RESEARCH PROJECT NO. 2005-053
EVALUATION OF TUF-STRAND FIBER CONCRETE ADDITIVE

FINAL REPORT
DECEMBER 2009

Prepared by:
Tyson R. Clouser, P.E.

PENNSYLVANIA DEPARTMENT OF TRANSPORTATION
BUREAU OF CONSTRUCTION AND MATERIALS
ENGINEERING TECHNOLOGY AND INFORMATION DIVISION

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16. Abstract

The purpose of this research project was to evaluate the constructability, material and design performance of a Tuf-Strand polypropylene fiber reinforced Class AA concrete used in a concrete patch. The Tuf-Strand fibers were used as a concrete additive replacing the welded wire fabric reinforcement used in concrete patches. The Tuf-Strand fibers did not perform satisfactorily and the Department will not recommend the use of this product in future concrete patch applications.

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Evaluation of Tuf-Strand Fiber Concrete Additive

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Conducted By:
The Pennsylvania Department of Transportation
Bureau of Construction and Materials
Engineering Technology and Information Division
Evaluations and Research Section

The Pennsylvania Department of Transportation and the Federal Highway Administration sponsored this work. The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or the policies of the Pennsylvania Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification or regulation. The Pennsylvania Department of Transportation and the Federal Highway Administration does not endorse products, equipment, processes, or manufacturers. Trademarks or manufacturers names appear herein only because they are considered essential to the object of this report.

Executive Summary

The price of steel has been steadily increasing in recent years. This report evaluates the performance of a concrete additive named Tuf-Strand. This additive took the place of welded wire fabric reinforcing steel used in two 10-inch depth concrete road patches. Tuf-Strand is a 2-inch length polypropylene fiber reinforcement that is manufactured by the Polysteel Atlantic Limited and distributed by the Euclid Chemical Company (PE 05-041).

The fibers were introduced at the central mix plant as the concrete was discharged from the mixing bowl into two transit mixer trucks prior to being delivered to the project for placement. The 2-inch length fibers were dispersed throughout the Class AA Concrete (3,750 psi, 28 day compressive strength) at a rate of 5 lbs/ C.Y. as recommended by the manufacturer.

This research project has allowed both short-term and long-term (June 2005 – August 2007) visual monitoring of the performance of the test section of patches containing the fiber additive. The Department was hopeful that the addition of the polypropylene fibers would initially prevent or retard shrinkage cracking, and that the long-term performance of the fibers would prevent cracking due to loading and/or freeze-thaw.

Patches containing welded wire fabric steel reinforcement were compared to the two adjacent concrete patches using Tuf-strand fiber reinforcement. The two concrete patches were evaluated for 2 years and were visually inspected with photographic documentation of any crack locations. The results have shown that the concrete with Tuf-Strand added to it performed satisfactorily the first year. However, during the 2nd (and final) field evaluation (August 2007), the concrete with Tuf-Strand added to it contained noticeably more cracking than the adjacent patches with steel welded wire reinforcement.

The product did not perform as well as the control section. Therefore, it is not recommended that Tuf-Strand be used lieu of welded wire fabric steel reinforcement in future concrete patching.

Metric Conversion Factors*

To Convert From:	To:	Multiply By:
Length		
foot (ft)	meter (m)	0.3048
inch (in)	millimeter (mm)	25.4
yard (yd)	meter (m)	0.9144
mile (statute)	kilometer (km)	1.609
Area		
square foot (ft^2)	square meter (m^2)	0.0929
square inch (in^2)	square centimeter (cm^2)	6.451
square yard (yd^2)	square meter (m^2)	0.8361
Volume		
cubic foot (ft^3)	cubic meter (m^3)	0.02832
cubic yard (yd^3)	cubic meter (m^3)	0.00315
gallon (U.S. liquid)	cubic meter (m^3)	0.004546
ounce (U.S. liquid)	cubic centimeter (cm^3)	29.57
Mass		
ounce-mass (avdp)	gram (g)	28.35
pound-mass (avdp)	kilogram (kg)	0.4536
ton (metric)	kilogram (kg)	1000
ton (short, 2000 lbm)	kilogram (kg)	907.2
Density		
pound-mass/cubic foot	kilogram/cubic meter (kg/m^3)	16.02
mass/cubic yard	kilogram/cubic meter (kg/m^3)	0.5933
pound-mass/gallon(U.S.)**	kilogram/cubic meter (kg/m^3)	119.8
pound-mass/gallon(Can.)*	kilogram/cubic meter (kg/m^3)	99.78
Temperature		
deg Celsius (°C)	Kelvin (°K)	$t^{\circ K} = (t^{\circ C} + 273.15)$
deg Fahrenheit (°F)	Kelvin (°K)	$t^{\circ K} = (t^{\circ F} + 459.67) / 1.8$
deg Fahrenheit (°F)	deg Celsius (°C)	$t^{\circ C} = (t^{\circ F} - 32) / 1.8$

