

Introduction

- Around 10B tons of concrete are used every year, making it the most used man-made material [1].
- It has high compressive strength, but low tensile strength (5-8% its compressive strength) [2].
- Fibers in concrete:
 - Fiber-reinforced concrete (FRC) has increased tensile strength and crack resistance, among other properties [3].
 - Synthetic fibers (e.g., steel and polypropylene) are unsustainable, which has led to increased research on renewable natural fibers (NFs), such as hemp.
 - In concrete, the porosity and cellulosic structure of NFs makes them prone to degradation from hydrolysis, mineralization, and fiber debonding [4],[5].
- Using tensile testing and microscopy, this study will test the effects of two coatings on the durability and reinforcement ability of hemp twine in concrete.

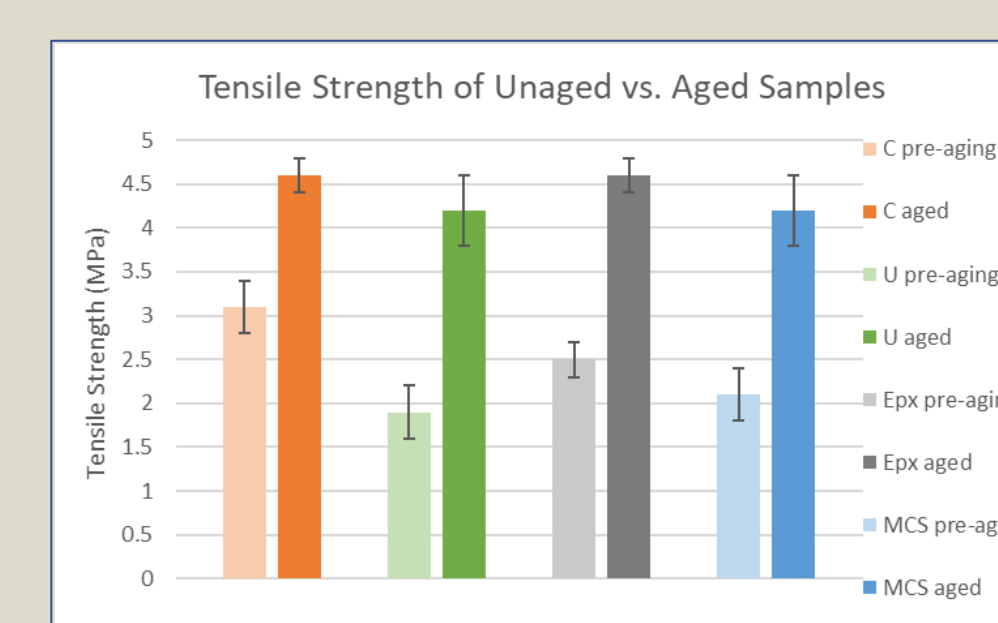


Figure 3: Comparison of tensile strengths before and after aging. For each column pair, the aged strengths are on the right.

