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Use of Solid Waste Materials as Fine Aggregate Substitutes in Cementitious Concrete Composites: 1996 Semisequicentennial Transportation Conference Proceedings

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Ahmed Elsawy, Industrial Technology, University of Northern Iowa

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The Use of Solid Waste Materials as Fine Aggregate Substitutes in Cementitious Concrete Composites

IBRAHIM SHEHATA, SHAHRAM VARZAVAND, AHMED ELSAWY, AND MOHAMMED FAHMY

The purpose of this paper is to evaluate the possibility of using granulated plastic, glass, and fiberglass waste materials to partially substitute for the fine aggregate (sand) in concrete composites. Portland Type I cement was mixed with the aggregates to produce the cementitious concrete composites. Four volume fractions of each of the waste aggregates were used (5, 10, 15, and 20 percent). Three ASTM standard mechanical tests were conducted on the specimens under study: compressive, flexural, and splitting tensile tests. The compressive and splitting tensile strengths as well as the modulus of rupture and elasticity of the concrete mixtures were determined. The results of the mechanical properties were analyzed in comparison to the control specimens. Scanning electron microscopy (SEM) was used to study the relationship between these mechanical properties and the microstructure and interfacial features of the concrete composites. Optical photographs of tested specimens after failure were also obtained to show the general fracture behaviors of the different composites. The main findings of this investigation revealed that the three waste materials could be used successfully as partial volume substitutes for sand in concrete composites. Key words: non-recyclable glass waste, plastics waste, fiberglass waste, cementitious concrete, fine aggregates.

The problem of disposing and managing solid waste materials in the United States and other industrial countries has become one of the major environmental, economical, and social issues. A complete waste management system including source reduction, reuse, recycling, land-filling, and incineration needs to be implemented to control the increasing waste disposal problems (*1*). Of the above options, recycling is the most promising waste management process for the disposal of materials in the waste stream (*2*). The two main potential markets to utilize recycled waste materials successfully are the transportation and construction industries. Special applications which would not require high strength concrete can be found in the transportation industry. Furthermore, the potential uses of most recyclables in the construction industry are almost endless.

Many virgin and waste materials are widely used in concrete composites as fiber reinforcements (e.g. steel, glass, plastics, sisal and jute) (*3–7*). However, the idea of using municipal waste materials as aggregates for use in structural concrete has not found many applications yet (*8*). For example, it was believed that the presence of crushed glass in aggregates tends to produce unworkable concrete mixtures, and that the high alkali content of such aggregates would affect the long-term durability and strength of the composite. Recently, using different types of waste materials (such as vegetable and plastic materials) in concrete composites as aggregates has been investigated (*3,9,10*). Results of such research efforts showed the possibility of using these materials in concrete composites effectively. The purpose of this study was to investigate the possibility of using plastics, glass, and fiberglass granulated solid waste materials as partial aggregate substitutes to the sand in a Portland cement concrete mixtures to produce concrete composites

EXPERIMENTAL DESIGN AND SAMPLE PREPARATION

The solid waste materials used in this study and obtained from different locations were plastics, fiberglass, and glass. The plastic waste materials were a combination of both the PET (soda bottles without metal caps and paper labels) and HDPE (milk jugs). The glass waste materials were a combination of both the non-recyclable clear window glass and fluorescent bulbs with a very small amount of contaminants. The fiberglass waste materials were a combination of unsaturated polyester base resin, styrene, continuous filament fiberglass, catalyst (methyl ethyl ketone peroxide), triethyl phosphate (TEP), gelcoats (styrene), and less than 0.5 percent contaminants (solem alumina trihydrate and calcium carbonate). Concrete composite specimens containing only one of these aggregate waste materials were prepared. Four different volume percentages (5, 10, 15, and 20 percent) were utilized of each granulated aggregate substitute. Control concrete composite specimens were also prepared to be used as reference point to compare the concrete composites containing waste materials.

