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RESEARCH ARTICLE

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EXPERIMENTAL STUDIES ON SHRINKAGE BEHAVIOR OF FLY-ASH REPLACED SLURRY INFILTRATED HYBRID FIBRE REINFORCED CONCRETE

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ABSTRACT

The main objective of this research programme is to find out the shrinkage characteristics of Slurry Infiltrated hybrid Fibre Reinforced Concrete (SIFCON) using Fly-ash as a partial replacement to cement by 25%.Cement-sand slurry used is of the proportion 1:2 with a water cement ratio of 0.6. The shrinkage cracks formed after 5hr, 10hr,24hr,and 28th days from the date of casting are studied in brief. Investigation of the different fibres including planned for usage of 6 % (by volume fraction) for mono fibres are Galvanized Iron Fibre(GIF), Waste Plastic Fibre(WPF), Nylon Fibre(NF), Jute Fibre(JF), Coir Fibre(CF) and different hybrid fibrecombinations 2% (1%+1%, by volume fraction) used are (GI+WPF), (GI+NF), (GI+JF), (GI+CF).

Key words:SIFCON, shrinkage cracks, fly-ash, hybrid fibres, mono fibres.


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INTRODUCTION

Concrete is the most extensively used material in civil engineering and is the primary component in most infrastructures. In the future, there seems to be very less or no alternative to concrete as a construction material. Although strength of concrete is most important, it is also very much needed that the concrete is durable, workable and provide a good service life. For bridges, offshore structures, highway and airport pavements and machine foundations, concrete should possess high fatigue strength. For nuclear containers exposed to very high temperatures, the concrete must have high resistance to thermal cracking. All these requirements made the engineers to think seriously and to find out the appropriate technology for improving the performance of concrete. Increase in demand and decrease in supply of aggregates for the production of concrete results in the need to identify new sources of aggregates. SIFCON gains importance because eliminates the use of coarse aggregate. The principle of sustainable construction development requires prudent use of natural resources with best quality. SIFCON could be the one better solution.Slurry Infiltrated Fibrous Concrete (SIFCON), is a high performance cement based composite which contains a high content of steel fibres.

In concrete, mortar and cement paste shrinkage takes place from the very beginning of the life of the material. In early age volume change can be both swelling and shrinking, but later shrinkage will be prominent, which is caused by water movement in the porous and rigid body. During the hydration of cement (in the first 2-8 hours), while the cement paste is plastic, it undergoes a volumetric contraction (plastic shrinkage), while in cement paste as in any other fine-grained suspension, water content moves towards the external surface of the specimen. Shrinkage occurs in almost all types of concrete. Fibre reinforced concrete, hybrid fibre reinforced concrete, SIFCON are also undergo shrinkage. The brittle nature of concrete results in sudden unpredictable failure. SIFCON is made by pre-placing short discrete fibres in the moulds to its full capacity or to the desired volume fraction, thus forming a network. The fibre network is then infiltrated by a fine liquid cement-based slurry or mortar. The fibres can be sprinkled by hand or by using fibre-dispensing units for large sections. Vibration is imposed if necessary during placing the fibres and pouring the slurry.

The main differences between FRC and SIFCON, in addition to the clear difference in fibre volume fraction, lie in the absence of coarse aggregates in SIFCON which, if used, will hinder the infiltration of the slurry through the dense fibre network. SIFCON is playing an important role and is considered as a special type of fibre concrete with high fibre content. The application of SIFCON includes earthquake resistant structures, repair and retrofit of structural components, and pavement overlay, precast concrete products, military applications such as anti-missile hangers, underground shelters, aerospace launching platforms etc.

OBJECTIVES OF THE WORK

The main objective of this research programme is to find out the shrinkage characteristics of Slurry Infiltrated Hybrid Fibre Reinforced Concrete (SIHFCON) using fly-ash as a partial replacement to cement by 25%.In this project work attempt is made to find out the shrinkage characteristics of Slurry Infiltrated Hybrid Fibre Reinforced Concrete with shrinkage moulds of size 300*500*30mm. The cracks formed after 5hr, 10hr, 24hr and 28th day from the time and date of casting are studied in detail. In this investigation the different fibres planned for usage are Galvanised Iron Fibre (GIF), Waste Plastic Fibre (WPF),Nylon fibre (NF),Jute fibre(JF),Coir fibre(CF)and different hybrid fibre combinations used here are (GIF+WPF), (GIF+NF), (GIF+JF), (GIF+CF).

