Penerbit Akademia Baru

Journal of Advanced Research in Engineering Knowledge

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2600-8440

Characteristic of Slurry Infiltrated Fibrous Concrete (SIFCON) Produced by Partially Replacing Cement by Mineral Admixtures and Steel Fibers by Waste Plastic Fibers

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Sadat Ali Khan[1,*], Gobinath Selvaraju[2]

[1] Faculty of Engineering, Science and Technology, The Maldives National University, Male', Maldives
[2] Dhirajlal Gandhi College of Technology, Tamil Nadu India, India

ARTICLE INFO

Article history:
Received 5 June 2019
Received in revised form 4 July 2019
Accepted 12 July 2019
Available online 21 July 2019

ABSTRACT

SIFCON or Slurry infiltrated fibrous concrete is one of the recommended type of concrete to be used in construction industry particularly for structures carrying cyclic loads. Use of Slurry infiltrated fibrous concrete imparts higher impact strength, flexural strength, ductility and crack resistance property to the structure. However the cost of production of Slurry infiltrated fibrous concrete is higher due to high volume of cement and use of steel fibers. Presently lot of efforts are being put to reduce the cost of construction by different ways. Reducing the cost of concrete is one of the important criteria. The best way to reduce the cost of concrete production is by replacing a part of cement by a material which is cheaper than cement and would not affect the performance of concrete. In this work, some efforts are made to replace a part of cement by mineral admixtures such as Silica fume, metakaolin and Ground granulated blast furnace slag. And a part of steel fibers were replaced by waste plastic fibers. Tests were conducted on hardened concrete produced with these mineral admixtures and waste plastic fibers and the results were compared to that of ordinary Slurry infiltrated fibrous concrete. The results show that the SIFCON produced by replacing 20% of cement by mineral admixtures and replacing 50% steel fibers with waste plastic fibers possess equivalent strength as the ordinary SIFCON, whereas the higher percentage of replacement reduced the strength.

Keywords:
Cyclic loads; impact strength; flexural strength; silica fume; metakaolin; ground granulated blast furnace slag

1. Introduction

Concrete structures are seen everywhere in the world. The importance of concrete in the modern society could not be underestimated. Concrete structures have been regarded as durable material requiring little or no maintenance. However experiences show that many concrete structures are showing the signs of deterioration for a period of only 20-30 years.

Conventional concrete possess high compressive strength but does not perform well when subjected to tensile forces. Plain concrete fails even under a small tensile stress. So to add tensile

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[*] *Corresponding author.*
E-mail address: sadat.ali@mnu.edu.mv (Sadat Ali Khan)

strength to the plain concrete reinforcing steel is added. Concrete can be prepared using locally available cheap materials. But it is to be noted that production of cement involves consumption of lot of heat energy and also there will be emission of CO2 during the conversion of limestone into cement and extraction of limestone will also have an adverse effect on environment. It is important to look for other alternative materials which can reduce the requirement of cement for the concrete.

The preferred alternative material should be cost effective when compared to cement but should not affect the performance of concrete hence we can reduce the consumption of cement considerably. At present, the alternatives used in the construction industry to reduce the consumption of cement are mineral admixtures such as Fly ash, Ground granulated blast furnace slag, silica fume, Metakaolin, rice husk ash etc which are all by-products or waste materials in one or other way that cause environmental pollution. These mineral admixtures can be used in concrete to replace the cement partially and these admixtures do not affect the performance of the concrete when they are used in minimum or optimum percentage. This way it helps reducing a certain part of environmental waste.

On the other hand we have lot of plastic waste generated which is again an environmental concern. The effective way to reduce the plastic waste is by recycling and reusing. But it is also possible to use the plastic waste in concrete industry. Certain types of plastics when used in concrete slightly enhance the tensile and shear strength of concrete.

