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Original Research Article

# Behaviour of short polymer-high strength concrete columns under eccentric compression

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ABSTRACT

Engineers have been looking for ways to combine two or more materials in order to take advantage of their strong features. This is how the hybrid materials were born. A very common type of such a construction material is the reinforced concrete. The present paper presents the results of the experimental and numerical investigations of the behaviour of short hybrid concrete columns subjected to short-time eccentric compression. The columns are made of high strength concrete, in the compression part, and polymer concrete located in the tensioned part. At the age of 28 days the columns were subjected to eccentric compression, with constant eccentricity. The influence of the second order effects, such as creep, was neglected. From the experimental results it can be concluded that the type of reinforcement can have a significant effect on the ultimate carrying capacity of the hybrid columns. The numerical simulations by means of non-linear finite element analysis are in good agreement with the experimental results.


## 1. Introduction

The role of polymers in modern concrete constructions and repair works is constantly increasing. Polymers are either incorporated in the cement-aggregate mix, to replace part of the cement as a binder, or used as a single binder. What is obtained is an advanced construction composite material with improved mechanical properties and friendly with the environment [1]. A very common example of a traditional hybrid material is the reinforced concrete. It is so widely spread and used that it is not considered a hybrid material anymore.

The incorporation of polymers greatly improves strength, freeze–thaw resistance [2,3], adhesion, impermeability, chemical resistance and the durability of mortars and concretes [4–6]. A few years later, the ACI Committee 548 in 2003 issued a report [7] in which the same properties were listed for the polymer concrete.

To the normal process of cement hydration, polymer modifications add a process of coalescence. As cement

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hardens, there form small spaces between the aggregate particles. These spaces are what allow water to penetrate, and do damage in freezing conditions. Polymer particles coalesce to fill these voids. That is why the concrete becomes less permeable and better protected against freezing [8]. Interestingly, polymer concrete does not produce bleed water. It makes an excellent overlay because it needs very little finishing. It is more accurate to say that it dries, than to call it curing. The polymer bonds not only to the concrete and the aggregate in the mix but also in the underlying concrete. It is for that reason that it is used to resurface concrete [9]. The patch method used to repair deteriorated reinforced concrete structures should produce patches that are dimensionally and electrochemically stable, resistant against penetration of deterioration factors, and mechanically strong. Today, the patch repair materials that are widely used contain admixtures, such as silica fume and polymers, to improve the performance of cement mortar [10].

Extensive research works have been conducted in determining the material characteristics of different types of polymer concrete [11–14]. The obtained results strongly recommend this modern material for the use in civil engineering structures. Despite its improved mechanical properties, compared to traditional Portland cement concrete, polymer concrete still exhibits brittle failure behaviour in its post-peak region [15,16]. Therefore it should be used in conjunction with either traditional reinforcement [17] or together with different types of fibre reinforcement [18,19].

The main objective of this research work is to assess the structural behaviour of the polymer concrete. Even though there has been quite extensive research done in the field of using polymers in construction materials, the experimental research is very seldom completed by numerical models. The combination of the two materials with different properties such as high strength concrete and polymer concrete was used for obtaining short reinforced hybrid columns. In the present paper both the experimental results and the finite element (FEM) analysis of the behaviour of short hybrid columns subjected to eccentric compression are presented.

## 2. Materials and experimental procedure

### 2.1. *High strength concrete*

The high strength concrete of grade C 70/85 has been prepared with cement CEM I 42.5R, SR EN 197-1:2002 [20] in a dosage of 550 kg/m$^3$, with an addition of 10% silica fume from the cement mass. The mix proportion of the high strength concrete is presented in previous research papers [21,22]. The material properties of the high strength concrete, used in the compression zone of the columns, were determined experimentally and are summarised in Table 1. The compressive strength was determined according to SR EN 12390-3:2003 [23] specifications on three cylinders subjected to a uniaxial compression test with a loading rate of 0.6 N/mm$^2$/s. The tangent modulus of elasticity, Ec, was determined according to STAS 5585-71 [24]. The values obtained for the modulus of elasticity are similar to the ones obtained and published by other researchers [25].

All specimens and cylinders were cast at the same time, from the same batch of concrete.

### 2.2. *Polymer concrete*

The tension zone of the columns was cast out of polymer concrete. The mix proportion of the polymer concrete is given in Table 2. Fly ash was used as filler. Even though the mechanical properties of concrete using fly ash are tremendously improved, there are still concerns about the radioactivity levels of fly ashes in construction materials [26] and therefore strict regulations were put in place by the authorities [27].

The mechanical properties of the polymer concrete having the mix proportion shown in Table 2 were experimentally determined, according to SR EN 13412:2007 [28], and published in a previous extended study [12]. The values for the mix used in the present paper are summarised in Table 3. The bond strength of the polymer concrete to the high strength concrete was also determined as is given in Table 3.

### 2.3. *Reinforcement*

The reinforcement used in the experimental procedure was both with smooth surface, made of mild steel (OB37 type) and with ribs, made of high strength steel (PC52 type) [29]. The mechanical properties of the longitudinal reinforcement were determined experimentally by means of the uniaxial tensile tests on 10 mm diameter steel bars, for the mild steel, and 12 mm diameter steel bars, for the high strength steel. The obtained yield strength was fy=318 MPa and the ultimate tensile strength was fu=484 MPa. The corresponding values for the PC52 type were 360 MPa and 540 MPa for the yield strength and ultimate strength, respectively.

Fig. 1 shows the reinforcement layout of the hybrid concrete columns (b) and the cross-section of the considered specimens. The shear reinforcement consisted of Φ6 smooth

**Table 2 – Mix proportion for the polymer concrete.**

| Polymer concrete | Epoxy resin (%) | Fly ash (%) | Aggregate (%) | |
|---|---|---|---|---|
| | | | 0–4 mm | 4–8 mm |
| | 12.4 | 12.8 | 37.4 | 37.4 |

**Table 1 – Mechanical properties of the high strength concrete (average values of 3 determinations).**

| HSC | Young's modulus (Ec) | | Compressive strength (fcm) | | Bending tensile strength (fti) | | Splitting tensile strength (ftd) | |
|---|---|---|---|---|---|---|---|---|
| | (GPa) | COV (%) | (MPa) | COV (%) | (MPa) | COV (%) | (MPa) | COV (%) |
| | 39.07 | 1.2 | 90.3 | 1.5 | 5.53 | 1.34 | 4.01 | 1.9 |