*The reference source for information on SI units and more exact conversion factors is "Metric Practice Guide" ASTM E380.
** One U.S. gallon equals 0.8327 Canadian gallons

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Introduction

Typically large concrete pavement patches (as shown in photographs 1 and 2) use steel welded wire fabric for reinforcement as indicated on the typical section illustrated in Publication 72M PennDOT Standard for Roadway Construction on RC-26 sheet 1 of 5. Proper location and effectiveness of the welded wire fabric is subject to attentiveness of the constructors as illustrated below. With the cost of steel steadily increasing over the past few years, this research project sought to evaluate whether or not Tuf-Strand polypropylene fiber reinforcement, manufactured by the Polysteel Atlantic Limited and distributed by the Euclid Chemical Company (PE 05-041), could be used as a concrete additive to replace the steel welded wire fabric reinforcement.

Photographs 1 and 2 illustrate a typically prepared concrete pavement patch area with welded wire fabric reinforcement steel before and during concrete placement.

This research project allowed both short-term and long-term visual monitoring of the performance of the test patches containing the fiber additive. Polypropylene fiber reinforcement has been used in other applications, but not in a concrete patch on an interstate highway. The addition of the polypropylene fibers initially (short-term) may prevent or retard shrinkage cracking. Patched cement concrete roadways on many projects are overlaid with a Superpave bituminous overlay for ride quality shortly after the patches are placed and cured. However, on this project, the road surface of the entire project was diamond ground to achieve ride quality, thus allowing the concrete fibers in the patch to remain exposed. Over the long term, the fibers may prevent cracking due to loading and/or freeze-thaw. The 2-inch length polypropylene fibers (see photographs 3 and 4 on page 2) were dispersed throughout the Class AA Concrete (3,750 psi, 28 day compressive strength) at a rate of 5 lbs/ C.Y. as recommended by the manufacturer.

The polypropylene fibers were introduced at the central mix plant as the concrete was discharged from the mixing bowl into two transit mixer trucks, owned by New Enterprise Stone and Lime, just prior to being delivered to the I-99 project for placement (see photographs 5 and 6 on page 5).

Two patches containing Tuf-strand fiber reinforcement were compared to adjacent concrete patches using welded wire fabric reinforcement. The two experimental concrete patches were evaluated for 2 years or 4 freeze/thaw seasons and were inspected every 6 months with photographic documentation of any crack locations.

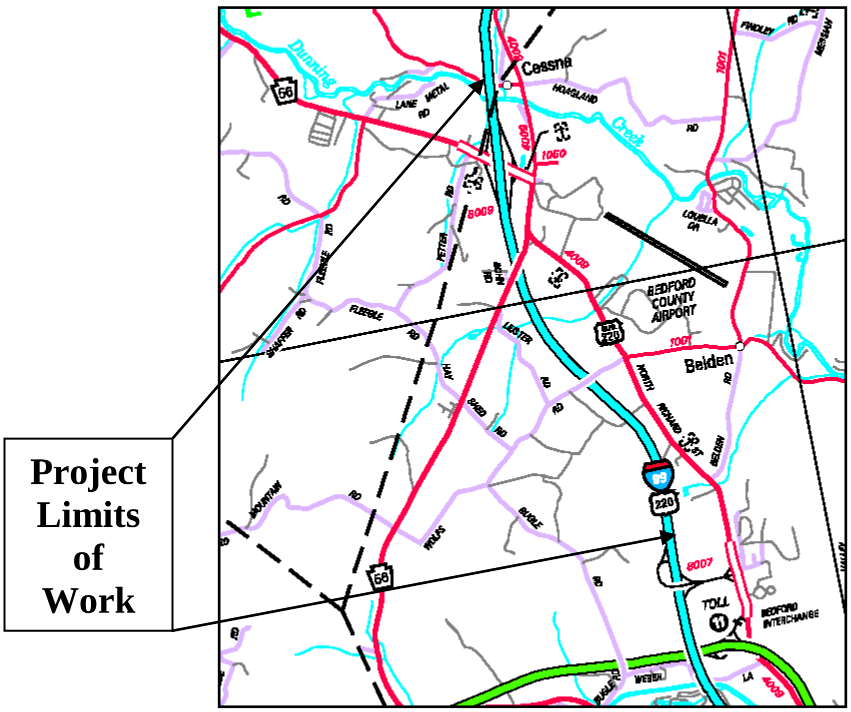
Photograph 3, These are the Tuf-Strand Fibers before they are added to the batched concrete mixture.

