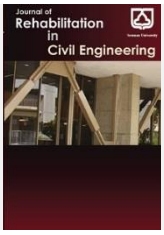

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Behavior of Nylon Fiber Reinforced Concrete at Elevated Temperature

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ABSTRACT

Incorporating fibers into reinforced cement concrete significantly enhances the structural suitability under impact and seismic loads by augmenting the stiffness and energy-saving efficiency of the material. Concrete cracks activate the vital fiber behavior called the bridge effect, enhancing the structure's strength and ductility. Since adding fibers to the concrete mix does not reduce water content but rather impairs workability due to the friction generated between fibers and the mixed paste, resulting in fiber balling. This phenomenon diminishes the performance of fiber-reinforced concrete. Adequate distribution and dispersion of fiber in the mix increases the strength and thus avoids the occurrence of fiber balling. According to reviews, nylon fiber dosages ranging from 1.5% to 3% result in effectively performing nylon fiber-reinforced concrete, which exhibits sufficient strength, durability, and flexibility. In this study, experiments have been conducted to better understand the behavior of nylon fiber-reinforced concrete at elevated temperatures by using 17 mm, 25 mm, and 50 mm nylon fiber at 1.5% and 3% dosages. When comparing different temperatures, such as normal temperature condition and elevated temperature conditions (400 °C and 800 °C), always 1.5% dosage has shown the best result for compressive strength and split tensile strength. Here, 3% dosage of nylon fiber has shown reduced mechanical strength because of the effect of fiber balling. As far as compressive strength has taken into account in three temperature cases (normal temperature, 400 °C and 800 °C), 1.5% dosage and 50 mm length of nylon fiber has achieved the most effective strength result. Besides, when split tensile strength has been concerned, 1.5% dosage and 25 mm length of nylon fiber have given the best result compared to other lengths and dosage in three temperature conditions.

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1. Introduction

In the modern age concrete is one of the most fundamental, long-lasting, and widely used manufacturing composite materials. Aggregate, cement, and water are combined to create the composite material known as concrete. However, concrete exhibits weakness in tension and is prone to cracking.

To address this issue, fiber-reinforced concrete has been introduced. It has been established that the placement of tiny, precisely spaced, and consistently distributed fibers into concrete serves as crack arresters, meaning that once the concrete begins to crack, the fibers start functioning [1]. When fibers are added, the concrete remains heterogeneous. This form of concrete is known as “Fiber Reinforced Concrete” [2].

Fiber-reinforced concrete (FRC) is a composite material consisting of Portland cement, aggregate, and various fibers. Throughout history, fibers have been used for reinforcement. In ancient times, straw and horsehair were commonly used as fillers when making mud bricks and mortar. Asbestos fibers were included in concrete during the early 1900s [3]. Fiber-reinforced concrete garnered attention when the concept of composite materials emerged in the 1950s. Early in the 1960s, Romualdi, Batson, and Mandel published studies that made FRC well-known among academic and business research scientists all over the world [4].

Metal, polymer, glass, and other fibers are used to reinforce concrete. Among these, nylon fibers stand out as the most popular and well-known due to their strength, durability, and flexibility. Incorporating nylon fibers into conventional concrete enhances its load-resisting capacity. Compared to conventional cement concrete, Nylon Fiber fiber-reinforced concrete offers superior flexural, compressive, and tensile strength, as well as increased frost resistance and reduced permeability [5].

The uniformly dispersed fibers in fresh concrete bolster its resistance against plastic shrinkage fractures. The consistently dispersed fibers in hardened concrete prevent micro fractures from turning into macro cracks and causing problems [6].

Furthermore, these fibers bridge and thereby keep existing micro-fractures together, enhancing the concrete against segregation. In contrast, Nylon fibers enhance performance in resisting splitting and the development of high stress. Furthermore, these fibers bind the bridge and the ensuing macro-fractures together, protecting the concrete against degradation. Fig.1. represents the effect of fiber-reinforced concrete in developing concrete strength to carry a greater load than plain concrete.

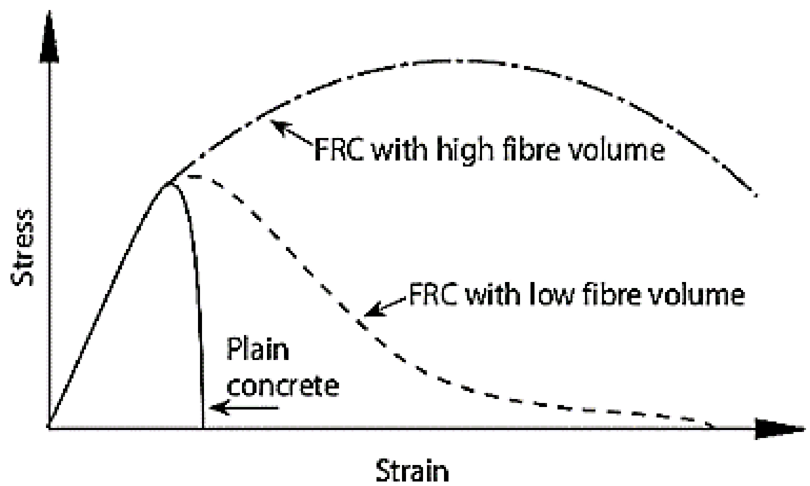

Fig. 1. Usual curve of stress-strain for Fiber Reinforced Concrete [7].

Concrete elements exposed to fire undergo structural changes such as alterations in tensile strength, compressive strength, and the strength of reinforcing steel, as well as experiencing the comparative spalling effect, which can lead to the disintegration of concrete buildings. Incorporating fibers into concrete can enhance its durability when subjected to heat [8].

Therefore, the objective of this study is to generate information on conventional concrete and Fiber Reinforced Concrete exposed to fire. The property of FRC at elevated temperatures has not received sufficient attention. This research provides a comparison of the structural behavior of conventional concrete (CC) and nylon fiber-reinforced concrete (NFRC) obtained under different temperature conditions.

The proposed study's major goal is to compare the effectiveness of employing nylon fiber in concrete to conventional concrete at elevated temperatures. The objectives to achieve this goal are outlined below:

- To conduct a review of existing literature to gather information and data regarding the characteristics of conventional concrete and nylon fiber-reinforced concrete at normal and elevated temperatures.
- To plan experimental setup varying lengths and percentages of nylon fiber at two different temperatures.
- To compare the mechanical properties of conventional concrete and nylon fiber-reinforced concrete at normal and elevated temperatures based on experimental values.

2. Experimental programs

2.1. Material properties

Materials used in this study are described below:

Fig. 2. Cement.

Fig. 3. Coarse Aggregate.

Fig. 4. Fine Aggregate.

Cement: In this study, Ordinary Portland Cement, branded as "Premier Cement," was utilized, as depicted in Fig. 2.

