MODELLING OF FREEZING AND THAWING EFFECT ON THE DEFLECTIONS OF RC BEAMS MADE OF RECYCLING AGGREGATE CONCRETE

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Summary:
Concrete resistance to cyclic freezing and thawing is typically controlled on the samples in an unloading state. Very few experimental tests have been only conducted on the concrete samples subjected to combined static load and frost effects. An experimental program was undertaken by the research team of Bialystok University of Technology to study the behaviour of structural members made of recycling aggregate concrete (RAC) subjected to long term static load and freezing and thawing cycles. In the paper the authors describe an innovative testing procedure for RC model beams made of RAC under constant bending moment and cyclic freezing and thawing. The aim of such studies was to clarify the effects of interaction of climatic and mechanical load on the deformability and cracking state of RC beams made of recycling aggregate concrete. The beams located in the climatic chamber have achieved over doubled deflection values in comparison with analogical beams loaded in room temperature. The tests made on an innovative beams made of recycled aggregate concrete with an insert of high strength concrete showed significantly increased RC beam's stiffness, reducing their deflections by over 30%. The results of current, as well as further planned research will let us develop the guidelines for using recyclable materials in concrete structural elements. Both adopted technical solutions and research procedure, as entirely innovative designs, were enclosed in submission to the patent register.

Keywords: recycled concrete, freezing and thawing cycles, static and thermal loads, RC beam deflections

Introduction

In accordance to sustainable development of the building industry and, furthermore, increasing demand for building materials and raising amount of construction concrete wastes (produced for example as a result of demolitions or rebuilding the existing structures), the need of recycling such wastes becomes even more sensible, also demanded by the EU (Council Directive 91/156/EEC, 1991). One of the responses to this need is the use of recycled aggregate concrete (RAC). The previous studies done by some researches (Ajdukiewicz and Kliszczewicz, 2012), (Xiao and Zhang, 2007), (Rahal, 2007) or (Lapko and Grygo, 2013) showed that the application of concrete waste for recycled aggregate concrete (RAC) revealed some significant differences in the behavior of structural elements made of RAC compared to members totally made of natural aggregate. The beams made of RAC cracked earlier and showed greater deflections at comparable loads, as well as grater shrinkage strain and creep characteristics.

The previous studies shows that the use of RAC in structural members is associated with an increased risk for the building structures. The study on application of RAC in structural members like RC beams were conducted in the Bialystok University of Technology (Lapko and Grygo, 2010, 2013). Apart from the compressive and tensile strength of RAC, the durability of such concrete is a very important aspect, influenced by freezing/thawing effect (Yao et al., 2012). The research of the RAC carried out up to now was conducted on the unloaded samples. Very few experimental tests have been only conducted on the concrete samples subjected to combined static load and frost effects, (Mu et al., 2002), as can be seen in Fig. 1. The use of such materials in structures requires a brand new approach, taking into consideration the interaction of stress state and deformation of sample elements subjected to static load and freezing/thawing cycles.

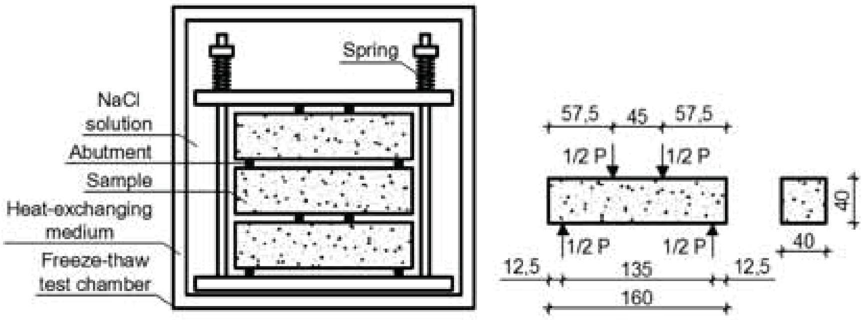

Fig.1. Combination of mechanical load with freezing and-thawing cycles and chloride penetration (Mu et al., 2002)

Essence of research, shown in the figure above, make up determine the influence of combination different kind of loads: static, climatic and physical-chemical effects. In Fig. 2 there are presented schematically research concrete stands for testing of concrete beams (1800×130×180mm) reinforced with glass FRP composite bars (Laoubi et al., 2006). The beams were exposed to 100, 200 and 360 freeze/thaw cycles (−20°C to +20°C) either in an unstressed state or loaded in bending to cause a tensile stress equals to 27% of the ultimate tensile strength of the GFRP bar. The conditioned beams were tested up to failure in a four-point bending set-up over a clear span of 1500 mm.