Photograph 4, These are the Tuf-Strand Fibers after they were added to a batched concrete mixture. A small sample of the fresh batched Class AA Concrete with the Tuf-Strand fibers was washed and these fibers were collected from the remaining aggregate. Note that the Tuf-Strand fibers swell and become frayed to enhance blending into the cement paste of the concrete.

Project Information

The prime contractor on this pavement rehabilitation project was New Enterprise Stone and Lime, New Enterprise, Pennsylvania. Tuf-Strand was added to approximately 20 C.Y. of Class AA concrete at a central mix plant. The concrete produced for this project was used for 10-inch depth concrete patches on I-99, Bedford County, Engineering District 9-0 (see attached Project Location Map below) during June of the 2005 construction season.

Figure 1, Research Project Location Map



SR 0099-SRI, Bedford County, Engineering District 9-0
The project is located from the PA Turnpike interchange to north of the Cessna Interchange on I-99 near mile marker 1
Federal Project FPN X091-147-H100
Contract Number 70789
The ADT is 7,180 and 9% trucks for the southbound lanes of I-99 in the segment where the two concrete pavement patches are located.

Construction

Placement

The contractor did not modify the approved concrete mix design for the addition of the fibers on this project (see Appendix B). There were no problems adding the fibers to the concrete mix at the central mix plant (see photographs 5 through 8). The experimental concrete patches were located adjacent to mile marker 1 on the south bound travel lane (see photographs 10). The patches were inscribed on a corner of the patch with the date of placement to locate the patches over the period of study (see photograph 11). The day of placement was cloudy with light wind. The high temperature was in the mid-60's, with 50-60% relative humidity.

The slumps of the concrete with the Tuf-Strand fiber additive were consistent at 2 ½" on the project and 3 ¼" at the plant. The air content of the plastic concrete tested in the field was 5.4%. All concrete for the additional control patches met minimum strength and field acceptance test criteria for temperature, plastic air and slump. The modified concrete mix with the polypropylene fibers was placed in two large concrete patches with no reinforcing steel (see photographs 12 and 13). The concrete was placed and consolidated with a vibrator then leveled with a power roller screed (see photographs 14 and 15). A stiffer concrete mixture was anticipated due to the addition of the Tuf-Strand fibers (see photograph 16). The concrete patches finished satisfactorily, but the concrete mix could have been a little creamier to provide a better surface finish (see photographs 18 and 19). The patches were cured with white curing compound (see photographs 20 and 21). The completed patches are seen in photographs 22 and 23. Identical placement, finishing, and curing methods were employed for both the control patches and the experimental patches.

There is no cost data available for the Class AA Concrete with the Tuf-Strand fiber additive because the polypropylene fibers were donated by Euclid Chemical Company for this study.

Testing

All Class AA concrete samples collected on this project were taken in accordance with ASTM C 31/C 31M-03a Standard Practice for Making and Curing Concrete Test Specimens in the Field (see photograph 9 on page 6). All laboratory testing was conducted by the Materials Testing Division (MTD) of the Bureau of Construction and Materials. Concrete compression test results were performed in accordance with ASTM C 1212. Concrete tensile and flexural strength testing were performed at 28 days:

- In accordance with ASTM C 496-96 Splitting Tensile Strength of Cylindrical Concrete Specimens (cylinders).
- In accordance with ASTM C 293-02 Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading).
- In accordance with ASTM C 78-02 Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

All concrete test results are presented in Tables 1 through 7 and photographic results of the destructive testing of the samples are located in Appendix A on page 14. These test results can be directly compared between samples that contain the fiber additive and samples of plain cement concrete. A bar chart illustrating a direct comparison of the concrete test results is shown in Figure 2 on page 9.

