Scotchcast™ Polyolefin Fibers
Comparative Technical Data

The information contained herein is from testing conducted under contract by the South Dakota School of Mines and Technology for the South Dakota Department of Transportation and is described in detail in study SD94-04. The concrete specimens tested were from actual full depth placements.

These test results show that 3M fibers improve hardened concrete material performance characteristics like steel fibers do. This is significant because 3M fibers combine the structural advantages of steel fibers and the material advantages of polyolefin.

The data presented is based on concrete mixes in Tables 1 and 2.

Summary of Typical Test Results Included
• **Toughness** (ASTM and JCI Standards) – Results based on the load/deflection curve show elastic/plastic behavior of 3M fiber reinforced concrete (FRC) and post crack load carrying capacity similar to steel FRC.
• **Flexural Strength** – 3M FRC increased the ability of concrete to withstand loads in flexure by approximately 13%.
• **Fatigue Strength/Endurance** – 3M FRC was able to endure two million fatigue cycles at a load similar to steel FRC, approximately 30% greater than plain concrete.
• **Impact Strength** – 3M FRC was over two times greater than steel FRC for failure due to impact loads and almost 14 times greater than plain concrete.
• **Crack Width Comparison** – Average crack width was reduced from 12.3 mils (312 µm) for plain concrete to 3.6 mils (91 µm) for 3M FRC.

• **Compressive Strength** – 3M fibers do not significantly affect compressive strength.

**Toughness ASTM and JCI Standards**

**Test Standards and Methods**
– ASTM C 1018–Test Method for Flexural Toughness and First Crack Strength of Fiber- Reinforced Concrete (Using Beam With Third-Point Loading),

• **Significance of Test**
These tests were designed to show the ductile, elastic/plastic behavior and post crack load carrying capacity of fiber reinforced concrete.

The results of these tests yield load deflection curves, toughness indices, ratios and factors that indicate how fiber concrete can be expected to perform under static flexural loads.

• **Test Results**
The results show that steel fibers and 3M fibers produce similar substantial toughness improvements to concrete. Figure 1–Load Deflection Curve below shows the plastic(ductile) behavior of concrete using steel fibers and 3M fibers compared to the brittle behavior of plain concrete. Both steel FRC and 3M FRC provide significant post crack load carrying capacity.

**Table 1 Concrete Mixes and Proportions**

<table>
<thead>
<tr>
<th>Mixture Type</th>
<th>Fiber Diameter</th>
<th>Fiber Length</th>
<th>Water/ Cement Ratio</th>
<th>Cement lbs/yd$^3$ (kg/m$^3$)</th>
<th>Fly Ash lbs/yd$^3$ (kg/m$^3$)</th>
<th>Coarse Aggregate lbs/yd$^3$ (kg/m$^3$)</th>
<th>Fine Aggregate lbs/yd$^3$ (kg/m$^3$)</th>
<th>Fibers lbs/yd$^3$ (kg/m$^3$) (vol. %)</th>
<th>Water lbs/yd$^3$ oz/yd$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain Concrete</td>
<td>NA</td>
<td>NA</td>
<td>0.47</td>
<td>519 (308)</td>
<td>114 (68)</td>
<td>1770 (1050)</td>
<td>1270 (753)</td>
<td>0</td>
<td>242</td>
</tr>
<tr>
<td>Steel FRC</td>
<td>0.8 mm</td>
<td>59 mm</td>
<td>0.50</td>
<td>525 (311)</td>
<td>113 (67)</td>
<td>1634 (969)</td>
<td>1331 (789)</td>
<td>66 (39) (0.5%)</td>
<td>263</td>
</tr>
<tr>
<td>3M FRC</td>
<td>0.63 mm</td>
<td>50 mm</td>
<td>0.50</td>
<td>525 (311)</td>
<td>113 (67)</td>
<td>1634 (969)</td>
<td>1331 (789)</td>
<td>25 (15) (1.6%)</td>
<td>263</td>
</tr>
</tbody>
</table>

