

HYBRID REINFORCEMENT OF TRC FROM FLAX AND AR GLASS

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ABSTRACT. This article focusses on the possible use of hybrid reinforcement from inorganic and organic materials in a thin concrete plates, such as Textile-reinforced concrete. Organic materials, such as flax, jute, or sisal, have high tensile strengths. Young's modulus is, on the other hand, problematic, so the combination with inorganic textiles goes hand in hand. Natural fibres are renewable materials, making them an environmentally friendly material, so using them as a partial substitution of inorganic materials would make concrete reinforcement more sustainable. In this article, four-point tests of hybrid reinforced concrete plates with alkali-resistant glass and flax are presented. In addition, a hybrid reinforcement cross-sectional microscopy was done to evaluate the impregnation with epoxy resin.

KEYWORDS: Natural materials, natural fibres, alternative reinforcement, hybrid reinforcement, textile-reinforced concrete, flax, flexure test.

1. INTRODUCTION

Faced with climate change, we need to make our society more sustainable. Carbon dioxide emission needs to be reduced, even if we are talking about concrete reinforcements. Alternative reinforcements, such as inorganic textiles (carbon, AR-glass, basalt), helped to invent a textile-reinforced concrete (TRC). TRC consists of fine-grained concrete and noncorrosive reinforcements (rovings), which enables one to make as thin samples as few centimetres.

However, we can push this composite material even further, and inorganic textiles can be substituted with organic textiles such as flax, jute, hemp, or sisal. These materials are renewable, compostable, inexpensive, and can be produced sustainably, so their environmental impact is low [1–3]. On the other hand, these characteristics make them not durable in an alkaline and wet environment, so some kind of protection is needed (impregnation or coating) [4–6]. Today, they are already used in polymer composites for applications in the automobile or aviation industry [2].

A lot of research has been done on the mechanical characteristics of natural fibres. They have a low density of around 12 000–15 000 kg m⁻³, tensile strength of up to 1 000 MPa and even Young's modulus is promising, as high as 70 GPa for flax, which is equal to AR-glass values [7, 8]. On the other hand, when all fibres are combined into a roving, the values of Young's modulus are drastically lower. Due to homogenisation with epoxy resin, it is possible to achieve usable values for use in concrete [9].

To evaluate the potential substitution of inorganic

reinforcement, five types of concrete plates were designed for the four-point flexural test. Hybrid reinforcement was created from AR-glass and flax, and its composition was checked under the microscope.

2. PREPARATION OF SAMPLES

Five different samples were prepared for the four-point flexural test of hybrid reinforcement in a concrete. All samples had dimensions 100 × 20 × 40 mm and were reinforced with four rovings. There were five types of reinforcement: AR-glass as reference, combination of AR-glass and one flax, AR-glass with two flaxes, AR-glass with three flaxes and five flaxes.

The material characteristics of the yarns are shown in Table 1. HobbyBeton by Baunit was used for the concrete [10]. It has declared strength 25/30 and the largest grain is up to 4 mm, which is convenient for such small samples. For the impregnation and homogenisation of rovings, LAMEPOX 23 epoxy resin was used. It has a tensile strength of 81 MPa and Young's modulus is 3.3 GPa [11].

	T [tex]	ρ_r [g cm ⁻³]	A_r mm ²
Flax	460	0.46	1.00
AR-glass	2 400	2.54	0.95

TABLE 1. Material characteristic of yarns.

The reinforcement was made by combining selected yarns together. They were twisted for better manipulation. All rovings were submerged into epoxy resin

and then stretched on a frame. In the end, the rovings were sprinkled with fine-grained silica sand to ensure better bond with the concrete matrix.



FIGURE 1. Homogenised hybrid rovings from AR glass and flax with epoxy resin and sprinkled with sand (top) and concreted samples in a framework (bottom).

Hardened rovings were cut into desired lengths to put them in a framework. The reinforcement was pressed with a board at one end and stretched with a rubber band with a crocodile at the other end to ensure that it will stay stretched during the concreting and that it will have the desired cover layer and position (Figure 1).