The approved concrete mix design should yield a compressive strength of 4,950 psi. However, the Tuf-Strand mix only achieved an average of 3,750 psi. A copy of the concrete mix design is located in Appendix B on page 25. The reason for this discrepancy in achieving the design strength was investigated by the District Materials Unit; however a cause was not determined.

Photographs 5 and 6, Tuf-Strand Fibers are introduced into the central mix plant and discharged into two concrete transit mixer trucks. The Tuf-Strand Fiber vendor wanted to just drop the plastic sack of fibers into the chute but was strongly advised against this practice by the Department plant inspection staff.

Photographs 7 and 8, The texture and consistency of the Class AA Concrete with the Tuf-Strand Fiber additive blended into the mixture.

Photographs 9 and 10, Samples of the Class AA Concrete were collected in the field. Concrete cylinders were cast for both compressive and tensile strength tests. Beams were also cast for flexural testing at 28 days. Mile Marker and Informational Signs were used as land marks to locate the two concrete patches for evaluation after the construction project is completed.

Photograph 11, The patch was inscribed with the date on the corner of the patch to help locate the patch.

Photographs 12 and 13, The prepared patch area with no welded wire fabric reinforcement steel.

Photographs 14 and 15, The concrete being placed and vibrated to consolidate the plastic concrete in the patch. A power roller screed was used to level the concrete in the patch area.

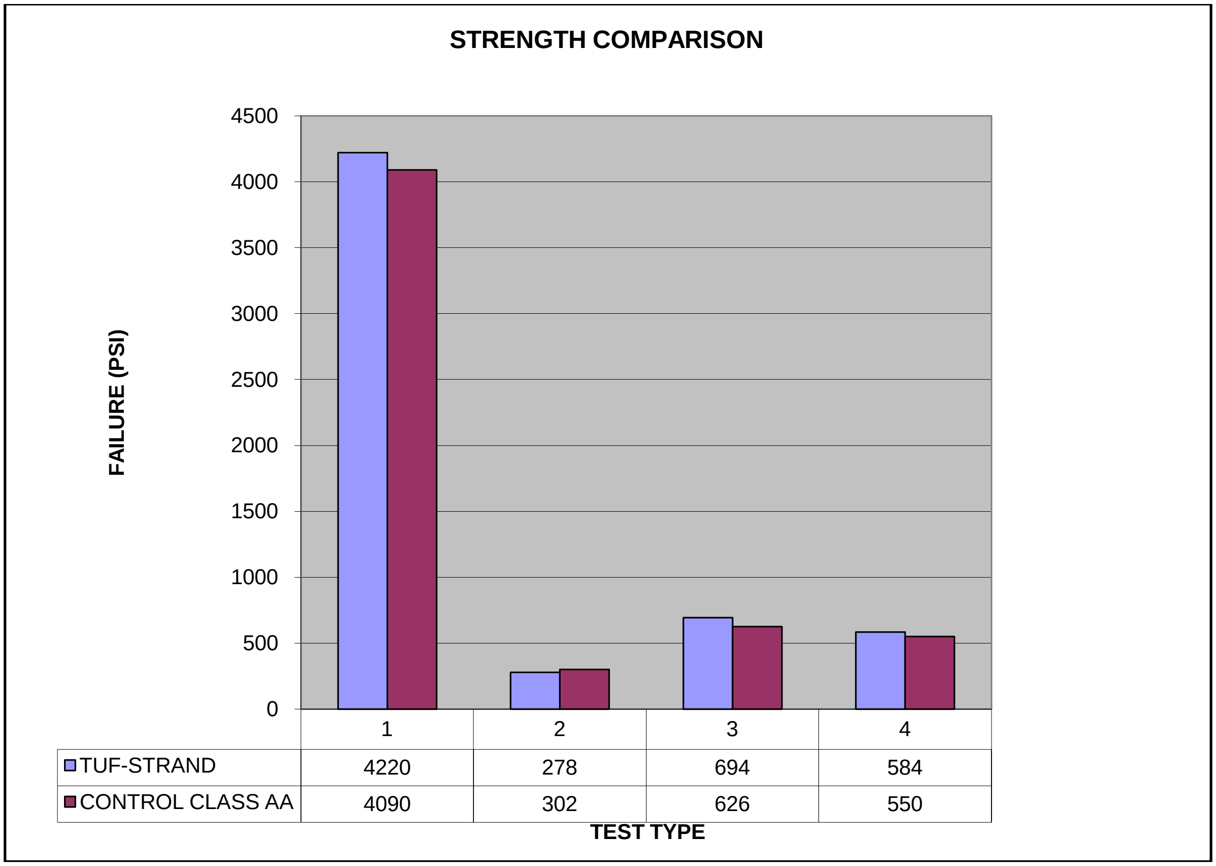
Photographs 16 and 17, The Tuf-Strand fibers in the freshly placed concrete just prior to being consolidated with a concrete vibrator.

