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# Study and experimental investigation of flow and flexural properties of natural fiber reinforced self compacting concrete

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**Abstract**

The essentiality of self -compacting concrete can be understood from the fact that there is an increasing problem of lack of skilled labor in the construction industry. The benefit of SCC is that it provides faster construction period and allows an early development of strength for concrete. The above paper deals with flexure and flow properties of self -compacting concrete reinforced with a combination of steel with sisal and abaca fibers. Three percentages of sisal (0.5%,1%,1.5%)or three of abaca (0.5%,1%,1.5%) are mixed with a uniform 0.3% and 0.6% of steel fibers. Split tensile strength and flexure strength are evaluated at 7 days and 28 days for various specimens of self -compacting concrete made by variation of fiber provides an understanding of mechanical properties and tests like Slump flow, J –ring and U-box test are performed for an understanding of flow of self - compacting concrete


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***Keywords:*** Self Compacting Concrete; Flexure; Flow; Sisal; Abaca; Steel

## 1. Introduction

Self-compacting concrete (SCC) is a concrete which is formed without any need for vibration. To ensure that

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adequate amount of compaction is received by the concrete and it has proper homogeneity the idea of self-compacting concrete was given for the first time by Hajime Okamura in the 1980's. Self-compacting concrete is a high-performance concrete which is able to flow in its own weight and is able to provide the necessary homogeneity even when there is heavy reinforcement. It provides with good flowing ability and is able to pass to complicated structures and also provides with resistance to segregation. These are a few important properties associated with self-compacting concrete. These properties are achieved by a few modifications like increase in amount of fineness, reducing the water-powder ratio and by use of Superplasticizer. [1] The output in terms of shrinkage and creep is increased by increasing fineness content as it causes the increase in the volume of paste in the self- compacting. [2] In order to improve the segregation resistance of SCC there is use of stabilizer called viscosity modifier agent (VMA). This also allows for a reduction in segregation and also reduces chances of shrinkage and creep. [3] The concrete has to have a proper proportion as because if it is not homogenous during placing and after compaction it might lead to segregation, bleeding Here follows further instructions for authors. Honeycombing in order to compose a freshly prepared SCC. In the above study we investigate the effect of various dosages of fibers percentages along with steel fibers on mechanical properties of SCC. [1,3].

## 2. Materials

### *2.1 Cement and Water*

Ordinary Portland cement (Ramco Cement Supplier) of 53 grade is used in the mix design. Water-cement ratio is 0.42 for this mix design. The test on the cement was done to find out the specific gravity and the Initial Setting time of the cement given by

$$\frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4) * 0.79} = 3.21 \text{ g} \quad (1)$$

Initial setting time of the cement is 30 minutes for 53 OPC Grade cement. [4]

### *2.2 Coarse Aggregate and Fine Aggregate*

Sand is used as a Fine aggregate ranging from 0-2 mm aggregate and angular aggregate of size between 8.00 mm to 16 mm are used as a coarse aggregate.

Fig.1. Coarse Aggregate

Fig.2. Fine Aggregate

*2.3 Fly Ash*

Class F fly Ash is used in the above experiment. It mainly consists of silica and alumina. Class F fly Ash has a lower calcium content than Class C fly Ash. The chemical composition of Class F fly Ash is listed below. Ref the Table 1 .

Table 1 Chemical Composition of Class F Fly Ash

| Properties | Requirement (%) |
|---|---|
| Silica ($SiO_2$) | 58.5 |
| Iron Oxide ($Fe_2O_3$) | 3.32 |
| Alumina ($Al_2O_3$) | 28.20 |
| Calcium Oxide (CaO) | 2.21 |
| Magnesium Oxide (MgO) | 0.36 |
| Alkalies ($Na_2O$+$K_2O$) | 1.84 |
| $SO_3$, max | 4.3 |
| Moisture Content, max | 2.80 |
| Loss on Ignition, max | 4.17 |

*2.4 Superplasticizer*

VARAPLAST PC 432 is used as the Superplasticizer. It is different than the conventional Superplasticizer used because of the sulfonated melamine and naphthalene formaldehyde condensate which creates electrostatic repulsion of particles. It gives a very high ultimate strength concrete and minimal voids and having optimum density. The setting time varies from 1-4 hrs depending on the dosage. Ref Table 2.

