Mechanical and toxicological aspect of carpentry wood waste biochar in concrete as partial cement replacement

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Introduction

Concrete is known for its long lifespan and durability in different environments. Exposure to various environmental conditions for several years could eventually contribute to the deterioration of its mechanical properties. This can be in most cases seen as cracks on the concrete surface or as concrete degradation, where concrete starts crumbling. The crumbled concrete particles can circle the ecosystem due to precipitation, surface water, or even wind. In aquatic ecosystems, leaching of various substances from concrete particles could appear. Leached substances could, therefore, have a toxic effect on the organisms inside the ecosystem.

Since concrete depends on natural resources for the production of natural aggregate and cement as key components, researchers are constantly looking for a sustainable replacement, which would not deteriorate concrete mechanical and phytotoxic properties. Several past studies confirmed that the use of different waste materials as partial cement replacement in concrete is one of the most promising ways of successful waste reuse and natural resource consumption reduction (Grădinaru et al., 2019; Mehta, 2001). One such material is wood waste biochar, where wood waste is used as the main feedstock for biochar production. Biochar as partial cement replacement in concrete could successfully replace a certain part of cement in concrete with no significant effect on its mechanical properties and in some cases even improved them (Legan et al., 2022; Senadheera et al., 2023). However, less is known about how biochar content in concrete affects its phytotoxicological potential, which is equally important as mechanical properties (Rodrigues et al., 2017).

When wood waste is used as feedstock for biochar production, the main concern is related to what was the purpose of this wood or where it has been used. No concern was reported regarding forestry wood waste, while carpentry wood waste raise a concern due to impregnation, which is used to protect wood from moisture and different organisms. Most of the preservatives contain heavy metals, which despite high temperatures during the pyrolysis of wood waste retain in biochar, while some volatilize into the air. From the biochar surface, heavy metals could leach into the ecosystem and cause toxic effects, which could also appear when biochar is used as cement replacement in concrete (Kim et al.,2020; Marcińczyk et al., 2023).

Materials and Methods

Water-to-cement ratio of conventional and biochar-containing concrete was 0.45. Ordinary Portland cement (CEM I 42.5 N) was used for concrete preparation. In biochar-containing concrete, carpentry wood waste biochar was used as 5% replacement of the cement volume in concrete. Mechanical properties of hardened concrete were determined according to Slovenian standards for testing of concrete (SIST EN 1015-11:2020) Samples of concrete were tested at the age of 28 days and 3 months after moulding.

Daphnia magna toxicity test was used for toxicological of biochar-containing concrete leachates. Acute test was performed according to OECD Guideline for testing of chemicals (*Daphnia sp.* Acute Immobilisation Test; No. 202; 2004). Daphnia magna growth medium (ISO Test water) was prepared according to OECD Guideline (*Daphnia sp.* Acute Immobilisation Test; No. 202; 2004). Leachates were prepared using growth medium and grinded concrete particles. After weighted concrete samples (10, 50, and 100 mg) were added to the growth medium in 500 mL Erlenmeyer flasks and put on the shaker. After 7 days, leachates were carefully filtered. First, 20 mL of concrete leachate and 10 daphnids were added in each flask, which were then covered with parafilm and kept in the dark for 48 h (21.0±0.2 °C). After 48 h the number of moving daphnids in each flask was determined.

Results and Discussion

Strength test results presented in Figure 1 showed biochar-containing concrete had 5% higher 28-day compressive strength than conventional concrete. 3-month strength test also revealed 3-month compressive strength of conventional and biochar-containing concrete was comparable. In the past review (Legan et al., 2022), it was found that the biochar dosage when replacing cement is crucial to avoid the decrease of compressive strength. Replacing 5% of cement was within the recommended biochar dosage range (0.5-24%) for strength increase, which was confirmed according to the presented results.

Results of 48 h toxicity test are presented in Figure 2. It was found that the inhibition of 10 mg L^{-1} conventional and biochar-containing concrete leachate was negligible (less than 1%). Although inhibition of 50 mg L-1 and 100 mg L^{-1} conventional and biochar-containing concrete were higher than in 10 mg L^{-1} concrete leachates, these differences are due to data distribution and large standard deviations insignificant. According to the OECD guideline (*Daphnia sp.* Acute Immobilisation Test; No. 202; 2004), the test is valid if, in the control sample (growth medium), not more than 10% of daphnids should have been immobilised. Results presented in Figure 2 showed, that regardless of the concentration of the concrete leachates, the inhibition values were up to 10%, which could indicate that the presence of leached substances from concrete did not significantly contribute to higher toxic effects and were comparable to control (growth medium). Therefore, the toxic effect of both concrete leachates could be negligible. However, additional replications of the test need to be done to confirm such findings with greater certainty and more exact values.

Figure 1. Compressive strength of conventional and biochar-containing concrete.

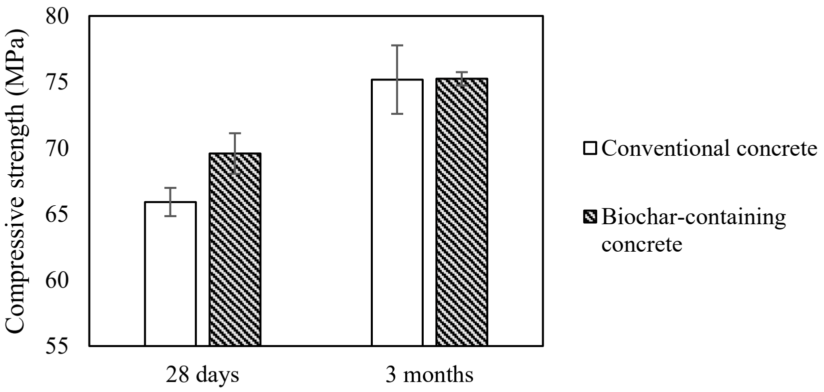
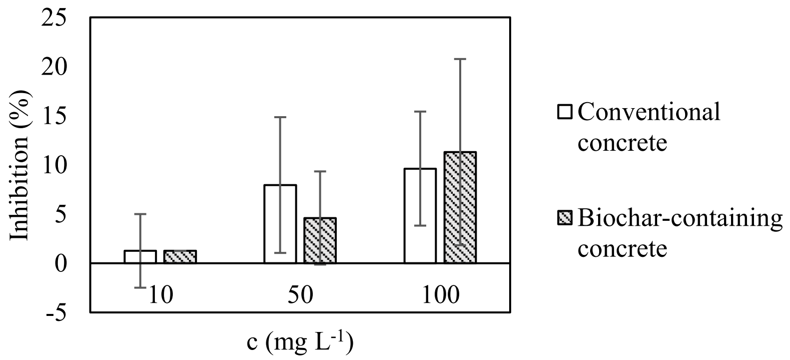


Figure 2. Results of toxicity test with *Daphnia magna*.



Conclusions

Strength results showed the compressive strength improved due to biochar in concrete as 5% cement replacement and confirmed its suitability regarding one of the crucial mechanical properties such as compressive strength for building materials, especially for concrete. According to toxicity results, it can be assumed that higher concentrations of biochar-containing concrete leachate showed more toxic effects on *Daphnia magna*, while in lower leachate concentrations conventional concrete was more toxic. Regardless of these results, none of the concrete leachate caused significant inhibition in investigated concentrations therefore, biochar-containing concrete can be marked as non-toxic in the aquatic environment.

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