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EVALUATION OF COMPRESSIVE STRENGTH OF SYNTHETIC FIBER REINFORCED CONCRETE

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This paper evaluates the effect of discrete fibers in concrete on the pulse velocity and mechanical properties of FRC. Two different type of synthetic fibers consisting of Polypropylene and Nylon were investigated. The effect of concrete mix proportions such as types of fiber, volume fraction of fiber, water-to-cement ratio (w/c), and curing conditions were examined. An experimental program was designed and conducted on 100 mm x 200 mm cylindrical specimens to evaluate the properties of FRC. The compressive strength obtained from the Compression Test Machine (CTM) was compared to those calculated from UPV. The difference between two types of synthetic fibers on concrete properties were investigated. Results show that the highest compressive strength of Polypropylene Fiber Reinforced Concrete (PFRC) was achieved at 0.5% fiber volume fraction, whereas for Nylon Fiber Reinforced Concrete (NFRC) the highest compressive strength was obtained at 1.0% fiber volume fraction. Additionally, results show that the available equations relating UPV to compressive strength of concrete need modifications when used for different fibers. Therefore, either new or modified empirical equations are needed for better estimation of mechanical properties of FRC.

Keywords: Polypropylene, Nylon, UPV, Compression test, Fiber volume fraction, Empirical equation.

1 INTRODUCTION

Concrete is recognized as a cost effective and versatile construction material with a high compressive strength. However, concrete is a relatively brittle material that lacks flexural and tensile strength along with its tendency to crack either in early ages or in the long term. Cracking can affect the overall integrity of the mixture and not allow it to keep or achieve its desired mechanical capability. The need for high strength, crack resistant, and lightweight concrete resulted in the development of FRC (Grija *et al.* 2016). The mail role of fibers in cementitious materials is to decrease the possibility of cracking, improve the tensile strength, toughness, and to enhance the deformation characteristics of the material. The mechanical properties of FRC greatly depends on the types of fiber used. Synthetic (Polypropylene and Nylon) fibers are Non-Magnetic, rust free, Alkali resistant, safe, easy to use, cheap, abundant, and of consistent quality (Madhavi *et al.* 2014). The advantages/benefits of using synthetic fibers include: 1) Optimizing the mechanical bond with concrete, 2) Reduces the formation of plastic shrinkage cracking in concrete, 3) Provides multi-dimensional reinforcement, 4) Improves impact, shatter, abrasion, and freeze thaw resistance of concrete, and 5) Enhances durability and toughness of concrete (Nycon 2019, Saxena and Saxena 2015). One of the experimental programs conducted to explore the effects of addition of various proportions of synthetic fiber on the mechanical properties of concrete, proves that the compressive strength (CS) of FRC increases when the volume fraction of fiber increases up to 0.5%, then it starts decreasing (Mohod 2015). In another investigation on synthetic fibers, it was observed that adding 1.0% of fibers resulted in more strength compared to normal concrete (Subramanian *et al.* 2016). In this study, two different types of synthetic fibers (Polypropylene and Nylon) are selected, and the effect of these two synthetic fibers on the compressive strength and ultrasonic pulse velocity of concrete is investigated. Fibers are added with varying fiber volume fractions to concrete, and destructive and non-destructive tests were conducted to determine the optimum fiber volume fraction. The validity of existing equations relating UPV to compressive strength of concrete is also investigated for both types of fibers.

2 EXPERIMENTAL PROGRAM

The experimental program consisted of casting 100 mm x 200 mm cylindrical specimens with varying the volume fractions of fibers (V_f) (ranging from 0% to 1.5%) of Polypropylene and Nylon fiber. The preparation and curing of the concrete specimens was done according to ASTM C192 (2016). Additionally, four different water to cement ratios (0.32, 0.40, 0.50, and 0.60) were considered. The specimens were tested at the ages of 28 and 44 days for CS and UPV. The CS was measured with the compression test machine (CTM) according to ASTM C39 (2018), and the UPV was determined concerning ASTM C597 (2016). The properties of each fiber are shown below in Table 1. The outline of the experimental work is shown in Table 2.

