WHITE PAPER /// ADDITIVE MOLDING

HIGH-PERFORMANCE NATURAL FIBER COMPOSITES

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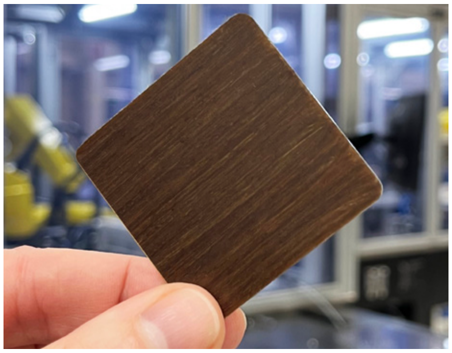
ABSTRACT

Natural fibers have the potential to bring sustainability benefits to the composites industry as they achieve wider adoption in various applications. This paper presents mechanical testing results of an ARRIS-designed natural fiber thermoplastic composite in comparison to similarly produced glass and carbon fiber-based materials.

- ARRIS produced a flax fiber reinforced composite with Additive Molding that competes with similarly produced glass fiber reinforced material in stiffness.
- The flax fiber reinforced composite by ARRIS is not only more than 500% stiffer than the neat polymer, but also exceeds the stiffness-to-weight performance of the glass fiber composite.

The results demonstrate that this natural fiber composite material applied with Additive Molding by ARRIS, an innovative manufacturing, materials, and software technology, can compete with current high-performance materials.



ARRIS revealed flax fiber composites for structural applications in early 2023 (view).

BACKGROUND

Composite materials have found applications in virtually all markets, from bathtubs to spaceships. In some markets, composites are still the newcomer, while in others, the hard-earned reputation of composites is well established.

Across their varied applications, composites are commonly chosen because they are considered “high-performance” materials. In the materials industry, earning the title of “high-performance” typically demands high strength, high stiffness, and low weight. We combine these attributes when we examine the specific properties, or the strength-to-weight and stiffness-to-weight performance of the material. The higher the specific properties, the more demanding applications we can expect to address.

In recent years, consumers have begun to demand not only high performance, but also improved sustainability and reduced environmental impact. We believe the material champions of the future will combine high specific properties with environmentally responsible feedstocks and processes.

One promising approach to meeting both of these demands lies in the adoption of plant-based reinforcements from sources such as jute, sisal, flax, hemp, kenaf, and pineapple to produce Natural Fiber Composites (NFCs). These reinforcement fibers have been found to have competitive properties, especially specific stiffness, compared to glass fibers (1,2).

Plant-based fibers have a long history of use as both fillers and reinforcements—from ancient builders reinforcing clay with straw to modern marine engineers using flax fibers to build performance yachts. Natural fibers are widely known and appreciated for their sustainable nature, biodegradability, and low carbon footprint. For instance, life cycle analyses have calculated the production of flax fibers can result in greenhouse gas emissions below 1.0 kg CO2e per kg of flax fiber (3), while carbon fiber production results in up to 31 kg CO2e per kg of carbon fiber (4). This is <5% compared to carbon.

Natural fibers also present challenges compared to their synthetic counterparts. Man-made fibers such as carbon, glass, Kevlar, and basalt fibers are manufactured by steady, well-controlled processes which deliver a consistent and uniform product. Natural fibers, however, reflect the variations of the biological processes which produce them, resulting in less consistent fiber form and length, and sensitivity to high temperatures. These characteristics result in processing challenges that prevent natural fibers from being drop-in replacements in many applications. As new solutions to these challenges are developed, the advantages of natural fibers and NFCs can be realized across more products and applications.

ARRIS Composites' Additive Molding technology is already pushing the boundaries on low-waste manufacturing of high-performance products. We're passionate about raising the bar on the environmental responsibility of our products without compromising performance.

Armed with ARRIS' in-house material development tools and Additive Molding technology, we set out to determine if we could produce a natural fiber composite that can compete with ARRIS' current high-performance material options.

TEST & RESULTS

The strengths and stiffnesses of natural fibers vary across different plant species (1,2) with some exhibiting tensile modulus values similar to e-glass fibers (approximately 60-70 GPa). For the present work, the properties and availability of flax fibers made it our first choice.

Three samples of experimental materials were produced in-house at ARRIS Composites—utilizing flax fiber for one, e-glass fiber for another, and standard modulus carbon fiber for the third. All three included the same grade of bio-based polyamide matrix (BioPA) and fiber volume content. The lesser degree of filament organization in natural fiber stocks can lead to lower fiber volume fraction in flax fiber composites than typically seen with synthetic fibers.

However, ARRIS' material production technology maintains the fiber length and orientation of the flax fibers—attributes critical to reaching the performance potential of the material regardless of fiber volume fraction. To maintain the best comparison between fiber types, materials with glass and carbon fibers were specifically produced with similar fiber loadings to flax.

Mechanical test samples were molded utilizing ARRIS' proprietary Additive Molding technique, following established best practices for material handling, preparation, and molding conditions. Samples were produced from each material in geometries appropriate for tensile and flexure testing per ASTM D 3039 (5) and ASTM D 790 (6). Final as-molded fiber volume fractions were in the range of 27-29 %-vol.

Measured properties for all three materials fall within ranges expected for the polymer and fiber loadings examined. The test results presented in Table 2 have been normalized to those of GF/BioPA to illustrate their values relative to one another. While no directly comparable results for Flax/BioPA could be found in literature, reported values that are available (1,2,7,8,9) support that these test results are a reasonable representation of the performance that can be expected from Flax/BioPA at the examined fiber loading.