The cement-sand slurry used is of the proportion 1:2 with a convenient water cement ratio of 0.6. The percentage of fibres (by volume fraction) used in the experimentation is 6% for mono fibres and for hybrid fibres is 2% (1%+1%) for hybrid fibres.

MATERIALS AND METHODOLOGY

The materials used in this study include ordinary portland cement (OPC 43), Fly-ash, fine aggregate, mixing water, galvanised iron fibre(GIF), waste plastic fibre (WPF), Coir fibre, Jute fibre, Nylon fibre.

- **Cement**

  Ordinary Portland cement of 43 grade was used in this work. It was tested as per IS 8112-1989 recommendation.The cement used was ACC cement from the regional distributors.

- **Fine aggregate**

  Natural sand confirming to IS 383-1970 of Zone II is used. Specific gravity, moisture content and absorption capacity of fine aggregate is calculated according to the procedures confirming to IS 2386 and results obtained comply with the code specifications

- **Water**

  Water fit for drinking is generally considered fit for making concrete. Water should be free from acids, oils, alkalies, vegetables or other organic Impurities. Soft waters also produce weaker concrete. Water has two functions in a concrete mix. Firstly, it reacts chemically with the cement to form a cement paste in which the inert aggregates are held in suspension until the cement paste has hardened. Secondly, it serves as a vehicle or lubricant in the mixture of fine aggregates and cement.

- **Fly-ash**

  The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash. This fly ash is pozzolanic in nature, and contains less than 20% lime (CaO). Possessing pozzolanic properties, the glassy silica and alumina of Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime—mixed with water to react and produce cementations compounds.

- **Galvanized iron fibres(GIF)**

  GI fibres were procured locally. Round GI wire of 1mm diameter was cut to the required length of 50 mm giving an aspect ratio of 50. The ultimate strength and density of fibres was found to be 395 MPa and 7850 kg/m^3 respectively. These GI fibres are commercially available at regional stores.

- **Waste plastic fibre(WPF)**

  The WPF fibres were obtained by cutting the waste plastic buckets and other waste plastic to recycle and reuse. Fibres are cut to a length of 50 mm and width of 3mm obtaining aspect ratio of 50. Density of WPF fibre was found to be 280 kg/m^3

- **Nylon fibres (NF)**

Nylon is a string light synthetic fibre. Nylon thread made from the polymerization of an amine and acid chloride. Nylon fibre were collected from local distributors. Its density is 1150kg/m^3. They are cut to a length of 50mm obtaining aspect ratio of 50.

- **Jute fibres (JF)**

  Jute Fibre (JF) were collected from local distributors. Its density is 1440 kg/m^3. They are cut to a length of 50mm obtaining aspect ratio of 50

- **Coir Fibre (CF)**

  Coir is a versatile fibre extracted from husk of the coconut fruit. Coir Fibres were collected from local distributors. Its density is 1330 kg/m^3. They are cut to a length of 50mm obtaining aspect ratio of 50.

- **Waste plastic fibre(WPF)**

  The waste plastic fibres were obtained by cutting the waste plastic buckets. Fibres are cut to a length of 50 mm and width of 3mm obtaining aspect ratio of 50. Density of WPF fibre was found to be 280 kg/m^3

CASTING OF SPECIMEN

Following points are noted while filling shrinkage moulds.

1. The cement, is weighed as per the calculated amount and dry mixed uniformly later with weighed quantities of fly-ash and fine aggregates with required amount of water in a batching tray.
2. Quantity of fibre required for particular shrinkage mould is calculated as shown above and is weighed separately.
3. Moulds are cleaned thoroughly and lightly oiled to reduce damage caused for specimen at the time of de-moulding.
4. Naming on the moulds to identify the combination of fibres.
5. Steel mesh is placed inside the mould.
6. Fibres are randomly distributed inside the mould as per the obtained quantity
7. The mould is mechanically vibrated using standard mechanical vibrator to infiltrate slurry into the fibre matrix.
8. After slurry was poured into the mould and was kept in sunlight and air for 5hrs
9. Prepare the glass and glass sheet for the marking of the cracks formed on the specimen.
10. Trace the number of cracks, length and width of crack after 5hrs by using black colour marker
11. Similarly after 10hrs again mark the cracks by using red colour marker
12. Similarly after 24hrs again mark the cracks by using green colour marker
13. After 24hrs demould the specimen and transfer it into the curing tank
14. After 28 days of curing once again trace the cracks with yellow colour marker