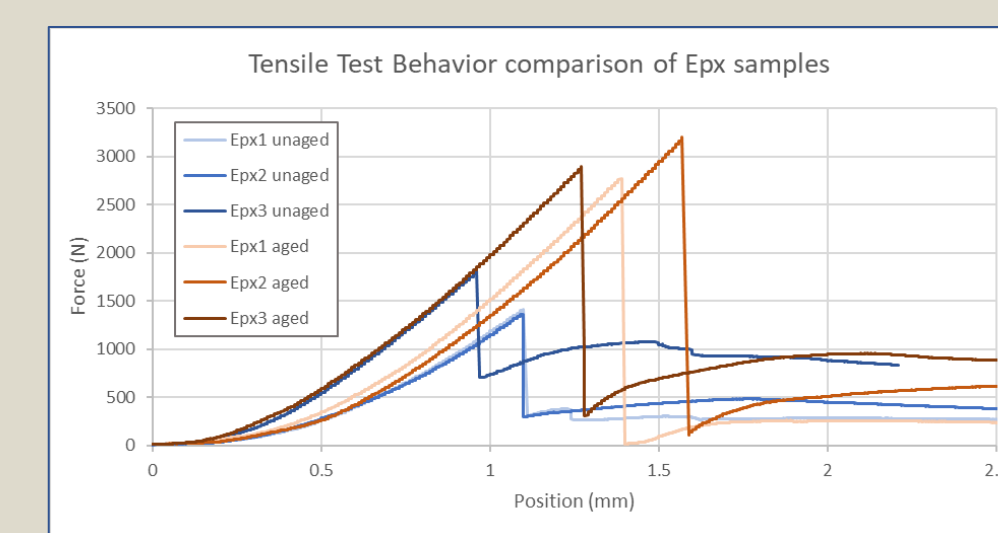


Figure 4: Tensile behavior of epoxy samples. Note the strength post-breakage.

Results

Tensile Testing

- Initial tensile strengths were 3.1±0.3MPa, 1.9±0.3MPa, 2.5±0.2MPa, and 2.1±0.3MPa for the control, uncoated, epoxy and MCS samples, respectively.
- After degradation, tensile strengths were 4.6±0.2MPa, 4.2±0.4MPa, 4.2±0.4MPa, and 4.6±0.2MPa for the control, uncoated, epoxy, and MCS samples, respectively.
- For the same order, these correspond to strength increases of 48.3%, 121.1%, 84.0%, and 100.0%. (see **Figure 3**). Continued curing during the wet/dry procedure is likely the cause of these increases.
- Only the epoxy samples were able to provide reinforcement after the concrete broke (see **Figure 4**). For the unaged samples, this was roughly 600N±200N, and for the aged samples, this was around 500N±200N.

Microscopy

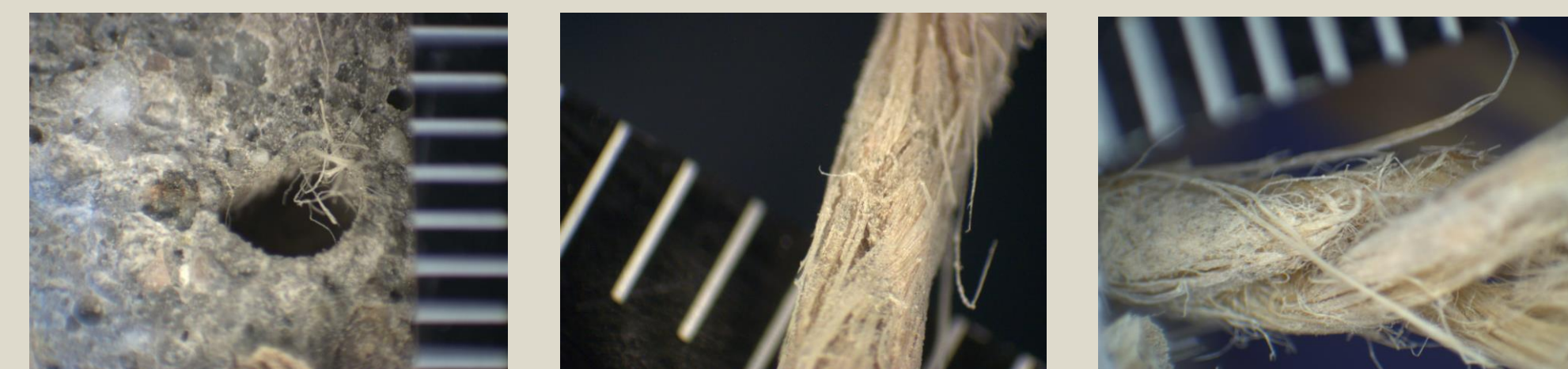


Figure 5: From left: twine hole, unaged twine, aged twine. (Agustines, 2022).

- For the uncoated samples, some fibers at the surface bonded with the concrete but these tended to detach from the twine (see **Figure 5**, left).
- Other than a slight loosening of the twine, wet/dry cycling didn't have a big effect (center, right).