After the concreting, the samples were covered with a foil to prevent water evaporation, and the next day they were put in a climatized chamber. After 28 days, the samples were tested by the four-point bending test.

With the samples, reference prisms $40 \times 40 \times 160$ mm were also concreted to verify the material characteristics of the concrete mixture.

3. EXPERIMENT AND RESULTS

The experiment was carried out on a Zwick/Roell Z100 hydraulic press. Setup and a broken specimen is seen in Figure 2. The samples were tested by a four-point bending test with a crossbar speed of 2 mm min^{-1} . Force and displacement were recorded.

In the Table 2, the results of the measurements are presented. It can be seen, that the more flax yarns were added, the more strength decreases. This

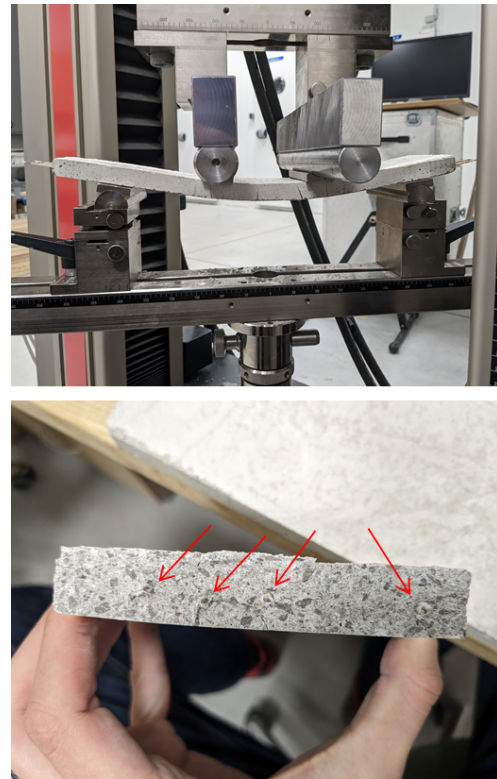


FIGURE 2. Four-point bending test in process (top). Broken specimen. The arrow indicates the cuts of the rovings (bottom).

is probably because the young modulus of AR-glass is higher than the flax's.

	F [N]	σ_{max} [MPa]
Hybrid_x4_1Glass	1929.50	17.08
Hybrid_x4_1Glass+1Flax	1376.61	13.31
Hybrid_x4_1Glass+2Flax	1537.11	13.75
Hybrid_x4_1Glass+3Flax	1272.25	11.22
Hybrid_x4_5Flax	846.66	7.40

TABLE 2. Measured strengths of plates reinforced with four hybrid rovings. F is the maximal measured strength. σ_{max} is the stress on a ideal cross-section without cracks.

In Figure 3, the chart of the measurements can be seen. After the first peak, which indicates the flexural strength of the concrete, all samples show a multiple crack behaviour with strengthening. This ductile behaviour is desirable because the structure shows it is collapsing, but not at sudden.

At first glance, the 'G' sample with only glass rovings is the strongest. The other samples show smaller drops after the peaks, indicating that the crack width is smaller than at the glass specimens. Probably, it is due to the diameter of the reinforcement. Thicker reinforcement can withstand higher contact stress.

Some of the samples have small peaks in the chart. It is probably caused by the epoxy resin, which can