There have been lot of development in concrete industry to enhance different properties of the concrete namely fibre reinforced concrete, Light weight concrete, high performance concrete, high density concrete, self-compacting concrete, SIFCON etc. Slurry infiltrated fibrous concrete (SIFCON) is a type of concrete produced by infiltrating slurry through a matrix of steel fibers. The volume of fibres in SIFCON will be about 1 to 4 percent. SIFCON possess higher compressive, impact, Flexural and shear strength and considerable tensile strength. As SIFCON has higher impact strength it can be used for the members which carry cyclic or dynamic loads such as deck slab of bridges, pavements etc. The use of SIFCON would be beneficial in those applications where concrete or SFRC has not performed as expected or where high strength and ductility are required.

One of major concerns today in the Highways is the deterioration of bridge decks due to the use of de-icing chemicals. Many methods to control this deterioration has been tried. One common technique has been to increase the thickness of concrete cover over the top reinforcing bars in combination with the use of epoxy coated bars.

If SIFCON is used as a topping material the thickness of the cover can be reduced to half of conventional concrete and also epoxy-coating bars may not be necessary. One must also consider the effect of reduced dead load on the supporting structure. In addition the exceptional crack resistance and durability of SIFCON would reduce future maintenance cost and extend the overall life of the structure.

In this work an effort has been made to develop SIFCON by replacing a part of cement by mineral admixtures and a part of steel fibers by waste plastic fibers. Use of Mineral admixtures and waste plastic fibres reduces the cost of production of SIFCON considerably. The mineral admixtures used are Silica fume, Metakaolin and Ground granulated blast furnace slag. Silica fume is also known as micro-silica is a by-product obtain during the production of Silica, Metakaoline is the anhydrous calcined form of the clay mineral kaolinite and Ground granulated blast furnace slag is obtained by quenching molten iron slag from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. The SIFCON produced with different ratios of mineral admixtures to cement and waste plastic fibers to steel fibers were tested for Compressive, flexural, shear, impact and tensile strength and convincing results were obtained.

2. Materials and Methodology

The materials used in this study include ordinary Portland cement, fine aggregate, Silica fume, Metakaoline, Ground granulated blast furnace slag, mixing water, steel fibres, waste plastic fibres and high density poly ethylene fibres.

2.1 Properties of Materials

Table 1
Ordinary Portland cement

Specific surface	3250 cm^2/gm
Normal consistency	34%
Specific gravity	3.15
Setting time	
a)Initial	35min
b) Final	320min
Compressive strength	41.4N/mm^2

Table 2
Silica fume

Specific gravity	2.28
Specific surface	15000-20000 cm^2/gm
Bulk density	1350-1510 kg/m^3

Fig.1. Silica fume

Table 3
Metakaolin

Specific gravity	2.48
Average particle size	1.5 µm
Bulk density	1550-1680 kg/m^3

Fig. 2. Metakaolin

Table 4
GGBS

Specific gravity	2.85
Specific surface	450-475 m^2/kg
Bulk density	1250 kg/m^3

Fig. 3. GGBS

Table 5
Fine aggregates

Specific gravity	2.58
Water absorption	2.5%
Bulk density	1750 kg/m^3

Fig. 4. Sand

Steel fibers

Steel fibers of length 35mm and width 1mm having aspect ratio 35 are used.

Fig. 5. Steel fibers

HDPE

High density polyethylene fibres are procured from cutting HDPE oil cans. Fibres are cut to a length of 35 mm, 1mm thick and width of 3mm obtaining as aspect ratio of 35. Density of HDPE fibre was found to be 900 kg/m^3.

Fig. 6. High density polyethylene fibers

Waste plastic fibers

Waste plastic fibers are obtained by cutting the waste plastic materials like buckets, Jugs, tubs etc. The size of the fibers used here is 35mm length and 1mm wide. The density of WPF varies in the range of 230 – 300 kg/m3and Aspect ratio of waste plastic fibers is 35.