Photographs 18 and 19, The concrete patch being finished with a bull float shortly after the power roller screed was removed.

Photographs 20 and 21, The application of the white curing compound after finishing.

Photographs 22 and 23, The completed concrete patch with the Tuf-Strand fibers.

Figure 2, Class AA Concrete Comparison Test Results



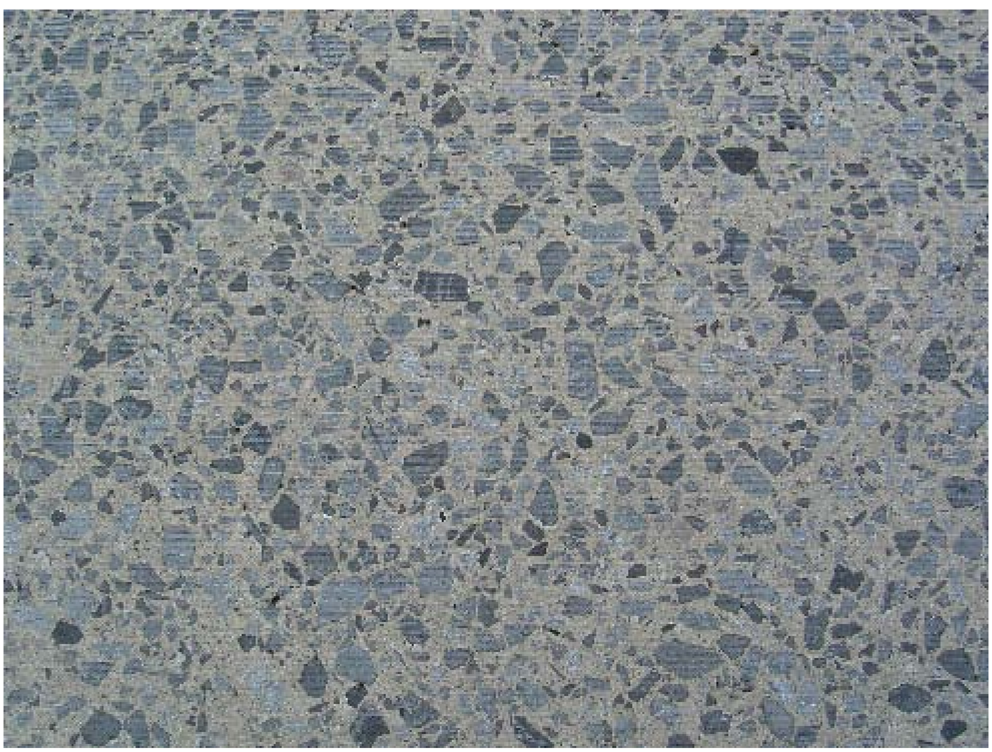
TEST 1	ASTM C 1212 Concrete Compression Strength of Cylindrical Concrete Specimens (cylinders)
TEST 2	ASTM C 496-96 Splitting Tensile Strength of Cylindrical Concrete Specimens (cylinders)
TEST 3	ASTM C 293 Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)
TEST 4	ASTM C 78-0 Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

Performance
The first visual field evaluation of this product was completed on June 21, 2006 by Garth Bridenbaugh, P.E., of the Bureau of Construction and Materials. The experimental slabs using Tuf-Strand were performing the same as the control sections using welded wire fabric reinforcement.

