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Optimization of fibre reinforcement for waste aggregate cement composite

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HIGHLIGHTS

- ▶ Engineered steel and propylene fibre are important type of concrete reinforcement.
- ▶ We examine fibre reinforced concretes based on waste ceramic aggregate.
- ▶ Mechanical properties tested according to European Standard EN 14651 are under consideration.
- ▶ Integral simplex design is employed.
- ▶ Optimal mix of fibre reinforcement for waste aggregate cement matrix is defined.

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ABSTRACT

Fibre reinforced cement composites (FRCCs) created on the basis of waste ceramic aggregate (WCA) were mixed, cast into specimens and tested. There were harnessed steel and polymer fibres to modify cement matrix and the total volume of fibres was equal to 1.2% and fixed for all mixes. The research programme was prepared with the help of experimental design and integral simplex design was employed for optimization. Achieved results were presented in a form of contour ternary plots. Apart from investigation of basic properties of SFRCC such as workability, density and ultimate compressive strength there were performed full tests according to European Standard EN 14651. Calculated values of f_{LOP} strength and values of four different residual strengths ($f_{R1}, f_{R2}, f_{R3}, f_{R4}$) allowed to classify tested FRCC according to fib Model Code 2010 and assess their structural aptitude. The main aim of the research programme was optimization of the composite's mechanical properties regarding different fibre reinforcement.

1. Introduction

Modifying concrete by the addition of fibres creates a whole range of technological problems primarily associated with properties of freshly-mixed concrete [9,17]. Fibres which are basically long needlelike particles significantly influence consistency and workability of fresh concrete mix. Apart from the sheer volume of added fibres this influence depends on both properties of fibres (aspect ratio, rigidness/flexibility of a fibre, roughness of a surface) and properties of concrete (paste volume, maximum aggregate size, shape of aggregate particles). For the last 50 years ordinary concrete [9,17] and later on fine aggregate concrete [7,11] have been reinforced by fibres. Thus concrete–fibre interaction and properties of such composites in fresh and hardened state have been thoroughly tested and described. In the last decade growing ecological awareness has generated an increasing interest in harnessing different types of waste as aggregate for concrete production. Probably, the most promising recycling process is using ceramic waste from construction industry as coarse aggregate for concrete [6]. This topic has already generated a significant research effort [8,19], which resulted in successful applications in concrete elements characterized by less demanding mechanical characteristics, such as pavement slabs [4,8,19]. Replacing traditional coarse aggregates by waste ceramic aggregate (WCA) influences the homogeneity of mechanical properties of cast concrete and mechanical properties themselves. To evade those issues one can modify concrete mix based on WCA by an addition of engineered fibres. Hooked steel fibres proved to be a very good solution for enhancing limited mechanical properties of concretes based on other than ceramic waste aggregates [7,11] and thus promise achieving satisfactory results in the case of WCA. Due to very specific properties of waste ceramic aggregate such as: much lower apparent specific gravity comparing to ordinary aggregate, very

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high water absorptivity, rough surface and irregular shape, the efficiency of concrete–fibre interaction is unknown resulting in unknown mechanical characteristics of hardened composite. The conducted research programme aimed to answer both questions.

2. Waste ceramic aggregate and other materials

The harnessed ceramic waste was sourced from an ordinary building site. It consisted of broken and crushed ceramic wall blocks and traditional bricks partially contaminated by cement mortar. This ceramic waste represents the waste "produced": in building construction during transportation to the building site, during the execution of several construction elements (e.g. facades, partition walls) and on subsequent works, such as the opening grooves [6]. Ceramic waste was the raw material for production of waste ceramic aggregate in two main stages: grinding and sieving. Ceramic waste and ground ceramic waste are presented in Fig. 1. Fine (<1 mm) and coarse (⩾1 mm) fractions of ground ceramic waste were separated using mechanical rectangular sieve set (according to EN 933-1:1997). The grading characteristic of coarse fractions is presented in Fig. 2. Other tested properties of WCA are summarized in Table 1.