**Table 2—Properties of Fresh Concrete**

<table>
<thead>
<tr>
<th>Mixture Type</th>
<th>Unit Weight lbs/ft$^2$ (kg/m$^2$)</th>
<th>Slump (inches)</th>
<th>Air Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain Concrete</td>
<td>147.08 (87.26)</td>
<td>1.25</td>
<td>6.6</td>
</tr>
<tr>
<td>Steel FRC</td>
<td>148.73 (88.23)</td>
<td>3.25</td>
<td>4.5</td>
</tr>
<tr>
<td>3M FRC</td>
<td>145.85 (86.52)</td>
<td>0.25</td>
<td>4.9</td>
</tr>
</tbody>
</table>
Toughness indices and ratios are calculated based on the area under the load deflection curve and are an indication of the FRC’s ductility and toughness. The toughness indices and ratios are slightly higher for 3M FRC indicating that it is more ductile and tougher than steel FRC. Both steel FRC and 3M FRC have toughness ratios near two, which indicates near perfect plastic behavior. See figures 2 and 3 on this page.

• Test Comparisons
Improvement in toughness is a desirable property because it indicates increased energy absorption capacity to failure and ductile mode of failure. It provides increased resistance to dynamic and impact loads such as earthquakes, blasts and suddenly applied loads.

• Property Improvement Benefits
3M fibers significantly improve toughness properties of concrete similar to using steel fibers but 3M fibers also
have the benefit of being a synthetic material. Improved toughness relates to increased durability, increased service life, increased crack resistance and post-crack load carrying capacity. All concrete cracks. Once plain concrete cracks, the concrete fails to carry any load across the cracks. 3M fibers give concrete the ability to carry loads even when cracked. Other synthetic fibers do not exhibit the significant resistance to flexural cracking and increased post-crack load carrying capacity that steel and 3M fibers do. These property improvements help concrete last longer and help reduce maintenance. That means the service life of a structure may be significantly increased and costly replacement may be delayed. 3M fibers may also help reduce initial construction cost.

**Modulus of Rupture (Static Flexural Strength)**

- **Test Standards and Methods**
  ASTM C 78 Test Method for Flexural Strength of Concrete

- **Significance of Test**
  This test determines the ability of 3M FRC to withstand static loads that will cause deflection and then cracking in the concrete as compared to plain concrete and steel FRC.

- **Test Results**
  These results show that 3M FRC improved early strength against cracking similar to steel FRC.

- **Test Comparisons**
  Modulus of rupture is shown on the load deflection curve as the maximum load (first crack). See Figure 1. Also, since modulus of rupture is measured at the load when first crack occurs, compare these results to first crack results shown in Figure 6 Impact Strength.

- **Property Improvement Benefits**
  3M fibers improve concrete modulus of rupture as compared to plain concrete and similar to improvements by steel fibers. A higher modulus of rupture shows that the fibers can help concrete resist cracking due to non-moving loads that may be placed on it during service such as: equipment in manufacturing plants or on offshore drilling platforms, inventory in warehouses, stationary vehicles in parking ramps, stationary airplanes in hangars, water in treatment and storage facilities and the dead load of the structure itself.

**Fatigue Strength and Endurance**

- **Test Standards and Methods**
  ACI 544.2R.89 Flexural Fatigue Endurance and ASTM C 78 Test Method for Flexural Strength of Concrete

- **Significance of Test**
  The greatest advantage to adding fibers to concrete is the improvement of fatigue characteristics. In many structures flexural fatigue strength and endurance limits are needed properties. Thus a new material like 3M fibers needs to show performance improvements in this test. These properties are useful in designs requiring structural concrete members to perform satisfactorily under high stress levels subjected to a large number of load cycles. Fatigue specimens were tested for 60 day modulus of rupture before fatigue cycle loading. Test specimens were subjected to two million load cycles at 20 cycle per second. The loads applied during fatigue cycling were a minimum of 10% of prefatigue modulus of rupture and a maximum of 50% to 85% of the pre-fatigue modulus of rupture. Two million cycles is believed to represent typical life span fatigue loading.

- **Test Results**
  Figure 5 shows the maximum flexural stress that could be endured for two million fatigue cycles and the flexural strength before fatigue testing. The steel FRC has a slightly higher maximum flexural fatigue stress than 3M FRC although they both perform similarly when compared to plain concrete.