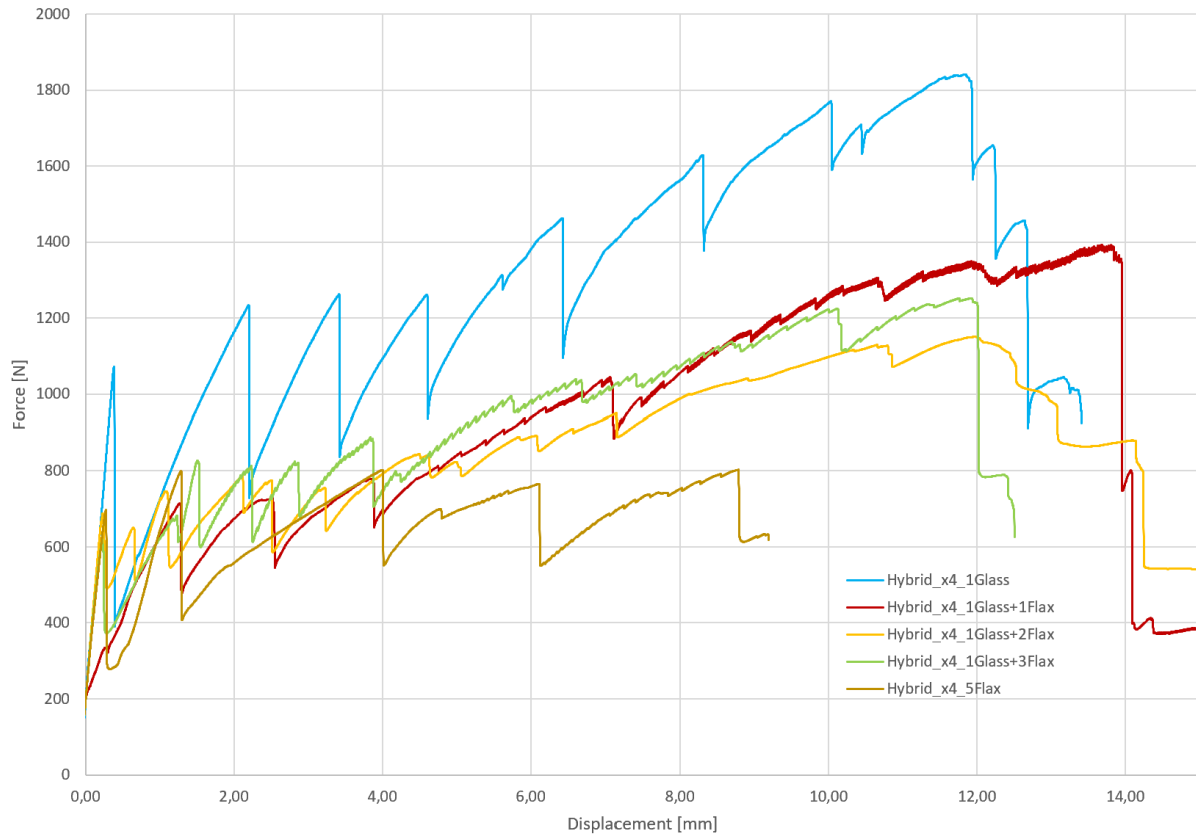


FIGURE 3. Force-displacement chart of representative samples of plates reinforced with hybrid rovings. The number next to 'Flax' and 'Glass' corresponds to the number of yarns used.

be too weak to withstand loads, so it started to crack slowly and with that the rovings were slightly pulled out. The tests were accompanied with periodic sounds, which strengthen this conclusion. Another feature that could have had an impact was the twisting of the samples. It seems that the rovings were twisted too much because with the twisting, the yarns are shortened and then when the force is applied in tension, they tend to untwist themselves.

Reference concrete prisms were tested first by a three-point bending test and then in compression. The results were consistent in all batches of specimens. The average compression strength was 44.75 ± 4.44 MPa and the flexural strength was 7.29 ± 0.47 MPa.

In addition, some of the reinforcements were placed in epoxy resin and polished to obtain a good image under a VHX-6000 microscope. These images are seen in Figure 4 with a close-up on the bottom, where individual fibrils can be seen. It shows us that the reinforcements were properly impregnated and that both materials are perfectly bonded without cavities or spaces.