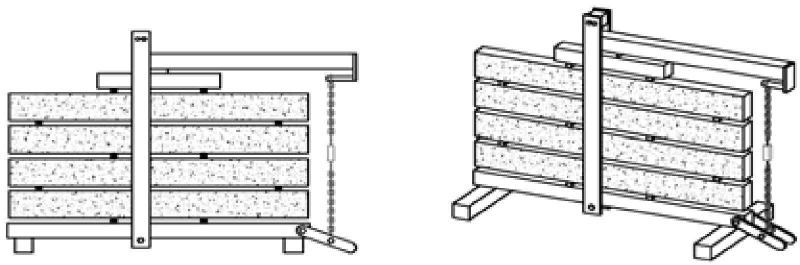

Fig. 2. Method of testing of concrete prisms under freeze-thaw cycles and sustained load (Laoubi et al., 2006)

The deep overview of recent scientific publications on deformability (deflections, strains and crack widths) in RC beams made of recycling aggregate concrete (RAC) shows that there is the lack of tests results for members under combined sustained static load and on freezing and thawing cycles.

An experimental program has undertaken by the research team of Bialystok University of Technology to study the behaviour of structural elements made of recycled aggregate concrete (RAC) in response to long-term static load and freezing/thawing cycles (Lapko et al. 2013). In the paper the authors describe an innovative testing procedures for RC model beams made of RAC under constant bending moment and cyclic freezing and thawing. The aim of such studies was to clarify the effects of interaction of climatic and mechanical load on the deformability and cracking state of RC beams made of recycling aggregate concrete.

Conducted research

The experimental investigation on RC model beams has been conducted with the use of following types of model RC beams:

- SR - RC beams entirely made of recycled aggregate concrete,
- SN - reference RC beams entirely made of natural aggregate concrete,
- SRW - innovative RC beams made of recycled aggregate concrete with the insert of high-strength concrete (HSC) located in the compression zone (Fig. 3).

The concept of such innovative beams was developed in the Bialystok of University of Technology (Grygo et al., 2013).

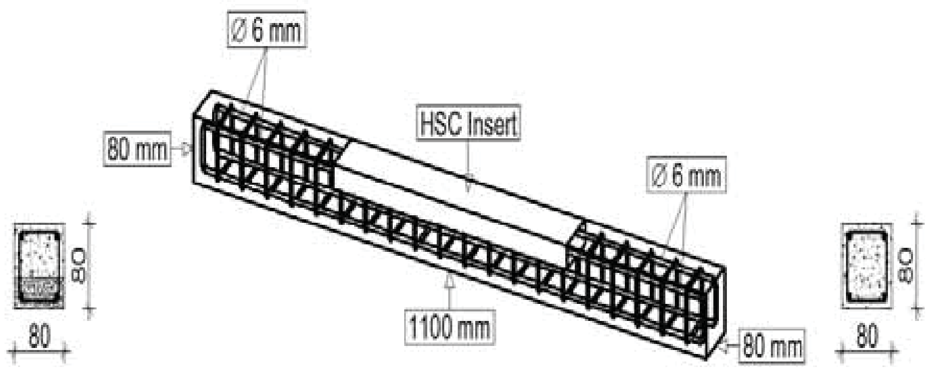

Fig. 3. Scheme of innovative SRW beam made of recycling aggregate concrete with HPC-HSC insert (identical dimension and reinforcement was applied in all SR and SN beams)

After 28-days-curing of concrete, the compressive strength, bending strength and modulus of elasticity of concrete were tested. The loading forces causing the cracks appearance was also defined. The results of the material tests are given in the Table 1.

Table 1. Properties of concrete used in the tested RC model beams after 28 days of curing

CONCRETE PROPERTIES	SN	SR	HSC
Mean compressive strength [MPa]	30,68	31,20	109,63
Mean values of concrete modulus of elasticity [GPa]	29,75	27,73	48,63

For the purposes of the studies on influence of the freezing/thawing cycles on the RC beams deflections an innovative stand shown in the Fig.4 has been designed. The three-point loading scheme was assumed. The tested free standing model beams were turned back during the long term tests so that the tensioned zone was located in the upper part of model beam.

