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The Use of Recycled Polymer Fibers as Secondary Reinforcement in Concrete Structures

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This paper presents the results of a feasibility study undertaken to identify the potential for using recycled high-density polyethylene (RHDPE) fiber as secondary reinforcement in Portland cement concrete structures. This study demonstrated that: 1) It is feasible to use recycled high density polyethylene fibers as secondary reinforcement for temperature and shrinkage influences in Portland cement concrete structures, 2) RHDPE fibers appear to be able to be produced more economically than virgin polypropylene fibers, 3) RHDPE fibers appear to overcome several of the negatives presented by the virgin polypropylene fibers, including floating to the surface and impact on slump, and 4) Shrinkage crack propagation was controlled as effectively by the RHDPE fibers as by the virgin polypropylene fibers. Four very important concerns relative to the use of RHDPE that were reserved for later study subject to the success of this study are: 1) the potential challenge of the alkaline reaction of the RHDPE material, 2) RHPD's performance under extreme temperature cycling, water migration rate studies, 3) its performance under extreme temperature cycling, and 4) the impact of long-term plastic shrinkage.

Key Words: Polymer Fibers, Secondary Reinforcement, Concrete, Recycling, Portland Cement

Introduction

Waste is one of the main challenges of our times. Since l950, the total waste in landfills has increased 500% (Bilwatsch, 1991). The three primary sources of plastics that end up in solid waste are the resin producer, the processor and fabricator, and the consumer. Four primary alternatives exist for dealing with plastic waste: landfill, ultraviolet degradation, incineration, and recycling. Of these alternatives, recycling holds the greatest promise for returning the resins to service at a high economic level on the material value scale.

Of all these plastic wastes, high density polyethylene (HDPE) is used in a greater percentage of the products that are destined for short term highly visible packaging, i.e. bottles for bleach, motor oil, toiletries, milk containers, etc.

Therefore, these recycled containers become an excellent candidate for reuse in secondary recycled applications (Modern Plastics, 1988). In order to reduce this municipal solid waste growth, additional demand for recycled HDPE must be generated from industries, including construction (Wilkinson, l990). Indeed, construction is projected to rank second only to packaging in the use of recycled plastics. Much of this demand can be accomplished by diverting the construction industry away from the use of virgin polymers as secondary reinforcement, wherever possible, to the use of recycled polymers.

Virgin polypropylene fibers have been used successfully in the construction industry for over eighteen years as secondary reinforcement. They offer the construction industry an option to the standard welded wire fabric (WWF). Welded wire fabric has many advantages; however, it is subject to tremendous cost fluctuations because of world steel market influences. Also, it rarely ends up in the exact physical location in the slab that the designer intended because of the physical process of field placement. In addition, it does not readily adapt to the evolving technologies which use equipment that must travel over the area normally occupied by the WWF. For these reasons, more designers are going to the polymer type fiber (PF) as secondary reinforcement. Many of the major construction industry companies like J. A. Jones, The Bechtel Corp. and The Parsons-Main Co. have completed major projects using PF type secondary reinforcement successfully. Many major construction projects, like the new Denver airport, have incorporated PF type reinforcement. The PF industry claims that it has enjoyed double-digit growth in product volume sales each year for the past thirteen years (Fibermesh, 1994).

Polypropylene fibers have gained wide acceptance in spite of several shortcomings:

1. Raw material cost fluctuates wildly with the cost of petroleum,
2. Many designers perceive that the percentage of material actually required to provide the necessary reinforcement exceeds the amount recommended by the suppliers
3. The fibers 'float up' to the surface of the concrete matrix during finishing causing additional time and work to finish the slabs properly
4. The addition of the fibers to the concrete matrix decreases the 'slump', making placement more difficult thus requiring the addition of more water, which degrades the concrete strength, or plasticizer which adds to the basic cost.

Goals and Objectives of this Research

The primary purposes of this investigation were to determine:

1. If it was feasible to use recycled high density polyethylene (RHDPE) as a replacement material for welded wire fabric (Zolo and Hays, 1991) as temperature and shrinkage reinforcement in Portland cement concrete structures.
2. If RHDPE that has been sorted from municipal waste, properly cleaned and mechanically 'shaved' into multi-dimensional fibers, would economically fulfill the performance criteria presently being met by virgin polypropylene products.
3. If RHDPE fibers can be used successfully structurally and economically while overcoming some of negatives associated with the virgin polypropylene products.