4. CONCLUSION

Five different hybrid reinforcements combined from glass and flax were tested in thin plates of concrete. The four-point bending test was performed on plates

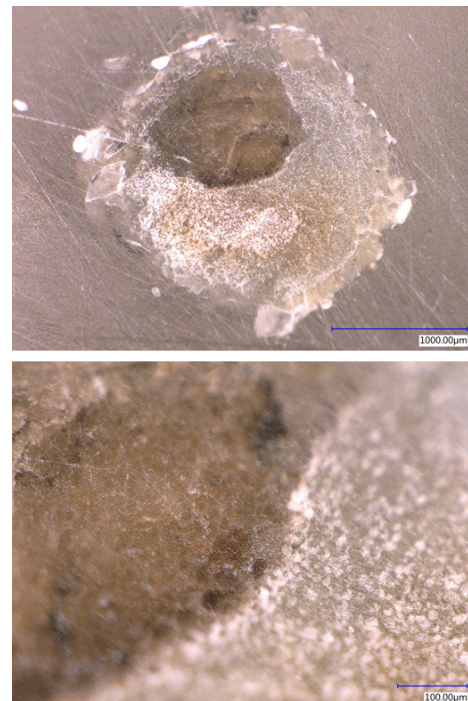


FIGURE 4. The cross section of 1Glass+1Flax roving.

with dimensions of $100 \times 20 \times 400$ mm. The results showed these conclusions:

- Twisting of yarns should not be done in an excessive

amount to reduce the phenomenon of 'untwisting' during the experiment.

- The combination of AR-glass and flax leads to lower strengths but also lower crack widths.
- The combination and impregnation of different yarns did not show any flaws in the cross section under the microscope.

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REFERENCES

- [1] S. Joshi, L. Drzal, A. Mohanty, S. Arora. Are natural fiber composites environmentally superior to glass fiber reinforced composites? *Composites Part A: Applied Science and Manufacturing* **35**(3):371–376, 2004. <https://doi.org/10.1016/j.compositesa.2003.09.016>
- [2] R. K. Malviya, R. K. Singh, R. Purohit, R. Sinha. Natural fibre reinforced composite materials: Environmentally better life cycle assessment – a case study. *Materials Today: Proceedings* **26**:3157–3160, 2020. <https://doi.org/10.1016/j.matpr.2020.02.651>
- [3] T. Rousakis. Natural fibre rebar cementitious composites. In *Advanced High Strength Natural Fibre Composites in Construction*, p. 215–234. Elsevier, 2017. <https://doi.org/10.1016/b978-0-08-100411-1.00009-1>
- [4] J. A. Halip, L. S. Hua, Z. Ashaari, et al. Effect of treatment on water absorption behavior of natural fiber-reinforced polymer composites. In *Mechanical and Physical Testing of Biocomposites, Fibre-Reinforced Composites and Hybrid Composites*, p. 141–156. Elsevier, 2019. <https://doi.org/10.1016/b978-0-08-102292-4.00008-4>
- [5] J. Wei, C. Meyer. Degradation mechanisms of natural fiber in the matrix of cement composites. *Cement and Concrete Research* **73**:1–16, 2015. <https://doi.org/10.1016/j.cemconres.2015.02.019>
- [6] M. Torres-Arellano, V. Renteria-Rodríguez, E. Franco-Urquiza. Mechanical properties of natural-fiber-reinforced biobased epoxy resins manufactured by resin infusion process. *Polymers* **12**(12):2841, 2020. <https://doi.org/10.3390/polym12122841>
- [7] T. Väisänen, A. Haapala, R. Lappalainen, L. Tomppo. Utilization of agricultural and forest industry waste and residues in natural fiber-polymer composites: A review. *Waste Management* **54**:62–73, 2016. <https://doi.org/10.1016/j.wasman.2016.04.037>
- [8] L. Yan, B. Kasal, L. Huang. A review of recent research on the use of cellulosic fibres, their fibre fabric reinforced cementitious, geo-polymer and polymer composites in civil engineering. *Composites Part B: Engineering* **92**:94–132, 2016. <https://doi.org/10.1016/j.compositesb.2016.02.002>
- [9] J. Hájek, T. Vlach, J. Řepka, V. Žďára. Verification of material characteristic of natural fibers for concrete reinforcement. *Acta Polytechnica CTU Proceedings* **47**:42–46, 2024. <https://doi.org/10.14311/app.2024.47.0042>
- [10] Hobby beton. [2024-08-29]. <https://www.merkur.si/hobbybeton/>
- [11] Lamepox 23 epoxy laminating resin 1230 g. [2024-08-29]. https://www.samsonkammik.si/lamepox_