Coarse Aggregate: Locally available crushed stone chips were used as coarse aggregate by following ASTM C-33 guidelines which is shown in Fig. 3. In this study, 80% of 20mm down coarse aggregate and 20% 0f 12 mm down coarse aggregate were used. Fig. 5 illustrates the gradation curve for coarse aggregate by maintaining ASTM C-33 guideline [9].

Fine Aggregate: In this study, locally available Sylhet sand (red sand) was used as fine aggregate which is shown in Fig. 4. Fig. 6 shows the gradation curve for fine aggregate by maintaining ASTM C-33 guideline [9].

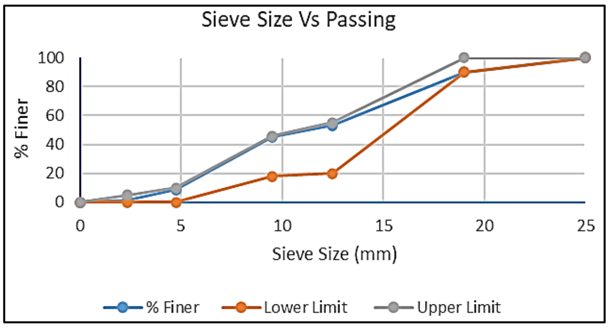

Fig. 5. Gradation curve for coarse aggregate.

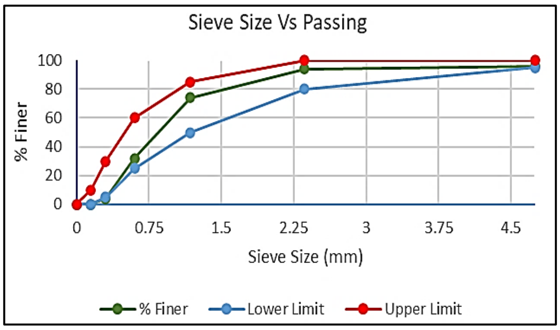

Fig. 6. Gradation curve for fine aggregate.

Nylon Fiber: Nylon is a thermally stable porous polymer with hydrophilic properties and a wide range of material resistance. The properties of nylon fiber are determined by the production circumstances and fiber dimensions [10].

The major reason for utilizing nylon fiber is to enhance the mechanical properties of concrete. Nylon fibers are beneficial in improving the cohesion of concrete mixes, enhancing resistance to plastic shrinkage during curing, preventing spalling, impact, and resisting abrasion [11]. The properties of nylon fiber are presented in Table 1, and variations in fiber length are depicted in Fig. 7.

The melting point of nylon fiber should be known to ensure material integrity and performance in high-temperature applications. The melting point of nylon fiber was 210 °C.

Table 1. Properties of nylon fiber used in the research.

Length (mm)			Diameter (mm)	Aspect ratio (L/D)			Color	Specific gravity	Tensile strength (MPa)	Density (kg/m^3)	Melting point (oC)
17	25	50	0.07	242	357	714	White	1.13	558	1130	210

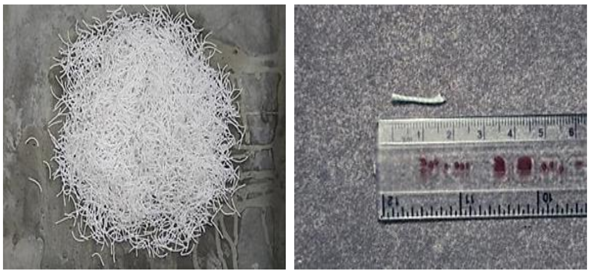

Fig. 7. (a) 17 mm Nylon Fiber.

Fig. 7. (b) 25 mm Nylon Fiber.

Fig. 7. (c) 50 mm Nylon Fiber.

Water: Portable water with a pH of 6.5 to 9.5 has been used for curing and mixing.

2.2. Description of test specimens

Here, RFL(PVC) pipes were used as cylinder molds. This study involved the use of 42 cylindrical molds, with each cylinder having dimensions of four inches (100 mm) in width and seven inches (175 mm) in height. Among the 42 concrete cylinder specimens, 21 cylinder specimens were created for the compressive test, 21 cylinder molds were prepared for the split tensile test, and 6 specimens were created for each variation based on the length and percentage of nylon fiber as well as temperature. Fig. 8 represents the cylinder mold specifications used in the study.

Fig. 8. Cylinder Molds.

2.3. Concrete mix design

The main objective of concrete mix design is to obtain the desired strength of concrete. In this study, the mix ratio of concrete is considered as 1:1.5:3 (C: FA: CA) and also the design strength of concrete is assumed 20 MPa. The water-to-cement ratio (w/c ratio) is taken as 0.48. The fiber weight is calculated according to the percentage of 1.5% and 3% of fine aggregate. Based on the mix ratio (1:1.5:3), the required amount of materials for conventional concrete and nylon fiber-reinforced concrete is presented in Table 2.

Table 2. Mix proportions of the concrete used in the experimental works.

Specimen name	% of nylon fiber	Length of nylon fiber	Water (kg)	Cement (kg)	Coarse aggregate (kg)		Fine aggregate (kg)	Fiber (kg)
					20 mm	12 mm		
$CC1_T$; $CC2_T$; $CC3_T$; $CC1_C$; $CC2_C$; $CC3_C$	No Fiber	No Fiber	0.259	0.539	1.426	0.361	0.874	No Fiber
$NF1_T$; $NF2_T$; $NF3_T$; $NF1_C$; $NF2_C$; $NF3_C$	1.5	17	0.259	0.539	1.426	0.361	0.874	0.013
$NF4_T$; $NF5_T$; $NF6_T$; $NF4_C$; $NF5_C$; $NF6_C$	3	17	0.259	0.539	1.426	0.361	0.874	0.026
$NF7_T$; $NF8_T$; $NF9_T$; $NF7_C$; $NF8_C$; $NF9_C$	1.5	25	0.259	0.539	1.426	0.361	0.874	0.013
$NF10_T$; $NF11_T$; $NF12_T$; $NF10_C$; $NF11_C$; $NF12_C$	3	25	0.259	0.539	1.426	0.361	0.874	0.026
$NF13_T$; $NF14_T$; $NF15_T$; $NF13_C$; $NF14_C$; $NF15_C$	1.5	50	0.259	0.539	1.426	0.361	0.874	0.013
$NF16_T$; $NF17_T$; $NF18_T$; $NF16_C$; $NF17_C$; $NF18_C$	3	50	0.259	0.539	1.426	0.361	0.874	0.026

2.4. Concrete mixing and casting of specimens

Concrete was mixed by using the mixer machine. At the beginning, Coarse Aggregate (CA) along with Fine Aggregate (FA) and cement were mixed in the machine at dry condition. Then the required quantity of water as per mix design was added in the machine. Mixing was continued for a total duration of 4 minutes. For NFRC, after adding water, the nylon fibers were dispersed by hand in the mixture to ensure uniform distribution of fibers in the concrete. After the mixing was done, the workability of fresh concrete was measured by using a slump cone. Subsequently, the concrete mix was poured into the prepared cylinder molds, which were lubricated beforehand on the inside. The concrete was placed in each mold in three layers, each of which was compacted using a tamping rod. Finally, the top surface of the mold was smoothed using a smooth steel trowel. The construction process of cylinder specimens is depicted in Fig.9.

