Concrete Composite – Sustainable Material for Floating Islands

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Abstract. The aim of the paper is presenting of a nature-friendly achievement of an artificial floating island made from concrete composite with dispersed reinforcement (fibre reinforced concrete). Fibre reinforced concrete is referred to as a material contributing to sustainable construction, as utilisation of fibre reinforced composites enhances durability and resiliency of structures and structural elements. The paper describes the floating island design, its shape and manufacturing process. The focus is also on the composition of fibre reinforced concrete and testing of its material characteristics. The successful application of fibre reinforced concrete in the floating island approved efficiency of fibre reinforced concrete as a material with high potential to meet demands of sustainable building.

Keywords: sustainable concrete use, floating island, fibre reinforced concrete, mechanical properties

1. Introduction
Concrete has a reputation of material with a high environmental impact. Unjustifiably. In comparison with other structural materials, the assessment usually shows better result for concrete. The pure public reputation of concrete is probably caused by global numbers; concrete is the most commonly used structural material and its production volume is the largest of all building materials.

2. Minimizing of concrete production impacts
Particular concrete components play a varying role in the environmental impacts of concrete. In the analysis of reduction of concrete production impacts, the influence of concrete components – aggregate, cement, water shall be considered.

The extraction of aggregates influences the appearance of the landscape, affects the underground and surface waters. Mining may adversely affect hydrogeological conditions. Environmental impacts also include the further processing of extracted stone, especially crushing.

Cement production accounts for 80% of the total energy consumption embodied in concrete. It is the most demanding process also regarding assessment of the carbon footprint, i.e. CO₂ production. In production of a tonne of Portland clinker, more than 800 kg of CO₂ is generated. 55% of CO₂ is released during calcination of limestone, and the remaining 40% is caused by the combustion of fuel. Therefore, many research projects focus on reducing the amount of cement, and substitution binders are used that partly or fully replace cement in the concrete mix.
Water for concrete production should be clean. Drinking water is commonly used because its use does not require any testing. In the so-called wasteless technology, recycled water is used. Recycled water contains an increased proportion of fine particles (cement, aggregate and admixtures), which is not uniform and can vary over time. The quality and properties of recycled water must be taken into account in the design of the concrete mixture to reach the required consistency of fresh concrete, what may complicate the concrete production.

In the effort to minimize concrete production impacts, not only individual concrete components’ impact should be focused on. Also, other principles should be considered, such as choosing the appropriate shape of the structure / element, which corresponds with the straining and stresses in the element, correct design and efficient use of the material, based on knowledge and understanding of the material features. Special types of concrete – cement composites with controlled properties, fibre reinforced concrete, high performance concrete, etc. may be used if appropriate [1]. Along with effective use and economic profit, the application of special cement composites may bring additional architectural and aesthetic benefits. A high durability of the material is recommended. Durable structures require less maintenance during the life cycle and less repairs. In case of more durable structures, it will take longer to reach the stage, when demolition and construction of a new building are needed. The environmental impacts and economic disadvantages associated with construction are then offset by longer operation of the structure without repairs and remedies. High initial costs and lack of information on the new concrete composites are often a reason of refusing the modern and more suitable material. The modern concrete composites need to be promoted by engaging and motivating exploitatons.

3. Promoting application of concrete fibre reinforced concrete

The story combines two aspects of sustainable construction. The first aspect is the exemplary approach of a producer of the concrete mixture component to the protection of environment, the other is the application of progressive material and the demonstration / proof of the advantages and the beneficial properties of the advanced concrete composite.

Natural aggregates for concrete production, are necessarily linked to excavation activities. Excavation influences the nature of the landscape; in the extreme case the excavation may create a moonscape. The related company has a responsible approach to the environment and the areas affected by the excavation works are a challenge for them to create unique natural habitat. In the area where gravel is excavated from lakes, a pleasant landscape is created with a variety of plants and animals bound to water sources. Despite mining in progress, the surrounding landscape is not adversely affected. The revitalization of the entire territory is taken already during the excavation process. The afforestation of shores of the excavation lakes is provided by natural species indigenous to the region, as this leads to the creation of more stable, natural and more environmentally friendly communities.