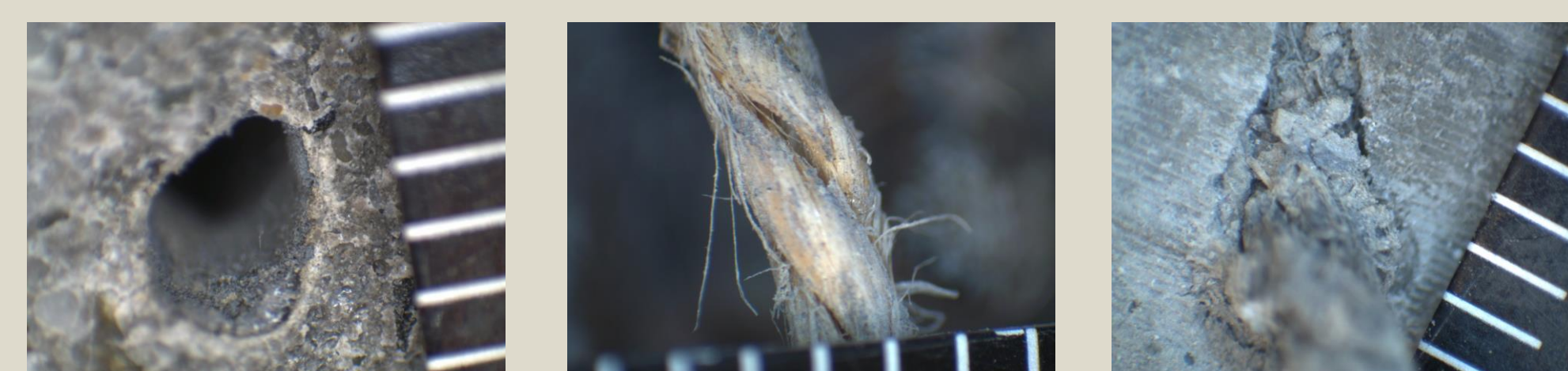


Figure 6: From left: twine hole, unaged twine, pullout sample (Agustines, 2022).

- For MCS-coated twine, microscopy revealed that the silica fume coating mostly stuck to the concrete (see **Figure 6**, left, center) allowing the twine to slip free. This was not changed due to the wet/dry cycling.
- The concrete only stuck to the surface of the coating (right).



Figure 7: From left: unaged twine, broken aged twine, aged twine (Agustines, 2022).

- For the epoxy-coated twine, microscopy showed that the epoxy coating tended to be shaved off during tensile testing (**Figure 7**, left), and that it likely penetrated beyond the twine surface (center).
- The twine was not visibly impacted by the aging procedure (center, right).

Sample Mass Monitoring

- The wet phase didn't fully soak the samples.
- The FRC samples absorbed less water during the 2nd air drying period.

