Lost shuttering for columns as possible applications of dispersely reinforced concrete with polypropylene fibers

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Abstract. There are various practical applications of dispersely reinforced concrete with polypropylene fibers; one of them could be achieving formworks for concrete columns. This paper presents some practical tests showing the combined effect of a lost shuttering made by dispersely reinforced concrete with fibers and a steel reinforced concrete core, for round and square shaped columns. The test results could be considered a contribution to the development of knowledge in the dispersely reinforcement area using one type of polypropylene fibers for which information on their application field are little or missing.

1. Introduction

The rapid, dynamic and diversified evolution of society is compelling the construction sector to follow this trend, thus responding to the strength, safety and comfort requirements that ensure the smooth running of different human activities.

The constructions development of both vertical (office buildings, dwellings, hotels) and horizontal (industrial halls, shops with surface areas of thousands of square meters) requires precise techniques and technologies that can capitalize a range of new materials. In this context, the use of simple concrete or reinforced or pre-stressed concrete is somewhat restricted by specific phenomena such as cracking, fire resistance, shrinkage, shock resistance, wear resistance, durability, and so forth.

For this reason, various in-depth studies and research have been carried out showing that an improvement in concrete performance can be achieved by adding in their masses dispersed reinforcement in the form of fibers made from different materials [1–9].

Consequently, the realization of dispersely reinforced concrete is one way to maintain the competitiveness of concrete as one of the main building materials [10, 11].

However, fiber-reinforced concrete cannot replace conventional reinforced one. There are areas of application in which fiber reinforced concrete can be used alternatively or in addition to classic reinforced one (regular), providing constructive and economic advantages.

The use of fibers of any kind will improve the properties of regular concrete [12].

The opportunity to use fibers as reinforcement occurs in the case of using a small percentage of steel reinforcement or in the case of constructive steel reinforcement of regular reinforced concrete. The possibilities of use increase due to the improved cracking behaviour, the reduction of the deformations due to drying contractions or the increase in the shear resistance.
The fields of use for fiber-reinforced concrete have an extensive range, including: concrete pipes, supporting walls, thin facade elements, prefabricated steps, airport runways, car foundations, lost formwork, concrete guniting consolidation works for tunnels, etc. [13, 14].

Most dispersely fiber reinforced concrete applications are based on the idea of improving the strength properties. However, the role of fiber reinforcement is not so much in the improvement of the resistance, but in controlling the fracturing process and thereby in improving the ductility, the properties of energy absorption in case of an impact, shock and temperature variations.

From this point of view, C.D. Johnstone’s observations are relevant [15]: "only if engineers stop thinking about resistance, it will not be difficult to find many other areas of application of these new materials, and improvements will also be made".

2. Experimental method

Practical applications of dispersely reinforced concrete with polypropylene fibers are varied; one of them could be achieving formworks (shuttering) for concrete columns.

This study is part of a larger research which focuses on finding efficient building elements made of dispersed reinforced concrete with polypropylene fibers, such as: concrete tiles for pavements, concrete pillars and boards for fences, lost formwork for lintels, beams, etc. [10, 11, 12, 16].

![Figure 1. Different building elements made of dispersely reinforced concrete with polypropylene fibers.](image_url)

The efficiency of some reinforced concrete elements with polypropylene fibers was pursued not only from the point of view of the final mechanical characteristics (increased strengths at different stresses), frost resistance - thaw, permeability, etc., but especially in relation to the price to be paid. It was considered that if the improvements to conventional concrete (simple or reinforced with steel bars) through fiber-dispersed reinforcement are more than the additional cost of fibers, without affecting other characteristics such as workability, ease of operation, visual appearance, etc., these elements could be considered effective.

2.1. Polypropylene fibers used

Polypropylene fibers are varied and have different uses. The chosen type of fibers was Fibrofor® Multi, produced by BruggContec AG, CH-8590 Romanshorn, Switzerland, some of the cheapest on the market and with a limited area of application.
The choice of fiber type was based not only on the lack of information regarding its limited application domain, but also on other criteria, such as: price per kilogram, fibers quantity recommended by manufacturer to be added to mixture, their physical and mechanical characteristics. This study aims to develop the applicability domain of these cheap polypropylene fibers.

