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EXPERIMENTAL STUDY OF EFFECT OF RECYCLED AGGREGATE ON THE BEHAVIOUR OF REINFORCED BEAM ELEMENTS

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Abstract: *This article deals with a numerical analysis of concrete beam elements. The main goal is to verify the use of recycled concrete in load-bearing elements under bending strain. Concretes with two types of recycled aggregate namely recycled concrete and recycled masonry were compared with a normal reference concrete. The concretes beams were designed with the same geometry, reinforcement, and same concrete strength class but with different aggregates. The major differences in performances between the individual specimens are caused by the effect of the lower modulus of elasticity of recycled aggregate concrete as well.*

Keywords: Recycled aggregates, Concrete, Bending, Beam, Deflections.

1. Introduction

The words ecology and sustainability are getting more publicity in recent years in the world and especially in developed countries in Europe. The European Green agreement aims to ensure that Europe becomes the first climate-neutral continent by 2050. Construction is one of the segments that have a high share of greenhouse gas emissions. Concrete recycling is one of the ways to reduce the carbon footprint in construction.

The paper deals with the comparison of the beams of identical dimensions and reinforcement. However concrete material is different. The beam made of recycled concrete aggregate and recycled masonry aggregate is compared with the reference beam made of normal concrete mix. Different deformation and strength properties of concrete indicate different behaviour and values of bending resistance and deflections.

2. Experiment

Three beams of the same dimensions 150x350x4500 mm were supported by steel I profile and loaded by a typical 4-point bending load scheme (*Fig. 1*). The loading process was defined by an applied force, one step was equal to 2.5 kN. The results of the experiment are listed at the end of the article in comparison graphs. The beams were made by company ERC-tech Inc. and tested in Laboratory TAZÚS, Brno.

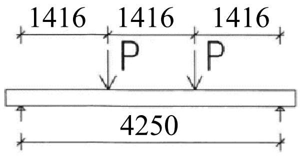

Fig. 1: 4-point bend load scheme

Properties of concretes were determined from tests, in particular modulus of elasticity and compressive strength (*Tab. 1*). A tension test of reinforcement bars was not performed. Reinforcement class B500B

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according to Eurocode 2 with the mean yield strength of 550 MPa and modulus of elasticity 200 GPa was used. The aragement of the reinforcement is presented in *Fig. 2*.

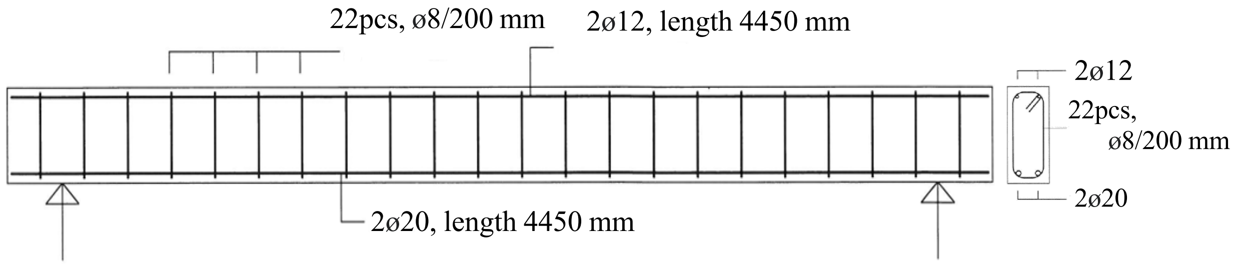

Fig. 2: Scheme of reinforcement of the beam

Tab. 1: Table of tested parameters of concretes

Concrete mixture	Cube compression strength [MPa]	Modulus of elasticity [GPa]
reference concrete	37.8	30.5
concrete from recyclated aggregate - brick	42.2	12.9
concrete from recyclated aggregate - concrete	40.0	18.6

