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RESEARCH ARTICLE

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AN INVESTIGATION ON THE SHRINKAGE CHARACTERISTICS OF GGBFS BASED SLURRY INFILTRATED HYBRID FIBRE REINFORCED CONCRETE

PRUTHVIRAJ B S[1], SHREEPAD DESAI[2], Dr. PRAKASH K B[3]

[1]P.G. Student, Civil Engineering Department, Government Engineering College, Haveri, Karnataka, India

[2]Associate Professor, Civil Engineering Department, Government Engineering College, Haveri, Karnataka, India

[3] Principal, Government Engineering College, Haveri, Karnataka, India

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PRUTHVIRAJ B S

SHREEPAD DESAI

Dr. K. B. Prakash

ABSTRACT

The main objective of this research programme is to find out the shrinkage characteristics of Slurry Infiltrated Hybrid Fibre Reinforced Concrete (SIHFCON) using ground granulated blast furnace slag (GGBFS) as a partial replacement to cement by 30%. The shrinkage cracks formed after 5hr, 10hr, 24hr and 28th days from the time and date of casting are studied in detail. In this investigation the different fibres planned for usage are Steel Fibre (SF), Galvanised Iron Fibre (GIF), High Density Polyethylene Fibre (HDPEF), Waste Plastic Fibre (WPF), Poly Propylene Fibre (PPF), Waste Coiled Steel Fibre (WCSF) and different hybrid fibre combinations used are (SF+GIF), (SF+HDPEF), (SF+WPF), (SF+PPF), (SF+WCSF).

The cement-sand slurry used is of the proportion 1:2 with a water cement ratio 0.45, and with dosage of super plasticizer. The percentage of fibres (by volume fraction) used in the experimentation is 8 % for mono fibres and (4%+4%) for hybrid fibres.

Key words: SIFCON, GGBFS, hybrid fibres, mono fibres, shrinkage.

INTRODUCTION

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.

Hybrid fibre reinforced concrete in which more than one fibre types are used as secondary reinforcement has become a very popular construction material which is directly related to recent development in concrete technology. The brittle nature of concrete results in sudden unpredictable failure. By using hybrid fibre combinations of steel and polypropylene fibres or others the explosive failure behaviour of high strength concrete (HSC) may be avoided.

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

In the world of concrete technology 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, bridge deck 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 ground granulated blast furnace slag (GGBFS) as a partial replacement to cement by 30%. The shrinkage cracks formed after **5hr**, **10hr**, **24hr and 28th days** from the time and date of casting are studied in detail. In this investigation the different fibres planned for usage are Steel Fibre (SF), Galvanised Iron Fibre (GIF), High Density Polyethylene Fibre (HDPEF), Waste Plastic Fibre (WPF), Poly Propylene Fibre (PPF), Waste Coiled Steel Fibre (WCSF) and different hybrid fibre combinations used here are (SF+GIF), (SF+HDPEF), (SF+WPF), (SF+PPF), (SF+WCSF).

The cement-sand slurry used is of the proportion 1:2 with a water cement ratio 0.45. The percentage of fibres (by volume fraction) used in the experimentation is 8 % for mono fibres and (4%+4%) for hybrid fibres.

MATERIALS AND METHODOLOGY

The materials used in this study include ordinary portland cement (OPC 43), ground granulated blast furnace slag(GGBFS), fine aggregate, mixing water, steel fibre(SF), galvanised iron fibre(GIF), high density polyethylene fibre (HDPEF), waste plastic fibre (WPF), waste coiled steel fibre (WCSF), poly propylene fibre (PPF).

- **Cement**

  In this experimental work, 43 grade ordinary Portland cement (OPC) conforming to IS: 8112 – 1989 was used. The cement used was Rajashree cement from the local 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.

