TECHNICAL PAPER

Investigation of **flexural performance** of concrete reinforced with **twisted and embossed macro polypropylene fibers** based on experimental comparison

Abstract

Macro synthetic fibers are increasingly used in concrete reinforcement due to their durability, ease of use, and cost-effectiveness compared to traditional steel reinforcement. These fibers enhance the toughness, durability, and crack resistance of concrete structures. Twisted fibers are primarily used to enhance concrete's crack resistance, tensile strength, and overall durability, making them an essential component in modern construction. Embossed fibers refer to fibers with a textured surface that are added to the concrete mix to enhance its properties. These fibers are typically used to improve the structural integrity, durability, and performance of concrete. While fiber-reinforced concrete (FRC) has been widely used for decades, the development of textured or embossed fibers offers additional advantages due to their increased surface area and improved bonding capabilities. Twisted fibers are an innovative type of reinforcement material used in concrete to improve its mechanical properties. These fibers are specifically designed with a helical or twisted shape, which enhances their bond with the concrete matrix, making them highly effective in increasing the tensile strength, toughness, and durability of concrete. This article is to evaluate the contribution of twisted, and emboss fibers to concrete.

KEYWORDS

Residual strength, fiber reinforced concrete (FRC), twisted fibers, embossed fibers, flexural performance, macro fibers, polypropylene

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INTRODUCTION

Fiber reinforced concrete (FRC) is concrete made primarily of hydraulic cements, aggregates, and chopped reinforcing fibers. Fibers suitable for reinforcing concrete have been produced from steel, glass, organic and polymers synthetic fibers[1]. Polymer synthetic fibers can consist of different shapes. The most commonly used types are twisted, fibrillated, embossed and monofilament structures. The purpose of the fibers is to increase residual strength, crack resistance of the concrete.

ASTM C 7508[2] defines macro polyolefin fiber which has linear density greater than or equal to 580 denier (equivalent diameter ≥ 0.3 mm). Macro fibers range includes fibers with a length of 12-65 mm and tensile strength greater than 345 MPa[2].

According to ACI 544, the length and diameter of the fibers used for FRC do not exceed 76 mm and 1 mm respectively[1].

EXPERIMENTAL PROGRAM

2.1 | Fiber properties

PP macro fibers in the shape of twisted and embossed were manufactured with length of 54 mm. Mechanical properties of the fibers in accordance with ISO 2062[3] were measured, using Zwick tensile testing instrument (model: Xforce HP). The characteristics of the fibers are shown in Table 1. The amount of fibers added to concrete designs was 4 kg/m^3. This corresponds to a fiber volume fraction of 0.44%. Figure 1 denotes the fibers used in this work.

Characteristic	Macro fibers
Polymer	Polypropylene
Length (mm)	54
Fiber cross-sectional shape	Circular/rectangular
Specific gravity (g/cm3)	0.91
Melting point (oC)	150-160

Table 1. Characteristics of the fibers

2.2 | Concrete mixing design

The proportion of the components in prepared mixture was as follows: Portland cement type II/A-M, 320 kg/m^3; coarse aggregate: 939 kg/m^3 (maximum dimension of 22 mm); fine aggregate: 916 kg/m^3 (maximum dimension of 4 mm); and water: 176 kg/m^3, super plasticizer %1. Coarse and fine aggregates obtained from local mines. Chemical composition of cement in Table 2 is shown.

In this work, in order to achieve the most ideal distribution of the components in the mixture, the dry aggregate was placed in the mixer and were mixed for 2 min. After the addition of cement, mixing operation was continued for a further 1 min. water and super plasticizer were added and mixing was continued for another 2 min. Finally, fibers were added mixing was continued for another 3 min. Workability of fresh concrete was determined through the slump test in accordance with EN 12350-2[4] Slump of the control sample was 200 mm and the slump of concrete reinforced with twisted and embossed fibers was found to be 150, 150, 170 mm, respectively.

In this work, five series of concrete designs included three 150 × 150 × 600 mm prismatic samples were casted. Series 1 was plain concrete and was used as a control sample. Series 2, 3, 4 contained twisted and embossed macro-PP fibers, respectively. The samples were cured for 28 days under standard conditions.

