Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Volume 13, Issue 01 January 2024

Investigation of The Strength and Durability Characteristics of Fiber-enhanced Ternary Blended Self-compacting Concrete

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Abstract-
The compaction of concrete is one of the prominent factors to be considered to obtain the desired strength of the concrete. The mechanical vibrators are mostly used in the site for compaction of the concrete. But, compactions are not done properly in sites and this affects the strength and durability properties of the concrete. The concrete that flows by its own weight is named as Self-Compacting Concrete (SCC). The flow ability of conventional concrete can be improved by developing or introducing self- compacting concrete. But the cost of SCC is very high due to the high cementitious content and super plasticizer. This high cost can be brought down by using the Supplementary cementitious materials (SCMs). Very fine particle size of these SCMs enables pore refinement in the concrete and subsequently improves both the mechanical and durability properties of the concrete. Various tests were conducted to evaluate the fresh, mechanical and durability properties of the SCC. Total nine mixes are prepared for optimizing the mix namely (TBC 1 to 9).Ternary blended SCC mix (TBC9) containing 70% of Ordinary Portland Cement, 20% of fly ash, and 10% of silica fume has enhanced the mechanical and durability properties of SCC. Therefore TBC9 mix was considered as the optimized mix. The alkali-resistant glass fibers were added with the optimized mix (TBC9). The increase in the glass fiber content in TBC mixes decreases the compressive strength values. The addition of glass fiber in SCC increases the splitting tensile strength 17 % higher than the splitting tensile strength values of TBC9 mix. The glass fiber reinforced self-compacting concrete mixes increases the energy absorption values more than the optimized mix.

keywords— Flyash; Self Compacting Concrete; Silica Fume; Supplementary cementitious materials; Mechanicial Properties.

I.INTRODUCTION

The concrete is one of the broadly used building materials in the world. The casting of concrete is a very simple method by mixing some locally available cement, fine aggregate, coarse aggregate and water which attains some required strength. However, the fresh and the hardened properties of un-designed concrete are unpredictable and it creates considerable issues in all aspects pertaining to the properties of the concrete. The compaction of concrete is one of the prominent factors to be considered to obtain the desired strength of the concrete. The mechanical vibrators are mostly used in the site for compaction of the concrete. But, compactions are not done properly in the sites and this affects the strength and durability properties of the concrete. To overcome all these defects due to compaction, a new concrete is developed which is called as Self-Compacting Concrete (SCC). The concrete that flows by its own weight is named as Self- Compacting Concrete (SCC). The flow ability of conventional concrete can be improved by developing or introducing self-compacting concrete. The SCC has high flow ability and it leads the concrete to flow in any architectural structures and through congested reinforcement elements. The SCC was first developed in Japan to overcome the defects in concrete due to insufficient compaction and lack of skilled laborer's. In 1990's, many researches in Japan and Europe countries focused on the field of SCC. The placing of SCC was comparatively easier than that of the conventional concrete. The main difference in the design of SCC is, the content of coarse aggregate is comparatively less than that of the fine aggregate. This reduces the blockage of concrete in the congested reinforcement.

The self-compacting concrete shall satisfy three basic requirements such as, filling ability, passing ability and segregation resistance (Paulo Ricardo et al. 2019) (Rahmat & Yasin 2012). The filling ability shows that the speed of the concrete flow by its own without any external force. The passing ability is an important property of SCC. The concrete can flow easily between the congested reinforcements without any segregation. SCC has to maintain its homogeneity during mixing and placing of the concrete in a structure without segregation and bleeding.

1.1 Advantages of SCC

- SCC can flow and fill easily in the formwork by its own weight without any segregation and bleeding.
- SCC is more suitable for architectural structures, congested reinforced structures, thin walls and deep foundations.
- SCCdoesnotrequireskilledlaborsandensurefasterpaceinconstruction.
- SCC improves the durability properties of the concrete.
- SCC reduces noise due to the absence of the vibrator.

1.2 supplementary cementitious materials.

The supplementary cementitious materials are suitable alternative material for the cement. The cost of SCC is very high due to the high cementitious content (300 – 600 kg/m3) as per EFNARC-2005 and super plasticizer. This high cost can be brought down by using the natural (metakaoline, RHA, etc.,) and artificial (fly ash, silica fume, GGBS etc.,) SCMs. Very fine particle size of these SCMs enables pore refinement in the concrete and subsequently improves both the mechanical and durability properties of the concrete (Kavitha et al. 2015). The addition of water initiates the reaction of SCMs with calcium hydroxide to produce C-S-H (Kavitha et al. 2015). The addition of SCMs decreases the cost of the concrete by reducing the cement content and improves the fresh, mechanical and durability properties of the concrete (Mostafa et al. 2015).

