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A Study Conducted to Investigate the Feasibility of Recycling Commingled Plastics Fiber in Concrete

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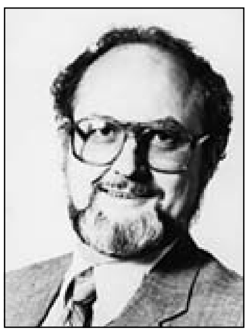

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Introduction

Manufacturing industries contribute significantly to wealth creation in the United States, but they also generate approximately 5.5 billion tons of non-hazardous waste and 0.7 billion tons of hazardous waste per year. The direct cost of handling and disposing of the hazardous waste alone in the United States is estimated to be $50 billion per year (NSF, 1995).

In the United States the paradigm of manufacturing is shifting from pollution disposal to themes of industrial ecology and environmentally conscious manufacturing. The National Science and Technology Council (1994) outlined an environmental strategy to support this new paradigm and lay the groundwork for long-term national economic growth based on this transition.

One part of the environmentally conscious manufacturing movement is the use of waste to create other products, thus offering significant potential for reducing costs to industry and society. An example of this is using plastics for reinforcement in concrete. Natural polymers have been used by builders since ancient times to improve the properties of construction materials as indicated by Chandra and Yoshihiko (1994). Today, synthetic polymers such as polypropylene, polyethylene, and acrylic are used for fiber reinforcement in concrete as explained by the Portland Cement Association (1993).

Since synthetic polymer fibers are already being used for reinforcement in concrete, it would seem logical to assume that recycled commingled plastics (a mixture of different plastics which are not easily separated or sorted) could offer similar benefits if used in fiber form. This article describes a funded recycling research project which investigated the feasibility of utilizing mixed varieties of plastics in extruded fiber form for use as reinforcement in concrete. The firm involved will be referred to as company "XYZ" for purposes of this article. The specific name of the company has been withheld to enable honest discussion of the project.

Background

Plastic wastes are separated into two categories based on their use, (1) post-consumer or public waste and (2) manufacturing waste. Manufacturing waste constitutes a very small percentage of the municipal waste stream. This is largely due to the fact that plastics manufacturers have been recycling their own waste since commercial-scale plastics processing began (Nir, Miltz and Ram, 1993). The post-consumer waste represents the largest constituent going into the municipal waste stream (approximately 90-95%) (Rebeiz, 1992). As a result, the post-consumer waste has been the focus of government regulations and environmental concerns related to plastics in recent years because most of it ends up in the municipal waste stream. Rebeiz (1992) cites the difficulty in collecting these materials and the fact that they are usually contaminated as the key reasons why they are so routinely discarded rather than recycled.

The post-consumer waste described in this study consisted of commingled plastics which came from greeting card racks that were produced by company XYZ. The racks consisted of high impact polystyrene (HIPS), acrylic, and a hot melt used to bond some of the parts. One of the HIPS parts used in the card racks had a colorant added to it.

Previously received damaged card racks were landfilled. Due to increased landfill costs the plastic was separated and sent to a recycling firm. The company was interested in other recycling alternatives.

Purpose

The purpose of this study was to generate new knowledge about recycling commingled plastics and help support the environmental strategy outlined by the National Science and Technology Council (1994). This research focused on using the commingled plastics in fiber form. The objectives of this project were to:

1. Determine the feasibility of extruding specific commingled plastic fibers.
2. Conduct testing on concrete specimens containing commingled plastics in fiber form to identify a feasible recycling alternative for these materials.
3. Disseminate the results.

Methodology

This study consisted of three phases. Phase I of the study consisted of testing for the compression and flexure strength properties of non-air-entrained concrete (concrete without an air-entrainment additive to resist the affects of freezing and thawing) that contained plastic fibers in various quantities.

The plastic greeting card racks from company XYZ were shredded with a plastic granulator. The material was ground to approximately 3-7 millimeters in size.

A multistrand die was designed and precision machined for the extruder in the plastics laboratory in the department so the extrusion of the granulated commingled plastics could be studied to determine the most efficient method of creating fiber. Figures 1 and 2 show the multistrand die which was used in the study. The plastic granules were extruded to produce fibers approximately 0.010" to 0.030" in diameter and cut to one inch lengths for use in the concrete. The type and amount of plastics fiber added to each batch mix in phase one is shown in table 1.

The concrete materials used in this study included: torpedo FA1 sand, 0.75 inch CA11 crushed stone, gray type I portland cement, and air-entrainment (only used in phases 2 and 3). The batch mix specified by the Portland Cement Association (Kosmatka & Panarese, 1992) for one cubic foot of concrete was used for this study. Four batch mixes were used in phase one of this study for comparison. Each batch mix consisted of four compression and two flexure specimens. A 1.5 cubic foot capacity cement mixer was used to mix the concrete. The specimens were prepared according to the C192 American Society for Testing of Materials (ASTM) Standard (Making and Curing Concrete Test Specimens in the Laboratory). A slump test was conducted for each batch mix using the ASTM 143 standard (Slump of Portland Cement Concrete).