An interesting achievement in the field of land rehabilitation is the care of strictly protected birds - common terns (Sterna hirundo), which are protected under the EU Council Directive 79/409 / EEC on the conservation of wild birds. The artificial nesting sites are created on sand gravel lakes. Initially, wooden floating islands were made. After verifying that this nesting method is convenient for birds, the decision was made, to create a floating island from durable material – concrete.

The project was divided into several sub-stages. Firstly, a draft of the island shape and construction was prepared and requirements on concrete properties were specified. The concrete mixture was proposed, and properties of concrete were tested in laboratory. The production technology was thought out and a prototype was elaborated. Finally, the prototype was tested in real conditions.

3.1 Design of the artificial floating island

For the design of artificial floating islands, the principal requirements were specified:

- the artificial island shall float in stable position;
- the shape of the island shall enable connection of several islands together;
- the upper deck shall be drained;
• the dimensions of the island must enable its transportation on a commonly used lorry (oversize transport shall be avoided);
• the weight of the island must enable its placing on water by a commonly used small trucks crane.

Material chosen for manufacturing of the island was fibre reinforced concrete (FRC). Fibre reinforced concrete (FRC) is an advanced modern material. Compared to common concrete it is more tough, more durable, more ductile. Cracking in FRC elements has favourable layout; the width of cracks is smaller. FRC influences the failure mode of members; the rupture may change from the brittle failure mode to the ductile failure, what tributes to reliability of structures.

If FRC is used, the thickness of the element can be reduced, while maintaining the same resistance as a conventional concrete element. FRC members are more durable than concrete members. That’s why FRC material can be classified more environmentally friendly than conventional concrete.

3.2 Properties of the fibre reinforced concrete
The mixture design proposed high-strength fibre reinforced concrete with synthetic (polymeric) fibres. The volume content of fibres is 0.55%. Fine aggregates were used with max grain size 8 mm. The proposed FRC is easily compactable and it has very low permeability. The mixture composition is in the table 1.

| Component          | Description / value                                      |
|--------------------|---------------------------------------------------------|
| Aggregate          | mined fine aggregates - fraction 0 / 4                  |
|                    | mined coarse aggregates - fraction 4 / 8                |
| Cement             | CEM I 42,5 R                                           |
| Admixture          | microsilica compacted                                    |
| Plasticizer        | two types of carboxylate based plasticizers             |
| Water / cement ratio| 0.48                                                    |
| Super-plasticizing admixture | PCE with a long-term consistence                     |
| Fibre reinforcement | high-modulus synthetic macro-fibres                    |

A test wall with thickness of 60 mm was concreted to verify that concrete in the thin element will be sufficiently dense without air voids and non-compacted areas. The test demonstrated demanded density of FRC (see figure 1).

Figure 1. Test specimen for verification of concrete density in a thin wall
Conventional tests were used to determine material characteristics. For the fresh mixture testing, five batches of 48 litres volume were mixed. The slump flow test detected diameter of the concrete spread ranging from 560 mm to 650 mm; the average from all measurements was 600 mm. The density of fresh FRC mixture was 2290 kg/m$^3$ and the air content was 1.6%.

Material characteristics of the hardened concrete were tested on cubes 150/150/150 mm (compressive strength and tensile splitting strength), cylinders 150/300 mm (modulus of elasticity) and prisms 150/150/700 (flexural strengths). Results of the test are shown in the table 2 and figure 2.