Table2.Properties of VARAPLAST PC 432.

| Properties | Content (%) |
|---|---|
| Calcium Chloride | NIL |
| Specific Gravity | 1.10 at 20°C |
| Air Entrainment | <1 |
| Chloride Content | NIL |

*2.5 Viscosity Modifying Agent (VMA)*

VARAPLAST VMA is used as the viscosity modifying admixture. It is specially developed for producing enhanced viscosity concrete. It has appreciable stability, resistance to segregation. It has a maximum shell life of 6 months.

The characteristics of the VMA are: enhanced workability, no effect on the air content of concrete, increases concrete viscosity, no impact on concrete setting time, doesn't affect the compressive strength of concrete. [5]

## *2.6 Steel and Natural Fibers: Sisal and Abaca*

Steel Fibers are used as a reinforcement material for concrete. It also has effect in reducing plastic shrinkage cracking, increases the tensile strength and toughness, resistance to freezing and thawing and reduces the maintenance and repair cost. Abaca and Sisal fibers are also used as reinforcing agents with steel fibers to increase the concretes workability and strength characteristics. The costs of the fibers are much cheaper than the steel fibers. Sisal is obtained from the sisal plant known as the Agave sisalana whereas abaca is obtained from the banana stem. [6]. Ref Fig3, Fig4 and Fig5. Ref Table 3.

Fig.3. Sisal Fiber in use

Fig.4. Abaca Fiber in use

Fig.5. Steel Fiber in use

Table 3. Properties of Fibers

| Properties | **Steel** | **Sisal** | **Abaca** |
|---|---|---|---|
| Tensile Strength (MPa) | 1450 | 385-728 | 650-780 |
| Elongation of Break % | 2.57 | 2.75 | 2-4 |
| Diameter (mm) | 0.6 | 0.8-1.2 | 1-3 |
| Aspect Ratio | 27 | N.A | N.A |
| Density (g/cm$^3$) | 7.85 | 1.58 | 1.30 |
| Young's Modulus (GPa) | 210 | 9-22 | 29-32 |
| Moisture | 0.03 | 6.55 | 5.6 |

*2.7 Mix Design of Self Compacting Concrete*

The mix design of self -compacting concrete is given in the following table: Ref Table 4.

Table 4 Composition of HFR-SCC Mix.

| Component | Weight per $m^3$ of concrete (kg) |
|---|---|
| Cement OPC | 470 |
| Fly Ash | 92 |
| Coarse Aggregate | 610 |
| Fine Aggregate | 915 |
| Water | 200 |
| Superplasticizer | 4.0 |

The mix design is based on the above approach. We evaluate the water requirement and optimize the flow and stability of the paste. The next step is to determine the required amount of fiber to be added for required structural feasibility. Then the specimens are checked for the amount of variation (sensitiveness) to structural feasibility for a small change in quantities along with the addition of a suitable amount of coarse aggregate. Finally, the production of freshly prepared SCC was done in a mixer, and then the required tests were performed.

## 1. Experimental Investigation

The tests that are to be performed by having a variation of the percentages of fibers used and the type of fibers used: Slump Flow Test, U-box Test, J-Ring Test for determining flow properties and Flexure Strength Test and Split Tensile Strength Test for determining flexure properties of samples. Refer Fig6.

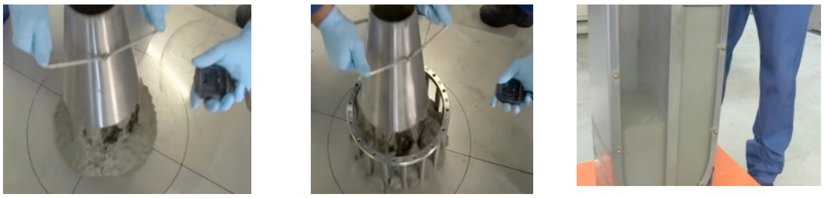

Fig.6. Experimental Investigation of Flow characteristics from left Slump Flow Test, in the centre U Box Test and at the right J-Ring Test

