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Exploring High-Strength Self-Compacting Concrete: An Investigative Study

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Abstract

Presently, Self-Compacting Concrete (SCC) emerges as a cutting-edge variant within the concrete landscape. This type of concrete opens a new horizon in construction industries, as the concrete may flow on its own weight and does not require external vibration for compaction. For this reason, it reduces the labor costs, energy, and time required for placement It has the capability to smoothly spread into the intricate spaces of the formwork and encompass the reinforcing elements without difficulty. Much research has been done on the fresh and hardened properties of SCC (Self-compacting concrete), but it has been found that, from the aspect of strength, SCC does not possess any significant values. This paper contains laboratory work on the high strength of SCC to see what significant changes have been achieved in the hardened properties of SCC using fly ash, GGBS, and silica fume. We aim to make M-40 concrete. Currently, we are trying to make high-strength SCC in our research laboratory by changing the aspect ratio of fly ash, GGBS, superplasticizer, etc., and seeing the different properties in the hardened state.

Keywords: SCC, GGBS, superplasticizer, silica fume, strength

INTRODUCTION

Self-compacting concrete (SCC) revolutionized the construction industry when it was introduced in the early 1980s by Professor Okumara at Ouchi University. In contrast to conventional concrete, SCC presents numerous unique attributes, rendering it an appealing option for contemporary construction endeavors.

These features include its environmental friendliness, reduced labor requirements, ability to navigate congested reinforcement effortlessly, and its self-compacting nature, eliminating the need for vibration during placement. Furthermore, SCC boasts enhanced surface finish, hardened properties, and flowability, preventing segregation of concrete components while evenly penetrating spaces with a slump exceeding 600 mm. The heavy weight of SCC facilitates easy penetration into desired locations, rendering it highly advantageous for various applications.

The significance of this research lies in its aim to establish simplified guidelines for producing SCC, facilitating its adoption through a straightforward trial and error approach. This aspect is particularly essential, considering SCC's heightened environmental and economic

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advantages when juxtaposed with traditional concrete. Leveraging industrial by-products like Silica Fume and GGBS, abundantly produced in India, not only enhances the sustainability of concrete production but also addresses waste management challenges. By optimizing superplasticizer dosage and incorporating mineral admixtures, the research endeavors to maintain the required workability of SCC in alignment with EFNARC guidelines.

Despite its numerous advantages, the widespread adoption of Silica Fume SCC faces barriers such as the lack of simplified concrete proportioning guidelines and the need to promote economic and environmentally sustainable construction practices. This research aims to address these challenges by providing generalized guidelines for concrete mix proportioning and exploring the utilization of locally sourced mineral admixtures, particularly from West Bengal, to enhance the performance of SCC. By effectively utilizing Silica Fume, a by-product of the silicon industry, this research also contributes to reducing cement isolation and waste, thereby promoting efficient resource utilization in concrete production [1–3].

LITERATURE REVIEW

The two main problems that the global community had when utilizing SCC, which were the lack of an appropriate mix design process and a rheology testing method. They suggested a mix design approach for SCC that relies on the compatibility of superplasticizers in concrete and mortar mixtures, then trail mixes. To accomplish the self-compact ability, it was stressed that testing the finished product for passing, filling, flow, and segregation resistance was more important [4].

The way sand and gravel are packed and graded affects the development of SCC when using a polycarboxylic ether-type superplasticizer (SP). The Chinese design method was used, which minimizes aggregate packing and fills up spaces in loose aggregate with paste. For powder-water combinations examined using a Haegerman cone, fundamental relations were derived. The hardened concrete test demonstrates that SCC mixes can be created by applying Andersen's packing theory and Funk, Dinger, and Elkem's modifications. The created SCC blend satisfies all technical and practical requirements while having a medium strength and low cost [5].

The study focused on formulating Self-Compacting Concrete (SCC) without utilizing a Viscosity-Modifying-Agent (VMA). The water-to-powder (w/p) ratio was standardized at 1.18 to 1.215, with the incorporation of a polycarboxylic ether-based superplasticizer.. By using the Japanese method, for the entire trial mixes, 50% coarse aggregate by volume of concrete and 40% fine aggregate by volume of mortar were mixed with the SP content (ranging from 0 to 3.8%) until they achieved the SCC flow properties.