The second visual field evaluation was conducted on August 22, 2007 by Gary Hartman, P.E. and Garth Bridenbaugh, P.E., both of the Bureau of Construction and Materials. This evaluation yielded significantly different results from the previous year. The southern experimental patch had an approximately ¼" crack the entire width of the slab. It was located near the midpoint and appeared to be top-down cracking. The northern experimental patch had smaller cracking than the southern experimental slab, but the cracking was in the same location on the slab. Both of these experimental sections showed failure in tension from the continued and heavy loading the slabs received. One of the most important duties of reinforcement in concrete is protection from tensile failure. Nearby patches of similar age and mixture that were constructed using conventional steel reinforcing had no visible cracks during this evaluation.

Photograph 24 - Northern Experimental Slab

Photograph 25 - Southern Experimental Slab



Photograph 26 - Control Slab

Conclusion

Although the concept of using fibers for reinforcement in concrete patches sounds promising, the data collected during this project shows that the fibers do not provide the same degree of reinforcement properties than that of conventional welded wire mesh. The Department does not recommend future use of this product in applications where highway traffic loads will be present.

Acknowledgements

Thanks to Michael A. Mahoney, Structural Fiber Technology Manager from The Euclid Chemical Company for donating the Tuf-Strand fibers for evaluation on this project. Special thanks to Bruce C. Ebersole from the Physical Testing Laboratory of the Materials Testing Division for scheduling and conducting the tests in a timely manner and also to Kurtis Wagner from the Engineering Technology and Information Division, Bureau of Construction and Materials for creating several graphics and providing pictures throughout the report. Finally, thanks to John Hughes, P.E. and Garth Bridenbaugh, P.E., for providing construction information in their report cited below.

Bibliography

Hughes, John J. and Bridenbaugh, Garth D. “Evaluation of Tuf-Strand Fiber Concrete Additive, Construction Report.” Harrisburg: Pennsylvania Department of Transportation, August 2005.

APPENDIX A
LABORATORY TEST RESULTS OF THE CLASS AA CONCRETE WITH AND WITHOUT THE TUF-STRAND FIBER ADDITIVE

TUF-STRAND CLASS AA CONCRETE

The test results from three concrete test cylinders submitted to MTD for testing. These were **6"X12" cylinders with Tuf-Strand Fibers**. The cylinders were tested for 28 day compressive strength.

Table 1, ASTM C 1212 Concrete Compression Strength of Cylindrical Concrete Specimens (cylinders).

Increment	Length	Diameter	Concrete Corrected Compressive Strength
#	inches	inches	PSI
1	12.0	6.0	4410.0
2	12.0	5.99	4060.0
3	12.0	5.99	4180.0
Average Compressive Strength			**4220.0**

Table 2, ASTM C 496-96 Splitting Tensile Strength of Cylindrical Concrete Specimens (cylinders).

Increment	Length	Diameter 1	Diameter 2	Load	Splitting Tensile Strength
#	inches	inches	inches	Lbs	PSI
4	12.0	5.99	5.97	31700	281
5	12.0	5.98	5.97	31900	283
6	12.0	6.00	5.987	49300	437
7	12.0	5.99	5.99	21400	190
8	12.0	5.98	5.99	25800	229
9	12.0	5.97	5.97	27900	248
Average Splitting Tensile Strength					**278**

Table 3, ASTM C 293 Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading).

Center Point Loading			
Width	Depth	Load	Modulus of Rupture
Inches	Inches	Lbs	PSI
6.00	6.10	5790	700
6.00	6.06	6310	773
6.00	6.07	4990	609
Average Center Point Modulus of Rupture			**694**

TUF-STRAND CLASS AA CONCRETE

Table 4, ASTM C 78-0 Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading).

Third Point Loading			
Width	**Depth**	**Load**	**Modulus of Rupture**
Inches	**Inches**	**Lbs**	**PSI**
6.02	6.13	7170	571
6.03	6.14	7860	622
6.02	6.14	6030	478
6.02	6.10	8140	654
6.00	6.10	7150	576
6.06	6.07	7460	601
Average Third Point Modulus of Rupture			**584**

TUF-STRAND CLASS AA CONCRETE

ASTM C 1212 Concrete Compression Strength of Cylindrical Concrete Specimens (cylinders).

Photographs 27 and 28, The concrete cylinders fractured during testing but still maintained their shape because of the Tuf-Strand fiber additive.

TUF-STRAND CLASS AA CONCRETE

ASTM C 496-96 Splitting Tensile Strength of Cylindrical Concrete Specimens (cylinders).