The mix design is based on strength criteria and durability criteria used for moderate environment. Cubes, Cylinders were tested for, split tensile, flexural strength after 7 and 28 days curing. For Flexure and Split Tensile Strength, the age of curing has been taken as 7 and 28 days. The ratios by weight of Cement, fine aggregate, and coarse aggregate have been obtained based on a reference of the EFNARC guidelines and Okamura and Ouchi work on self - compacting concrete. [7]

*3.1 Slump Flow Test*

The slump flow test is used to assess the horizontal free flow without presence of obstructions. The test method is based on the test method for determining the slump and the indicators: Diameter of the concrete circle and T500 sec (time taken from the initial flow to the flow of concrete at 500mm diameter) gives the measure of the filling ability and the viscosity of the concrete.

The procedure for doing the experiment is to first clean the internal surface of the mould with the application of the oil by using a paintbrush. Then the mould is placed on a smooth horizontal base plate which is non- porous. Fill the mould with the prepared mix of the concrete in three equal layers. Without tamping with the rod, remove the excess layer of the concrete and level it with the help of a trowel. From the concrete remove the mould immediately and slowly in the vertical direction. Measure the difference between the height of a mould and that of the height of the specimen as the slump height. The outcome of slump flow test on the various mixes is: [4]. Ref Table 5, Table 6, Fig7 and Fig8.

Table 5. Fiber Proportion in SCC Mix

| Sample Code | Fiber Volume $V_f$(%) | | |
|---|---|---|---|
| | Sisal | Abaca | Steel |
| SCC Mix | - | - | - |
| Mix1 | 0.5 | - | 0.3 |
| Mix2 | 1.0 | - | 0.3 |
| Mix3 | 1.5 | - | 0.3 |
| Mix4 | 0.5 | - | 0.6 |
| Mix5 | 1.0 | - | 0.6 |

| Sample Code | Fiber Volume $V_f$(%) | | |
|---|---|---|---|
| | Sisal | Abaca | Steel |
| Mix6 | 1.5 | - | 0.6 |
| Mix7 | - | 0.5 | 0.3 |
| Mix8 | - | 1.0 | 0.3 |
| Mix9 | - | 1.5 | 0.3 |
| Mix10 | - | 0.5 | 0.6 |
| Mix11 | - | 1.0 | 0.6 |
| Mix12 | - | 1.5 | 0.6 |

Table 6. Slump Flow variation in SCC Mix Proportion

| Sample Code | Flow Diameter (mm) | $T_{500}$ (sec) |
|---|---|---|
| SCC Mix | 610 | 6.0 |
| Mix1 | 590 | 6.0 |
| Mix2 | 480 | 11.0 |
| Mix3 | 470 | 16.0 |
| Mix4 | 520 | 10.5 |
| Mix5 | 475 | 13.0 |

| Sample Code | Flow Diameter (mm) | $T_{500}$ (sec) |
|---|---|---|
| Mix6 | 445 | 16.0 |
| Mix7 | 590 | 6.3 |
| Mix8 | 500 | 10.50 |
| Mix9 | 480 | 16.0 |
| Mix10 | 580 | 6.1 |
| Mix11 | 540 | 10.5 |
| Mix12 | 470 | 16.5 |