Among nine different mixtures tested, three formulations labeled SCC-1 to SCC-5 successfully passed flow tests such as V-Funnel, Slump, and L-Box. These mixtures yielded Self-Compacting Concrete (SCC) with normal strength ranging from M25 to M30 after 28 days, achievable with a cement content ranging approximately from 350 kg/m³ to 414 kg/m³ [6]. The study confirms the robustness of SCC through parameters like slump flow and J-ring tests. Additionally, incorporating a Viscosity-Modifying-Agent (VMA) significantly enhances the robustness of SCC.Variations in sand content do not pose a detrimental effect on self-compatibility. However, an increase in gravel content can lead to heightened segregation, while higher levels of fly ash may marginally reduce segregation resistance within Self-Compacting Concrete (SCC). It is anticipated that fluctuations in cement content could negatively impact both strength and segregation resistance [7].

Alterations in water content significantly influence self-compactability, resulting in noticeable increases in slump flow and reductions in V-funnel flow.

The concept of Low-Fines Self-Compacting Concrete (SCC), characterized by approximately 350 kg/m³ of total fines, is designed to attain compressive strengths ranging from 25 to 35 MPa [8].

Optimal Viscosity Modifying Agents (VMA) were evaluated using three different types of polycarboxylate ether superplasticizers to ensure compatibility. By decreasing both total fines and cement content, it is possible to lower the unit cost of SCC, thereby obviating the need for additional fillers (approximately 100 to 150 kg/m3). Such adjustments serve to bolster robustness [9].

The determination of cement content within the mix is contingent upon various factors, including strength requirements, class specifications, density, and water-cement ratio. The remaining fines are supplemented by filler material. The integration of VMA holds the potential to revolutionize the Ready-Mix Concrete (RMC) industry [10].

The study involved testing three different Self-Compacting Concrete (SCC) mixtures and two conventional concrete mixes, cured under both air and underwater conditions. Specifically, the research focused on assessing the micro cracking and porosity of the SCC surface layer, known as the "skin concrete." Water permeability was evaluated by measuring water flux up to 56 days, with a comparison made between different SCC mixtures and normal concrete. Interestingly, it was observed that the flux was higher in air-cured specimens compared to those cured underwater, especially in SCC mixtures.

Another aspect investigated the impact of mineral admixtures, such as fly ash and blast furnace slag, on the flowing ability and segregation resistance of SCC. The study found that partial replacement of Ordinary Portland Cement (OPC) with fly ash and blast furnace slag significantly improved the flowing ability of the concrete. The optimal proportions were identified as 10-20% fly ash and 25-45% slag cement by mass, leading to enhanced flowing ability and strength characteristics.

Additionally, a slump test was conducted for high workability concrete, revealing a beneficial correlation between slump values and flow. The laboratory test indicated satisfactory slump flow values, affirming the high workability of the concrete.

Furthermore, a rapid method was developed to assess the resistance to segregation of SCC. A comprehensive test program was carried out using SCC with different water-binder ratios, paste volumes, aggregate combinations, and mineral admixtures. The test successfully determined the segregation resistance of SCC in both vertical and horizontal directions, providing valuable insights into the method and apparatus used for testing.

Overall, these findings contribute to the understanding of SCC properties and the influence of mineral admixtures on concrete performance, offering insights into improving the flowing ability, strength characteristics, and segregation resistance of SCC mixtures.

