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Binary, Ternary and Quaternary Effect of Fillers on Fresh and Hardened Properties of Self Compacting Concrete (SCC)

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***Abstract*—This paper presents the detailed investigation of the combined effect of the cementitious materials (Fillers) on the fresh and hardened properties of Self Compacting Concrete (SCC). Totally four cementitious blends like Ordinary Portland Cement (OPC), Fly ash (FA), Marble Powder (MP) and Lime stone powder (LP) were used for this study. The investigation includes the Binary effect (OPC+FA), Ternary effects (OPC+FA+LP or OPC+FA+MP) and Quaternary effect of fillers (OPC+FA+LP+MP) in the fresh and strength properties of SCC. The Control mixture contained Ordinary Portland Cement (OPC) with 25 % of Fly ash (FA) by the weight of OPC, while the remaining mixtures incorporated with MP and LP. The use of fillers (LP and MP) reduced the cost as well as the hydration in cement. The total binder content of 550 kg/m3 and water binder ratio of 0.34 were taken as constant for all the mixes. This paper presents the experimental investigation of fresh properties like Slump flow test, L Box, U Box ,V funnel and T50 time and the Hardened properties in the strength aspects like Compressive strength, Split tensile strength and the Flexure strength were carried out for all the mixes and the results were compared with the control mix. Based on the results the feasibility of using the filler in SCC was studied. As a whole, all the mixes satisfy the workability characteristics of SCC. But the mix combined with all the fillers produced better results in strength aspects as well as workability aspects than all other mixes.**

Keywords*: *Self Compacting Concrete (SCC), Ordinary Portland Cement (OPC), Fly ash (FA), Marble Powder (MP), Lime stone powder (LP), Fillers.

I. INTRODUCTION

Self Compacting Concrete (SCC) was first developed in 1988 in Japan. SCC is defined as the concrete that settles by its own weight with high fluidity. The characteristic feature of SCC is that it can easily pass through the form work and congestion reinforcement without any external vibration, thereby conserving the energy which would have otherwise been utilized for vibration. It is desirable to have SCC with high passing ability, resistance to segregation & bleeding during transportation and placing. To obtain these properties superplasticizer and high volume of powder content are used. Due to high powder content (OPC) it makes the SCC costlier even with lower labor cost and also leads to increased shrinkage and thermal expansion of concrete. To address these problems cement is partially replaced with mineral admixtures (FA, LP and MP). Doing so will yield not only economical concrete but also help to conserve environment by preventing the disposal of FA, LP and MP. The major differences between SCC and vibrated concrete are i) SCC do not require any vibration. ii) Using SCC eliminates noise of vibration. iii) SCC reduces the labor cost.

II. RELATED WORK

More number of researches have been done concerning with use of fillers to achieve the Self Compactability characteristics and to reduce the material cost. Replacement of cement with limestone powder as mineral admixture in SCC with 3o% fly ash show improved workability and mechanical properties up to 20 % [Beeralingegowda et al.,2013].

Compressive strength of binary and ternary SCC decreased with the increase in natural pozzolanic and marble dust content, but strength at 28 and 90 days indicate that even with 40% (natural pozzolana + marble powder), suitable strength could be achieved [Belaidi 2012].

The test result showed that an optimization of self-compacting concrete mixture seems to be achievable by the simultaneous use of rubble powder and coarse recycled aggregate with improved fresh concrete performance and unchanged concrete mechanical strength [corinaldesi 2011].

It was found to have good consistency and workability for all the ten mixes at a constant w/p ratio of 0.41 and constant SP dosage of 1.0% of weight of cement. Comparison of workability test results of different combinations of mixes with the reference mix shows that with decrease in the percentage of fly ash in the mixes, the mix becomes dense and hence less workable [Dilraj Singh 2012].

According to the test results, it is concluded that the workability of fresh SCC has not been affected up to 200 kg/m3 MD (marble dust) content. However, the mechanical properties of hardened SCC have decreased by using MD, especially just above 200 kg/m3 content [Ilker Bekri Topcu 2009].

Table 1. Physical Properties of Ordinary Portland Cement (53 Grade)

S. No.	Property Of Cement	Values
1	Fineness Of Cement	7.5%
2	Grade Of Cement	53
3	Specific Gravity	3.15
4	Initial Setting time	28 min
5	Final Setting Time	600 min

The utilization of LP, BP and MP in SCC improved the fresh and hardened properties of SCC. The use of limestone and chalk powder as fillers could be used successfully in producing SCC mixes. The compressive strength of SCC mixes was greater than that of the conventional concrete [Mucteba Uysal 2011].