Photographs 29 and 30, The Tuf-Strand fibers in the concrete kept the cylinders in one piece after the destructive testing.

Photographs 31 and 32, The Tuf-Strand fibers in the concrete kept the cylinders in one piece after the destructive testing. The control concrete cylinder split in half.

TUF-STRAND CLASS AA CONCRETE

ASTM C 78-0 Flexural Strength of Concrete
(Using Simple Beam with Third-Point Loading).
ASTM C 293 Flexural Strength of Concrete
(Using Simple Beam with Center-Point Loading).

Photographs 33 and 34, The Tuf-Strand fibers in the concrete kept the beams in one piece after testing. The control beam split into two pieces.

CONTROL CLASS AA CONCRETE

The test results from three control concrete test cylinders submitted to MTD for testing. These were **6"X 12" control cylinders with no Tuf-Strand Fibers**.

One cylinder was tested in accordance with **ASTM C 1212 Concrete Compression Strength of Cylindrical Concrete Specimens (cylinders)** for 28 day compressive strength which yielded **4090.0 psi**.

Table 5, ASTM C 496-96 Splitting Tensile Strength of Cylindrical Concrete Specimens (cylinders).

Increment	Length	Diameter 1	Diameter 2	Load	Splitting Tensile Strength
#	**inches**	**inches**	**inches**	**Lbs**	**PSI**
2	12.0	5.99	5.98	29200	259
3	12.0	6.00	5.99	39000	345
Average Splitting Tensile Strength					**302**

The test results from three 28 day strength, control concrete, 6" X 6"X 20" test beams submitted to MTD for testing. One beam was tested in accordance ASTM C 293 Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading). Two beams were tested in accordance with ASTM C 78-0 Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading). All samples were tested with a span length of 18".

Table 6, ASTM C 293 Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading).

Center Point Loading			
Width	**Depth**	**Load**	**Modulus of Rupture**
Inches	**Inches**	**Lbs**	**PSI**
5.94	5.99	4940	**626**

Table 7, ASTM C 78-0 Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading).

Third Point Loading			
Width	**Depth**	**Load**	**Modulus of Rupture**
Inches	**Inches**	**Lbs**	**PSI**
5.98	6.01	6260	522
6.00	6.02	6970	577
Average Third Point Modulus of Rupture			**550**

CONTROL CLASS AA CONCRETE

ASTM C 496-96 Splitting Tensile Strength of Cylindrical Concrete Specimens (cylinders).

Photograph 35, This control cylinder for Class AA split into two pieces.

CONTROL CLASS AA CONCRETE
ASTM C 496-96 Splitting Tensile Strength of Cylindrical Concrete Specimens (cylinders).

Photographs 36 and 37, The fractured control cylinder for Class AA split into two pieces.
CONTROL CLASS AA CONCRETE

ASTM C 496-96 Splitting Tensile Strength of Cylindrical Concrete Specimens (cylinders).

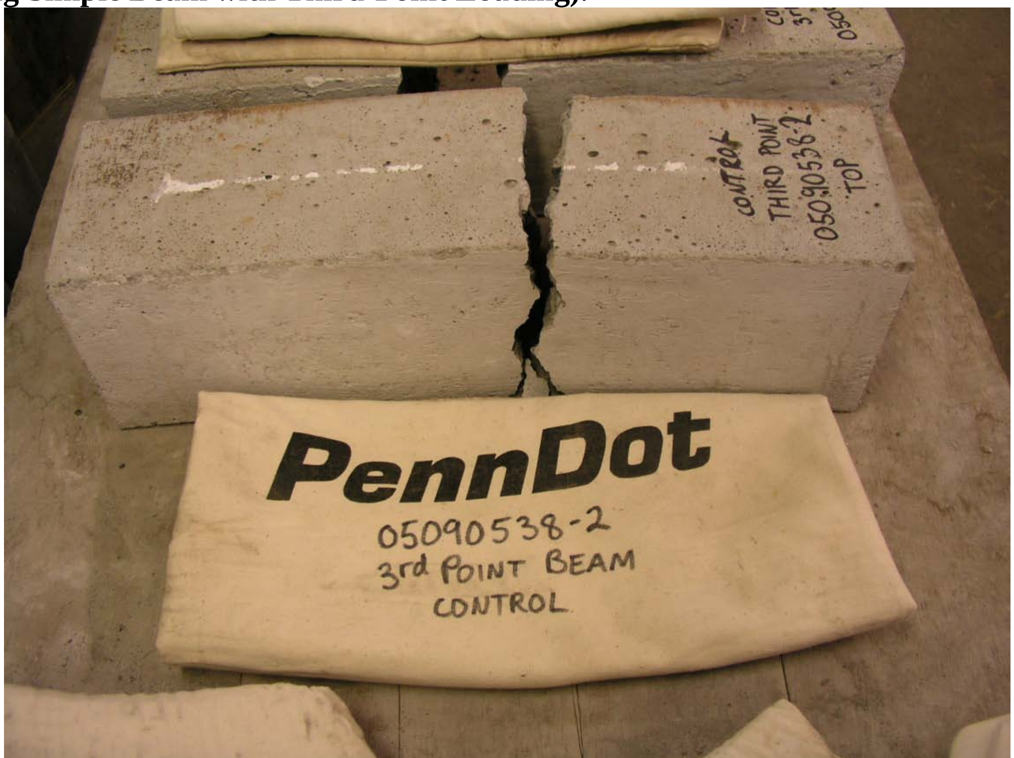
Photograph 38, This control cylinder for Class AA nearly split into two pieces.

