Nycon Nylon Fibers
Add to Hydration Efficiency
of Cement

BACKGROUND: It is common knowledge that the strength of concrete can continue to increase long after the standard 28 day compressive or flexural strength tests are run. The hydration of the cement, the chemical bonding of cement particles and water is the means of developing strength in the concrete. As long as there is moisture available in the concrete, the hydration of the cement can continue. The hydration process requires an ambient temperature at or above 40 degrees F. The optimum ambient temperature range for cement hydration is 60-80 degrees F.

The chemical combination of cement and water produces an exothermic reaction, which means heat is generated. The generation of heat is a factor of the concrete mass/volume, the temperature of the concrete when placed and the ambient temperature. The higher the concrete temperature and/or ambient temperature the greater the potential chemical combination activity and the companion heat of hydration. Higher heat of hydration levels combined with the mass/volume of the concrete can produce higher drying shrinkage, which translates into more potential cracking.

Although concrete is considered a homogeneous material, in fact, there is not a true uniform distribution of ingredients. Therefore, not all the surfaces of the cement particles may be in contact with sufficient water to initiate the chemical reaction. That is why time and the movement of water within the concrete are important to both initial and long-term increases in the compressive strength.

THEORY: Nylon fibers, which are manmade, are known to be hydrophilic (absorbs water). Typically, both Nylon 6 and Nylon 66 will absorb 4-5% moisture. This moisture may enter the fiber during the extrusion/production process from moisture in the air from the free water in the concrete mix. The maximum quantity absorbed from the free water in the concrete would not exceed 1 ounce per 1.0 pound of Nycon nylon fiber per cubic yard of concrete. Absorption is a physical action, which means the water is not bonded in any way to the fiber. The water fills accessible voids within the discreet fibers. This moisture can be removed from the fiber by oven drying or by capillary action. The point of this comment is to illustrate that the water is not permanently captured in the fiber.

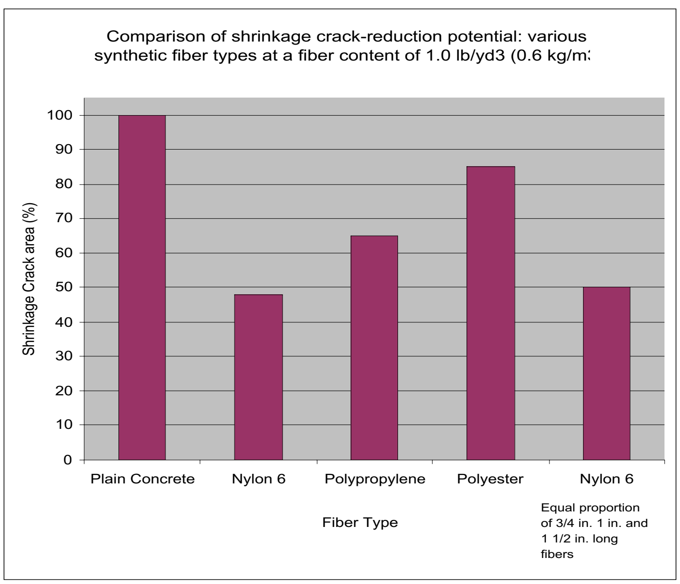
It is important to note the physical action (absorption) will occur before the chemical reaction (hydration of cement), as it does not require a catalyst or special conditions to occur. As the concrete ages it will commence to dry out. Even exterior placed concrete, which will always be exposed to moisture/water, will dry out—never to regain the moisture level found when the concrete was placed. There are a number of reasons why the concrete will never regain its original moisture level, one being the reduced permeability of the concrete as it hardens and gains strength.

Nycon nylon fibers provide an opportunity to maximize the hydration of the cement particles, specifically the cement particles that surround the Nycon nylon fibers. With Nycon nylon fiber absorbing moisture, we can look at the fibers as a reservoir for water within the concrete matrix. This water will be released to the mortar matrix surrounding the fiber during the initial drying stages of the concrete or when the moisture level in the fiber exceeds that in the mortar. This 'new' moisture can then potentially react with cement particles that have only partially reacted or have yet to react. It must be noted neither the absorption nor the dissipation of the moisture alters the dimensions of the fiber.

This presence of moisture, which migrates into the mortar is uniquely available from Nycon's nylon fibers. Thus the strength of the mortar within the contact zone of the fibers will potentially optimize at a much higher level than would be anticipated with a polypropylene based fiber, which is hydrophobic.