3. Non-linear analysis

The model was analysed in Sofistik computing program, particularly in ASE module. The non-linear finite element (NLFEA) model is shown in *Fig. 3*. Concrete was defined by elastoplastic material with a non-associated flow rule called LADE which is recommended for concrete material (Sofistik ASE manual, 2022). These material characteristics are based on three-dimensional failure criterion with parameter η_1. It requires 3 parameters for concrete and rocks, two for characterization of the strength (in our case compression and tension), and *m* parameter which describes the curvature of the failure surface in meridian planes (Lade, P.V., 2014). This parameter can vary for concrete between 1 and 2. (Sofistik AQUA manual, 2022). Concretes elements were created by 3D BRIC elements, and reinforcement was generated as 1D BEAM elements. Supports were created as springs with nearly infinite stiffness in the axial direction, no lateral stiffness, and rupture stress converging to 0. The load was generated by deformation. I_1 and I_3 are parameters that define the stress state of the material in the three-axis system and $\rho.a$ is atmospheric air pressure.

$$\eta_1 = \left(\frac{I_1^3}{I_3} - 27\right) * \left(\frac{|I_1|}{\rho.a}\right)^m \tag{1}$$

$$I_1 = \sigma_{I} + \sigma_{II} + \sigma_{III} \tag{2}$$

$$I_3 = \sigma_{I} * \sigma_{II} * \sigma_{III} \tag{3}$$

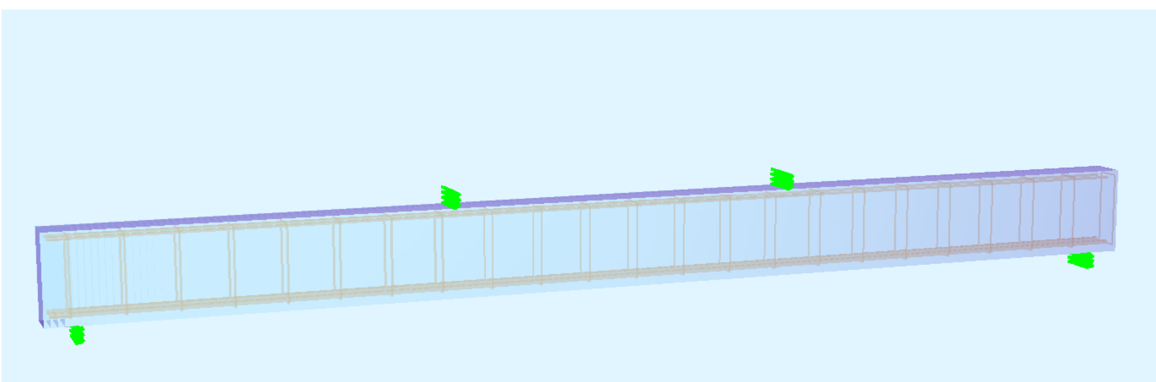

Fig. 3: Non linear finite element model of the reinforced concrete beam

4. Comparing the results

Deflections of beams in the middle of the span are presented in *Fig. 4* to *Fig. 6*. The results of the loading test are compared with NLFEA models with variable factor *m* (1.25, 1.6, 2.0). The graphs show that NLFEA model has lower stiffness compared to experimental beams. Models of beams created from recycled materials (*Fig. 5* and *Fig. 6*) show adequate values of bending resistance achieved by yielding of the reinforcement. Model for reference concrete overestimates the experimental performance.

