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16. Abstract

As part of its ongoing recycling efforts, the Texas Department of Transportation (TxDOT) is attempting to reduce solid waste generation by 40 percent, and to spend at least 10 percent of its budget for consumable supplies, material, and equipment. Accordingly, the agency is evaluating every opportunity to use or reuse waste materials.

Because of the high volumes of concrete produced every year for TxDOT construction projects, the agency has begun evaluating the feasibility of incorporating recycled materials in roadway construction. Previous research has successfully used fly ash, silica fume, and other inorganic waste materials in concrete. This research project evaluated less likely candidates for concrete constituents by evaluating workability, compression strengths, and flexural strengths of portland cement concretes containing scrap plastic, crumb rubber, and recycled asphalt concrete pavement.

This research effort suggests that concrete for roadway construction can contain significant volumes of organic scrap materials, such as waste plastic, crumb rubber, and recycled asphalt concrete pavement. The applications recommended for proposed special provisions are minimal in their structural requirements. This allows the levels of scrap introduced into the concrete to balance the performance parameters of the existing specifications with as much of the intended scrap as is economically practical.

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INVESTIGATION INTO ORGANIC SCRAP MATERIAL SUBSTITUTIONS IN PORTLAND CEMENT CONCRETE

by

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Research Report Number 1349-1F

Research Project 0-1349
Recycled Materials in Concrete, Except Glass

conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION
in cooperation with the
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Federal Highway Administration

by the

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IMPLEMENTATION STATEMENT

This document presents the literature review and laboratory testing that was conducted by the researchers in order to recommend special provisions for incorporating scrap plastic, crumb rubber, and recycled asphalt concrete pavement into portland cement concrete construction projects. The recommended special provisions resulting from the findings in this study are expected to be evaluated for implementation by the Texas Department of Transportation in low-risk, non-structural applications. When implemented, the findings of this study should significantly reduce the burden on statewide landfills.

This report was prepared in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

DISCLAIMERS

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SUMMARY

As part of its ongoing recycling efforts, the Texas Department of Transportation (TxDOT) is attempting to reduce solid waste generation by 40 percent, and to spend at least 10 percent of its budget for consumable supplies, material, and equipment. Accordingly, the agency is evaluating every opportunity to use or reuse waste materials.

Because of the high volumes of concrete produced every year for TxDOT construction projects, the agency has begun evaluating the feasibility of incorporating recycled materials in roadway construction. Previous research has successfully used fly ash, silica fume, and other inorganic waste materials in concrete. This research project evaluated less likely candidates for concrete constituents by evaluating workability, compression strengths, and flexural strengths of portland cement concretes containing scrap plastic, crumb rubber, and recycled asphalt concrete pavement.

This research effort suggests that concrete for roadway construction can contain significant volumes of organic scrap materials, such as waste plastic, crumb rubber, and recycled asphalt concrete pavement. The applications recommended for proposed special provisions are minimal in their structural requirements. This allows the levels of scrap introduced into the concrete to balance the performance parameters of the existing specifications with as much of the intended scrap as is economically practical.

CHAPTER 1. INTRODUCTION

1.1 SCOPE

This report describes early attempts to incorporate three major waste materials groups into various Texas Department of Transportation (TxDOT) concrete applications. The waste materials evaluated for use in this project included PVC plastic, crumb rubber (CR), and recycled asphalt concrete (RAP). The intent was to determine feasible applications in which TxDOT might be able to use significant quantities of these materials, so as to reduce the burdens on landfills. After an extensive literature search, preliminary mix designs incorporating the waste materials were developed according to specifications for the intended applications. Specimens were made from these mix designs and tested to verify the strength requirements for the intended applications. The results of the study were used to draft recommended special provisions for concrete applications that could incorporate significant quantities of these scrap materials.

1.2 MOTIVATION

In 1993, the Texas Legislature enacted Senate Bill (SB) 1051, which included an amendment to the *Texas Solid Waste Disposal Act* (TSWDA) (Vernon's Texas Codes Annotated, Health and Safety Code, Chapter 361) to direct the Texas Natural Resource Conservation Commission (TNRCC) to prepare a Comprehensive Municipal Solid Waste Management Strategic Plan for Texas. This is the first comprehensive state plan for the management of MSW since the *Solid Waste Management Plan For Texas* was prepared by the Texas Department of Health in 1981.

The use of rubber, plastics, and RAP as additions to portland cement concrete has the potential to greatly reduce the amount of non-degradable materials in Texas landfills. These waste reduction efforts could help to conserve limited natural resources and could minimize air and water pollution. In addition, waste reduction efforts help conserve landfill space. Building new landfills is expensive and often conflicts with residential, agricultural, and other land uses.

1.3 WASTE STREAM ANALYSIS

1.3.1 Crumb Rubber

Car tires present a complex disposal problem. Because tires are designed to be indestructible, they do not break down in landfills and are thus difficult to recycle. Historically, scrap tires have been disposed of in solid waste landfills or stockpiles. Scrap tires take up a large volume of space and tend to float to the top of the landfill. In response to this problem, landfill owners have either quit accepting whole scrap tires or have began charging high disposal fees.

Industry figures show approximately 2 billion scrap tires currently stockpiled in the U.S., with as many as 240 million additional scrap tires being generated each year. Of these, 4.3

percent are exported, 7.7 percent are used for fuel, and 3.3 percent are recycled. This leaves almost 85 percent in stockpiles, illegal dumps, or landfills (Texas General Land Office, TGLO).

1.3.2 Plastics

Plastics make up approximately 8.3 percent of the municipal solid waste stream in Texas. Although less prevalent in landfills and far more difficult to recycle than many other materials, plastics are worthy of being recycled for several reasons (Texas General Land Office, TGLO):

- The durability of plastic, which makes it such a problem when disposed improperly, makes it an ideal material for recycling, since it can be remade almost endlessly.
- Recycling plastics consumes less energy than manufacturing virgin plastic.
- Since plastics are derived from oil and gas, recycling existing material conserves an important natural, non-renewable resource.
- Developing a viable plastics recycling industry in Texas creates new jobs.

