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An experimental study on flexural behavior of RC beams of Alccofine-based engineered concrete infusing steel fibers

A. Muralidhar*[*1] and Sunil Kumar Tengli[2]
[1] Research Scholar, School of Civil Engineering, REVA University, Bengaluru, Karnataka, India
Associate professor, Department of Civil Engineering, APS College of Engineering, Bengaluru, Karnataka, India
[2] Professor, School of Civil Engineering, REVA University, Bengaluru, Karnataka, India

Abstract

The innovations in concrete being engineered to the specific requirements have found a new dimension under sustainability. Alccofine is a sustainable construction material derived from GGBS. The primary objective of the study is to explore the potential of Alccofine particles in varying proportions in combination with 0.5% steel fibers to uplift the flexural strength of the engineered concrete. As concrete is known to be a brittle material once hardened, exhibits remarkable resistance to compressive stress, whereas, the ductility of concrete is comparatively low. The study is mainly focused on arriving at an optimum combination of Alccofine with constant steel fiber (0.5%) for the M70 grade of concrete based on the flexural behavior of RC beams. The experimental analysis on load vs deflection and the stress-strain graphs fetches the critical parameters such as ductility index and relative stiffness of the combinations. Based on these crucial flexure parameters, the 10% Alccofine with 0.5% steel highlights to be an effective combination of engineered concrete. Both under-reinforced and over-reinforced sections were implemented to these varying combinations. The results depict the extended deflection range for over-reinforced sections compared to under-reinforced sections. The overall observations through experimental analysis conclude that up to 10% Alccofine replacement to cement and the addition of 0.5% steel fiber enhances Young's modulus of the engineered concrete, thereby contributing to the ductile behavior of concrete. The fineness and uniformity of Alccofine particles play a significant role in the densification of microstructure of concrete thereby arresting the crack propagation through it effectively. The results of the experimentation on fresh and hardened properties were also positive for these combinations.

Keywords: *Alccofine, flexural behavior, ductility, steel fibers, sustainability.*

Author for Correspondence: A. Muralidhar*

INTRODUCTION

In the current intensity of global infrastructural development, the ecological balance is the need of the hour which amplifies the focus of research work towards sustainability. The implementation of sustainable materials in the field of construction practices is a major step that can have a huge impact on restoring the environmental balance. The use of supplementary cementitious materials which are especially industrial slags is a novel approach for sustainable construction materials. The materials like fly ash and GGBS have already passed through the codal provisions and appeared in the practice application range. This accelerated development in this field has motivated numerous such SCMs to enter the market with precise standardization. Alccofine is one such remarkable SCM (1) which is well-known for its ultrafine particle size promoting prepacking and densification of micro structure. The study is mainly about the proportion of replacement required to effectively blend with cement to contribute as a cementitious material, beyond which it will just act as a filler. The ultrafine particles will not only contribute to strength enhancement (2) but also reduce the heat of hydration. The main focus of the study is to check the compatibility of 0.5% steel fibers with Alccofine particles of varying proportions in enhancing the ductility thereby, the flexural properties of the concrete (3). The materials Alccofine available in India are Alccofine 1203 and Alccofine 1011. The former one has low calcium silicate content and is used in high-performance concrete, later one has high calcium content and has application as a grouting material. The role of Alccofine in the construction sector is prominent in its contribution to flowability because of the particle fineness and uniformity. This finer particle enhances the durability of concrete by its densification tendency of concrete microstructure and resistance to permeability. As Alccofine is a cementitious material it can assure promising results through primary hydration of 28 days. Many of the previous research articles have corresponding studies on these structural properties. Perhaps the study on the flexural behavior of Alccofine is limited and also some of the research works shared the observation that individually Alccofine alone isn't able to enhance the flexural strength of the concrete (3,4). keeping given these inputs from the literature, the study is formulated to introduce steel fibers in combination with Alccofine to address the research gap and arrive at a feasible solution.