Fig. 7. High density polyethylene fibers

2.2 Preparation of SIFCON

SIFCON is prepared by pouring cement slurry through to the matrix of fibers preplaced in to the molds. The mix ratio adopted was 1:1 (Cement: Sand) and volume of fibers adopted was 4%. Water cement ratio adopted was 0.45. The following table shows the different combinations of cement + mineral admixtures and Steel + plastic fibers.

Table 6
Preparation of SIFCON

Combinations	Cement + Mineral admixture	Steel + HDPE + WP Fibers
Set 1	90% cement + 10% silica fume	2% + 1%+1%
Set 2	90% cement + 10% Metakaolin	2% + 1%+1%
Set 3	90% cement + 10% GGBS	2% + 1%+1%
Set 4	80% cement + 20% silica fume	2% + 1%+1%
Set 5	80% cement + 20% Metakaolin	2% + 1%+1%
Set 6	80% cement + 20% GGBS	2% + 1%+1%
Set 7	75% cement + 25% silica fume	2% + 1%+1%
Set 8	75% cement + 25% Metakaolin	2% + 1%+1%
Set 9	75% cement + 25% GGBS	2% + 1%+1%
Set 10	100% + 0 + 0 (Control mix)	4% + 0 + 0

Each set includes samples for compression test, Shear, Tensile, Impact and Flexure test. After 24 hours of casting the samples were demoulded and cured for 28days.

2.3 Testing of Samples

The cured SIFCON samples were subjected to following test.

2.3.1 Compression test

Standard size of the Compression test specimen is 150×150×150 mm. The test sample is placed centrally on the compression testing machine and load is applied continuously and uniformly on the surface parallel to the direction of tamping. The load is increased until the specimen fails and the maximum load carried by each specimen during the test was recorded as shown in fig. 8.

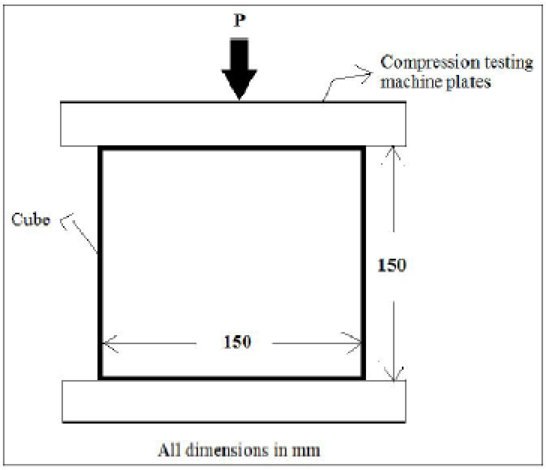


Fig. 8. Compression testing

Compressive strength was calculated as follows
Compressive strength = P/A

2.3.2 Tensile test

Standard Size of the tensile test sample is 150mm diameter and 300mm height. Diametrical lines were drawn on two ends of the specimen so that they are in the same axial plane. A plywood strip was placed on the center of the lower platen. The specimen was placed on the plywood strip and aligned such that the lines marked on the end of the specimen are vertical and centered over the plywood strip. The second plywood strip is placed lengthwise on the cylinder centered on the lines marked on the ends of the cylinder. Load is applied without shock and increased continuously to produce a split tensile stress until the specimen fails and no greater load can be sustained.

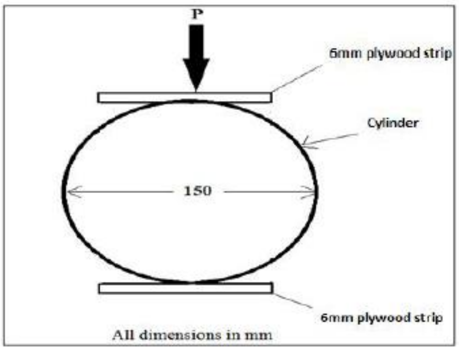


Fig. 9. Tensile testing

Split tensile strength = 2P/(πdL)
where,
P = Load in N
d = Diameter of cylinder = 150 mm
L = Length of cylinder = 300 mm

2.3.3 Flexural strength test

The standard size of the flexural test specimen is 100x100x500mm. Here we are applying two point loading on the beam specimen as shown in the fig.10. The load was applied till the beam breaks and failure load was noted down.

