**American Journal of Engineering Research (AJER)**
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-02, Issue-03, pp-20-26
www.ajer.us

Research Paper Open Access

# Comparison of Performance of Standard Concrete And Fibre Reinforced Standard Concrete Exposed To Elevated Temperatures

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***Abstract:*** Concrete elements exposed to fire undergo temperature gradients and as a result, undergo physical changes or spalling which leads to expose steel reinforcement. This causes distress in concrete structures. The performance of concrete can be improved with the addition of steel fibres to concrete especially when it is exposed to heat. Therefore, this study has been carried out to generate experimental data on standard concrete of grade M45 and Fiber Reinforced Standard Concrete exposed to elevated temperatures.

For each type of concrete six sets of cubes, cylinders, and beams have been cast. Each set contains 5 specimens. A total of thirty cubes, thirty cylinders, and thirty beams of Standard Concrete and Fiber Reinforced Standard Concrete have been cast, out of which 5 sets of standard concrete and fiber reinforced standard concrete are exposed to elevated temperatures of $50^0$C, $100^0$C, $150^0$C, $200^0$C and $250^0$C for 3 hours and the sixth set is tested at room temperature as control concrete.

These specimens have been tested for compressive strength, split tensile strength, and flexural strength in hot condition immediately after taking out from oven. The results are analyzed and final conclusions are drawn.

## I. INTRODUCTION

Concrete is a construction material composed of cement as well as other cementatious materials such as fly ash and slag content, aggregate (generally a coarse aggregate such as gravel, limestone, or granite, plus a fine aggregate such as river sand), water, and chemical admixtures. Apart from its excellent properties, concrete shows a rather low performance when subjected to tensile stress. Another rather recent development is steel fiber reinforced concrete (SFRC). The concept of using fibers as reinforcement is not new. Fibers have been used as reinforcement since ancient times.

**Effect of fibers in concrete**

Fibers are usually used in concrete to control plastic shrinkage cracking and drying shrinkage cracking. They also lower the permeability of concrete and thus reduce bleeding of water. Some types of fibers produce greater impact, abrasion and shatter resistance in concrete.

The amount of fibers added to a concrete mix is measured as a percentage of the total volume of the composite (concrete and fibers) termed volume fraction ($V_f$). $V_f$ typically ranges from 0.1 to 3%. Aspect ratio ($l$/d) is calculated by dividing fiber length ($l$) by its diameter (d). Fibers with a non-circular cross section use an equivalent diameter for the calculation of aspect ratio. If the modulus of elasticity of the fiber is higher than that of the matrix (concrete or mortar binder), they help to carry the load by increasing the tensile strength of the material.

**Some developments in fiber reinforced concrete**

The newly developed FRC named as Engineered Cementitious Composite (ECC) is 500 times more resistant to cracking and 40 percent lighter than traditional concrete. ECC can sustain strain-hardening up to several percent strain, resulting in a material ductility of at least two orders of magnitude higher when compared to normal concrete or standard fiber reinforced concrete. ECC also has unique cracking behavior. When loaded to beyond the elastic range, ECC maintains crack width to below 100 µm, even when deformed to several percent tensile strains.

Recent studies performed on a high-performance fiber-reinforced concrete in a bridge deck found that adding fibers provided residual strength and controlled cracking. By adding steel fibers while mixing the concrete, a so-called homogeneous reinforcement is created. This does not notably increase the mechanical properties before failure, but governs the post failure behavior. Thus, plain concrete, which is a quasi-brittle material, is turned to the pseudo ductile steel fiber reinforced concrete.

After matrix crack initiation, the stresses are absorbed by bridging fibers, and the bending moments are redistributed. The concrete element does not fail spontaneously when the matrix is cracked; the deformation energy is absorbed and the material becomes pseudo-ductile.

The steel fiber reinforcement not only improves the toughness of the material, the impact and the fatigue resistance of concrete, but it also increases the material resistance to cracking and, hence to water and chloride ingress with significant improvement in durability of concrete structures. Therefore, the use of SFRC in tunnel structures represents an attractive technical solution with respect to the conventional steel reinforcement, because it reduces both the labor costs (e.g. due to the placement of the conventional steel bars) and the construction costs (e.g. forming and storage of classical reinforcement frames, risks of spalling during transportation and laying). These preliminary SFRC examples exhibited reduced crack development and a lower risk of leakage and the falling off of concrete flakes, which often represents a concrete issue for tunnel road. Furthermore, the steel fiber reinforced details, such as the shear tooth of ring joints, was found to exhibit a higher ductility under localized force.