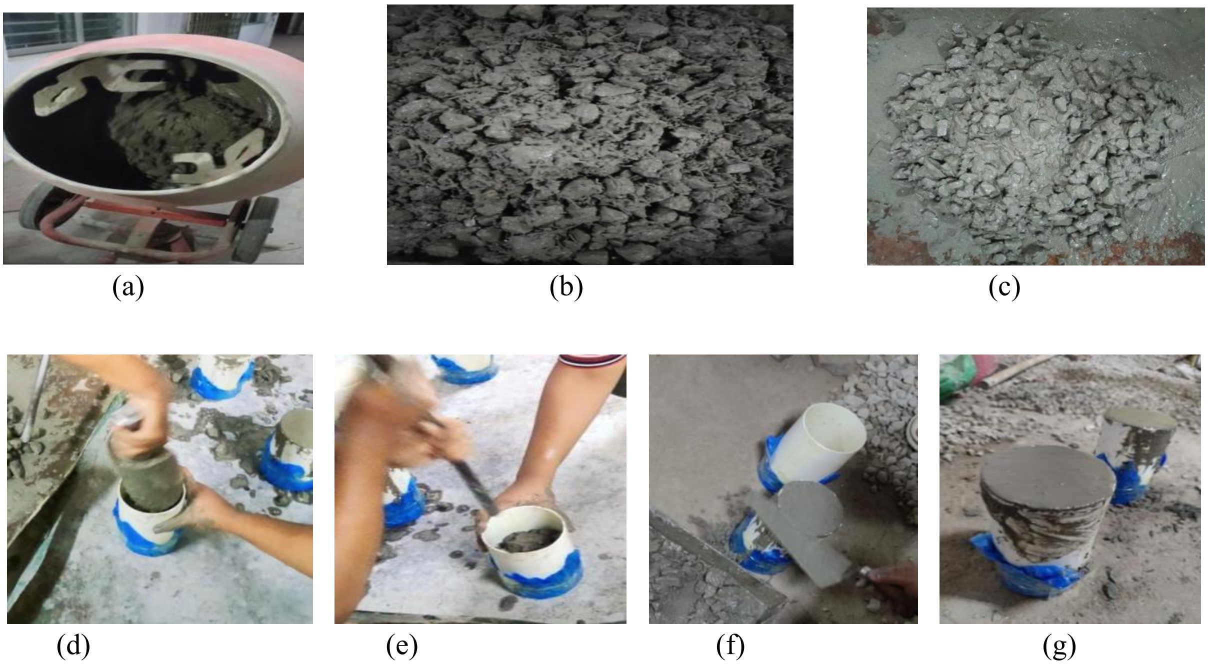

Fig. 9. (a) Concrete Mixer, (b) Conventional Concrete mix, (c) Nylon Fiber Reinforced Concrete mix, (d) Casting of a Concrete Specimen, (e) Compacting, (f) Leveling, (g) Constructed specimens.

2.5. Curing of concrete

The concrete specimens were kept in fresh water at submerged conditions for curing to ensure adequate moisture as requirements of the specification by ASTM C192/C192M-02 [12]. After curing for 28 days, the concrete cylinder specimens were used for the test. Fig. 10 illustrates the curing process of some concrete cylinder specimens.

Fig. 10. Curing of some concrete cylinder specimens.

2.6. Test on concrete

2.6.1. Slump Test

The purpose of this test is to assess the workability of the concrete mixture by evaluating the consistency of freshly poured concrete. ASTM C143/C143M specifies the use of a slump cone to gauge the slump value of the newly mixed concrete, as shown in Figure 11. [13].

Fig. 11. Slump test.

2.6.2. Heat Test of Specimens

The specimens' compressive and split tensile strength were tested after being cured for 28 days. Before testing, twenty-eight concrete specimens were heated to elevated temperatures (400°C and 800°C) for about an hour using an oven. Subsequently, the specimens were tested at normal temperature, 400°C, and 800°C to assess the variation in the strength of conventional concrete and NFRC. The heating of specimens at elevated temperatures in the oven is shown in Fig. 12.

Fig. 12. Specimen heat at elevated temperature in the oven.

2.6.3. Compressive and Split Tensile Strength Test

Compressive and split tensile strength were tested using a UTM (Universal Testing Machine) following ASTM C39/C39M and ASTM C496 test methods [14]. The tests involved applying a compressive load using the UTM. The compressive and split tensile strengths of the concrete were determined by dividing the maximum applied load at failure by the specimen's area. The test setup is shown in the following Figs. 13 and 14.

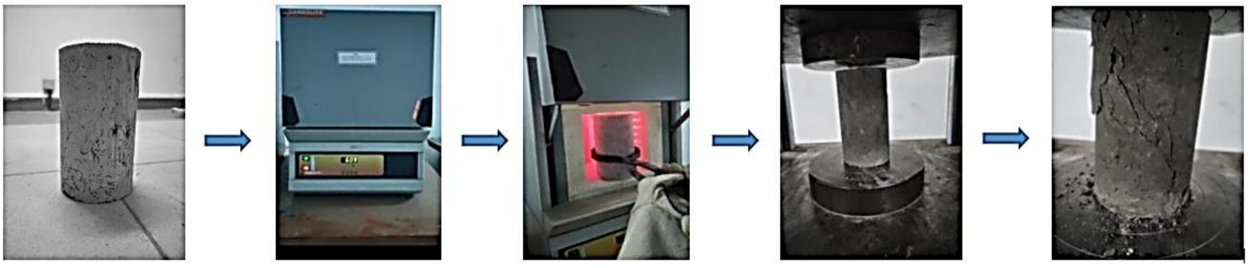

Fig. 13. Process of compressive strength test.