This study was undertaken to identify the potential for success of the RHDPE fibers as a partial replacement for the virgin polymers. The study was limited to specific structural and performance tests, which provided an indication of the validity of using the RHDPE as a structural material.

Four very important concerns relative to the use of RHDPE were reserved for later study subject to the success of this study:

1. The potential challenge of the alkaline reaction of the RHDPE material,
2. Its performance under extreme temperature cycling,
3. Water migration rate studies, and
4. Long-term plastic shrinkage.

This study was a jointly sponsored by The University of North Carolina at Charlotte, DOW Chemical Company and the LAW Engineering Company.

The Material

The polymer fibers used in the tests were of two different compositions. Fibers in test specimens marked 'FIBER MIX' (FM) were obtained from commercial stock supplied by the ready-mix company that supplied the concrete. This fiber was made from virgin polypropylene. The fiber mixed into the test specimens marked RHDPE were sheared in random lengths from clear plastic milk containers selected from waste stock. This material was cleaned with dishwashing detergent and rinsed in clear water prior to being sheared into fibers. The fiber dimensions varied in length from 19.05 mm (.75 in.) to 38.1 mm (1.5 in.) long by approximately 1.587 mm (.00625 in.) wide by 1 mm thick. The tensile strength of the FM fibers was quoted in manufacturer specifications as 44.81 N/mm^2 (6,500 psi).

The tensile strength of the RHDPE fiber as tested by LAW Engineering was 33.61 N/mm^2 (4,875 psi) based on an average of four "dog bone" specimens tested using ASTM **D882** as a general reference. The concrete supplied by Concrete Supply Company of Charlotte, N.C. was specified as Mix Code # 3700. Mix specifications (per cubic yard) were: strength, 27.58 N/mm^2 (4000 psi) cement: 517 pounds, coarse aggregate: 2000 pounds, fine aggregate: 1341 pounds, water: 325 pounds and design slump: 4 inches.

Experimental Procedure

The concrete was poured close to noon when the temperature was 21^{0}C, (70^{0}F). The pouring was concluded at 12:25 p.m. and the temperature was 23^{0}C, (74^{0}F). Thirty nine - 152.4 mm., (6 in.) diameter by 304.8 mm, (12 in.) high cylinders and twelve beams 152.4 mm x 304.8 mm) were poured by LAW Engineering laboratory technicians assisted by seven senior Civil Engineering Technology students from UNCC.

The cylinders were separated into lots containing a) no fiber, b) 0.1% fiber (by volume, 1.5 #/cu. yard) and c) 0.2% fiber (3.0 #/cu. yard). The ready-mix concrete was measured and placed into a portable mixer. The appropriate fiber quantity was then blended into the concrete matrix and thoroughly mixed by motorized drum mixer for five minutes to get uniform distribution of the fiber.

The concrete was then checked for unit weight, slump and air content, per ASTM C-173, and poured into the test cylinders and beams; they were then cured according to ASTM Designation C 192-90a. The specimens were tested on the seventh and twenty-eighth days per ASTM designations:

1. C-39 Compressive Strength
2. C-496 Splitting Tensile Strength
3. C-78 Flexural Strength

It was noted that in both the 0.1% and the 0.2% test specimens more than 100 FM fibers floated to the top and presented a 'fuzzy' appearance. Less than 5 RHDPE fibers were observed to float to the surface of their respective specimens.

Results and Discussion

Field Measurements

The following initial data were recorded while the specimens were being poured:

Table 1

Effect Of % of Fiber Content on Slump

SPECIMEN TYPE	% FIBER	SLUMP	AIR CONTENT
CONTROL	0.0%	4.75"	2%
RHDPE	0.1%	4"	2%
RHDPE	0.2%	3.5"	2%
FM	0.1%	3"	2%
FM	0.2%	2"	2%

These data suggest that the RHDPE fibers had less negative effect on the slump of the concrete as compared to the FM type fiber. This result may have important strength, productivity and cost related impacts; however, more testing will have to be done to statistically verify the real strength and economic impact of this variable.

Appendix ‘A’ shows the Summary of Laboratory results of the compressive strength tests, splitting tensile strength tests, and the flexural strength of the specimens at 7 days and 28 days for the control specimens with no (0%) fiber content (CONTROL), fibrillated (FIBER MIX) fiber specimens and the recycled high density polyethylene (RHPDE) specimens.