Chemical parameters	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O
%	22-23	5-6	2.5-3	57-60	1.7-2	3.2-3.6	0.2-0.4	0.5-0.7

Table 2. Chemical composition of cement

Figure 1. Fiber used (fiber 1) twisted, (fiber 2) embossed-1 and (fiber 3) embossed-2

2.3 | Experimental setup

The center-point flexural bending test based on EN 14651[5] was performed with a capacity of 100 kN. Compressive strength test based on EN 12390-3[6]. The sample dimensions are 150 × 150 × 600 mm. The deflection at the midpoint of the sample is measured using a CMOD (Crack Mouth Opening Displacement) placed at this point. The test is performed using a closed-loop displacement-controlled testing machine. All tests must be conducted on 28-day-old samples, and each test should be performed on at least three samples (see Figure 2). Load-deflection curves are obtained with a loading rate of 0.05 mm/min up to a 0.1 mm crack width, and 0.2 mm/min for crack widths between 0.1 mm and 4 mm. The obtained load-deflection curves are used to calculate the flexural strength and residual strengths of the concrete. These residual strengths are then used to determine the moment-carrying capacity of the concrete section.

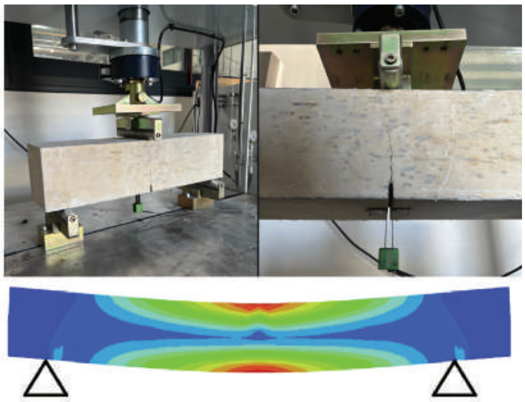

Figure 2. EN 14651 test setup – stress distribution

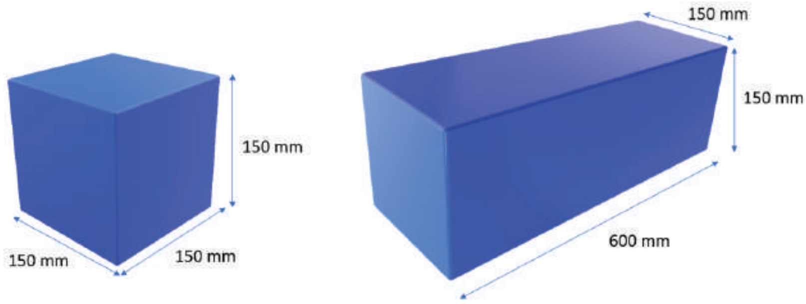

Figure 3. Specimens size

RESULTS AND DISCUSSIONS

It is clear that fiber reinforced concrete samples ductile behavior, plain concrete (control) sample is brittle. Ductility of Fiber reinforced concrete is resulting from the positive contribution of fibers in flexural strength and crack resistance, fiber leads to post-cracking performance. These results are consistent with other researches. Load- COD curves are given Figure 4-5 and EN 14651 test results are given Table 3.

