Study on pervious recycled aggregate fiber-reinforced concrete for airfield pavement

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Abstract. For the last several years, the attention has been devoted to the development of eco-friendly construction materials with the aim to reduce the environmental impact of construction. The integral part of this development is to find applications for which the recycled materials could be used efficiently. The presented study deals with the development of recycled aggregate fibre reinforced concrete which is going to be used for an innovative precast concrete pavement system. The system is being developed recently at Czech Technical University in Prague with the aim to provide a system for airfield pavement with rapid construction and recycled material utilization. The investigated material is going to be used for construction of a sub-base course which is underneath a surface course of precast concrete elements. Within the scope of the work, standard laboratory tests were conducted with the aim to observe mechanical properties of recycled aggregate fibre reinforced concrete. The obtained findings showed that the material exhibits ductile behaviour likely due to very long polypropylene fibres used for strengthening concrete matrix. On the contrary, the tested material has low modulus of elasticity in comparison with conventional concrete. Subsequently, the pilot construction of the sub-base course was carried out in order to examine both concrete mixture preparation and concrete course installation in practice. The obtained findings showed that a compaction ratio of the material is about 20%. Moreover, a flat surface of the sub-base course was hard to achieve considering the used manufacturing technology.

1. Introduction
In 2015, many countries in the world adopted the 2030 Agenda for sustainable development with the aim to improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests. The agenda includes 17 sustainable development goals which are supposed to help human beings to transform the world. One of these goals is to ensure sustainable consumption and production patterns by reducing waste generation substantially through prevention, reduction, recycling and reuse. The increasing needs for sustainability in the construction industry demand to seek for new applications of recycled materials. Particularly, in the concrete industry, various types of concrete additions, recycled plastics, recycled concrete aggregate (RCA) and recycled brick aggregate are used for concrete production in different ways. While concrete additions usually replace only cement partially [1, 2], recycled plastics are possible to use as fibrous reinforcement [3, 4], aggregate replacement [5] or even as a binder for polymer concrete [6]. RCA and recycled brick aggregate [7] are used as a partial or entire replacement for virgin aggregate in concrete.

The presented study deals with recycled aggregate fiber-reinforced concrete (RAFRC) with polypropylene fibers and RCA as a full replacement for virgin aggregate. The current findings about the performance of this material demonstrate that the quality of concrete strongly depends on the content
and quality of used RCA. Most of scientific experiments indicate that higher recycled aggregate content results in poor durability of recycled aggregate concrete (RAC), especially when fine recycled aggregate is used [8], and strength decay [9]. For instance, the recent experimental investigation [10] demonstrates that compressive strength of RAC with 10%, 20%, 40%, 70% and 100% RCA replacement decreased to 71, 66, 33, 17, and 13%, respectively, in comparison with reference concrete with natural aggregate. The investigation also showed that the cause of the failure of RAC in compression is the debonding between recycled aggregate and cement paste at their interface. However, a few experiments surprisingly show that the effect of RCA replacement is negligible on concrete compressive strength even when full replacement is applied [11]. The use of RCA also affects the workability of a fresh mixture as recycled aggregate tends to absorb a high amount of mixing water [12]. To ensure sufficient concrete workability, RCA is recommended to get saturated prior to mixing of all concrete components.

Although, the experimental experience with RAC is extensive, the material is used only rarely in the building industry due to its poor properties and durability. Namely, it concerns a sub-base of concrete pavements, hardcore filling, RAC blocks and bricks [13]. Currently, a new precast concrete pavement is being developed at Czech Technical University in Prague. The objective of the research is to develop a system with a rapid construction and utilization of recycled materials. The potential benefits of this system include high-quality concrete use for precast concrete elements, minimal weather restrictions concrete elements placement, shorter delay before opening to traffic and elimination of construction related early age failures [14]. Moreover, the use of recycled material enables to save natural resources. The proposed pavement system (figure 1) is classified as a rigid pavement composed of a two-layer sub-base and a two-layer surface course of precast concrete panels [15-17]. The sub-base consists of two layers 300 mm thick. The compacted recycled concrete aggregate layer is installed on the subsoil (existing soil) and the layer of RAFRC with polypropylene fibers is placed on top of it. The aim of the presented study was to observe the mechanical properties of RAFRC and its use for the construction of a sub-base course in practice.

![Figure 1. Proposed pavement system.](image)

2. Laboratory tests
The study on RAFRC focused on two fields. Firstly, standard laboratory tests were performed with the aim to observe mechanical properties of the investigated materials. In total, three concrete mixtures were tested with a different content of polypropylene fibers. The obtained data served for the development of material models used for a numerical simulation of a nonlinear behavior of the system. Secondly, only one concrete mixture was selected and used for the pilot construction of the sub-base course. The pilot construction was carried out in order to examine both the concrete mixture preparation and the concrete course construction in practice prior to construction of a test airfield pavement section.
2.1. **Concrete specimen preparation**