Flexural strength = PL/BD²
where,
P = Load in N
L = Effective length of beam = 400 mm
b = Width of the beam = 100 mm
d = Depth of the beam = 100 mm

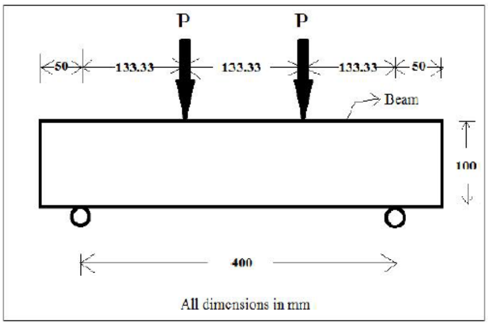


Fig. 10. Flexure testing

2.3.4 Shear strength test

The standard dimensions of the shear strength test specimen is shown in the fig.11. The specimen is placed in the compression testing machine and the load is applied until the cracks are developed and the specimen fails. The cracks and the failure load is notes down.

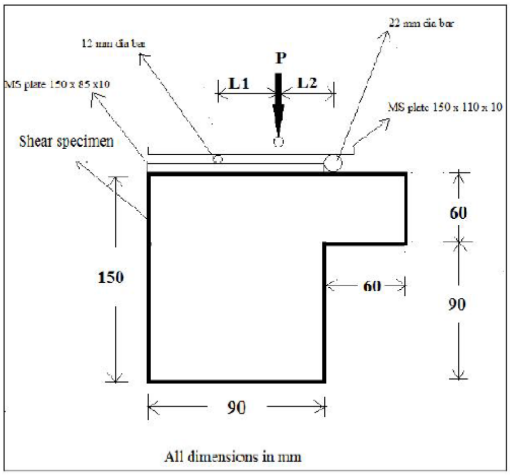
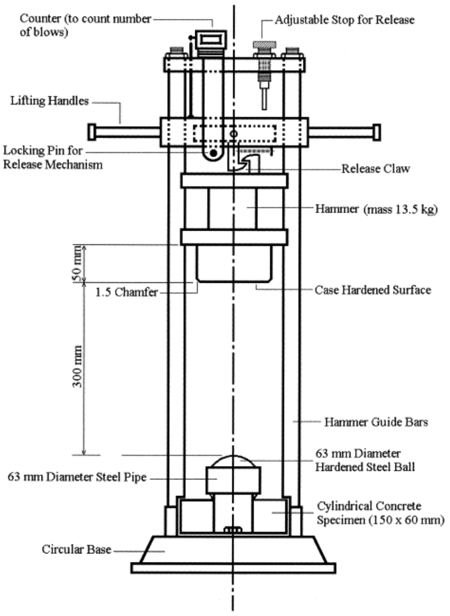


Fig. 11. Shear strength testing

Shear strength = Failure load/A
where,
Failure load = PL1 / (L1+L2)
P = Load in N
A = Area of shear surface = 60 x 150 mm2, L1 = 25 mm, L2 = 25 mm

2.3.5 Impact strength test

The standard test specimen thickness is 60mm, diameter 150mm. The test specimen is placed on the base plate. A bracket is placed over the test specimen which contains a cylindrical sleeve that positions a hardened steel ball on top of the test specimen. An ASTM D 1557 drop hammer used for compaction of asphalt and soils samples is then placed on top of the ball. The ultimate failure occurs when sufficient impact energy has been supplied to formation and spreading of the cracks. The number blows at failure are noted down.