Table 1. Fiber properties.

Fiber Material	**Specific Gravity**	**Length** (mm)	**Tensile Strength** (MPa)	**Corrosion Resistance**	**Color**	**Form**
Polypropylene	0.91	19	410	High	White	Macro fibrillated
Nylon	1.14	19	966	High	White	Multifilament

Table 2. Experimental study.

Maximum Nominal Size of Coarse Aggregate	4.7625 mm (0.1875”)
Cement Type	Type I/II
Specimen Geometry	Cylinder 100 mm x 200 mm (4”x8”)
Polypropylene Water to Cement Ratio	0.32, 0.40, 0.50, 0.60
Nylon Water to Cement Ratio	0.32, 0.38, 0.44, 0.50
Polypropylene Fiber Volume Fraction (%)	0.10, 0.25, 0.50, 0.75, 1.00, 1.50
Nylon Fiber Volume Fraction (%)	0, 0.10, 0.25, 0.50, 0.75, 1.00, 1.50
Curing (Days)	28, 44
Mix Design Proportions	1C:1.96FA:1.41CA:0.32W

2.1 Mixture and Specimen Preparation

The concrete was mixed in accordance to ASTM C192 (2016) using a laboratory mixer. First, all raw materials with the exception of the Polypropylene and Nylon fibers were added to the mixer and thoroughly mixed together for three minutes. Then, the mixture rested for one minute, followed by two to three minutes of final mixing where the Polypropylene and Nylon fibers were added gradually to ensure they were well dispersed. The mixing time of fibers should be kept to a minimum to avoid possible shredding of the fibers. After mixing, the fresh concrete was compacted into 100 mm x 200 mm cylinders. Lastly, a vibrating table was used to help reduce voids. The fiber to concrete volume fraction (V_f) employed in this study were up to a threshold limit of 1.5%. Table 3 shows the different concrete sample's mix proportions. The designations for Polypropylene and Nylon fiber in Table 3 are PF and NF respectively.

Table 3. Mix designs.

Name	**V_f, %**	**w/c**	**Cement (Kg/m^3)**	**Fine Agg. (Kg/m^3)**	**Coarse Agg. (Kg/m3)**	**Water (Kg/m^3)**	**Fiber (Kg/m^3)**
PF-1	0.1	0.32	464.0	840.5	582.7	148.2	0.96
PF-2	0.25	0.32	464.0	840.5	582.7	148.2	2.24
PF-3	0.5	0.32	464.0	840.5	582.7	148.2	4.49
PF-4	0.75	0.32	464.0	840.5	582.7	148.2	6.73
PF-5	1	0.32	464.0	840.5	582.7	148.2	8.97
PF-6	1.5	0.32	464.0	840.5	582.7	148.2	13.46
PF-7	1.5	0.40	464.0	840.5	582.7	185.2	13.46
PF-8	1.5	0.50	464.0	840.5	582.7	231.5	13.46
PF-9	1.5	0.60	464.0	840.5	582.7	277.8	13.46
NF-1	0	0.32	524.4	1027.9	739.5	167.8	0.00
NF-2	0.1	0.32	523.9	1026.8	738.7	167.6	0.91
NF-3	0.25	0.32	523.1	1025.3	737.6	167.4	2.27
NF-4	0.5	0.32	521.8	1022.7	735.7	166.9	4.55
NF-5	0.5	0.38	505.9	991.5	713.3	192.2	4.55
NF-6	0.5	0.44	490.9	962.2	692.2	215.9	4.55
NF-7	0.5	0.5	476.8	934.5	672.3	238.4	4.55
NF-8	0.75	0.32	520.5	1020.2	733.9	166.6	6.82
NF-9	1	0.32	519.2	1017.6	732.1	166.1	9.10
NF-10	1.5	0.32	516.6	1012.4	728.4	165.3	13.64

2.2 Ultrasonic Pulse Velocity (UPV)

The UPV method is described in the American standard, ASTM C597 (2016). This test method covers the determination of the propagation velocity of longitudinal stress wave pulses through concrete for the purpose of calculating compressive strength. An acoustical transducer produces longitudinal pulse waves while we keep it in contact with the surface of the concrete. After traveling through the cementitious material, the pulses are collected and converted into electrical energy with the help of another transducer that is located at a distance of L, from the first transducer. The pulse velocity (V) is calculated by dividing L by T, which is the transit time. The equations listed in Table 4 are single variable empirical equations for prediction of compressive strength of concrete based on UPV.