FlyAsh: Fly ash is the by-product of coal-fired power plants (Class F) and combustion of lignite or sub-bituminous coal power plant (Class C). Around 500 million tons of fly ash are produced per year (all over the world) and it is 80% of total ash produced in the world. The disposal of such huge quantity of fly ash creates an environmental harms and issues. Only 80 to 85 million tons of fly ash are utilized for cement manufacturing and other industrial purposes. The remaining quantities are disposed as landfills. The fly ash can be classified as C and F classes. The class C fly ash contains calcium oxide content up to 20% and Class F fly ash contains CaO content less than 5%. The formation of calcium silicate hydrate is high in the fly ash due to the high intensity of alumina and silica (Wgna et al. 2011).The replacement of fly ash in the cement content is effective up to 25% (by weight) (Mostafa et al. 2015). The High Volume of Fly Ash (HVFA) content in the concrete affects the heat of hydration process (Bilodeau & Malhotra 2000).

Silica Fume (SF): Silica fume is one of the by-products from silicon industries which have a high pozzolanic reactivity property. Moreover, the fineness of SF is 20000 m2/kg which is 100 times smaller than that of the OPC (Samahbhanja & Sengupta 2003). The silica fume contains more than 80% of SiO2 content. The quantity of SF in the concrete is limited to 12.5% of total cement content (Rashid et al. 2002). The appropriate mix proportioning of SF blended concrete can attain extremely high compressive strength at early ages (Ali et al. 2012) and SF improves its durability by reducing the pores size of the concrete (Samahbhanja & Sengupta 2003). The main disadvantage of SF blended concrete is the requirement of high-water content due to its fineness and water reducing admixtures which are mandatory to maintain the desired water/cement ratio (Samahbhanja & Sengupta 2003).

1.3 ternary blended concrete

The ternary blended concrete are produced by combining of two SCMs and substitute in concrete as a partial replacement for the cement. The shortcomings in one of the SCMs can get counteracted by other SCM when they are blended (Deepa et al. 2012) (Murthi & Sivakumar 2008). The ternary blended concrete helps to reduce the environmental impacts by consuming a huge chunk of the waste materials. The ternary blended concrete with limestone (LS) and natural pozzolana / FA decreases the production cost and increases the environmental benefits (Kemal et al. 2015). The ternary blended concrete with SF and low reactivity BFS improves the durability properties of the concrete. The addition of BFS helped in reducing the water demand and hence the required dosage of the superplasticizer (Ali et al. 2012). The self-compacting concrete with PCE based superplasticizer attained robust flow retention at low temperatures (Wgna et al. 2011).

1.4 Fiber Reinforced scc

The concrete is strong in compression and weak in tension. The shrinkage cracks were developed in the early ages of concrete and this shrinkage cracks decreases the strength of the concrete. The concrete is a brittle material with low tensile stress and impact strength. To overcome these defects, the fibers are added in the concrete. The fibers are the tiny pieces of reinforcing material which in turn can reduce the shrinkage cracks and increases the mechanical properties of the concrete (Siva kumar et al. 2017). The combined effect of self-compacting concrete and fiber reinforced concrete is to form as a fiber reinforced self-compacting concrete. The fiber reinforced self-compacting concrete improves both the mechanical and durability properties of the concrete. The fibers are classified as natural (coir, cotton, jute, etc.,) and artificial fiber (steel, glass, polypropylene, etc.,) with different size and aspect ratio. An alkali-resistant glass fiber in the concrete reduces crack propagation and enhances the durability properties of the concrete (Rao et al. 2012). The addition of glass fiber in the concrete can increase the efficiency up to 0.8% by weight of cement and a large quantity of glass fibers reduces the flow ability of SCC (Manohar et al. 2012).