Computation of the impact strength is as follows
Impact strength = WHN
Where,
W = Weight of the hammer = 45 N
H = Height of the drop = 457mm
N = Number of blows

3. Results and Discussions

The following results were obtained when the tests were conducted on the SIFCON samples.

a. Compression test results

Table 7
Compression test results

Combinations	Cement + Mineral admixture	Steel + HDPE + WP Fibers	Compressive strength (N/mm^2)
Set 1	90% cement + 10% silica fume	2% + 1%+1%	46.5
Set 2	90% cement + 10% Metakaolin	2% + 1%+1%	47.1
Set 3	90% cement + 10% GGBS	2% + 1%+1%	49.5
Set 4	80% cement + 20% silica fume	2% + 1%+1%	43.2
Set 5	80% cement + 20% Metakaolin	2% + 1%+1%	43.6
Set 6	80% cement + 20% GGBS	2% + 1%+1%	48.2
Set 7	75% cement + 25% silica fume	2% + 1%+1%	40.4
Set 8	75% cement + 25% Metakaolin	2% + 1%+1%	41.3
Set 9	75% cement + 25% GGBS	2% + 1%+1%	43.2
Set 10	100% + 0 + 0 (Control mix)	4% + 0 + 0	51.5

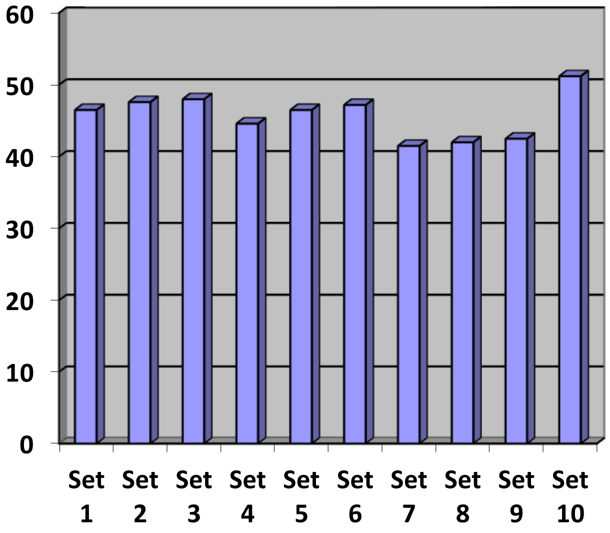


Fig. 12. Compression test results

From the above results it can observed that the control mix (Set 10) has a strength of 51.5N/mm^2. When 10% of cement was replaced with mineral admixtures the strength ranges from 46. 5N/mm^2 to 49.5 N/mm^2. When 20% of cement was replaced by mineral admixtures the strength obtained was in the range 43.2 to 48.2N/mm^2. And when the when 25% of the cement was replaced by mineral admixtures the strength drops and was in the range 40.4N/mm^2 to 43.2N/mm^2 which is too low when compared with the control mix. It can be seen that mix with replacement of cement by GGBS performs well under the compression.

3.2 Tensile strength test results

Table 8
Tensile strength test results

Combinations	Cement + Mineral admixture	Steel + HDPE + WP Fibers	Tensile strength (N/mm^2)
Set 1	90% cement + 10% silica fume	2% + 1%+1%	5.5
Set 2	90% cement + 10% Metakaolin	2% + 1%+1%	5.2
Set 3	90% cement + 10% GGBS	2% + 1%+1%	6.0
Set 4	80% cement + 20% silica fume	2% + 1%+1%	4.3
Set 5	80% cement + 20% Metakaolin	2% + 1%+1%	4.5
Set 6	80% cement + 20% GGBS	2% + 1%+1%	5.5
Set 7	75% cement + 25% silica fume	2% + 1%+1%	4.1
Set 8	75% cement + 25% Metakaolin	2% + 1%+1%	4.3
Set 9	75% cement + 25% GGBS	2% + 1%+1%	5.2
Set 10	100% + 0 + 0 (Control mix)	4% + 0 + 0	6.5