The main objective of the laboratory tests was to observe mechanical properties of three types of RAFRC which differ in the content of polypropylene fibers (table 1). Namely, it concerns RAC with no fibers and two types of RAFRC. Each mixture contains 0-32 mm RCA as a full replacement for virgin aggregate. The aggregate was obtained from the demolition of a highway concrete surface course. In order to design pervious concrete, mostly coarse aggregate was used (figure 2). Portland cement 42.5 R, characterized by high early strength in accordance with CSN EN 197-1, was used as a binder. Polypropylene fibers were used for two cement-based composites in order to strengthen their concrete matrix. The fibers used for the concrete mixtures were straight and extra-long (110 mm), in order to increase the bond strength between the fibers and concrete matrix.

| Table 1. Concrete mixture composition. |
|---------------------------------------|
| Concrete component | RAC | RAFRC 2.5 | RAFRC 5.0 |
| Recycled concrete aggregate 0-32 mm | 1650 | 1650 | 1650 |
| Portland cement (CEM I) 42,5 R | 260 | 260 | 260 |
| Water | 150 | 150 | 150 |
| Polypropylene fibers BeneSteel 110 mm | 0 | 2.5 | 5 |

**Figure 2.** Sieve analysis of recycled concrete aggregate.

For the purpose of the experimental tests, thirty specimens were produced in a laboratory of the university. Namely, it concerned three beams 700 x 150 x 150 mm, four cubes 150 x 150 x 150 mm and three cylinders 150 x 300 mm for each mixture. The manufacture of concrete was identical for all three mixtures. Firstly, recycled concrete aggregate was mixed with a small amount of water and fibers, if applicable, to get the aggregate saturated. After two minutes of mixing, cement was added into the mixture which was subsequently mixed for other two minutes. Then, the rest of the mixing water was added into the mixture and all concrete components were mixed together for other two minutes again until the mixture was homogenized. The important standpoint was to prepare a very dry consistency mixture which will be appropriate for rolling compaction with no vibrating. The use of a small amount of water also enabled to reduce concrete shrinkage.

Once a concrete mixture was prepared, test specimens were produced. First, the mixture was placed into a mold mid-height and compacted with a hand rammer compactor with a different steel head. A square-shaped head and a circular-shaped head were used for the compaction of beams together with cubes and cylinders, respectively, in order to ensure the efficient mixture compaction along a specimen surface. A concrete layer was subjected to at least 25 strokes of the hand rammer compactor which were distributed in a uniform manner over a mold. Subsequently, a concrete mixture was placed into the other
mold mid-height and compacted with a hand rammer compactor in the same manner again. Once the specimens were made, they were left in steel molds wrapped with a cling film in order to avoid any moisture loss. After one day, the molds were unwrapped and subsequently the specimens were demolded. Then, the specimens were wrapped again with a cling film and left in a laboratory for other twenty-seven days until testing. The reason why the specimens were not left in a water bath was to avoid any loss of cement particles by being washed away.

2.2. Experimental tests
To obtain fundamental mechanical properties of the investigated composites, standard quasi-static experimental tests were performed. Namely, a compression test, a four-point bending test and a modulus of elasticity test were performed with the aim to get compression strength, flexural strength, and modulus of elasticity, respectively, of the investigated composites (figure 3).

![Figure 3. Test setup: modulus of elasticity test (left) and four-point bending test (right).](image)

Standard strain-controlled compression tests were conducted on the cubes in the Inova 200F testing machine. The compression machine plates and concrete surfaces were treated in a way that the friction would be minimized. The steel plates of the compression machine were completely flat, smooth, and clean. The surfaces of the concrete specimen were also flat and as homogenous as possible. The strain rate was set to 0.01 mm/sec with the aim to simulate quasi-static loading. The peak loading force recorded during the tests was used for the determination of peak compressive strength.

The beams were used for standard strain-controlled four-point bending tests. Prior to the testing, impurities and loose grit were removed from all steel rollers of the testing machine and specimens in order to ensure a good contact between both elements. The specimens were installed on the bottom roller supports placed 600 mm from each other. Two upper rollers with the 200 mm span were positioned on the top of the specimens together with a cross member which divided the load applied by a press machine equally between the two rollers. The strain rate was set to 0.01 mm/sec to simulate quasi-static loading. The loading force and the deflection recorded during the tests were used for the elaboration of stress-displacement diagrams of the concrete composites.

The last tests conducted within the investigation were focused on the modulus of elasticity. Prior to the tests, the top and bottom surface of cylinders were adjusted with gypsy caps in order to ensure the smooth and parallel surfaces. Then, the specimens were placed into a stress machine and two strain gauges were attached to a specimen surface symmetrically with respect to the central axis of the specimens. Once the test was set up, the specimens were subjected to axial compression in accordance with EN 12390-13, particularly Method A - Determination of initial and stabilized secant modulus of elasticity. Then, the modulus of elasticity was derived from the relation between applied stress and corresponding strain.
2.3. Results

The data obtained from the experimental tests served for the determination of a mean value of both cube compressive strength ($f_{\text{cube}}$), flexural strength ($f_{\text{fl}}$) and modulus of elasticity ($E$) of the investigated composites (table 2). The results show that the mean value of the peak compressive strength decreased significantly with an increasing content of the polypropylene fibers. This fact confirms general findings about the performance of polypropylene fiber reinforced concrete. The main reason of this performance is likely caused by the decay of concrete matrix due to fibers.