Due to the current lack of design rules for Steel Fibers Reinforced Concrete (SFRC) structures, engineers have usually designed SFRC tunnel lining segments by adopting the same rules that are valid for concrete with conventional reinforcement. However, the post-cracking behavior of SFRC structure is dramatically different from conventional RC structures. Steel fibre reinforced concrete (SFRC) has been successfully used in various types of construction due to the fact that adding steel fibers improves the durability and mechanical properties of hardened concrete, notably flexural strength, toughness, impact strength, resistance to fatigue, and vulnerability to cracking and spalling.

Fire resistance is a characteristic of a structure assembly, referring to the ability of the assembly to withstand the effects of fire. The expected performance of a fire-resistant assembly is either to restrict the spread of fire beyond the compartment of fire involvement or to support a load, despite exposure to a fire.

If the structure is not totally damaged or has suffered serious damage in one part only, an assessment needs to be made of fire severity so that the amount of damage may be quantified. One of the main differences between standard fire resistance test and fires in structure elements is that real fires do not have a uniform intensity throughout the structures and may have reached different peaks in different parts. Therefore it is necessary to divide the whole structure in different zones and make severity assessment for each zone. Fire reports usually prepared by the fire brigade indicate time of start and finish, efforts required to control the fire and any other problems experienced. It gives duration of fire and qualitative judgment whether it was a small or large, more or less damaging and whether particular areas had higher temperatures than others had. Examination of debris from different types of materials helps in judging the maximum temperatures achieved in different parts giving an idea about fire severity.

As per the existing practice, the comparison of standard concrete and standard fiber reinforced concrete exposed to different temperatures of standard fire has been dealt. This procedure is expensive as well as time consuming, since a large experimental research program is needed to cover all significant problem variables.

The study of behavior of concrete at elevated temperatures has achieved great importance in recent times because the accumulated annual loss of life and property due to fires is comparable to the loss caused by earthquakes and cyclones. This necessitates development of concrete mix of fire resisting.

**Research Significance**

The objective of this study is to generate experimental data base for compressive strength, flexural strength and split tensile strength of standard concrete and steel fiber reinforced standard concrete which are exposed to elevated temperatures of $50^0$C to $250^0$C for 3 hours. The tests have been conducted immediately on specimens in hot condition after taking out of oven.

**Review of Literature**

Nguyen Van Chanh[1] carried out investigations on mechanic properties, technologies, and applications of SFRC. As it is now well established that one of the important properties of steel fibre reinforced concrete (SFRC) is its superior resistance to cracking and crack propagation. As a result of this ability to arrest cracks, fibre composites possess increased extensibility and tensile strength, both at first crack and at ultimate, particular under flexural loading; and the fibres are able to hold the matrix together even after extensive cracking. The net result of all these is to impart to the fibre composite pronounced post – cracking ductility which is unheard of in ordinary concrete. The transformation from a brittle to a ductile type of material would increase substantially the energy absorption characteristics of the fibre composite and its ability to withstand repeatedly applied, shock or impact loading.

Mehrdad Mahoutian et al[2] have proposed that adding of fibers into the concrete is an efficient method of increasing the mechanical properties of concrete. The most famous of fibers used in the concrete are steel, glass and polypropylene fibers. The addition of fibers significantly improves many of the engineering properties of mortar and concrete, notably impact strength and toughness. Tensile strength, flexural, failure strength and ability to spalling are also enhanced. Moreover addition of fibers makes the concrete more homogeneous and isotropic material.

Chih-Ta Tsai et al[3] presents the way durability has been introduced to steel fiber reinforced concrete in Taiwan. It is generally acknowledged that steel fibers are added to improve the toughness, abrasion resistance, and impact strength of concrete. However, a locally developed mixture design method, the densified mixture design algorithm (DMDA), was applied to solve not only the entanglement or balling problem of steel fibers in concrete or to produce steel fiber reinforced self-consolidating concrete (SFRSCC) with excellent flow-ability, but also to increase the durability by reduction in the cement paste content. By dense packing of the aggregates and with the aid of pozzolanic material and superplasticizer (SP), concrete can flow honey-like with less entanglement of steel fibers. Such SFRSCC has already been successfully applied in several projects, such as construction of a low radiation waste container, bus station pavement, road deck panel, and two art statues.