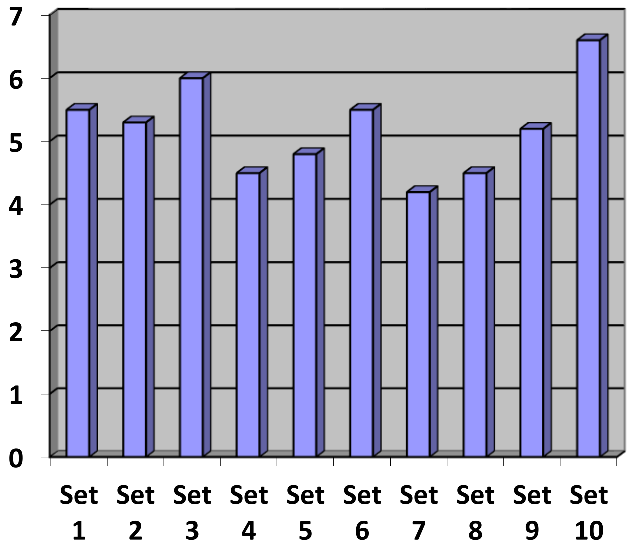


Fig. 13. Tensile strength test results

From the above results it can observed that the control mix (Set 10) has a tensile strength of 6.5N/mm^2. When 10% of cement was replaced with mineral admixtures the strength ranges from 5.2N/mm^2 to 6.0 N/mm^2. When 20% of cement was replaced by mineral admixtures the strength obtained was in the range 4.3 to 5.5/mm^2. And when the when 25% of the cement was replaced by mineral admixtures the strength drops considerably and was in the range 4.1N/mm^2 to 5.2N/mm^2 which is too low when compared with the control mix. It can be seen that mix with replacement of cement by GGBS performs well under the tensile force.

3.3 Flexural Strength Results

From the above results it can observed that the control mix (Set 10) has a flexural strength of 15.4N/mm^2. When 10% of cement was replaced with mineral admixtures the strength ranges from 14.0N/mm^2 to 14.10 N/mm^2. When 20% of cement was replaced by mineral admixtures the strength obtained was in the range 12.5 to 12.8N/mm^2. And when the when 25% of the cement was replaced by mineral admixtures the strength drops and was in the range 11.3N/mm^2 to 11.8N/mm^2 which is too low when compared with the control mix. It can be seen that at all the mixes perform in a similar way under the flexure.

Table 9
Flexural Strength Results

Combinations	Cement + Mineral admixture	Steel + HDPE + WP Fibers	Flexural strength (N/mm^2)
Set 1	90% cement + 10% silica fume	2% + 1%+1%	14.0
Set 2	90% cement + 10% Metakaolin	2% + 1%+1%	14.1
Set 3	90% cement + 10% GGBS	2% + 1%+1%	14.0
Set 4	80% cement + 20% silica fume	2% + 1%+1%	12.5
Set 5	80% cement + 20% Metakaolin	2% + 1%+1%	12.8
Set 6	80% cement + 20% GGBS	2% + 1%+1%	12.6
Set 7	75% cement + 25% silica fume	2% + 1%+1%	11.8
Set 8	75% cement + 25% Metakaolin	2% + 1%+1%	11.3
Set 9	75% cement + 25% GGBS	2% + 1%+1%	11.5
Set 10	100% + 0 + 0 (Control mix)	4% + 0 + 0	15.4