A local commercial testing firm cured the compression and flexure specimens and conducted the tests. The compression specimens were tested according to the ASTM C39 standard (Compressive Strength of Cylindrical Concrete Specimens) to determine the ultimate strength of the specimens. The tests were run on the following cure dates: 7 days, 14 days, 28 days (two specimens were broken on the 28th day). Standard procedure at the testing firm used in this study is to test two specimens at 28 days and take the average since this is the optimum cure time for concrete.

The flexure specimens were prepared in the same manner as the compression specimens and tested

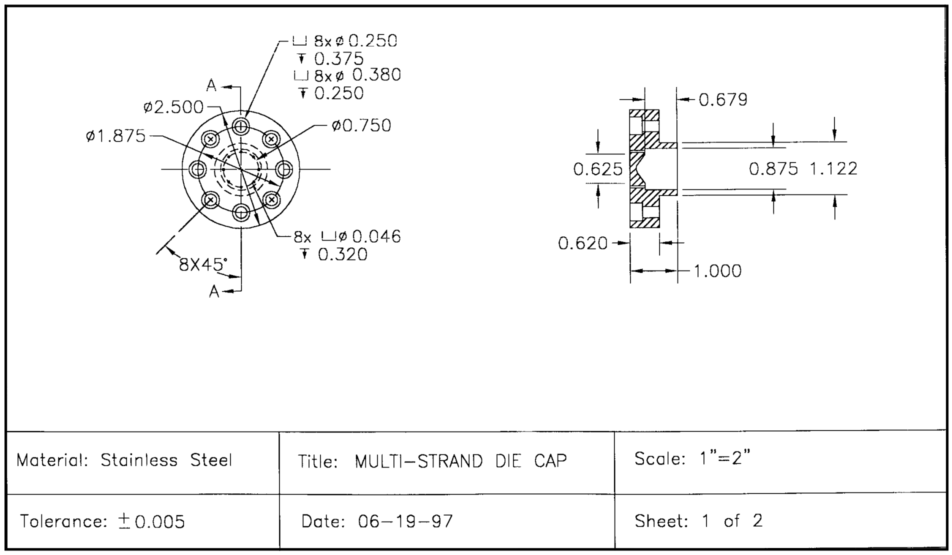

Figure 1. Cap for the multistrand extruder die.

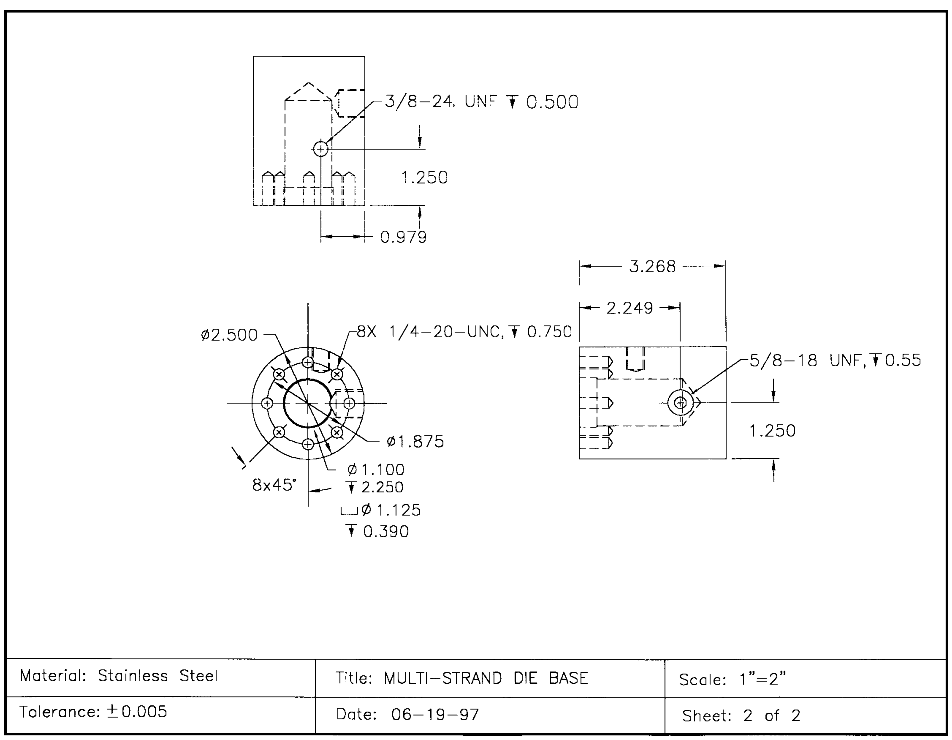

Figure 2. Base for the multistrand extruder die.