At the present time, recycling is in its infancy; only about 2 percent of all plastics are currently being recycled nationwide (Rathje et al., 1992). Although no studies are now available on how much plastic is being recycled in Texas, it is probably much lower than even 2 percent, according to Wellman, Inc., the nation's largest purchaser of scrap plastic.

1.3.3 Recycled Asphalt Pavement

The use of RAP is gaining popularity, especially in the reconstruction of asphalt pavements. However, the use of RAP as an aggregate in concrete pavements has not been fully investigated. Among the reasons for using RAP as a coarse aggregate replacement are the following:

- The use of RAP aggregates would slow the depletion of high quality virgin aggregates for reconstruction and rehabilitation.
- The scarcity of quality local aggregates will necessitate purchasing them from other locations. This will increase transportation and manpower costs that will ultimately increase the cost of the aggregates.
- The increasing lack of landfill space creates a need to recycle as many materials as possible.
- Existing roadways would be convenient quarries, eliminating long-distance transportation costs and reducing delivery time.

1.4 FACTORS AFFECTING THE USE OF THESE MATERIALS IN CONCRETE

Several factors affect the decision to include organic scrap materials in any portland cement concrete application. Typically, only after weighing the pros and cons of each of the pertinent areas will organic scrap materials be considered for use as fillers in concrete. Included among these considerations are such factors as technical makeup and relative volumes of the scrap, local availability, volume of concrete needed for the construction application. and the effects of the scrap upon the durability of the concrete for site specific applications.

While most of these factors are self-explanatory, items such as chemical composition should be researched and discussed in terms of physical and chemical compatibility with portland cement concrete; also to be researched are such durability issues as creep, shrinkage, chemical decomposition over time, strength, and the effects of changing moisture and temperature. Also size, gradation, and hazardous or incompatible contaminants must be evaluated before batch designs using scrap can be developed and accepted.

Environmental and economic impacts are involved on a much higher level than ever before, with community landfills becoming much more selective and with hazardous materials dump sites becoming very expensive. Local authorities are under increased pressure to reconsider long-term environmental-economic relationships at both the local and state levels. Obviously, some types of scrap materials may not be used locally in concrete or in other construction applications, but policies will likely be developed to provide guidance on their use.

1.5 ORGANIZATION OF THIS REPORT

Chapter 1 discusses the reasoning behind this research project, its scope and factors influencing the implementation of the finding in this study. Chapter 2 provides a review of relevant background information and current trends in the technical literature about RAP, tire scrap, scrap plastics, and their use in concrete. Chapter 3 describes the testing and materials used in the experimental program that the researchers employed to verify the application specification properties of the mix designs.

Chapter 4 presents the results from each of the three tests in the experimental program, while Chapter 5 provides special provisions for TxDOT Standard Specifications of several lower strength concrete applications. The final chapter, Chapter 6, presents and discusses conclusions and recommendations for implementation and for further work in this area of incorporating organic scrap materials in concrete. Recommendations for demonstration projects in the field are also presented.

CHAPTER 2. BACKGROUND AND LITERATURE REVIEW

An extensive literature search was conducted using the Engineering Index for periodicals and the Online Computer Library Center for books and reports. While there is a significant amount of information on the use of recycled materials, most of the information is limited to the use of recycled materials in asphalt.

2.1 CRUMB RUBBER

Crumb rubber is derived from the treads of scrap tires that have been shredded to various sizes. This is becoming a popular and effective method for disposing of a non-biodegradable material. The pollution control agency of Minnesota documented 23 sites throughout the state that have used over 61,200 cubic meters of scrap tires for lightweight fill in embankments (MNDOT, 1992). Scrap tires have also been used as subbase drainage layers in highways. This is an effective way of disposing of tire chips, given that the material creates a void system sufficiently large to allow for proper drainage (Hughes, 1993).

Recent research on the use of scrap tires for aggregates (Edlin, 1993) included crumb rubber. In this work, the researchers reported that the increase in rubber content produced a decrease in slump. The method of tire shredding also affected the slump. In addition, the concrete unit weight decreased as the rubber content increased. This is attributed to the lower unit weight of the rubber. Furthermore, the higher the rubber content, the lower the compressive and tensile strengths of the concrete produced. When the fine aggregate was replaced entirely by crumb rubber, losses of up to 60 percent of compressive strength and 50 percent of the tensile strength were reported.

2.2 RAP

Presently, RAP is used primarily in asphalt pavement. There has been very little investigation of RAP as an aggregate replacement in PCC. The Iowa Department of Transportation conducted tests using a blend of RAP and recycled concrete as replacements for aggregates in a PCC mix. The compressive and tensile strengths reported were 50 percent less than that of the concrete having only recycled concrete as aggregates. Several problems were encountered with the RAP when trying to establish mix designs. First, the moisture content was difficult to establish. The heating of the aggregates causes the volatiles to evaporate. This produces a weight loss that is due to the evaporation of both water and volatiles. Second, the fines stick to the asphalt, which can lead to an inaccurate sieve analysis.

RAP has also been used in Austria in both asphalt and concrete pavement. It was reported that crushed concrete particles may contain up to 20 percent RAP particles without impairing the quality of the concrete (Sommer, 1992). It should be noted that this was in a concrete slab that was 280 mm deep.

The most recent work available was done in 1994 (Olorunniwo). RAP was used as a replacement for both coarse and fine aggregates by weight. The following conclusions were reported:

1. The higher the RAP content, the higher the slump. The RAP fine aggregate is coarser than that of the sand it replaced in the mix; thus, less surface area needs to be lubricated.
2. The higher the RAP content, the higher the air content.
3. The higher the RAP content, the lower the compressive strength; this is possibly due to the poor bond at the RAP-paste interface. The reduction in strength was 358 kPa per percent increase in RAP content.
4. The higher the RAP content, the lower the flexural strength. The strength was reduced by 34 kPa per percent increase in RAP.