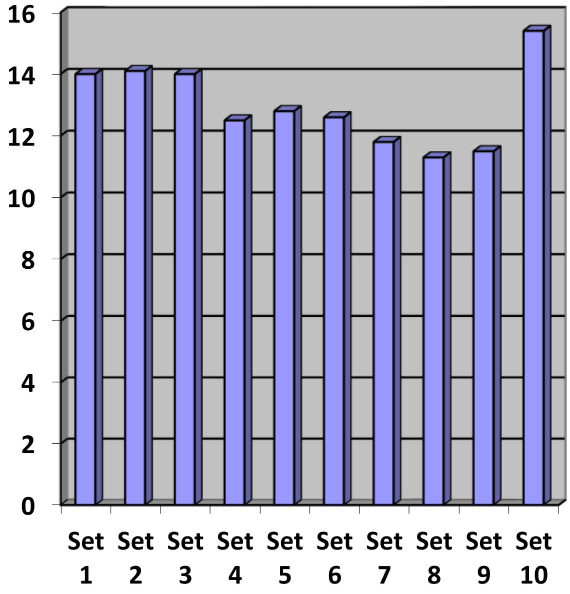


Fig. 14. Flexural Strength Results

3.4 Shear Strength Results

Table 10
Shear Strength Results

Combinations	Cement + Mineral admixture	Steel + HDPE + WP Fibers	Shear strength (N/mm^2)
Set 1	90% cement + 10% silica fume	2% + 1%+1%	13.2
Set 2	90% cement + 10% Metakaolin	2% + 1%+1%	13.0
Set 3	90% cement + 10% GGBS	2% + 1%+1%	13.2
Set 4	80% cement + 20% silica fume	2% + 1%+1%	12.0
Set 5	80% cement + 20% Metakaolin	2% + 1%+1%	12.4
Set 6	80% cement + 20% GGBS	2% + 1%+1%	12.2
Set 7	75% cement + 25% silica fume	2% + 1%+1%	11.0
Set 8	75% cement + 25% Metakaolin	2% + 1%+1%	11.10
Set 9	75% cement + 25% GGBS	2% + 1%+1%	11.20
Set 10	100% + 0 + 0 (Control mix)	4% + 0 + 0	14.2

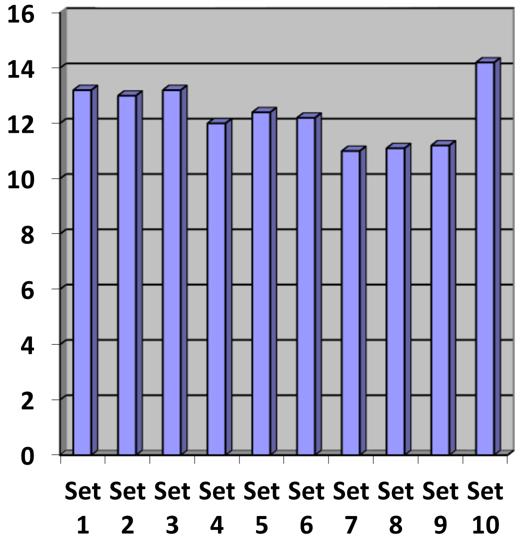


Fig. 15. Shear Strength Results

From the above results it can observed that the control mix (Set 10) has a flexural strength of 14.2N/mm^2. When 10% of cement was replaced with mineral admixtures the strength ranges from 13.0N/mm^2 to 13.20 N/mm^2. When 20% of cement was replaced by mineral admixtures the strength obtained was in the range 12.0 to 12.4N/mm^2. And when the when 25% of the cement was replaced by mineral admixtures the strength drops and was in the range 11.0N/mm^2 to 11.2N/mm^2 which is too low when compared with the control mix. It can be seen that at all the mixes perform in a similar way under the shear stress.