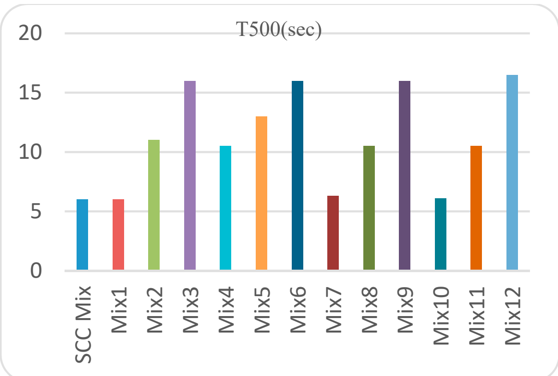


Fig.7. Graphical Representation of $T_{500}$ of Various Mixes

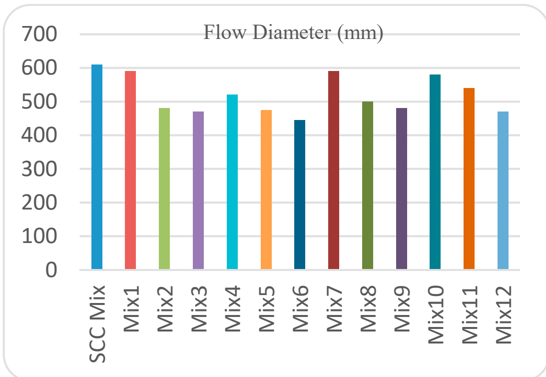


Fig.8. Graphical Representation of Flow Diameter of Various Mixes

In the test results obtained from the Slump Flow Test, there is variation in the diameter and the $T_{500}$ for various mixes which implies that the fiber content can induce affect in the workability of the concrete. In fig 7 and 8, it is identified that the Mixture with low content of sisal, abaca and steel fibers, the workability can be improved. Dosage with 0.5% of Sisal/Abaca with 0.3% of Steel fibers proves the maximum workability characteristics of Hybrid fiber SCC and close to the standard requirement of SCC. So, which implies $V_f > 0.8\%$ hybrid mixes did not satisfy the SCC requirement. The abaca fiber proves to be a better compliment with steel than Sisal.

### *3.2 J-Ring Test*

It's the measure of the ability of concrete to flow or the passing ability through obstruction and reinforcement places. The slump flow apparatus is used along with J ring for the above purpose. The test is used as a quality control test in the field. The cone is kept at the center of the flow table along with the J-Ring and is filled with concrete. The concrete is then released to allow the concrete to flow.

In determining the measurements, a tape or a ruler is used to determine the diameter of the circle formed by the concrete upon its flow and a stop watch is used for noting the time of flow of concrete for T500. The main superiority of the test is in determining the measurements, a tape or a ruler is used to determine the diameter of the circle formed by the concrete upon its flow and a stop watch is used for noting the time of flow of concrete for T500. The main superiority of the test is that it accounts for the obstruction by considering bars of the J-Ring through which the concrete flows and as result, it gives a difference in height of the concrete as it passes through the gaps and finally the flow stops. Ref Table 7. Ref Fig9 and Fig10. The outcome of J-ring flow test on the various mixes is:

Table 7. J-Ring Flow variation in SCC Mix Proportion

| Sample Code | Flow Diameter (mm) | $T_{500}$ (sec) |
|---|---|---|
| SCC Mix | 370 | 8.0 |
| Mix1 | 360 | 8.3 |
| Mix2 | 335 | 12 |
| Mix3 | 331 | 18 |
| Mix4 | 350 | 11 |
| Mix5 | 325 | 13.5 |
| Mix6 | 320 | 16 |

| Sample Code | Flow Diameter(mm) | $T_{500}$ (sec) |
|---|---|---|
| Mix7 | 365 | 8.1 |
| Mix8 | 340 | 12 |
| Mix9 | 330 | 18 |
| Mix10 | 350 | 8 |
| Mix11 | 310 | 11.5 |
| Mix12 | 300 | 16.5 |

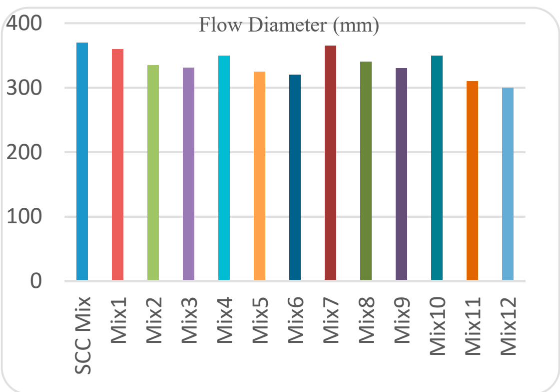


Fig.9. Graphical Representation of Flow Diameter of Various Mixes

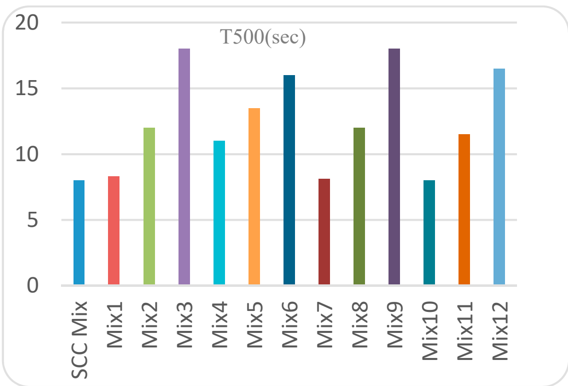


Fig.10. Graphical Representation of $T_{500}$ of Various Mix

Similar results have been obtained in the J-ring test when compared with Slump Flow but there has been a decrease in the values of all mixes due to the presence of reinforced steel bars in the J-ring that obstructs the flow and increases the viscosity of the concrete. Ref Fig11 and Fig12.