2.3 SCRAP PLASTIC

Concrete, specifically portland cement concrete (PCC), is a material that has the potential to be used as a tool for the reduction of scrap plastics in landfills. In this study, polyvinyl chloride (PVC) was used as a replacement filler for the fine aggregates of a given mix.

Previous work in this area includes work done at The University of Texas at Austin (Sanders). Conclusions reported from this work include the following:

1. Workability was most affected by small size and high angularity of the plastic particles.
2. A 4-percent replacement caused a reduction in slump from 10 to 77 percent.
3. No segregation of mixes was visible.
4. The strength of the mixes was reduced due to the lack of bonding between the plastic and cement paste and the increased surface area of the plastic particles.

2.4 PROPERTIES OF CONCRETE CONTAINING ORGANIC SCRAP MATERIALS

Concrete strengths were reduced proportionately to the replacement percentage of the scrap materials. The effects on impact resistance, scaling resistance, and chloride penetration were negligible. Freeze-thaw durability and abrasion resistance were slightly enhanced by the addition of scrap materials.

2.5 USE OF OTHER SCRAP MATERIALS IN PCC CONCRETE

A survey of state DOTs using scrap materials completed in 1994 produced the following information: Blast furnace slag produced generally poor to good results, with 13 states reporting. Coal fly ash produced good to excellent results, with 40 states reporting. Silica fume produced good results with two states reporting. Recycled PCC produced good results, with 13 states reporting (Quality Construction Task Force, QCTF).

CHAPTER 3. EXPERIMENTAL PROGRAM

3.1 INTRODUCTION

This project sought to minimize laboratory tests in order to investigate feasibility and environmental concerns before proceeding into the more costly refinements of the batch design for specific applications. Only limited laboratory work was needed, however, since the literature search proved mostly that, once researchers had shown that strength reductions in the concrete were inevitable, the research was discontinued.

3.2 PROPERTIES INVESTIGATED

The properties of interest in this evaluation of concrete containing organic scrap materials included slump, flexural strengths at seven days, and axial compressive strengths at 28 days. These properties were selected for evaluation because minimum or maximum values are specified by TxDOT for various applications of portland cement concrete. The goal of the laboratory work was to verify suggested special provisions in mix designs, which include scrap materials and which meet all specifications (except original materials specifications) for the applications of interest. A secondary objective was to find a feasible and economical mix design that incorporated the most scrap material while using the least amount of cement, and still have the resulting batch meet the specified performance parameters for the given applications.

3.3 VARIABLES

The variables investigated were the effects of different cement contents on the strength of concrete containing two replacement levels of scrap for aggregates, from three types of scrap materials.

3.3.1 Type of Material

The materials used were RAP and crumb rubber supplied by TxDOT, and scrap PVC plastic from a local company involved with finding uses for waste PVC generated by the communications and electrical cable industry. The choice of these materials was based on their relatively large volumes of scrap. The physical properties for each of the three materials are shown in Tables 1.1 through 1.3.

3.3.2 Level of Replacement

While these materials differ dramatically in size, shape, and density, they are all nonetheless organic, lighter than the aggregates they replace, and pose problems in their disposal or reuse. Three scrap materials were used to replace 7.5 and 15 percent of the volume of appropriately sized aggregate constituents in the mix.

Table 3.1 Sieve analysis of crumb rubber

Sieve Size (mm)	Cumulative Percentage Passing
2.39 (#8)	100
1.19 (#16)	86
0.58 (#30)	43
0.30 (#50)	16
0.15 (#100)	4
0.075 (#200)	1
pan	0

Fineness Modulus = 2.52
Specific Gravity = 0.92

Table 3.2 Sieve analysis of PVC

Sieve Size (mm)	Retained Cumulative Weight, %
9.53 (3/8)	0
4.75 (#4)	9
2.39 (#8)	88
1.19 (#16)	99
0.58 (#30)	100
0.30 (#50)	100
0.15 (#100)	100

Fineness Modulus = 4.95
Specific Gravity = 1.35

Table 3.3 Sieve analysis of RAP

Sieve Size (mm)	Percent Passing
19.05	100.0
12.7	97.3
6.35	70.8
4.75 (#4)	57.8
2.39 (#8)	30.8
1.19 (#16)	15.2
0.58 (#30)	1.1
0.30 (#50)	0.1
0.15 (#100)	0.0

Replacement levels are based on the size aggregates the scrap materials are meant to partially replace. For this reason, CR replaced 7.5 percent of the volume of sand in three batches, and 15 percent in three additional batches. PVC replaced 7.5 percent of the coarse aggregate volume in three batches, and 15 percent in three additional batches.

The RAP replacements were more complicated because the process that converts asphalt concrete into RAP produces a much wider range of particle sizes, including both coarse and fine aggregates. The overall size distribution of the RAP dictated that a weighted average be used for calculating replacement values. Using the 7.5 percent mix as an example yields replacement values of 5.18 percent for the coarse aggregate and 11.25 percent for the fine aggregate.

3.3.3 Cement Content of Batch

The cement contents were proportioned equivalent to five, six, and seven sacks per cubic yard of concrete.

3.4 MATERIALS USED IN THE LABORATORY TESTING

3.4.1 Portland Cement

The portland cement used in all batching was Lehigh's Type I/II, which conforms to ASTM 150 standard specifications for both Type I and Type II cements. The cement mill test report for the cement is shown in Table 3.4.