Mould size of 300x500x30mm

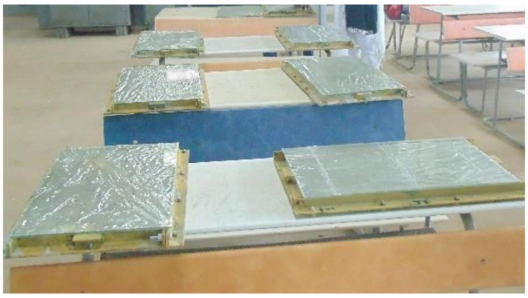
Aligned Mould for Casting the specimen

Spreading of fibre

Slurry infiltrated into mould

Alignment of specimen for observation

Observation of cracks



Alignment of specimen for marking

Marking of Cracks

TEST RESULTS

Overall results of maximum length of cracks: Following table gives the overall results of maximum length of cracks for SIFCON produced with mono fibers and hybrid fibers using fly-ash .The variation of max length of crack is represented in the form of graph as shown in fig 1

Table 1:Overall result of max length of cracks

Description of concrete	Maximum length of cracks (mm)			
	For 0 to 5hrs	For 5-10	For 11- 24hrs	For 28days
SIFCON produced with mono fibre GIF	70	0	0	0
SIFCON produced with mono fibre WPF	2044	587	37	0
SIFCON produced with mono fibre NF	1433	26	0	0
SIFCON produced with mono fibre JF	773	0	0	0
SIFCON produced with mono fibre CF	1198.8	116	0	0
SIFCON produced with hybrid fibre (GIF+WPF)	947	148	0	0
SIFCON produced with hybrid fibre (GIF+NF)	1334	20	13	0
SIFCON produced with hybrid fibre (GIF+JF)	48	77	0	0
SIFCON produced with hybrid fibre (GIF+CF)	793	116	107	0

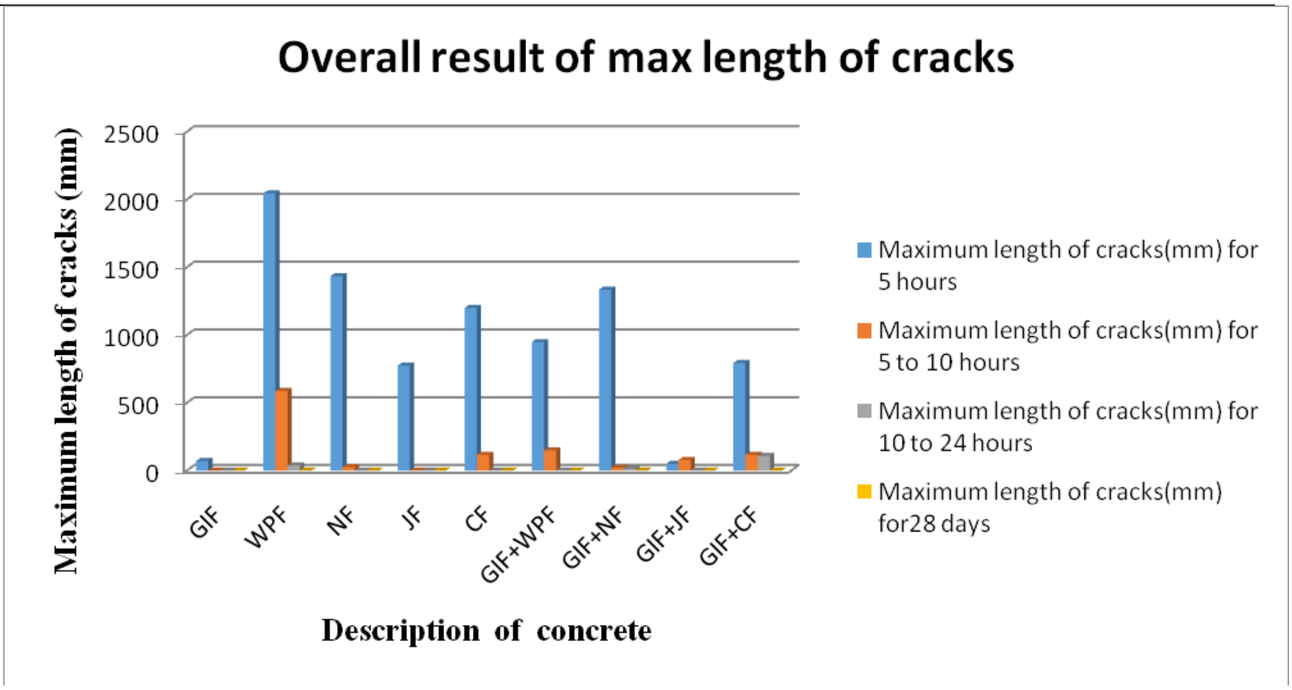


Fig 1: Variation of maximum length of crack

Overall results of maximum width of cracks: Following table gives the overall results of maximum width of cracks for SIFCON produced with mono fibers and hybrid fibers using GGBFS. The variation of maximum width of crack is represented in the form of graph as shown in fig 2