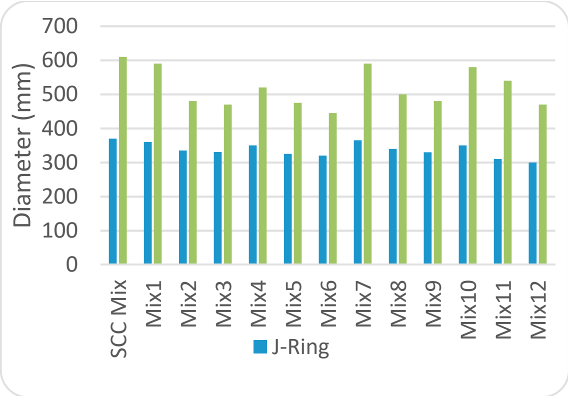


Fig.11. Comparison of Diameter of J-ring and Slump Flow

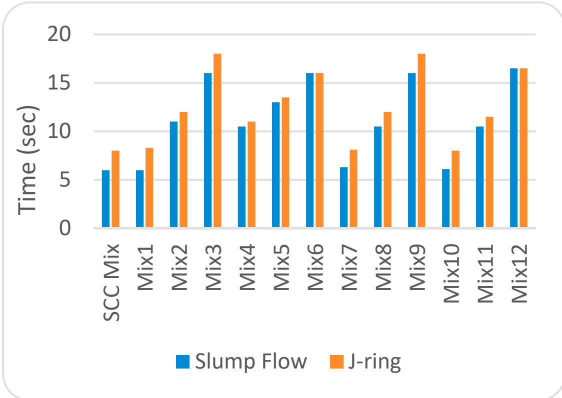


Fig.12. Comparison of $T_{500}$ of J-ring and Slump Flow

In figure 11 and 12, the data comparison of Slump Flow with J-Ring is given with considering both the indicators – Diameter and T500. The results show that the J-ring test gives a more quality control and is a better field test for assessing the workability of concrete as it considers all the parameters of passing ability.

### *3.3 U-Box Test*

The test measures the filing ability of concrete. It consists of a vessel with a small opening at the central axis of the apparatus in the bottom that contains a sliding gate thus diving the two sections of the vessel and the sliding gate has reinforcement bars through which the concrete flows. The difference in the height is measured between left and right sections. If the flow of concrete is as free as water, at rest it will be horizontal i.e. $h_1$-$h_2$ = 0. Therefore, the nearest to this test value to ($h_1$-$h_2$=0), the better the flow and passing ability of concrete. The following table shows the variation of the ratio $h_1/h_2$ on the mix used. Ref Table 8.

Table 8.U-Box Test Flow variations of different SCC Mixes

| Sample Code | $h_1$ (mm) | $h_2$ (mm) | $h_2/h_1$ | Remarks |
|---|---|---|---|---|
| SCC Mix | 320 | 320 | 1.000 | Best |
| Mix1 | 320 | 312 | 0.975 | Best |
| Mix2 | 320 | 250 | 0.781 | Good |
| Mix3 | 320 | 123 | 0.384 | Blocking |
| Mix4 | 320 | 280 | 0.875 | Good |
| Mix5 | 320 | 168 | 0.525 | Blocking |
| Mix6 | 320 | 130 | 0.406 | Blocking |
| Mix7 | 320 | 315 | 0.984 | Best |
| Mix8 | 320 | 265 | 0.828 | Good |
| Mix9 | 320 | 126 | 0.393 | Blocking |
| Mix10 | 320 | 290 | 0.906 | Best |
| Mix11 | 320 | 245 | 0.765 | Good |
| Mix12 | 320 | 133 | 0.415 | Blocking |