Table 3.4 Cement mill test report

CHEMICAL REQUIREMENTS				
		Specifications		Test Results
		ASTM	AASHTO	
Silica Oxide, Minimum Percent		20.0	20.0	20.8
Alumina Oxide, Maximum Percent		6.0	6.0	4.8
Iron Oxide, Maximum Percent		6.0	6.0	3.9
Magnesia Oxide, Maximum Percent		6.0	6.0	0.9
SO_3 (C_3A less than 8%), Maximum Percent		*	*	3.6
Loss on Ignition, Maximum Percent		3.0	3.0	1.2
Insoluble residue, Maximum Percent		0.75	0.75	0.17
Tricalcium Aluminate, Maximum Percent		8	8	6
Tricalcium Silicate, Maximum Percent			55	55
OPTIONAL CHEMICAL REQUIREMENTS				
Total Alkalies, Max. % (Na20 equiv.)		0.60	0.60	0.5
PHYSICAL REQUIREMENTS				
Specific surface,	Min.(M^2/kg)	160	160	
Wagner	Max.(M^2/kg)		220	197
Specific surface,	Min.(M^2/kg)	280	280	
Blaine	Max.(M^2/kg)		400	327
Gillmore, Initial Set, Minimum (Minutes)		60	60	187
Gillmore, Initial Set, Maximum (Minutes)		600	600	315
Vicat,	Min (Minutes)	45	45	
Initial Set	Max (Minutes)	375	375	124
Air Content, Volume Maximum Percent		12	12	5
Autoclave Expansion, Maximum Percent		0.8	0.8	-0.01
3 Day Minimum Compressive Strength, kPa.		12.4	12.4	24.1
7 Day Minimum Compressive Strength, kPa.		19.3	19.3	31.2

3.4.2 Fine Aggregates

Fine aggregates used in this research project were a commercial all-purpose siliceous concrete sand from the Colorado River in Austin, Texas. The gradation of the sand is shown in Table 3.5, and the properties are presented in Table 3.6.

3.4.3 Coarse Aggregates

Siliceous river gravel from the Colorado River in Austin, Texas, was used for the coarse aggregate. River gravels are more likely to be used statewide in more of the selected applications than crushed limestone, which must be hauled in to most areas at an expense greater than that required for local river gravel. The coarse aggregate properties are shown in Table 3.7.

Table 3.5 Fine aggregate gradation

Sieve Size	Percent Passing	ASTM C 33-90 Limits (%)
4	97.5	95-100
8	81.6	80-100
16	73.4	50-85
30	58.2	25-60
50	18.1	10-30
100	2.0	2-10

Table 3.6 Fine aggregate properties

Property	ASTM Specification	Value
Bulk Specific Gravity (oven dry)	C 128-88	2.63
Absorption Capacity (%)	C 128-88	0.62
Fineness Modulus	C 33-90	2.7

Table 3.7 Coarse aggregate properties

Property	ASTM Specification	Value
Bulk Specific Gravity (oven dry)	C 127-88	2.63
Absorption Capacity (%)	C 127-88	0.37

3.4.4 Water

Batching water used in all mixes was supplied by the City of Austin.

3.4.5 Water Reducer

An ASTM C 494 Type A water reducer admixture was used to maintain workability as the water/cement ratio was lowered.

3.4.6 High Range Water Reducer

An ASTM C 494 Type F high range water reducer (HRWR), commonly known as super plasticizer or "super," was used to improve workability.

3.4.7 Scrap Materials

The scrap materials used in these specimens included crumb rubber, RAP, and PVC scrap. Their properties are described earlier in section 3.3.1.

3.5 MIX DESIGN

The mix designs used in the laboratory evaluations were developed to determine minimum cement contents necessary to allow the concrete containing scrap materials to achieve the strength requirements for given applications. Two levels of the specified scrap material were evaluated for each of three cement contents. Water/cement ratios were kept at 0.35 because that ratio produces high quality concrete, is easily reproducible, and the amount of water reducer and high range water reducer needed to improve workability is minimal. Only enough WR and HRWR was added to the mix to assure that the batch would meet the slump requirements for the intended application. No air entraining agents were used in these mix designs. Batch sizes were 0.06 cubic m (2 cubic ft) in order to accommodate the slump test, three beam specimens, and three cylinders for each mix. The general batch design is shown in Table 3.8. Scrap materials substituted at indicated replacement percentages on a volume basis. Additional details for each mix design are shown in Table 3.9.

Table 3.8 General batch design for laboratory testing

Mix	Cement, Kg.	Coarse Agg., Kg.	Fine Agg., Kg.	Water, Kg	W/C	Water Reducer, mm^3	Super-Plasticizer, mm^3
7 sack	298.5	771.1	580.6	106.6	0.36	775	1945
6 sack	255.8	771.1	580.6	90.7	0.35	668	1665
5 sack	213.2	771.1	580.6	76.2	0.36	556	1389

3.6 MIXING PROCEDURE AND EQUIPMENT

Before batching the materials, the moisture content was adjusted for the aggregates and water. Scrap materials were measured as a percent replacement by volume of the coarse and fine aggregates. Water reducer was added to the batch water before placing in the mixer. The aggregates and scrap materials were placed in the mixer and mixed for approximately 15 seconds.

Table 3.9 Variations in mix designs for laboratory evaluations

Mix designation	Additional water added to meet initial slump, kg.	Initial slump, mm.	HRWR added to initial slump, cc.	Slump after addition of HRWR, mm.	Ambient Temp., °Celsius	Relative humidity, %
C5	3.11	51	82	216	30	62
C6	1.28	32	90	216	31	55
C7	0.37	64	98	229	30	62
CR5-7.5	2.27	64	70	203	31	55
CR5-15	2.07	38	70	203	32	51
CR6-7.5	1.60	32	90	216	32	49
CR6-15	1.49	64	75	203	32	49
CR7-7.5	0.76	70	76	210	30	56
CR7-15	0.33	25	76	222	29	58
PVC5-7.5	1.56	38	92	216	27	58
PVC5-15	3.23	32	95	210	28	58
PVC6-7.5	2.27	25	94	216	32	54
PVC6-15	2.27	25	90	203	32	51
PVC7-7.5	0.69	38	100	203	27	62
PVC7-15	1.31	32	100	210	27	67
RAP5-7.5	1.81	38	72	210	29	58
RAP5-15	1.84	57	72	210	29	58
RAP6-7.5	1.10	51	100	197	29	59
RAP6-15	1.55	57	100	210	29	59
RAP7-7.5	0.23	25	90	216	29	60
RAP7-15	0.23	44	85	216	29	60

The mixer was stopped and the cement and 75 percent of the batch water were added. The drum was restarted, and the remaining water was added while the mixer was turning. The mixer was stopped after 4 minutes, and a slump test was performed according to ASTM C 143-90. Extra water was then added to the mix, and slump readings were taken until a 25- to 50-mm slump was achieved. Superplasticizer was added to the mix, and slump readings were taken until a 203- to 280-mm slump was achieved, mixing 2 minutes between each reading.