Addition of fly ash in SCC increases filling and passing ability of concrete. Superplasticizer content in SCC reduced water demand. Fly ash is industrial waste from thermal power station. Utilization of these waste products as cement replacement will not only help to achieve economical mix, but it is envisaged that it may improve the microstructure and consequently the durability of concrete. This provides solution to disposal problems and other environmental pollution [Prajapati Krishnapal et al., 2012].

On the basis of the results obtained in this study it is possible to manufacture self-compacting concrete using fly ash and dolomite powder with acceptable fresh and hardened properties. The test results showed that among the mineral admixtures used, FA and GBFS significantly increased the workability and compressive strength of SCC mixtures. Replacing 25% of PC with FA resulted in strength of more than 105 MPa at 400 days [Salim Barbhuiy 2011].

SCC containing the specified replacement levels of different binders as proposed in this investigation was found to be complying with all the workability requirements as per EFNARC (2002).

It was observed that 15% Micro silica and 25% Fly ash will give optimum strength for M100 grade at water /powder ratio of 0.22. The effect of Na2So4 on these mixes is nil where as HCL and H2So4 had substantial impact [Sesha Phani et., al 2013].

III. Performance Requirements

There are three distinct fresh properties which essentially define SCC and which are fundamental to its performance both in the plastic and hardened state. These properties are also interrelated and must be maintained for a required period of time after mixing. To achieve these properties, the material selection, proportioning and quality control including production control are critical.

The three essential fresh properties required by SCC are:

- Filling Ability: - The concrete must have the ability to flow and completely fill all parts within the formwork under its own weight without leaving voids. As it is highly fluid it has the ability to flow considerable distances both horizontally and upwards and fill vertical elements from the bottom.
- Passing Ability: - The concrete containing the required aggregate size must have the ability to flow through and around restricted spaces between steel reinforcing bars and other embedded objects under its own weight and without blocking or segregation.
- Segregation Resistance: - The concrete must be able to satisfy both the filling ability and passing ability requirements while it still remains homogeneous both during transport and placing and after placing.

In this paper, we propose to design a Mobility oriented Trust System which attains trust convergence and authentication to the mobile nodes. The concept of trust is important to communication and network protocol designers where establishing trust relationships among participating nodes is critical to enabling collaborative optimization of system metrics. These relations are based on the evidence generated by the previous interactions of entities within a protocol. In general, if the interactions have been faithful to the protocol, then trust will accumulate between these entities." Trust has also been defined as the degree of belief about the behavior of other entities; the trust has the following features:

IV. Benefits of Self Compacting Concrete

- Ability to completely fill the complex formwork and encapsulate areas of congested steel reinforcement without any compaction and yet with reduced risks of voids and honeycombing.
- Ability to develop higher early and ultimate strengths and enhanced durability properties compared with conventional vibrated concretes.
- Potential for improved surface finishes with reduced making good costs related to poorly compacted surfaces.
- Using SCC the cost incurred on manpower can be saved.

V. Mix Proportions

A. Materials used

Cement: Cement is the major constituent for most of the concrete. The ordinary Portland cement (53 Grade as per IS: 8114-1978) was used in this investigation.

Aggregate: Aggregate (fine & coarse aggregate) that which satisfies the IS: 383-1970 was used for this study. Fine aggregate passing through 4.75mm & coarse aggregate of size 12.5 mm was used. Normally minimum coarse aggregate content is used in SCC.

Mineral Admixtures: FA, LP, MP were used as a mineral admixture in this investigation. Fly ash is nothing but waste which is obtained from coal. Fly ash confirming IS: 3812 was used. Fly ash should highly fine & should have lower carbon content. The physical and chemical properties are stated in the tables below.

Table 2. Specific Gravity of Materials

S. NO	Specific gravity				
	Fly Ash	MP	LP	Coarse Aggregate	Fine Aggregate
1	2.12	2.7	2.51	2.806	2.78

Superplasticizer: Plasticizers are additives that increase the plasticity or fluidity of the material to which they are added; these include plastics, cement, concrete, wallboard, and clay. Plasticizers for concrete increase the workability of the wet mix, or reduce the water required to achieve the desired workability, and are usually not intended to affect the properties of the final product after it hardens.

