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RHEOLOGICAL BEHAVIOUR OF THE TRIPLE BLENDED STEEL FIBER SELF-COMPACTING CONCRETE

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***Abstract*— This research paper deals with rheological behaviour of triple blended fibrous Self-Compacting Concrete (SCC) by using cement 53 grade conforming to IS: 12269-2013 is blended with supplementary cementation materials(SCM) like flyash(F-type) and condensed silica fume (CSF) at the different dosage to get good C-S-H gel in the concrete, which will enhance the strength and durability of the hardened concrete. Metallic fibres like Steel of diameter around 1mm; with aspect ratio changing from 20 to 40 at an interval of 10 were mixed to get beneficial mechanical properties at four different percentages (0.2, 0.4, 0.6 and 0.8). Required numbers of trials are made to full fill the requirements of rheological properties as per directions of EFNARC-2005 for S.C.C criteria. The mathematical equations are extracted from the experimental workability results of three blended steel fibre self-compacting concrete for flowablity, passingability, and resistance against segregation through slump cone, V-funnel and L-box tests respectively.**

Keywords— Mineral Admixtures, Chemical admixtures, Steel fiber, Aspect ratio, and rheological properties

I. INTRODUCTION

Rheological properties like flow ability will cause significant changes to solve the practical problems in the dense reinforced zones, and thin concrete structural elements, where the external compaction is too tricky. It is necessary to develop a concrete with beneficial rheological properties at the site. SCC has been used to achieve the adequate flow ability in fresh state. Some of the mineral and chemical admixtures are mandatory to fulfil the SCC criteria. The chemical admixtures like superplasticizer (B233 of M/S BASF India limited) and viscosity modifying agent (VMA) Glenium-2 are adopted in this experimental investigation. The SCM such as flyash (low calcium flyash F type), condensed silica fume or metakaolin will improve the workability in the concrete even in the lower water-power ratios. The rheological properties are severely affected when the more quantity of chemical additives are added. The apparent viscosity enhanced with the increase of the shear rate. Due to this shear thickness, and shear thinning should be carried out in the concrete. More recently, from experimental investigation, it is observed the high performance cement interruption when water to powder ratio is below 0.4. It will reveal the shear thickening behaviour.
II. Experimental results are presented in section III. Concluding remarks are given in section IV.

II. DETAILS OF THE PRESENT ARTICLE:

The current technical paper deals with the experimental investigation on the rheological properties like flow, segregation, and passing ability. The steel fibrous self-compacting concrete with the triple blending of cement with SCMs such as flyash and condensed silica fume in addition to ordinary steel wires of diameter 1mm was used in the base mix of the steel fibre self compacting concrete (SFSCC). The base mix without steel fibres is as per the **IS 10262-2013**[1] provisions. The aggregate proportions are rearranged in such a way that the ratios of fine to total aggregate is in limits; that is 0.55 to 0.64 to satisfy the needs of the SCC as per guide lines given in **EFNARC** (The European Federation of National Associations Representing for Concrete). The mixed blending indicates that the replacement of cement by flyash at 20%, and 10% of cement is by condensed silica fume in each mix.

Chemical admixtures such as superplasticizer(SP), viscosity modifying agent(VMA) are adopted for enhancement of flowability and workability. The Workability tests such as slump flow, V-funnel and L box tests were evaluated by following EFNARC-**2015**[2] directions to satisfy the SCC needs. The percentage of fiber content is taken from 0.20 to 0.80 (in four stages) of the volume of the concrete. Aspect ratio 20, 30, and 40 were used for each percentage. The rheological properties are checked from the experimental investigation.

Recommended specifications as per ACI norms –

As per specifications of ACI-237R[3] self-consolidated concrete, an excellent rheological property of the SCC should get a slump flow value crossing 600mm without separation of aggregates. The SCC should maintain the flow and self-compacting for 90 minutes. It would be able to flow in a slope of 3^0 in the horizontal surface. It can be pumpable through pipes with a length of at least 100m.

III. LITERATURE REVIEW

Okamura, H, Ouchi, M[4] reported the present and future applications of the SCC, and developed the mix design approach for the rearrangement of fine aggregate (FA) to total aggregate (TA) ratios, until the rheological properties are achieved by the SCC.