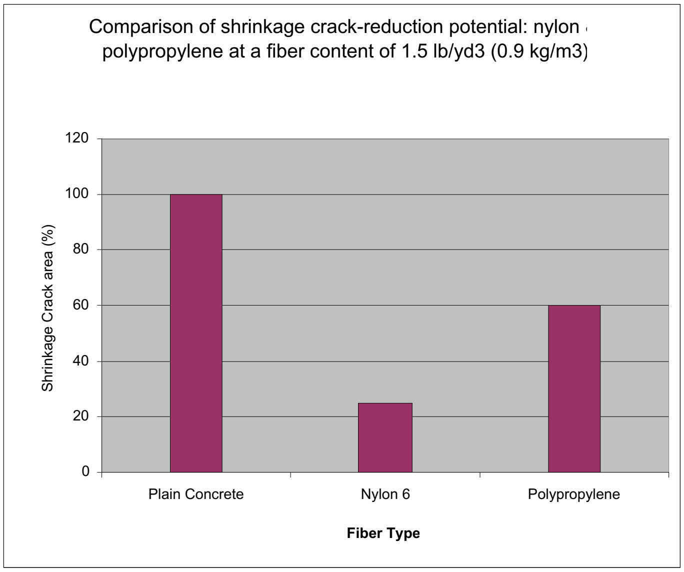
This theorized strength gain at the interface of the Nylon fiber and mortar would then increase the bond between the two materials. This potential increase in the mechanical bond, available when Nycon' nylon fibers are used, can be verified through the reported results for various tests.

FIGURE 1. [1]



The increased bond strength between the matrix and Nycon nylon fiber can then be used to explain why the reduction in hardened concrete shrinkage is seen when Nycon nylon fibers are compared to other fiber types and configurations. We will use Figure 1 and Figure 2 to illustrate this improved bond. It can be observed in Figure 1 the 1.0 pound (453.6g) of Nycon nylon fiber reduces the crack area to approximately 48% of the plain concrete whereas 1.0 pounds (453.6g) of the polypropylene fiber only reduces the crack area to 65% of the plain concrete. In Figure 2 the polypropylene fiber at 1.5 pounds (680g) per cubic yard only reduces the crack area to approximately 60% -- a 5% improvement over the 1.0 pound (453.6g) of polypropylene. **Thus it can be concluded that 1.0 pound of Nycon nylon fibers will produce a greater reduction in shrinkage crack area than the polypropylene fibrillated fibers at 1.5 ponds (680g) per cubic yard.**

FIGURE 2. [1]



These quantifiable benefits will translate into reduced hardened concrete micro and macro shrinkage cracks, reduced fatigue from wetting and drying and freezing and thawing. This comparison of fibers from different chemicals can best be made when the fiber surface area, fiber length and fiber configuration are similar. A list of research papers can be furnished for further evaluation.

DISCUSSION: How has this theory been proven? Fortunately there are a number of standard tests that can be used to determine the validity of this theory. First, it is necessary to understand Nycon nylon fibers provide an isotropic reinforcement system. This means the Nycon fibers are 3-dimensionally distributed throughout the mortar portion of the concrete. This reinforcement system is like a network of wires that take concentrated or uniform stresses and distributes them to a larger mass of concrete than would be possible for a plain concrete or a concrete with a single plain of reinforcement (i.e. welded wire fabric—WWF). Impact strength, shrinkage resistance and rebar debonding or pull-out tests are typical of those tests used to quantify the contribution of synthetic fiber reinforced concrete versus plain concrete. In terms of how the concrete reacts to the various tests, it is understood that the performance of plain concrete will also reflect WWF reinforced concrete, since the WWF has no influence on the mortar matrix of the concrete.

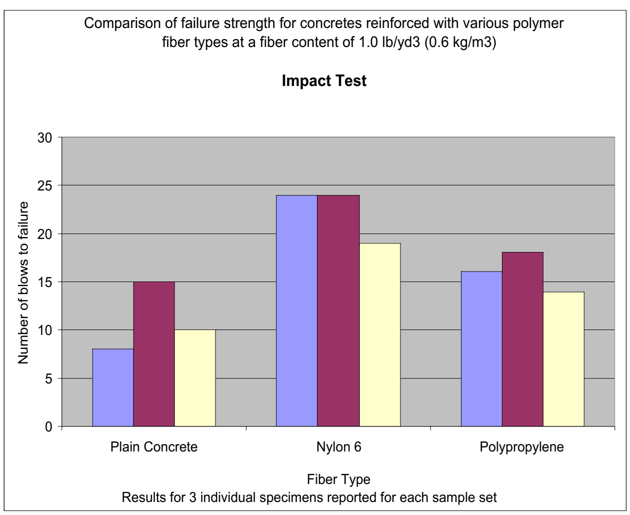
In a research report prepared by Dr. Balaguru of Rutgers University dated January 1991, he relates the findings of his rebar pull-out tests conducted in the university laboratory wherein he compares plain concrete and concrete reinforced with 1.0 pound (453.6g) of Nycon _" (19mm) long nylon fibers. Dr. Balaguru used ASTM test method C234 as the basis of his program. Dr. Balaguru concluded that the Nycon nylon fiber reinforced concrete had improved ductility and increased the rebar pull-out strength which reflects the bond between the mortar matrix and steel rebar. This work mirrors the data generated by others. In the rebar pull-out test, Nycon's nylon fiber reinforced concrete failure will occur beyond the extreme circumference of the rebar. The bond strength at the fiber-mortar interface is critical to the additional mass involved in resisting the pull out. This additional mass of concrete has become part of the matrix resisting the pull out as a result of the 3-dimensionally-dispersed fibers distributing the stresses beyond the typical failure zone. The moisture contributed by Nycon fiber to enhance the cement hydration at the mortar-fiber interface is a major contributing factor.

