Natural Fibers with Improved Dispersion for Sustainability and Durability in Shotcrete

By Jisha Hechel

In recent years, the construction industry has increasingly turned to sustainable and eco-friendly materials to enhance performance while reducing environmental impact. Sustainability in shotcrete involves reducing its environmental footprint through innovative measures. As the most widely used construction material in the world, cement production is responsible for a significant portion of global carbon emissions. One way to reduce the impact of shotcrete on our environment is to incorporate renewable resources, while also ensuring that the quality structures are durable and long-lasting.

Azelis, a global distributor of specialty chemicals and additives, has a large network of application labs that provide innovative solutions to producers looking to enhance their formulas using our specialty additives portfolio. Our Building & Construction lab has worked extensively to give customers valuable insight on the benefits of using natural fibers in shotcrete, as well as the best way to implement the material for optimal performance.

MiniFIBERS natural fibers, derived from sustainable plant sources, have been shown to perform as well as synthetic fibers composed of polypropylene and fiberglass. This reduces the environmental impact of the raw materials, as well as creating a high-performing, robust shotcrete formulation that is resistant to microcracking and tensile stress.

BACKGROUND

In an article published in 2023, we presented a study comparing various sources of natural fibers against traditional shotcrete formulations containing synthetic fibers. These studies demonstrated that in all hardened concrete tests, the natural fibers performed comparably to the synthetic fibers. These performance properties included compressive strength, tensile strength, dimensional stability (dry shrinkage), and flexural strength.

In this updated article, we present our latest work, exploring the practical aspects of natural fibers in shotcrete. The crucial element of dispersing natural fibers was carefully considered. Due to the length and nature of plant-based fibers, the entangling and bundling of fibers in the shotcreted concrete mixture was a challenge to overcome. Having well-dispersed fibers is essential to the integrity of the structure, as well as the consistency of the shotcreted sections performance.

Out of the natural fiber offerings in the MiniFIBERS portfolio, jute fibers were the most abundantly available. Jute is the second-most-produced natural fiber in the world, after cotton. Therefore, the recent round of testing used these as our preferred source of natural fibers. In addition to jute, MiniFIBERS carries an extensive variety of synthetic fibers, specializing in Short Stuff fibrillated high-density polyethylene fibers that are significantly shorter than traditional fibers, and offer a variety of unique properties for many industrial applications, including cementitious mortars and concrete. We leveraged our experience to help with dispersion of the jute fibers and found tremendous synergies when combining the benefits of the Short Stuff fibers with jute fibers.

TESTING

The Azelis Building & Construction lab spent years investigating the use of natural fibers in shotcrete. Previous findings indicated that the replacement of synthetic fibers with natural fibers had an overall beneficial effect on properties, but there was an inconsistent distribution of the natural fibers due to their inherent bundling behavior. We conducted a series of trials to improve the dispersion and distribution of the natural fibers in the concrete network.

The objective was to conduct dispersion evaluation trials using a variety of potential dispersing agents. Once an ideal dispersion solution was identified, we incorporated it into a shotcrete formulation and evaluated some key performance properties, such as density, air content, compressive strength, and flexural strength.

TEST DESIGN – IMPROVED DISPERSION OF NATURAL FIBERS

In an effort to efficiently evaluate the natural fibers dispersion, the Azelis lab created a simple slurry with a constant amount of water and fiber. The mixture was placed in a benchtop stand mixer and mixed on medium speed for 2 minutes.

Various dispersion additives were added to the

	Control - Jute Alone	Jute + Short Stuff	Jute + Superplasticizer	Jute + Wetting Agent	Jute + Microsilica	Jute + Cement Dry Blend
Ingredients	**Grams**	**Grams**	**Grams**	**Grams**	**Grams**	**Grams**
Lab Type IL Cement						118.35
Microsilica					118.35	
Superplasticizer			3.55			
Wetting Agent				2.35		
Jute - 6mm	2.95	2.95	2.95	2.95	2.95	2.95
Short Stuff Fibers		2.95				
Water	500	500	500	500	500	0

Table 1: Slurry Designs

Fig. 1: Slurry Results

water-fiber slurry system to improve the dispersion (Table 1). These included powered cement superplasticizer, powdered wetting agent, microsilica, and Short Stuff. Another trial was conducted using a dry-blending technique with jute fibers in cement.

RESULTS – IMPROVED DISPERSION OF NATURAL FIBERS

A sample of the slurry was placed in a clear petri dish to assess the fiber dispersion (Fig. 1). It was very apparent, based on visual evaluation, that the best natural fiber distribution came from combining the jute fibers with Short Stuff fibers in the mixing water. This combination resulted in a much more uniformly dispersed slurry and allowed all the stubborn bundles of natural fibers to unwind and form a homogenous network.

TEST DESIGN – FULL SHOTCRETE FORMULA WITH IMPROVED DISPERSION

Once the optimal dispersion system was identified — in this case, a slurry containing half jute fibers and half Short Stuff fibers in water — we evaluated the performance in a full-scale shotcrete formulation.