1.5 Research Approach

The Figure 1 shows the methodology of the present research work. After review of literatures, the materials were collected and their properties were assessed. The mix proportion of SCC was calculated by using IS: 10262 -2019 and ternary blended SCC mix proportions were arrived. The optimized ternary blended SCC mix was found by the mechanical and durability studies.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Volume 13, Issue 01 January 2024

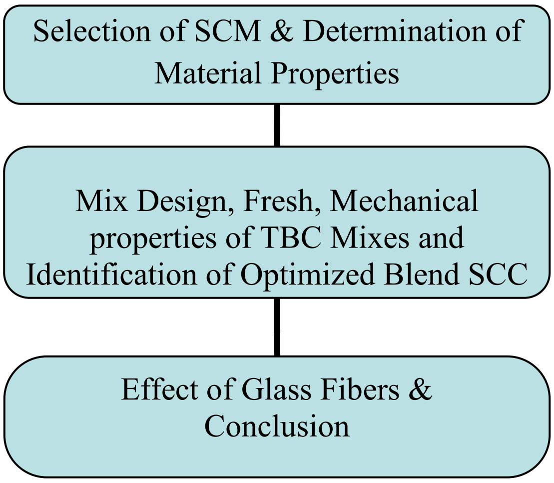

Figure-1: Research Approach

2. OVERVIEW OF PREVIOUS STUDIES

Chris & Goodier (2003) discussed the history, development, future scopes of self-compacting concrete in a detailed manner. They stated that the supplementary cementitious materials were suitable for both vibrated and non-vibrated (SCC) concrete. The physical and chemical properties of these SCMs had made some notable difference in the production of SCC. The differences created by SCMs can be adjusted by changing the degree of compaction in the vibrated concrete. They also reported that the practice was not suitable for SCC. It was also observed that the SCC needs high powder content to obtain cohesiveness.

Hajime & Masahiro (2003) investigated the mechanisms of SCC. The rational method of mix design was used in their research work. The coarse and fine aggregate were fixed as 50 and 40% (by volume) respectively. From the results, they observed that the water reducing admixtures (superplasticizer) were mandatory to attain the required SCC properties. The segregation of ingredients shall be avoided when the concrete flows in the congested reinforcement. The properties of self-compacting concrete were affected due to the flow of mortar, coarse aggregate volume, powder content and type of SCMs.

Jones et al. (1997) compared durability performance of ternary blended and normal concrete. From the experimental results they concluded that the ternary blended mixes showed good resistance to chloride ion penetration when compared with that of the normal concrete. The combination of two supplementary cementitious materials blended concrete improved the strength and durability properties of concrete more than that of the binary blended concrete.

Medhat & Michael (2006) studied the durability properties of ternary blended concrete containing fly ash (with different calcium content) and silica fume. The expansion of concrete after alkali-silica reaction was studied with different mix proportions. The ternary blended concrete with fly ash (low calcium content) + silica fume showed less expansion after alkali- silica reaction when compared with that of the other binary and ternary blended concrete mixes.

Ylmaz et al. (1991) studied the performance of concrete with addition of glass fibers. They analyzed micro structural interface reactions by using EDAX and SEM analysis. From the results they concluded that the glass reinforced concrete increased the tensile strength. However, glass fiber reinforced concrete was not much effective as the normal reinforced concrete.

3. CHARACTERISTICS OF MATERIAL AND MIXING RATIOS

3.1 Properties of Cement and Cementitious Materials

Table 1 Physical properties of OPC 53-grade

Physical properties	Achieved Results
Specific gravity	3.12
Consistency	31%
Initial setting time	42 minutes
final setting time	250 minutes

Table 2 Chemical compositions of OPC 53-grade

Chemical compositions	Values (%)
SiO_2	20.56
Al_2O_3	5.05
Fe_2O_3	3.15
CaO	62.54
MgO	2.72
K_2O	0.34
Na_2O	0.38

Table 3 Fly Ash Physical Characteristics

Physical properties	Achieved Results
Specific gravity	2.12
Fineness	517 m^2/kg
Bulk density	1134 kg/m^3
Physical form	Powder
Color	Dark gray

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Volume 13, Issue 01 January 2024

Table 4 Chemical compositions of fly ash

Chemical compositions	Values (%)
SiO_2	58.23
Al_2O_3	25.35
Fe_2O_3	6.24
CaO	2.67
MgO	1.36
K_2O	0.84
Na_2O	0.53

Table 5 Physical Attributes of Silica Fume

Physical properties	Achieved Results
Specific gravity	2.26
Fineness	20000 m^2/kg
Bulk density	656 kg/m^3
Physical form	Powder
Color	Light gray

Table 6 Silica fume Chemical Constituents

Chemical compositions	Values (%)
SiO_2	94.4
Al_2O_3	0.62
Fe_2O_3	0.15
CaO	1.12
MgO	0.72
K_2O	1.15
Na_2O	0.22

3.2 Chemical Admixture

Poly-carboxylic ether based superplasticizer were used as a chemical admixture to improve the fresh properties of SCC. The properties of superplasticizers are presented in Table 7.