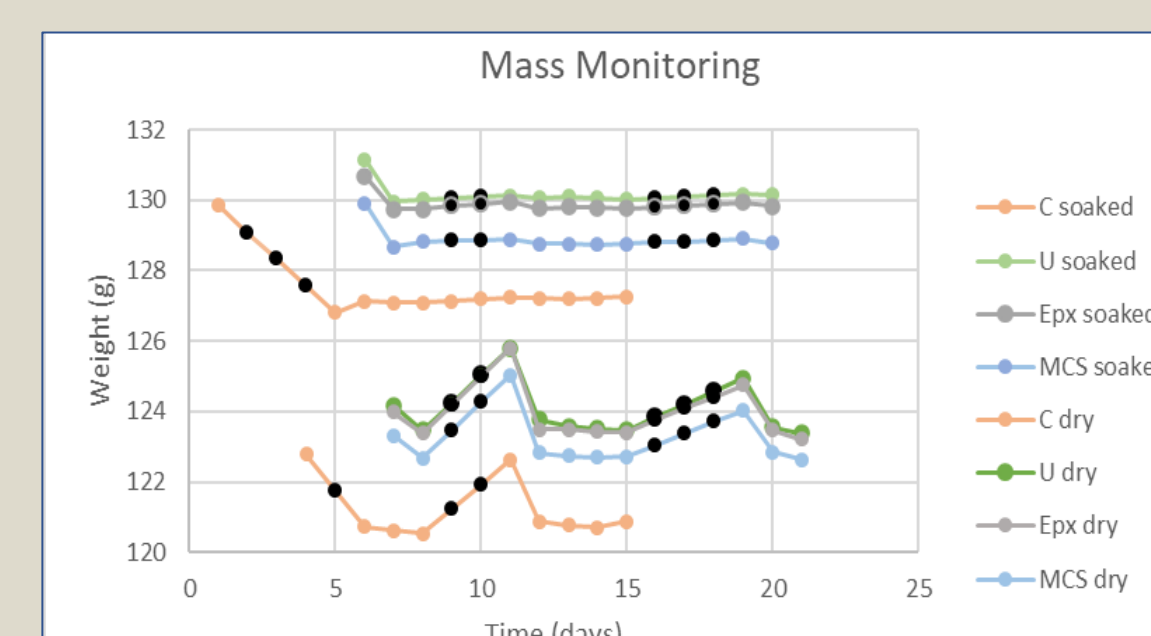


Figure 8: Mass monitoring graph. Soaked weights are above, dry weights below. Blackened areas are interpolations.

Materials and Methods

Hemp twine preparation:

- 3 batches of 3 cm strands: uncoated, epoxy coated, and methyl cellulose and silica fume (MCS) coated (see **Figure 1**). Methyl cellulose is a biodegradable adhesive, and silica fume is a pozzolanic ("cement-like") material.



Figure 1: From left: uncoated twine, MCS-coated twine, and epoxy-coated twine. Scale in mm. (Agustines, 2022)

Concrete sample preparation:

- "Dog bone" samples cast according to the ASTM C307-18 standard.
- 4 categories (6 samples each): control, uncoated, epoxy, and methyl cellulose silica (MCS) (see **Figure 2**).
- 10-11 fibers oriented lengthwise per sample.
- Half dog bones (3 per category) with 1 fiber half-embedded (see **Figure 2**).
- Cured for 28 days in water.



Figure 2: From left: curing dog bone samples, half dog bone samples, and the tensile testing setup (Agustines, 2022).

Degradation

- Wet/dry cycle: 4h in tap water, 18h in an oven at 60 C, and air drying/cooling time in between. 8 cycles using the oven and 2 using air (over weekends).
- Weighed samples before and after wetting to track changes (mass monitoring).

Testing

- Tensile testing of aged and unaged dog bones (see **Figure 2**) for comparison.
- Microscopy of half dog bones and tested samples to examine fibers and coatings.

Discussion and Conclusions

- It was hypothesized that the tensile strength provided by the twine would be an indicator of twine degradation. This was not generally found to be the case, due to weak twine-concrete bonding.
- From tensile testing and microscopy, 3 important points can be deduced:
 1. The spotty surface-level bonding of the uncoated twine and the concrete made the twine-concrete bond weak.
 2. Since the silica fume tended to stick to the concrete, allowing the twine to slip free, the methyl cellulose adhesive was ineffective. However, silica fume has the potential for strengthening the fiber-concrete bond if its bond with the fiber can be improved.
 3. The epoxy solidified the collection of fibers that make up twine into one hard "fiber". The shaved epoxy hints at how this fiber acted as a reinforcement: it dragged on the surrounding concrete as it was pulled out.

- **In conclusion**, testing natural fiber durability in concrete should not operate on the assumption that the fibers will provide tensile reinforcement, since this depends on the strength of the fiber-concrete bond. Also, twine and fibers will most likely behave differently when used as reinforcement, since the former is made up of multiple fibers.

Further research in this area should:

- Conduct comprehensive testing of epoxy-coated natural fibers
- Test different fiber contents
- Develop non-tensile based methods to test NF durability
- Study the differences between fibers and twine as reinforcement
- Look into why the FRC samples experienced a larger percent increase in tensile strength, compared to control samples.

References

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