Zhimin Wua, Yunguo Zhang [5], are did the work related study on the workability of self-compacting concrete(light weight), and the conclusions of this work stated that lightweight aggregate would have more rheological properties compared to the ordinary dense aggregates.**Rahmat Madandoust, Malek Muhammad,Ranjbar&YasinMousavi, S**[6]**,** observed behaviours of the self-compacting concrete when it is in the fresh state; which contains the expanded polystyrene, and extracted the physical parameters of the self-compacting concrete.**Mahesh,Y.V.S.S.U, and Manu Santhanam** [7] are reported the easy methods for characterize rheology of self-compacting concrete.**Ganesh Babu K, and Dinakar P**[8] are examined the behaviour of the self-compacting concrete due to SCMs, such as flyash, and concluded the optimum dosages, which mainly contribute to the workability properties of the SCC." **Yahia, A, Tanimura, M.** [9] done the experimental investigation for the rheological behaviour of highly flow cement mortar containing limestone filler, and studied the affect of this powder content , w/p ratio on the experimental results..**Govindaswamy,T, Malathy R** [10] are reported mix design flow chart for various grades of SCC, and examined the influence of the fine to total aggregate ratios on the characteristic strength of the concrete. **Frank Winnefeld, Andreas Leemann**[11]are discussed the influence of viscosity modifying agents on cement mortar, fresh concrete, its contribution towards rheological properties of the concrete. **Jean-Yves Petit, Kamal Khayat** [12] are developed the yield stress and viscosity models mathematically for cement mortar and self-consolidating concrete. **Augustine,U, Elinwa, M,Mamuda**[13] are done the investigation on the fresh concrete properties of the self-compacting concrete with sawdust ash as one of the supplementary cementatious material (SCM) in SCC.**Gang Lu, Kejin Wang** [14] are discussed the rheological behaviour of highly flow-able cement mortar using the concept of fluid mechanics.

IV. EXPERIMENTATION

Materials adopted:

Ordinary Portland cements (53 Grade): Ordinary Portland cement is used and examined the physical and chemical parameters in accordance to **IS: 10269-2013**[14].

Fine Aggregate (FA|): In the present investigation, sand from zone –II is used as fine aggregate. The physical parameters of combined fine aggregate like specific gravity, gradation curve, fineness modulus(FM),and bulk density are examined in accordance to IS-2386 part-1 reaffirmed 2016, its specific gravity and the fineness modulus are 2.64, 2.82 recorded respectively.

Coarse Aggregate (CA): The granite aggregate of maximum size 12mm is adopted. The physical properties of CA like specific gravity, bulk density, gradation, and fineness modulus are examined as per the specifications **IS-2386**[15]. The specific gravity and the fineness modulus are 2.60, 5.48 recorded respectively.

Fly ash: In this experimental work, the low calcium fly ash such as F-type used as a one of the partial replacement to cement material; which is collected from Vijayawada thermal power plant station (VTPS), Andhra Pradesh. The specific surface area of fly ash is found nearer to a value of 4750 cm^2/gm.It is approximately equal to 53 grade of the cement particle fineness.

Condensed Silica Fume (CSF): CSF collected from M/s V.B.C Ferro Alloys Ltd (Vizag Bottling Company) Rudraram, nearer to Hyderabad in India. Its fineness was recorded double that of the fly ash; its magnitude is examined by Blane's apparatus and found 10,000cm^2/gm.

Viscosity Modifying Agent (VMA):

The addition of VMA at optimum dosage causes to minimise the property of the highly fluid mix to separation. Glenium-2 used as VMA of make M/s. BASF INDIA Ltd. is adopted in this work.

Superplasticizer: Superplasticizer in this investigation is B233 of M/s. BASF India Ltd was employed here.

Steel Fibres: Mild steel fiber of 1mm diameter used at various aspect ratios of 20, 30, and 40. Percentage of steel fibers varied from 0.20 to 0.80 in four stages.

Water: Ordinary potable water used for concrete making.

Mix Design for concrete: The M40 grade of the concrete is designed as per provisions of IS 10262-2009[16]. The detail of the essential mix is presented in table 1 and the design mix for SCC employed in this work is shown in table 2. SCMs such as flyash and CSF are used as replacement to cement at optimum percentages of 20 and 10 respectively to achieve triple blending. The water / binder ratio is maintained at 0.45.

Table.1 Concrete Mix Proportions for M40 (OCC)*

Sl. No.	Grade	Cement	Fine Aggregate	Coarse Aggregate	Water/ Cement
1	M_{40}	1	1.38	2.4	0.45

Table.2 Concrete Mix Proportions for M40 (SCC)**

Sl. No.	Grade	Cement	Fine Aggregate	Coarse Aggregate	Water/ Cement
1	M_{40}	1	2.22	1.3	0.45

***OCC- Ordinary cement concrete**
****SCC-self compacting concrete.**

Optimum Dosages of Chemical Admixtures used: By gradually increasing the dosages of superplasticizer and VMA by trial, the final dosages of 1.0 and 0.15 were arrived to achieve the final triple blended fibrous self-compacting concrete mix for the percentage of steel fibers up to 0.4. The percentages of steel fibers are 0.6 and 0.8, the superplasticizer is 1.2 and VMA is 0.2 used to fulfil the requirements of SCC

Workability Tests: Workability tests as per the EFNARC-2015[1] specifications such as flow(|Slump cone), V-Funnel(Passing ability) and L-Box (segregation resistance) were done and results for typical cases are shown in tables 4 to 6.