- **Ground granulated blast furnace slag**
  It is procured from Visveswaraya Iron and Steel Plant Bhadravathi. GGBFS powder is almost white in colour in the dry state. Specific gravity of GGBFS is 2.9
- **Steel fibres (SF)**
  In the present work steel fibres of 1mm thickness and 50mm length giving aspect ratio of 50 were used. Fibres of crimped shape were found suitable from literature studies. The density and ultimate tensile strength was found to be 7850 kg/m^3 and 395 MPa respectively. Steel fibres were obtained from stewools india (p) ltd. Nagpur.
- **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 and are generally used for electrical work.
- **High density polyethylene fibers (HDPEF)**
  High density polyethylene fibers are procured by cutting oil cans available in petrol pumps They are cut to a length of 50 mm and width of 1mm obtaining aspect ratio of 50. Density of HDPE fiber was found to be 900 kg/m^3.
- **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
- **Poly propylene fibre (PPF)**
  Poly propylene fibres are readily available in the market in standard dimensions. The fibres used here are of length 12mm which is prescribed by the manufacturers for the concrete work. The density of PPF is found to be 930kg/m^3.
- **Waste coiled steel fibre(WCSF)**
  The waste coiled steel fibre used is of length 50mm and diameter 2mm obtaining aspect ratio of 25. Density of wcsf fibre was found to be 7850 kg/m^3.

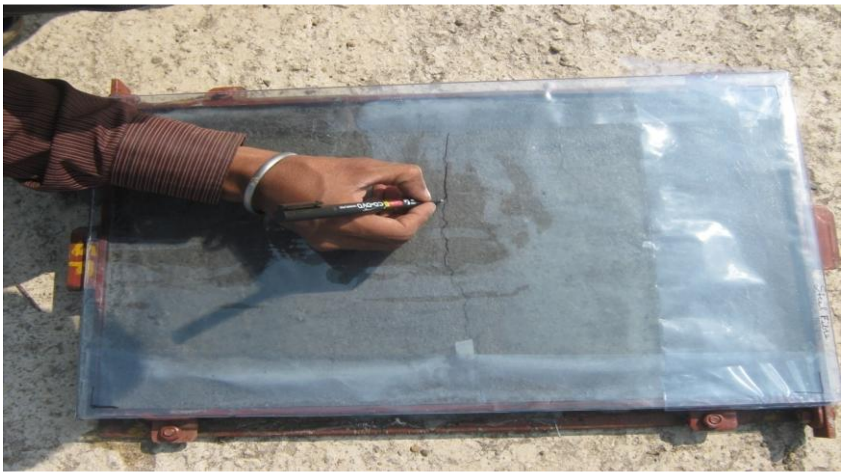
Casting of specimen

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 ggbfs 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 and lightly oiled.
4. Naming on the moulds to identify the combination of fibres
5. Steel mesh is placed inside the mould to induce restrained shrinkage cracks
6. Fibres are distributed inside the mould as per the calculated quantity
7. After this the slurry was poured into the mould and was kept in sunlight and air for 5hrs
8. Place the glass and plastic sheet for the marking of the cracks formed on the specimen
9. Trace the number of cracks, length and width of crack after 5hrs by using black colour marker
10. Similarly after 10hrs again mark the cracks by using red colour marker
11. Similarly after 24hrs again mark the cracks by using green colour marker
12. After 24hrs demould the specimen and transfer it into the curing tank
13. After 28 days of curing once again trace the cracks with yellow colour marker

Shrinkage moulds of size 300*500*30mm

Cast specimens



Marking of cracks on plastic shrinkage

Test results

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

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Table 1: Overall results 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 SF	210	135	65	28
SIFCON produced with mono fibre GIF	276	124	36	12
SIFCON produced with mono fibre WCSF	395	196	108	63
SIFCON produced with mono fibre HDPEF	590	264	114	94
SIFCON produced with mono fibre WPF	95	54	23	0
SIFCON produced with mono fibre PPF	670	246	46	11
SIFCON produced with hybrid fibre (SF+GIF)	118	53	0	0
SIFCON produced with hybrid fibre (SF+WCSF)	76	39	13	0
SIFCON produced with hybrid fibre (SF+HDPEF)	124	46	24	0
SIFCON produced with hybrid fibre (SF+WPF)	65	12	0	0
SIFCON produced with hybrid fibre (SF+PPF)	160	95	0	0