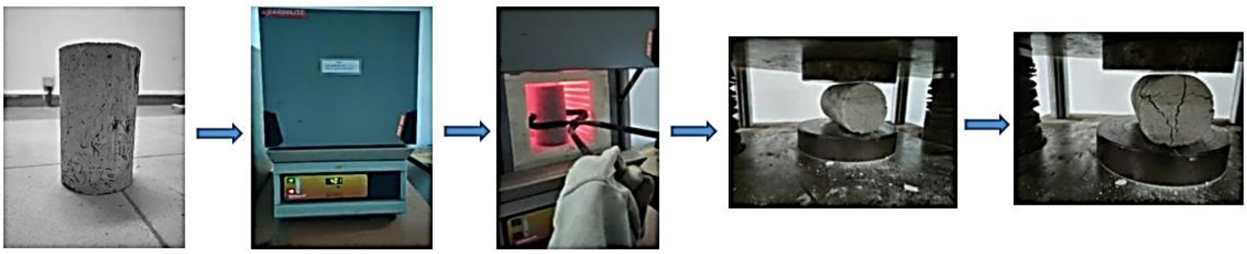

Fig. 14. Process of split tensile strength test

2.7. Correction factor

According to ASTM C31/C31M-12, the standard size of a concrete cylinder for compressive and split tensile strength test is 6”x12” (150mm x 300mm) [15]. However, in this study, 4”x7” (100mm x 175mm) cylinders were used due to space limitations in the oven. Therefore, a correction factor had to be applied to determine the actual test results for the 6”x12” concrete specimens.

According to ASTM C42-77, if the length-to-diameter ratio is 1.75 or less, then the obtained compression test result needs to be multiplied by the appropriate correction factor [16]. The correction factor values are provided in Table 3.

Table 3. Correction factor for compression test.

L/D	1.75	1.50	1.25	1.00
Factor	0.98	0.96	0.93	0.87

In this study, a mold with a height of 7 inches (175 mm) and a diameter of 4 inches (100 mm) was used. The L/D ratio of the test specimen is 7/4=1.75, for which the correction factor is 0.98. Therefore, the obtained result had to be multiplied by 0.98 to determine the actual compression test result.

For the split tensile test, ASTM C496/C496M-11 code was followed [17]. However, unlike the compression test code, a correction factor was not provided. Tran and Graubner (2018) determined the correction factor in their research article to convert the split tensile strength of any size of specimen to the standard size 6”x12” (150 mm x 300 mm) [18]. Fig. 15 illustrates the correction factor for split tensile strength.

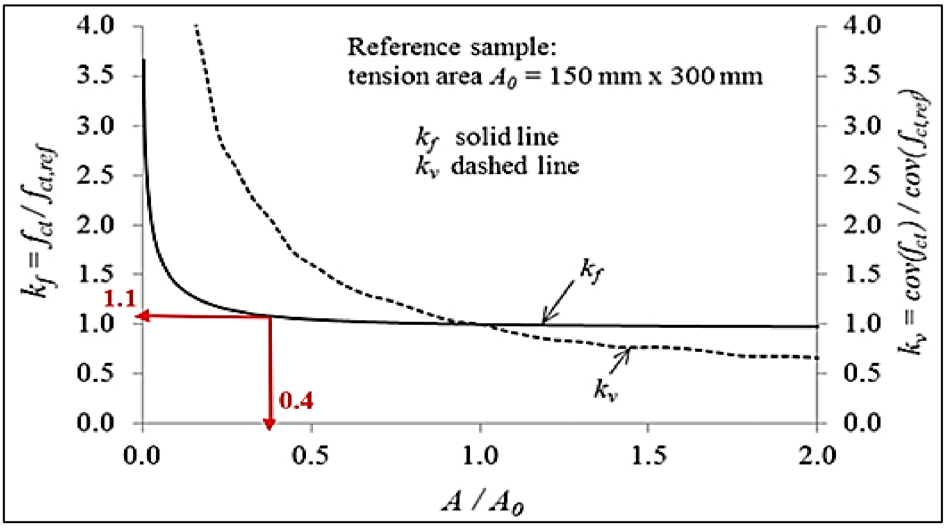

Fig. 15. Correction factor for split tensile strength. [18].

According to ASTM C496/C496M-11 [17],

The tension area in splitting tensile strength is (π DL).

Tension area of standard sample, A_0 = (π x 6”x12”) or (π x 150 mm x 300 mm)

And, Tension area of test sample, A = (π x 4”x7”) or (π x 100 mm x 175 mm)

So, the area ratio, $\frac{A}{A_0} = \frac{(\pi \text{ x } 100 \text{ mm x } 175 \text{ mm})}{(\pi \text{ x } 150 \text{ mm x } 300 \text{ mm})} = 0.4$

Now, using the area ratio 0.4, the correction factor is found 1.1.

Therefore, the obtained result had to be multiplied by 1.1 to determine the actual split tensile test result.

3. Result and discussion

3.1 Slump test result

The study assessed slump values in accordance with ASTM C143/C143M, demonstrating changes in material, water content, or mix proportions. Therefore, controlling the quality of the concrete produced is critical. Table 4 represents the slump values for different fiber lengths and fiber percentages.

Table 4. Slump values for different fiber length and fiber percentages.

Fiber Length (mm)	Fiber percentage (%)	Slump value (mm)	Degree of workability
No fiber	No fiber	150	High
17	1.5	40	Low
	3	33	Low
25	1.5	20	Very Low
	3	14	Very Low
50	1.5	14	Very Low
	3	12.5	Very Low

Figs. 16, 17, 18 & 19 represent the slump values for different fiber lengths and fiber percentages.

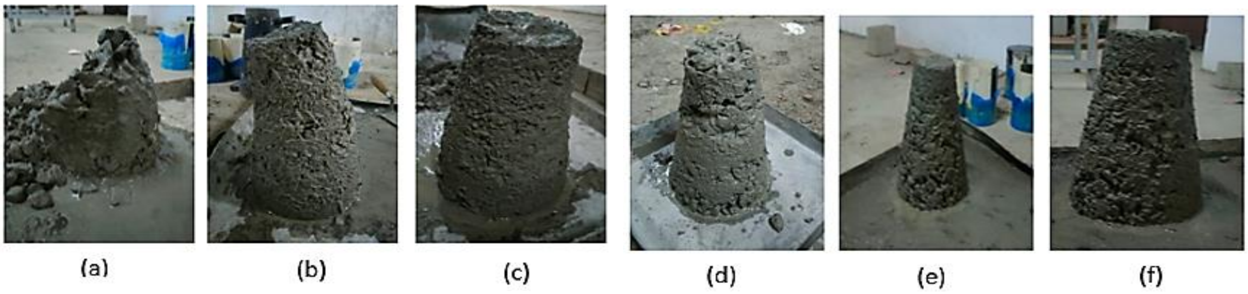

Fig. 16. Slump value for sample specimen of (a) conventional concrete (b) NFRC (17 mm,1.5% nylon fiber) (c) NFRC (17 mm, 3% nylon fiber) (d) NFRC (25 mm,1.5% nylon fiber) (e) NFRC (25 mm, 3% nylon fiber) (f) NFRC (50 mm,1.5% nylon fiber) (g) NFRC (50 mm, 3% nylon fiber).