Batch Mix Number	Quantity of Plastics
1	Normal amount of commingled plastic fibers (one pound) per cubic yard).
2	No plastic fibers were added.
3	One-half the normal amount of plastic fibers.
4	One and one-half the normal amount of plastic fibers.

Table 1. Quantities of Plastic Fibers in the Non-air-entrained Concrete Batch Mixes -- Phase I

according to the ASTM C78 standard (Flexure Strength of Concrete Specimens Using Simple Beam with Third Point Loading) to determine the ultimate flexural strength. The tests were run on the following cure dates: 14 days, 28 days (one specimen was broken on each test date).

The second phase of this study involved the investigation of the effects of commingled plastics fibers in air-entrained concrete. Air-entrainment cement additive is used to improve durability to repeated freezing and thawing. This phase of the project called for conducting compression, flexure, and freeze-thaw tests to investigate the feasibility of recycling the plastics waste in air-entrained concrete.

An air meter was used to take the air content readings. The desired air content for the project was 6% because the American Concrete Institute recommends between 4.5% and 8% air content for the location of the research.

Concrete specimens were prepared following the ASTM C192 standard. A slump test was conducted for each batch mix using the ASTM C143 standard and the air content was measured using the C231 standard (Standard Test Method for Air Content of Freshly Mixed Concrete by The Pressure Method). The same quantities of commingled plastics fibers were added as in phase one of the study. However, two control groups were used this time for comparisons, one with no plastic fiber and a second containing commercial plastic fiber in the normal amount (see table 2). The compression and flexure specimens were tested by the same local commercial testing firm used in phase one of the study. The specimens were cured in a curing room until they were tested. The compression tests were conducted at the following intervals: 7, 14, and 28 days. Two compression specimens were always tested at the 28 day interval to obtain an average. The flexure tests were conducted at 14 and 28 days.

The air-entrained concrete batch mixes were also tested for their ability to withstand freezing and thawing conditions over time. The freeze-thaw tests were conducted according to the ASTM C666 standard (Resistance of Concrete to Freezing and Thawing). These specimens went to a second commercial testing facility where they were cured and subjected to 354 cycles of freezing and thawing. Measurements were taken at various intervals with a precise dial-indicator instrument to determine the amount of expansion in the specimens as a result of these conditions. Passing these tests is a good indication that the concrete and plastics mixture will perform well in a natural freeze-thaw environment.

The batch mixes for the third phase of the study are shown in Table 3. This group of tests was conducted to focus on specific quantities of commingled plastics in the batch mixes and to gather more data with regard to the strength and durability of these batch mixes compared to the two control groups.

The procedures for preparing the specimens and testing them was the same as in the previous phase with two exceptions. The first exception was that no 14 day flexure test was conducted. Another exception was that a second flexure specimen and two additional compression specimens for each batch mix were run through freeze-thaw cycles for 28 days and then tested. This was done to investigate the durability of the concrete.

Conclusions

Figure 3 shows the compression strength values for the non-air-entrained concrete used in phase one of the study. The results of the compression tests show good strength values for all of the

Batch Mix Number	Quantity of Plastics
1	Normal amount of commingled plastic fibers (one pound) per cubic yard).
2	No plastic fibers were added.
3	One-half the normal amount of plastic fibers.
4	One and one-half the normal amount of plastic fibers.
5	Normal amount of commercial plastic fibers.

Table 2. Quantities of Plastic Fibers in the Air-Entrained Concrete Batch Mixes -- Phase II

Batch Mix Number	Quantity of Plastics
1	Normal amount of commingled plastic fibers (one pound) per cubic yard).
2	No plastic fibers were added.
3	Twice the normal amount of plastic fibers.
4	Normal amount of commercial plastic fibers.

Table 3. Quantities of Plastic Fibers in the Air-Entrained Concrete Batch Mixes -- Phase III

concrete specimens. A minimum of 2500 psi is often required by code in a compression application. The strength values far exceeded the minimum in all cases. Most interesting is that batch mix number four, which had the largest amount of plastic fiber, had better strength than the specimens in batch mix numbers one and three with lower amounts of fiber. Batch mix number four also had comparable strength values to batch mix number two which did not contain any plastics fibers.

Figure 4 shows the compressive strength values for the air-entrained concrete used in phase two of the study. Once again, the batch mixes with the commingled plastics fiber (1, 3, and 4) show comparable strength values to the two control groups (2 and 5). Batch mix number four, which contained one and one-half times the normal amount of plastic fibers, showed strength values as good or better than the two control groups (2 and 5) in both early cure time tests and the 28 day tests.