The procedure followed to prepare the tested specimens was chosen in accordance with ACI 211 standards. Tap water at room temperature (about 73°F) and Type I Portland cement with a specific gravity of 3.15 were used. The coarse aggregates were smooth and round with an average maximum size of 3/8 inch (9.5 mm) diameter. The oven-dried rodded unit weight was 101 lb/ft^3 (1,601 kg/m^3) and the specific gravity of these aggregates was 2.64. The fineness modulus (FM) and specific gravity of the sand aggregates were 2.7 and 2.7 respectively. Absorption and moisture content were 0.31 percent and 0.51 percent for the coarse aggregates and 1.01 and 4.85 percent for sand aggregates respectively. The specific gravity and FM were 1.27 and 3.4 for the plastic waste aggregates; 2.13 and 2.1 for the glass aggregates; and 1.37 and 1.6 for the fiberglass aggregates based on ASTM standards. The recommended slump considered in this study was between 25.4 and 76.2 mm. Also, the average specified 28-day compressive strength (f'c) of the developed cementitious concrete composites was 20.7 MPa. All the prepared specimens were cured for 28 days to reach the maximum required strength. The procedure followed in making and curing

Department of Industrial Technology, University of Northern Iowa, Cedar Falls, Iowa 50614-0178.

all the tested concrete specimens was in accordance with ASTM C192-90a standards.

In this investigation, three mechanical testing methods were conducted. A Compression test, ASTM C39-86 standard, was used to measure the compressive strengths (f'c) of the control and concrete composites. Molded and capped concrete cylinders 76 mm diameter and 152 mm height specimens were used. The splitting tensile strengths (T) of the control and the concrete composites under investigation were evaluated by conducting the splitting tensile test (ASTM C496-90 standard). The standard cylindrical specimens used in this test were similar to those used in the compression test. The test method for the modulus of rupture (R) and modulus of elasticity (E) of the concrete composites were conducted using simple beam with center-point loading in accordance with ASTM C293-79 standard. The beam dimensions were 50 mm width X 50 mm thickness X 152 mm span length with one 25.4 mm overhanging distance from both ends. After conducting each mechanical testing, all the fractured specimens were preserved to generate photographs to study the general fracture modes of these composites. Representatives samples of the fractured compression test specimens were used for further scanning electron microscopy (SEM) studies.

EXPERIMENTAL RESULTS

Figure 1 shows the best curve fitting for the obtained (f'c) values for the cementitious concrete composites tested in this study. In general, this figure reveals that all the values of (f'c) of the new cementitious concrete composites containing waste aggregate materials are higher than the average specified 28-day compressive strength (20.7 MPa). However, all these values of (f'c) are below the actual obtained value for the control concrete composite (by at least 15 percent). An exception to this conclusion was the case of adding 20 percent glass aggregate substitute where the value of (f'c) for this concrete composite was comparable to that of the control one. The figure also shows that at 5 and 10 percent aggregate substitutes, the three types of new concrete composites (containing plastics, glass, and fiberglass) have close (f'c) values. However, at 15 percent aggregate substitutes, it can be seen that there is a significant difference between the glass concrete composite and both the plastics and fiberglass ones. Figure 2 shows the trends for the obtained (T) values for the new cementitious concrete composites, and reveals that all the (T) values of these concrete composites are within a range between 3 and 3.45 MPa. This means that there is no significant difference in the (T) values among these concrete composites based on their percentages of aggregate substitutes used. However, the figure clearly shows that the (T) values of the concrete composites containing fiberglass substitutes are better than those containing glass and plastics substitutes. Indeed, all these (T) values are found to be below the actual ones obtained for the control concrete composite by at least 11 percent. The Figure also shows that the (T) values of all the tested fiberglass concrete composites and glass concrete composites at 5 and 20 percent aggregate substitutes are the closest values to that of the control concrete composite.

Based on the (R) values depicted on Figure 3, the glass-containing concrete composites are the most consistent composites within the selected range of 5 and 20 percent aggregate substitutes followed by fiberglass and finally plastics concrete composites. It is to be noticed that the three concrete composites (containing 5 and 20 percent glass aggregate as well as the one containing 5 percent plastics aggregate) have the higher (R) values than the control composite. The figure shows that for up to 10 percent aggregate substitutes, all the (R) values of the tested concrete composites are close (within the expected experimental error). There are only four tested concrete composites that have significant differences between their