Table 4. Compressive strength of FRC in terms of UPV.

Equation No.	Reference	Equation
1	Tarun *et al.* 2004	fc = -109.6+33V
2	Architectural Institute of Japan 1983	fc = 21.5V-62
3	Ali-Benyahia *et al.* 2017	fc = 0.6401V^2.5654

Where pulse velocity (V) is in Km/sec and compressive strength of concrete, (fc), is in MPa.

2.3 Compression Test Machine (CTM)

In addition to UPV, the CTM is also used for determination of compressive strength of concrete according to ASTM C39 (2018).

3 RESULTS AND DISCUSSION

In this part, we present the experimental measurements and analyze the test results. The experimental program was designed to measure the CS and UPV of PFRC and NFRC.

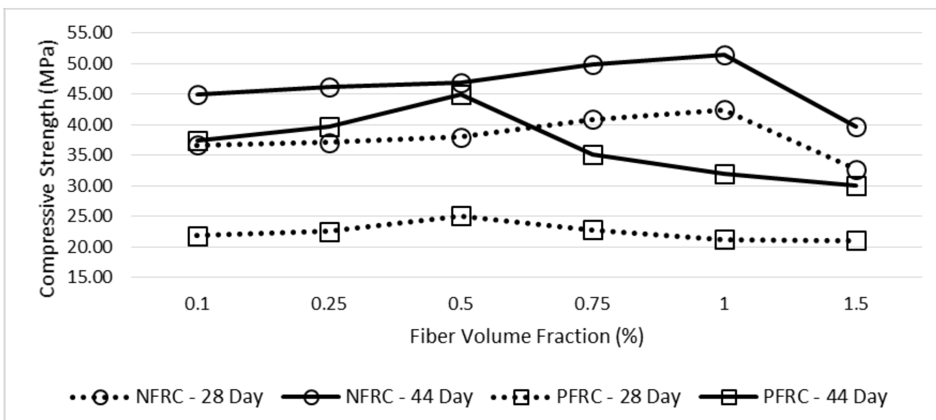

Figure 1. Compressive strength of concrete obtained from CTM vs fiber volume fraction (V_f).

Figure 1 depicts that the CS of NFRC increases when the V_f of fibers increase. The highest compressive strength belonges to the mixes with the fiber volume fraction of 1.0% for both 28 and 44 days. It was observed that the CS of PFRC increases with when we increase the the fibers up to 0.5% fiber volume fraction then starts to decrease. Therefore, the optimum fiber volume fraction for PFRC is 0.5%. It happened at both 28 and 44 days, but it's more obvious at age of 44 day. It is observed that for similar mix proportion of the two syntatic FRCs, NFRC carries more compressive force before failure because of the higher tensile strength of Nylon fibers shown in Table 1, which is in good agreement with previous research (Hanif *et al.* 2017). Figure 2 depicts how synthetic fibers alter the propagation of pulse velocity in concrete. The UPV of NFRC increases and the UPV of PFRC decreases with increasing V_f of fibers. Additionally, the difference in the 28 and 44 day compressive strength in NFRC is less than the those of PFRC.