S. P. Singh et al[4] investigated to study the fatigue strength of steel fibre reinforced concrete (SFRC) containing fibres of mixed aspect ratio are presented. Approximately eighty one beam specimens of size 500 mm x 100 mm x 100 mm were tested under four-point flexural fatigue loading in order to obtain the fatigue lives of SFRC at different stress levels. About thirty six static flexural tests were also carried out to determine the static flexural strength of SFRC prior to fatigue testing. The specimens incorporated 1.0, 1.5 and 2.0% volume fraction of corrugated steel fibres. Each volume fraction incorporated fibres of two different sizes i.e. 2.0 mm x 0.6 mm x 25 mm and 2.0 mm x 0.6 mm x 50 mm by weight of the longer and shorter fibres in the ratio of 50% - 50%. Fatigue life data obtained has been analyzed in an attempt to determine the relationship among stress level, number of cycles to failure and probability of failure for SFRC. It was found that this relationship can be represented reasonably well graphically by a family of curves. The experimental coefficients of the fatigue equation have been obtained from the fatigue test data to represent the curves analytically.

L. Sorelli and F. Toutlemonde[5] have focused on the application of SFRC in tunnel lining segments, as an alternative to conventional RC segments. Because of the structural applications of Steel Fiber Reinforced Concrete (SFRC) have recently been increasing due to the improvement of material properties, such as in the material toughness under tension and durability. However, because the behavior of such structures is fairly different from conventional Reinforced Concrete (RC) structures the classic design method should be critically reviewed considering the post-cracking resistant mechanism. Based on an accurate experimental investigation on full scale specimens, a smeared crack model, which implements the Hilleborg's criteria, was used. In order to assess the SFRC reliability, a wide population of tensile tests on cylinders drilled out from a reference full scale specimen was carried out. The tensile constitutive relation, which is the fundamental property for SFRC materials, was chosen on a probabilistic fashion accounting for the actual dispersions of fiber in the tunnel segment due to the casting procedure. According to the finite element analysis, the structural response of such structures was found to be very sensitive to the fiber dispersion. Finally, the AFREM recommendation for SFRC materials and the simplified 'struts and ties' model were evaluated by means of a parametric analysis.

K.Srinivasa Rao et al[6] carried out studies for proper understanding of the effects of elevated temperatures on the properties of HSC. The paper reports results of laboratory investigations carried out to study the effects of elevated temperatures ranging from $50^0$C to $250^0$C on the compressive strength of HSC made with both ordinary Portland cement (OPC) and Portland pozzolana cement (PPC). The residual compressive strengths were evaluated at different ages. The results showed that at later ages HSC made with Portland pozzolana cement performed better by retaining more residual compressive strength compared to concrete made with ordinary Portland cement.

M.Potha Raju et al[7] carried out a study aimed to study the effect of elevated temperatures ranging from 50 to $250^0$C on the compressive strength of high-strength concrete (HSC) of M60 grade made with ordinary Portland cement (OPC) and pozollana Portland cement (PPC). Tests were conducted on 100 mm cube specimens. The specimens were heated to different temperatures of 50,100,150,200 and $250^0$C for three different exposure durations of 1, 2 and 3 h at each temperature. The rate of heating was maintained as per ISO-834 temperature-time curve for standard fire. After the heat treatment, the specimens were tested for compressive strengths. Test results were analysed and the effects of elevated temperatures on PPC concrete were compared with OPC concrete. The PPC concrete exhibited better performance than OPC concrete.

**Experimental Programme**

**Table – 1:** Total quantities used in present work

| Ingredient | Quantity per m$^3$ of concrete | |
|---|---|---|
| | Standard Concrete | Standard Fiber Reinforced Concrete |
| Cement | 256.328 kg | 256.328 kg |
| Fine Aggregate | 267.571 kg | 267.571 kg |
| Coarse Aggregate | 943.677 kg | 943.677 kg |
| Fibers | ------ | 15.288 kg |
| SP 430 | 2.05 lts | 2.05 lts |
| Water | 103.3 lts | 103.3 lts |

**Casting of test specimens**

In the present work, the compressive strengths of Standard Concrete and Standard Fiber Reinforced Concrete were evaluated after exposing them to elevated temperatures for three hours duration and testing is made in hot condition immediately after taking out from the oven.