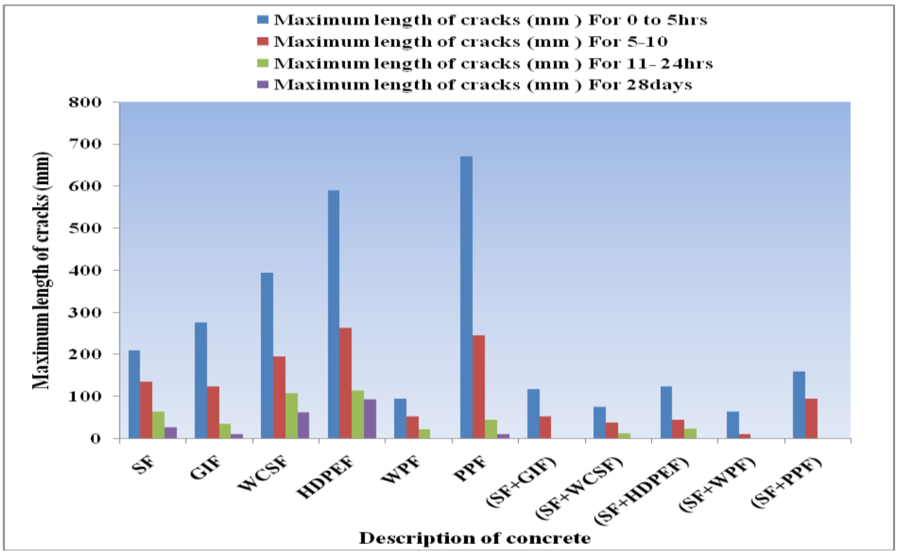

Fig 1: Variation of maximum length of crack

Overall results of maximum width of crack : 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 max.width of crack is represented in the form of graph as shown in fig 2

Table 2: Overall results of max width of cracks

Description of concrete	Maximum width of cracks (mm)			
	For 0 to 5hrs	For 5-10	For 11- 24hrs	For 28days
SIFCON produced with mono fibre SF	0.02	0.02	0.01	0.01
SIFCON produced with mono fibre GIF	0.03	0.03	0.02	0.01
SIFCON produced with mono fibre WCSF	0.03	0.03	0.02	0.01
SIFCON produced with mono fibre HDPEF	0.03	0.03	0.02	0.01
SIFCON produced with mono fibre WPF	0.02	0.01	0.01	0
SIFCON produced with mono fibre PPF	0.02	0.02	0.01	0.01
SIFCON produced with hybrid fibre (SF+GIF)	0.02	0.01	0	0
SIFCON produced with hybrid fibre (SF+WCSF)	0.02	0.01	0	0
SIFCON produced with hybrid fibre (SF+HDPEF)	0.02	0.01	0.01	0
SIFCON produced with hybrid fibre (SF+WPF)	0.02	0.01	0	0
SIFCON produced with hybrid fibre (SF+PPF)	0.02	0.01	0	0