Table 2 Overall result of max width of cracks

Description of concrete	Maximum width of cracks (mm)			
	For 0 to 5hrs	For 6-10	For 11- 24hrs	For 28days
SIFCON produced with mono fibre GIF	0.1	0	0	0
SIFCON produced with mono fibre WPF	7.1	0.35	0.1	0
SIFCON produced with mono fibre NF	3.3	0.05	0	0
SIFCON produced with mono fibre JF	3.55	0	0	0
SIFCON produced with mono fibre CF	5.3	0.2	0	0
SIFCON produced with hybrid fibre (GIF+WPF)	5.15	0.2	0	0
SIFCON produced with hybrid fibre (GIF+NF)	1.35	0.05	0.05	0
SIFCON produced with hybrid fibre (GIF+JF)	0.1	0.15	0	0
SIFCON produced with hybrid fibre (GIF+CF)	0.8	0.2	0.35	0

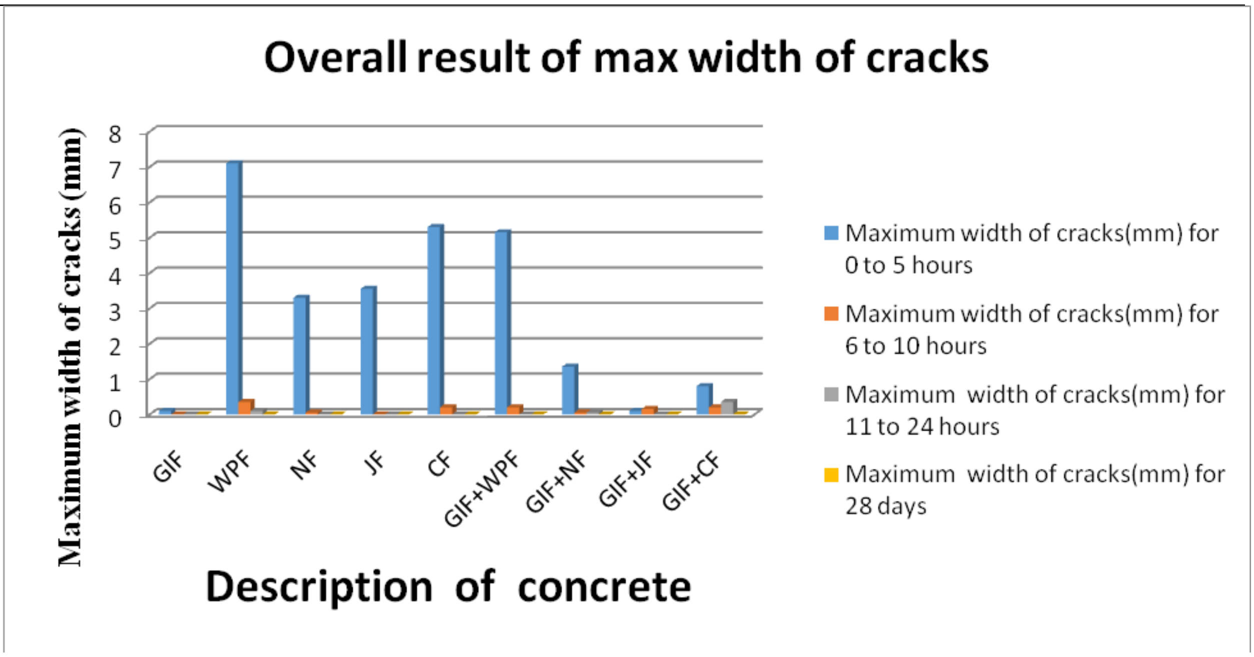


Fig 2: Variation of maximum width of crack

Overall results of total number of cracks: Following table gives the overall results of maximum no of cracks for SIFCON produced with mono fibers and hybrid fibers using GGBFS. The variation of total number of cracks is represented in the form of graph as shown in fig 3