METHODOLOGY

The experimental program encompassed the examination of nine control mixtures, assessing workability and compressive strength through various tests on fresh concrete and cube specimens at ages of 7, 14, and 28 days. Materials utilized included 53-grade Ordinary Portland Cement, fly ash, silica fume, river sand, coarse aggregate, water, and a super-plasticizer. Investigated variables included water-cement ratio, fly ash and silica fume replacement percentages, binder content, and testing ages within specified ranges Table 1-3

Table 1. Experimental program

Number of concrete mixes investigate	**Properties investigated**	**Details of methods/specimens used**	**Number of specimen tested for each mix**	**Test ages (days)**	**Total number of specimen tested**	**Standards referred**
9 control mix	Workability	T_{50cm} slump flow, V-funnel, J-ring	At each age	On fresh concrete	-	EFNARC
9 control mix	Compressive strength	150x 150x 150 mm cube	3	7, 14, 28	120	IS: 516

Table 2. Material Used

Ingredient Used	Key features
Cement	53 grade Ordinary Portland Cement
Fly Ash	Siliceous fly ash, a mixture of fields I & II from ESP from Kola ghat Thermal power plant and confirming to IS:3812
Silica Fume	An Amorphous polymorph of silicon di-oxide, silica
Fine aggregate	River sand conforming to zone II of IS:383
Coarse aggregate	Crushed, angular graded coarse aggregate of 12.5 mm nominal maximum size as per IS:383
Water	Lab tap water
Chemical admixture	A SNF based super-plasticizer Sikament 2004 NS (A SIKA PRODUCT) with solid content 38.5%

Table 3. Key variables affecting the properties of concrete, which has been investigated.

Independent variables affecting strength of concrete	Range of study
W/C ratio	0.35 – 0.28
Fly ash and silica fume replacement as % of total binder	15% - 25%
Binder Content	500 Kg/m^3
Age	7 – 28 days

Mix Designation

The following mix designation has been followed. The alphabet A and B represents the cementitious material content of 500 kg/m^3 respectively. The alphabets E, F, and G refer to W/C ratios of 0.35, 0.30, and 0.28 respectively. The alphabets I, J, K, L stand for fly ash replacement of 10, 15, 20, 25% respectively. The numerical value 10, 15, 20, 25 stand for Silica Fume replacement of 10%, 15%, 20% and 25% respectively. For example EI10 stands for a sample which binder content is 500 kg/m^3 with W/C ratio 0.35, where the cementitious material is replaced by both 10% of fly ash and 10% of Silica fume table 4.

Table 4. The Physical and Chemical Properties of Aggregates and Super Plasticizers

S.N.	Properties	Calculation
1	Aggregates size	= 12.5 mm
2	Specific gravity of coarse aggregate	= 2.876
3	Bulk density of loose coarse aggregate	= 1491 kg/m^3
4	Specific gravity of fine aggregate	= 2.67
5	Bulk density of loose fine aggregate	= 1289 kg/m^3
6	Specific gravity of cement	= 3.15
7	Volume ratio of fine aggregates	= 54%
8	Volume ratio of coarse aggregates	= 46%
9	Specific gravity of super plasticizer	= 1.22
10	Solid content of super plasticizer	= 38.5%
11	Air content in SCC	=2%
12	Designed strength of SCC $[(f_{ck}') \rightarrow f_{ck} + 1.65\ S]$	= 58.25 Mpa
13	Fineness modulus of fine aggregate	= 2.6638
14	Fineness modulus of coarse aggregate	= 6.6497

Results And Discussion

The findings suggest that higher levels of fly ash and silica fume replacement result in decreased workability, demonstrated by reduced slump flow and increased V funnel and J ring times. However, this decrease in workability correlates with enhanced compressive strength, particularly notable at elevated replacement percentages. This relationship persists consistently at both 7 and 14 days, with higher replacement levels yielding higher strengths, particularly evident at lower water-cement ratios. Table4-7 and Figure 1-5

Table 4. Mix Designation

SL No	Mixes	Binder content (kg/m^3)	w/c	Cement replacement by Fly ash (%)	Cement replacement by silica fume (%)
1	AEI10	500.00	0.35	10	10
2	AEJ15			15	15
3	AEK20			20	20
4	AEL25			25	25
5	AFI10	500.00	0.30	10	10
6	AFJ15			15	15
7	AFK20			20	20
8	AFL25			25	25
9	BGI10	500.00	0.28	10	10
10	BGJ15			15	15
11	BGK20			20	20
12	BGL25			25	25

