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EXPERIMENTAL STUDIES ON RC BEAMS MADE OF RAC WITH HSC INCLUSIONS IMPROVING THEIR STRUCTURAL BEHAVIOUR

The paper presents the effect of strengthening of precast RC flexural members made of recycled aggregate concrete (RAC) using a inclusions made of High Strength Concrete (HSC). This concept is based on precast concrete inclusions made of HSC located in the most stressed compression zone of the bending elements. The research was carried out on simply supported beams made of normal strength concrete with precast HSC inserts located in the most stressed zone of the innovative beams in comparison to the reference homogeneous RC beams. The experimental studies concerned on deformability flexural capacity under short and long term loading. The results of investigation as well as numerical and theoretical simulations, which have been performed for the tested beams, reveal some positive effects, such as more that 20% higher flexural capacity and stiffness of the beams with HSC inclusions compared to the reference homogenous beams. The results allow to conclude that in the future, some part of precast concrete production can be used in the building process.

1. Introduction

For several years developed countries put more emphasis on energy conservation, renewable energy sources and waste recycling. The construction and use of buildings in the EU account for about half of all our extracted materials and energy consumption and about a third of our water consumption [1], [2], [3]. The sector also generates about one third of all waste4 and is associated with environmental pressures that arise at different stages of a building's life-cycle including the manufacturing of construction products, building construction, use, renovation and the management of building waste.

A combination of policies would help create a full recycling economy, such as product design integrating a life-cycle approach, better cooperation along all market actors along the value chain, better collection processes, appropriate regulatory framework, incentives for waste prevention and recycling, as well as public investments in modern facilities for waste treatment and high quality recycling. Better construction and use of buildings in the EU would influence 42% of our final energy consumption, about 35% of our greenhouse gas emissions and more than 50% of all extracted materials; it could also help us save up to 30% water [2].

Life-time costs of buildings should increasingly be considered rather than just the initial costs, including construction and demolition waste. Better infrastructure planning is a prerequisite in achieving resource efficiency of buildings and also mobility. Poland, along with its accession to the European Union, has been obliged to comply with the environmental protection requirements. European Union Directives predict a systematic increase of 8-10% of annual amount of processed waste. By 2020, waste is managed as a resource. Waste generated per capita is in absolute decline. Recycling and re-use of waste are economically attractive options for public and private sectors due to widespread separate collection and the development of functional markets for secondary raw materials. More materials, including materials having a significant impact on the environment and critical raw materials, are recycled.

Consumption of resources and related environmental impacts throughout a building's lifecycle can be reduced by [1]:

• Promoting better design that weighs resource use against the needs and functionality of the building and considers scenarios for deconstruction;

• Better project planning which ensures a greater use of resource and energy efficient products;

• Promoting more resource efficient manufacturing of construction products by, for example, using recycled materials, reusing existing materials and using waste as a fuel;

• Promoting more resource efficient construction and renovation by, for example, reducing construction waste and recycling/re-using materials and products so that less is sent to landfill.

The recycling or reuse of materials or even whole products is increasingly important as a means to improve the efficient use of materials and to avoid negative impacts associated with virgin material. However, the overall balance depends to a large extent on the existence of an efficient recycling system at local, regional or national level which presents an attractive and cost-efficient alternative to landfill. The attractiveness of recycling alternatives is governed by the length of transport distances to recycling sites, achieving the necessary level of purity of the recycled materials and recycling and production processes. Within the framework, special attention will be given to increasing the use of recycled materials and the reduction of construction and demolition waste (CDW). CDW makes up a third of total waste generated in the EU. A large majority of CDW is recyclable but with the exception of a few Member States recycling up to 90%, the average recovery for EU is just below 50%.

Concrete is the most used material in buildings and its recycling reduces natural resource depletion and landfilling of waste. Concrete can often be recycled at demolition or construction sites close to urban areas where it will be reused thereby reducing transport demand with savings in cost and related emissions. The research concerning concrete made with the use of secondary aggregates has been conducted for years in many countries. In 1977, Japan developed the first world's standard for concrete made of recycled aggregates. In 1985, the first international conference on problems with production of this concrete was organized in Rotterdam. The problems with the use of secondary aggregates were noticed in the available literature and scientific studies [5, 6, 7, 8, 9].