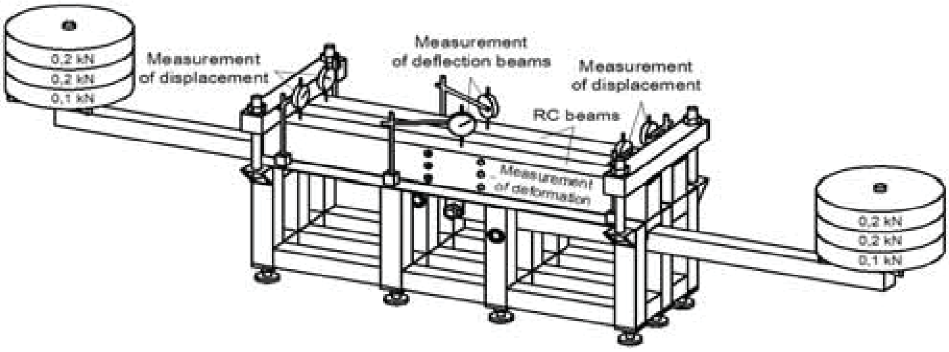

Fig. 4. The scheme of research stand with two tested model beams under static load and freezing and thawing cycles (Lapko et al., 2013)

The stands were located in the climatic room (with the working place of 2000 x 3000 mm), allowing the temperature changes from -20 ºC to +25ºC in a 4-hour period. Three stands were placed inside the climatic room, while the fourth - the reference one - was located outside the climatic chamber in room temperature. Two model beams were placed on every stand. The tested RC beams were subjected to the concentrated loading force of 3.50 kN passed on by the 7:1 lever ratio extension arms with the load of 0.50 kN placed on their ends (Fig. 5).

The conducted research has been planned for 200 full cycles of freezing and thawing, with the continuous measurement of beams deflections (in the mid span and on the supports) using waterproof dial indicators. There were also measured concrete strains by the use of Demec extensometer in the mid span of the tested beams (see Fig.4). The program of a continuous research enclosed an initial measurement of concrete compressive strength, flexural strength and value of elasticity module, repeated for every 25 cycles. The plan of experimental works are schematically shown in Fig. 6.

Fig. 5. The research stands with the model RC beams in the climatic room during the tests

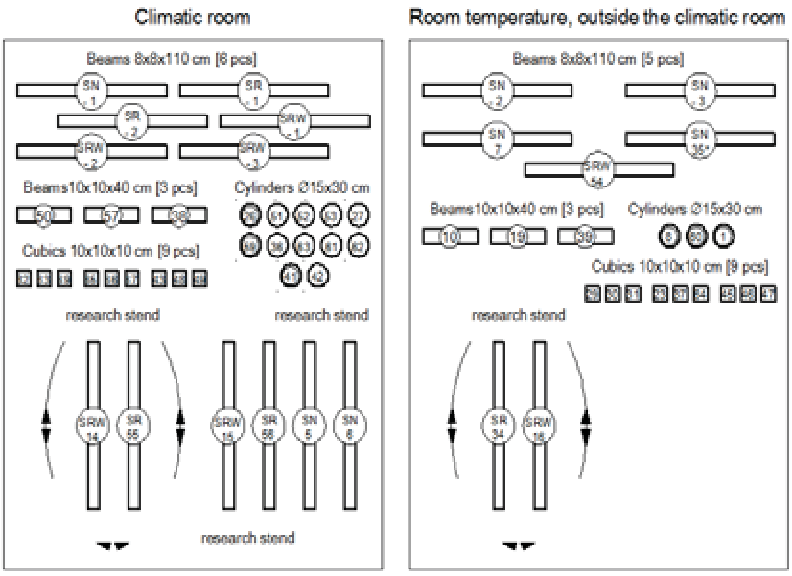

Fig. 6. Plan of experimental tests for combined static load and freezing and thawing cycles

The properties of recycling aggregate concrete (cube and cylinder strength for compression and flexural tension using concrete prisms) were successively tested for every 25 cycles of freezing-and thawing cycles.

Chosen test results

In this paper the results of registered twenty-four-hour deflection changes of the RC model beams subjected to the static load equal to 350 kN combined with freezing/thawing cycles (in the case of beams located in the climatic room). The diagrams of beam deflections versus number of freezing/thawing cycles values are presented in Fig.7 for beams made of RAC (series RW) and innovative beams with an reinforcing HPC-HSC insert (Series of SRW).