Table 5. Mix Proportioning

Mixes	w/c	Cement (kg/m^3)	Fly ash(kg/m^3)	Silica fume(kg/m^3)	Aggregates (kg/m^3)		Water (kg/m^3)	S.P(%)
					C.A	***F. A***		
AEI10	0.35	400	50	50	809.31	821.35	135	2.0
AEJ15		350	75	75	809.31	821.35		
AEK20		300	100	100	809.31	821.35		
AEL25		250	125	125	809.31	821.35		
AFI10	0.30	400	50	50	809.31	821.35	120	2.5
AFJ15		350	75	75	809.31	821.35		
AFK20		300	100	100	809.31	821.35		
AFL25		250	125	125	809.31	821.35		
BGI10	0.28	400	50	50	780.00	844.00	140	3.0
BGJ15		350	75	75	780.00	844.00		
BGK20		300	100	100	780.00	844.00		
BGL25		250	125	125	780.00	844.00		

Table 6. Fresh properties of self-compacting concrete (SCC)

Mix ID	W/C ratio	T50cm slump flow (sec)	V funnel (sec)	J ring (mm)
AEI10	0.35	4	10	5
AEJ15		3	11	8
AEK20		4	9	7
AEL25		4	8	6
AFI10	0.30	4	11	6
AFJ15		4	12	9
AFK20		4	10	10
AFL25		3	11	8
BGI10	0.28	3	12	10
BGJ15		4	10	8
BGK20		7	10	13
BGL25		7	10	14

Table 7. Hardened properties of self-compacting concrete (SCC)

Sl. No	Mixes	Binder (kg/m^3)	W/c	Compressive strength (MPa)		
				7 days	*14 days*	*28 days*
1	AEI10	500	0.35	28	40	58
2	AEJ15			30	42	59
3	AEK20			27	38	54
4	AEL25			28	38	56
5	AFI10	500	0.30	29	37	58
6	AFJ15			30	42	56
7	AFK20			27	38	60
8	AFL25			29	38	58
9	BGI10	500	0.28	26	45	58.5
10	BGJ15			27	45	58
11	BGK20			28	46	59
12	BGL25			30	40	60

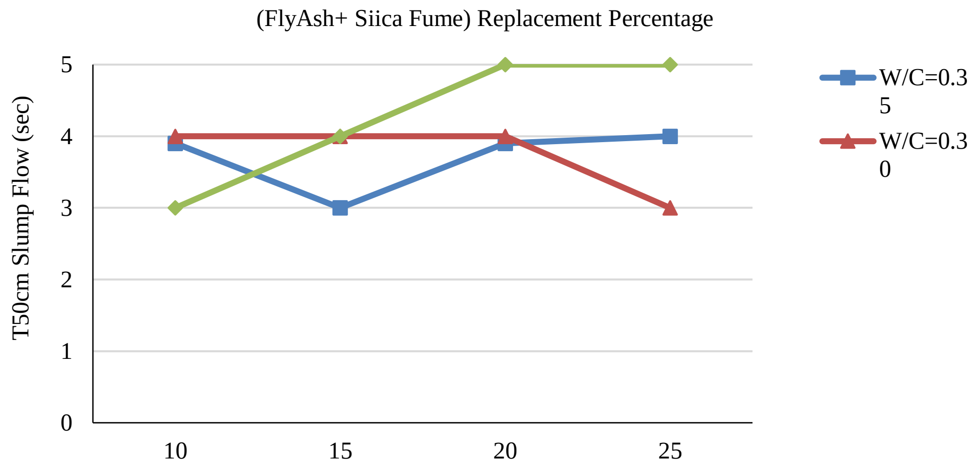

Figure 1. The Relationship Between T50cm Slump Flow and (Fly ash + Silica Fume) Percentage at Binder Content 500 kg/m^3 for W/C Ratio 0.35,0.30, and 0.30, 0.28