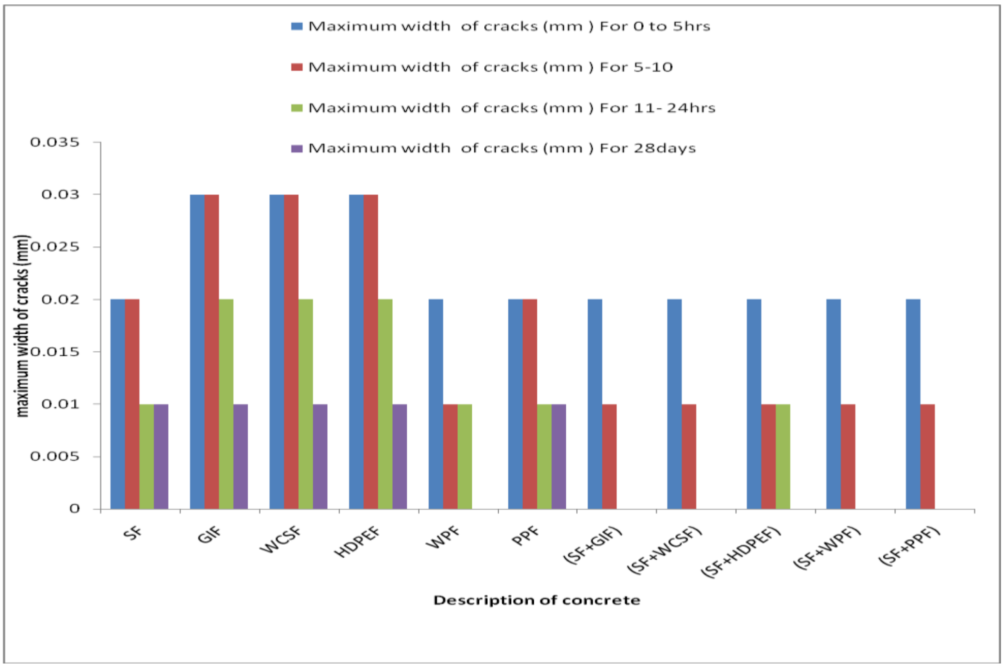

Fig 2: Variation of maximum width of crack

Overall results of total no 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 results of total number of cracks

Description of concrete	Total no of cracks			
	For 0 to 5hrs	For 5-10	For 11- 24hrs	For 28days
SIFCON produced with mono fibre SF	6	19	5	2
SIFCON produced with mono fibre GIF	9	10	3	1
SIFCON produced with mono fibre WCSF	5	10	2	1
SIFCON produced with mono fibre HDPEF	11	16	8	3
SIFCON produced with mono fibre WPF	9	4	2	0
SIFCON produced with mono fibre PPF	5	5	8	2
SIFCON produced with hybrid fibre (SF+GIF)	4	5	0	0
SIFCON produced with hybrid fibre (SF+WCSF)	2	3	2	0
SIFCON produced with hybrid fibre (SF+HDPEF)	5	2	6	0
SIFCON produced with hybrid fibre (SF+WPF)	2	3	0	0
SIFCON produced with hybrid fibre (SF+PPF)	3	6	0	0