It should however be noted that the use of recycled aggregate concrete carries some dangers. One of these problems is the high porosity of such aggregate which is the result of the presence of old cement mortar in its composition. This old cement mortar, which surrounds natural aggregate, can cause its increased absorption and shrinkage of concrete. Another problem is the use of concrete demolition with different properties. Those aggregates are obtained from demolition materials with various primary strength ranging from 5 to 40MPa. The reduction of compressive strength of the concrete from recycling as com-pared to the concrete from natural aggregate was estimated at the average of $8 \div 30\%$, the reduction in tensile strength - $10 \div 20\%$, and the modulus of elasticity - $10 \div 40\%$. The increased shrinkage of concrete in the range of $50 \div 55\%$ is also visible [10, 11]. In order to eliminate the risks that carries the use of RAC is proposed to use the local inclusion made of high strength concrete (HSC).

2. A concept of local use of HSC for the needs of strengthening of RC precast concrete members made of RAC

The concept is based on the use a precast concrete strengthening inserts made of High Performance Concrete (HPC) and located in the most stressed compression zone of the member made of recycling aggregate concrete (RAC). The fig.1 presents the concept of constructing a load-bearing RC beams and plates formed by the connection of normal strength concrete, e.g. RAC, (in the tension zone) with a layer made of High Strength Concrete (HSC) and located in the most stressed fragment of compression or/and shear zone. Preliminary tests showed that such concept has much more favorable characteristics compared to traditional solutions entirely made of normal strength recycling aggregate concrete.

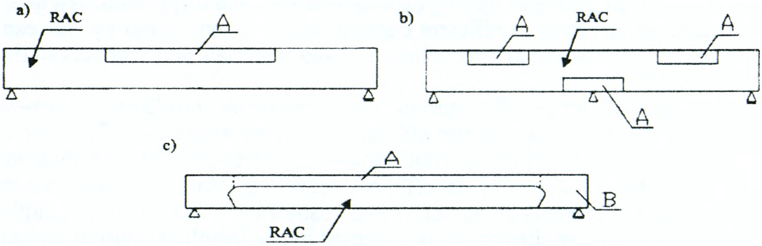

Figure 1 – The concept of strengthening of RC beams using insert made of HPC and located in compressed zone (A) or shear zone (B)

The concept of an innovative RC beam structure made of recycling aggregate concrete is based on an application of thin layered precast concrete strengthening inserts made of high strength concrete with $f_{ck} \approx 100$ MPa on the basis of good quality natural aggregate. During the construction the precast HSC insert is located in the central part of compressive zone of a structural member (like simply supported beam or slab) and it is jointed with an arrangement of steel reinforcement (top flexural bars and vertical stirrups). Then the complex system is located in the form and casted with recycling aggregate concrete (RAC). After hardening process of concrete the HSC strengthening insert is durable connected with surrounding recycled aggregate concrete and assured against slip at the connected horizontal surfaces. The constructional scheme of innovated flexural structure is shown in fig. 2.

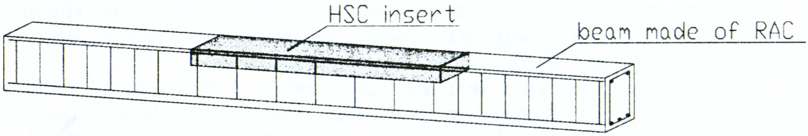

Figure 2 – Technological scheme of an innovative RC beam with the insert made of HSC

3. Experimental investigation of RC beams with HSC inclusions

Research Group at the Department of Building Structures Technical University in Bialystok ran in the years 2010–2013 in the frame of Grant with the financial support provided for the National Centre of Research and Development (NCBR) research on the behavior of a hybrid reinforced concrete beams that were shaped with RAC concrete (base layer) composed with a layer of HPC in the compression zone [12,13,14]. These studies have shown that so shaped composite structures made from two different concretes have a flexural capacity (bending load) and serviceability characteristics (deflection, crack) much more favorable compared to the homogeneous structure, entirely made of ordinary concrete (NORM).

Four series of full scale beams were prepared taking into account the results of the above dimensional analysis. Flexural steel bars arrangement (reinforcement ratios) were differed depending of the series of the beam. Stirrups spacing (Ø 6 mm) was constant at the shear span of the beams and equal to 120 mm. The cross-section dimensions of full scale beams were equal to 120×200 mm. The HSC inserts with the thickness 50 mm and 1400 mm in length were located in the centre of compression zone of innovative beams (see fig.3).