Figure 5 shows the compressive strength values for the air-entrained concrete used in phase three of the study. Batch mix number three, with twice the normal amount of plastic fiber in it, showed better compressive strength values than any of the other batch mixes at all cure times.

Figure 6 shows the flexure strength values of the concrete without air-entrainment used in phase one of the study. The strength values were clustered in a similar range. Batch mix number three, with one-half the normal amount of plastic fiber, had the highest flexure strength (1190 psi) as compared to 1090 psi in the control group (batch mix number 2).

Figure 7 shows the flexure strength values for the air-entrained concrete used in phase two of the study. The specimen for batch mix number two was mistakenly tested at 14 days instead of the 28 day cure time. All the specimens had good flexure strength.

Figure 8 shows the flexure strength values for the air-entrained concrete used in phase three of the study. In this phase only one concrete beam was prepared for each batch mix and the flexure testing was conducted at 28 days. Figure 8 shows there is very little

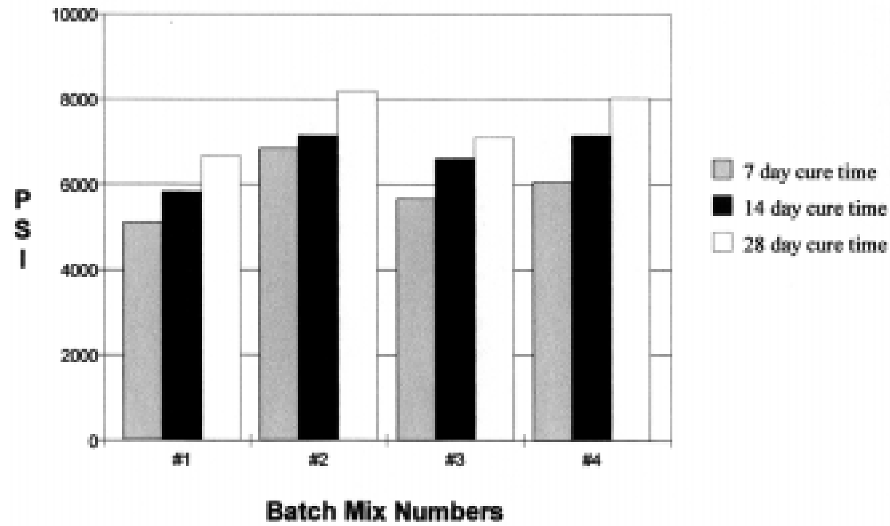

Figure 3. Compressive strength values for concrete specimens without air-entrainment - Phase I.

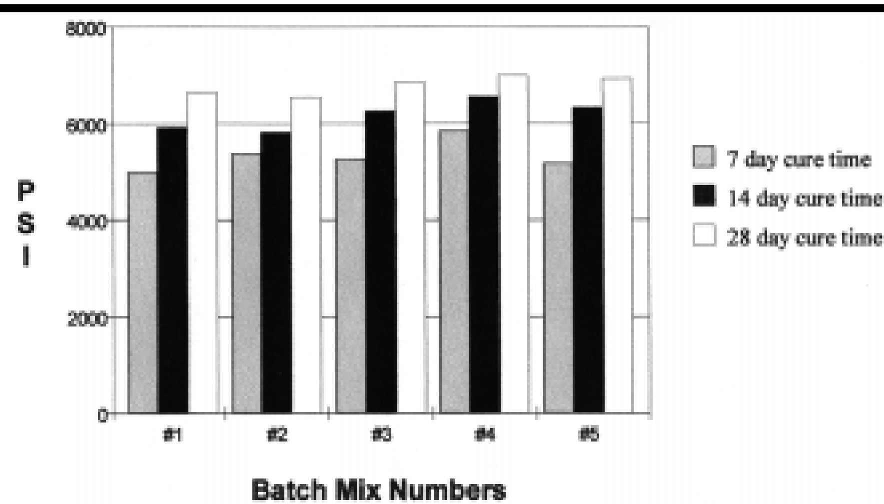

Figure 4. Compressive strength values for concrete specimens with air-entrainment - Phase II.