GLENIUM B233 is an admixture of a new generation based on modified polycarboxylic ether. The product has been primarily developed for applications in HPC where the highest durability and performance is required. GLENIUM B233 is free of chloride and low alkali. It is compatible with all types of cements. It consists of a carboxylic ether polymer with long side chains. At the beginning of the mixing process it initiates the same electrostatic dispersion mechanism as the traditional superplasticizer, but the side chains linked to the polymer backbone generates a steric hindrance which greatly stabilizes the cement particles ability to separate and disperse. Steric hindrance provides a physical barrier (alongside the electrostatic barrier) between the cement grains. With this process, flowable concrete with greatly reduced water content is obtained. The optimum dosage of SP should be determined with trial mixes.

Table 3. Chemical properties of fillers

S.No	Constituents	% By Weight of Sample			
		Cement	Fly Ash	Marble Powder	Lime Stone Powder
1	SiO2	20.67	42.54	2.08	4.32
2	Al2O3	6.21	23.59	-	1.47
3	Fe2O3	2.06	12.36	0.74	1.16
4	MgO	0.82	2.62	0.86	0.8
5	CaO	64.89	13.78	41.48	41.65
6	Na2O	0.06	1.44	-	-
7	K2O	0.55	2.49	-	-
8	SO3	2.71	0.55	-	-

B. Mix Composition

The mix composition should satisfy all the performance criteria for the concrete in both the fresh and hardened states as per EFNARC specification. For the fresh states of concrete, the requirements are laid out in No.6 in EFNARC specification; whereas for the hardened states of concrete should satisfy the requirements of EN 206. All the mix proportions adopted in this paper were verified to meet the aforementioned criteria.

Four mixes with different percentages of fillers were prepared. Three mixes were prepared to partially replace 40% of the cement content with fillers (FA+MP+LP). The concrete made using OPC in which 25% of the cement content was replaced with fly ash, was taken as the control mix. Compressive strength, split tensile strength and flexural strength were examined for those mixes. The European Federation has framed certain specifications and guidelines for better design and use of high quality SCC. The mix proportions and quantity of materials for the mixes were obtained by trial and error method with the help of EFNARC guidelines. As per EFNNARC specifications the total powder content is 400 – 600 kg/m^3, coarse aggregate content is 28 - 35 % by volume of mix. Water content should not exceed 200 liters/m^3The sand content balances the volume of the other constituents. Glenium B233 was used as superplasticizer. We evaluate mainly the performance according to the following metrics.

VI. EXPERIMENTAL INVESTIGATION

A. *Test Methods for Fresh Concrete Properties*

Several test methods have been developed and together with visual inspection are often utilized to verify the performance of fresh SCC. However, none of these methods are standardized as yet, either nationally or internationally.

Some of these test methods include the Slump-flow test, Funnel test, U Type & Box Type tests, T50 Test, J-Ring test, the Orimet test and the GTM Screen Stability Test. Some of these tests are described below:

Slump Flow Test

This is a test method for evaluating the flowability of SCC, where the slump flow of SCC with coarse aggregates having the maximum size of less than 40 mm is measured. The basic equipment is the same as for the conventional slump test. However, the concrete placed into the mould is not tampered. When the slump cone has been lifted and the sample has collapsed, the diameter of the spread is measured rather than the vertical distance of the collapse. Slump flows for SCC mix can range from 650 to 800mm. Observations of the flow should look for no separation of grout from the mix, no fringe of water at the edge or on the surface, and an even distribution of aggregate in the patty. Filling ability is directly proportional to the slump flow of concrete. The equipment setup is shown in the Fig.1.

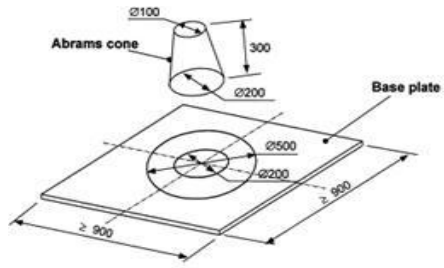

Fig.1 Slump Flow Test Apparatus

U- Box test

A U-Box is a U-shaped box divided into two sections that are separated by a door. One side of U-Box is filled with concrete with the door in place. The other side of U-Box has rebar placed in it of a given size and spacing. The door is removed and the concrete flows through the rebar, reaching an equilibrium height on the other side of the U-box. The height of the concrete is measured. This test measures the ability of the concrete to flow through rebar and fill a form. The higher the concrete flows on the other side of the U-box, the greater the ability of the concrete to flow through dense rebar and around corners in a form. For the better flow, the difference between heights of concrete in the 1^{st} & 2^{nd} compartment should be nearly zero.

