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Research Paper

Effects of polypropylene fibre on the compressive and splitting tensile strength of concrete

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Concrete is a versatile construction material comprising of cement, aggregates, water and occasionally admixture. It is very good in compression and weak in tension. To complement for the deficiency in the tensile zone; cracks, reinforcements (steel, fibre, etc.) have been found suitable. A good example of fibre is polypropylene. A concrete grade (M20) was batched and synthetic fibre (polypropylene) was used. Two categories of concrete specimens; with and without propylene fibre. The fibre was introduced in varying percentages (0.2%, 0.4%, and 0.6%) by weight of concrete. The compressive strength of concrete containing 0.4% polypropylene fibre at 28 days has the highest value of 32.22N/mm^2 as compared to 30.22N/mm^2, 30.49N/mm^2 and 30.39N/mm^2 for 0%, 0.2%, and 0.6% respectively. The splitting tensile strength at 7 days increases from 6.176 N/mm^2 to 8.386 N/mm^2 as the percentage of fibre increases from 0% to 0.4%.

1 Introduction

A composite material that consists essentially of a binding medium, such as a mixture of Portland cement and water, within which are embedded particles or fragment, usually a combination of fine and coarse aggregate [1]. The tensile strength of concrete is much lower than its compressive strength, it is typically reinforced with steel bars; reinforced concrete. Concrete has better resistance in compression while steel has more resistance in tension. Conventional concrete has limited ductility, low impact and abrasion resistance and little resistance to cracking. A good concrete must possess high strength and low permeability. Hence, alternative Composite materials are gaining popularity because of ductility and strain hardening. To improve the post cracking behaviour, short discontinuous and discrete fibres are added to the plain concrete. Addition of fibres improves the post peak ductility performance, pre-crack tensile

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strength, fracture strength, toughness, impact resistance, flexural Strength resistance, fatigue performance etc. The ductility of fibre reinforced concrete depends on the ability of the fibres to bridge cracks at high levels of strain. Addition of polypropylene fibres decreases the unit weight of concrete and increases its strength. The aggregate constitutes typically 75% of the concrete volume, or more, and therefore its properties largely determine the properties of the concrete. For the concrete to be of good quality, the aggregate has to be strong, durable, and free of silts, organic matter, oils, and sugars. Otherwise, it should be washed prior to use [1], because any of these impurities may slow or prevent the cement from hydrating or reduce the bond between the cement paste and the aggregate particles. While aggregate, cement, and water are the main ingredients of concrete. As afore mentioned, concrete is very weak in tension and parts of defects observed are cracks around the tension zone. To complement for this, there is need to reinforce the concrete. The construction industry is very much interested in making the weight of concrete to be as light as possible while still exhibiting adequate strength, as in the case of ferro-cement. Fibres have been found useful as better cracks arrestor.

Polypropylene fibres are new generation chemical fibres. They are manufactured in large scale and have fourth largest volume in production after polyesters, polyamides and acrylics. About 4 million tons of polypropylene fibres are produced in the world in a year [2]. Polypropylene fibres are hydrophobic, that is they do not absorb water. Therefore, when placed in a concrete matrix they need only be mixed long enough to insure dispersion in the concrete mixture. Polypropylene fibres are thermoplastics produced from Propylene gas. Propylene gas is obtained from the petroleum by-products or cracking of natural gas feed stocks. Propylene polymerizes to form long polymer chain under high temperature and pressure. However, polypropylene fibres with controlled configurations of molecules can be made only using special catalysts. Polypropylene fibres were formerly known as Stealth. These are micro reinforcement fibres and are 100% virgin homo-polymer, polypropylene graded monofilament fibres. They contain no reprocessed Olefin materials.

In our today's environment, one may say that during the cleaning of our surroundings which later results in burning of refuse amongst which is polypropylene fibre (rope). By burning of this material, it holds a great risk in contributing to the depletion of the ozone. Locally, we made use of this rope for stretching on our cloth. Rather than this isolated purpose, we can use it as an additional material in concrete by increasing or strengthening the concrete by providing adequate compressive strength, tensile strength and crack arrester amongst other.

