The Egyptian International Journal of Engineering Sciences and Technology

https://eijest.journals.ekb.eg/

Vol. 43 (2023) 19–31

DOI: 10.21608/eijest.2023.159306.1180

ISSN:1687-1006

Effect of Silica Fume and Fly Ash on Fresh and Hardened Properties of Self-Compact Concrete

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ARTICLE INFO

Article history:

Received 29 August 2022
Received in revised form 23 November 2022
Accepted 10 January 2023
Available online 11 January 2023

Keywords:

Self-Compacting Concrete
Super-Plasticiser
Silica Fume
Fly Ash
VMA Additions

ABSTRACT

Self-compacting concrete (SCC) is a leading concrete type with a superplasticizer and a stabilizer which remarkably eases and increases the flow rate to flow through complex geometrical configurations under its self-weight. All fresh concrete mixture groups are tested for slump flow test and L-Box test. While hardened concrete cubes, cylinders, and prism specimens are tested for compression, tension, and flexure respectively. Fresh results by using slump flow and L-box test to attain the Dm, T50, and PL, while the hardened results to get the compressive, tensile, and flexural strength. The main objective of this study is to evaluate the mechanical properties and behavior of SCC under different conditions of binder content, Viscosity-Modifying Admixture (VMA) ratios, and SA or FA ratios. Viscosity-modifying admixture (VMA) can be added as an alternative to adding more cement powder or supplementary cementitious materials to improve the cohesion and stability. The main parameters include; the binder content, fly-ash content, silica fume content, and the VMA addition ratios. To achieve this goal an experimental study is performed. Eighteen concrete mixes are prepared with various binder contents of 350,400, and 450 kg/m3, VMA addition ratios of 1, 1.5, and 2% and 15% of cement of replacement of silica fume and fly ash. In addition to the use of three different sizes form crushed dolomite. The mechanical properties were plotted versus the VMA ratios at binder contents of 350, 400, and 450 kg/ m3, at specific ratios of VMA (1%, 1.5%, and 2%) for 15% of SF and FA separately after 28days. Results exhibit that the mechanical properties improved by increasing the binder content and decreasing the addition ratio. Optimum cases for compressive strength at binder contents of 450 kg/ m3, VMA of 1%, and SF of 15%, and tensile strength at binder contents of 450 kg/ m3, VMA of 2%, and SF of 15%, and flexure strength at binder contents of 450 kg/ m3, VMA of 1%, and SF of 15%. Methods, results, and discussion are presented in detail

1. INTRODUCTION

Self-compacting concrete (SCC) is a flowing type of concrete mixture that consolidate under its self-weight [1]. It can be placed in hard conditions and in sections with congested reinforcement appropriately because of its highly fluid nature. Civil researchers continuously strive to improve the mechanical properties of self-compact concrete. SCC is vital to the production of concrete with appropriate high reinforcement and spaces that vibrators impossible to reach [2], [3]. Also, SCC assists in minimizing the inducing sound-related damage in construction areas by the vibration of concrete. Another benefit of SCC is that the needed time to place huge sections is relatively less [4]. The American Concrete Institute (ACI) (2007) states this type of concrete is “a highly flowable, non-segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation” [1]. In Japan during the 1980s, the construction industry faced a decrease in skilled labor. As a result, SCC is developed to overcome the issues of workmanship, primarily through Okamura’s research [4]. To study the features and properties of SCC through a fundamental study on concrete workability, a committee was established by Ozawa et al [5] at Tokyo University. In 1988, the first available self-

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compacting concrete was completed and named "High-Performance Concrete", and later suggested as "Self-Compacting High-Performance Concrete". In Japan, the volume of SCC in construction has risen steadily over the years [6]. Data show that the usage of SCC in the precast concrete industry is three times higher than that in the ready-mixed concrete industry this is due to the rising cost of SCC. In 2002, the evaluated average price of SCC provided by the RMC industry in Japan was 1.5 times that of conventional concrete [7]. The use of SCC offers many benefits to the construction practice. First, the elimination of the compaction work results in a shortening of the construction time and therefore improved productivity. Also, the application of SCC leads to a reduction of noise during casting, better working conditions, and the possibility of expanding the placing times in inner city areas. Other advantages of SCC are an improved homogeneity of concrete production and excellent surface quality without blowholes or other surface defects [8]. The fresh SCC essential features are those that influence the compacting process and also the properties that make SCC characterized from other types of concrete. The filling ability, passing ability, and segregation resistance are three fresh properties for SCC that must be protected while transporting and placing. All three properties are interconnected and relied on each other. Changing one property will lead to change in all others. Specifically, poor filling ability or high segregation resistance may lead to poor passing ability, i.e. blocking. So, SCC is regarded as a means between filling ability and segregation resistance [9]. The filling ability is defined as the concrete capability to move both horizontally and vertically freely under its self-weight. Without vibrating the concrete, SCC has to fill any space within the formwork without keeping air entrapped inside the concrete or at the surface. Passing ability is defined as the concrete capability to move openly within and also surrounding the heavy steel bars with no obstacle. In other words, the ability of the SCC to flow through tight openings such as spaces between steel reinforcing bars, under its own weight. Segregation resistance: concrete have to maintain its homogeneity when placed and flowing. There is no aggregate splitting from the mix or water from particles, and no need for coarse aggregate to go down in fresh concrete under gravity. In other words, the resistance of the components of SCC to migration or separation remains uniform throughout the process of transport and placing [10, 11, 12].