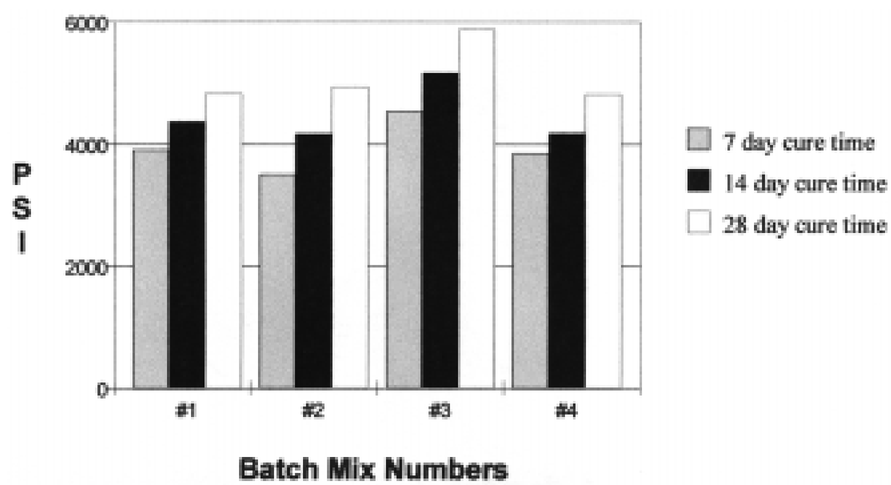

Figure 5. Compressive strength values for concrete specimens with air-entrainment - Phase III.

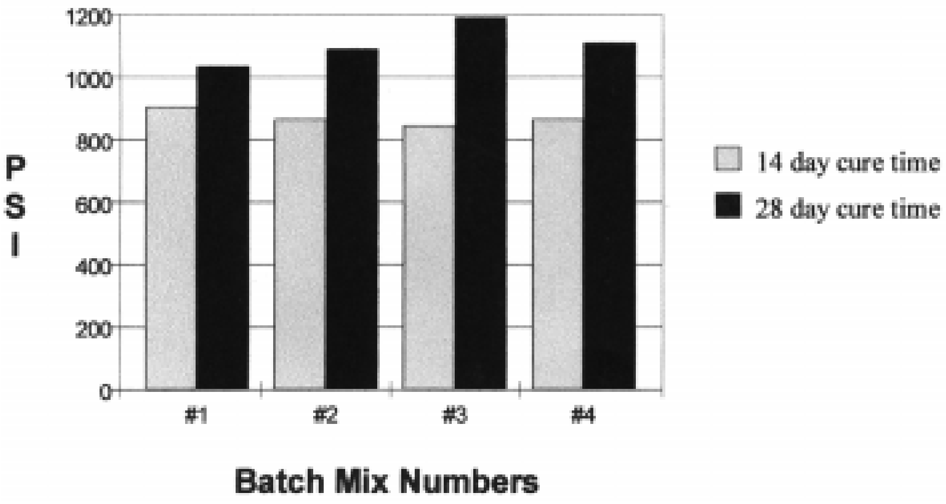

Figure 6. Flexure strength values for concrete specimens without air-entrainment – Phase I.

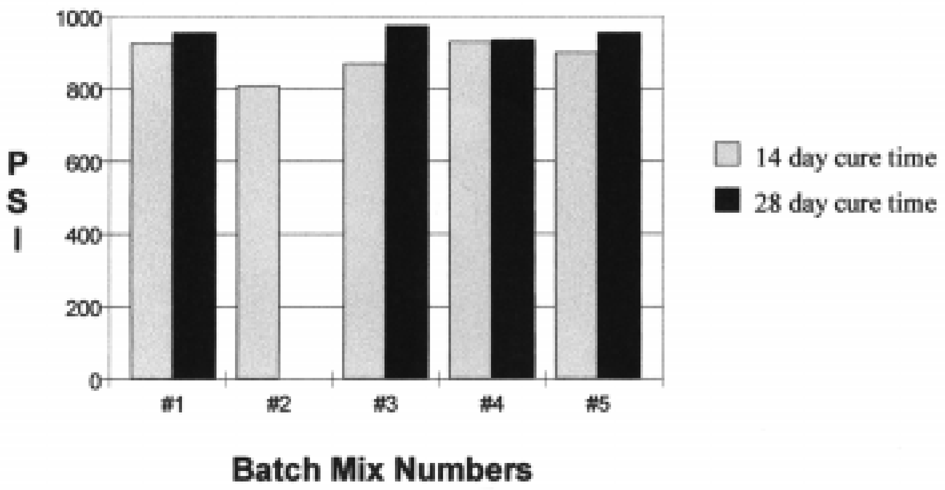

Figure 7. Flexure strength values for concrete specimens with air-entrainment - Phase II.