Table 3 Overall result of total no of cracks

Description of concrete	Total no of cracks			
	For 0 to 5hrs	For 6-10	For 11- 24hrs	For 28days
SIFCON produced with mono fibre GIF	2	0	0	0
SIFCON produced with mono fibre WPF	19	12	2	0
SIFCON produced with mono fibre NF	19	2	0	0
SIFCON produced with mono fibre JF	14	0	0	0
SIFCON produced with mono fibre CF	20	5	0	0
SIFCON produced with hybrid fibre (GIF+WPF)	11	4	0	0
SIFCON produced with hybrid fibre (GIF+NF)	19	1	1	0
SIFCON produced with hybrid fibre (GIF+JF)	2	3	0	0
SIFCON produced with hybrid fibre (GIF+CF)	20	4	10	0

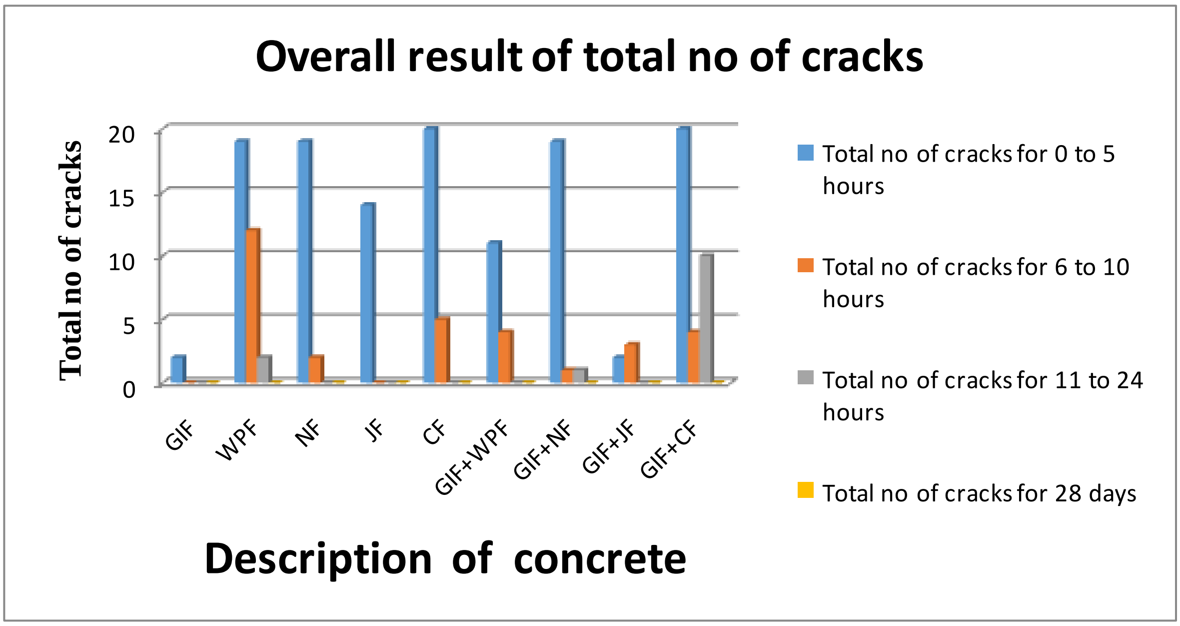


Fig 3: Variation of total number of cracks

Overall result of area of cracks: Following table gives the overall results of area of cracks for SIFCON produced with mono fibers and hybrid fibers using GGBFS. The variation of area of cracks is represented in the form of graph as shown in fig 4

Table 4 Overall result of area of cracks

Description of concrete	Area of cracks (mm^2) For 0 to 5hrs	For 6-10	For 11- 24hrs	For 28days
SIFCON produced with mono fibre GIF	7	0	0	0
SIFCON produced with mono fibre WPF	4877	21	3.7	0
SIFCON produced with mono fibre NF	4729	13	0	0
SIFCON produced with mono fibre JF	2745	0	0	0
SIFCON produced with mono fibre CF	6354	23.8	0	0
SIFCON produced with hybrid fibre (GIF+WPF)	14512	29.6	0	0
SIFCON produced with hybrid fibre (GIF+NF)	1801	1	0.65	0
SIFCON produced with hybrid fibre (GIF+JF)	4.8	12	0	0
SIFCON produced with hybrid fibre (GIF+CF)	635	23.2	37.45	0