The concrete was placed in the cylinder and beam molds using three layers that were each rodded 25 times. After finishing the surfaces, we covered the cylinders with plastic caps and the beams with burlap. All the specimens were then covered with a polyethylene tarp. After 24 hours the specimens were demolded, marked, and placed in a moisture curing room. The beams were tested for flexural strength after 7 days, while the cylinders were tested for compressive strength after 28 days.

CHAPTER 4. TEST RESULTS

4.1 INTRODUCTION

The intent of this research project was to develop specifications for the use of the three waste materials in portland cement concrete. This was to be done primarily through a thorough review of all pertinent literature available on the subject. All laboratory work undertaken to verify the validity of the mix design for which the specifications were to be written was to be approved in advance by TxDOT. For this reason the only testing conducted during the project was slump, 7-day flexural, and 28-day compressive strengths.

4.2 SLUMP TESTS

Each batch was tested according to TxDOT Test Method Tex-415-A (ASTM C 143) to determine its workability. The results of this testing are presented in Table 3.9.

4.3 FLEXURAL STRENGTHS

Third-point flexural tests were conducted on beam specimens measuring 15 cm x 15 cm x 52 cm. Specimens were made according to TxDOT Test Method Tex-448-A (ASTM C 78) and cured in a moist cure cabinet at 22° C and 100 percent relative humidity for seven days before testing. The results of these tests are shown in Figure 4.1.

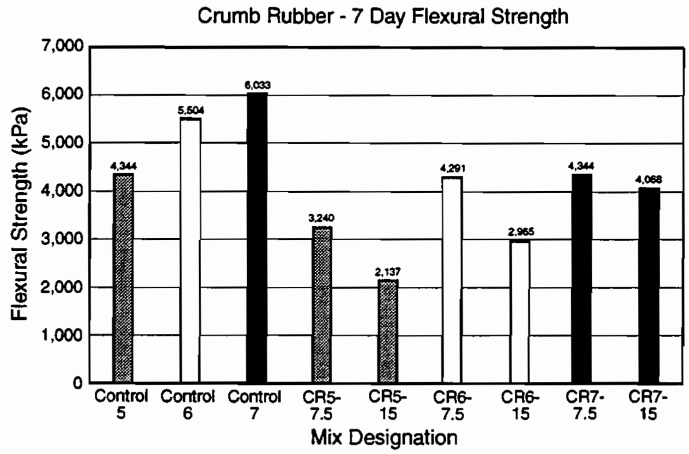
4.4 COMPRESSION STRENGTHS

Compressive tests were conducted on cylindrical specimens measuring 10 cm in diameter x 52 cm long. Specimens were made according to TxDOT Test Method Tex -418-A (ASTM C 39) and cured in a moist cure cabinet at 22° C and 100 percent relative humidity for 28 days before testing. The results of these tests are shown in Figure 4.2.

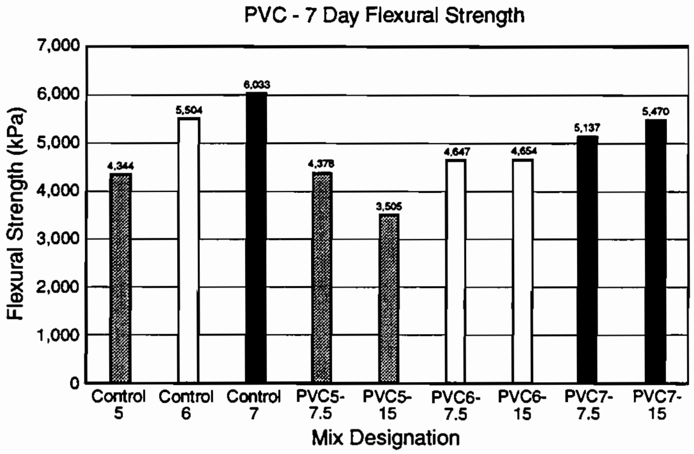
4.5 GENERAL OBSERVATIONS

All of the mixes, regardless of cement content or type of scrap material, had uniform distribution of the replacement materials.

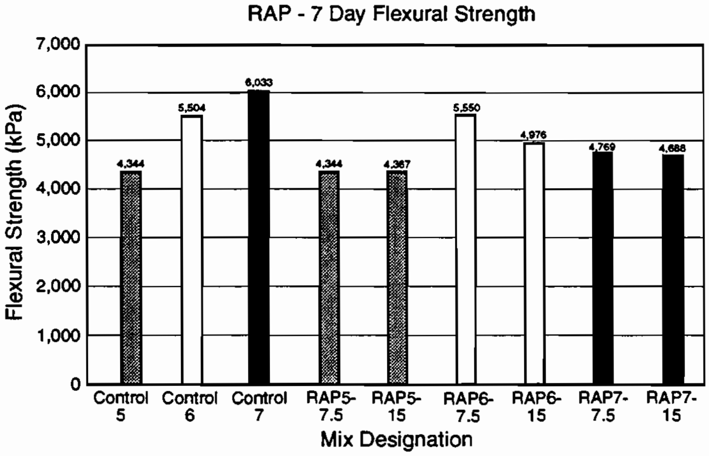
The 5-sack mixes used were gritty and dry owing to the high sand content, but strengths and workability were adequate after the addition of the high range water reducer. The 6- and 7-sack mixes seemed much more cohesive. The workability could still be improved by using less sand and more coarse aggregate. The 5- and 6-sack mixes with crumb rubber at a replacement value of 15 percent by volume did not meet minimum flexural strengths required for many field applications.