The fundamental concept of reinforced concrete lies in the fact that concrete that is weak in carrying tensile stresses is counteracted by introducing reinforcing bars. Keeping this fundamental logic in consideration, the steel fibers were introduced into the concrete which will enhance the ductility of concrete at the micro level, thereby arresting the crack propagation. The concrete sections that demand sufficient tensile strength wouldn't be balanced by over-reinforced sections as they pose higher deflection issues. To fulfill this structural demand for tensile strength, the infusion of steel fibers would suit to be an effective remedy (4). For the present study, the crippled steel fibers are implemented. These fibers pose a three-dimensional arrest of macro crack propagation by acting as a bridge to transfer the tensile stresses through cracks. Hence, through experimentation, the study has come up with encouraging results through load deflection and stress-strain analysis of the RC beams with Alccofine and steel fibers. The role of shear-resisting rebars was also been shared by these steel fibers. Along with these structural properties, the flowable self-compacting concrete was also achieved by adding, the Master Glenium sky 8233 superplasticizer to the concrete mix, similar to previous studies by El Dieb (5). These polycarboxylate ether-based polymers have a remarkable tendency to disperse the coated cement particles to achieve a higher grade of flowability and meanwhile, profoundly reduce the water-cement ratio. The combination of Alccofine and fly ash holds good for the performance of the concrete (6). Many studies have repeatedly explored the mechanical properties of Alccofine-based concrete mixes giving an overview of its percentage replacements to be an optimum combination with cement (7,8). The durability properties in contribution with densified microstructure were also explored for Alccofine-based mixes in combination with GGBS (9), fly ash (8), microfibers (10), and also as a geopolymer concrete mix. The ultrafine particle size of Alccofine has made it possible to achieve self-compacting concrete (11). These Alccofine-based mixes hence stay successful in achieving the durability of concrete (12).

ARTICULATION OF MATERIALS

OPC grade 53 is adopted throughout the research work. Locally available fine aggregates conforming to zone II as per IS 383 2016 are used. coarse aggregates of 10 and 12mm size were used. Alccofine as an SCM of varying percentages from 0,5,10,15% is implemented with 0.5% steel fibers to assess the effect of these mineral admixtures on strength properties. To obtain self-compacting concrete 1% dosage of Master Glenium Sky 8233 plasticizer is used. 30% fly ash is replaced with cement in the concrete mix.

The specific gravity of Alccofine lies between cement and fly ash. Whereas, the bulk density is remarkably low compared to cement and fly ash which indicates its compact ability and void-filling ability. Similarly, the fineness of Alccofine particles as given in Table 1, is also significant compared to cement and fly ash. The coarse aggregates and fine aggregates fill up the major volume of concrete, whereas, these three as a novel combination with varying particle sizes from fine to finer, finer to finest (cement to fly ash, fly ash to Alccofine) create an excellent combination for densification of pore structure. Meanwhile, the fineness of Alccofine is attributed to accelerated pozzolanic reactions. The fineness of Alccofine particles also increases the specific area of the matrix. This can demand comparatively more dosage of chemical admixtures to promote the self-compacting concrete. One more observation from the morphological characterization is that the Alccofine particles are irregular in shape. This could have affected the flow properties. But, because of its ultrafine particle size, it might have a negligible impact on the flow hindrance by its surface morphology. Applying fly ash in the mix can balance this minor hindrance by its spherical particle morphology.

Based on these preliminary material characteristics the percentage of replacements can be investigated to arrive at optimum replacements. The results of the physical and chemical characterization of cement, fly ash, and Alccofine 1203 are given in Tables 1 and 2 respectively. The physical characterization of aggregates is tabulated in Table 3 and the properties of superplasticizer Master Glenium 8233 are given in Table 4.