2. EXPERIMENTAL WORK

The experimental work aims to produce self-compact concrete to study the effect of mixed constituents on its mechanical properties for fresh and hardened concrete.

2.1 Materials

2.1.1 Cement

Cement is a binder, a substance that sets and hardens independently, and can bind other materials together. The most use of cement is the production of mortar and concrete for bonding natural or artificial aggregates to form a strong building material that is durable in the face of environmental effects. The cement that is utilized is a product from Sina cement Factory where Portland cement (I) of high grade 53 shows the cement used in this study. It is received in bags weighing 50 kg; stored on wooden plates in dry conditions to prevent possible setting caused by atmospheric moisture.

2.1.2 Aggregates

The coarse aggregate is crushed dolomite with three different sizes of 20mm, 10 mm, and 5 mm, and these different sizes are used in the self-compact concrete mixes.
The coarse aggregate has a specific gravity of 2.619 and water absorption of 0.96%. While, the fine aggregate is local siliceous sand having a specific gravity of 2.59, a fineness modulus of 3.10, and a dry unit weight of 1.68 (t/m3). The sand and crushed limestone used in this study are obtained from Abu-Zaabal quarries, where all aggregates are washed to remove dust, silt, clay, loam, organic materials, and any other possibly harmful substances.

2.1.3 Fly ash (FA)

The concrete rheology and microstructure are improved to a great level through the fly ash's physical properties. Fly ash makes the concrete denser, and so low permeability, primarily by lowering the need for water in concrete and enhancing the microstructure of concrete. In concrete, the percentage that is used by class F ash is 15% to 25% by mass of cementitious matter. It should be stored in dry conditions at room temperature and should not be affected by frost. Fly ash (class F) with Lower calcium, attained through Sika Company, consists of a light grey fine powder, owing specific gravity of 2.2. A sample is analyzed in the laboratory of the faculty of science at Zagazig University to attain its chemical properties. The chemical properties of fly ash (Class F) is shown in Table (1).

Table (1): Chemical properties of fly ash (Class F).

Property	Measured values (%)
SiO2	56.9
AL2O3	31.1
Fe2O3	6.07
CaO	1.3
MgO	0.97
SO3	0.05
Na2O	0.09
K2O	1.0
LOI	0.8
CL	0.04

2.1.4 Silica fume (SF)

Silica fume, obtained from Sika Company, consists of a grey fine powder with a specific gravity of 2.2. Silica fume should be stored in a dry environment, not sensitive to frost. Silica fume is added with the cement and aggregates at the batching plant before the gauging water. The optimum wet mixing time is 60 seconds. The advantages of silica fume are the high stability of green concrete, highly increased durability, increased ultimate strengths, increased abrasion resistance, increased water tightness, increased gas tightness, and reduced chloride penetration entrance results when an air entraining agent is used at once.

2.1.5 Super-plastisizer

Sika Viscorete, obtained from Sika Company at Al_oboor city, is a liquid brown color with a specific gravity of 1.1 t/m3 and the package weight is 5 kg.

2.2 Production of the S.C.C

A mechanical mixer is used to produce the self-compact concrete. Sand, crushed aggregate, and binder content (cement, silica fume, and fly ash) are mixed in the mixer pan for a period of 30 seconds, then water and VMA are added to the dry materials, and the mixing continued for another 3 to 4 minutes till a homogenous mix is produced. The inner surfaces of the wooden molds are well-oiled before placing and casting the concrete. After mixing, a slump flow and L-box test are conducted then fresh concrete is cast in the molds.

2.2.1 Mix design of SCC

In our study, the weight of a one-meter cube is approximately used to determine quantities in cubic meters for the materials required. The quantities for mix design are shown in Tables (2, 3, and 4).

Table (2): Binder content (350 kg /m3), silica fume 15%, fly ash 15 %, VMA 1, 1.5, 2 % - Sand/total aggregate is 45%, water content determinate as slump flow test.

Binder content	**Cement Kg/m3**	**Silica Fume Kg/m3**	**Fly Ash Kg/3**	**Water Kg/m3**	**Sand Kg/3**	**Gravel Kg/m3**			**VMA Kg/3**
						2.5-5 mm	**5-10 mm**	**10-14 mm**	
350	350	_	_	280	712	392	348	130	_
	298	53	_	280	681	374	333	125	3.5
	298	53	_	280	679	373	332	125	5.25
	298	53	_	280	677	373	331	124	7
	298	_	53	280	681	374	333	125	3.5
	298	_	53	280	679	373	332	125	5.25
	298	_	53	280	677	373	331	124	7

Table (3): Binder content (400 kg /m3), silica fume 15%, fly ash 15 %, VMA 1, 1.5, 2 % - Sand/total aggregate is 45%, water content determinate as slump flow test.