We conducted our tests using a basic concrete formulation containing 28% Type IL cement, 5% microsilica, graded sand, and a small dose of performance additives out of the Azelis Building & Construction portfolio, including BASF Melflux 4930 (a superplasticizer based on polycarboxylate ether) and Vinapor AE 3914 (air entrainer). The water-cement ratio remained a constant 0.32 (Table 2).

The objective was to evaluate a shotcrete formula with the fiber slurry against a control with no fibers. The addition of fibers to the shotcrete mix initially created a less flowable mix due to the increased surface area and water demand from the fiber addition. To achieve similar flow properties

	Control - No Fibers	Jute-Short Stuff Slurry
Ingredients	%	%
Lab Type IL	28	28
Lab All Purpose Sand	66.9	66.8
Red 106 Microsilica	5	5
Melflux 4930	0.075	0.114
Vinapor AE 3914	0.003	0.003
Minifibers ESS 20		0.0625
Jute - 6mm		0.0625
Total	100	100
Water	10.56	10.56
Water/Cementitious Ratio	0.32	0.32

Mix Protocol
Mix fibers in water for 2 minutes
Pour dry mix into water - let sit for 30 sec
Mix 30 sec speed 1 (~135RPM)
Scrape 15 sec
Mix 1.5 minutes speed 1

Table 2: Shotcrete formulations and mix protocol

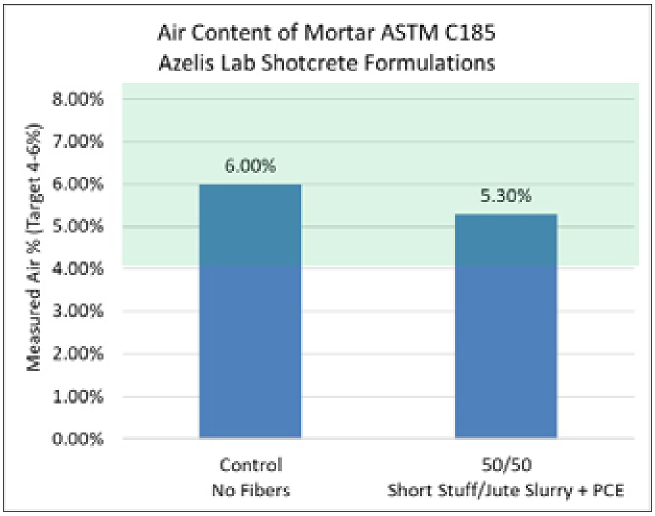


Fig. 2: Air Content

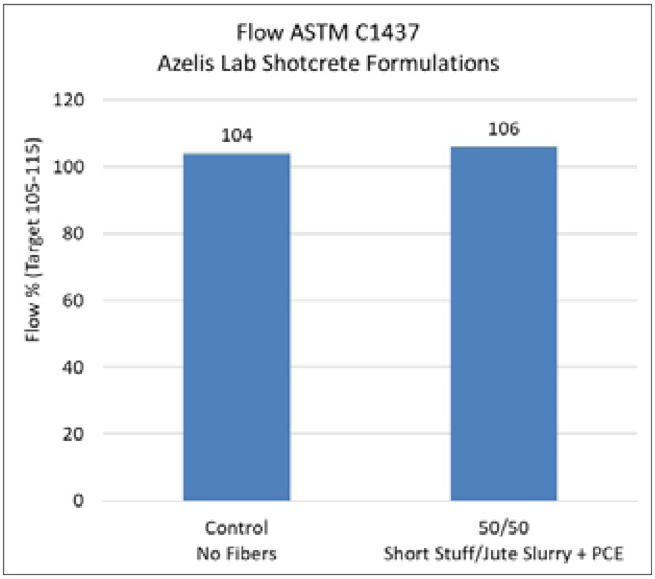


Fig. 3: Flow

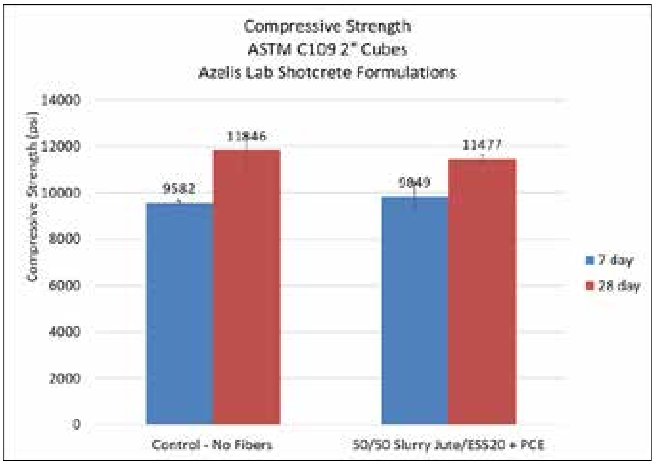


Fig. 4: Compressive Strength

to the control, we added additional superplasticizer, rather than increasing the water, which would have a detrimental effect on the properties.