The ACI 544 Impact Test uses a 10-pound hammer dropped 18" (457.2mm) onto a 2 _" (63.5mm) diameter steel ball sitting on a concrete disk which imparts a concentrated impact load to a concrete disk. The test is used to measure two properties: one, number of blows to first crack and, two, number of blows to total failure. The number of blows to first crack will show the ability of the fiber to distribute load throughout the mass while the number of blows from first crack to total failure reflects the performance of the fiber-mortar bond. Dr. Balaguru in another research program used this test method to show Nycon fibers significantly modified the concrete's first crack and long term performance. At 1.0 pound per cubic yard, number of blows to first crack increased by more than 75%, when compared to plain concrete. Total failure results showed a 105% improvement for the Nycon fibers over the plain concrete. This test provides an excellent means of visually showing an increase bond between the mortar and fibers. It can also be used to demonstrate the difference in the cracking pattern of the failed plain concrete specimens and the Nycon fiber reinforced concrete specimens.

Typically, the plain concrete specimen has developed fewer cracks, which are much longer and wider, whereas the Nycon reinforced specimen has more cracks which are shorter and narrower. Thus, confirming that Nycon fibers are isotropic reinforcement, which produce more uniform distribution of leads within the mass.

Looking at the failed disks, one immediately sees that the pieces of the failed plain concrete are discrete (disconnected) with no bond whatsoever between the pieces. Conversely, even after the Nycon reinforced specimens have failed per the test method definition, the fibers are still holding the pieces together, which demonstrates the quality of the bond at the mortar-fiber interface. Additionally, this continuing bond after the pieces of the disk have separated up to 5-8mm displays the ability of the fiber to transfer load across the crack well beyond first crack. When we talk about transferring load across a crack, it then can be said the Nycon fibers reduce the potential of catastrophic failure, thus making Nycon fibers an excellent candidate for secondary reinforcement of concrete structures exposed to potential of seismic activity.

FIGURE 3. [(1)]



Finally, shrinkage tests may be the best indicator of how the Nycon fibers bond in the concrete by controlling expansion and contraction. Everyday exterior concrete is exposed to changes in ambient conditions. Changes in temperature and moisture translate into changes in the concrete's mass. This movement over many days, months and years will cause fatigue. Fatigue leads to cracking, which then can lead to reduced durability and limited usable life. Dr. Balaguru in an April 1994 report provides data on results from ASTM C490. From his report, the dramatic reduction in hardened concrete shrinkage with the Nycon fibers when compared to the plain concrete can be seen.

SUMMARY: The enhanced bonding of the Nycon fibers due to the moisture retention properties of the nylon can be quantified. With the increase in bond comes an increased 'life cycle index' meaning greater durability and reduced maintenance costs when compared to other forms of secondary reinforcement. Remember that ACI defines secondary reinforcement as that reinforcement used to hold the concrete together after it cracks. Nycon's nylon fibers provide an isotropic reinforcement that adds long term durability for equal or less front-end cost.

(1)Source:
Balaguru, Perumalsamy N., and Shah, Surendra P. Fiber-Reinforced Cement Composites. New York: McGraw-Hill, Inc., 1992.

Authors:

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Bob joined the Nycon team in 1999, to spearhead the company's research and development and advance the application of fiber technology throughout the construction industry. A registered professional engineer, Bob has a B.E. in civil engineering and is a recognized industry authority on construction. He has numerous professional affiliations, notably with ASTM Committees C-9, C-17 and D-4 and ACI Committees 544, 549, 440 and E701, among others. Bob is a published author of over thirty journal papers, a frequent lecturer at industry events, chairman of various industry committees, and is co-founder and former president of the Synthetic Fiber Association. Professionally, he is listed in *Marquis Who's Who in Finance and Industry, Marquis Who's Who in Science and Engineering, Marquis Who's Who in the United States, Men of Achievement,* and *Who's Who 2000*.

Robert Cruso, President

Robert Cruso, Nycon's president, studied Engineering and Construction Sciences at Roger Williams University in Rhode Island. Mr. Cruso began his career in construction in 1980 as a sales engineer in the exterior wall façade industry. In his current position, he works with Nycon's customers and industry associates worldwide to optimize Nycon's fiber applications. His memberships include the American Concrete Institute's (ACI) Committee 544 for Fiber Reinforced Concrete, ACI's 544-F Sub-Committee for Testing Fiber Reinforced Concrete, the American Society for Testing and Materials (ASTM) Main Committee C 09 on Concrete and Concrete Aggregates, and the Synthetic Fiber Association. Mr. Cruso was also a past treasurer and a director of the Synthetic fiber Association.

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