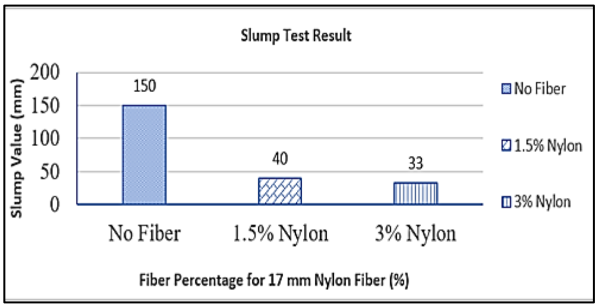

Fig. 17. Slump value for 17 mm nylon fibrous NFRC.

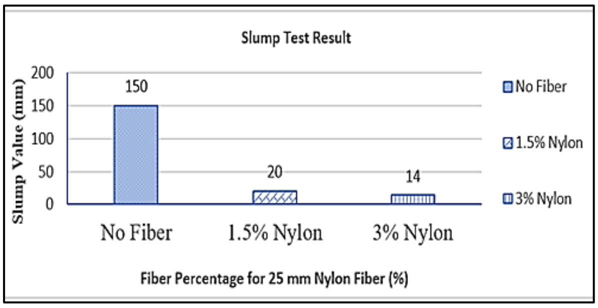

Fig. 18. Slump value for 25 mm nylon fibrous NFRC.

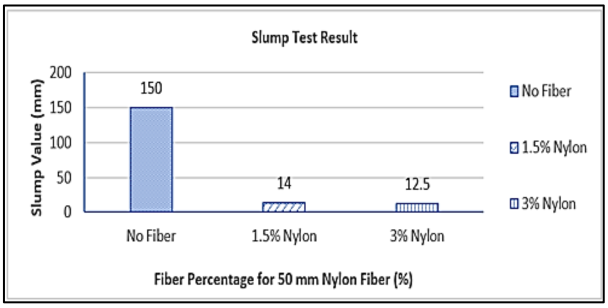

Fig. 19. Slump value for 50 mm nylon fibrous NFRC.

From Figs. 17, 18, and 19, it can be observed that the inclusion of fibers like nylon in concrete reduced the workability of the concrete. The bar graphs for three different lengths of nylon fiber show that with an increase in fiber length and percentage, the slump value decreased, indicating a reduction in workability. When the fiber volume increased, it made the movement of aggregates more difficult by reducing the lubricating effect of the cement paste.

3.2 Compressive strength test result

After 28 days of curing, the experimental results for compressive strength were obtained following the ASTM C-39 standard. Twenty-one compressive strength tests were conducted using three different lengths and percentages of nylon fibers. Three tests were performed on conventional concrete cylinder specimens, and the remaining tests were conducted on nylon fiber-reinforced concrete cylinder specimens. Three temperature ranges were considered to evaluate the effectiveness of nylon fiber-reinforced concrete (NFRC).

Table 5 represents the compressive strength for different fiber lengths and fiber percentages at different temperatures.

Table 5. Compressive strength for different fiber lengths and fiber percentages at different temperatures.

Fiber length (mm)	Percentage (%)	Temperature (ºC)	Specimen name	Load (kN)	Compressive strength of 4” x 7” Specimens (MPa)	Conversion Factor	Compressive strength converted for 6” x 12” Specimens (Mpa)
No Fiber	No Fiber	-	$CC1_C$	98.5	12.5	0.98	12.3
		400	$CC2_C$	71.8	9.1		9.0
		800	$CC3_C$	31.7	4.0		4.0
17	1.5	-	$NF1_C$	143.9	18.3		18.0
		400	$NF2_C$	80.5	10.2		10.0
		800	$NF3_C$	49.5	6.3		6.2
	3	-	$NF4_C$	104.9	13.4		13.1
		400	$NF5_C$	55.4	7.1		6.9
		800	$NF6_C$	43.2	5.5		5.4
25	1.5	-	$NF7_C$	151.6	19.3		18.9
		400	$NF8_C$	86.2	11.0		10.8
		800	$NF9_C$	55.6	7.1		6.9
	3	-	$NF10_C$	103.2	13.1		12.9
		400	$NF11_C$	64.7	8.2		8.1
		800	$NF12_C$	35.9	4.6		4.5
50	1.5	-	$NF13_C$	166.8	21.2		20.8
		400	$NF14_C$	98.9	12.6		12.3
		800	$NF15_C$	74.2	9.5		9.3
	3	-	$NF16_C$	138.2	17.6		17.2
		400	$NF17_C$	81.4	10.4		10.2
		800	$NF18_C$	53.2	6.8		6.6

Fig. 20 represents the compressive strength test results for normal temperature condition. From Fig. 20, it can be observed that the mixture containing 1.5% of 50 mm nylon fibers appears to perform well under normal temperature conditions.

Fig. 21 to Fig. 24 represent compressive strength for different lengths and percentages of nylon fibrous concrete specimens.

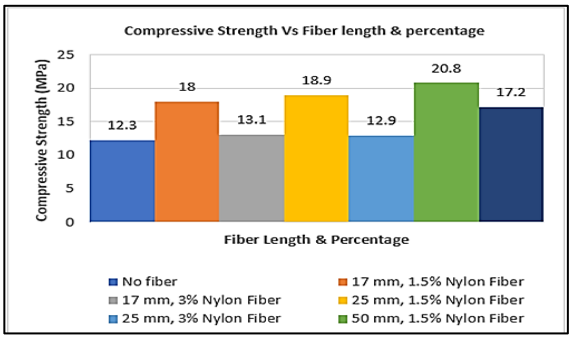

Fig. 20. Compressive Strength comparison histogram (in normal temperature).

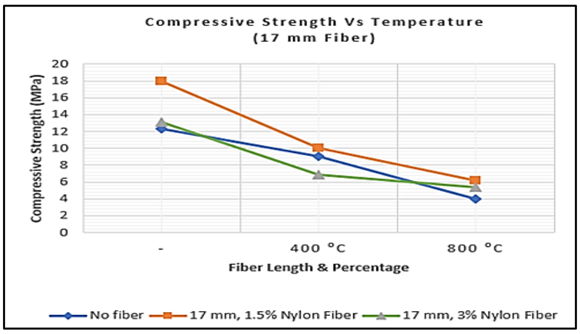

Fig. 21. Compressive strength comparison graph of 17 mm nylon fibered NFRC with conventional concrete at elevated temperatures.

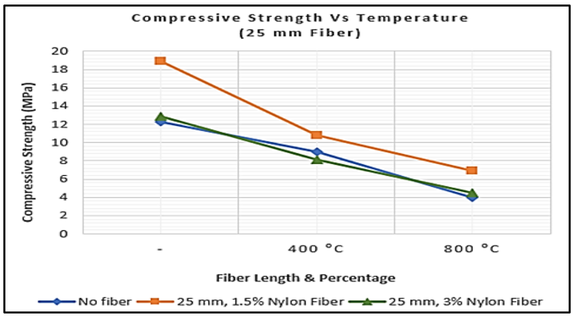

Fig. 22. Compressive strength comparison graph of 25 mm nylon fibered NFRC with conventional concrete at elevated temperatures.