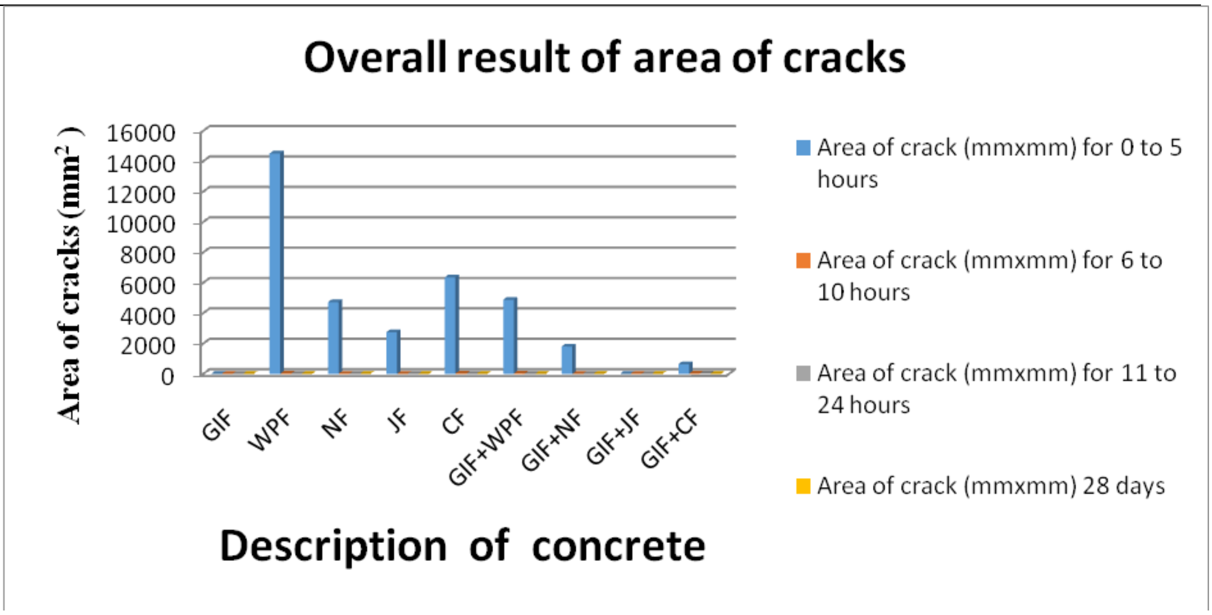


Fig 4: Variation of area of crack

OBSERVATIONS

Following observations were made based on the experimentation conducted on shrinkage characteristics of fly-ash based SIFCON.

1. It is observed that the shrinkage parameter as measured from max length of cracks for SIFCON produced with hybrid fibre combination (GIF+WPF), is much less than the SIFCON produced with corresponding mono fibre GIF. For 0-5 hrs, the max length of crack for SIFCON produced with hybrid fibre combination (GIF+WPF) is 947 mm, where as that for SIFCON produced with corresponding mono fibre WPF is found to be 2044 mm. This is true for 5-10 hrs, 11-24 hrs and for 28 days shrinkage cracks observations.

   It is observed that the shrinkage parameter observed from max length of crack produced with SIFCON hybrid fibre combination (GIF+NF) is much less than the SIFCON produced with corresponding mono fibre WCSF. For 0-5 hrs, the max length of cracks for SIFCON produced with hybrid fibre (GIF+NF) is 1334 mm, where as SIFCON produced with corresponding mono fibre WCSF is found to be 1433 mm. This is true for 5-10 hrs, 11-24 hrs and for 28 daysshrinkage cracks observations.

   It is observed that the shrinkage parameter observed from max length of crack produced with SIFCON hybrid fibre combination (GIF+JF) is much less than the SIFCON produced with corresponding mono fibre JF. For 0-5 hrs, the max length of cracks for SIFCON produced with hybrid fibre (GIF+JF) is 48 mm, where as SIFCON produced with corresponding mono fibre JF is found to be 773 mm. This is true for 5-10 hrs, 11-24 hrs and for 28 daysshrinkage cracks observations.

   It is observed that the shrinkage parameter observed from max length of crack produced with SIFCON hybrid fibre combination (GIF+CF) is much less than the SIFCON produced with corresponding mono fibre CF. For 0-5 hrs, the max length of cracks for SIFCON produced with hybrid fibre (GIF+CF) is 739 mm, where as SIFCON produced with corresponding mono fibre CF is found to be 1198.8 mm. This is true for 5-10 hrs, 11-24 hrs and for 28 daysshrinkage cracks observations. This may be attributed to the fact that the SIFCON produced with hybrid fibres may act synergistically and prevent the formation of shrinkage cracks at different time intervals. Also to some extent the added hybrid fibre may prevent the evaporation of water which is responsible for shrinkage.

