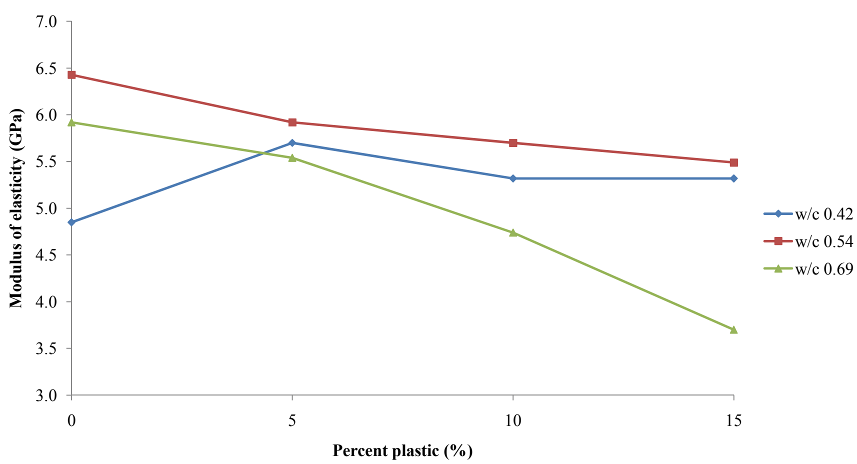

Figure 2: Relationship between modulus of elasticity and percent plastic [18]

Density

Marzouk et al. reported that the reference mortar had an apparent bulk density of 2000 kg/m^3 and that the density was not significantly affected by the amount of sand replaced up to 30% with PET. However, as the amount of aggregate replaced by PET was further increased, the density decreased significantly. At 100% PET aggregate, the bulk density was approximately 1000 kg/m^3. The density was slightly larger for the aggregate with the largest maximum aggregate size. They demonstrated that bulk density decreases with increased replacement of sand with PET [20].

In the study by Ismail and Al-Hashmi, the sand was substituted by waste plastic, consisting of polyethylene and polystyrene, to make concrete. The dry density decreased with the increase in plastic content, but all the mixes had higher dry densities at 28 days than required for the concrete to be classified as lightweight. The lowest density achieved was 2224 kg/m^3 for the concrete with 20% plastic replacement, which was lower than the dry density of 2400 kg/m^3 measured for the control. The lower density is due to the 67% lower density of the plastic compared to sand [21].

Water Absorption

Babu and Babu studied the water absorption of concrete made with EPS aggregate. The absorption rate of all the concretes tested was low, indicating a "good" quality concrete. The concretes with higher levels of EPS had lower initial and final absorption than the concretes with less EPS. The total absorption of the concretes with EPS was between 3 and 6% and decreased with an increase in silica fume content [15].

Marzouk et al. investigated the durability of mortar containing waste PET by looking at its sorptivity. They showed that as the amount of PET increased, the coefficient of sorptivity decreased for substitutions up to 50%. Since PET does not absorb water, they concluded that the water must travel around the PET to penetrate the mortar, therefore slowing down the amount of water uptake. All the rates of absorption were less than 6%. They suggested that this type of mortar will be very durable [20].

THERMOSETTING PLASTICS AS AGGREGATE REPLACEMENT

Compressive Strength

Dweik et al. used melamine-formaldehyde (MF), a thermosetting plastic, as filler in concrete to replace a portion of the sand from 0 to 60%, in 10% increments. Both mortar and concrete were tested. The compressive strength of mortar, made with w/c 0.43 and 0.45, and the compressive strength of concrete, made with w/c equal to 0.55, 0.6 and 0.65, was tested. The gradation of the MF was classified as fine to medium according to British standards. Compared to the control, the compressive strength increased for mixes containing up to 30% MF as sand replacement and decreased for the higher percentages. The maximum strength of both mortar and concrete occurred around 30% MF. The mortar specimens had a 20% greater strength than the control at w/c of 0.45. For the specimens with w/c of 0.43, the strength was 22% greater than the control. For the concrete samples, the compressive strength increased by 19% for the w/c of 0.65 and 43% for the w/c of 0.6 compared to the control. The increase in strength, when MF was used, was attributed to a) better gradation of MF and sand when used in combination, b) the smooth, semi-angular shape of the MF particles which achieved a good bond and c) MF particles may have bonded chemically with the cement providing better bond strength [22].

Tensile Strength

To determine the tensile strength of specimens containing MF as sand replacement, Dweik et al. used the direct tension test on mortar specimens. It was determined that the tensile strength was greatest at 20% sand replacement and that it was 16% greater than that of the reference mortar. However, beyond 30% replacement of sand with MF, a large decrease in the tensile strength was reported [22].

CONCLUDING REMARKS

The literature review has revealed that research is being carried out to determine viable uses of post consumer waste in concrete. The scope of the study was limited to the use of WG and plastics in concrete and mortar and the effect of the replacement on the mechanical and physical properties. Chemical effects that were examined were limited to the use of WGP as pozzolans. ASR, which is a potential concern for concrete containing glass, was not treated in this paper.

The findings from this review are divided into two groups. The first presents the causes that are attributed to conflicting results and they are:

1) The wetting angle of the plastics, an indicator of whether the material is hydrophobic or hydrophilic, was not measured.
2) Water was used for some studies to increase the workability, resulting in a variation in the w/c. The w/c in this case becomes a variable and will distort the results significantly given w/c is an indicator of strength, density and water absorption.
3) Replacement of aggregate by weight or volume has different effect on the composition of the mixture.
4) Using compressive strength tests to evaluate the effects of the WGP as pozzolans without any chemical test to determine the degree of hydration can be misleading as the WGP can act as either a filler leading, to a high packing density, or as a pozzolan, leading to a denser microstructure. Both will yield higher strength, but the percentage increase is different for both cases.
5) The inclusion of too many variables, such as different type of glass or different type of plastics, makes it impossible to determine the causes and effects, given that the properties of the added material are different.

Secondly, the following can be stated:

1) Use of WG as aggregate in concrete blocks can be viable provided it can be proven ASR will not be a damaging factor.
2) The percentage replacement of fine aggregate with WG can be as high as 30%.
3) WGP can be a feasible replacement for Portland cement. The cost of collecting, separating and crushing WG to very fine particles (<40 μm) needs to be comparable to the cost of other pozzolans such as fly ash, slag and silica fume and needs to be less than that of cement.
4) WGP particle sizes as a function of degree of hydration, need to be studied to ensure that the addition of WGP will yield a pozzolanic reaction and not ASR [23].
5) Use of plastics as fine aggregate in mortar and concrete blocks appears to be viable. The interaction between the cement paste and plastics need to be studied in order to better understand its long-term effects on mortar and concrete.

From this review it can be seen that, WG and plastics have been evaluated widely as replacement for aggregate and cement in recent years. However, a comprehensive investigation is still needed to determine their viability and long-term performance as replacement in concrete block production.

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