Table 1: Physical Properties of Cement, Fly ash, Alccofine-1203

Physical properties	**Specific gravity**	**Bulk density, gm/cc**	**Fineness**		
Cement	3.12	1.11	6.50%		
Fly Ash	2.23	1.6	360m^2/kg		
Alccofine	2.88	0.68	**D10**	**D50**	**D90**
			1.5	4.5	9

Note: Cement - IS 12269: 1987, Fly ash [class F] - ASTM C 618

Table 2: Chemical Properties of Cement, Fly Ash, Alccofine-1203

Chemical compounds	**Chemical composition by mass (%)**		
	Cement	**Fly ash**	**Alccofine**
SO_3	-	1.35	0.12
SiO_2	21.3	62.63	35.60
Al_2O_3	4.5	23.34	21.40
Fe_2O_3	4.0	3.93	1.30
MgO	2.4	0.46	7.98
CaO	63.1	2.04	33.60
SO_2	2.2	-	-
Loss on ignition, % by mass	0.39	0.3	0.58

Table 3: Properties of Coarse and Fine Aggregates

Ingredients	**Coarse aggregates**		**Fine aggregates**	
Properties	Gradation	Specific Gravity	Gradation	Specific Gravity
Values	10 mm	2.7	Zone II	2.6

Table 4: Properties of Master Glenium 8233 (Superplasticizer)

Form	**Specific gravity**	**pH**	**Solid content**	**Relative density**	**Chloride content**	**Dosage**	**Aspect**	**Chemical type**	**air entrainment**
Viscous liquid	1.08	>6	>32%	1.08 ± 0.02 at 25° C	<0.2%	250 - 750ml/ 50kg of binder	Reddish brown liquid	Modified polycarboxylic ether	<1% at normal dosages

EXPERIMENTAL PROGRAM

The flexural strength test using loading frame is conducted to analyse the behavior of RC beams at tension and compression zones upon using Alccofines in combination with steel fibres. The impact of steel fibre addition on the flexural behaviour especially in the tension zone of the RC beam was examined. The length of the beams was measured and divided equally into three parts (L/3) before placing the beam specimen into the loading frame to apply two-point loading. The beam was painted in white to enhance the visibility of crack propagation and identify the fractures on the beams as shown in Fig 1. The position of the hinged and roller supports in the loading frame was modified based on the length of the beam specimen and then the beam was placed. To calculate the capacity of the simply supported beams, a two-point loading condition was used. capacity of the hydraulic jack is 500kN. With the use of an I-section steel spreader, the load is progressively imparted to the beam and transmitted to the beam specimen. To monitor the strain deviation during loading, two surface strain gauges of linear and lateral design with a 5 mm gauge length were installed on the concrete surfaces of all beams. Using an LVDT (Linear Variable Differential Transformer), the mid-span deflection was detected. A load cell was used to calculate the load after it was applied by the hydraulic jack in 10kN increments. At each load increment, observations such as surface strain, deflections, and fracture propagation on the face of the beam were recorded. The initial crack load, final crack load, kind of failure, load-bearing capability, load-deflection response, first diagonal crack load, strain development, energy absorption, ductility index, crack formation and propagation, and failure modes were carefully monitored and tabulated. The loading frame setup is as shown in Fig 2. The flexural strength at the micro level gets enhanced in the concrete matrix because of the steel fiber addition which can influence the crack propagation, crack dimensions, and also the mode of failure. This in turn indicates the strengthening of the tension zone by crack arrest at the micro level. The ductility of the concrete matrix is also a parameter related to the tensile stress-carrying tendency of the matrix.