**Table 2. Tests of hardened fibre reinforced concrete**

| Test                                           | Minimal value | Maximal value | Average |
|------------------------------------------------|---------------|---------------|---------|
| Compressive strength at age 24 hours [MPa]     | 1.5           |               |         |
| Compressive strength at age 3 days [MPa]       | 39.4          | 40.5          | 40.0    |
| Compressive strength at age 7 days [MPa]       | 53.3          | 54.6          | 54.0    |
| Compressive strength at age 28 days [MPa]      | 70.0          | 78.0          | 72.8    |
| Compressive strength at age 90 days [MPa]      | 72.5          | 81.4          | 76.4    |
| Watertightness at age 28 days [mm]             | 6             | 11            | 8       |
| De-icing agents - 150 cycles                   | 39.2          | 58.8          | 48.4    |
| Bending tensile strength [MPa]                 | 5.71          | 6.26          | 6.02    |
| Tensile splitting strength 7 days [MPa]        | 11.2          | 11.9          | 11.5    |
| Tensile splitting strength 28 days [MPa]       | 11.4          | 15.5          | 13.1    |
| Modulus of elasticity [GPa]                    | 31.5          | 34.0          | 32.8    |

The effect of fibres on the toughness and ductility of the composite is proven in flexural tests performed with prisms 150/150/700 mm in a four-point bending test.

![Figure 2. Results of flexural tests (Load – deflection curve)](image)
3.3 Shape of the artificial floating island

The shape of the element results from above mentioned demands and the need to resist water pressure, eventually pressure of ice on the water level.

The basic shape is a prism with hexagonal base. The shape is both suitable for carrying of water pressure and allows simple joining of the elements to larger units in a form of a honeycomb pattern (see figure 3).

![Figure 3. Assembling of artificial floating island - three elements joint together](image)

Utilisation of FRC allowed to minimize thickness of walls of the element. The stability in floating is based on theoretical analyses; it is provided by optimizing the distribution of mass in the element, especially the solid heavy bottom. Above the water level, there is a drained deck with a raised edge and drain holes. A five-centimetre concrete layer separates the upper deck and the internal cavity, which is filled with hardened polystyrene. The height of the element is 1.7 meters, the dimensions in plan were derived so that the hexagon is inscribed in a circle with a diameter of 2 meters. The total weight is less than three and a half tonnes. Thus, the element can be transported on conventional trucks.

A reusable formwork was used for casting of the element. The top deck with the raised edge was formed with a polystyrene insert. Plastic pipes for draining of the deck are inserted into the edge. The walls and bottom floor are concreted after a technology break. Concrete rebars are embedded in the work joint to provide connection of the upper and lower parts of the element.

In the bottom, lifting hooks are fixed for manipulation and transport, and for anchoring the island in the lake. The element is manufactured bottom up and in this position, it is also transported (figure 4).

The first artificial island was launched in the water in July 2009. The element was carried on the water level by the truck crane bottom up (figure 5) and in the water, the island slowly turned to stable position bottom down. Since then, more than 40 artificial islands have been manufactured. They are installed on water levels in the Czech Republic and surrounding countries.
The floating island can serve as an artificial island for habitation by water birds and other species and growing of plants, for recreation, for landing of small boats and other purposes, whether sporting or agricultural. The advantage of the proposed solution are favourable shape, dimensions and weight, which enable simple transport of the element and creating of larger area by joining of elements together.

![FRC element for artificial floating islands after demoulding](image1)

![Transporting of the element by the truck crane](image2)

4. Conclusions

The advances in concrete mix design, production technology, inventions in advanced materials, new use of traditional materials, new perspectives in the designing concrete structures should lead to a change of understanding concrete as a material hostile to the environment.

Concrete composites with dispersed reinforcement (fibre reinforced concretes) have a great potential to meet the requirements of "sustainable" building. These advanced materials enable reduction of the element dimensions, which brings decrease in the consumption of the material. The fibre reinforced concrete is durable, so the need for repairs is reduced and the service life of the structure is prolonged.

A positive example of utilization of the advanced material in an interesting application where the benefits of material are effectively exploited can help to extended use of this composite and contribute to sustainable constructions. The presented achievement was prepared in cooperation of nature conservationists from Ornithological Society, concrete and concrete components producers and members of scientific institution.

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