Document: *"Final report of the bilateral research project between Austria and Serbia (Oead project number: RS 10/2022)"*
Project funded by: *OeAD – Agentur für Bildung und Internationalisierung*
Project number: *RS 10/2022*
Project uploaded to: *The report has been submitted on the OeaD (WTZ) online platform for project tracking*
Year of the report submission: *2024*

Final report
"BIO-based cementitious composites with recycled aggregates (BIO-gates)"

Objectives of the project

The construction industry is a major CO_2 emitter, with concrete production alone responsible for 8-9% of global greenhouse gas emissions. Concrete, the most widely used construction material, consists mostly of natural aggregates like sand and gravel, which make up 70% of its volume. The extraction of these aggregates leads to resource depletion, erosion, deforestation, and damage to ecosystems. Traditional concrete reinforcement, typically steel or synthetic fibers, further adds to environmental strain. In response to this information, research is focused on reducing CO_2 emissions and resource consumption in construction. Efforts using recycled aggregates from construction and demolition waste (CDW), and exploring natural fiber reinforcements. CDW, accounting for 30% of EU waste, offers an efficient way to replace natural aggregates in concrete. Additionally, fibers from plants like hemp, flax, and sisal provide sustainable alternatives to traditional reinforcement, reducing dependency on non-renewable resources and promoting eco-friendly materials. The project's objective was to design eco-friendlier fiber-reinforced concrete materials compared to conventional fiber-reinforced, natural aggregate-based cementitious concrete for outdoor applications subject to impact loads. The study focused on exposure class XC4, as defined by the European Committee for Standardization. The approach involved replacing natural aggregates with recycled aggregates and substituting traditional fibers (such as steel, glass, and synthetics) with hemp fibers.

Experimental campaign and results

Firstly, in Vienna (Asutria), the four sets of six prism specimens (with the dimension of 4x4x16cm^3) were prepared. These comprised one set with natural aggregate, another with recycled aggregate, and two sets of their counterparts with short hemp fibers (fiber length of 10 mm and a dosage of 0,5 vol%). After 28 days, the mortars' physical (density and water absorption) and mechanical properties (compressive- and flexural strength, along with energy absorption capacity) were examined. The results supported the justified use of recycled aggregate in fibre reinforced cement-based composites, but since there were dropped of the mechanical properties (compressive strength 41%, flexural strength 14% and energy absorption capacity 27%) it was decided that on the concrete level, besides a full replacement of the natural aggregate with the recycled aggregate, additionally a half replacement (50 wt%) will be conducted, to try to reduce the decrease of the mechanical properties.
Subsequently, the concrete cubes six groups of three specimens (15x15x15cm^3) were prepared in Novi Sad (Serbia), incorporating 0wt%, 50wt% and 100wt% replacement of natural aggregate with recycled material and additionally their counterparts with short hemp fibres (fiber length of 10 mm and a dosage of 0,5 vol%). In the second year of the project, these cubes underwent testing for in fresh state physical properties (air content and slump test) and in harden state physical- (density and water absorption) and mechanical properties (compressive- and wedge splitting test). Not all results are included in the report, as some are still being prepared for scientific publication. Firstly, the air content and workability proved to stay almost constant, when the natural aggregate was substituted with recycling one (in all dosages), which is presented in Table 1. After the fibres' addition, the air content increased and the workability decreased (Table 1).

Table 1. - Air content and Slump test results of all mixture: natural aggregate substitution with recycled aggregate in 0wt%, 50wt% and 100wt% and two groups of the concrete (group A - plain concrete; group B - fibre-reinforced concrete)

	Air content (%)	Slump (mm)
A0	2,2	23
A50	2,1	23
A100	2,2	23
B0	3	10
B50	3,2	12
B100	3,2	13

The increase in compressive strength observed in both groups (Group A - plain concrete, and Group B - fiber-reinforced concrete) following the addition of natural aggregate. It is also noteworthy that the compressive strength decreased after the introduction of fibers, likely due to the increased porosity of the composites caused by the fibers (Figure 3).