Fig 1: The Cast Beams are Painted White and Ready for Testing

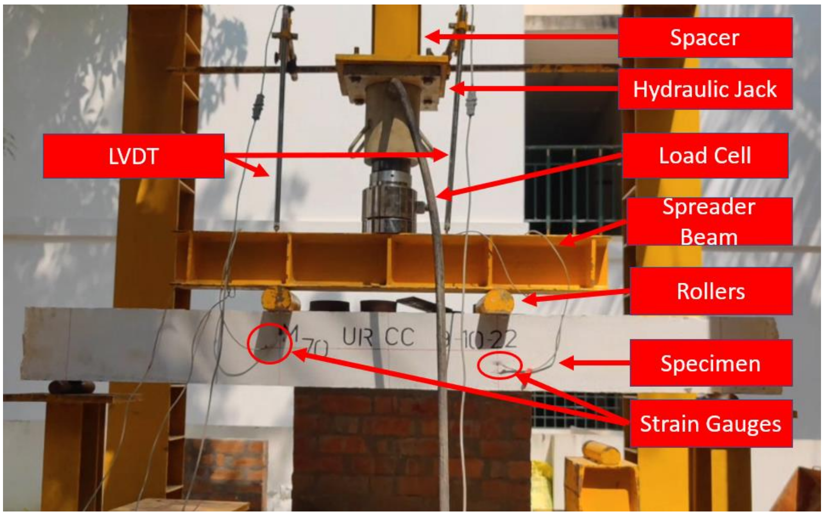


Fig 2: Loading Frame Set Up for Testing RC Beam

MIX DESIGN OF CONCRETE AND REINFORCEMENT DETAILING

Table 5 indicates the mix proportion of M70 grade of concrete with varying dosages of Alccofine from 0,5,10,15% in the mix and steel fiber (0.5%), fly ash (30%), superplasticizer (1%), water to cement ratio (0.25) were maintained constant.

Table 5: Mix Proportioning [Mix Design as per IS 10262-2019 (13)] for Alccofine-based Self Compacting Concrete.

Ingredients	M70 Grade of concrete			
% of Alccofine	**0%**	**5%**	**10%**	**15%**
Cement (C)	546	518.7	491.4	464.1
Fly Ash (F)	228	228	228	228
Alccofine (A)	0	27.3	54.6	81.9
Water Content	195	195	195	195
Fine aggregate	700	700	700	700
Coarse aggregate	685	685	685	685
SP (1%)	7.6	7.6	7.6	7.6
Free W/C ratio	0.25	0.25	0.25	0.25
steel fibers (0.5%)	3.87	3.87	3.87	3.87

Note: All the values of weights are in kg/m^3

The reinforcement detailing of the beam is shown in Fig 3.

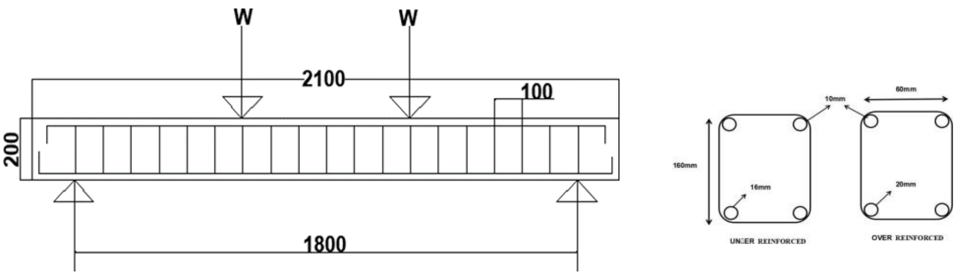


Fig 3: Reinforcement detailing of RC beam

Steel details	Top steel bars	Bottom steel bars	Stirrups
Under reinforced beam	2#10mm dia bars	2# 16 mm dia bars	8mm dia @100 mm c/c spacing
Over reinforced beam	2# 10mm dia bars	2#20 mm dia bars	8mm dia @150 mm c/c spacing

RESULTS AND DISCUSSION

The experimental results on fresh properties of self-compacting concrete and flexural analysis of the RC beams are discussed in the following sections. The load-deflection behavior and load-cracking behavior of RC beams are analyzed through experimental results.

