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# Utilization of recycled plastic for plastic-based concrete

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**Abstract.** The environmental aspects of sustainable development in the construction industry consist in the utilization of secondary raw materials in a design and construction of new structures. The fact that China significantly reduced the import of plastic waste in 2017 raises the question of dealing with this waste in other states. A complicated recycling process of waste plastics puts pressure on scientific community to find new, more efficient ways of using this waste. The paper deals with the behaviour and mechanical properties of a completely innovative material called waste plastic-based concrete composed of natural aggregate and plastic waste which replaces cement as a binder. The completely unique composition of this concrete required to firstly test production technology and subsequently to conduct standard quasi-static experimental tests to obtain basic knowledge about the behaviour and mechanical properties of this composite. The obtained knowledge show that special attention must be paid to the production of the material which takes place under elevated temperature. The investigated composite has a relatively high tensile strength compared to conventional concrete and brittle fracture behaviour. In the next phases of the research the optimization of the production technologies and the composition of the composite will be provided.

## 1. Introduction

Currently, several studies deal with the utilization of recycled plastic as a binder for concrete. Recycled polyethylene terephthalate is used for this purpose. This polymer is currently used for production of beverage bottles and food packaging. Millions of tons of PET bottles are produced every year and it is desirable to deal with the utilization of this polymer, because PET is not biodegradable. The utilization as a binder in concrete is an effective way of recycling, which also leads to cement saving in the construction industry. This cement saving helps to reduce the consumption of raw materials and negative effects on the environment. Some recent studies [9,10] compared a polymer concrete made from virgin and recycled polymer. These studies reported that properties of these polymer concretes differ only insignificantly. Waste PET is usually during the processing depolymerized and unsaturated polyester resin (UPR) is obtained. Accelerator and initiator are added to the resin immediately before mixing with filler. A disadvantage is the expensive process of recycling of waste PET and its treatment before using as a concrete binder. Production costs are significantly lower, when another manufacturing process is selected – cut pieces of raw PET waste are heated together with the filler and melted. However, only few studies deal with this technology.

Several studies ([4],[8]) reported that the compressive and flexural strength of polymer concrete containing as a binder recycled waste PET were higher compared to conventional concrete containing as a binder cement. The seven-day compressive strength of samples containing 9 % of resin reached



approximately 60 MPa [2]. The study [6] reported, that the compressive strength reached even 80 MPa, when the samples contained 10 % of resin.

A very fast strength development is also significant [9]. After 24 hours, 75% of its final compressive strength was obtained. After 4 days, 83% of its final strength was obtained. The compressive strength of conventional concrete reached after 24 hours approximately 20% of its final compressive strength. Therefore, this concrete is suitable for precast elements production, because the fast strength development allows to speed-up a manufacture. Some studies (e.g. [7]) observed a different failure mode of concrete containing plastic aggregate. Samples did not exhibit the brittle failure, which is typical for conventional concrete and did not separate in two parts.

The ratio of tensile and compressive strength of polymer concrete is higher, in comparison to conventional concrete. The ratio of tensile and compressive strength of conventional concrete is about 10 to 15 %. In case of polymer concrete, this ratio is about 30 – 50 % [1]. Polymer concrete differ from conventional concrete also in creep behavior. The study [2] report that the creep strains grow rather fast at early ages in comparison with ordinary concrete. The polymer concrete shows more than 20% of its long-term creep within the first two days, and about 50% during the first 20 days.

An advantage of polymer concrete is a lower porosity and water absorption. The study [3] report that the water absorption is only 0,47 %. These properties caused that this concrete is more resistant to chemical attack, compared to conventional concrete. Therefore, polymer concrete is suitable for sewage pipes surface or floors in chemical plants.

A disadvantage of this material is a lower heat resistance due to low melting point of the polymer (approximately 260 °C). Hence, the mechanical properties change at higher temperatures. The study [6] report that increasing the temperature from 25°C to 60°C leads to the reduction in the compressive strength by 40 % and to the reduction in the elastic modulus by 35-40 %.

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The mechanical properties of the material depend primarily on the polymer concrete composition - the filler and resin content, the type of aggregate and the admixtures. Study [10] report that an increase in compressive strength with increasing resin content. Specifically, the compressive strength of samples containing 5 % of resin reached 5 MPa. For 10 % resin content, the compressive strength increased to 12 MPa, for 20 % resin content even to 20 MPa. The study [11] reported that the compressive strength is also influenced by the maximum size of aggregate particle. The compressive strength increased with increasing particle size up to 10 mm particle size, when larger particles was used, the compressive strength reduced.