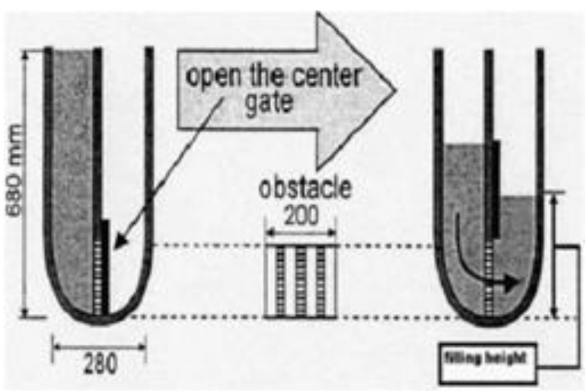

Fig.2 U Box Test Apparatus

L-Box test

The method aims at investigating the passing ability of SCC. It measures the reached height of fresh SCC after passing through the specified gaps of steel bars and flowing within a defined flow distance. With this reached height, the passing or blocking behavior of SCC can be estimated. For better flow of concrete the blocking ratio (H2/H1) should be nearer to one.

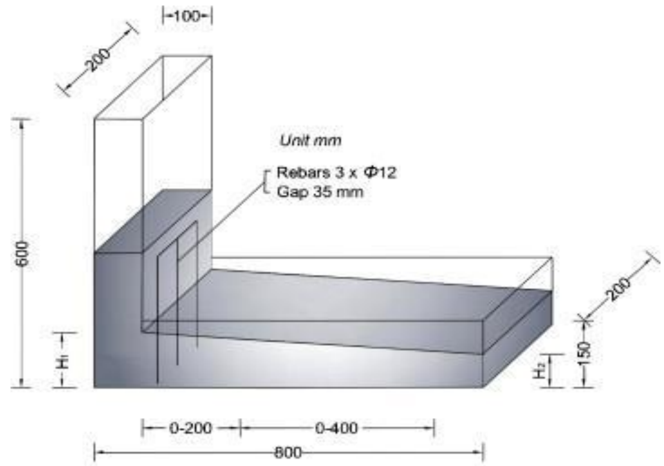

Fig.3 L Box Test Apparatus

V Funnel Test

A test method for evaluating the material segregation resistance of SCC, using a funnel where the efflux time of SCC with coarse aggregates having the maximum size of less than 25 mm is measured. Funnel test of concrete equivalent to the Marsh Funnel for grout testing. A V- shaped box is made with a narrow opening at the bottom. A gate is fixed, at the bottom of the box. The box is filled with concrete. The gate is opened and the time for the concrete to flow out of the box is measured. Time required to empty the V funnel for SCC is 8-12 seconds. Low flow times indicate a lower plastic viscosity of the mix. This test provides a qualitative assessment of the SCC mix viscosity.

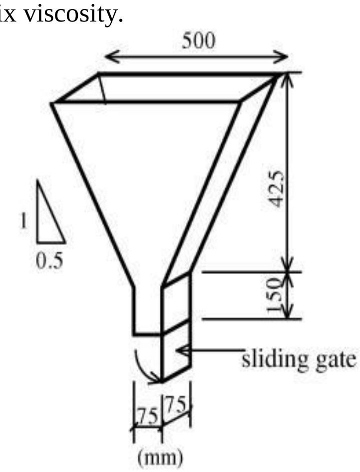

Fig.4 V Funnel Test Apparatus

B. Test Methods for Hardened Concrete Properties

Compressive Strength

Compression test develops a rather more complex system of stresses. Due to compression load, the cube or cylinder undergoes lateral expansion owing to the Poisson's ratio effect. The steel plates do not undergo lateral expansion to the some extent that of concrete, with the result that steel restrains the expansion tendency of concrete in the lateral direction. This induces a tangential force between the end surfaces of the concrete specimen and the adjacent steel plates of the testing machine. It has been found that the lateral strain in the steel plates is only 0.4 of the lateral strain in the concrete. The dimension of test specimen used was 150x150x150mm concrete cube.

Split Tensile Strength

Tensile strengths are based on the indirect splitting test on cylinders. This is also sometimes referred as, "Brazilian Test". This test was developed in Brazil in 1943. At about the same time this was also independently developed in Japan. The test is carried out by placing a cylindrical specimen horizontally between the loading specimen of a compression testing machine and the load is applied until failure of the cylinder, along the vertical diameter. The loading condition produces a high compressive stresses immediately below the two generators to which the load is applied. But the larger portion corresponding to depth is subjected to a uniform tensile stress acting horizontally. It is estimated that the compressive stress is acting for about 1/6 depth and the remaining 5/6 depth is subjected to tension. 150 mm diameter and 300 mm height concrete cylinders were used to test the split tensile strength.