Table.3 Quantities of Materials required with Mineral Admixtures
(20% Fly Ash and 10% CSF)

Sl. No.	Materials required	Quantities in Kg. per m^2 for M_{40}
1	Cement	344
2	Flyash	95
3	CSF	48
4	Fine	1082
5	Coarse	634
6	Water	216

Table 4.Typical workability results for admixture SCC (20% flyash ,10% CSF) with steel fibers only at maximum aspect ratio.

% of steel fiber	% of SP	% of VMA	Slump flow in mm		V-funnel Passing ability in sec		L -BOX H2/H1	
			Experiment	Limits#	Experiment	limits	Experiment	Limits#
0.0	1	0.1	690	650 - 800	8	6-12	0.90	0.8-1.0
0.2	1	0.1	660		10		0.90	
0.4	1.1	0.1	660		10		0.92	
0.6	1.2	0.2	660		10		0.92	
0.8	1.2	0.2	650		12		0.95	

 # asper the guidelines of the EFNARC-2005

Flow requirements: Some trials are made for getting the rheological requirements for the FTSCC (Fibrous Triple blended Self Compacting concrete) like flow, passing, and resistance of segregation, for various percentages of steel fibres to the different dosage of the SP and VMA for the maximum aspect ratio (40).These tests are performed as per the recommendations of the EFNARC and ACI[17].

V RESULTS AND DISCUSSION:

Workability Results: In this investigation, M40 concrete mix was designed. It can be observed that superplasticizer (Glenium B223) varied from 1.0 to 1.2% percentages and Viscosity Modifying Agent (Glenium 2) adopted in the investigation to maintained at 0.10 to 0.2%,because of variation in the percentages of steel fibre and aspect ratio.

Flow Ability: The concrete with triple blending (flyash 20% & CSF 10%) and 0.8 percentage of steel fibre are critical for the rheological properties. The mineral admixtures like CSF contribute towards enhancement in flow properties, because of the silicate reaction with CH (|calcium hydrate). The requirement of the flow was decreased with the increased percentage of steel fibre. The FTSCC can satisfy the recommendations of ACI and EFNARC with the use of SP and VMA at 1.2 and 0.2 % respectively for 0.8 percentage of steel and maximum aspect ratio 40. As percentage of fiber content increased the flow diameter of the SCC is reduced due to interference of the fiber content and its aspect ratios. The variation of slum flow value is shown in fig 1.

The regression equation for the experimental value is extracted as

$$y = -27.23\ln(x) + 694.08 \text{----------------------} (1)$$

y= slump fall in mm,
x= percentage of steel fiber

Passing Ability: With the same concrete mix the passing ability with the V-funnel was carried out as per the standards are given by EFNARC and ACI, the variation of passing ability in seconds is measured in time and plotted in the fig 2.the mathematical equation is generated and checked the validity of the experimental values.

$$y = 3.0887x^{0.3192} \text{---} (2)$$

y= passing ability in seconds,
x= percentage of steel fiber

Segregation Resistance (With L – box): With the above concrete mix, did the experimental work for studying the segregation ability by performing the L- Box test as per the provisions of the EFNARC. The variation is studied and plotted in fig 3, the expression for the passing ability is developed and checked the validity with the experimental work.H2 is the head of the concrete in the horizontal limb of the L box before flow; H1 is the head of the concrete in the vertical limb of the L- box. H1 and H2 are the level of the concrete in vertical and horizontal limbs after the flow is stoped.

$$y = 0.0283\ln(x) + 0.8949 \text{--------------------} (3)$$

y= head of the concrete (H2/H1),
x= percentage of steel fiber
The mathematical models for slump fall, passing ability and segregation resistance are represented in the equations (1), (2), and (3).The percentage of error from the experimental value and the mathematical equation is observed as R^2=0.98, a statistical measure that determines the proportion of variations (flow, passing and segregation in this work) in the dependent variation (percentage of fiber content) that can be examined.
Hence the above equations may be used for the above properties as long as fiber content in the SCC is limited to 0.8 percentages.