Table 2: Measured mechanical properties normalized to GF/BioPA values. Neat BioPA properties from manufacturer's datasheet.

MEASURED PROPERTIES, NORMALIZED TO GF/BIOPA				
Material	**Tensile Strength [MPa]**	**Tensile Modulus [GPa]**	**Flex Strength [MPa]**	**Flex Modulus [MPa]**
Neat BioPA	0.1	0.12	0.3	0.15
Flax & BioPA	**0.3**	**0.88**	**0.4**	**0.91**
Glass & BioPA	1.0	1.00	1.0	1.00
Carbon & BioPA	2.1	2.80	1.7	1.32

While carbon clearly remains a step beyond both glass and flax in all measured properties, the flax composite is competitive with the glass composite in stiffness, falling only about 9-12% behind glass in flex and tensile moduli.

The competition between flax and glass becomes even more interesting upon examining the specific properties presented in Table 3. When we account for the lower density of flax fibers, we can see that the flax composite beats the glass composite in stiffness-to-weight performance for both tensile and flex properties.

Table 3: Specific mechanical properties normalized to GF/BioPA values.

SPECIFIC PROPERTIES, NORMALIZED TO GF/BIOPA					
Material	**Density [g/cm³]**	**Tensile Strength [MPa]**	**Tensile Modulus [GPa]**	**Flex Strength [MPa]**	**Flex Modulus [MPa]**
Neat BioPA	1.13	0.2	0.16	0.3	0.19
Flax & BioPA	**1.23**	**0.4**	**1.06**	**0.5**	**1.07**
Glass & BioPA	1.53	1.0	1.00	1.0	1.00
Carbon & BioPA	1.31	2.5	3.12	2.0	3.00

CONCLUSIONS

Using ARRIS' Additive Molding technology, we produced a flax fiber reinforced composite that could compete with similarly produced glass fiber reinforced material in stiffness.

For some applications, flax could immediately be considered as a candidate for drop-in replacement of glass, providing both similar stiffness and a reduction in part weight. For other applications, improved designs can take advantage of flax's lower density to permit use of inherently stiffer geometries. And in all cases, parts made with flax fiber reinforcement inherit the many other benefits of natural fibers, most notably sustainable and renewable feedstocks.

Figure 1: Three carbon plates made at ARRIS Composites in Berkeley, CA (flax on right, carbon and glass on left).

ARRIS is already attracting attention in the performance footwear industry by offering key advantages which are unachievable with traditional molding technologies. The addition of natural fiber composites for Additive Molding will push the possibilities further. Plates for running shoes (Figure 1) that already leverage ARRIS' design optimization to increase performance and reduce weight may be enhanced further thanks to the unique properties and low density of natural, sustainable fibers.

We are excited to begin addressing the unique processing challenges related to natural fiber composites, and we will take these results to the next level.

ARRIS' in-house material development and unique Additive Molding process give us the freedom to imagine and design solutions in-step with the evolution of new materials. We're eager to evaluate additional fiber types and sources, experiment with new bio-derived and recycled polymers, and optimize fiber content and molding conditions to maximize performance.

The future of natural fiber composites by ARRIS is truly promising and exciting, especially when combined with our current use of bio-derived polymers and low-waste molding process. The team at ARRIS is proud to lead the way to more responsible and sustainable manufacturing of high-performing composite parts at scale.

To learn more about what's possible with Additive Molding by ARRIS, an innovative manufacturing, materials, and software technology, visit arriscomposites.com.

REFERENCES

1. Saheb, D Nabi, and J. P. Jog. "Natural Fiber Polymer Composites: A Review." Advances in Polymer Technology, vol. 18, no. 4, 1999, pp. 351–363.
2. Zhu, Jinchun, et al. "Recent Development of Flax Fibres and Their Reinforced Composites Based on Different Polymeric Matrices." Materials, vol. 6, no. 11, 12 Nov. 2013, pp. 5171–5198, doi.org/10.3390/ma6115171. Accessed 30 Sept. 2020.
3. De Beus, Niels, et al. Carbon Footprint and Sustainability of Different Natural Fibres for Biocomposites and Insulation Material. Nova Institute, Aug. 2019.
4. Das, Sujit. "Life Cycle Assessment of Carbon Fiber-Reinforced Polymer Composites." The International Journal of Life Cycle Assessment, vol. 16, no. 3, 22 Feb. 2011, pp. 268–282, doi.org/10.1007/s11367-011-0264-z.
5. ASTM D 3039-17, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials. West Conshohocken, PA, ASTM International.
6. ASTM D 790-15, Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials. West Conshohocken, PA, ASTM International.
7. Bos, Harriëtte Louise. "The Potential of Flax Fibres as Reinforcement for Composite Materials." Research.tue.nl, 2004, research.tue.nl/en/publications/the-potential-of-flax-fibres-as-reinforcement-for-composite-mater, doi.org/10.6100/IR575360. Accessed 10 Mar. 2021.
8. Andersons, J., et al. "Stiffness and Strength of Flax Fiber/Polymer Matrix Composites." Polymer Composites, vol. 27, no. 2, 2006, pp. 221–229, doi.org/10.1002/pc.20184. Accessed 6 Oct. 2021.
9. Spārniņš, Edgars. Mechanical Properties of Flax Fibers and Their Composites. 29 Oct. 2009.