The study [3] deals with the influence of admixtures on the strength of polymer concrete. In the frame of this study, there was the compressive strength of samples containing fly ash, bitumen and nano-calcium carbonate investigated. The best results were obtained for the samples contained fly ash. For 15 % content of fly ash, the compressive strength increased by 32 %, the flexural strength even by 79 %, compared with samples without any admixtures. This is probably caused by a surface of fly ash particles with large negative charge, which supports the development of stronger links with polymer mix. Further cause is probably the increase of crystallization degree of PET and the improvement of the concrete workability. The addition of bitumen also improved the compressive strength of polymer concrete, but only up to content of 5 %. For this bitumen content, the compressive strength increased by 10,7%. When the bitumen content was higher than 5 %, the compressive strength decreased. The influence of nano-calcium carbonate content on the compressive strength was not significant.

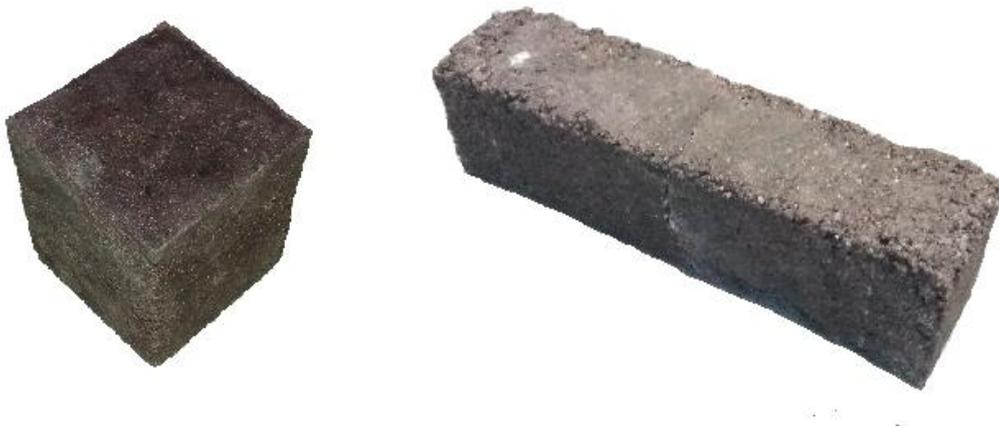
Several studies [5,9] analyze dependence of mechanical properties on the amount and kind of accelerator and initiator, which are used during the polymer concrete production. The study [9] reported that properties of polymer concrete are significantly influenced by the amount ratio of accelerator, initiator and resin. Therefore, it is necessary to find the optimal amount ratio of these compounds. This study reported that the optimal content of initiator is 2% and optimal content of accelerator is 0,5%. In this study, methyl ethyl ketone peroxide (MEKP) was used as an initiator and

cobalt naphthenate was used as an accelerator. The study [5] compared the compressive strength of polymer concrete made by using two kinds of initiator - methyl ethyl ketone peroxide (MEKP) and benzoyl peroxide (BPO). According to this study, using methyl ethyl ketone peroxide (MEKP) as an initiator leads to higher compressive strength.

## 2. Experimental programme

### 2.1. Preparation of the samples

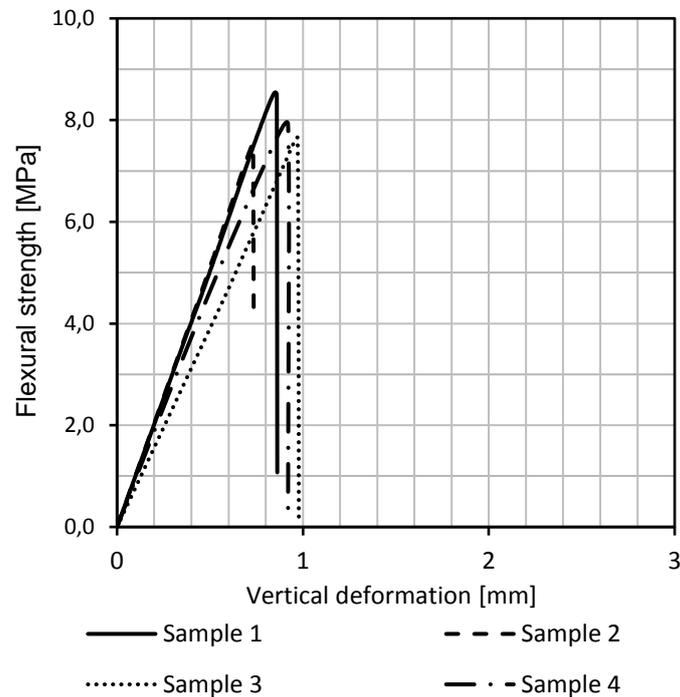
The samples were made of fine aggregate (aggregate size 0 - 4 mm) and waste PET which was cut into small pieces. The production consists in homogenizing the mixture of plastic waste and fine aggregate in the weight ratio of 23:77 at high temperature. At first, the aggregate was heated up to a temperature of about 430 °C. After that, the PET waste was added to the aggregate and melted. After mixing the two components, the temperature decreased, and the mixture was homogenized. Optimal workability of the mixture was reached at about 310 °C, when the consistency of the mixture was viscous. Then, the mixture was placed into the prepared forms. The forms were pre-heated to eliminate the thermal shock which could cause a surface disruption of the samples. After that, the moulds with the mixture were left at room temperature and after cooling, the samples were removed from the moulds. Overall, eight samples were made, four samples were cube shaped and four samples were beam shaped. The dimensions of cube shaped samples were 100 x 100 x 100 mm and the dimensions of beam shaped samples were 50 x 50 x 200 mm (figure 1).