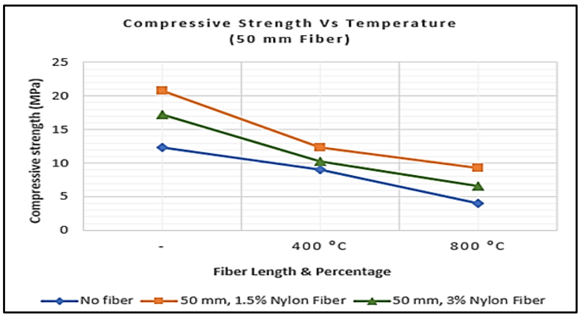

Fig. 23. Compressive strength comparison graph of 50 mm nylon fibered NFRC with conventional concrete at elevated temperatures.

From Figs. 21, 22, and 23, it can be observed that for all three length variations (17 mm, 25 mm, and 50 mm), the maximum compressive strength was found in nylon fiber with a 1.5% variation for all temperature conditions when compared with conventional concrete and the 3% nylon fibrous concrete variation.

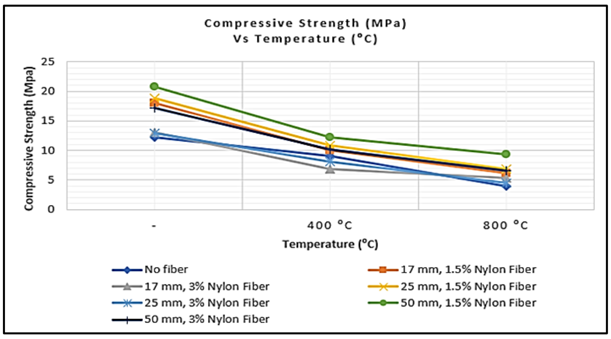

Fig. 24. Compressive Strength comparison graph at different temperatures.

From Fig. 24, considering all conditions, the optimum solution can be identified. Here, it appears that using 1.5% of 50 mm nylon fiber in the concrete mixture shows potential for achieving desirable compressive strength at both normal and elevated temperatures.

The percentage of loss in compressive strength when the specimens are exposed to high temperatures (400°C and 800°C) is presented in Table 6 as a percentage of the original strength.

Table 6. Compressive strength improvement checks for different length of fiber with different percentages at different temperatures.

Fiber Length (mm)	Fiber percentage (%)	Compressive strength increases for using fiber (%)		
		(Room temperature)	(400°C)	(800°C)
17	No Fiber	-	-	-
	1.5	46.3	11.1	55
	3	39.8	No increase	35
25	No Fiber	-	-	-
	1.5	53.7	20	72.5
	3	4.9	No increase	12.5
50	No Fiber	-	-	-
	1.5	69.1	36.7	132.5
	3	39.8	13.3	65

It can be noted from Table 6 that for 17 mm and 25 mm lengths of fiber, 1.5% nylon fiber usage is effective for both normal temperature and elevated temperature. It can be also noted that 50 mm is not recommended if the elevated temperature is low and for higher elevated temperature case 1.5% of 50 mm fiber can be used in NFRC.

3.3. Crack generation for compression test

Fig. 25 represents different types of crack formation due to compression test.

(a) (b) (c) (d) (e) (f)

Fig. 25. (a) Type 2 cracking: Vertical cracks running through one end and no well-defined cone on other end, (b) Type 5 cracking: Side fractures at top, (c) Type 3 cracking: Columnar vertical cracking through both ends, (d) Type 2 cracking: Well-formed cone on one end, (e) Type 4 cracking: Diagonal fracture with no cracking through ends, (f) Type 1 cracking: Less than 1 in. (25 mm) of cracking through caps.

From Fig. 25, it can be observed that during compression load application, fibrous concrete cylinders potentially generate lateral tension, initiating and propagating fractures. When the expanding crack reaches the interface, the tip of the fracture becomes dulled. Debonding at the fiber-matrix interface begins when the expanding crack approaches a fiber due to tensile forces perpendicular to the anticipated plane of the expanding fracture. The blunting process reduces the stress concentration at the fracture tip, preventing the crack from propagating further and even altering its path [19].

3.4. Split tensile strength test result

After 28 days, the cylinder specimens underwent the ASTM C-496 test to ascertain their split tensile strength. Twenty-one split tensile strength tests were conducted employing three distinct lengths and three different percentages of nylon fibers: 0.0%, 1.5%, and 3.0%. Among these tests, three were carried out on conventional concrete cylinder specimens, while the remaining were performed on specimens reinforced with nylon fibers.

Table 7 represents the split tensile strength for different fiber lengths and fiber percentages at different temperatures.

Table 7. Split tensile strength for different fiber length and fiber percentages at different temperatures.

Fiber length (mm)	Percentage (%)	Temperature (ºC)	Specimen name	Load (kN)	Split tensile strength of 4" x 7" Specimens (MPa)	Conversion Factor	Split tensile strength converted for 6" x 12" Specimens (Mpa)
No Fiber		-	$CC1_T$	63.5	2.3	1.1	2.5
		400	$CC2_T$	43.2	1.6		1.7
		800	$CC3_T$	10.6	0.4		0.4
17	1.5	-	$NF1_T$	65.3	2.4		2.6
		400	$NF2_T$	44.8	1.6		1.8
		800	$NF3_T$	19.1	0.7		0.8
	3	-	$NF4_T$	52.7	1.9		2.1
		400	$NF5_T$	41.8	1.5		1.7
		800	$NF6_T$	10.4	0.4		0.4
25	1.5	-	$NF7_T$	82.5	3.0		3.3
		400	$NF8_T$	47.5	1.7		1.9
		800	$NF9_T$	23.8	0.9		1.0
	3	-	$NF10_T$	58.8	2.1		2.4
		400	$NF11_T$	34.6	1.3		1.4
		800	$NF12_T$	15.9	0.6		0.6
50	1.5	-	$NF13_T$	56.8	2.1		2.3
		400	$NF14_T$	36.8	1.3		1.5
		800	$NF15_T$	27.8	1.0		1.1
	3	-	$NF16_T$	46.4	1.7		1.9
		400	$NF17_T$	28.9	1.1		1.2
		800	$NF18_T$	22.2	0.8		0.9

Fig. 26 depicts the split tensile strength test results for normal temperature conditions. Upon analysis of Fig. 26, it can be observed that 1.5% of 25 mm nylon fiber in the concrete mixture appears to exhibit the most potential at normal temperature conditions.

Fig. 27 to Fig. 30 represent split tensile strength for different lengths and percentages of nylon fibrous concrete specimens.