In the course of the research work, the following were looked into: the characteristics of the cement; gradation of the fine aggregate; the workability of the fresh concrete; the compressive strength of concrete; and the effects of varying percentages of polypropylene fibre on the concrete.

1.1 Literature Review

When tensile stress is transferred to fibres, the micro cracks are arrested and thus improve the split tensile strength of concrete. Hsie et al. [3]; reported that polypropylene fibres have good ductility and dispersion so they can restrain the plastic cracks. Xiao and Falkner [4]; also reported that polypropylene fibres can be utilized to control fresh and hardened properties of concrete, and that Polypropylene fibres can decrease the plastic shrinkage. Thirumurugan and Sivakumar [5], reported that fibre addition has significant control on the failure modes of concrete and random orientation of fibres improve the fracture properties of concrete. Mohod [6]; concluded that the optimum value of fibre content of 0.5% was found satisfactory for compressive and splitting tensile strength of concrete grades 20 and 30 respectively. Kumar and Muthukannan [7], carried out experimental investigations on M15, M20 and M25 grade fly ash concrete reinforced with 0%, 0.5% and 1% polypropylene fibres. The compressive strength also increased with increase in fibre content up to 1% for all the three grades of concrete. Patel et al. [8], found that the compressive, split tensile and flexural strength improved on addition of 1.5 % of polypropylene fibre in the concrete. Gencel et al. [9]; conducted the split tensile strength using fibres up to 9 kg/m^3. It is found that the split tensile strength increased with increasing fibre content. Fibres tend to bridge the micro cracks and hamper the propagation of cracks. When tensile stress is transferred to fibres, the micro cracks are arrested and thus improve the split tensile strength of concrete.

Murahari and Rao [10]; studied the effect of polypropylene fibres in fly ash concrete. Fibre volume fraction of 0.15%, 0.2%, 0.25% and 0.3% was used in fly ash concrete with class C fly ash of specific gravity 1.96, obtained from NLC. Fly ash content was varied as 30%, 40% and 50%. 12 mm (40%) and 20mm (60%) coarse aggregate with specific gravity of

2.7 were used. The cube specimens were tested for 28days and 56 days strength. The compressive strength gained maximum strength at early age as observed for all fly ash and polypropylene fibre concrete. It is also observed that the compressive strength increased gradually from 0.15% to 0.3% fibre content.

Different formulas are proposed by building codes to compute the modulus of elasticity of concrete structures. Most of them based on the compressive strength are suitable for normal strength concrete. In the technical literature, similar formulas can be also found for high strength concrete. Thus, for both normal-strength (NSC) and high-strength (HSC) concrete, the Comité Euro-International du Béton and the Fédération Internationale de la Précontrainte (CEB-FIP) Model Code[10] and Euro code 2[11] link the elastic modulus E to the compressive strength (σ) as $E= 22,000(\sigma_B/10)^{1/3}$ [11].

2 Materials and Procedure

2.1 Materials

The materials used in the course of the research include the following: polypropylene fibre, cement, aggregates (sharp sand and granite), and portable drinking water. The polypropylene fibre (PF) in form of rope was gotten from the market, the cement and aggregates (sharp sand and granite) were obtained from a got A & K construction limited, a contractor constructing some building in Kwara State University, Malete, Nigeria.

The binder (cement) plays a very vital role in the strength of concrete and hence, its qualities were determined by subjecting to the following tests: fineness test, initial & final setting time, consistency test. In addition, particle size distribution analysis was a carried out on the fine aggregate (sharp sand) so as to determine its uniformity coefficient.