**Figure 1.** Waste plastic-based concrete samples.

### 2.2. Experiments

The detection of basic mechanical properties of the waste plastic-based concrete was the aim of the experiments. The beam shaped samples were used for the three-point bending test, the distance of the supports was 180 mm. The deformation-controlled test was conducted with rate 0.02 mm/s. The loading force and the mid-span deflection were monitored. The obtained experimental data are demonstrated in flexural strength-deformation diagram. The diagram describes a relationship between flexural strength of waste plastic-based concrete and deformation. The cube shaped samples were used for the compression test. As in the flexural test, the loading force and the vertical deformation were monitored during compression test and subsequently used for the elaboration of a compressive strength-deformation diagram (figure 2). This diagram shows the relation between the compressive strength of waste plastic-based concrete and deformation.

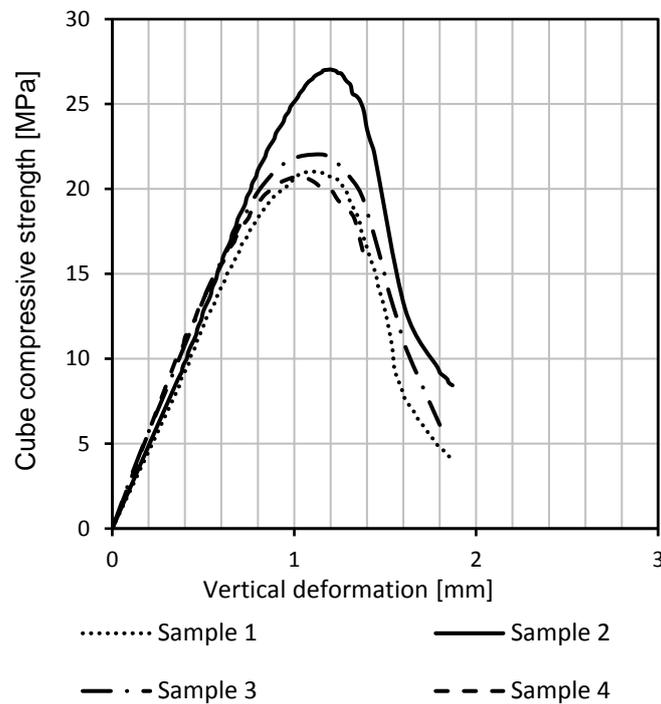


**Figure 2.** Flexural strength - deformation diagram of waste plastic-based concrete.

### 3. Results

The findings show that the mechanical behaviour of the waste plastic-based concrete is very similar to the mechanical behaviour of conventional concrete. The mechanical behaviour of the waste plastic-based concrete under the tensile stress is linear until a brittle failure occurs. The influence of ductile behaviour of plastic waste on the mechanical properties of the investigated composite is negligible. The reason may be either the low content of plastic waste in the composite mixture or the change in plastic properties caused by elevated temperature while being heated up during the production. As a consequence the waste plastic-based concrete is not possible to consider as a ductile material with post cracking tensile strength. This fact is limiting for the utilization of this material. On the other hand, the obtained values of the peak tensile strength ranged from 7.54 MPa to 8.55 MPa and the average value of tensile strength was 7.91 MPa. This value of tensile strength corresponds to the tensile strength of high performance cement-based concrete.

The behaviour of the waste plastic-based concrete under the compressive stress is also similar to conventional cement-based concrete. At first, the mechanical behaviour is linear. Later, under higher compressive stress, the material starts yielding until the peak compressive strength is reached. The measured values of the compressive strength ranged from 20.69 MPa to 27.03 MPa and the average value of compressive strength was 22.7 MPa. Based on the stress-strain diagram obtained from experiments, it seems that the elastic modulus of this waste plastic-based concrete is lower than elastic modulus of conventional concrete (figure 3).



**Figure 3.** Compressive strength - deformation diagram of waste plastic-based.

#### 4. Conclusion

The waste plastic-based concrete made of waste PET is a composite material which enables to utilize the waste material. The properties of this material differ not significantly from the properties of conventional cement-based concrete. The low ductility and the brittle tensile failure limit the utilization field of this material. However, the advantage of this material consists in its high tensile strength. Currently, there are not many findings about this material and only few experiments have been conducted so far. It is desirable to provide more experiments which verify the properties of the material.

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