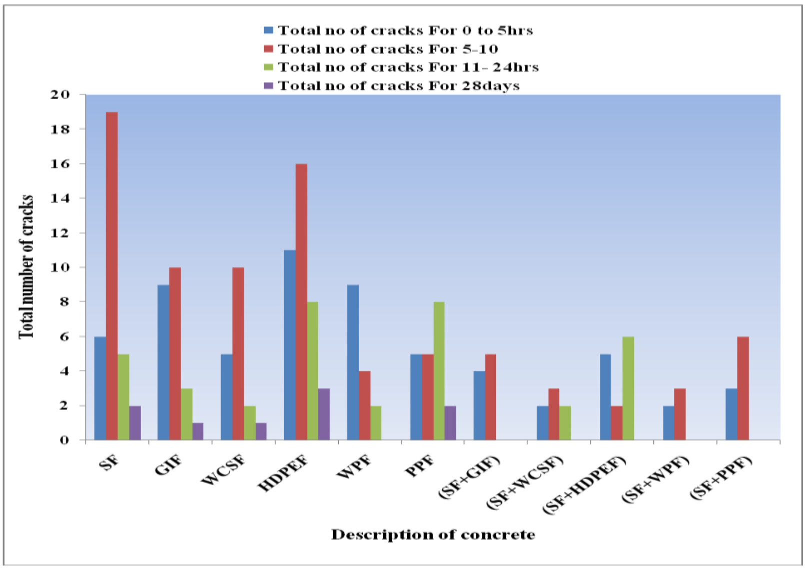

Fig 3: Variation of total number of cracks

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 5-10**	**For 11- 24hrs**	**For 28days**
SIFCON produced with mono fibre SF	4.20	2.70	0.65	0.28
SIFCON produced with mono fibre GIF	8.28	3.72	0.72	0.12
SIFCON produced with mono fibre WCSF	20.10	7.38	0.92	0.11
SIFCON produced with mono fibre HDPEF	17.70	7.92	2.28	0.94
SIFCON produced with mono fibre WPF	1.90	0.54	0.23	0
SIFCON produced with mono fibre PPF	7.90	3.92	1.08	0.63
SIFCON produced with hybrid fibre (SF+GIF)	2.36	0.53	0	0
SIFCON produced with hybrid fibre (SF+WCSF)	1.52	0.39	0	0
SIFCON produced with hybrid fibre (SF+HDPEF)	2.48	0.46	0.24	0
SIFCON produced with hybrid fibre (SF+WPF)	1.30	0.12	0	0
SIFCON produced with hybrid fibre (SF+PPF)	3.20	0.95	0	0

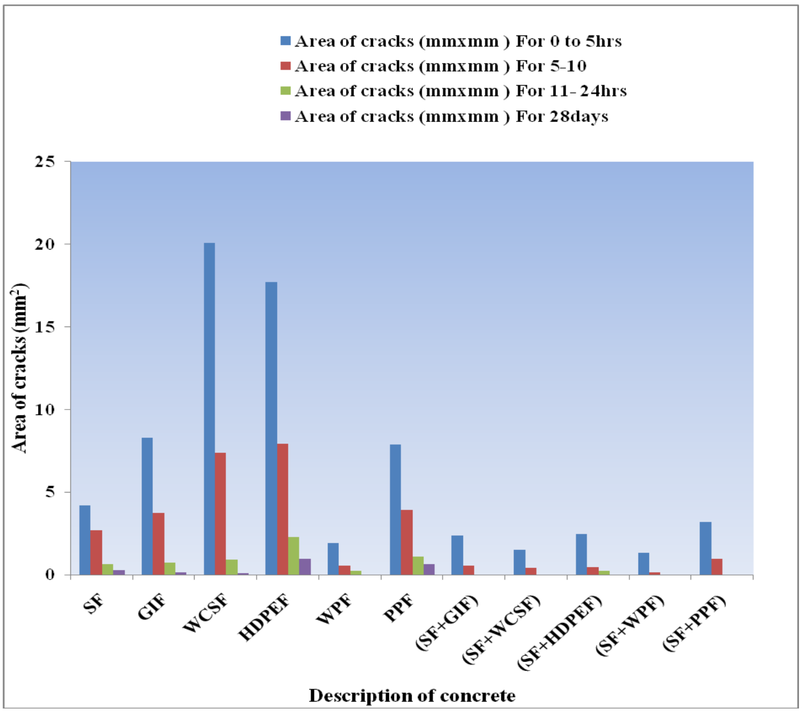

Fig 4: Variation of area of cracks

OBSERVATIONS AND DISCUSSIONS

Following observations were made based on the experimentation conducted on shrinkage characteristics of GGBFS based SIFCON

The shrinkage as measured from max length of cracks, max width of cracks, total no of cracks and area of cracks

The shrinkage parameter as measured from max width of cracks for SIFCON produced with hybrid fibre combination such as (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) are much less than the SIFCON produced with corresponding mono fibre.

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It 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

CONCLUSIONS

1) The shrinkage parameter as measured from max length of cracks for SIFCON produced with hybrid fibre combination such as (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) 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 (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) 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 (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) 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 (SF+GIF), (SF+WCSF), (SF+HDPEF), (SF+WPF) and (SF+PPF) are much less than the SIFCON produced with corresponding mono fibre.

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