Fresh Properties of Concrete

The fundamental fresh properties of self-compacting concrete were explored through experimentation under EFNARC guidelines. It is indeed necessary to study the flow properties of Alccofine-based mixes to assess their contribution in carrying the concrete matrix through the reinforcement cage practically (14,15) Table 6 brief about the results of the tests on fresh properties.

Table 6. Test results on Flow properties on M50 Grade SCC

Flow properties tests	Proportion of Alccofine replacements				Standard values	parameter
	0A+F	**5A+F**	**10A+F**	**15A+F**		
V Funnel test (secs)	11	9	8	8	6 to 12 secs	Filling ability
U Box test (mm)	23	25	27.9	28.6	0 – 30mm (H_2-H_1)	Passing ability
L Box test (mm)	0.8	0.8	0.94	0.99	0 .8–	Passing ability

		9			1mm(H_2/H_1)	
Slump flow test (mm)	700	740	770	780	650-800mm	Flowability

Note: The standard values were as per EFNARC guidelines.

It is observed from the results that as the dosage of Alccofine increases the time taken for the concrete to flow from the V-funnel decreases which shows good flowability. Similarly, the ratio of the passing ability of concrete through the reinforcement in the L-box horizontally was increasing. Even the U box test also indicates the remarkable passing ability of this engineered concrete. slump flow test being the prominent flow test method also depicts encouraging results for these mixes which are introduced with ultrafine Alccofine particles.

Load Vs. Deflection Behavior Study

The flexural properties of Alccofine-based mixes in combination with steel fibers are the main focus of this study. As the steel fibres help enhance the ductile behavior of the concrete at the micro level it in turn improves the flexural property of concrete (16). The load vs deflection behavior of SCC beams with two distinct mixtures and reinforcements is depicted graphically in Fig 4. The beams are rigid and uncracked before loading. The tension zone of the beam fractures when the induced load is increased, causing the beam to bend. The formation of new cracks and enlargement of existing cracks are caused by the continued increase of load. According to test results, the beams with steel-reinforced have deflection behavior which is highly parallel to the loads, demonstrating beam stiffness.

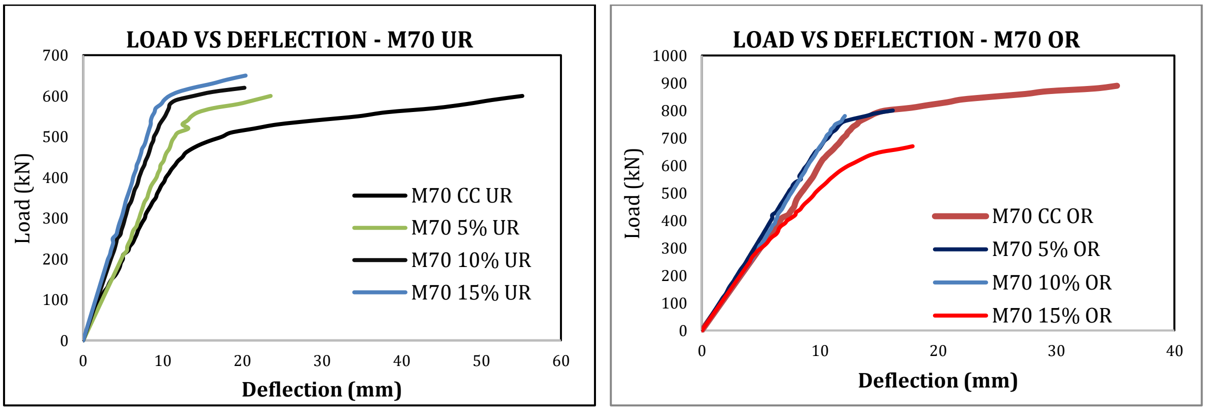
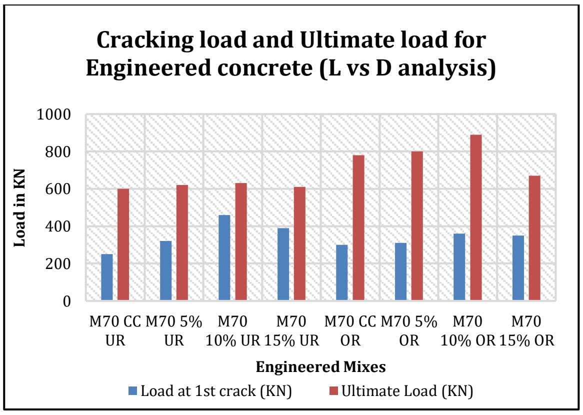