Portland cement CEM I 42.5 (EN 197-1:2000) and tap water (EN 1008:2002) were harnessed for composing all mixtures. Natural washed sand of post-glacial origin (a byproduct of hydroclassification of all-in-aggregate) was used as fine aggregate. This waste sand and its applications in various cementitious composites (including fibre reinforced concrete) were described in numerous previous publications [11,13,14]. All mixes were modified by the dosage of 2% of highly effective superplasticizer (type FM) containing admixture of silica fume and characterized by density equal to 1.45 g/cm^3. This superplasticizer and its influence on properties of the fresh mix and hardened concrete, was described in previous work [11]. There were used three types of engineered fibres: two hooked steel fibres and continuously embossed polymer fibre. Those fibres represent the most popular types of fibres widely used in civil and structural engineering industry all over the world [10,12]. Main geometrical and mechanical properties of all three types of fibres are summarized in Table 2. Geometry, quality and detailed mechanical properties of used engineered steel fibres are described in the previous publication [12] (polymer fiber see Fig. 3).

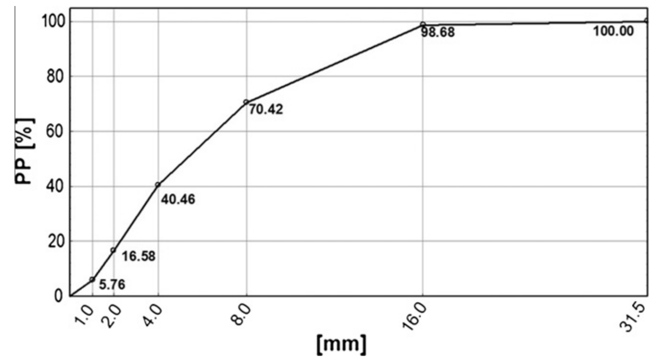

Fig. 2. Grading of WCA.

Table 1
Properties of WCA.

Specific gravity	2700 kg/m^3
Apparent specific gravity	1800 kg/m^3
Loose bulk density	948 kg/m^3
Compacted bulk density	1170 kg/m^3
Water absorptivity by weight	22%

3. Experiment design

In order to generate a mathematical experimental design which would reflect fibre reinforcement possible to employ, three types of engineered fibres were chosen. The choice of fibre types was based on statistical analysis of the assortment commercially available on the world market. Steel fibres and polymer fibres are the most commonly used all over the world. In case of steel fibre 67% of sold fibre consist of the hooked type [10,12] and this type was chosen as the most representative. In case of polymer fibre, "structural" polypropylene fibres are the most popular and gain more and more interest both in industry and in research programmes. The chosen three fibre types were coded as follows (X_1; X_2; X_3). Due to different specific gravity of steel and polymer, both steel and polymer fibres were added to cement matrix by volume. Taking into account experience of multiple researchers [22,29] it was decided that the volume of fibres added to concrete mix will be constant for all mixtures and equal to 1.2%. Due to this simple assumption it was possible to apply an integral simplex design also called 'a mixture design' [1]. The sum of volume of all three used fibres (1.2%) always equals 100% of fibres composition. This design was described in detail in Table 3 and spacing of measuring points was shown in Fig. 4. Additionally to the experiment design the pure concrete was batched and cast, too.

The object of the experiment was considered as a complex material whose structure is unknown and unavailable for an observer. Still the 'input' and 'output' parameters are known [18,24]. The examination results were statistically processed and values bearing the gross error were assessed on the basis of Smirnow–Grabbs criterion. The objectivity of the carried out experiments was assured by choosing the sequence of the realization of specific experiments from a table of random numbers. All calculations connected with specifying and graphic interpretation of the received mathematic model were carried out with the help of Statistica 8.0 computer programme [3]. Contour plots were achieved by using polynomial fit. Fitted functions are characterized by correlation coefficient equal to at least 0.90.

4. Mix design, curing and casting

Large water absorptivity of the WCA disabled application of ordinary methods of concrete mix preparation. To achieve stable properties of the fresh concrete mix, WCA was pre-saturated for 7 days in tap water. Such a long period of pre-saturating was

Fig. 1. Raw ceramic waste and ground ceramic waste.