2.2 Procedure

A total number of thirty-six concrete cubes; three specimens for each percentage of the fibre and sixteen cylindrical concrete; two specimens each for percentage of the fibre were produced. The research followed a sequential procedure in which the concrete was batched by volume using ratio 1:2:4; 1 volume by part of cement, 2 volumes by part of sharp sand and 4 volumes by part of granite and the procedure goes thus:

1. The concrete was firstly produced using the above ratio (1:2:4) without the addition of polypropylene. The properties (slump test and compacting factor test) of the concrete specimens were determined in the fresh state. Concrete cubes of size 150mm x 150mm x 150mm were produced in order to determine the compressive strength in the hardened state (control test)
2. The polypropylene was cut and separated into different lengths (120mm and 160mm) and introduced in varying percentages as fibres the for production of concrete. The 120mm rope was used in the case of production of concrete cube specimen for the compressive strength test and that of the 160mm used in the production of concrete cylinder for the splitting tensile strength test.
3. The fibres were introduced randomly in varying percentages of (0%, 0.2%, 0.4%, and 0.6%) by weight of the concrete; and properties (slump test and compacting factor test) in the fresh state were determined. Cubes of size 150mm x 150mm x 150mm and cylindrical shape of 100mm x 200mm for both compressive and splitting tensile strength respectively (test experiment).
4. The concrete cubes and cylindrical concrete specimens produced were cured in water for 7 days, 14 days, and 28 days respectively.
5. The compressive strengths of the cubes and splitting tensile strength of concrete cylinders were determined for both the control and test experiments.

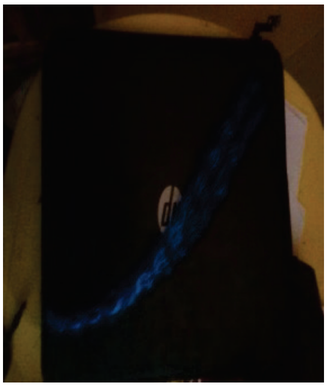


Fig. 1 – Polypropylene fibre

Fig. 2 – Cylindrical sample

Fig. 3 – Apparatus for fineness of cement

Fig. 4 – Curing of concrete cubes

Fig. 5 – Splitting tensile test

Fig. 6 – Compressive strength test

3 Results and discussion

The following tables and figures below show the result of the research work. The compressive and splitting tensile tests of the concrete specimens were determined in the hardened state using the equations 1 and 2 below.

$$\text{Compressive strength} = \frac{load(N)}{Area\ of\ cubes(mm2)} \times 1000 \quad (1)$$

$$\text{Splitting tensile strength (Ts)} = \frac{2P}{\pi LD}\ (\text{N/mm}^2) \quad (2)$$

$$\text{Modulus of Elasticity= E= } 22{,}000(\sigma_B/10)^{1/3} \quad (3)$$

$$\text{Compacting factor } (\text{C.F}) = \frac{partially\ compacted}{Fully\ compacted} = \frac{17.40}{18.74} = 0.928 < 1\ (adequate)$$

Table 1: Result of fineness test of cement

S/No.	Test Samples	Fineness (%)
1	OPC	4.2

Table 2: Results of Initial setting time of cement

No. of Trial	1	2	3	4	5	6	7
Dropping Time	9.35	9.5	10.05	10.2	10.35	10.5	11.05
Penetration (mm)	40	40	40	40	38	36	34

Initial Setting Time: 95 min (1hr: 35minutes)

Table 3: Result of final setting of cement

No. of Trial	1	2	3	4	5	6	7
Dropping Time	11.2	11.35	11.5	12.05	12.2	12.35	12.5
Impression	⊙	⊙	⊙	⊙	⊙	⊙	•
Remark	Highly noticed	Highly noticed	Noticed	Noticed	Fairly noticed	Fairly noticed	Not noticed

Final Setting time: 200mins (3hrs:20minutes)

Table 4: Particle size distribution table of the sharp sand

Sieve N0 (mm)	Weight of sieve (g)	Sieve wt + sample (g)	Weight retained (g)	% weight retained	% weight passing
4.74	460	476	16	1.6	98.4
2.36	422	478	56	7.2	92.8
1.18	377	615	238	31	69
0.85	366	476	110	42	58
0.425	324	549	225	64.5	35.5
0.3	320	445	125	77	23
0.212	310	455	145	91.5	8.5
0.15	306	357	51	96.6	3.4
0.063	295	324	29	99.5	0.5
Base	276	281	5	100	0