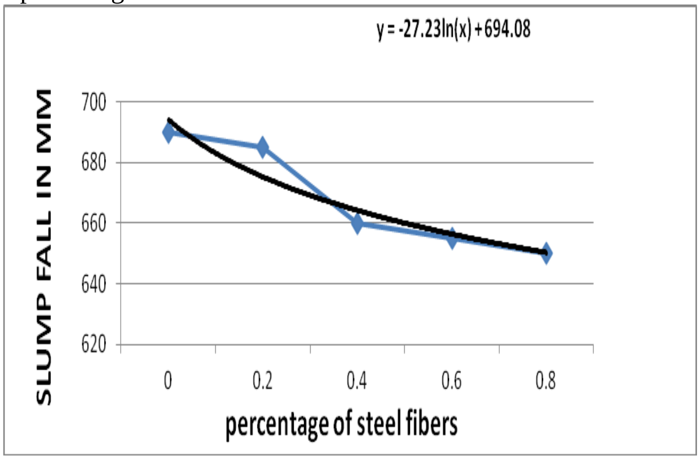

Fig 1.The variation of slump fall values with different percentages of steel fiber of aspect ratio 40

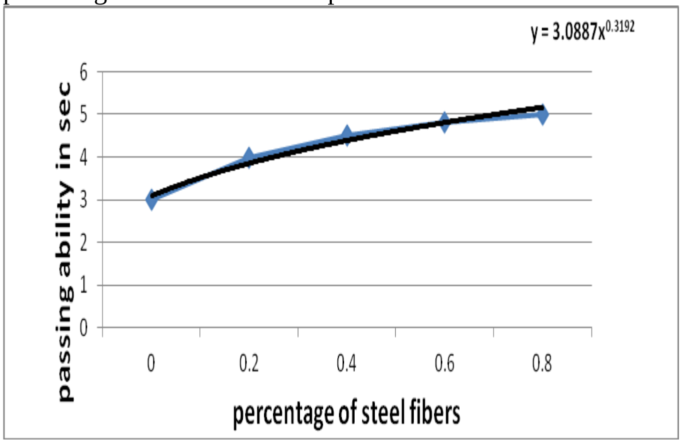

Fig 2. The variation of passing ability with the with different percentages of steel fiber of aspect ratio 40

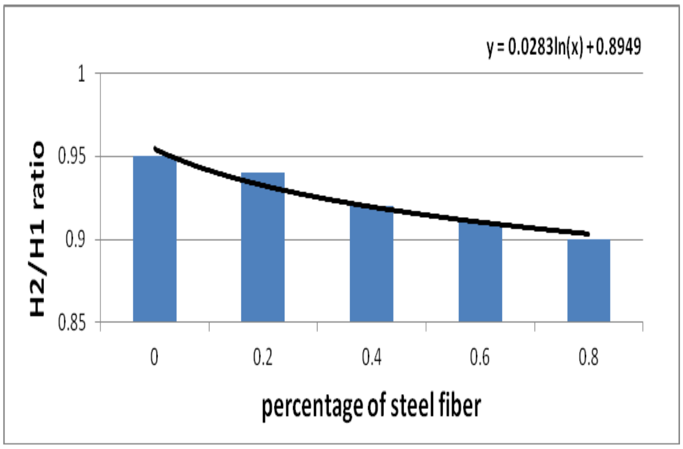

Fig 3. The variation of H2/H1 with the with different percentages of steel fiber of aspect ratio 40

V. CONCLUSIONS

The following conclusions are drawn from the laboratory experimental investigation,

1. The maximum percentage of superplasticizer is 1.1, and the VMA is 0.1 respectively for the mass of cement, for the percentage of steel fiber up to 0.4 for volume of the concrete. Later for 0.6 and 0.8 the optimum dosage of SP and VMA are 1.2 and 0.2 % respectively, to fulfill the recommendations of the rheological behavior of the Self-compacting concrete.
2. The concrete mix with these blending (cement, flyash and silica fume) will have better flowability properties compared to the same concrete without SCMs.
3. The optimum steel fiber observed with 0.80% and an aspect ratio of 40 with muti blending. The slump fall is changed from 690mm to 650mm, due to the presence of the fibers, beyond this percentage of the steel fibers; there is interference of the flow properties of the SCC.
4. The ability of passing for the self-compacting concrete noted in seconds is increased from 8 sec to 12 sec in the V-funnel test for 0.8percentage of steel fiber with the maximum aspect ratio of 40. Steel fiber takes more time to vacant the V-funnel due to its density of the material is gradually increased with the enhancement in the percentage of steel fibers.
5. The L- box apparatus clearly indicates that there is a fall of H2 to H1 value for the concrete from 0.95 to 0.92, due to higher percentage of fiber content.
6. In field, SCC with steel fibers in the concrete helps in maintaining required rheological properties, up to percentage of fiber and aspect ratio are 0.8 and 40 respectively.

VI. ACKNOWLEDGEMENTS

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