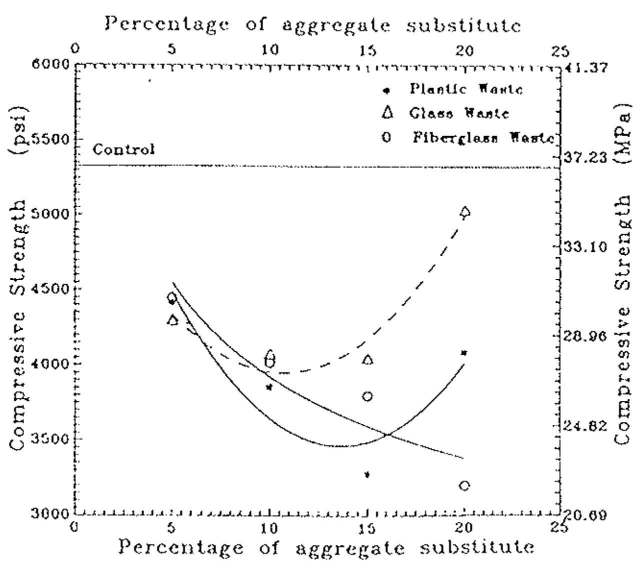

FIGURE 1 The compressive strength versus the percentage of aggregate substitutes in the studied cementitious concrete composites.

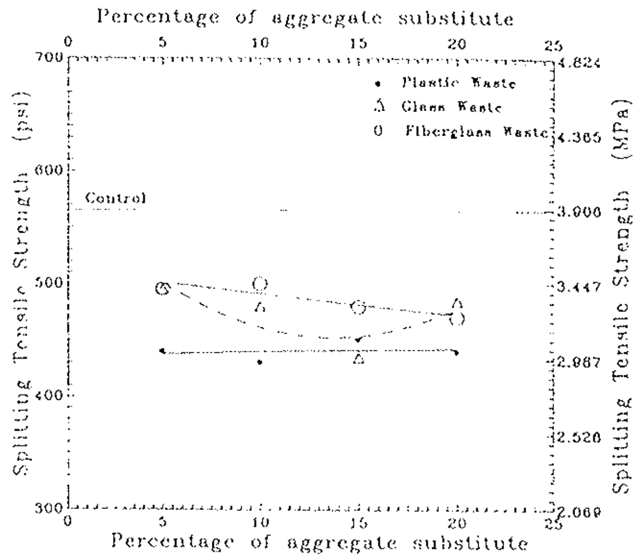

FIGURE 2 The splitting tensile strength versus the percentage of aggregate substitutes in the studied cementitious concrete composites.

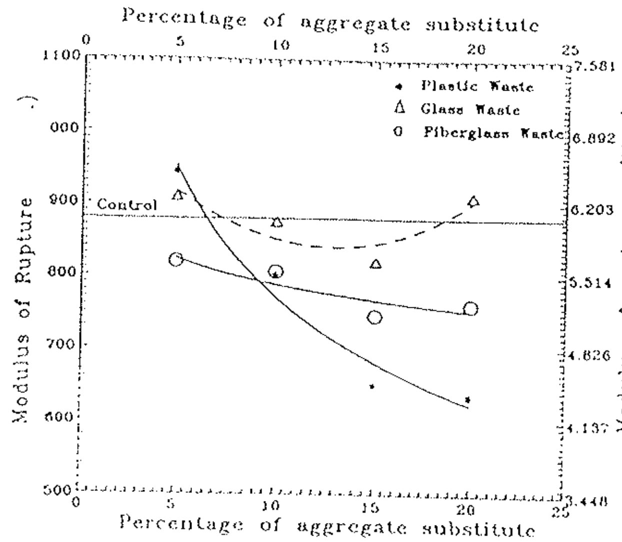

FIGURE 3 The modulus of rupture versus the percentage of aggregate substitutes in the studied cementitious concrete composites.

R values and that of the control composite. These four composites are the 15 and 20 percent plastics and fiberglass concrete composites. Based on the (E) values depicted on Figure 4, the fiberglass cementitious concrete composites are the most consistent composites within the selected range of 5 and 20 percent aggregate substitutes followed by glass and finally plastics concrete composites. It be noted that only two concrete composites (containing 15 and ... percent plastics aggregate) have lower stiffness than that of the control concrete composite. The rest of the tested concrete composites have stiffness values equal to or greater than the control composite.

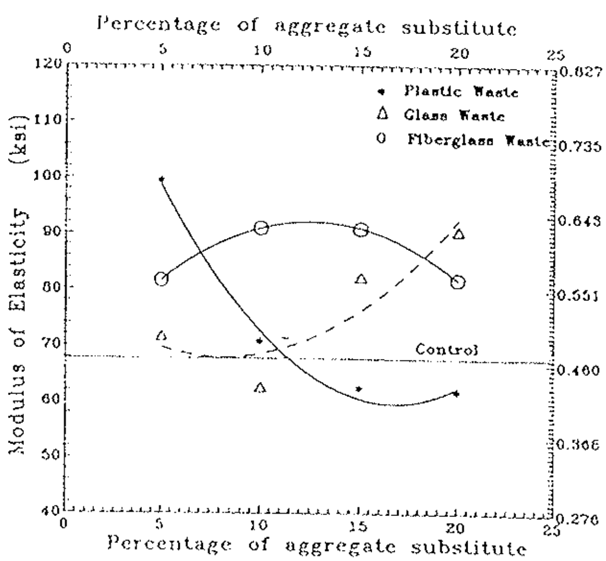

FIGURE 4 The flexure modulus of elasticity versus the ...ntage of aggregate substitutes in the studied cementitious c...ete composites.