Table 5: Compressive strength of concrete with varying percentage of polypropylene fibre

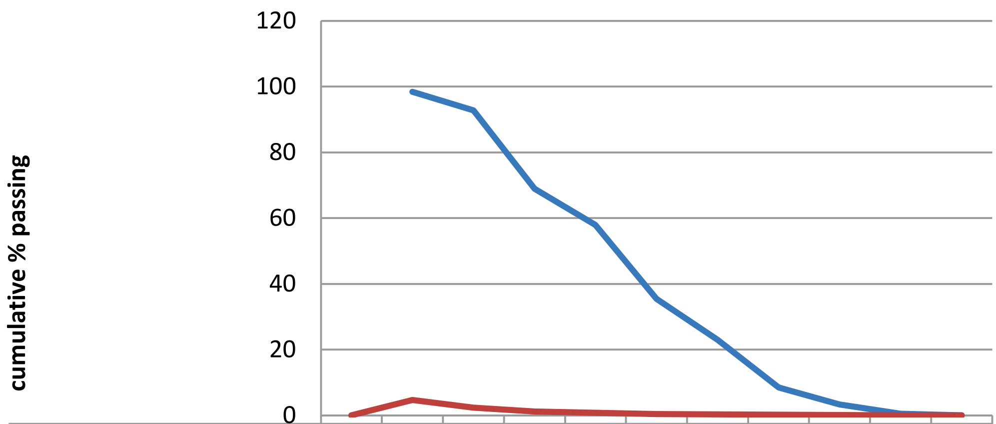
Polypropylene (%)	Age (days)	Crushing load (kN)			Compressive strength (N/mm^2)			Average compressive strength (N/mm^2)
		1	2	3	1	2	3	
0	7	556	572	528	24.71	25.42	23.47	24.53
0.2	7	566	565	560	25.16	25.11	24.88	25.05
0.4	7	564	550	552	25.06	24.44	24.53	24.67
0.6	7	540	515	512	24	22.88	22.75	23.21
0	14	604	603	600	26.84	26.8	26.67	26.77
0.2	14	636	580	540	28.27	25.78	24	26.02
0.4	14	546	550	548	24.23	24.44	24.36	24.34
0.6	14	596	590	586	26.48	26.22	26.04	26.25
0	28	668	688	684	29.68	30.58	30.4	30.22
0.2	28	688	670	700	30.58	29.78	31.11	30.49
0.4	28	740	735	700	32.89	32.67	31.11	32.22
0.6	28	680	685	687	30.22	30.44	30.53	30.39

Table 6: Modulus of Elasticity of concrete with varying percentage of polypropylene

Age	Polypropylene (%)	Modulus of Elasticity (Mpa)
7	0	29670.29
	0.2	29878.49
	0.4	29726.63
	0.6	29128.25
14	0	30547.25
	0.2	30259.27
	0.4	29593.49
	0.6	30348.17
28	0	31806.86
	0.2	31901.31
	0.4	32493.60
	0.6	31866.39

3.1 Discussion of Results

The initial setting time of cement of 95minutes obtained is more than the minimum of 30 minutes and the final setting time of 200 minutes of cement obtained is not above the maximum 600 minutes as specified by IS 269 [12]. The fineness of cement obtained is 4.2%, which does not exceed the maximum of 10% [12].