Table 7 Superplasticizer Traits and Attributes

Properties	Values
Type	Poly-carboxylic ether
Specific gravity	1.22 at 30 ^{0}C
Form	Liquid
Color	Light brown
Recommended dosage	0.6-1.5 litres per 100 kg of cement
Chloride content	Nil as per IS: 456-2000

3.3 Glass Fiber

Alkali-resistant glass fiber with the aspect ratio of 857.14 was used in this investigation. The sample of glass fiber are shown in Figure 2 and the properties of glass fiber are tabulated in Table 8.

Fig 2 Glass fiber

Table 8 Attributes of Alkali-Resistant Glass Fiber

Physical properties	Values
Modulus of elasticity	72 GPa
Specific gravity	2.68
Filament diameter	14 micron
Length	12 mm
Aspect ratio	857.14

3.4 MIX PROPORTIONS OF SCC

The M30 grade of self-compacting concrete mix was designed as per the guidelines of IS: 10262-2019. To maintain the desired fluidity and segregation resistance, the designed mix proportions were verified with the European Federation of National Associations Representing for Concrete (EFNARC-2005) guidelines. The superplasticizer dosage was determined by trial-and-error process and it is around 2.0% by weight of total powder content for all mixes. The normal SCC design mix (NM) is presented in Table 9.

Table 9 Design mix of SCC

Constituent materials	Obtained design mix value	EFNARC-2005 guidelines
Powder (Cementitious material)	514 kg/m^3	380-600 kg/m^3
Coarse aggregate	785kg/m^3	750-1000 kg/m^3
Fine aggregate	908 kg/m^3	48-55 %
Water	204 kg/m^3	150-210 kg/m^3

International Journal of Engineering Research & Technology (IJERT)
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Table 10 Properties of Water

Properties	Obtained values	Limits as per Code
pH Value	7.8	Shall not be less than 6.0
Chloride content	126	500mg/l
Total hardness	96	200mg/l
Total dissolved solids	160	2000mg/l

The M30 grade SCC mix proportion is shown in Table 11 and various ternary blended SCC mix proportions (TBC1 to TBC15) are given in Table 12. The total cementitious material content (OPC+ fly ash+ silica fume) was maintained as 514 kg/m3 for all the mixes. TBC 9 is obtained as optimum.

Table 11 Mixing Ratios for Normal Self-Compacting Concrete (NM)

	Cement	Fine Aggregate	Coarse Aggregate	Water
Weight (kg/m^3)	514	908	785	204
Mix proportion	1	1.76	1.52	0.4

Optimized ternary blended SCC (TBC9) was selected from the mechanical and durability properties. Glass fiber was added (0.2, 0.4, 0.6 and 0.8% weight fractions of total cementitious materials) to the optimized ternary blended SCC mix and Table 13 shows the mix proportions of glass fiber reinforced ternary blended SCC mixes (GFTBC1 to GFTBC4).

Table 12 Proportions of Ingredients in Ternary Blended SCC Mix

Mix	Cementitious materials			FA kg/ m3	CA kg/ m3	SP kg/ m3
	OPC (%)	F (%)	SF (%)			
NM	100	0	0	908	785	10
TBC1	85	10	5	908	785	10
TBC2	82.5	10	7.5	908	785	10
TBC3	80	10	10	908	785	10
TBC4	80	15	5	908	785	10
TBC5	77.5	15	7.5	908	785	10
TBC6	75	15	10	908	785	10
TBC7	75	20	5	908	785	10
TBC8	72.5	20	7.5	908	785	10
TBC9	**70**	**20**	**10**	**908**	**785**	**10**
TBC10	70	25	5	908	785	10
TBC11	67.5	25	7.5	908	785	10
TBC12	65	25	10	908	785	10
TBC13	65	30	5	908	785	10
TBC14	62.5	30	7.5	908	785	10
TBC15	60	30	10	908	785	10