**Table 1.** Characteristics of polypropylene fibers (according to manufacturer) [13].

| Characteristics                  | Details                                      |
|----------------------------------|----------------------------------------------|
| Dosage: minimum                  | 0.6 kg/m³                                    |
| Dosage: maximum                  | 0.9 kg/m³                                    |
| Fire-resistant concrete          | 2.0 kg/m³                                    |
| Form factor                      | Multifilament                                |
| Diameter                         | 34 µm                                        |
| Length (+/- 5%)                  | 6.3 mm (type 63)                             |
|                                  | 12.7 mm (type 127)                           |
| Density                          | 0.91 g/cm³                                   |
| Resistance to acids / alkali     | Inert                                        |
| Tensile strength                 | 300 – 400 MPa                                |
| Modulus of elasticity            | 4900 MPa                                     |
| Melting point                    | 150°C                                        |
| Colour                           | White                                        |
| Packing                          | Bags 0.9 kg                                  |

2.2. **Composition of concrete used**

Before starting the experimental program, it was necessary to establish the preliminary composition of the concrete to be used. To establish the composition of the concrete, the following information must be known:

- the class of concrete: C20/25 class was chosen;
- the characteristics of the elements which will be executed, fact which implies a specific granulometric curve of aggregates and appropriate workability;
- the conditions for transportation – transportation was not necessary as the mixing was made where the placing of concrete took place, in a mixing machine with a 50 liters load;
- the conditions of concrete placing – manually by compacting rod;
- the conditions of hardening – normal, the store and trial of the elements are made in the lab.

Considering all factors and after preliminary trials, the following concrete compositions were obtained:
Table 2. R1 – cement mortar formula.

| Component                      | R1   |
|--------------------------------|------|
| river aggregate 1720 kg/m³: type 0 … 4 | 1720 kg/m³ |
| cement CEM IV/B 42.5N           | 390 kg/m³  |
| water                          | 250 litres/m³ |
| A/C ratio                      | 0.64  |
| plasticiser                    | no    |
| polypropylene fibres type Fibrofor®Multi | 0.9 kg/m³  |

Table 3. R2 – concrete formula.

| Component                      | R2   |
|--------------------------------|------|
| river aggregate 1720 kg/m³: type 0 … 4 | 771 kg/m³ |
| type 4 … 8                      | 422 kg/m³  |
| type 8 … 16                     | 422 kg/m³  |
| cement AV I42.5R                | 456 kg/m³  |
| water                          | 235 litres/m³  |
| A/C ratio                      | 0.51  |
| plasticiser                    | Viscocrete 20HE  |
| polypropylene fibres type Fibrofor®Multi | 0.9 kg/m³  |

2.3. Experimental elements
The components for the fibrous dispersed-reinforced concrete thin walls (tubes) were produced in order to be used as circular or rectangular columns shuttering. Two types of lost shuttering were produced: some of circular-shaped tubes and others which were rectangular-shaped, figure 3.

The circular ones have an external width of 200 mm, the walls’ thickness of 25 mm and the height of 500 mm. The cross-section of the rectangular ones is square-shaped, with the side of 150 mm, the walls’ width of 25 mm and the height of 700 mm.

All shuttering components, both circular and rectangular, were produced from micro-concrete based on R1 formula by means of a single type aggregate, with the grain between 0 – 4 mm.

These components were produced in order to determine the input regarding the safe bearing capacity growth of the regular concrete column cast inside the ring (of the lost shuttering).

The circular internal column was produced from reinforced concrete with 6 longitudinal PC52 steel bars with Ø10mm and OB37 steel hoop enclosure with Ø4mm, figure 4 [17].

The rectangular internal pole was produced from reinforced concrete with 4 longitudinal PC52 steel bars with Ø10mm and OB37 steel marginal hoop enclosure, figure 4 [17].

The concrete used to produce the internal columns was prepared according to formula R2.
Parallel to these poles, cast inside the dispersed-reinforced concrete shuttering, other (full) circular-section, respectively (full) square-section concrete poles of the same type were cast and enclosed similarly, having the external size equal to that of the ring (either circular or rectangular).

Therefore, two models were produced, namely a classic one, with a homogenous cross-section (named SC1, SC2, SP1), cast in a regular wood shuttering and the second one, with a mixed cross-section (named SCC1, SCC2, SPC1), produced from two concrete classes (an external layer of dispersed-reinforced concrete, practically representing the equivalent of the concrete coating layer of the first component and a core of regular reinforced concrete).