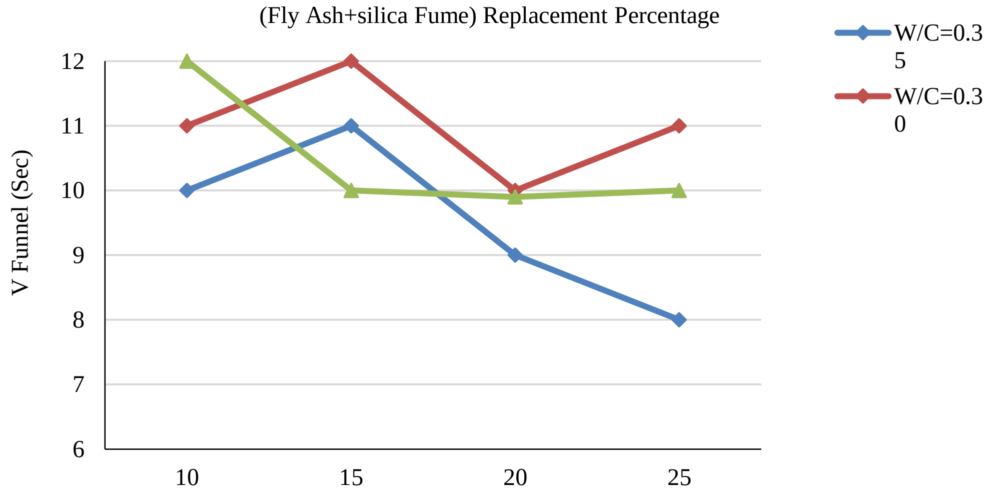

Figure 2. The Relationship Between V Funnel and (Fly ash + Slica fume) Percentage at Binder Content 500 kg/m^3 for W/C Ratio 0.35, 0.30, 0.28

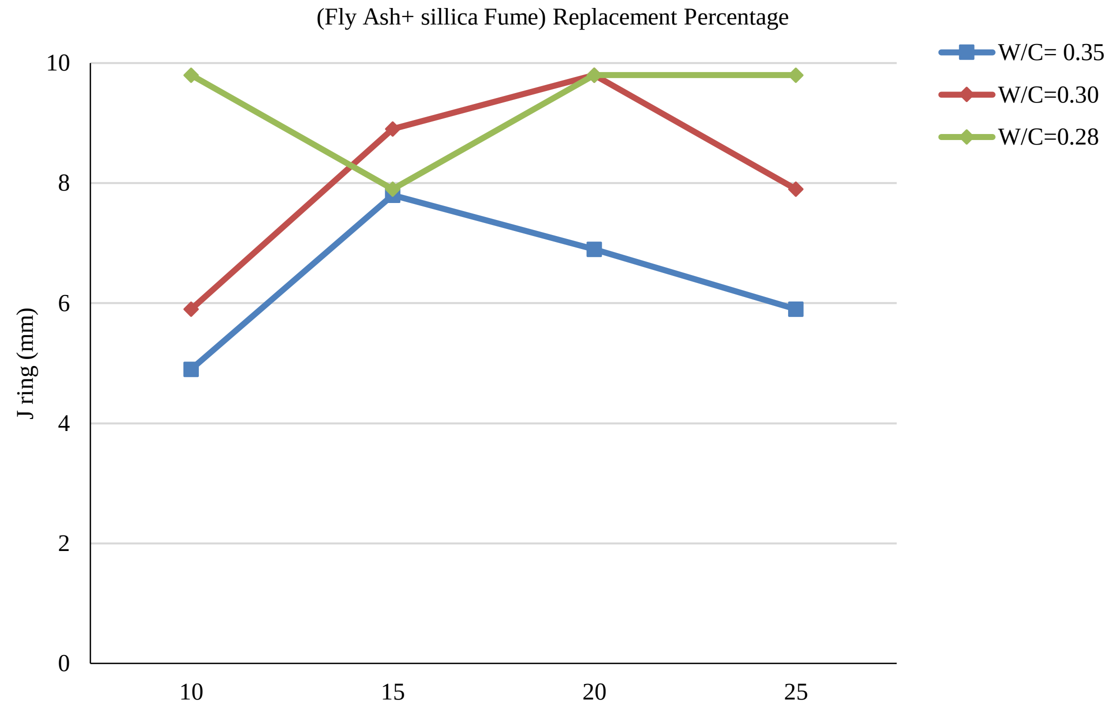

Figure 3. The Relationship Between J Ring and (Fly Ash + Silica Fume) Percentage at Binder Content 500 kg/m^3 W/C Ratio 0.35, 0.30, 0.28