a. Crumb Rubber

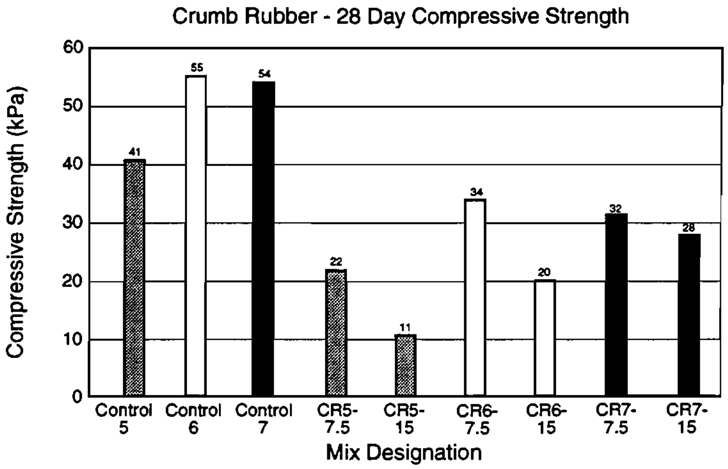


b. PVC

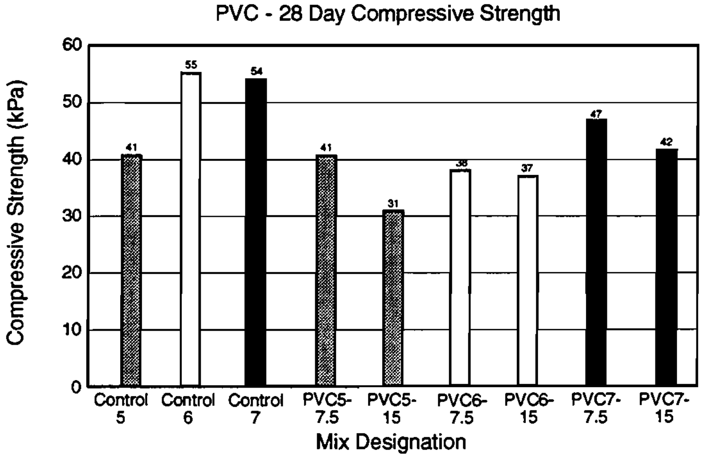


c. RAP

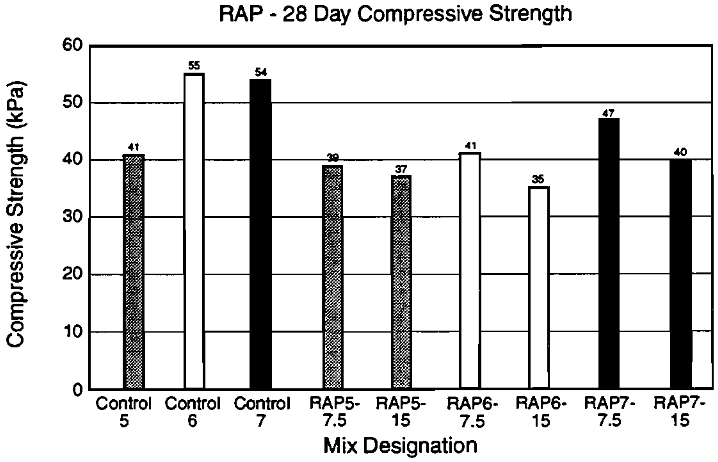
Figure 4.1 Seven-day flexural strength for scrap materials



a. Crumb Rubber



b. PVC



c. RAP

Figure 4.2 Twenty-eight-day compressive strength for scrap materials

CHAPTER 5. SPECIAL PROVISIONS FOR TXDOT CONSTRUCTION SPECIFICATIONS

Although our original intentions were to provide specifications, we decided during the course of the project that special provisions might make the incorporation of these organic waste materials in many common applications easier for the engineers involved in the construction projects. The special provisions recommended are for items that minimize the structural demands of the concrete. This conservative approach makes sense to researchers and design people alike. If any problems or failures should occur, liabilities are minimized and public safety is not jeopardized. The items for which the special provisions are proposed include Riprap, portable and permanent concrete barriers, curbs and gutters, sidewalks, erosion retards and medians, and directional islands. These special provisions are presented in Appendix A.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

6.1.1 Previous Research

An extensive literature search indicated that few reports of efforts to incorporate organic scrap materials in concrete have been published. This is probably due to the fact that concrete mixes containing these materials exhibit lower strengths than the same mixes not having these materials. Furthermore, as one increases the level of organic scrap included in a given mix design, the strength of that concrete is lowered.

6.1.2 Laboratory Testing

Laboratory testing by the Construction Materials Research Group (CMRG) was intended only to verify the viability of the special provisions recommended by researchers. Testing indicated that working limits for the incorporation of these scrap materials may be established at different levels for various TxDOT applications of portland cement concrete. These levels are dependent on the properties of intended specific base mix designs before substituting the scrap for aggregates. The following list contains specific guidelines for each scrap material, as indicated from batch evaluations conducted at the CMRG. Recommended usage rates are given in ranges because each construction project will weigh the performance parameters of the concrete versus the economic and other incentives associated with the decision to use scrap in their concrete application.