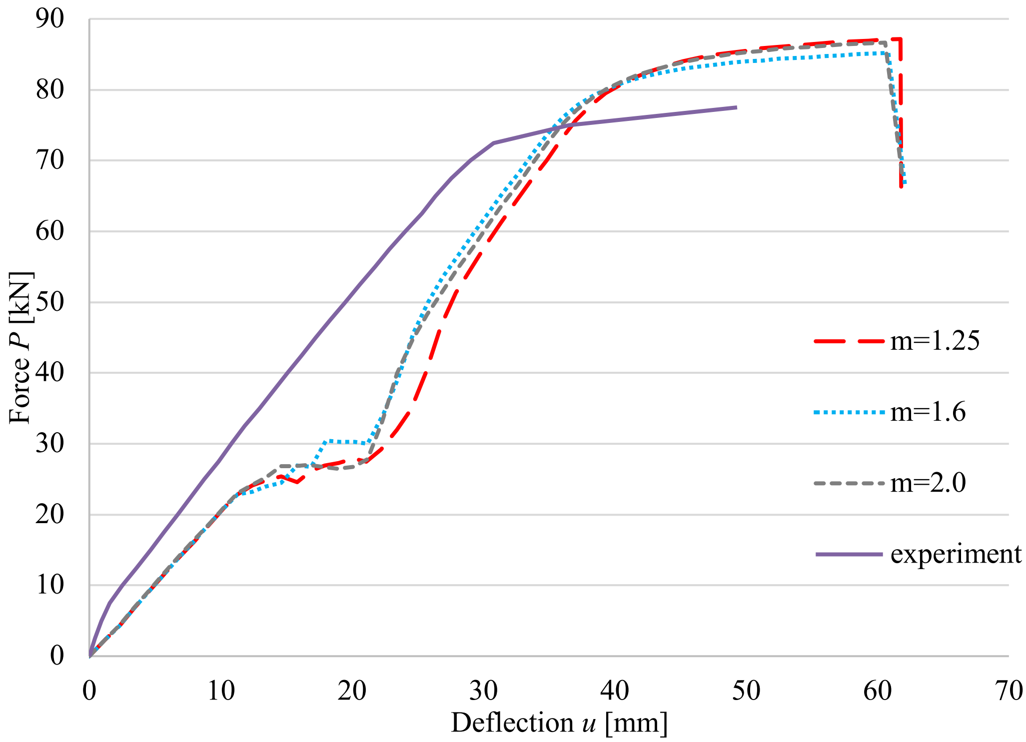

Fig. 4: Force – deflection diagram, reference concrete

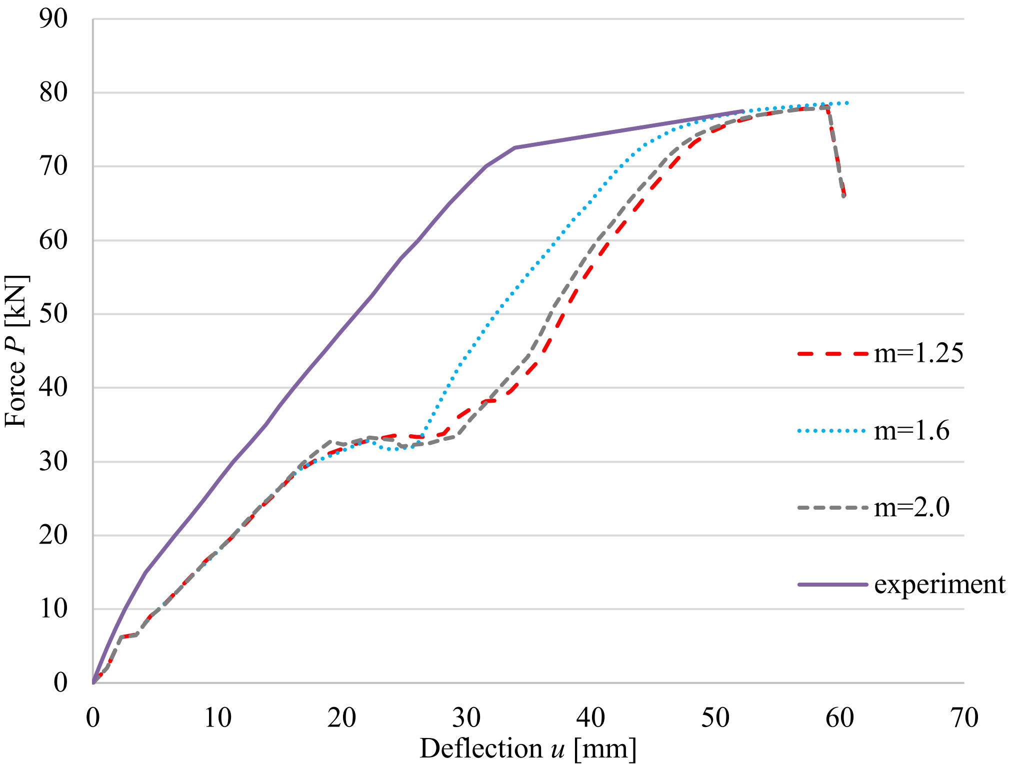

Fig. 5: Force – deflection diagram, recycled aggregate – brick

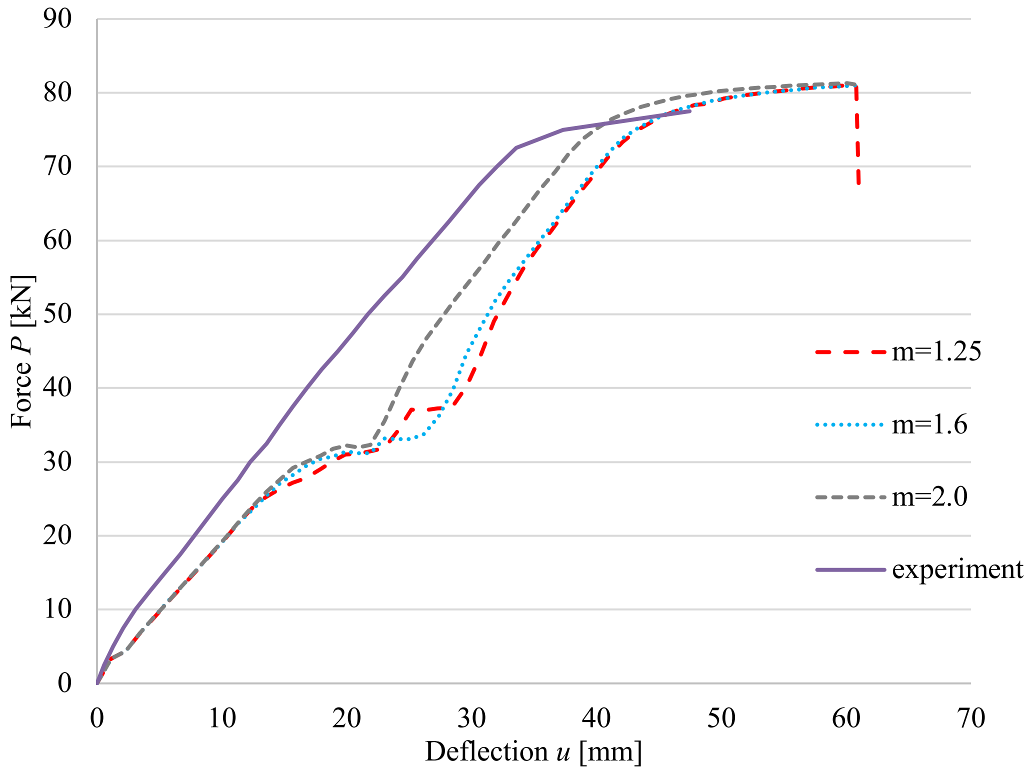

Fig. 6: Force – deflection diagram, recycled aggregate – concrete

5. Conclusion

The non-linear analysis confirmed the results of the experiment. Different values for modulus of elasticity caused by different aggregate mixtures affect final deflection only in a small manner. Although concrete mixtures made from recycled aggregates got greater strength in compression. The ultimate bendindg resistance of beams made from recycled aggregates is comparable to the reference beam.

- Based on experiments, despite the considerably reduced value of the modulus of elasticity of concretes with recycled aggregates the beams showed only 10 % greater deformation when the yield point was reached.
- According to the experiment and analysis, the beam from reference concrete with lower strength has similar bending resistance
- Factor m in the analysis influenced the behaviour of beams only after the stage of cracking. It does not affect the overall bending resistance.

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