Cumulative % passing		98.4	92.8	69	58	35.5	23	8.5	3.4	0.5	0
Sieve size	0	4.74	2.36	1.18	0.85	0.425	0.3	0.212	0.15	0.063	0

Fig 7: Particle size distribution analysis of fine aggregate

The figure 7 above illustrates a curve with uniformity coefficient (Cu) of 4.14 which is less than six and hence, the sand is said to be poorly graded [13]. The table 5 shows that the compressive strength of concrete containing 0.4% polypropylene fibre at 28 days has the highest value of 32.22N/mm^2 as compared to 30.22N/mm^2, 30.49N/mm^2 and 30.39N/mm^2 for 0%, 0.2%, and 0.6% respectively. The figure 8 & 9 show that the splitting tensile strength at 7 days increases from 6.176 N/mm^2 to 8.386N/mm^2 as the percentage of fibre increases from 0% to 0.4%. There was a bit of increase in the compressive strength from 0 to 0.1% contrary to the work of Madhavi et al. [2], the addition of fibres up to a volume fraction of 0.1% does not affect the compressive strength.

The splitting tensile strength decreases at fibre content greater than 0.4% as against that obtained by Kumar and Muthukannan [7] (strength satisfactory up to a content of 0.5% fibre) and Patel el al. [8] (satisfactory to a content of 1.5 % of polypropylene fibre in the concrete). The modulus of elasticity of the concrete increases from 31806.86Mpa at 0% propylene fibre to 32493.60Mpa at 0.4%

The compacting factor of concrete is 0.928, which is less than 1.0 as stated by ASTM [13].