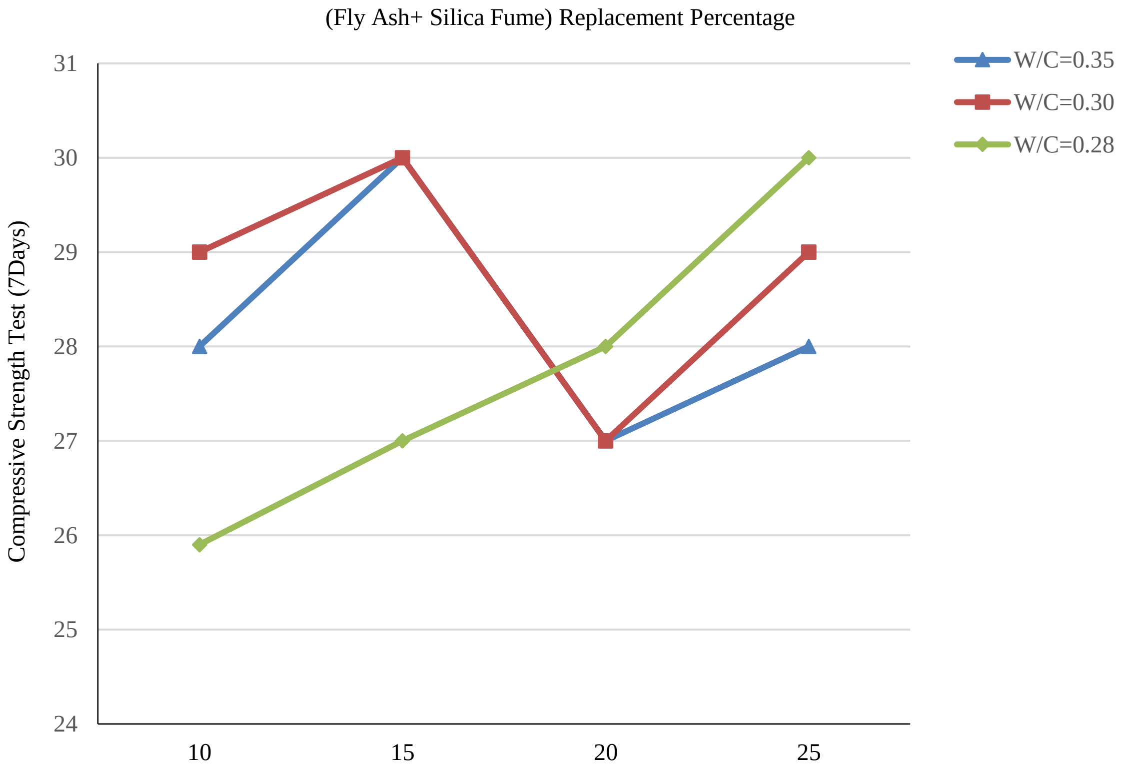

Figure 4. The Relationship Between Compressive Strength at 7 days and Different (Fly Ash + Silica Fume) Replacement Percentages & w/c – 0.35, 0.30, 0.28