Flexural Strength

Dimension of the prism (test specimen) is 100x100x500mm.The mould should be of metal, preferably steel or cast iron and the metal should be constructed with the longer dimension horizontal and in such a manner as to facilitate the removal of the moulded specimens without damage. The tamping bar should be steel bar weighing 2 kg, 40 cm long and should have a ramming face 25 mm square. The testing machine may be of any reliable type of sufficient capacity for the tests and capable of applying the load at the rate specified. The permissible errors should not be greater than ± 0.5% of the load applied where a high degree of accuracy is required and not greater than ± 1.5% of the load applied for commercial type of use.

VII. RESULT AND DISCUSSION

A. *Fresh Properties of SCC*

The fresh properties like slump flow, V funnel, U Box, L Box and T50 tests are conducted for all the mixes immediately after the mixing process and the test results are given in Table 4. The slump flow diameter for all mixes lies between 650 to 800 mm. The main purpose of adding fillers in SCC is to reduce the water powder ratio as well as to increase the flow properties. Fig.5 showed that the quaternary bended mix produce better performance in slump flow test when compared to binary and ternary blends. The water powder ration is kept constant for all the mixes and the superplasticizer content is varied while to meet the specifications. T_{50} was also conducted for all the mixes. The time taken by all the mixes to spread 50 cm diameter was also measured during slump flow test. Lower time indicates higher fluidity. This test is mainly conducted to check the viscosity of the mix.

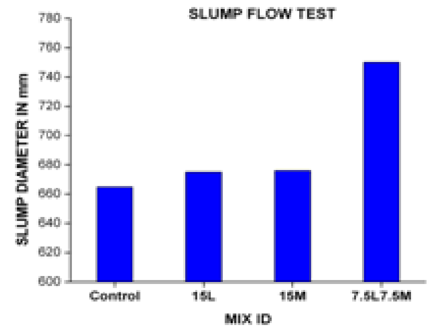

Fig.5 Slump Flow Test Results

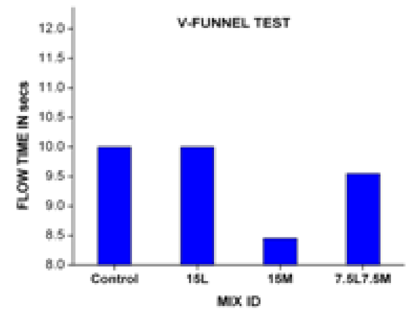

Fig.6 V Funnel Test Results

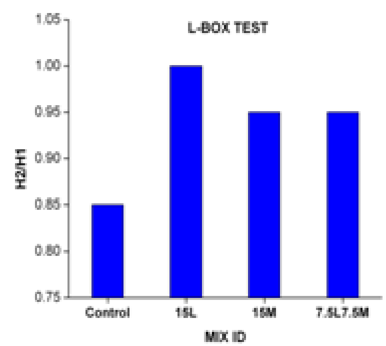

Fig.7 L Box Test Results

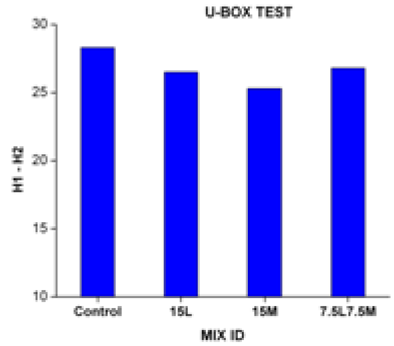

Fig.8 U Box Test Results

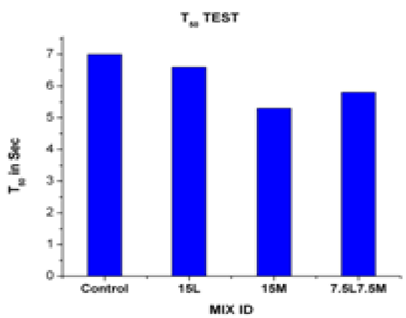

Fig.9 T50 Test Results

From Fig. 6, 7 & 8, it was cleared that compared to quaternary effect, the mix with 15 % MP produced better results in V funnel, U box and L box tests. The standard values for self compacting concrete recommended by EFNARC specification are given in Table4. All the mixes satisfy the EFNARC (European Federation of National Associations Representing for Concrete) specifications in fresh state. The workability of SCC is high when compared to the vibrated concrete. The high degree of workability is achieved by the use of finer materials and admixtures. In 15M mix, the addition of superplasticizer is less when compared to all other mixes with same water powder ratio.