CONTROL CLASS AA CONCRETE
ASTM C 293 Flexural Strength of Concrete
(Using Simple Beam with Center-Point Loading).

Photographs 39 and 40, The flexural test beam specimens and the line of fracture.

CONTROL CLASS AA CONCRETE

ASTM C 78-0 Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading).



Photographs 41 and 42, Flexural test beam specimens.

APPENDIX B
THE APPROVED CONCRETE MIX DESIGN
FOR NEW ENTERPRISE STONE AND LIME CO., INC.
NEW ENTERPRISE, PENNSYLVANIA

Concrete Mix Design

Material Class: AA
Date: 06/02/2005
District: 9-0
CMS No: 70789

Contractor Name: New Enterprise Stone and Lime, Co., Inc. New Enterprise, Pa 17045
SR 0099 Section SRI
Concrete Producer: New Enterprise Stone and Lime, Co., Inc. Plant: Ashcom

MATERIAL	TYPE	PRODUCER-LOCATION	SUPPLIER CODE	S.G.	ABS.	LAB
Cement	1	St. Lawrence Cement-Hagerstown, MD	SLCC415	3.15		90-148
Pozzolan	GGBFS	Aucern-New Orleans, LA (grade 120)	LONST15	2.92		03-058
Fine Aggregate	A	New Enterprise-Ishman	NEW55E14	2.59	1.20	03-036304
Coarse Aggregate	#57	New Enterprise-Ashcom	NEW05B14	2.80	0.31	03-030464
Water		Cove Creek				
Admixture	AEA	Degussa-Cleveland, OH (MBVR)	8.5 Oz/100# C+P		oz/ cy (as required)	
HRWR	A	Degussa-Cleveland, OH (200-N)	29.0 Oz/100# C+P		oz/ cy (as required)	
Retarder (100XR)	D	Degussa-Cleveland, OH (100-XR)	Oz/100# C+P		oz/ cy (as required)	
Water Reducer			Oz/100# C+P		oz/ cy (as required)	
Fiber	Tuf-Strand	Euclid Chemical Co. Cleveland, OH				5 lbs./ cy

Strength Data Based On: 0.47 W/C Ratios Taken From Work Sheet Dated: 12/06/04

Compressive Strength: 7 days 4174 avg. psi 28 days 5960 avg. psi % solids used F.M.

Mix No.	Trial Mix	1
W/C Ratio by Wt.	0.47	0.43
(Gals per Bag)	(5.31)	(4.86)
Cement, lbs.	441	441
Pozzolan, lbs	147	147
Water, lbs	276	252
Coarse Aggregate (SSD) lbs	1887	1887
Fine Aggregate (SSD) lbs	1149	1211
Total, lbs	3900	3938
Unit Weight, lbs/CF	144.44	145.85
Water, gals	33.2	30.4
Mortar Content, CF	16.76	16.76
At Point of Placement		
Slump	3	3
Air	6.0%	6.0%

Designed by: Mark Moyer of NES&L Date: 01/06/05
Reviewed for Materials Engineer: Sam Stevanus Date: 01/31/05