Statistical procedures were used to analyze the data obtained and to determine the significant differences among the values of the mechanical properties of the tested concrete composites. Specifically, a two-way ANOVA was used to determine whether the types and percentages of aggregate substitutes as well as their interaction have any significant effects on each of the mechanical properties of the new cementitious concrete composites. One-way ANOVA and Tukey HSD procedures were also used to identify the significant differences among the values of the mechanical properties of the control concrete composite and those values for the new concrete composites containing different percentages of aggregate substitutes. The results obtained, in general, enhanced the graphical analysis discussed above and proved the importance of using statistical analysis as a powerful tool in this type of study.

SEM micrographs suggested that no significant differences should be expected among all the new composites containing up to 10 percent aggregate substitute materials since the existence of these materials in the concrete composites was scarce. However, some basic and important features of plastics, glass, and fiberglass containing concrete composites were clearly shown. For example Figure 5 shows a crack propagation through the plastics aggregates which were not tightly bonded to the cement paste. These plastic

FIGURE 5 SEM micrograph for the failure of plastics aggregate phase in cementitious concrete composite containing 10% plastics aggregate substitute.

aggregates acted as crack arrestors and energy absorbers in their concrete composites. The existence of these aggregates was one of the main reasons to hold the shape of the concrete cylinders tested under compression load even after complete failure of these cylinders. Figure 6 shows the good interfacial bonding between the cement paste and glass aggregates which acted as crack arrestors preventing cracks from propagating through them. Finally, Figure 7 shows the strong bonding between the glass fiber filaments (crack arrestors) and cement paste which was not bonded to the unsaturated polyester base resin (styrene). On the other hand, when more than 10 percent aggregate substitutes were added, significant differences were seen between these composites (e.g. aggregate density and distribution, porosity, hydration products, pull out phenomenon, crack propagation patterns). In general, it was found that through the analysis of the SEM and fracture photographs, such characteristics as crack type, propagation, and arrest phenomena of

X200 10 KV 150 m
(a) 10% glass aggregate

X110 10 KV 270 m
(b) 15% glass aggregate

FIGURE 6 SEM micrograph for the microstructure of a fractured concrete composite containing 10% glass aggregate substitute.

these composites can be evaluated qualitatively. These techniques are invaluable tools which can be used to compare the properties of different types of concrete composites qualitatively and to predict the fracture modes under different loading systems.

CONCLUSIONS

This study was conducted to evaluate the effect of using solid waste materials as substitutes for fine aggregates on the mechanical properties of cementitious concrete composites. It can be concluded that granulated waste materials such as plastics, glass, and fiberglass can be used in cementitious concrete composites without seriously hindering its mechanical properties up to the composition range used in this study (20 percent). The notion that such granulated waste materials would render the mix unworkable was not supported by this study. Furthermore, no clear evidence of deterioration of the composite durability was noticed. This research also supports the idea that all three waste materials, as used within the ranges specified, acted as crack arrestors in all the composites prepared. As expected, the plastic granules did not bond well to the cementitious matrix, while the glass and fiberglass ones seemed more bonded to it. Only plastic material substitutes were noticed to fracture under load and allow partial crack propagation through them, while the glass and fiber glass granules either arrested the cracks completely or deflected them when encountered. In general, the use of granulated plastics, glasses, and fiberglass waste materials is, indeed, a viable solution to recycling such materials in concrete composites.

FIGURE 7 SEM micrograph for the microstructure of a fractured concrete composite containing 10% fiberglass aggregate substitute.

SUGGESTIONS FOR FUTURE WORK

Based on the current study, it is suggested to 1) study the economical aspects involved in such research, 2) investigate the possibility of increasing the volume fractions beyond the range used in this study, and 3) investigate the possibility of using other types and forms of waste materials in cementitious concrete composites.

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APPENDIX IV