![Figure 4. Plan of shuttering and reinforcement for circular (a) and rectangular columns (b).](image)

These elements were centric compression tested. So, since the casting, metallic plates were provided centrically and in a slightly higher position than their lip (approx. 4 mm). As a result, the components’ core only received energy.

For other two elements (circular shaped) the force applying was done across the whole cross section.

### 3. Results

For the elements tested using metallic plates to center the applied force, the following were observed during trials:

- the circular column SC1, with regular reinforced concrete cross-section, collapsed when charged with 40.0 kN; the collapse was due to cracks along the compressive stress (classical collapse) [17], figure 5;
- the circular column SCC1, with mixed cross-section, made of a regular reinforced concrete core and a fibrous dispersed-reinforced concrete ring, collapsed when charged with 36.7 kN; the collapse was due to longitudinal cracks based on ring bending stress, figure 5;
- the rectangular column SP1, with regular reinforced concrete cross-section collapsed when charged with 31.5 kN; the collapse was due to cracks along the compressive stress, in the centre of the square sides (classical collapse) [17], figure 6;
- the rectangular column SPC1, with mixed cross-section, made of a regular reinforced concrete core and a fibrous dispersed-reinforced concrete ring, collapsed when charged with 27.3 kN; the collapse was due to longitudinal cracks located on the edges of the square sides (due to the bending stress specific to the sides of the square representing the lost shuttering), figure 6;
Figure 5. Columns SC₁ and SCC₁ during trials.

Figure 6. Columns SP₁ and SPC₁ during trials.

Figure 7. Collapse of fibrous dispersed-reinforced concrete columns.
- the confined columns had a similar reaction to the benchmark ones (margin of 87-91% of the bearing capacity), their efficiency being economically assessed as follows: the costs relative to the materials and the specialized labor force and the placement time were reduced by replacing the wooden or metallic classical shuttering with these dispersed-reinforced concrete lost shuttering;
- for a bearing capacity equal or even greater than the classically-executed poles, lost shuttering can be produced having a wider diameter so that the internally cast component has the same cross-section as a classically executed one; in this case, the efficiency is ensured by the greater (concrete coating) protection layer leading to longer durability of the component and the reduction or even elimination of costs relative to the materials and labor corresponding to the finishing / overcoating of the element, because the fibrous reinforced concrete surface does not have damages, faults, coring etc.

For the elements tested by applying the force across the whole cross section, the following were observed during trials:
- the circular-shaped SC2 column with the regular reinforced concrete cross-section loaded on the entire transverse surface collapsed at a 46.75 kN load; the failure occurred due to the occurrence of longitudinal cracks (classic failure), figure 8;
- the circular shaped SCC2 column with the mixed cross-section made of conventional reinforced concrete in the core and the dispersely reinforced concrete as an outline ring, loaded over the entire transverse surface, collapsed at a load value of 45.0 kN; the failure also occurred because of the appearance of longitudinal cracks due to the tensile stresses in the ring, figure 8.

![Figure 8. Failure mode for columns when the force was applied over the entire cross-section](image)

- the first cracks occurred around the force of 20.0 kN for both columns, with the distinction that in the case of the regular reinforced concrete one they developed faster, having larger openings at the same values of the load than those from the confined column;
- as mentioned above, by the almost equal bearing capacity between the two columns (the confined pillar reaching 96.7% of the standard one value), it would appear that the solution for the execution of the columns in lost formwork made of reinforced concrete with
polypropylene fibers can be efficient by reducing material and labor costs and shortening execution time; it removes the need to purchase or make wooden or metal shuttering and reduces the workforce for their execution, installation and dismantling;

- the outer surface of the columns made using lost formwork of dispersed reinforced concrete did not show defects, segregation, asperity, so it can be an economical solution (no need for finishing, plastering) for the apparent elements.

Figure 9. The bearing capacity of the confined columns compared to the benchmark ones.

4. Conclusions
A final conclusion of the experimental program is that it has led to convergent results which, on the one hand, have confirmed the research so far, and on the other hand, created the premises for their continuation and opened new roads and directions for seeking solutions to improve the materials and building elements currently being used.

Dispersely reinforcement with polypropylene fibers is beneficial between certain limits such as the used concrete class, the type and granulation of the sand and grit, the nature and size of the loadings to which the element is subjected, the physical dimensions and the possibility of suitable compacting of the concrete elements made with this material.

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