Summary of Laboratory Test Results

Compression Strength Results

In compression, the RHDPE specimens showed only moderate advantage over the CONTROL and FIBER MIX specimens at 7 days (6% over CONTROL and 3% over FIBER MIX); however, at 28 days, the RHDPE with 0.1% fiber shows an average of 5% greater compressive strength over the control and 10% over the FIBER MIX specimens. It should be noted in Appendix ‘A’ that the compressive strength of the RHDPE with 0.2% fiber dropped back to a 3% advantage over FIBER MIX. Note also that the average of the FIBER MIX specimens with 0.1% fiber content had not yet reached the design strength of the mix.

Flexural Strength Results

Flexural strength tests were run using only the CONTROL concrete beams and the 2% RHDPE reinforced beams. The results indicate that the RHDPE did increase the flexural strength of the beam.

Splitting Tensile Strength Results

The RHDPE specimens at 0.1% again showed the most interesting results at the 28-day test for splitting tensile strength. They out-performed the control specimens and they exceeded the capacity of the FIBER MIX specimens by 2.6%.

Fiber Distribution

No statistical analysis was made of the distribution of either the FM fibers or the RHDPE fibers in any of the specimens; however, physical observation with the naked eye indicated that distribution of both fiber types in all specimens was reasonable uniform.

Shrinkage Crack Mitigation

Two separate flat panel tests were performed to compare the abilities of the two different polymer fibers to resist shrinkage cracking. No ASTM specification was available for this test so actual field construction conditions were simulated as closely as possible. Both tests were conducted using the four thousand-pound concrete mix referenced above. The concrete was placed into wood forms measuring 76 mm thick by 609.6 mm wide by 914.0 mm long. Three of these test panels were used: panel ones mix contained 0.1% of 'FM' fiber, panel two mix contained 0.1% of RHDPE, panel three contained no (0%) shrinkage reinforcement. All panels were underlain with a polyethylene vapor barrier to minimize base surface drag. Test number one was poured under job conditions: 23^0C, (74^0 F), with a controlled wind velocity of 10 to 15 mph. The relative humidity was 70 percent. Test two was performed when the temperature varied between 29^0C (84^0 F). and 31^0C (89^0 F), with a relative humidity of 64% and an average controlled wind velocity of 32 K/hr. (20 mph) to 41 K/hr. (25 mph) Neither test produced micro-cracking in any of the samples. This test will be run again under more extreme drying conditions.

Cost Comparisons

Cost comparisons of the RHDPE material with the FM material were most difficult to correlate. The retail cost of the FM was quoted at between two dollars and sixty-six cents ($2.66) per pound ($5.91/kg.) to as much as four dollars and sixty-six cents ($4.66) per pound ($10.35/kg.). The RHDPE material was obtained from a contract recycler in bailed (not clean) condition for eight cents ($.08) per pound ($.17/kg.). This price was for clear milk bottles. (The fiber used in the tests were from clear stock). Colored bottles were quoted at four cents ($.04) per pound ($.09/kg.). In addition to this cost, we added cleaning, handling, cutting and packaging costs of approximately twenty-four ($.24) to thirty two cents ($.32) per pound ($.71/kg.), giving us a total of thirty two cents ($.32) to forty cents ($.40) per pound ($.89/kg.). No profit or overhead allowances have been added. Further, as stated, RHDPE was not available commercially; therefore, best estimates from commercial suppliers were used.

These relative costs would suggest that the RHPD material could enjoy a significant pricing advantage. This apparent pricing advantage is due primarily to the following factors: (a) the initial raw material cost is lower for the RHDPE and (b) the cost of production is lower because it involves only the cleaning and shearing process. The melting, pelletizing, extrusion, and shaping of the FM fiber is eliminated. All other costs associated with getting the material to the marketplace should be similar for both materials.

The most difficult part of validating the actual recycled material cost was with regard to the variation in raw material cost due to possible increased demand for RHDPE and the 'social contribution' cost of the municipal collection process. That is, as new markets are developed for this material and municipalities adjust their cost sharing for the collection process, the raw material cost will likely increase. In addition, since the original patents on the FM material have expired, more competition has entered the marketing arena and this may create a downward pressure on the retail pricing structure of the virgin polymer material. However, given the obvious differential between the combined production costs of the RHDPE and retail cost of the FM materials, there exists potential advantage for the RHDPE materials.