***Work:***

To produce Standard Concrete and Fiber Reinforced Standard Concrete, the major work involves designing an appropriate mix proportion and evaluating the properties of the concrete thus obtained. Modern concrete mix designs can be complex. The design of a concrete, or the way the weights of the components of a concrete is determined, is specified by the requirements of the project and the various local building codes and regulations.

The design begins by determining the "durability" requirements of the concrete. These requirements take into consideration the weather conditions that the concrete will be exposed to in service, and the required design strength. Many factors need to be taken into account, from the cost of the various additives and aggregates, to the tradeoffs between, the "slump" for easy mixing and placement and ultimate performance. In the present work standard concrete of 45 mix and w/b ratio of 0.5 is used. Compressive strength tests were conducted to know the strength properties of the mixes. Initially a simple mix design was followed and modifications were made accordingly while arriving at trial mixes to get an optimized mix which satisfies both fresh, hardened properties and economy. Finally a simple mix design for standard concrete have been developed according to IS 10262-1982[8].

Strengths have been compared between standard concrete and fiber reinforced standard concrete exposed to fire. Exposures are made for 50$^0$C, 100$^0$C, 150$^0$C, 200 $^0$C, 250 $^0$C for a time interval of 3 hours. Immediately after exposure compressive strength, flexural strength, and split tensile strengths have been determined in hot conditions.

Steel fibres of 0.41 w/b (aspect) ratios and straight fibers of 0.5 mm diameter and 50 mm length were added to the above mix.

Concrete: The mix proportion was 1: 1.04: 3.68 with water cement ratio of 0.41. The slump was found to be 80 mm. The cement used was Ordinary Portland Cement (OPC) conforming to IS 12269-1987[9]. The fine aggregate used was natural river sand conforming to zone IV of IS 383-1970[10]. The coarse aggregate used was crushed stone passing IS 20 mm sieve and retained on IS 4.75 mm sieve. Potable water of pH value 6.72 was used. The experimental program can be identified in two stages, first, to develop self standard concrete of M45 mix, which satisfy specifications given by Indian Standards. Then, in the second stage characteristics of compressive, bending and splitting tensile strengths exposed to different temperatures were studied by adding and without adding fibers.

The program consisted of arriving at mix proportions, weighing the ingredients of concrete accordingly, mixing them in a standard concrete mixer and then testing for the fresh properties of respective concrete. If fresh properties satisfy standard specifications, 9 Standard cubes of dimensions 150 mm x 150 mm x 150 mm were cast to check whether the target compressive strength is achieved at 7-days and 28- days curing. If either the fresh properties or the strength properties are not satisfied, the mix is modified accordingly. Standard cube moulds of 150 mm X 150 mm X 150 mm made of cast iron were used for casting standard cubes. The standards moulds were fitted such that there are no gaps between the plates of the moulds. The moulds then oiled and kept ready for casting. After 24 hours of casting, the specimen were demoulded and transferred to curing tank where in they were immersed in water for the desired period of curing.

For comparing strengths for M45 grade, standard concrete and fiber reinforced standard concrete, a total of 36 cubes, 36 cylinders and 36 beams were caste. Out of which, 18 cubes, 18 cylinders and 18 beams are tested for each type of concrete.

The concrete was mixed in a rotary mixer so as to ensure better mixing and to avoid any loss of materials. The mixer was hand-loaded with coarse aggregate first, then with fine aggregate and then with cement for Standard type of Concrete. And for the Fiber Reinforced Standard concrete the same is repeated with the inclusive of Fibers in the last. During the rotation of the mixer, first water was added to the ingredients inside and then with the required amount of super plasticizer. The rotation was continued up to 2 minutes. The mixer was tilted and the concrete was unloaded on a clean platform. Oil was applied to the inside faces of the moulds to avoid any sticking of concrete to the walls of the moulds.

**Cubes**

To study the compressive strength of concrete, 18 cubes of 150 mm size for each type of concrete were cast. 150 mm cube moulds were filled with concrete and placed on table vibrator and vibrated for 1 minute, after the compaction was completed, the surfaces of the cubes were leveled with a trowel and were marked for identification. These specimens were demoulded after 24 hours of casting.