Table 13 Mix proportions of GF reinforced ternary blended SCC mixes

Mix	Cement (%)	FA (%)	SF (%)	Glass Fiber (%)
GFTBC1	**70**	**20**	**10**	**0.2**
GFTBC2	**70**	**20**	**10**	**0.4**
GFTBC3	**70**	**20**	**10**	**0.6**
GFTBC4	**70**	**20**	**10**	**0.8**

GFTBC1- Glass fiber reinforced SCC mix1
GFTBC2- Glass fiber reinforced SCC mix2
GFTBC3- Glass fiber reinforced SCC mix3
GFTBC4- Glass fiber reinforced SCC mix4

4. EXPERIMENTAL INVESTIGATION

1. Normal Consistency & Setting Times

The quantity of water required to make cement paste was determined from the consistency test. The Vicat apparatus was used to find the consistency of cement paste as per the guidelines of IS: 4031(Part4)-1988.

The setting time values are obtained by using Vicat apparatus as per guidelines of IS: 4031(Part5)-1988.

Table 14 Test Results of Consistency and Setting Times of Cement

Mix Id	Consistency Value (%)	Initial Setting Time (min)	Final Setting Time (min)
NM	31	42	220
TBC1	33	57	237
TBC2	34	57	261
TBC3	35	60	265
TBC4	35	66	287
TBC5	35	72	300
TBC6	37	74	307
TBC7	39	93	313
TBC8	39	99	319
TBC9	39	106	325
TBC10	42	112	341
TBC11	42	112	360
TBC12	43	124	370
TBC13	47	136	372
TBC14	47	148	393
TBC15	49	152	399

The consistency value of OPC (NM) mix was 31%. The standard consistency values of TBC mixes were gradually increased with increase in fly ash and silica fume content. The ternary blended mixes required more water for consistency mix than the OPC mix. The high surface area of fly ash and silica fume increases the consistency value.
The initial and final setting time of OPC mix was 42 and 220 minutes respectively. The initial and final setting time of TBC mixes were in the range of 57 to 152 minutes and 237 to 399 minutes respectively. From the results, inclusion of SCMs in OPC increases the initial and final setting time.

5. FRESH PROPERTIES OF TERNARY BLENDED SELF- COMPACTING CONCRETE

A normal workability test was not suitable to study the fresh properties of the Self-Compacting Concrete (SCC). The foremost fresh characteristics of SCC such as passing ability, flow ability and segregation resistance were assessed by using slump flow test, T500 mm slump flow time test, L-box test, V-funnel test and V-funnel T5 minutes test as per the guidelines of EFNARC-2005. The fresh properties of normal SCC mix (NM), ternary blended SCC mixes (TBC1to TBC15) and glass fiber reinforced SCC (GFTBC1 to GFTBC4) were assessed by slump flow test, T500 mm slump flow time test, L- box test, V-funnel test and V-funnel T5 minutes test. EFNARC-2005 guidelines are presented in Table 15

Table 15 EFNARC-2005 guidelines

Properties of fresh SCC	Name of experiment	EFNARC-2005 guidelines
Filling ability	Slump flow test	550-800 mm
	T500 mm Slump	2-5 seconds
Passing ability	L-box test	0.8-1.0
Segregation resistance	V-funnel test	8-12 seconds
	V-funnel T5minutes	+3 seconds

5.1 Slump Flow Test and T500 mm Slump Flow Time Test

Fig-3 Slump flow test

The filling ability of SCC was obtained by using the slump flow test and T500 mm slump flow test. The experiments were performed on the flat horizontal base plate and the base plate with 500 mm diameter circle was marked. The slump cone with 200 mm bottom diameter, 100 mm top diameter and height of 300 mm was placed in the center of the base plate. Approximately six liters of prepared SCC mix was filled in the slump cone up to the top level of the slump cone without any compaction and the excess concrete was removed. The cone was lifted vertically and allow the concrete to subside. At the same time the stop watch was started to measure the time taken by the concrete to cross 500 mm diameter circle (T500 mm slump flow time test). The experimental setup of slump flow test and T500 mm slump flow time test of SCC was shown in the figure 3.