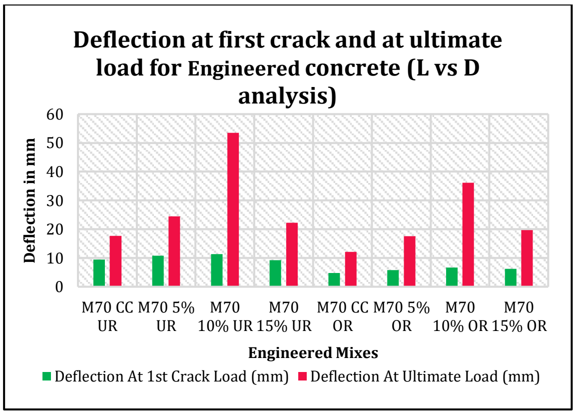
Fig 4: Load Vs Deflection Analysis of Under-Reinforced and Over-Reinforced Sections

Table 7. Outputs from Load vs. Deflection analysis at First Crack and Ultimate Load

Beam label	Load (KN)		Deflection (mm)		Moment (KN-m)	
	1st Crack	Ult. Load	1st Crack	Ult. Load	1st Crack	Ult. Load
M70 CC UR	250	600	9.5	17.67	101.3	243.0
M70 5% UR	320	620	10.8	24.44	129.6	251.1
M70 10% UR	**460**	**630**	**11.36**	**53.49**	**186.3**	**255.2**
M70 15% UR	390	610	9.28	22.25	158.0	247.1
M70 CC OR	300	780	4.81	12.11	121.5	315.9
M70 5% OR	310	800	5.81	17.57	125.6	324.0
M70 10% OR	**360**	**890**	**6.64**	**36.2**	**145.8**	**360.5**
M70 15% OR	350	670	6.22	19.66	141.8	271.4



(a)



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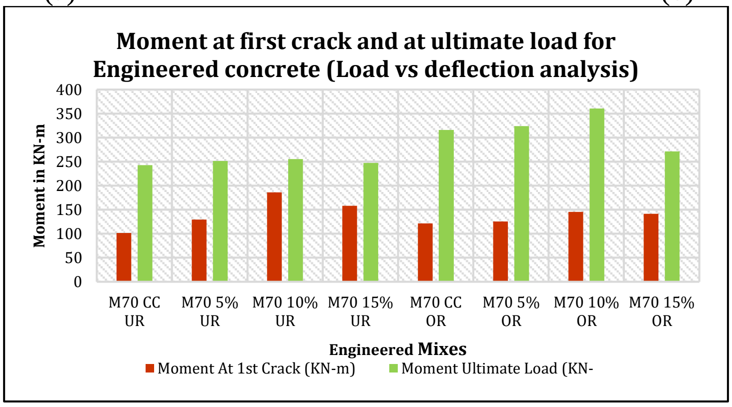

(c)

Fig 5: Load Vs Deflection Analysis a) Cracking Load and Ultimate Load For Engineered Concrete b) Deflection at First Crack and Ultimate load c) Moment at First Crack and Ultimate Load

It can be observed from the above test results tabulated in Table 7 and the graphs plotted in Fig 5 a), 5 b), 5 c), corresponding to the reading given in Table 7 for M70 grades that there is an increase in the ultimate strength as well as the deflection at ultimate load up to 8-10% for both under reinforced and over reinforced sections which indicate the increase in flexural properties of SFRSCC due to the addition of Alccofine and steel fibers into the concrete. it is also observed that it is maximum when 10% of Alccofine is added to the mix and declining flexural characteristics are observed at 15% Alccofine replacement. One more observation is that the ultimate load-carrying capacity for over-reinforced beams is higher than the under-reinforced beams, but the deflection characteristic of the beam is less due to the reason that concrete yields earlier than steel in under-reinforced sections. Thus, under-reinforced sections are preferred in structures.