**Preparation of cylindrical specimens**:

Cylindrical moulds (150mm diameter and 300 mm height) were used to determine the splitting tensile strength. Eighteen cylinders were cast of compacted for each batch of the mix. Specimens were removed from the moulds after 24 hrs and cured in water. Testing of specimens were carried out after 28 days of curing and then exposed to elevated temperatures.

**Preparation of beam specimens**:

Beam moulds (500 mm X 100 mm X 100 mm) were used to determine the flexural strength. Eighteen beams were cast and compacted for each batch of the mix. Specimens were removed from the moulds after 24 hrs and cured in water. Testing of specimens were carried out after 28 days of curing and then exposed to temperatures.

**Curing of Specimens**

After the specimens were demoulded, these were stored under water at room temperature until tested at an age of 28 days. The specimens were cured in a water tank for 28 days.

After 28 days of casting, all the specimens were taken out of curing tank and stored under laboratory air drying conditions until required for high temperature exposure or for any load test.

**Testing of Specimens**

After curing for 28 days, the specimens were tested for compressive strength and tensile strength of concrete in a 200-Ton compression testing machine and flexural strength in Universal Testing Machine according to IS 516-1959[11].

The cubes, cylinders and beams were tested immediately on removal from oven after exposing them to relevant temperatures.

The bearing surfaces of the compression testing machine were wiped clean. The cubes and cylinders to be tested were placed concentrically and in such a manner that the load was applied to the opposite sides of the cube as cast, that is, not on the top and bottom. Then the load was applied without shock and increased continuously at a rate of approximately 140 kg/sq cm/minute until the resistance of the cube to the increasing load breaked down and no greater load could be sustained. The maximum load applied to the cube was then noted down. In the similar manner beams were tested under UTM for flexural strength.

**Exposing Specimens to elevated temperatures and Testing**

To determine the strength after exposed to elevated temperatures, the specimens were heated in oven. After exposing to specified temperatures for three hours, these specimens were tested for respective strengths in hot condition immediately after taking out of the oven.

**Heating Specimens**

The test specimens were subjected to temperatures from 50°C to 250°C at intervals of 50°C each for three hours duration. The specimens were heated to the specified target temperatures.

The specimens were placed on each tray of oven .The target temperatures was set in the control panel after the specimens were placed inside the oven. Initially the temperature inside the oven was 27°C. It took some time for the oven to reach the target temperature depending upon the set temperature i.e., more time for higher temperatures.

Following attainment of the desired temperature, the exposure continued for three hours. Then the oven was switched off and the specimens were taken out of the oven and were tested in hot condition.

**Discussions**

## II. COMPARISON OF SC AND FRSC FOR COMPRESSIVE STRENGTH

The compressive strength of SC (standard concrete) and FRSC (fibre reinforced standard concrete) specimens exposed to different elevated temperature is expressed as percentage of 28 days compressive strength of SC (standard concrete) at room temperature. The variation of compressive strength with temperature has been plotted as shown in Fig-1

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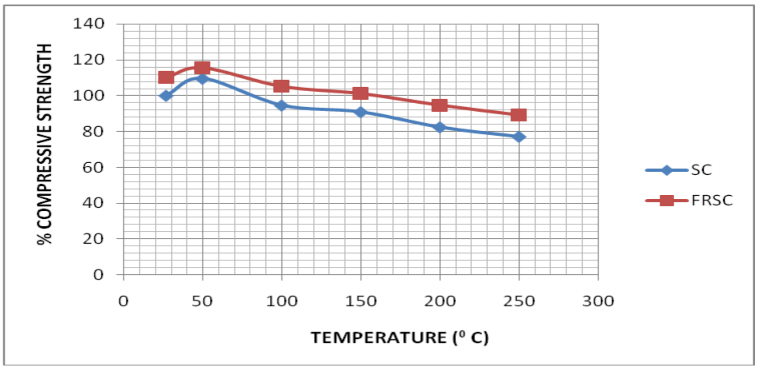


**Fig. 1 Comparsion of variation compressive strength with temperature for SC and FRSC.**

From Fig 1, it can be observed that FRSC exhibits more compressive strength than the SC at the all temperatures. As the temperature is increased FRSC maintained low decreament profile than SC resulting in more percentage compressive strengths after $100^0$C. The difference between compressive strength of FRSC and SC varies in the range is 6-10 percentage.