1. Crumb Rubber — Replacement of fines only on a volume basis of 7.5 to 15 percent.
2. RAP — Replacement of a portion of both the fines and coarse aggregates depending on the average sieve analysis of the candidate RAP. RAP varies significantly with the design and age of the asphalt concrete and seal coats. Typically RAP replaces the fines and CA on a volume basis ranging from 7.5 to 15 percent.
3. PVC Plastic — There are too many types of plastic scrap to evaluate in the short duration of this project. The researchers decided to pick a scrap material from a relatively high volume source that is readily available in our area. The plastic evaluated was PVC. This scrap was generated from electrical wire casings and is available in many sizes. Because of the size of the scrap evaluated in this study, it was used as a replacement for fine aggregates on a volume basis in the range of 7.5 to 15 percent.

6.2 RECOMMENDED RESEARCH

Because this initial research project was only a feasibility study to develop some working specifications for concrete containing scrap materials, very little work was done to establish the best ways of fully implementing these efforts. We therefore recommend the following:

1. Continue to investigate the use of other scrap materials from other significant sources.
2. Develop a method for characterizing scrap materials in such a way as to ensure uniformity in applications and batch designs. This should be done in anticipation of annual scrap use commitments that may supersede specifications for only CR, RAP, or PVC.
3. Further investigate the environmental effects of using scrap materials classified as hazardous.
4. Investigate methods for improving the bond between the matrix and the scrap materials.
5. Investigate the presence or development of various incentives to increase conscientiousness and willingness to incorporate these scrap materials into applications of non-structural concrete.
6. Conduct one or more field studies in a district to verify workability of the special provisions with the existing specifications, and determine the reactions of the district and contractor to the actual use of these materials for given applications.

REFERENCES

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3. Rathje, W. L., and C. Murphy, *Rubbish! The Archaeology of Garbage*, Harper Collinis, New York, 1992.
4. Minnesota Department of Transportation, "Using Shredded Tires as Lightweight Fill Material for Road Subgrades: A Summary Report," (draft), 1992.
5. Hughes, C. C. (ed.), "Scrap Tire Utilization Technologies," *National Asphalt Pavement Association: Information Service No. 116*, 1993, pp. 1-29.
6. Edlin, N. N., and A. B. Senouci, "Observations on Rubberized Concrete Behavior," *Cement, Concrete and Aggregate CCAGDP*, Volume 15, No. 2, 1993, pp. 74-84.
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8. Olorunniwo, A., *Effects of Recycled Scrap Tires and Asphalt Pavement on the Engineering Properties of Portland Cement Concrete*, Master's thesis, The University of Texas at Austin, 1994.
9. Sanders, D., *The Behavior of Portland Cement Concrete with the Incorporation of Waste Plastic Fillers*, Master's thesis, The University of Texas at Austin, 1993.
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APPENDIX A
SPECIAL PROVISIONS

SPECIAL PROVISION TO ITEM 432: RIPRAP

For this project, **Item 432**, "**Riprap**," of the **Standard Specifications** is hereby amended with respect to the clauses cited below, and no other clauses or requirements of this Item are waived or changed hereby.

Article 432.3. **Materials**. The first paragraph is voided and replaced by the following:
All materials shall conform to the pertinent requirements of the following items:

Item 420, "Concrete Structures"
Item 421, "Portland Cement Concrete"
Item 431, "Pneumatically Placed Concrete"
Item 440, "Reinforcing Steel"

with the following exceptions:

(1) **Portland Cement Concrete, Subarticle (4) Coarse Aggregate** is supplemented by the following:

For this project, either recycled asphalt concrete pavement (RAP) or scrap plastic may be used as a substitute for up to 10% of the coarse aggregate. When RAP or scrap plastic is used, then the term "coarse aggregate" shall also apply to coarse aggregate plus RAP or plus scrap plastic.

OR

(2) **Portland Cement Concrete, Subarticle (5) Fine Aggregate** is supplemented by the following:

For this project, crumb rubber (CR) may be used as a substitute for up to 10% of the fine aggregate. When CR is used, then the term "fine aggregate" shall also apply to fine aggregate plus CR.

SPECIAL PROVISION TO ITEM 512: PORTABLE CONCRETE TRAFFIC BARRIER

For this project, **Item 512, "Portable Concrete Traffic Barrier,"** of the **Standard Specifications** is hereby amended with respect to the clauses cited below, and no other clauses or requirements of this Item are waived or changed hereby.

Article 512.2. <u>Materials</u>. The first paragraph is voided and replaced by the following:
All materials shall conform to the pertinent requirements of the following items:

Item 421, "Portland Cement Concrete"
Item 437, "Concrete Admixtures"
Item 440, "Reinforcing Steel"
Item 442 "Metal for Structures"
Item 526 "Membrane Curing"

with the following exceptions:

(1) Portland Cement Concrete, Subarticle (4) Coarse Aggregate is supplemented by the following:

For this project, recycled asphalt concrete pavement (RAP) or scrap plastic may be used as a substitute for up to 10% of the coarse aggregate. When RAP or scrap plastic is used, then the term "coarse aggregate" shall also apply to coarse aggregate plus RAP or plus scrap plastic.

(2) Portland Cement Concrete, Subarticle (5) Fine Aggregate is supplemented by the following:

For this project, crumb rubber (CR) may be used as a substitute for up to 10% of the fine aggregate. When CR is used, then the term "fine aggregate" shall also apply to fine aggregate plus CR.

SPECIAL PROVISION TO ITEM 514: PERMANENT CONCRETE TRAFFIC BARRIER

For this project, **Item 514**, "**Permanent Concrete Traffic Barrier**," of the **Standard Specifications** is hereby amended with respect to the clauses cited below, and no other clauses or requirements of this Item are waived or changed hereby.