Analysis of Load-Cracking Behavior

Smaller fractures first become apparent in the zone of continuous moment. Crack develops depending on the type of reinforcing used and the strength of the concrete. When it comes to loading, flexural cracks are often formed perpendicular. At the bottom of the beam, fractures initiated to propagate with an increase in the applied load. Old cracks became larger and new cracks were formed with the incremental stress. The fractures are distant from the flexural zone and become inclined as the load on the beam increases, and these cracks slowly spread to the point on the compressive zone in the beam. The results of load vs cracks are given in Table 8. It can be seen from the results that, the cracks that are present or formed after the loading phase of the beam is completed, the crack width fall expanded into several cracks, and also the length of the cracks extended. It is observed that the number of cracks varies from 10-20 numbers and the length of cracks is more than the half width of the beam sections. It is also noticed that the maximum crack width of the beam was 2mm for the M70 grade of concrete. The crack propagation of the beam sections was observed to be low due to the addition of steel fibers which act as a bridge to transfer the tensile stresses generated in the beam section. The crack patterns of the failed RC beams are shown in Fig 6.

Table 8: Crack Details of the RC Beam Section Tested for Flexural Behavior

Beam label	Ultimate load (kN)	Deflection (mm)	Max. crack Width (mm)	Max. crack length (cm)	No. of cracks
M70 CC UR	600	17.67	5	19	16
M70 5% UR	620	24.44	2	17	**9**
M70 10% UR	**630**	**53.49**	2	14.5	10
M70 15% UR	610	22.25	2	**14**	20
M70 CC OR	780	12.11	2	18	20
M70 5% OR	800	17.57	2	18	12
M70 10% OR	**890**	**36.2**	2	17	11
M70 15% OR	670	19.66	**1**	**8**	**9**

Fig 6: Indicates the Crack Pattern and Details of the Beams Tested under Loading Frame

Post Cracking Stiffness and Ductility Factor

The primary parameters that affect the shear resistance of concrete in concrete members from Vdc (shear resistance at the development of an angled crack) to Vu (ultimate shear resistance at peak load) are the aggregate interlock mechanism, dowel action of the reinforcement, and uncracked compression zone". In the current experiment, Vdc has been defined as the shear load at the initial diagonal fracture. The amount of Vdc was determined by visual observation while testing beams. Peak shear load Vu is the greatest weight that a beam can bear before failing. The SRF is defined as the ratio of the failure load to the load at the first diagonal fracture. Concerning this, post-cracking shear resistance and ductility were quantified as ductility factor (DF). The ratio of the deflection at the final load to the deflection at the load due to the first diagonal crack is known as the DF. The flexural behavior of Self Compacting Concrete with steel fibers is crucial to analyze, as these fibers hinder the flow properties of the concrete. An intense focus study is necessary to formulate the combination of steel fibers without compromising the flow properties of concrete (17).

Stiffness of engineered concrete mixes: Stiffness is considered to be the ability of a material to resist elastic deformation by an applied force. This is generally termed as force per unit deflection.