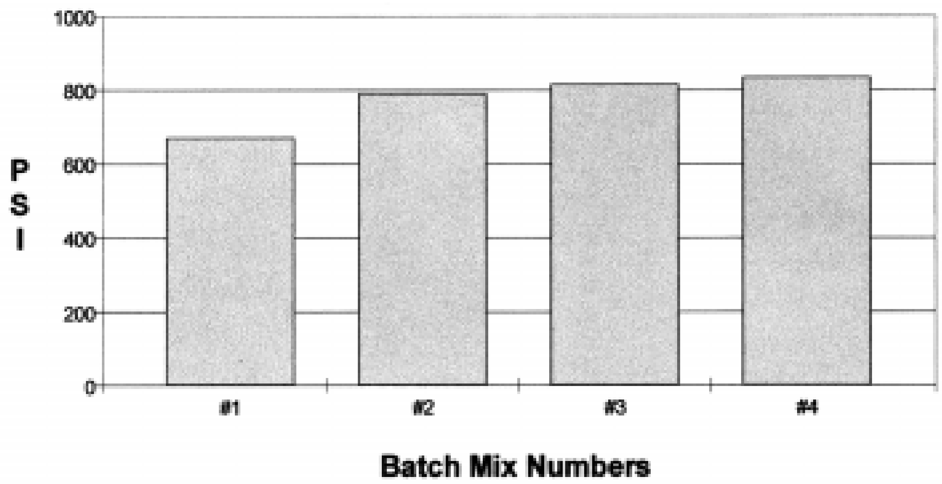

Figure 8. Flexure strength values for concrete specimens with air-entrainment - Phase III.

variation in the strength values. It also shows that batch mix number three, with twice the amount of plastic fiber, had the second highest strength value.

The results of the study also show a decrease in the strength values going from phase one to three. Adding air-entrainment will generally cause a reduction in the strength of the concrete. Figures 9 and 10 show the percent of air content in the specimens. Anywhere from 4% to 8% was the suggested amount. Figure 9 shows that the specimens in phase two had low air content readings and figure 10 shows that the percent of air content was high. Further indication of the affects of the air content can be seen by looking at batch number three in the third phase. The air content was the lowest of all four batches (5.5%) in that phase of testing and the compressive strength values were the highest at all cure times (see figures 5 and 10).

Another factor that can affect the strength of the concrete is the amount of water in the batch mix. The slump test is used to determine the consistency of the batch mix. Figures 11, 12 and 13 show the slump values for the batch mixes in the three phases of the study. The desired slump values for this study were between 3" and 5". The slump values in phase two most closely matched the desired range (see figure 12). The variance in slump values for the flexure specimens did not appear to substantially affect their strength. For example batch number one in phase two had a rather low slump (2.75") and yet its flexure strength was consistent with the other specimens in that phase (see figures 7 and 12).

Variance in slump values for the compression specimens appeared to have mixed results. Figure 11 shows that the compression specimens in batch number 2 in phase one had a 3" slump while batch number three had an 8" slump. Figure 3 shows slightly higher compression strength values for batch number two versus batch number three. This trend appears to be reversed in phase three as can be seen by reviewing the results of batches two and three in figures 5 and 13. In phase three the highest slump value resulted in the highest strength values.

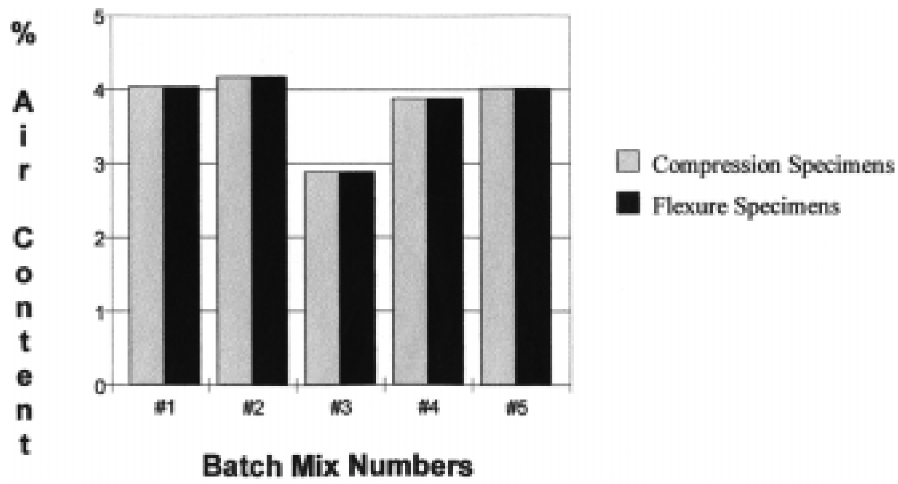

Figure 9. Percent air content for concrete specimens with air-entrainment — Phase II.