In U-Box test the ratio $h_2/h_1$ is the main indicator for identifying the passing ability of concrete. According to Table 8, fiber dosage $V_f$< 0.8 % Hybrid mix has the least deviation from the standard SCC closer to the standard value which makes them feasible SCC mix. As the fiber dosage increases the blocking capability increases and more resistance to the flow of concrete mix. Here the Abaca fibers prove to be more efficient in workability test than the Sisal fibers because by increasing the fiber dosage of Abaca the blocking characteristics is less initiated than the Sisal Fibers. All rectangular beams of dimension 100 x 100 x 500mm are casted to find flexural strength, 150 x 300mm dimension cylinder are casted to find split tensile strength.

### *3.4 Flexural Strength Test*

Flexural strength, also known as modulus of rupture, or bend strength, or transverse rupture strength is a property specific of a material, it's the stress at which a material yield in a flexure experiment. The transverse bending test is used most commonly for the above, in which a specimen having either a circular or rectangular cross-section is bent until fracture or yielding using three-point flexural test technique. The flexural strength represents the highest stress experienced by the material at the time when it's about to yield. Ref Fig13 and Fig14.

Fig.13. Flexural Strength Testing Machine

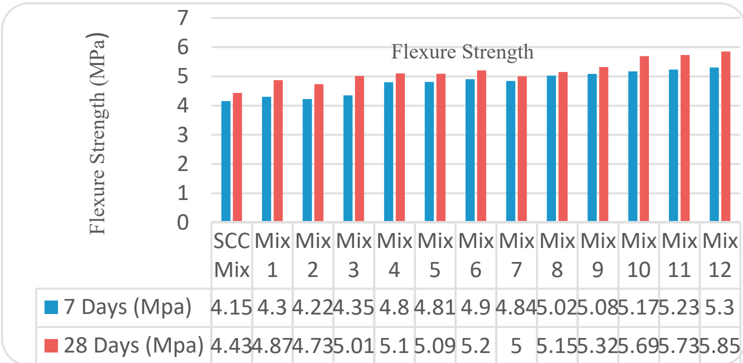


Fig.14. Flexural Strength of Concrete with Sisal/Abaca Fiber Dosage

The following Tabulation gives the variation of different flexural strength for various mixes. Ref Table 9.

Table **9.** Tabulation of Flexural Strength of various Mixes

| Sample Code | Flexural Strength | |
|---|---|---|
| | 7 Days (MPa) | 28 Days (MPa) |
| SCC Mix | 4.15 | 4.43 |
| Mix1 | 4.30 | 4.87 |
| Mix2 | 4.22 | 4.73 |
| Mix3 | 4.35 | 5.01 |
| Mix4 | 4.80 | 5.10 |
| Mix5 | 4.81 | 5.09 |
| Mix 6 | 4.9 | 5.2 |
| Mix 7 | 4.84 | 5 |
| Mix 8 | 5.02 | 5.15 |
| Mix 9 | 4.35 | 5.01 |
| Mix 10 | 5.08 | 5.32 |
| Mix 11 | 5.17 | 5.69 |
| Mix 12 | 5.3 | 5.85 |

In the Flexure Strength Test, the strength is affected due to the change in fiber dosage. According to the figure 14 and Table 9, by increasing the fiber dosage the strength increases and abaca fibers have much superiority in flexural strength than sisal. In this Abaca fibers are having strength in the range of 4.84-5.3 MPa for 7 days and 5.00-5.85 MPa for 28 days whereas in Sisal fibers the range lies between 4.15-4.9 MPa for 7 days and 4.43-5.20 MPa for 28 days. The result also signifies that by increasing the dosage of steel from 0.3 % to 0.6 %, results in the increase in flexural strength. This is due to the properties of steel and abaca fibers hence proves to be a good reinforcing material.

### *3.5 Split Tensile Strength Test*

The test is performed for tensile strength in which specimen is taken in a cylindrical form and is loaded for failure by compression along the diameter and is applied along the entire length. Ref Fig15 and Fig16.