## III. COMPARISON OF SC AND FRSC FOR SPLIT TENSILE STRENGTH

The split tensile strength of SC (standard concrete) and FRSC (fibre reinforced standard concrete) specimens exposed to different elevated temperature is expressed as percentage of 28 days compressive strength of SC (standard concrete) at room temperature. The variation of compressive strength with temperature has been plotted as shown in Fig-2.

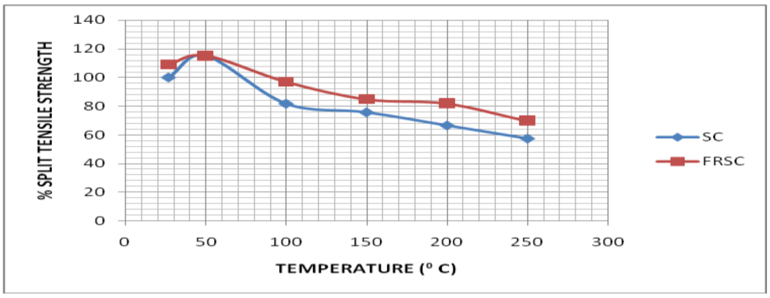


**Fig. 2 Comparsion of variation split tensile strength with temperature for SC and FRSC.**

From Fig 2, it can be observed that FRSC exhibits more split tensile strength than the SC at the all temperatures. As the temperature is increased FRSC maintained low decreament profile than SC resulting in more percentage split tensile strengths after $100^0$C. The difference between split tensile strength of FRSC and SC varies in the range is 0-12 percentage.

## IV. COMPARISON OF SC AND FRSC FOR FLEXURAL STRENGTH

The flexural strength of SC (standard concrete) and FRSC (fibre reinforced standard concrete) specimens exposed to different elevated temperature is expressed as percentage of 28 days compressive strength of SC (standard concrete) at room temperature. The variation of compressive strength with temperature has been plotted as shown in Fig-3.

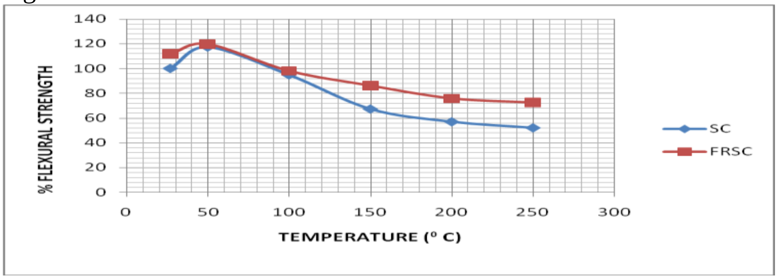


**Fig. 3 Comparsion of variation flexural strength with temperature for SC and FRSC.**

From Fig 3, it can be observed that FRSC exhibits more flexural strength than the SC at the all temperatures. As the temperature is increased FRSC maintained low decreament profile than SC resulting in more percentage flexural strengths after $100^0$C. The difference between flexural strength of FRSC and SC varies in the range is 0-20 percentage.

## V. CONCLUSIONS

1). An increase in compressive strength and tensile strength has been observed for both standard concrete and fiber reinforced standard concrete when exposed to a temperature of $50^0$C.
2). In the range of 50 to $80^0$C the split tensile strength of both standard concrete and fibre reinforced standard concrete is same.
3). Flexural strength of standard concrete is equal to that of the fibre reinforced standard concrete in range of $50^0$C-$80^0$C.
4). Beyond $50^0$C, both standard concrete and fibre reinforced standard concrete are found to loose compressive strength gradually.
5). Fibre reinforced standard concrete is found to exhibit more compressive strength split tensile strength and flexural strength than standard concrete at all temperatures.
6). The difference between compressive strength of fibre reinforced standard concrete and standard concrete varies in the range of 6-10percentage.
7). The difference between split tensile strength of fibre reinforced standard concrete and standard concrete varies in the range of 0-12 percentage.
8). The difference between flexural strength of fibre reinforced standard concrete and standard concrete varies in the range of 0-20 percentage.

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