Summary and Conclusions

Experiments were conducted on specimens made of four thousand pound (4,000 psi.) concrete, which contained varying amounts of polymer fiber reinforcement. The control specimens contained no fiber reinforcement. The other specimens contained either one or two tenths percent (by volume) of virgin polypropylene fiber reinforcement (FM) or one or two-tenths percent (by volume) of recycled high density polyethylene fiber reinforcement (RHDPE). Slump, compressive strength, splitting tensile strength and flexural strength tests were performed by LAW Engineering laboratory personnel on these specimens in accordance with appropriate ASTM testing guidelines. It should be noted that sufficient tests were made to develop an average, not a statistically based result.

On the basis of the test results and physical observations, the following conclusions have been made:

1. It may be feasible to use recycled high density polyethylene fibers as secondary reinforcement for temperature and shrinkage influences in Portland cement concrete structures, i.e. all of the tests indicated that the RHDPE fiber specimens provided a higher strength than did the specimens with the FM material.

2. RHDPE fibers appear to be able to be produced more economically than virgin polypropylene fibers. It can be concluded that about twice as much RHDPE fiber can be provided in a concrete mix using RHDPE as can be provided at the same cost using FM. In addition, there are additional savings in secondary costs associated with the reduction in municipal landfill site volume requirements.

3. RDPE fibers appear to overcome several of the negatives presented by the virgin polypropylene fibers, e.g. the RHDPE fibers do not appear to float to the surface as readily as do the FM fibers. This will cause a reduction in finishing time and costs as well as an improvement in concrete slab surface appearance. The slump of the concrete mix does not appear to be effected as negatively by the RHDPE fibers as by the FM fibers. This will allow the pouring of concrete mixes with lower percentage of water, which not only increases the basic concrete mix strength without negatively effecting the ease of pouring but also reduces the need for addition of plasticizers to enhance concrete workability. This results in additional cost savings.

4. Shrinkage crack propagation was controlled as effectively by the RHDPE fibers as by the FM fibers.

5. The flexural strength of the beam specimens was improved significantly; however, additional testing needs to be performed to get a more accurate statistical comparison.

The results of this feasibility study favor the use of RHDPE fibers as secondary reinforcing in Portland cement concrete structures. Additional study is being performed including sufficient specimens to provide statistically significant results.

Recommendations For Further Study

The tests performed in this study were primarily designed to provide an indication of relative advantages and disadvantages of the RHDPE fibers over the control as well as the FM specimens. This information will now be used to design further statistically significant research testing of the RHDPE fibers and other co-mingled waste polymers.

Additional testing to be performed will include:

1. The impact of alkaline reaction in Portland cement concrete on recycled polymers,
2. Water migration studies,
3. The reaction of Recycled Co-Mingled Polymer (RCP) fibers to extreme freeze-thaw conditions (Now underway with The Army Corp. of Engineers CRREL Laboratory),
4. The response of RCP fiber reinforced concrete to corrosive and caustic atmospheres
5. The damping effect of varying percentages of RCP in structures subjected to dynamic and/or vibration loading conditions,
6. The cost effectiveness of using RCP in different types of reinforced concrete structures,
7. The most effective methods for producing RCP fibers,
8. The response performance (in-service) of various configurations of RCP fiber,
9. The true effect of RCP fibers at varying concentrations on slump, concrete strength and workability.

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Appendix A

SUMMARY OF TENSILE STRENGTH AND ELONGATION
UNCC RHDPE Research Project

Specimen Number	Thickness, Inches	Width, Inches	Test Speed	Elongation, Percent
1	0.0210	0.250	2"/min.	952
2	0.0245	0.250	20"/min.	3.7
3	0.0205	0.250	20"/min.	5.5
4	0.0213	0.250	2"/min.	1005
		Tensile Strength in psi		
1		4950		
2		3410		
3		3510		
4		4880		