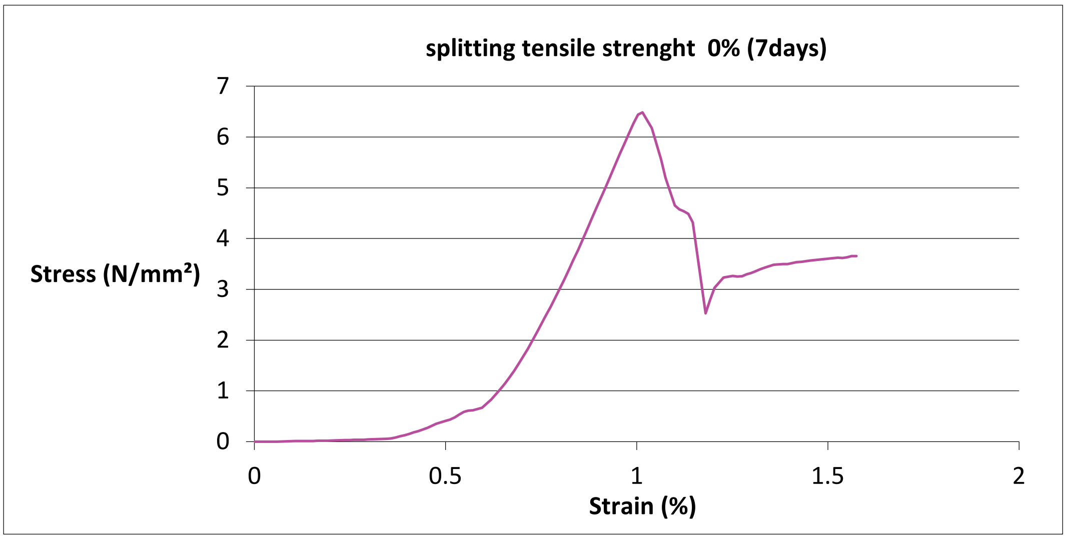


Fig 8: Graph of splitting tensile strength for 0% Polypropylene fibre

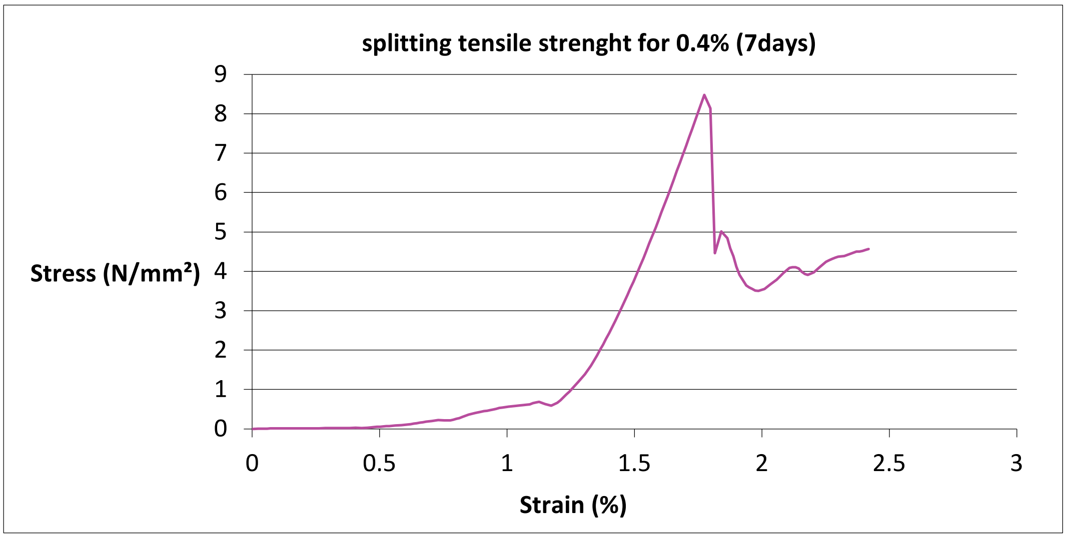


Fig 9: Graph of splitting tensile strength for 0.4% Polypropylene fibre

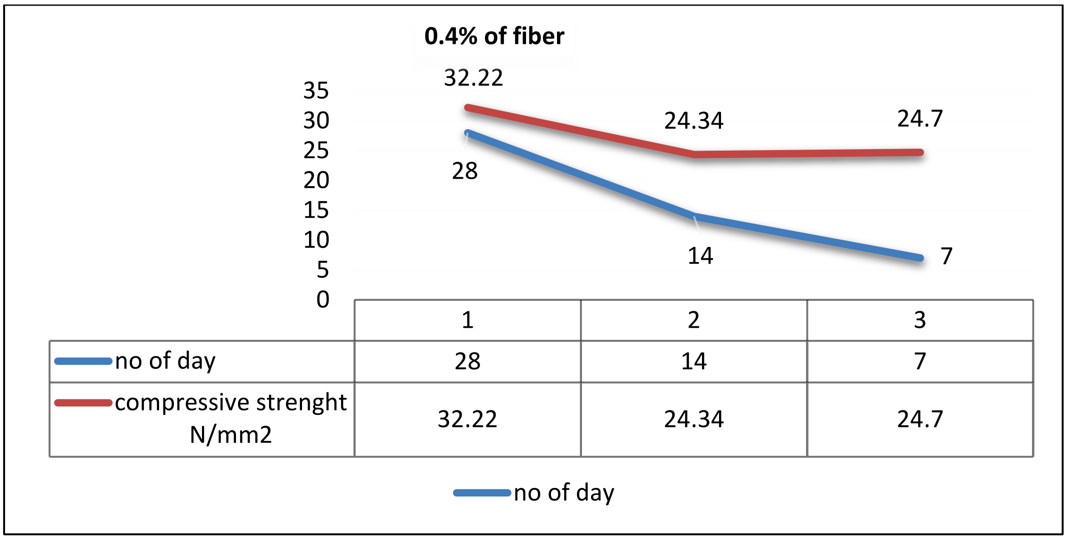


Fig 10: Graph of compressive strength of concrete for 0.4% Polypropylene fibre

4 Conclusion

In summary, it was observed that the characteristics of the cement used are satisfactory when compared with the standard specification. Also, the consistency of the concrete was adequate. Furthermore, it could be inferred that the compressive strength of concrete at early stage increases as the percentage of polypropylene fibre increases. In addition, the result of the particle distribution analysis shows that the sharp sand used is not well graded.

Lastly, the splitting tensile strength of the concrete increases as the percentage of polypropylene increases and optimum strength obtained at 0.4%fibre addition.

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