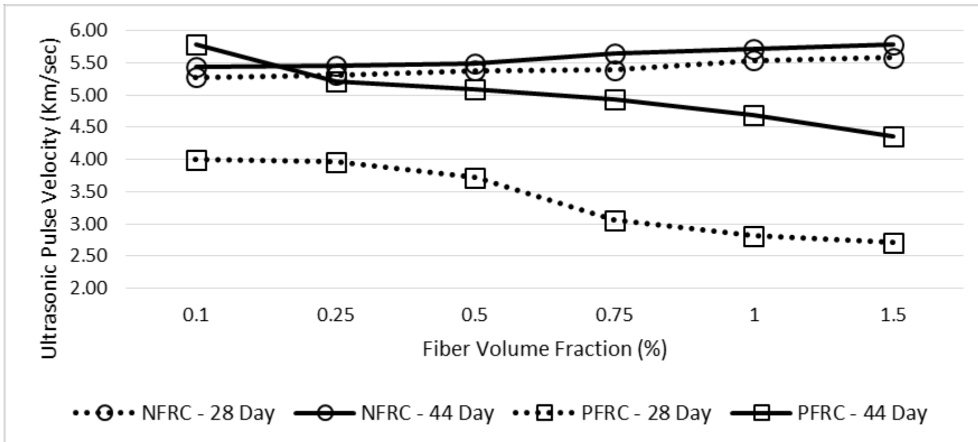

Figure 2. UPV vs fiber volume fraction (V_f).

In Figure 3, a comparison between the results obtained from the CTM at the age of 44 days is compared to the results from Eqs. (1) to (3) when using UPV results in them obtained at the same age of 44 days. It is observed that Eq. (3) is in better agreement with CTM results for nylon fiber mixes with V_f = 1% and less. Moreover, Eq. 3 is also in better agreement with the results for PFRC with V_f ranging from 0.25% to 1.5%. Other than the six V_f previously mentioned, a new experimental study is required for higher V_f's.

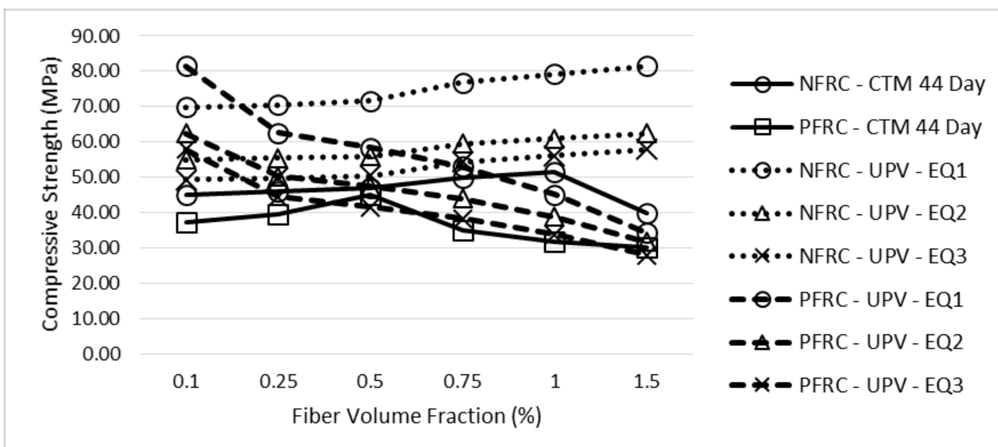

Figure 3. Comparison between compressive strength of concrete obtained from CTM vs those calculated using Eq. (1) to (3).

The effect of water to cement ratio on the compressive strength of PFRC and NFRC is presented. The fiber volume content is constant for all specimens and water content changes in different specimens. It can be observed that a decrease in w/c, increases the CS of synthetic FRC in 28 and 44 day old specimens. It is also observed that the effect of concrete age on CS of these mixes is more considerable in PFRC compared to NFRC, as a result of the difference in the mechanical properties of fibers as discussed earlier.

4 CONCLUSION

An experimental study was conducted to determine the effect of synthetic fibers on the mechanical properties and UPV of FRC. Results show that the optimum fiber volume fraction for PFRC is 0.5%. Whereas, the optimum fiber volume fraction for NFRC is 1.0%. Additionally, it was shown that the existing empirical equations relating UPV to FRC's compressive strength need modification to be implemented for prediction of the compressive strength of synthetic fiber reinforced concrete. It is also observed that different type of synthetic fibers show different behavior in 28 and 44 days and each type of these two FRC's comply with different type of equations. The examined equations only apply to a specific range of fiber volume fractions.

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