Table 9: Stiffness of Engineered Concrete Mixes

Beam Label	Load at 1st Crack (kN)	Deflection at 1st Crack Load (mm)	Stiffness (kN/mm)
M70 CC UR	250	9.5	26.3
M70 5% UR	320	10.8	29.6
M70 10% UR	460	11.36	40.5
M70 15% UR	390	9.28	42.0
M70 CC OR	300	4.81	62.4
M70 5% OR	310	5.81	53.4
M70 10% OR	360	6.64	54.2
M70 15% OR	350	6.22	56.3

From Table 9 consisting of test results data, it can be observed that the stiffness of the beam considered for the load and deflection at first crack indicates the formation of fractures during the loading of the beams. There it is showing abrupt shifts in the load-deflection curves. All categories of beams showed a reduction in beam stiffness as soon as an inclined or diagonal fracture was formed. Brittle failure was noticed in all the beams at maximum shear force. The stiffness is increasing at a rate of 10-15% from CC to 5% and 5% to 10%, indicating high stiffness results for 10% dosage of Alccofine in the mix with steel fibers and has reduced significantly for 15% dosage as the addition of 15% Alccofine makes the concrete brittle which reduces the load bearing capacity and thereby reduces the stiffness of the beam.

Ductility factor of engineered concrete mixes: From test results shown in Table 10 similar trend is observed for ductility factors also. The increment between 20-35% from cc to 5% and from 5% to 10% is observed. Amongst the combinations, it is higher for 10% and finally, it falls short for 15% this is also due to the increase in brittleness of concrete. The presence of steel fiber contributes to the enhancement of the ductility of the beam. It is observed that every fracture development in all categories of beams is due to flexural failure.

Table 10: Ductility Factor of Engineered Concrete Mixes

Beam Id	Deflection at 1st Crack Load (mm)	Deflection at Ultimate Load (mm)	Ductility Factor
M70 CC UR	9.5	17.67	1.9
M70 5% UR	10.8	24.44	2.3
M70 10% UR	11.36	53.49	4.7
M70 15% UR	9.28	22.25	2.4

M70 CC OR	4.81	12.11	2.5
M70 5% OR	5.81	17.57	3.0
M70 10% OR	6.64	36.2	5.5
M70 15% OR	6.22	19.66	3.2

CONCLUSIONS

From this experimental study, it is noticed that there is an improvement in fresh state properties of Self-compacting concrete with the increase in dosage of Alccofine. This may be due to the ultra-fine particle size of Alccofine so that the flowability and passing ability of the concrete is enhanced thus resulting in improved self-compacting properties of SFRSCC mix. The experimental results on various mechanical properties of SFRSCC like compression strength, flexural strength, and split tensile strength have increased from CC-5%AF-10%AF giving a max strength enhancement for 10% dosage of Alccofine added SFRSCC mix, and a loss in significant strength is seen for 15%AF. Thus, concludes to optimize, a 10% dosage of Alccofine as an effective replacement for cement. Based on the flexural behaviors like crack details, deflection values, and load characteristics, it is observed that a similar trend was followed by experimental values as they increased to 10% Alccofine dosage and decreased to 15% Alccofine Dosage. All the beam sections exhibit a flexural mode of failure.

The conditions of reinforcement such as under-reinforced and over-reinforced beams were analyzed through experimentation resulting in higher load-carrying capacity in over-reinforced sections compared to under-reinforced sections. In contrast, the deflection characters are vice versa resulting in less deflection in under-reinforced sections, because of the prior yielding of concrete earlier to steel. Thus, under-reinforced sections are often preferred in construction. In this research study, the ductility factor was analyzed for Alccofine-based self-compacting concrete under stress. To counteract the beam deformations and thereby limit cracking, the flexural stiffness of fiber-reinforced SCC beam specimens is enhanced by introducing steel fibers. The performance and flexural capacity of the SCC beams have been significantly improved by the addition of steel fibers. Despite the drawbacks of steel fibers, such as their weight and susceptibility to corrosion, steel fiber remains an important material that improves the flexural stiffness and ductility of reinforced Self-compacting concrete beams if taken care of these limitations. The overall research work concludes that the 10% dosage of Alccofine suits to be an optimum combination with 0.5% steel fibers for superior performance in both fresh properties and hardened properties.

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