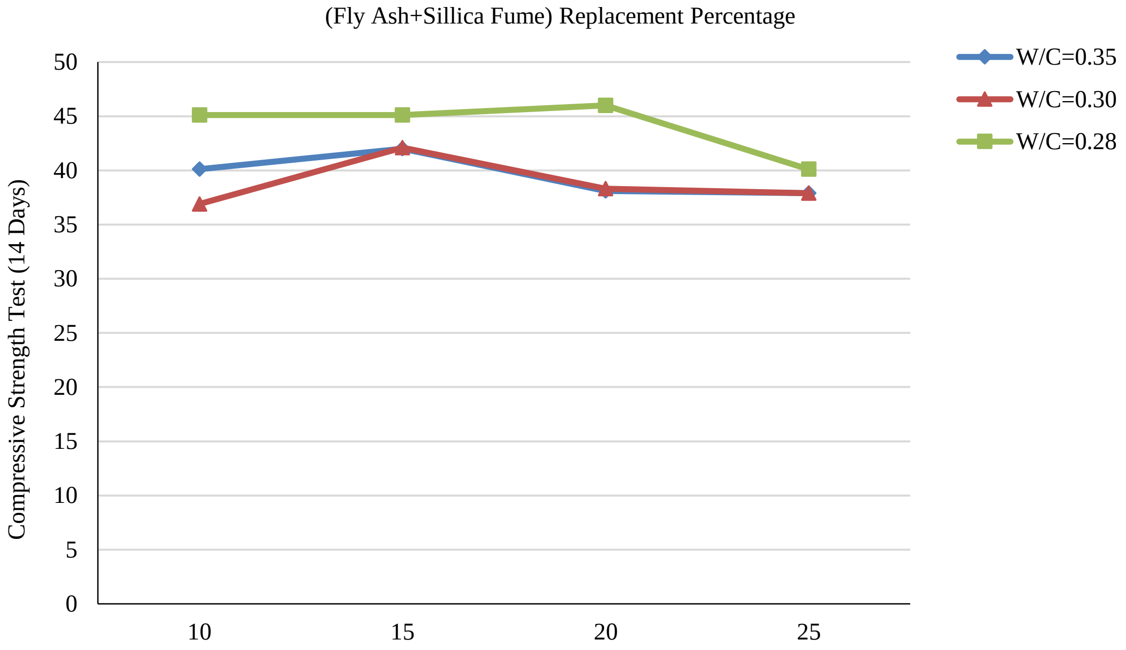

Figure 5. The Relationship Between Compressive Strength at 14 days and Different (Fly Ash + Silica Fume) Replacement Percentages & w/c – 0.35, 0.30, 0.28

CONCLUSION

A thorough investigation for finding the contribution of fly ash and silica fume on the properties of self-compacting concrete over a wide range of water-cement ratios and fly ash and slag replacement percentage percentages were performed. The following conclusions may be drawn in light of the experimental talks and findings that were provided in the preceding chapters:

a. This study aims to enhance understanding of the impact of fly ash and silica fume on Self-Compacting Concrete (SCC), utilizing materials readily accessible in the eastern region. The investigation spans a diverse spectrum of water-cementitious ratios, ranging from 0.35 to 0.28, and explores fly ash and silica fume replacement percentages of 10%, 15%, 20%, and 25% relative to the weight of cement. The result indicate that with fly ash and silica fume incorporation workability of fresh concrete decrease but with addition of chemical admixture the workability of the fresh concrete increases and the effect of segregation and bleeding are dramatically reduced.
b. The results of V funnel, J ring, and T50 cm slump flow tests indicates that with increase in replacement percentage of fly ash and silica fume and decrease in water – cement ratios an improvement in the workability occur.
c. It has been found that the workability is less for lower w/c ratios but gradually by the incorporation of chemical admixture it is found to have an dramatically increase in workability.
d. Replacement cement by fly ash and silica fume result in initial low early strength at 7 days due to low pozzolonic reaction of fly ash and silica fume, 28 days compressive strength ranges from 56 Mpa to 60 Mpa and high strength is possible to achieve with fly ash and silica fume incorporation in the mix.
e. The study reveals that the highest compressive strength of 60 MPa is attained with a low water-cement ratio of 0.28.and with the increase percentage of water – cementitious the value of the compressive strength is found to be reducing gradually.
f. Contribution of fly ash and silica fume in improving the strength of concrete has been found to be higher with low w/c ratio of 0.28 and the maximum compressive strength is found ranging from 56 to 60Mpa at 28 days.

g. From the study it has been observed that at 25% fly ash and 25% silica fume replacement with w/c ratio 0.35 and 500 kg/m^3 binder content it gives best result for the fresh properties of SCC and for same replacement at w/c ratio 0.28 and 500 kg/m^3 content it gives best result in strength test.
h. So it can be concluded that keeping the replacement percentage same and varying the w/c ratio from 0.30 to 0.28 and binder content from 500 to 525 kg/m^3 we can achieve High strength self-compacting concrete.

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