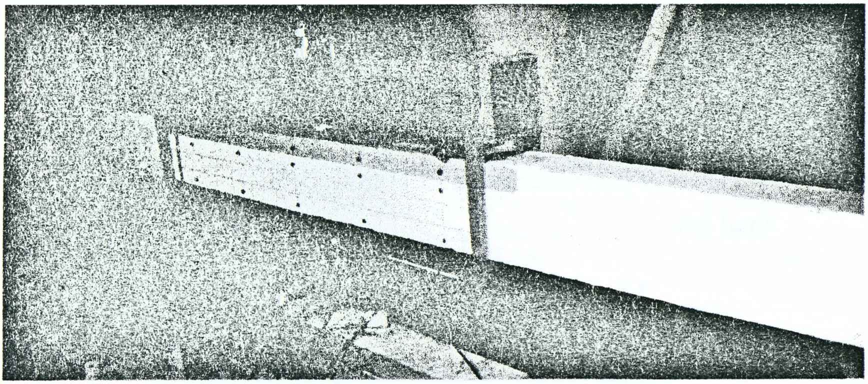

Figure 3 – View of full-scale beam with HSC insert before testing

In each series the following types of beams were prepared:

•Prototype beams Series S-RH (made of recycled aggregate concrete with the HSC insert).

•Reference beams Series S-N (natural aggregate concrete)

•Reference beams Series S-R (with coarse recycled aggregate concrete)

•Reference beams Series S-H (fully made of HSC).

The main data for concrete and reinforcement of tested full-scale beams are presented in Table 1. The load was subjected by two concentrated forces applied in the one-third of beam span's length. Reinforced concrete model beams were subjected to short time bending tests on the test stands. The specimens were gradually loaded every 2kN till to failure. During the process of loading the cracks were examined and deflections in the mid span of beam were measured. Also values of the cracking moment and the layout and width of crack openings were recorded. The diagrams of deflections recorded for reinforced concrete beams are shown in Fig.5, 6.

Table 1 – The specifications and main characteristics of tested full-scale beams

Series specification		The mean strength of concrete f_{cm} [MPa]	Flexural reinforcement	Reinforcement ratio [%]
Series1	S1-N	34.8	2Ø10+1Ø8	1.00
	S1-R	32.5		
Series 2	S2-N	36.1	2Ø14+1Ø12	2.00
	S2-R	36.7		
	S2-RH	34.7/112.0		
	S2-H	111.6		
Series 3	S3-N	30.3	3Ø16	2.90
	S3-R	33.8		
	S3-RH	33.4/112.0		
	S3-H	111.6		
Series 4	S4-RH	34.7	2Ø20+1Ø16	3.97
	S4-H	111.6		

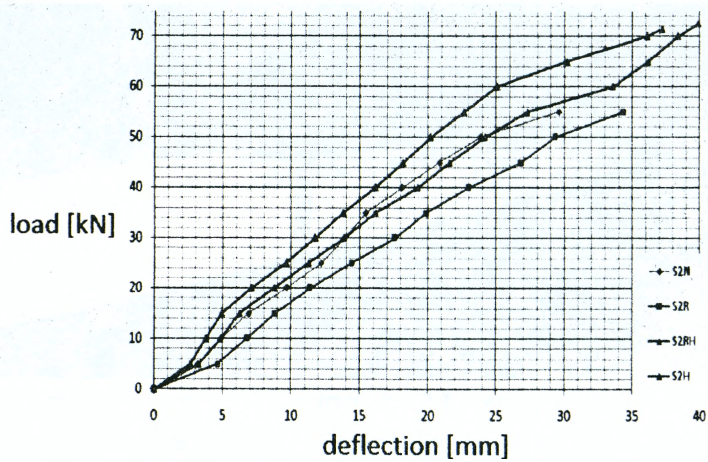

Figure 5 – Diagrams of mean deflection values versus loading forces
for full-scale beams of Series S2

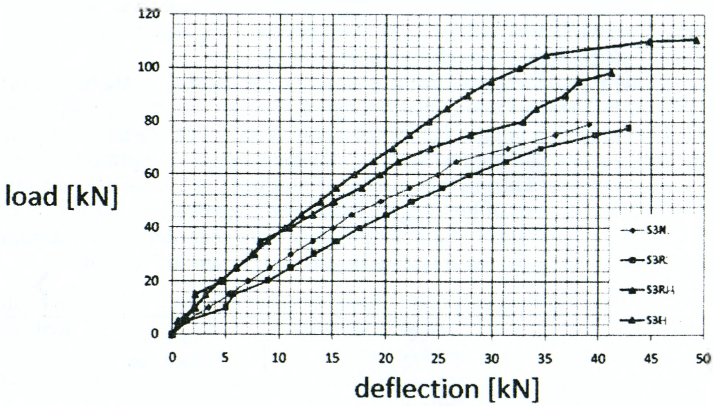

Figure 6 – Diagrams of mean deflection values versus loading forces
for full-scale beams of Series S3