   Thus it can be concluded that the shrinkage parameter as measured from max length of cracks for SIFCON produced with hybrid fibre combination such as (GIF+WPF), (GIF+NF), (GIF+JF), (GIF+CF) are much less than the SIFCON produced with corresponding mono fibre.

2. It is observed that the shrinkage parameter as measured from max width of cracks for SIFCON produced with hybrid fibre combination (GIF+WPF), is much less than the SIFCON produced with corresponding mono fibre WPF. For 0-5 hrs, the max width of crack for SIFCON produced with hybrid fibre combination (GIF+WPF) is 5.15 mm, where as that for SIFCON produced with corresponding mono fibre WPF is found to be 7.1 mm. This is true for 5-10 hrs, 11-24 hrs and for 28 days shrinkage cracks observations.

   It is observed that the shrinkage parameter as measured from max width of cracks for SIFCON produced with hybrid fibre combination (GIF+NF), is much less than the SIFCON produced with corresponding mono fibre NF. For 0-5 hrs, the max width of crack for SIFCON produced with hybrid fibre combination (GIF+NF) is 1.35 mm, where as that for SIFCON produced with corresponding mono fibre NF is found to be 3.3mm. This is true for 5-10 hrs, 11-24 hrs and for 28 days shrinkage cracks observations.

   It is observed that the shrinkage parameter as measured from max width of cracks for SIFCON produced with hybrid fibre combination (GIF+JF), is much less than the SIFCON produced with corresponding mono fibre JF. For 0-5 hrs, the max width of crack for SIFCON produced with hybrid fibre combination (GIF+JF) is 0.1 mm, where as that for SIFCON produced with corresponding mono fibre JF is found to be 3.55mm. This is true for 5-10 hrs, 11-24 hrs and for 28 days shrinkage cracks observations.

It is observed that the shrinkage parameter as measured from max width of cracks for SIFCON produced with hybrid fibre combination (GIF+CF), is much less than the SIFCON produced with corresponding mono fibre CF. For 0-5 hrs, the max width of crack for SIFCON produced with hybrid fibre combination (GIF+CF) is 0.8 mm, where as that for SIFCON produced with corresponding mono fibre CF is found to be 5.3 mm. This is true for 5-10 hrs, 11-24 hrs and for 28 days shrinkage cracks observations.

This may be attributed to the fact that the SIFCON produced with hybrid fibres may act synergistically and prevent the formation of shrinkage cracks at different time intervals. Also to some extent the added hybrid fibre may prevent the evaporation of water which is responsible for shrinkage.

Thus it can be concluded that the shrinkage parameter as measured from max width of cracks for SIFCON produced with hybrid fibre combination such as (GIF+WPF), (GIF+NF), (GIF+JF), (GIF+CF) are much less than the SIFCON produced with corresponding mono fibre.

3. It is observed that the shrinkage parameter as measured from total no of cracks for SIFCON produced with hybrid fibre combination (GIF+WPF), is much less than the SIFCON produced with corresponding mono fibre WPF. For 0-5 hrs, the total of crack for SIFCON produced with hybrid fibre combination (GIF+WPF) is11 , whereas that for SIFCON produced with corresponding mono fibre WPF is found to be 19 . This is true for 5-10 hrs, 11-24 hrs and for 28 days shrinkage cracks observations.

It is observed that the shrinkage parameter as measured from total no of cracks for SIFCON produced with hybrid fibre combination (GIF+NF), is much less than the SIFCON produced with corresponding mono fibre NF. For 0-5 hrs, the total no of crack for SIFCON produced with hybrid fibre combination (GIF+NF) is 19 , whereas that for SIFCON produced with corresponding mono fibre NF is found to be 19 . This is true for 5-10 hrs, 11-24 hrs and for 28 days shrinkage cracks observations.

It is observed that the shrinkage parameter as measured from total no of cracks for SIFCON produced with hybrid fibre combination (GIF+JF), is much less than the SIFCON produced with corresponding mono fibre JF. For 0-5 hrs, the total no of crack for SIFCON produced with hybrid fibre combination (GIF+JF) is 2 , whereas that for SIFCON produced with corresponding mono fibre JF is found to be 14 . This is true for 5-10 hrs, 11-24 hrs and for 28 days shrinkage cracks observations.