Appendix B

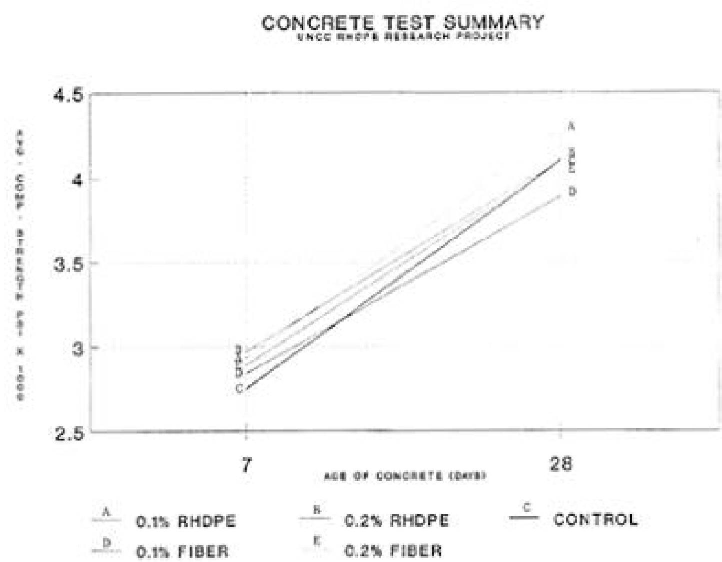

Figure 1. Compressive Strength Comparison

Appendix C

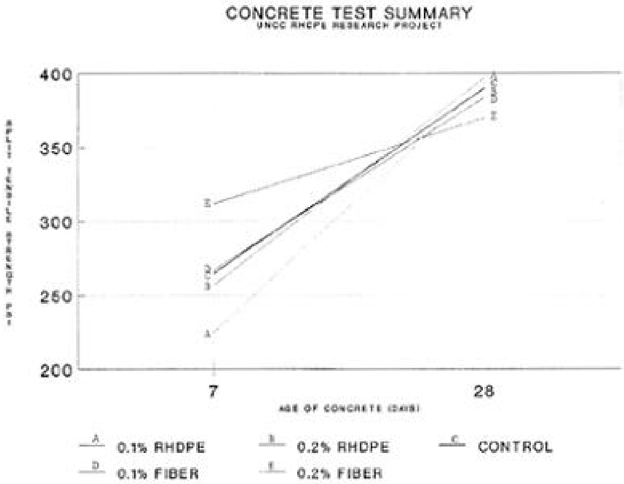

Figure 3. Splitting Tensile Strength Comparison

Appendix D

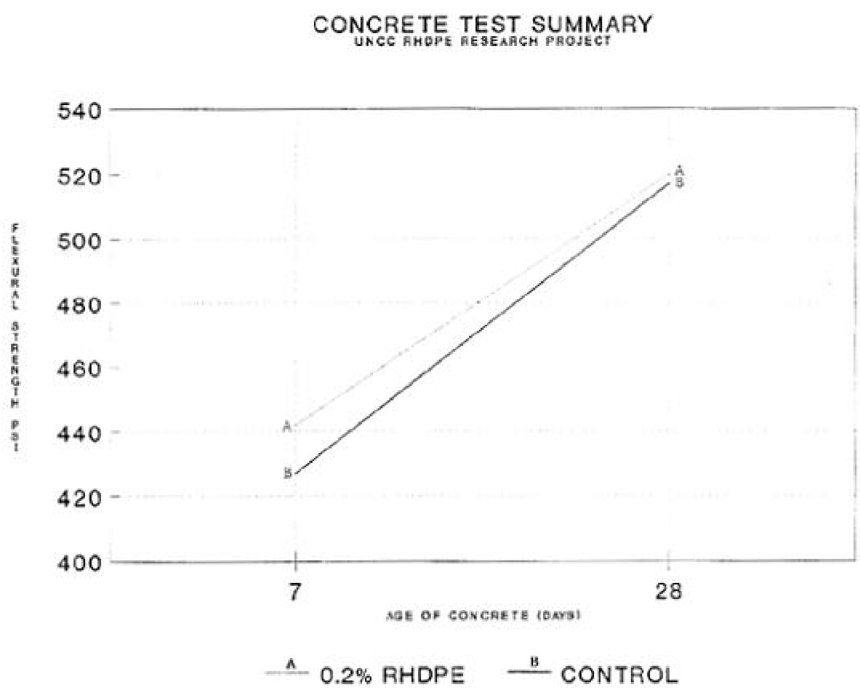

Figure 2. Flexural Strength Comparison