Article 514.2. Materials. The first paragraph is voided and replaced by the following:
All materials shall conform to the pertinent requirements of the following items:

Item 421, "Portland Cement Concrete"
Item 437, "Concrete Admixtures"
Item 440, "Reinforcing Steel"
Item 442 "Metal for Structures"
Item 526 "Membrane Curing"

with the following exceptions:

(1) **Portland Cement Concrete, Subarticle (4) Coarse Aggregate** is supplemented by the following:

For this project, recycled asphalt concrete pavement (RAP) or scrap plastic may be used as a substitute for up to 10% of the coarse aggregate. When RAP or scrap plastic is used, then the term "coarse aggregate" shall also apply to coarse aggregate plus RAP or plus scrap plastic.

(2) **Portland Cement Concrete, Subarticle (5) Fine Aggregate** is supplemented by the following:

For this project, crumb rubber (CR) may be used as a substitute for up to 10% of the fine aggregate. When CR is used, then the term "fine aggregate" shall also apply to fine aggregate plus CR.

SPECIAL PROVISION TO ITEM 529: CONCRETE CURB, GUTTER AND COMBINED CURB AND GUTTER

For this project, **Item 529**, "**Concrete Curb, Gutter and Combined Curb and Gutter**," of the **Standard Specifications** is hereby amended with respect to the clauses cited below, and no other clauses or requirements of this Item are waived or changed hereby.

Article 529.2. Materials. The first paragraph is voided and replaced by the following:
All materials shall conform to the pertinent requirements of the following items:

Item 360, "Concrete Pavement"
Item 420, "Concrete Structures"
Item 421, "Portland Cement Concrete"
Item 437, "Concrete Admixtures"
Item 440, "Reinforcing Steel"
Item 526 "Membrane Curing"

with the following exceptions:

(1) Portland Cement Concrete, Subarticle (4) Coarse Aggregate is supplemented by the following:

For this project, recycled asphalt concrete pavement (RAP) or scrap plastic may be used as a substitute for up to 10% of the coarse aggregate. When RAP or scrap plastic is used, then the term "coarse aggregate" shall also apply to coarse aggregate plus RAP or plus scrap plastic.

(2) Portland Cement Concrete, Subarticle (5) Fine Aggregate is supplemented by the following:

For this project, crumb rubber (CR) may be used as a substitute for up to 10% of the fine aggregate. When CR is used, then the term "fine aggregate" shall also apply to fine aggregate plus CR.

SPECIAL PROVISION TO ITEM 531: SIDEWALKS

For this project, **Item 531**, "**Sidewalks**," of the **Standard Specifications** is hereby amended with respect to the clauses cited below, and no other clauses or requirements of this Item are waived or changed hereby.

Article 531.2. __Materials__. The first paragraph is voided and replaced by the following:
All materials shall conform to the pertinent requirements of the following items:

Item 360, "Concrete Pavement"
Item 420, "Concrete Structures"
Item 421, "Portland Cement Concrete"
Item 437, "Concrete Admixtures"
Item 440, "Reinforcing Steel"
Item 526 "Membrane Curing"

with the following exceptions:

(1) **Portland Cement Concrete, Subarticle (4) Coarse Aggregate** is supplemented by the following:

For this project, recycled asphalt concrete pavement (RAP) or scrap plastic may be used as a substitute for up to 10% of the coarse aggregate. When RAP or scrap plastic is used, then the term "coarse aggregate" shall also apply to coarse aggregate plus RAP or plus scrap plastic.

(2) **Portland Cement Concrete, Subarticle (5) Fine Aggregate** is supplemented by the following:

For this project, crumb rubber (CR) may be used as a substitute for up to 10% of the fine aggregate. When CR is used, then the term "fine aggregate" shall also apply to fine aggregate plus CR.

SPECIAL PROVISION TO ITEM 532: CONCRETE EROSION RETARDS

For this project, **Item 532**, "**Concrete Erosion Retards**," of the **Standard Specifications** is hereby amended with respect to the clauses cited below, and no other clauses or requirements of this Item are waived or changed hereby.

Article 532.2. Materials. The first paragraph is voided and replaced by the following:

Unless otherwise shown on the plans, all concrete materials shall conform to the requirements of Item 421, "Portland Cement Concrete." When permitted on the plans,

(1) the base coarse materials may be used as aggregate, and/or
(2) recycled asphalt pavement (RAP) may be used as a direct replacement of up to 10% of the weight of the coarse aggregate, and/or
(3) properly graded scrap plastic may be used as a direct replacement of up to 10% of the weight of the coarse aggregate, and/or
(4) crumb rubber (CR) may be used as a substitute for up to 10% of the fine aggregate.

These substitutions may be made subject to compliance with the gradation requirements and approval of the engineer. Proportions of these aggregate substitutions shall be as shown on the plans.

SPECIAL PROVISION TO ITEM 536: CONCRETE MEDIANS AND DIRECTIONAL ISLANDS

For this project, **Item 536**, **"Concrete Medians and Directional Islands,"** of the **Standard Specifications** is hereby amended with respect to the clauses cited below, and no other clauses or requirements of this Item are waived or changed hereby.

Article 536.2. **Materials**. The first paragraph is voided and replaced by the following:
All materials shall conform to the pertinent requirements of the following items:

Item 420, "Concrete Structures"
Item 421, "Portland Cement Concrete"
Item 433, "Joint Sealers and Fillers"
Item 440, "Reinforcing Steel"
Item 526 "Membrane Curing"
Item 529 "Concrete Curb, Gutter and Combined Curb and Gutter

with the following exceptions:

(1) **Portland Cement Concrete, Subarticle** (4) **Coarse Aggregate** is supplemented by the following:

For this project, recycled asphalt concrete pavement (RAP) may be used as a substitute for up to 10% of the coarse aggregate. When RAP is used, then the term "coarse aggregate" shall also apply to coarse aggregate plus RAP.

(2) **Portland Cement Concrete, Subarticle** (5) **Fine Aggregate** is supplemented by the following:

For this project, crumb rubber (CR) may be used as a substitute for as much as 10% of the fine aggregate. When CR is used, then the term "fine aggregate" shall also apply to fine aggregate plus CR.