5.2 L-Box Test

L-box is used to find the passing ability of self-compacting concrete. Passing ability of the concrete is measured by indicating the blocking ratio. L-shaped rectangular section with reinforcement bars are placed at the joint of horizontal and vertical sections

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http://www.ijert.org
International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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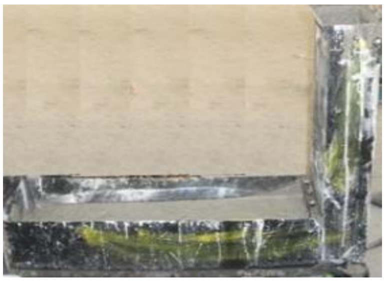

Fig 4- L-box test

The movable gate was fixed near the reinforcement bars to separate the sections. Figure 4 shows the experimental setup of L-box test. Around 14 liters of concrete was filled in the vertical section without compaction and allowed the concrete to stay for a minute in the vertical section. Then the gate was opened and the concrete was allowed to flow from the vertical to horizontal section through the reinforcement bars. The height of concrete in both the sections (H1 and H2) was measured. The blocking ratio was obtained from the ratio between H2 (Horizontal section) and H1 (Vertical section).

5.3 V-Funnel Test

The experimental setup for V-funnel test is shown in Figure 5. Twelve liters of concrete was mixed and filled in the V-funnel without any compaction. Then the lock at the bottom of the funnel was opened and the concrete was allowed to flow from the V-funnel under the gravity. The time taken for complete flow of concrete was noted as V-funnel time. The lock was closed immediately and again filled the V-funnel with same the concrete. After 5 minutes, the lock was released and the concrete was allowed to flow down. The time taken for complete flow of concrete was recorded as V-funnel T5minutes time.

Fig 5- V-Funnel test

Table16- Test Result of Fresh Properties

Mix Id	Slump flow (mm)	T500 mm Slump (sec)	Blocking ratio	V-Funnel (sec)
NM	760	2.6	0.87	8.70
TBC1	772	2.7	0.85	9.20
TBC2	770	2.8	0.90	9.60
TBC3	788	2.5	0.92	9.21
TBC4	780	2.6	0.87	9.42
TBC5	750	3.3	0.85	10.12
TBC6	728	3.5	0.85	10.60
TBC7	720	3.9	0.82	10.80
TBC8	704	4.2	0.84	11.08
TBC9	700	4.3	0.84	11.2
TBC10	680	4.5	0.82	11.42
TBC11	675	4.6	0.80	11.60
TBC12	660	4.9	0.82	11.40
TBC13	642	5.2	0.78	13.16
TBC14	626	5.4	0.76	13.43
TBC15	608	5.9	0.76	14.10

Table 17-Test Result of Fresh Properties of glass fiber reinforced ternary blended SCC mixes

Mix Id	Slump flow (mm)	T500 mm Slump (sec)	Blocking ratio (H2/H1)	V-Funnel (sec)
GFTBC1	640	4.8	0.82	11.6
GFTBC2	610	5.1	0.80	11.8
GFTBC3	580	5.3	0.76	12.1
GFTBC4	560	5.6	0.72	12.4

6. MECHANICAL PROPERTIES OF TBC MIXES

The mechanical characteristics of SCC were evaluated using the compressive strength test, splitting tensile strength test, flexural strength test. As per the guidelines of IS: 516–1959, concrete cube specimens of size 150 x 150 x 150 mm were cast and immersed in water for four different curing ages (7 and 28 days). Cylinders of size 150 mm diameter and 300 mm height were cast and immersed in water for three different curing ages (7 and 28 days). After curing, the cylinders were tested as per the IS: 5816–1999 guidelines. Prisms of size 100 × 100 × 500 mm were

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Volume 13, Issue 01 January 2024

cast and immersed in water for 28 days. After water curing, prisms were removed from the curing tank and tested in the flexural testing machine under two-point load under the loading rate of 400 kg/min IS: 516 – 1959.

Table 18 Strength Properties after curing 7 & 28 Days

Mix Id	Compressive Strength (Mpa)		Split Tensile Strength (Mpa)	
	7 Days	28 Days	7 Days	28 Days
NM	17.78	39.11	2.38	3.62
TBC1	18.13	40.89	2.49	3.74
TBC2	17.78	41.60	2.60	3.74
TBC3	18.84	41.96	2.60	3.96
TBC4	19.20	40.89	2.38	3.85
TBC5	19.20	41.96	2.60	3.96
TBC6	19.91	42.67	2.72	4.08
TBC7	19.91	42.67	2.94	4.19
TBC8	20.27	43.38	3.28	4.30
TBC9	**20.98**	**44.44**	**3.40**	**4.64**
TBC10	17.42	41.60	3.40	4.76
TBC11	17.42	40.53	2.83	3.85
TBC12	15.29	38.40	2.49	3.74
TBC13	14.58	35.20	1.81	3.28
TBC14	13.16	31.64	1.59	2.94
TBC15	11.02	30.58	1.36	2.49