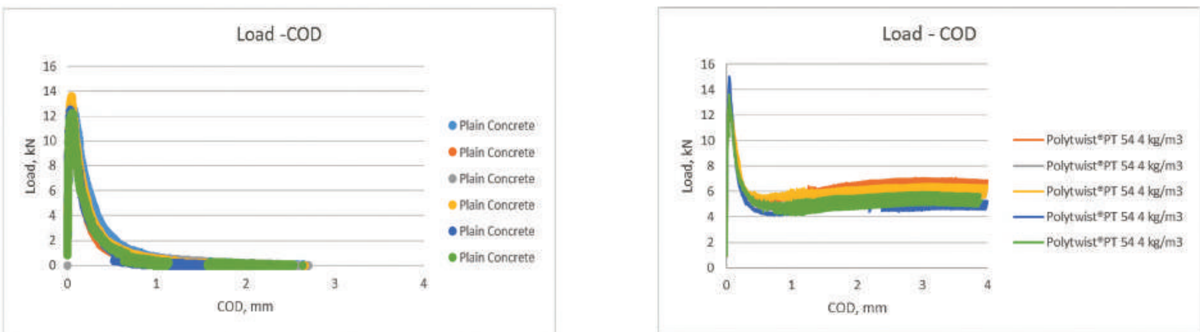

Figure 4. Load -COD – Plain - Polytwist® PT 54

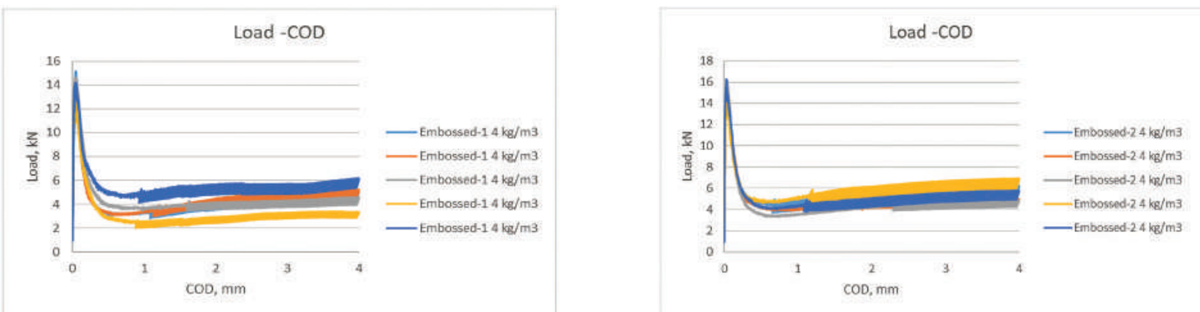

Figure 5. Load -COD – Embossed 1- Embossed 2

Sample ID	Proportional Limit, fctl- MPa	CMOD= 0,5 mm f_{r1}, Mpa	CMOD = 3,5mm f_{r4}, Mpa	MCC
Plain	4.1	0.5	0	≈0
Polytwist® PT 54	4.6	1.8	2.3	0.38
Embossed 1	4.6	1.2	1.5	0.25
Embossed 2	5.0	1.4	1.7	0.28

fr_1 =Residual strength at 0.5 mm, MPa

fr_4 = Residual strength at 3.5 mm, MPa

fctl = Flexural strength, MPa

$\sigma r_4 = 0.37^* fr_4$

$\sigma r_1 = 0.45^* fr_1$

MCC = Moment calculation coefficient

MCC = $0.1073^*fr_4 + 0.072^*fr_1$ $(0.29\sigma r_4 + 0.16\sigma r_1)$, calculated according to TR 34[7] equation 6.

Table 3. EN 14651 test results - Flexual and Residual Strength

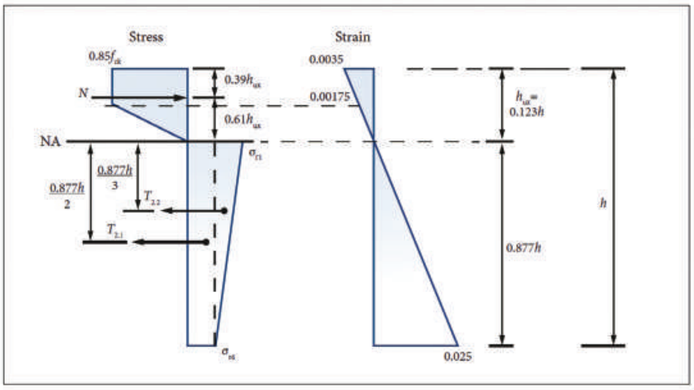

Figure 6. Stress block; fibre-reinforced concrete. (TR 34[7])

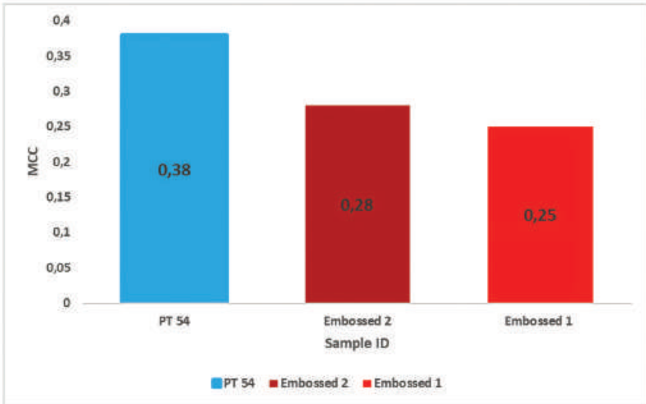

Figure 7. MCC Test Results

The use of twisted macro fibers has the highest residual strength of the comparison to the embossed types sample. Twisted fibers provided the concrete more ductility under bending. Use of advanced twisted macro fibers,it provides 36-52% increase in residual strength compared to embossed fiber. The main reason for this is that specially produced (softer and bendable) twisted fibers are more compatible with cement and aggregate and form a bond.

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