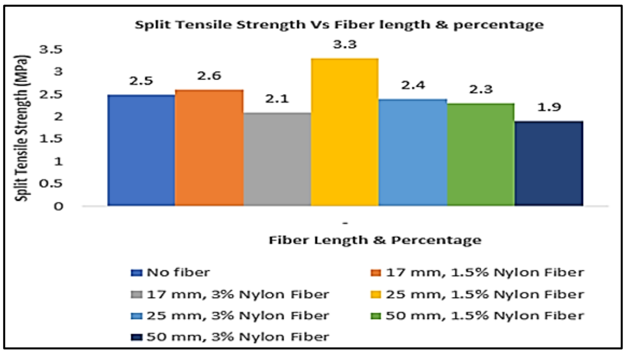

Fig. 26. Split Tensile Strength comparison histogram (in normal temperature).

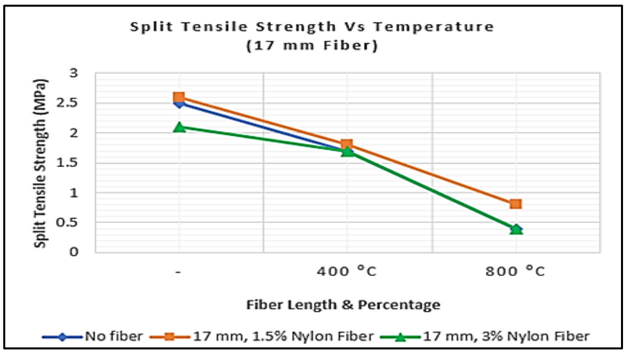

Fig. 27. Split Tensile strength comparison graph of 17 mm nylon fibered NFRC with conventional concrete at elevated temperatures.

Figs. 27, 28, and 29 show that for all three length variations (17 mm, 25 mm, and 50 mm) separately, the maximum split tensile strength was found in nylon fiber with a 1.5% variance for all the temperatures compared to conventional concrete and a 3% nylon fibrous concrete variation.

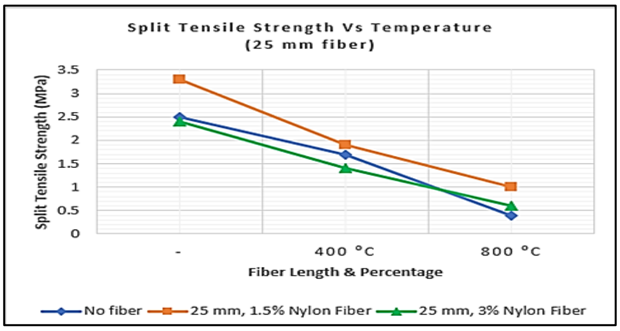

Fig. 28. Split Tensile strength comparison graph of 25 mm nylon fibered NFRC with conventional concrete at elevated temperatures.

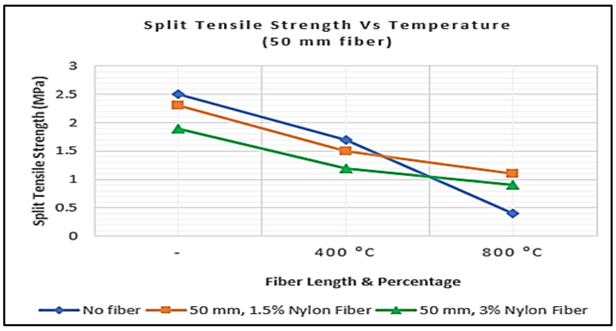

Fig. 29. Split Tensile strength comparison graph of 50 mm nylon fibered NFRC with conventional concrete at elevated temperatures.

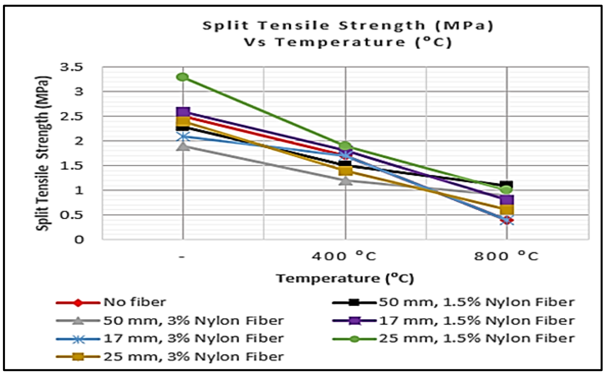

Fig. 30. Split Tensile Strength comparison graph at different temperatures.

From Fig. 30, it appears that the optimum solution can be obtained when considering all conditions. Specifically, incorporating 1.5% of 25 mm nylon fiber into the concrete mixture shows promising results for split tensile strength, both at normal and elevated temperatures.

From Fig. 20 to Fig. 30, it can be observed that compared to standard M20 concrete specimens, the use of both 1.5% and 3% fiber increased the strength. However, employing 1.5% fiber in NFRC yielded higher compressive and split tensile strength than utilizing 3% fibered NFRC, primarily due to the balling effect of the fiber, which exhibits a strong correlation with fiber length and percentage. Higher percentages of long fiber (½ inch – 2 inch) result in a higher possibility of the balling phenomena, which reduces the test specimen's capacity. Compressive and split strength steadily dropped as the temperature increased from atmospheric to 400 °C oven heat and subsequently to 800 °C oven heat. Micro-cracking within the concrete microstructure, an increase in pore size, and varying degrees of spalling are some potential causes of the strength loss that occurs with rising temperatures.

The percentage of loss in tensile strength when the specimens are exposed to high temperatures (400°C and 800°C) as a percentage of the original strength are shown in Table 8.

Table 8. Split Tensile strength improvement checks for different length of fiber with different percentages at different temperatures.

Fiber Length (mm)	Fiber percentage (%)	Split Tensile strength increases for using fiber (%)		
		(Room temperature)	(400°C)	(800°C)
17	No Fiber	-	-	-
	1.5	4	5.9	100
	3	No increase	No increase	No increase
25	No Fiber	-	-	-
	1.5	32	11.8	150
	3	No increase	No increase	50
50	No Fiber	-	-	-
	1.5	No increase	No increase	175
	3	No increase	No increase	125

It can be noted from table 8 that for 17 mm and 25 mm lengths of fiber, 1.5% nylon fiber usage is effective for both normal temperature and elevated temperature. It can be also noted that 50 mm is not recommended if the elevated temperature is low and for higher elevated temperature case 1.5% of 50 mm fiber can be used in NFRC.

3.5 Crack generation for split tensile test

Fig. 31 represents the Crack formation due to the split tensile strength test.