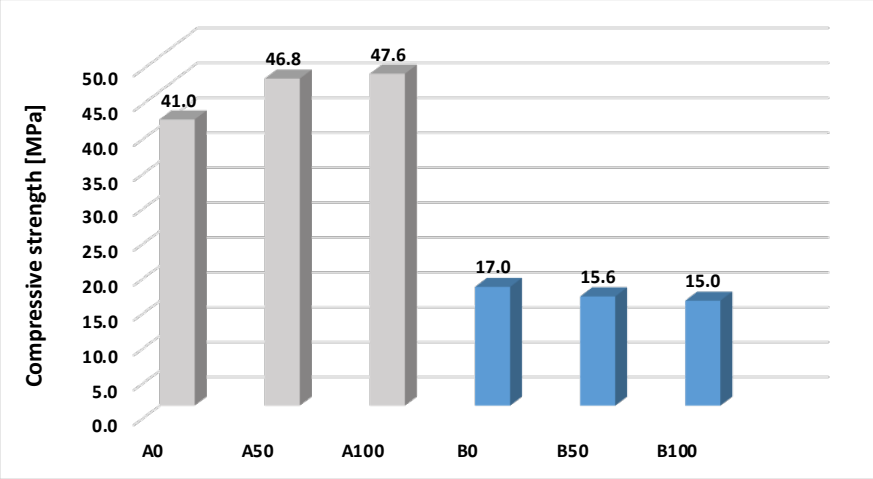

Figure 3. – Compressive strength of the concrete cubes with natural aggregate substitution with recycled aggregate in 0wt%, 50wt% and 100wt% (group A - plain concrete; group B - fibre-reinforced concrete)

Simultaneously, concrete plates (40x40x3.7cm^3) were manufactured and underwent 10 accelerated aging cycles of wetting and drying, followed by pull-out testing. At the same time, the same concrete plates were kept in water and tested at the same time as these underwent the accelerated aging, in order to investigate the composites' durability. For this purpose, the same six mixtures as in the case of the concrete cubes were used. A direct pull-off adhesion test was employed to assess the interfacial adhesion between concrete and an adhesive. Aluminium discs with a 50 mm diameter were bonded to the concrete surface and allowed to cure for 24 hours to ensure complete adhesion. The adhesive strength was measured using a pull-off adhesion tester, with the results recorded alongside the type of failure. To ensure data reliability, five concrete specimens from each group were tested. The results are shown in Figure 4.

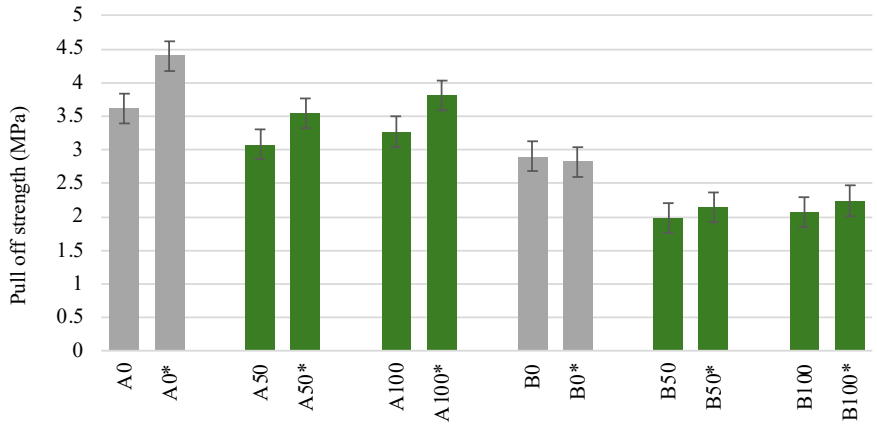

Figure 4. – Pull-off strength of of the concrete plates with natural aggregate substitution with recycled aggregate in 0wt%, 50wt% and 100wt% (group A - plain concrete; group B - fibre-reinforced concrete). * refers the values tested after the accelerated ageing.

As expected, the reference concrete made with natural aggregate without fibres demonstrated superior performance due to the quality of the aggregate used. Replacing natural aggregate with 50% and 100% recycled concrete aggregate as coarse aggregate resulted in a reduction in strength by 15% and 10%, respectively. This reduction is attributed to the inferior mechanical properties of recycling concrete aggregate, which often contains less dense and porous mortar compared to natural aggregate. The addition of fibres to the concrete mix further reduced pull-off strength. When compared to their corresponding mixtures without fibres, the strength reductions for concrete types B0, B50, and B100 were 20%, 35%, and 36%, respectively. This reduction can be linked to the “dilution” effect, observed during bulk density testing of fresh concrete. Saturated fibres dispersed within the concrete mix diluted it, decreasing bulk density and, consequently, the mechanical properties. All concrete types without fibres experienced strength gains after undergoing wet/dry cycles (accelerated ageing). The strength increases for A0, A50, and A100 were 22%, 15%, and 17%, respectively, which is likely due to carbonation, where $Ca(OH)_2$ converts to $CaCO_3$. This process alters the pore structure of the concrete, increasing its density and enhancing its strength, particularly surface hardness. In contrast, the accelerated ageing regime had a lesser impact on fibre-reinforced concrete. Within this group, B50 and B100 exhibited strength gains of 9%, while B0 showed a slight decrease of 3%.