It is observed that the shrinkage parameter as measured from total no of cracks for SIFCON produced with hybrid fibre combination (GIF+CF), is much less than the SIFCON produced with corresponding mono fibre CF. For 0-5 hrs, the total no of crack for SIFCON produced with hybrid fibre combination (GIF+CF) is 20 , whereas that for SIFCON produced with corresponding mono fibre CF is found to be 20 . This is true for 5-10 hrs, 11-24 hrs and for 28 days shrinkage cracks observations.

This may be attributed to the fact that the SIFCON produced with hybrid fibres may act synergistically and prevent the formation of shrinkage cracks at different time intervals. Also to some extent the added hybrid fibre may prevent the evaporation of water which is responsible for shrinkage.

Thus it can be concluded that the shrinkage parameter as measured from total no of cracks for SIFCON produced with hybrid fibre combination such (GIF+WPF), (GIF+NF), (GIF+JF), (GIF+CF) are much less than the SIFCON produced with corresponding mono fibre.

4. It is observed that the shrinkage parameter as measured from area of cracks for SIFCON produced with hybrid fibre combination (GIF+WPF), is much less than the SIFCON produced with corresponding mono fibre WPF. For 0-5 hrs, the area of crack for SIFCON produced with hybrid fibre combination (GIF+WPF) is 4877 mm^2, whereas that for

SIFCON produced with corresponding mono fibre WPF is found to be 14512 mm^2. This is true for 5-10 hrs, 11-24 hrs and for 28 days shrinkage cracks observations.

It is observed that the shrinkage parameter as measured from area of cracks for SIFCON produced with hybrid fibre combination (GIF+NF), is much less than the SIFCON produced with corresponding mono fibre NF. For 0-5 hrs, the area of crack for SIFCON produced with hybrid fibre combination (GIF+NF) is 1801 mm^2, whereas that for SIFCON produced with corresponding mono fibre NF is found to be 4729 mm^2. This is true for 5-10 hrs, 11-24 hrs and for 28 days shrinkage cracks observations.

It is observed that the shrinkage parameter as measured from area of cracks for SIFCON produced with hybrid fibre combination (GIF+JF), is much less than the SIFCON produced with corresponding mono fibre JF. For 0-5 hrs, the area of crack for SIFCON produced with hybrid fibre combination (GIF+JF) is 4.8 mm^2, whereas that for SIFCON produced with corresponding mono fibre JF is found to be 2745 mm^2. This is true for 5-10 hrs, 11-24 hrs and for 28 days shrinkage cracks observations.

It is observed that the shrinkage parameter as measured from area of cracks for SIFCON produced with hybrid fibre combination (GIF+CF), is much less than the SIFCON produced with corresponding mono fibre CF. For 0-5 hrs, the area of crack for SIFCON produced with hybrid fibre combination (GIF+CF) is 635 mm^2, whereas that for SIFCON produced with corresponding mono fibre CF is found to be 6354 mm^2. This is true for 5-10 hrs, 11-24 hrs and for 28 days shrinkage cracks observations.

This may be attributed to the fact that the SIFCON produced with hybrid fibres may act synergistically and prevent the formation of shrinkage cracks at different time intervals. Also to some extent the added hybrid fibre may prevent the evaporation of water which is responsible for shrinkage.

Thus it can be concluded that the shrinkage parameter as measured from area of cracks for SIFCON produced with hybrid fibre combination such as (GIF+WPF), (GIF+NF), (GIF+JF), (GIF+CF) are much less than the SIFCON produced with corresponding mono fibre.

CONCLUSIONS

The following may be drawn based on the experimentation conducted on the shrinkage characteristics of GGBFS based SIFCON.

1) The shrinkage parameter as measured from max length of cracks for SIFCON produced with hybrid fibre combination such as (GIF+WPF), (GIF+NF), (GIF+JF), (GIF+CF) are much less than the SIFCON produced with corresponding mono fibre.
2) The shrinkage parameter as measured from max width of cracks for SIFCON produced with hybrid fibre combination such as (GIF+WPF), (GIF+NF), (GIF+JF), (GIF+CF) are much less than the SIFCON produced with corresponding mono fibre.
3) The shrinkage parameter as measured from total no of cracks for SIFCON produced with hybrid fibre combination such as (GIF+WPF), (GIF+NF), (GIF+JF), (GIF+CF)are much less than the SIFCON produced with corresponding mono fibre.
4) The shrinkage parameter as measured from area of cracks for SIFCON produced with hybrid fibre combination such as (GIF+WPF), (GIF+NF), (GIF+JF), (GIF+CF) are much less than the SIFCON produced with corresponding mono fibre.

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