Table 19 Flexural Strength of ternary blended SCC mixes at 28 Days

Mix Id	Flexural strength (Mpa)
NM	5.12
TBC1	5.28
TBC2	5.20
TBC3	5.92
TBC4	6.16
TBC5	5.92
TBC6	6.32
TBC7	6.64
TBC8	6.80
TBC9	**6.88**
TBC10	5.92
TBC11	5.20
TBC12	4.88
TBC13	4.64
TBC14	4.72
TBC15	4.32

Table 18 demonstrates the enhancement in the compressive strength (at 7 & 28 Days) of concretes with fly ash replacement level up to 20%. Conversely, there is a reduction in compressive strength when the fly ash substitution levels are 25 and 30%. Among the sixteen mixes, the worst-case scenario was observed in TBC15 in which compressive strength after 7 days of curing reduced to the level of 38 and 31% respectively, when compared with NM.

A marginal increase in splitting tensile strength from 2.49 to 3.40 N/mm2 was observed at the early ages (7 days) up to the mix TBC10. Beyond that from TBC11 to TBC15, the strength showed a decreasing trend and was reported to have 1.36 N/mm2 for TBC15. At 28 days, the splitting tensile strength values of TBC9 and TBC10 were observed to be higher than that of other TBC mixes. TBC10 and TBC9 give 31.25 and 28.13% higher strength than that of the NM.

International Journal of Engineering Research & Technology (IJERT)
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7. MECHANICAL PROPERTIES OF GFTBC MIXES.

Table 20 Compressive, Split & Flexural strength test results of Glass Fiber reinforced Ternary Blended SCC mixes at 28 days

Mix	Compressive strength (Mpa)	Split Tensile Strength (Mpa)	Flexural strength (Mpa)
TBC9	44.44	4.64	6.88
GFTBC1	42.67	4.87	7.20
GFTBC2	40.89	5.10	7.44
GFTBC3	39.47	5.21	7.60
GFTBC4	38.76	5.44	7.68

8. DURABILITY STUDIES

The study of concrete mixes are not only concentrated on strength aspect, the durability properties are also fulfilled by the concrete to sustain in the various exposure conditions for many years. The life of the structures can be improved by the durable concrete. The penetration of aggressive ions, industrial liquids, water and gases are to be focused in the study of durability properties of concrete. The durability properties have been tested for normal SCC mix (NM), ternary blended SCC mixes (TBC1 to TBC15). Durability characteristics of SCC mixes were determined by conducting the following tests: water absorption test and Rapid Chloride Permeability Test (RCPT).

8.1 Water Absorption Test

The concrete cube specimens of size 150 x 150 x 150 mm were cast and immersed in water for 56 days curing. After curing, the cube specimens were dried by hot air oven at 105^{0}c for 24 hours. Then the cube specimens were removed from the oven and kept in the room temperature for few hours. The dry weight of the cube was recorded as W_{dry}.

Table 21- Water absorption test results of ternary blended SCC mixes at 56 days

Mix Id	Average Specimen weight (grams)			Initial Water absorption (%)	Saturated Water absorption (%)
	Wdry	Winit	Wsat		
NM	8262	8362	8438	1.21	2.13
TBC1	8275	8427	8476	1.84	2.43
TBC2	8162	8290	8368	1.57	2.52
TBC3	8310	8458	8508	1.78	2.38
TBC4	8254	8414	8491	1.94	2.87
TBC5	8218	8384	8456	2.02	2.90
TBC6	8196	8361	8449	2.01	3.09
TBC7	8322	8502	8628	2.16	3.68
TBC8	8296	8498	8589	2.43	3.53
TBC9	8324	8534	8624	2.52	3.60
TBC10	8302	8522	8613	2.65	3.75
TBC11	8255	8488	8561	2.82	3.71
TBC12	8326	8571	8630	2.94	3.65
TBC13	8406	8660	8736	3.02	3.93
TBC14	8356	8618	8697	3.14	4.08
TBC15	8324	8583	8689	3.11	4.38

8.2 Rapid Chloride Penetration Test

The cylindrical specimens were cast with the diameter and height of 100 and 50 mm respectively. After 28 days of curing, the specimens were coated with epoxy. Then specimen was kept between two halves of the test cell that contained sodium chloride and sodium hydroxide solutions which acted as an electrolyte (ASTM C 1202-2009). The potential of 60 V was applied to the specimen for 6 hours and the charge passed through the concrete was recorded for every 30 minutes.