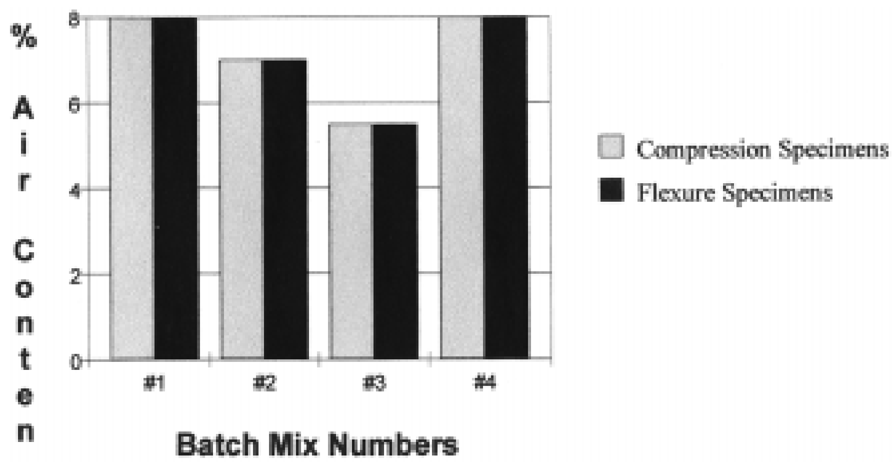

Figure 10. Percent air content for concrete specimens with air-entrainment — Phase III.

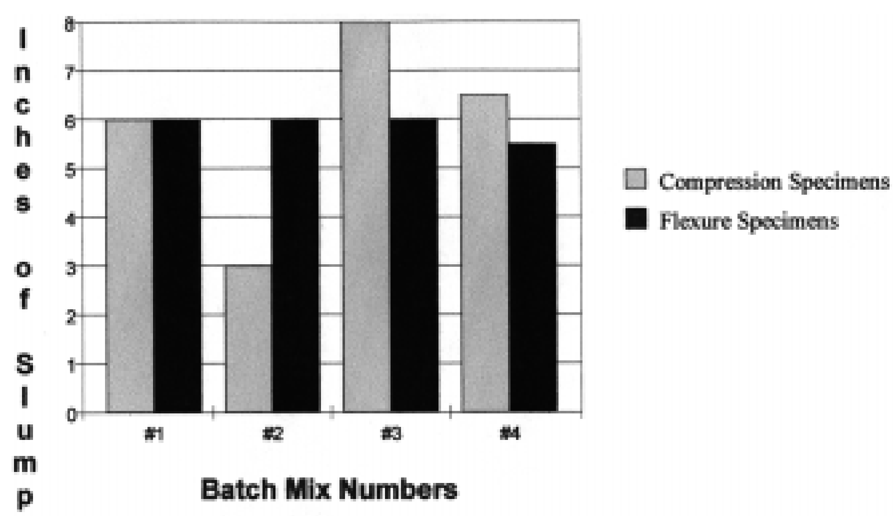

Figure 11. Slump values for concrete specimens without air-entrainment — Phase I.

Of particular concern was how the plastic would affect the expansion of the concrete during the freeze-thaw testing since they have different coefficients of thermal expansion. Any concrete specimen that expands over 0.06% is considered to have failed. Figure 14 shows that batch mix numbers one and two in phase two failed the freeze-thaw test with 0.114% and 0.065% expansion respectively and batches three, four, and five passed with 0.050%, 0.008%, and 0.024% expansion respectively. While it was encouraging to see that batches three to five passed this test, there did not appear to be consistency in the results in this phase because batches one and two failed the test. Batch number one had the normal amount of commingled plastics fiber and batch number two did not contain any plastic fiber. This inconsistency was one of the reasons for doing the third phase of tests.

Figure 14 shows that all the specimens in the third phase failed the freeze-thaw test. Again the results were inconsistent because batches two and four should have passed since they contained no plastic fiber and commercial plastic fiber respectively. At the same time the freeze-thaw test specimens were cycling through freezing and thawing conditions, one compression specimen for each batch mix was taken through 143 freeze-thaw cycles and then tested at 28 days to further examine the durability of the concrete. The specimens showed strengths similar to their counterparts that were tested without being exposed to these conditions (batch numbers one to four respectively - 4,510 psi, 4,180 psi, 4,992 psi, and 4,427 psi). Normal compression breaks were exhibited in the specimens.

Recommendations

The concrete containing recycled plastics fiber showed promising results in compression, flexure, but inconsistent results in freeze-thaw testing. Further testing would need to be conducted with more precise control of variables such as air and moisture content before further conclusions could be made. Commercial batch mixing would be needed to provide more precise control and determine the feasibility of using these commingled plastics fibers in real world applications.

Two variables, the length of fiber and diameter of the fiber, should also be investigated for their affect on the strength or characteristics of the concrete.