3.5 Impact Strength Results

Table 11
Impact Strength Results

Combinations	Cement + Mineral admixture	Steel + HDPE + WP Fibers	Impact strength at first crack (N-m)	Impact strength at first crack (N-m)
Set 1	90% cement + 10% silica fume	2% + 1%+1%	5068.3	6125.7
Set 2	90% cement + 10% Metakaolin	2% + 1%+1%	5016.2	6150.5
Set 3	90% cement + 10% GGBS	2% + 1%+1%	5102.4	6146.4
Set 4	80% cement + 20% silica fume	2% + 1%+1%	4645.1	5642.1
Set 5	80% cement + 20% Metakaolin	2% + 1%+1%	4575.2	5645.4
Set 6	80% cement + 20% GGBS	2% + 1%+1%	4585.6	5586.2
Set 7	75% cement + 25% silica fume	2% + 1%+1%	4256.4	5264.7
Set 8	75% cement + 25% Metakaolin	2% + 1%+1%	4325.5	5287.4
Set 9	75% cement + 25% GGBS	2% + 1%+1%	4276.4	5325.6
Set 10	100% + 0 + 0 (Control mix)	4% + 0 + 0	5423.5	6854.6

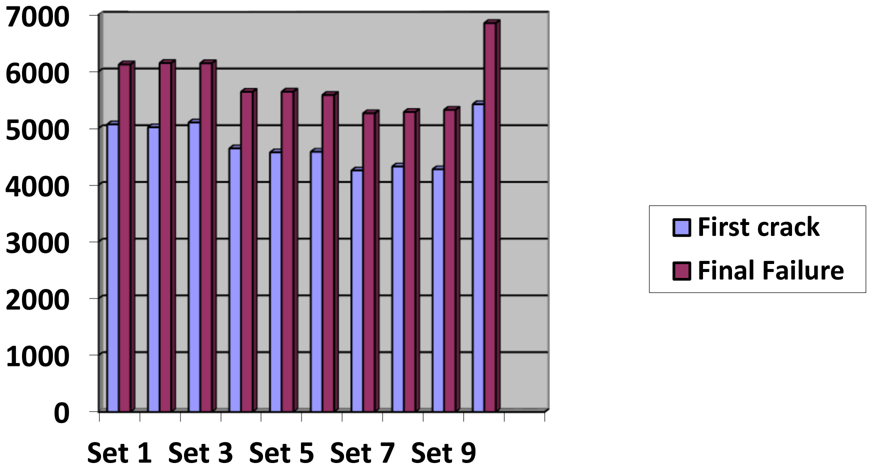


Fig. 16. Impact Strength Results

From the above results it can observed that the control mix (Set 10) has Impact strength of 6854.6N-m for final failure. When 10% of cement was replaced with mineral admixtures the strength ranges from 6125N-m to 6150 N/mm^2. When 20% of cement was replaced by mineral admixtures the strength obtained was in the range 5586 N-m to 5645 N-m. And when 25% of the cement was replaced by mineral admixtures the strength drops and was in the range 5264 N-m to 5325 N-m which is too low when compared with the control mix. It can be seen that at all the mixes perform in a similar way under the Impact load.

4. Conclusions

From the experiments conducted it can be observed that the strength of the SIFCON reduces as the percentage replacement of cement by mineral admixture is higher. But when the percentage replacement of cement was just 10% the strength obtained will be almost nearer to that of the control mix. However 10% replacement of cement by mineral admixtures does not seem to be much cost effective. So if we consider a higher percentage replacement of cement, it can be observed that strength of the SIFCON with 20% replacement of cement is almost nearer to that of the SIFCON produced with 10% replacement of cement by Mineral admixtures, where as if we observe the performance of SIFCON produced with replacement of 25% of cement by mineral admixtures is considerably low.

So we can say that the optimum percentage of replacement of cement by any mineral admixture should be 20. When we observe the performance of each mineral admixtures we can see that the ground granulated blast furnace flag is comparatively better. It can also be seen that 50% replacement of steel fibers with waste plastic fibers does not reduce the strength of the SIFCON significantly.

So after observing the experimental results it can be concluded that we can effectively reduce the cost of production of SIFCON by replacing 20% of cement by GGBS and by replacing 50% of steel fibers by waste plastic fiber without reducing the performance considerably.

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