| Specimen | RAC [MPa] | RAFRC 2.5 [MPa] | RAFRC 5.0 [MPa] |
|----------|------------|-----------------|-----------------|
|          | $f_{\text{cube}}$ | $f_{\text{fl}}$ | $E$  | $f_{\text{cube}}$ | $f_{\text{fl}}$ | $E$  | $f_{\text{cube}}$ | $f_{\text{fl}}$ | $E$  |
| 01       | 23.4       | 1.8             | 9 500          | 22.1       | 1.8             | 9 700          | 18.9       | 1.7             | 8 200          |
| 02       | 25.5       | 1.6             | 10 100         | 22.6       | 1.7             | 9 200          | 17.9       | 1.9             | 9 900          |
| 03       | 24.0       | 1.9             | 8 900          | 22.1       | 1.7             | 8 800          | 22.4       | 1.8             | 8 300          |
| 04       | 23.6       | -               | -              | 21.2       | -               | -              | 22.7       | -               | -              |

Mean 24.1 1.8 9 500 22.0 1.7 9 233 20.5 1.8 8 800

While the mean value of the peak flexural strength is more-less identical regardless of a fiber content, the residual strength (post-cracking strength) is affected by fibers significantly (figure 4). The RAC with no fibers exhibited a brittle failure typical of non-reinforced concrete. Whereas, the composites with polypropylene fibers showed very ductile behavior. They also had relatively high and constant residual strength. The reason of this ductile behavior likely consists in the geometry of the used fibers. As the fibers are 110 mm long, the anchorage strength is high and thus the fibers themselves are capable to withstand considerable tensile stress before a pull-out from concrete matrix. As expected, the residual strength increased with the content of the fibers. However, it is evident that RAFRC 5.0 shows an increased scatter of residual strength. This phenomenon was probably caused by the issue relating to the mixture preparation. Due to a high content of fibers and to the length of fibers, it was very hard to prepare a homogenized mixture with uniformly distributed fibers all over volume.

The modulus of elasticity of the investigated composites is almost identical regardless of the fiber content. In comparison with conventional concrete, the magnitude is significantly lower but typical of pervious concrete. The reason of the low modulus of elasticity mainly consists in the use of recycled aggregate and air void content.
3. Pilot construction

The pilot construction of a sub-base course was carried out, in order to examine both the concrete mixture preparation and the concrete slab installation prior to construction of a test airfield pavement section. Based on the obtained findings from the laboratory tests, the mixture used for the pilot construction contained 3 kg of the polypropylene fibers per cubic meter of recycled aggregate concrete. This content of fibers enabled to prepare a homogenized mixture with uniform distribution of fibers in a 2 cbm pan concrete mixer. The mixture was prepared, according to the procedure used for the preparation of the specimens for the laboratory tests.

Once the mixture was prepared, the sub-base course with a rectangular shape 3 x 4 m was constructed (figure 5). At first, the concrete mixture was moved by a loader from the mixer to the construction site and placed into a prepared pit. The mixture was uniformly distributed over the pit to form a 300 mm thick layer and subsequently compacted by a road roller with no vibration. The initial depth was immediately reduced to 240 mm which corresponds to the compaction ratio 20%. Considering the compaction ratio, the other layer of fresh concrete mixture was placed on top of the compacted layer to form the sub-base course of 300 mm thickness after the compaction. Once the construction was completed, the flatness deviation of the sub-base course was controlled with a 2 m spirit level. The results of the several measurements show that the flatness deviation ranged from 10 mm to 25 mm. This magnitude of geometric imperfection was likely caused by a type of concrete compaction. While compacting a fresh mixture, the road roller formed humps. Unfortunately, this magnitude of geometric imperfection does not enable to place precast concrete elements right on the top of the sub-base course and consequently a bedding fine aggregate layer might be necessary to use. The other option is to install the sub-base course by a paver finisher which is capable to spread concrete out and subsequently to level it off using a screed. However, a paver finisher might have difficulties working with fiber reinforced concrete which contains very long fibers.

![Concrete mixture placement](left) and rolling compaction with no vibration (right).

4. Conclusion

The presented study focused on the mechanical properties of pervious recycled aggregate fiber reinforced concrete and the use of this material for the construction of a precast concrete pavement system. The obtained results from the laboratory tests showed that the proposed material has very ductile behavior and high residual (post-cracking) strength. The reason of this performance is high anchorage strength of very long polypropylene fibers in concrete matrix. The pilot construction of the concrete sub-base course showed that the compaction ratio of the material is about 20%. However, the major concern consists in the flatness deviation which ranges from 10 to 25 mm over 2 m length of the sub-base course. The deviation of this magnitude would demand to use a fine aggregate bedding layer to level the surface prior to the installation of a surface course of precast concrete elements. In the near future, a finisher paver will be used for the construction of the proposed sub-base with the aim to find out if it is capable to place and level recycled aggregate fiber reinforced concrete course more efficiently.
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