Fig.15.Compression Testing Machine for Split Tensile Strength

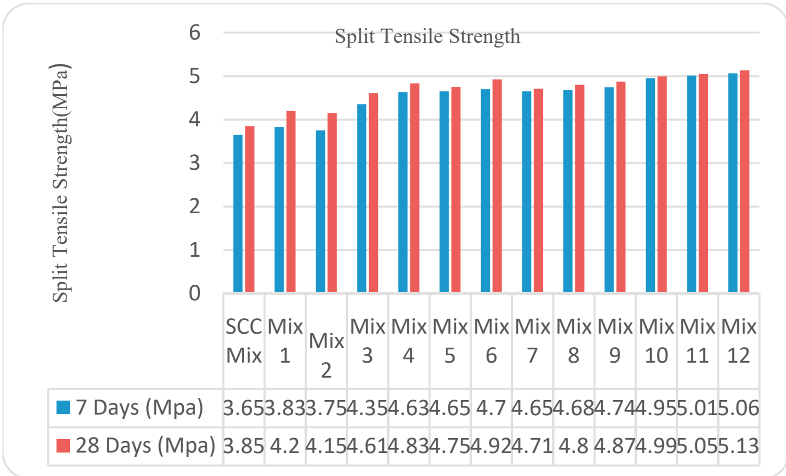


Fig.16. Split Tensile Strength Tensile Strength of Concrete with Sisal/Abaca Fiber Dosage

The following Tabulation gives the variation of different Split Tensile strength for various mixes: Ref Table 10.

Table 10. Tabulation of Split Tensile Strength of various Mixes

| Sample Code | Split Tensile Strength | |
|---|---|---|
| | 7 Days (MPa) | 28 Days (MPa) |
| SCC Mix | 3.65 | 3.85 |
| Mix1 | 3.83 | 4.2 |
| Mix2 | 3.75 | 4.15 |
| Mix3 | 4.35 | 4.61 |
| Mix4 | 4.63 | 4.83 |
| Mix5 | 4.65 | 4.75 |
| Mix6 | 4.7 | 4.92 |
| Mix7 | 4.65 | 4.71 |
| Mix8 | 4.68 | 4.80 |
| Mix9 | 4.74 | 4.87 |
| Mix10 | 4.95 | 4.99 |
| Mix11 | 5.01 | 5.05 |
| Mix12 | 5.06 | 5.13 |

In the Split Tensile Strength, the strength gets influenced by the dosage of fibers for reinforcement. In the Figure 16, it can be interpreted that the split tensile strength increases i.e. the tensile character increases with the increase in fiber dosage. In this abaca fibres are having a strength ranging from 4.65-5.06 MPa for 7 days test values and 4.71-5.13MPa for 28 days test value whereas for Sisal the strength ranges from 3.65-4.7 MPa and 3.85-4.92 MPa for 7 days and 28 days respectively. This indicates that the abaca fiber has more superiority in tensile characteristics than sisal fibers. The influence of steel fibers also plays a crucial role in imparting strength characteristics and according to the data it has been observed that the mix design of the concrete increased with a dosage of steel fibers along with natural fibers (sisal/abaca). Hence a better mix design would be the proper balance of abaca and steel fibers with 0.6 % of steel and 1.5 % of abaca fibers.

## 4. Conclusions

The experimental results indicate that the natural fibers have a good capability of using it as a reinforcement material along with steel for concrete mix. In the flow/passing ability experimental techniques like the Slump Flow, J-Ring and U-Box test, the concrete mix design with a low fiber content of sisal/abaca fibers with steel proves to be beneficial for the workability of concrete. Both the natural fibers prove be a good workability imparting quality but abaca fibers prove to be more efficient than sisal because of their cellulose component which has a microfibrils formation with high tensile strength and also due to the presence of lignin and pectin organic compounds that helps to bind the concrete mix without segregation. Hence low content of these fibers is preferred whereas, high content of fibers can compromise its workability. The main benefit of the abaca fibers is its imparting high strength to the concrete mix. According to the results, it was observed that high concentration of steel along with abaca fibers preferred the Tensile and Flexure characteristics of the concrete. The abaca fiber has a profitable use than the other artificial/man -made reinforcements because of its availability and also eco- friendly to the environment along with the structure. These fiber reinforcements can be used in the upcoming green building technologies**.**

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