Table 22- Chloride ion permeability as per (ASTM C 1202-2009)

Charge passed (Coulombs)	Permeability of chloride ion
> 4000	High
2000 – 4000	Moderate
1000 – 2000	Low
100 – 1000	Very low
< 100	Negligible

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Volume 13, Issue 01 January 2024

Table 23- Chloride ion penetration test results of ternary blended SCC mixes at 28 days

Mix Id	Total charge passed (coulombs)	Chloride ion penetration as per ASTM 1202-2009 criteria
NM	1121	Low
TBC1	787	Very low
TBC2	623	Very low
TBC3	642	Very low
TBC4	701	Very low
TBC5	688	Very low
TBC6	654	Very low
TBC7	587	Very low
TBC8	556	Very low
TBC9	539	Very low
TBC10	512	Very low
TBC11	498	Very low
TBC12	483	Very low
TBC13	446	Very low
TBC14	422	Very low
TBC15	438	Very low

CONCLUSION

Summarizing the observations, this section outlines conclusions regarding the influence of Supplementary Cementitious Materials (SCMs) like Fly Ash (FA) and Silica Fume (SF) on the fresh, mechanical, and durability aspects of Self-Compacting Concrete (SCC). Furthermore, it discusses the effects of incorporating glass fibers in the ternary blended SCC.

1. The NM and 10% replacement of fly ash blended concrete mixes can be categorized as SF3 class. From TBC5 to TBC12, the values lie in between 660 and 750 mm, these mixes can be categorized as SF2 class and are desirable for column and wall concrete works EFNARC-2005. Ternary blended SCC mixes with 30% of fly ash (TBC13 to TBC15) can be categorized as SF1 class. TBC3 (F10% + SF10%) exhibited the maximum flow value in comparison with other ternary blends. The slump flow values of glass fiber reinforced SCC mixes (GFTBC1 to GFTBC4) are in the range from 560 to 640 mm, and these mixes can be categorized as SF1 class. The slump flow value of all glass fiber reinforced SCC mixes conforms to EFNARC-2005 limitations.
2. The blocking ratio of all ternary blended SCC mixes is in the range from 0.76 to 0.92 and it is well below the limitation suggested in EFNARC-2005. Cement replacement with fly ash can improve the passing ability of SCC and decreases the blockage of coarse aggregate to some extent. Blocking ratio values all glass fiber reinforced SCC mixes were greater than0.8 except GFTBC3 and GFTBC4 mixes. The result shows that the high dosage glass fiber in SCC decreases the blocking ratio.
3. A marginal increase in the compressive strength was observed at early ages (7 and 14 days) up to a maximum level of 20% fly ash replacement. At higher replacement level of fly ash (say>20%), the desired strength at early ages was not attained.
4. The highest percentage of increase in compressive strength at 28 days test was attained in TBC9 mix as 13.64%. The enhancement in the compressive strength (at all ages) of concretes with fly ash replacement level is up to 20%. Conversely, there is a reduction in the compressive strength when the fly ash substitution levels are 25 and 30%. Among the sixteen mixes, the worst-case scenario was observed in TBC15. The reduction in strength at these later ages (21% at 28 days and 20% at 56 days) is less than that of reduction in strength reported at early ages (say, 7 and 14 days). This could be attributed to the enhancement in the pozzolanic reaction of fly ash at the later ages. Inclusion of glass fiber in the SCC reduces the compressive strength values and the maximum reduction in strength was found in GFTBC4 mix. Small pores on the fracture surface of the concrete may reduce the compressive strength of SCC.
5. The measured modulus of elasticity of NM and few TBC mixes are slightly less than the limiting value proposed in IS 456-2000. This could be attributed to the reduction in coarse aggregate content in the SCC mixes. Among all the SCC mixes, the maximum modulus of elasticity value was observed in TBC9. The elastic modulus value of TBC9 was 17.84% higher than the elastic modulus of normal (NM) SCC mix. Inclusion of glass fibers increases the elastic modulus values of SCC. GFTBC3 mix shows 7.22% high modulus of elasticity value more than the optimized ternary blended SCC mix.

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