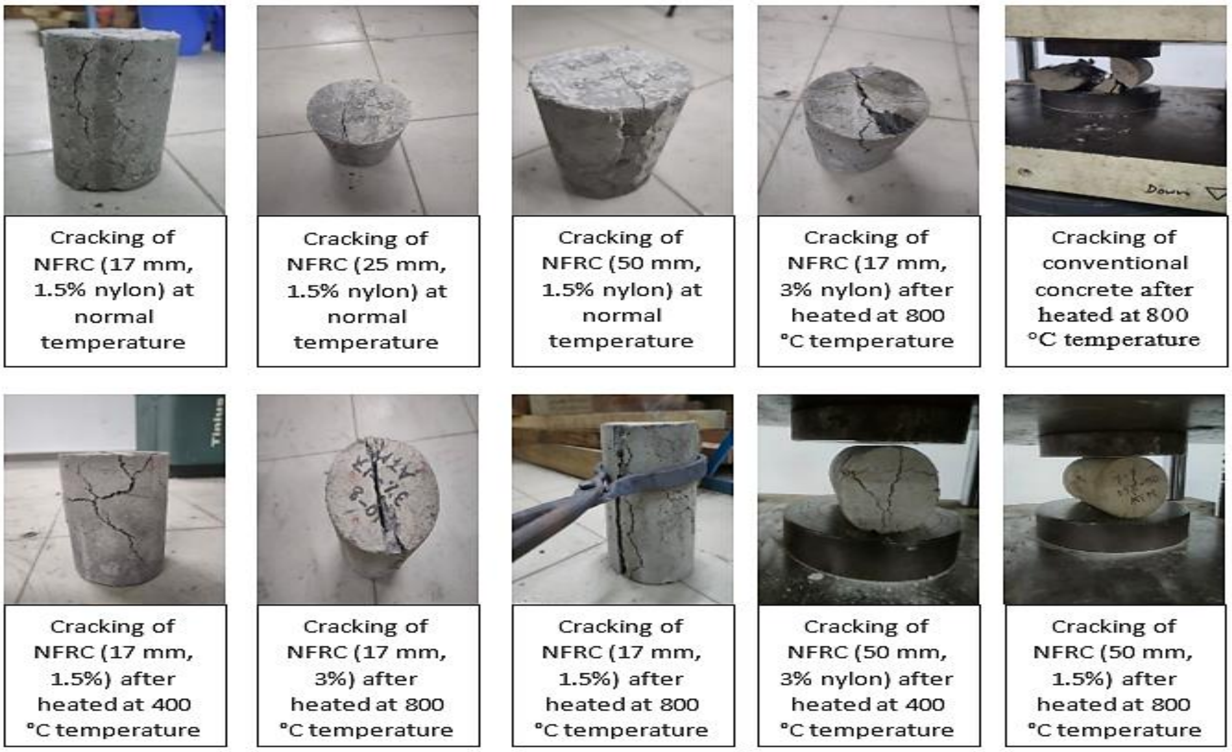

Fig. 31. Failure patterns of cylindrical specimens during split tensile strength.

From Fig. 31, it is notable that as the splitting initiated and continued, the fibers spanning across the split sections of the matrix responded by transferring stress from the matrix to the fibers, gradually supporting the entire load. This stress transfer enhanced the tensile strain capability of the fiber-reinforced concretes, thereby increasing their splitting tensile strength. This indicates that the bonding within concrete was improved by incorporating nylon fiber as an admixture, thus aiding in the reduction of cracks and enhancing durability [20].

3.6. Crack due to elevated temperature

Fig. 32 represents the Crack formation due to elevated temperature. Concrete exposed to the elevated temperatures of a fire can experience both mechanical and chemical changes. Potential mechanical changes include:

- Spalling - The expulsion of portions of concrete from the surface layer.
- External cracking - Thermal expansion & dehydration of concrete [21].

Due to these factors, both the split tensile strength and the compressive strength of the test specimens decreased with the increasing oven temperature from 400°C to 800°C. In this study, spalling was observed in some specimens heated to 800°C. Surface cracks caused by high heat were minimized by using NFRC, with NFRC containing 3% showing better performance in reducing cracks than 1.5% nylon fibrous concrete.

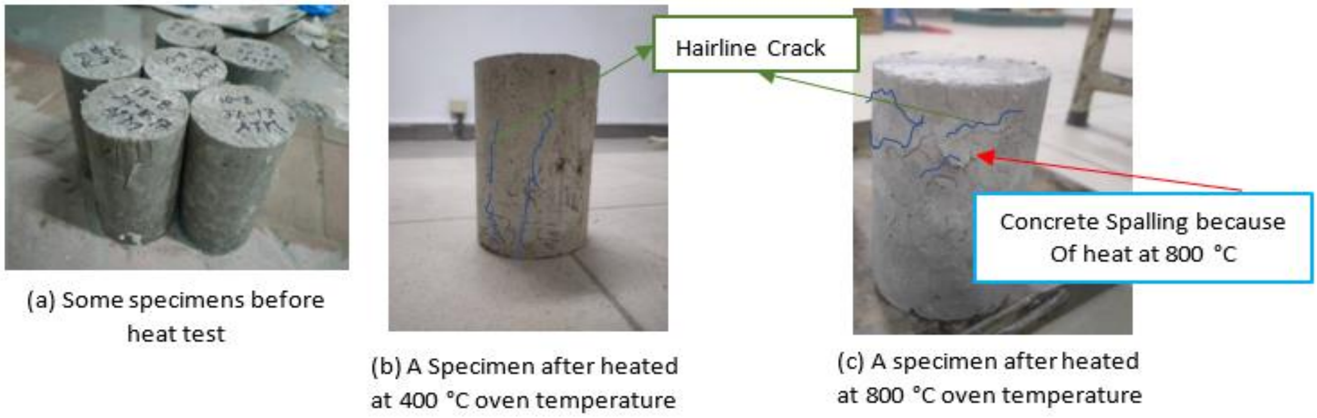

Fig. 32. Crack formation due to elevated temperature.

4. Conclusions

From the result and analysis of the study, it can be concluded that:

- As the fiber length and percentages increase, the workability of freshly poured concrete decreases while maintaining the same design mix ratio for both conventional concrete and NFRC.
- Strength (Compressive and tensile) decreased with increasing temperature for both conventional and Nylon fiber-reinforced concrete.
- 1.5% nylon fiber shows better compressive and split tensile strength compared with 3% nylon fiber at elevated temperatures.
- A 3% nylon fiber dosage reduces mechanical strength due to fiber balling, emphasizing the need for optimal fiber distribution.
- Compressive strength was tested under three temperature conditions: normal temperature, 400°C, and 800°C, where the combination of a 1.5% dosage and 50 mm length of nylon fiber achieved the most effective strength result.
- Considering the split tensile strength, 1.5% dosage and 25 mm length of nylon fiber provided the best result compared to other lengths and dosage in three temperature conditions.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors contribution statement

Abhijit Abhi: Project administration, Supervision, Writing - Original Draft, Investigation, Visualization, Data Curation.

Mir Mohiuddin: Data Curation, Formal analysis.

Maysha Ulfat: Methodology.

Sharmin Chowdhury: Conceptualization.

Raisul Shuvo: Writing - Review & Editing.

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