- **Test Comparisons**
  Modulus of rupture was tested before the fatigue test at 60 days to establish the upper and lower limits of the repetitive fatigue loading instead of using the 28 day test due to the increase in strength at 60 days. Compare with figure 4.

- **Property Improvement Benefits**
  3M FRC helps concrete to better endure fatigue cycling. Many structures require high fatigue strength. This property allows for maintaining the same section depth and gaining greater fatigue endurance or reducing the section depth for the same life span or both. Reduced cracking, reduced maintenance and longer concrete life may help reduce life cycle cost of structures. The potential to reduce section depth may also help reduce installation cost.
**Impact Strength**

- **Test Standards and Methods**
  ACI 544.2R-89 Impact Strength

- **Significance of Test**
  Shows the ability of concrete to withstand cracking and failure due to repeated impact loads.

- **Test Results**
  The comparison in Figure 6 shows that plain concrete has very low resistance to cracking and failure due to impact. The addition of fibers improves resistance to first crack and ultimate failure. There is a significant improvement in the ultimate impact resistance after first crack showing that the fibers efficiently absorb energy and carry the load. 3M fibers showed the greatest improvement in first crack strength and ultimate failure resistance. Impact resistance of 3M fibers shown in the chart below is over two times greater than steel fibers.

- **Test Comparisons**
  Compare toughness results to the improvement shown in Figure 6 to impact strength after first crack.

- **Property Improvement Benefits**
  Concrete made with 3M fibers has greater resistance to fracture and failure due to heavy impact loads and thus is more energy absorbing when compared to plain concrete or steel FRC. This improved impact resistance of 3M FRC means greater resistance to cracking or failure in such applications as:
  - Airport runway pavements—airplane landings.
  - Warehouse floors—loading and unloading, heavy equipment impact
  - Manufacturing Plants—impact from vibration of heavy equipment.
  Crack resistance means longer concrete life and reduced maintenance which may help reduce initial installation cost and life cycle costs.

**Crack Width Comparison**

- **Test Standards and Methods**
  ACI Committee 224 Recommendations

- **Significance of Test**
  This is an evaluation of actual cracks that occurred as compared to ACI 224 recommended maximum allowable crack widths.

- **Test Results**
  Figure 7 shows that 93% of cracks that did occur in 3M FRC were under 0.007 inches compared to only 18% under 0.007 inches for plain concrete. The 0.007 inch width is the ACI recommended tolerable crack width for exposure to deicing chemicals.

- **Test Comparisons**
  Impact strength, toughness, static flexural strength and fatigue endurance are all related to crack width because each of these tests identifies the point at which cracking occurs. For example, the load deflection curve identifies first crack. This comparison shows what fibers do to control crack width once the first crack appears.
• **Property Improvement Benefits**
  When cracking does occur, 3M FRC helps reduce crack width. Since all concrete cracks, controlling crack width once cracks occur helps to decrease concrete permeability which will help decrease the ability of corrosion causing agents to penetrate into the concrete. Controlling crack width directly affects maintenance and concrete life. Decreasing crack width helps increase service life. Furthermore, smaller crack widths contribute to the increased toughness, fatigue endurance and impact strength discussed earlier. See related tests for more information on benefits.

**Compressive Strength**

- **Test Standards and Methods**
  ASTM C 39 – Cylinder Compressive Strength and Static Modulus

- **Significance of Test**
  Determine compressive strength of concrete samples

- **Test Results**
  During the compression test plain concrete cylinders failed instantly (brittle failure) shattering into pieces with a loud noise at the first crack while the fiber concrete cylinders continued to sustain the load and underwent large deformations without disintegrating into pieces. The concrete was held together by the fibers. A visual observation of the ultimate failure of the cylinders in compression indicated that the 3M FRC specimens were more ductile than the steel fiber specimens.
  Typically adding any fiber to concrete does not increase compressive strength but some fibers at higher volume loadings can reduce compressive strength. The significance of these results is plain concrete, 3M FRC concrete and steel FRC compressive strengths were similar.

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