B. Hardened Properties of SCC

An experimental investigation is taken up to study the hardened properties of SCC. Compressive strength, Split tensile strength and flexural strength tests are conducted for all the mixes. The Compressive strength values were taken after 7, 14 and 28 days of water curing of SCC cubes for all the mixes. Split tensile strength values were taken after 7 and 28 days of water curing of SCC cylinders. The flexural strength value was taken for all the mixes after 28 days of water curing. The test results of all the mixes were shown in Table 5 & Table 6

.

Table 5 Compressive Strength of all mixes

Mix ID	Compressive Strength N/mm2		
	7 Days	14 Days	28 Days
Control	17	23.11	25.15
15L	24.31	24.98	35.95
15M	28.93	33.67	42.4
7.5L7.5M	25.56	30.34	38.6

Table 6 Split Tensile and Flexural Strength of all Mixes

Mix ID	Split Tensile Strength N/mm2		Flexural Strength N/mm2
	7 Days	28 Days	28 Days
Control	25.15	1.65	4
15L	35.95	2.32	5.1
15M	42.4	1.89	5.58
7.5L7.5M	38.6	2.31	5.74

From the Table, it is cleared that the addition fillers increase the hardened properties of SCC. The addition of marble increases the both compressive strength and flexural strength. In flexural strength, the quaternary mix produced better results than all other mixes.

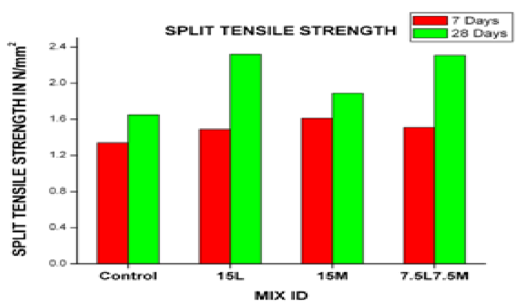

Fig.11 Test Results for Split Tensile Strength

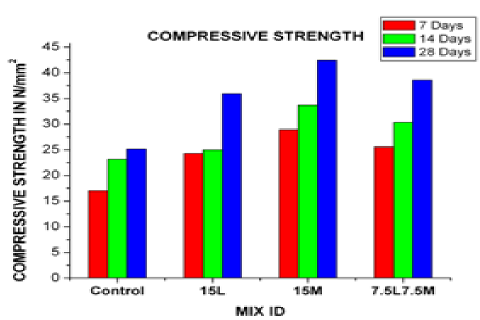

Fig.10 Test Results for Compressive Strength

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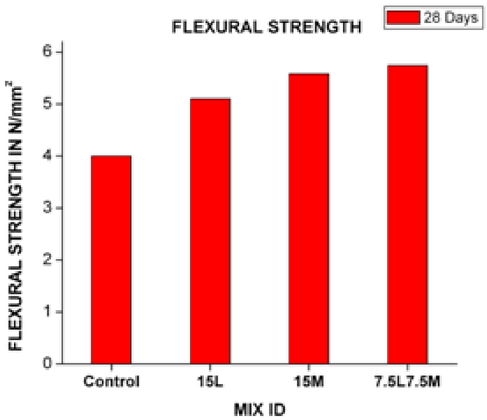

Fig.12 Test Results for Flexural Strength

VIII. CONCLUSIONS

The experimental investigations were done to determine the fresh and hardened properties of SCC incorporating with different filler materials.

From the Experimental results, it was found that all the mixes satisfied the requirements of SCC specified by EFNARC. Addition of fillers improves the fresh and hardened properties of SCC. Reduction of cement content will reduce the cost without affecting the strength considerably. Compressive strength of ternary fillers (OPC+FA+MP) is 68.5% greater than that of the control mix. While comparing this with quaternary fillers it is greater than 9.8% only. Split tensile strength of quaternary fillers (OPC+FA+MP+LP) is 40.6 % greater than that of control mix. While comparing this with quaternary fillers it is greater than 0.4% only. Flexural strength of quaternary fillers (OPC+FA+LP+MP) is 43.5% greater than control mix.

From the above discussion of test results, the addition of MP improves the fresh and hardened properties of SCC both in ternary and quaternary mixes.

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