Comments

This research project is one example of how an industrial technology department can service local industry's needs and support the environmentally conscious manufacturing movement. This type of work offers many research opportunities for faculty and students. It can very easily be used as the basis for experimentation and problem-solving type laboratory activities. One way to motivate students is to challenge them with project work like this which has the potential to improve the environment, help manufacturing companies, and benefit their community.

Additionally, this type of research is a means for faculty to stay current with technology and transfer their knowledge into the classroom. It is a means to examine the problems which face our society and allow everyone to benefit.

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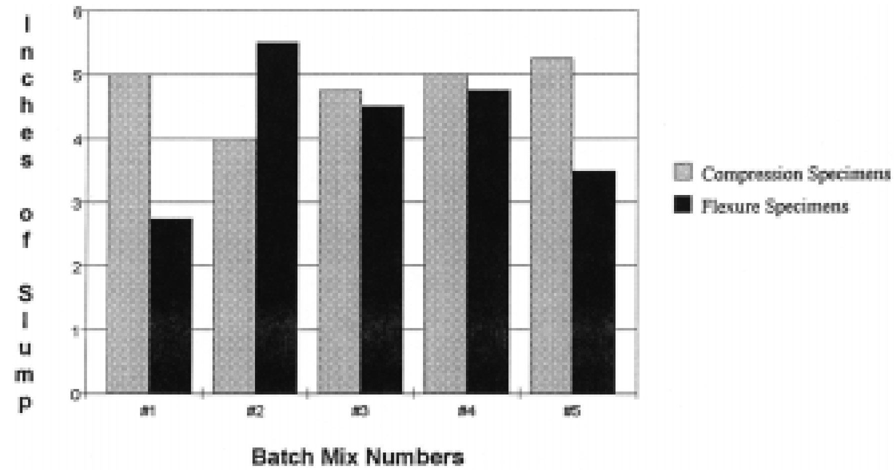

Figure 12. Slump values for concrete specimens with air-entrainment — Phase II.

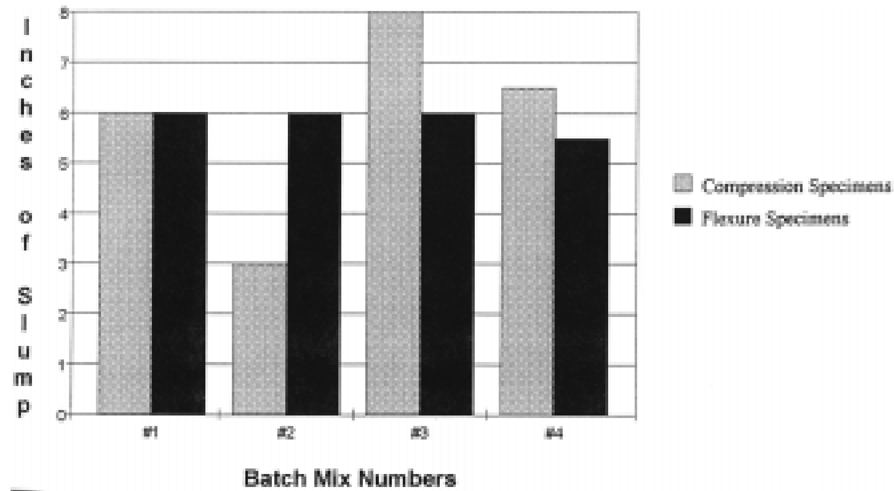

Figure 13. Slump values for concrete specimens with air-entrainment — Phase III.

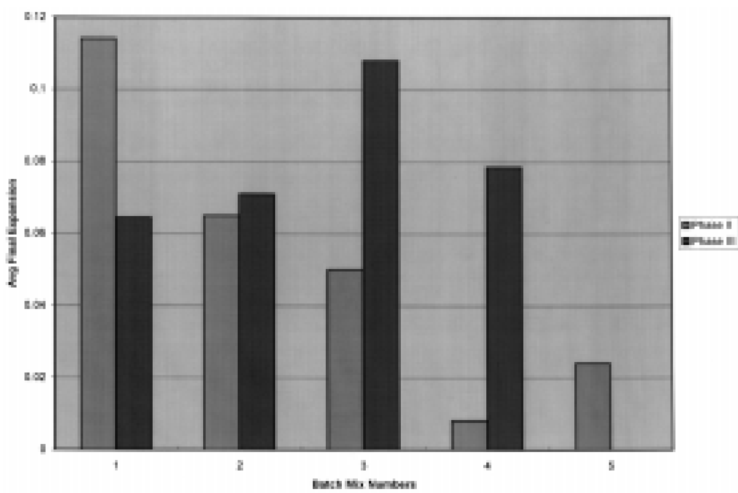

Figure 14. Aggregate freeze-thaw average final expansion percentages for concrete specimens with air-entrainment — Phases II and III.