TEST RESULTS – FULL SHOTCRETE FORMULA WITH IMPROVED DISPERSION

Azelis labs evaluated various properties of the shotcrete formulation containing MiniFIBERs natural fibers and Short Stuff in comparison to a formulation with no fibers. Air content, flow, compressive strength, and flexural strength are reported below.

Mortar density testing was performed following ASTM C185 (modified). The results correlated with air measurements. Air content was targeted at 6 +/-2%*. Air content was measured using a 0.026 ft^3 (0.75 l) mortar air meter employing the same method as a standard 0.25 ft^3 (7 l) air meter used in ASTM C231.

> *NOTE: A targeted 6% air was chosen to better understand "as shot" hardened state properties. It is understood that a higher air content of 12% before shotcrete is placed would typically be targeted assuming 50% of the air is removed in the application process. Since the material was unable to be pumped and shotcreted for the hardened state tests, a typical "as shot" air content was targeted to avoid high air contents impacting hardened state properties.*

The concrete mixture maintained air content within the targeted range when the natural fibers slurry was added (Fig. 2).

Flow and rheology are an essential attribute to shotcrete since it must be reliably sprayed. Typically, addition of fibers reduces the flowability in cementitious mortar. Actual spray testing was not conducted, so flow was used as an indicator of the rheology. To return the mortar to a comparable flow as the control, superplasticizer was added to the formulation. Flow was determined following ASTM C1437 using a shocking table (Fig. 3).

The mortar containing fiber slurry had the addition of superplasticizer to produce the same flowability as the control. The resulting formulation enhanced by fibers had excellent texture and creaminess, making it easy to smooth and finish.

The mortar was cured in a controlled lab environment with 50% relative humidity at 73°F (23°C) and the specimens were tested for compressive strength and flexural strength. Compressive strength was measured using 2-in. (50 mm) cubes following ASTM C109. Flexibility testing followed ASTMC580.

The formulation with natural fibers achieved compressive strength over 9000 psi (62 MPa) at 7 days, and over 11,000 psi (76 MPa) at 28 days (Fig. 4). The difference in compressive strength between the two sample sets was not statistically significant. It should be noted that the typical shotcrete performance requirement for compressive strength is around 6000 psi (41 MPa) at 28 days. This concrete mixture far exceeds this requirement, demonstrating its robustness and performance, and enabling cost savings through binder or admixture reduction.

The mortar containing fiber slurry had statistically higher flexural strength than the control with no fibers (Fig. 5). This improvement in flexural strength over the control is consistent with previous findings, and the newly homogenous distribution of fibers in the mortar network allows for consistent and repeatable results.

Conclusion

Azelis labs used a basic sanded shotcrete formulation (no coarse aggregate) to test the impact of MiniFIBERS natural fibers. Development of a practical method of proper dispersion was essential to prevent bundling of the natural fibers in the shotcrete. The typical performance requirements referenced were for “as-shot” mortar containing a targeted 6% air. Our lab concluded that using natural fibers in the concrete mortar allowed the shotcrete formulation to achieve excellent performance targets, while allowing for a lower carbon footprint due to the use of sustainable materials. These results reinforce our previous conclusions that natural fiber addition contributes to the enhanced performance of shotcrete formulations.

Processing natural fibers can present challenges when it comes to precision cutting. There are a minimal number of fiber processing companies that are capable of producing a consistent natural fiber cut to less than 0.4 in. (10 mm) in length. MiniFIBERS was founded on, and excels in, state-of-the-art fiber cutting technology and is a world leader in fiber processing.

By harnessing the strengths of Short Stuff fibrillated HDPE fibers, we were able to utilize jute natural fibers to their full potential. The resulting final shotcrete formulation had excellent plastic and hardened state properties that matched or exceeded the non-fiber control mixture. By incorporating natural fibers, a standard shotcrete formula can be transformed into a more durable, more flexible, and more environmentally sustainable product.

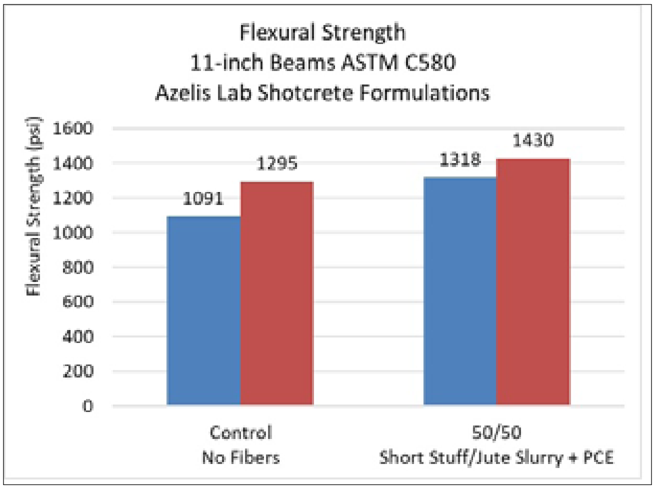
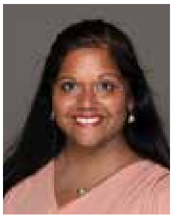


Fig. 5: Flexural Strength



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