Team meetings

In the first year of the bilateral project, we conducted the project team meetings in both countries, i.e., Austria (Vienna) and Serbia (Novi Sad), Figure 1, Figure 2. These meetings encompassed the delineation of project tasks, aligned with the initial year's implementation phases. Moreover, the exchange of materials for comparative experimental research in the laboratories of Vienna (Austria) and Novi Sad (Serbia), including recycled aggregate and hemp fibres, took place. In addition to this, the first specimens were prepared. Furthermore, the cement-based composites were designed, specifically mortar and concrete. In the following year all meetings in both countries were held to conduct the planned tests, analyse results and prepare the scientific publication.

In addition to regular meetings, both teams had the honour of organizing scientific conferences. The team in Vienna (Austria) organized a scientific conference on bio-based composites *5th International Conference on Bio-based Building Materials*, where the scientists from the whole world attended, and where also the team from Novi Sad had the opportunity to attend, and vice versa. The team from Novi Sad organized a regional conference *Conference Contemporary construction practice 2024*, where leading industrial companies, together with academia, had the opportunity to exchange best practice experiences and present their work and also the team from Vienna participated and presented their latest research.
Additionally, during the project, a PhD student, DI Bojan Poletanovic, from TU Wien (Vienna, Austria) had the opportunity to participate in the course "Selected Parts of Material Science" at the University of Novi Sad and pass the exam, as part of an Erasmus cooperation established through the bilateral project between TU Wien and the University of Novi Sad.

Figure 1. – Meetings in Vienna (Austria) of the team Novi Sad (Serbia)

Figure 2. – Meetings in Novi Sad and Divcibare (Serbia) of the team Vienna (Austria)

Further cooperation perspective

Building relationships between the research teams, along with exchanging expertise, knowledge, and ideas, forms the essential foundation for future collaboration. Sharing experiences from both national and international projects will assist the teams in preparing and submitting future joint proposals. As a result of this collaboration, both teams—now significantly expanded—have successfully submitted and secured another bilateral project (Project No: RS 11/2024), titled "Green Micro-reinforced Building Composites with Agricultural By-products," which will serve as a continuation and enhancement of the previous research. The strong

foundation for future collaboration is one of the most valuable outcomes of this partnership. The expertise, experience, and mutual trust gained throughout the project will be crucial for planned future cooperation in European research programs, such as Horizon 2020, Life+, Eurostars, and other bilateral/trilateral joint research initiatives, including the Austrian Science Fund's (FWF) Joint Project. Since both teams are part of the European Danube region, a joint research proposal is also planned within the EUREKA Danube Region Programs and/or the Interreg Danube Transnational Program.

Publications, presentations

Finished:

1. Supic, S., Poletanovic, B., Radonjanin, V., Malesev, M., Merta, I., & Pantic, V. (2024). Influence of accelerated ageing on pull-off strength of concrete produced with recycled concrete aggregate and blended with hemp fibres, IIn GNP 2024 PROCEEDINGS (pp. 619–626).

2. B. Poletanovic, I. Merta, (2024), Durability of the hemp fibre reinforced geopolymers, Conference Contemporary construction practice 2024, Ruma, Serbia

3. I. Merta, (2022). UPCYCLING CONRETE: recent research, future trends [Keynote Presentation]. 28. Congress of the society for testing and research of materials and construction of Serbia and 9. Congress of the association of the industry clay products of Serbia, Divčibare, Serbia.

4. I. Merta (2023), Recycled Aggregate Concrete – current challenges, [Keynote Presentation]. 26th Congress of the Society of Chemists and Technologists of Macedonia (SCTM), Ohrid, Republic of North Macedonia.

In submission process:

1. Supic S., Poletanovic B., Rodnjanji V., Malesev M., Pantic V., Merta I., Influence of the recycling aggregate and short hemp fibres on the physical and mechanical properties of cement-based concrete, Construction and Building Materials, expected in 2025.