The experimental tests conducted on full-scale innovative beams clearly showed that application of HSC inserts significantly increase flexural stiffness of such beams. For example, the average beam deflections of Series S2-RH (with reinforcement ratio 2.0%) at the load of 55 kN were lesser by about 20%, compared to the homogenous reference beams made of recycled aggregate concrete type of S2-R. The innovative beams Series S3-RH (reinforcement ratio 2.9%), at a load of 75 kN show mean deflections lesser by about 40%, compared to the reference beams totally made of RAC. Comparing results of deflections of reference full-scale beams, the recycled aggregate concrete beams Series S2-R showed mean deflection (at loading force 55 kN) about 15% larger compared to the beam S2-N made of natural aggregate concrete. The beam of Series S3-R (reinforcement ratio 2.9%) at a force of 75 kN showed nearly 11% greater deflection than S3-N beams.

The quantitative comparison of concrete compressive strain values registered for the tested beams of Series S3 are presented graphic on the Fig.7.

The results of measured compressive concrete strains presented in Fig.7 clearly show the effectiveness of the use of strengthening insert made of HSC, reducing deflections and compressive strains and increasing overall innovative beam stiffness, compared to reference beams type R and N. The short time tests were conducted till the failure. In the Table 2 the mean values of the critical forces for tested beams of Series S2 and S3 are presented. The results clearly showed that the innovative beams S-RH with HSC inserts failed in flexure at significantly higher critical load, compared to a reference beams S-N (made of natural aggregate concrete) and S-R (made of RAC). For example, the beams S3-RH revealed increase of flexural capacity about 35% higher compared to the reference beams type S3-R fully made of RAC. Mean values of critical loads were almost equal or even little greater than for the reference beams from Series S-H totally made of HSC.

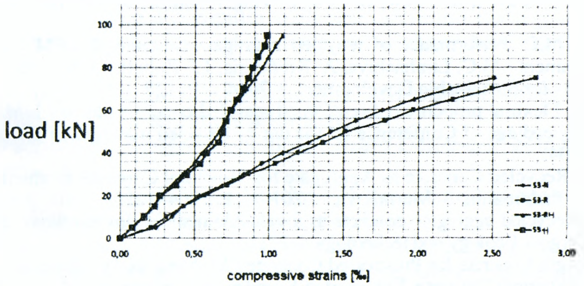

Figure 7 – Comparison of concrete compressive strains [‰] registered for tested full-scale beams of Series S3

Table 2 – Average values of critical forces for the full-scale beams of Series of S-2 and S-3

Beam Series	Average values of critical load N_R [kN]			
	Type N	Type R	Type RH	Type H
Series S-2	57.2	55.1	63.2	70.1
Series S-3	82.25	77.7	104.6	98.4

4. Conclusions

The experimental and numerical FEM analyses conducted on reinforced concrete composite beams made of recycled aggregate concrete with an insert made of HSC revealed various positive effects of strengthening compared to homogenous beams totally made of recycled aggregate concrete.

In analyzed cases the flexural capacities for innovative beams with HSC inserts compared to the homogenous reference beams was larger from 20% to 36%. This effect was greater for the beams with larger flexural reinforcement ratio.

Bending tests also conformed significantly reduced compressive strains compared with the strains and deflections measured in control beams made of recycled aggregate concrete. This positive static effects can be explained as the effect of redistribution of stresses and strains in hybrid beam.

The analyses showed also the possibility of applications of such concept of strengthening the structural concrete members in rehabilitation and reconstruction works.

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TO THE ISSUE OF STRESS-STRAIN STATE MODELING OF STEEL-CONCRETE COMPOSITE SLIM FLOOR SYSTEMS

Article relevance. Building is one of the key economic sectors, so it's technical and economic indicators, which based on significant scope work value, capital investments, are very important. At the same time forefront is acted the problem of reducing labor, material and energy intensity of construction.

Composite construction has proven popular because it combines structural efficiency with speed of construction to offer an economic solution for a wide range of building types [2].