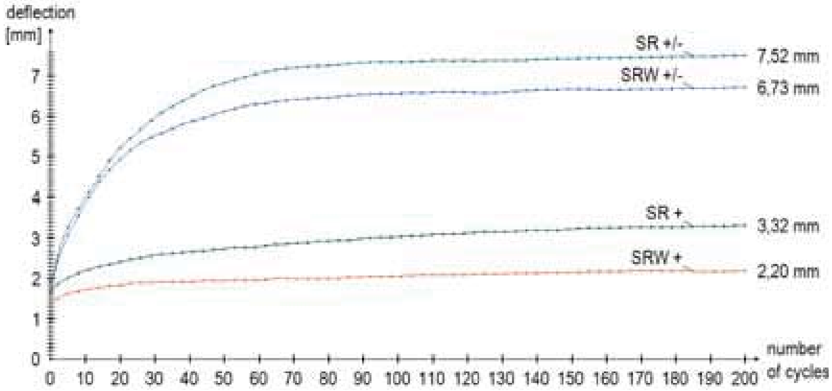

Fig. 7. Diagrams of the beams deflections versus number of cycles for the beam types: SR+/- and SRW+/- (tested in climatic room) and reference beams SR + and SRW+ (tested outside of climatic chamber in constant room temperature)

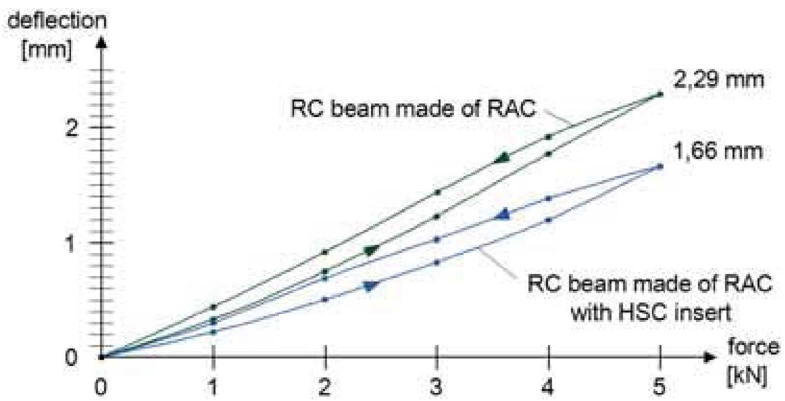

Fig. 8. The changes of deflections versus loading force for the beams type SR and SRW after 50 freezing/thawing cycles (from tests in the testing machine) (Lapko et al., 2013)

Moreover, an additional research procedure was carried out, on the basis of deflection and deformation measurement in accordance to these beams, which were exposed to the same static and thermal loads. After 50 freezing/thawing cycles, the beams were released and subjected to the loading forces in the testing machine outside the climatic room. The results of these tests are shown in Fig. 8.

After 95-days- curing of concrete samples in freezing/thawing conditions (after 200 cycles), the results of concrete compressive strength are presented in the Table 2.

Table 2. Mean compressive strength of concrete [MPa] used in the tested beams after 95 days of curing in different temperature condition

Time of curing - Series of samples	28 days (room temperature)	95 days (constant room temperature)	95 days 200 cycles of freezing/thawing
normal concrete - Series SN RAC - Series SR HPC - HSC	30,68 31,20 109,63	38,33 ↑ 25% 43,13 ↑ 38% 125,50 ↑ 14%	33,19 ↓ 13% 35,64 ↓ 17% 124,20 ↓ 1%

It can be clearly seen the increase of concrete compressive strength obtained for samples kept 95 days in constant room temperature compared to the age of 28 days, whereas the samples located in the climatic room with freezing/thawing cycles revealed visible decrease in concrete compressive strength in comparison with reference samples.

The results of the elasticity module of concrete tests (repeated every 25 cycles) are given in the Table 3.

Table 3. Changes of module of elasticity of concrete [MPa] depending to number of freezing/thawing cycles

Samples in climatic room	28 days	25 cycles	50 cycles	75 cycles	100 cycles
SN +/- SR +/- HSC +/-	28 27 49	28 26 50	29 28 51	30 29 50	31 27 52
Samples in constant room temperature	28 days	42 days	56 days	70 days	84 days
SN + SR + HSC +	31 28 49	31 28 52	33 29 52	34 29 53	36 31 54

Some number of samples are still in climatic room under freezing/thawing cycles and the tests on modulus of elasticity will be continued till to minimum 200 cycles.

Conclusions

1. The results, obtained so far confirm a significant influence of interaction of static load and freezing/thawing cycles on RC beams deflections. The RC beams made of recycling aggregate concrete located in the climatic room with changing temperature have achieved over doubled deflection values compared to analogical reference beams loaded outside climatic chamber in constant room temperature. This effect can be explained on the basis of decrease of beam stiffness due to destruction of concrete.

2. The tests made on an innovative beams made of recycled aggregate concrete with an insert made of HPC-HSC showed significantly increased RC beam's stiffness, reducing their deflections by over 30%.

3. The results of current, as well as further planned research, will elaborated the guidelines for the use of recycled aggregate concrete (RAC) in structural elements taking into account the durability criterion depending on effects of RAC resistance against freezing and thawing cycles.

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