Binder content	**Cement Kg/m3**	**Silica Fume Kg/m3**	**Fly Ash Kg/3**	**Water Kg/m3**	**Sand Kg/3**	**Gravel Kg/m3**			**VMA Kg/3**
						2.5-5 mm	**5-10 mm**	**10-14 mm**	
400	400	_	_	320	647	356	316	119	_
	340	60	_	320	633	348	310	116	4
	340	60	_	320	631	347	308	116	6
	340	60	_	320	629	346	308	115	8
	340	_	60	320	633	348	310	116	4
	340	_	60	320	631	347	308	116	6
	340	_	60	320	629	346	308	115	8

Table (4): Binder content (450 kg /m3), silica fume 15%, fly ash 15 %, VMA 1, 1.5, 2 % - Sand/total aggregate is 45%, water content determinate as slump flow test.

Binder content	**Cement Kg/m3**	**Silica Fume Kg/m3**	**Fly Ash Kg/3**	**Water Kg/m3**	**Sand Kg/3**	**Gravel Kg/m3**			**VMA Kg/3**
						2.5-5 mm	**5-10 mm**	**10-14 mm**	
450	450	_	_	360	582	320	285	106	_
	383	68	_	360	566	311	277	104	4.5
	383	68	_	360	564	310	276	103	6.75
	383	68	_	360	561	308	274	103	9
	383	_	68	360	566	311	277	104	4.5
	383	_	68	360	564	310	276	103	6.75
	383	_	68	360	561	308	274	103	9

2.3 Test Procedure

All fresh concrete mixture groups are tested for slump flow test and L-Box test. While hardened concrete cubes, cylinders, and prism specimens are tested for compression, tension, and flexure respectively. Where a sample of all failure modes of different specimens is shown in Figure (1).

Figure (1): Machine and Samples used in the Experimental Test.

2.3.1 Slump flow test

Slump term defines the uniformity and consistency of fresh concrete. The slump of a mixed concrete sample is scaled in inches. It is defined by the universally accepted testing procedure described by ASTM designation C-143. Slump flow tests were performed by placing the fresh concrete into a metal mold having a cone shape. This slump cone has a bottom diameter of 8 inches, a top diameter of 4 inches, and a height of 12 inches with an opening at both ends. Foot pieces and handles were attached to the mold, and tests were carried out on a flat, hard, non-absorbent surface.

During the slump flow test, the viscosity of the SCC mixture can be estimated by measuring the time taken for the concrete to reach a spread diameter of 20 inches (500 mm) from the moment the slump cone is lifted up. This is called the flow time (T50) measurement and typically varies between 2 and 10 seconds for SCC. T50 is the time for the fresh concrete to reach a diameter of 500 mm after lifting the slump cone. Slump flow test– Gate type 1 with three group mixtures with different binder contents is shown in Table (5).

Table (5): Slump flow test– Gate type 1, three group mixtures with different binder contents.

Name Mixture	F.A/S.F ratio	D1	D2	Dm (Mean Diameter)	T50
350 S1	**15%**	67	53	60	5.8
350 S1.5	**15%**	70	65	67.5	2.2
350 S2	**15%**	70	68	69	5.9
350 F1	**15%**	27	30	28.5	4.6
350 F1.5	**15%**	33	35	34	5.2
350 F2	**15%**	40	42	41	2.22
400 S1	**15%**	71	75	73	2
400 S1.5	**15%**	75	75	75	4.99
400 S2	**15%**	78	79	78.5	4.5
400 F1	**15%**	35	30	32.5	2.3
400 F1.5	**15%**	40	35	37.5	4.5
400 F2	**15%**	45	42	43.5	2.3
450 S1	**15%**	80	75	77.5	4.5
450 S1.5	**15%**	83	76	79.5	4.23
450 S2	**15%**	85	79	82	3.52
450 F1	**15%**	40	38	39	2.9
450 F1.5	**15%**	40	42	41	1.53
450 F2	**15%**	45	48	46.5	2.32

2.3.2 L-box test

The method objective is to examine SCC passing ability. It determines the height that is attained by the fresh SCC after passing through the reinforcement gaps and moving with a well-known flow distance. With this reached height, the passing or blocking behavior of SCC shall be determined.

L-box, as shown in Figure (2), two gate types categories that could be utilized, three and two smooth bars with 41 and 59 mm gaps, respectively. Put L-box in a secure and horizontal position. Fill the vertical area of the L-box with 12.7 liters of symbolical fresh SCC considered as an additional adapter mounted. Let concrete stay in the vertical area for one minute. The concrete will exhibit if it is stable or not through this period. Bring up the moving gate to enable the flowing out of the concrete from the vertical area to the horizontal area of the L-box. Once the flow is ceased, the heights H1 and H2 should be measured –Determine the average distance, named as Δh, along the box top edge and the concrete after the concrete flow is finished. L-Box results – Gate type 1 with three group mixtures with different binder contents is shown in Table (6- 7). The passing ratio PL; or blocking ratio is calculated by equations (1) and (2).

$$PL=\frac{H}{Hmax} \qquad (1)$$

$$BL= 1-\frac{H}{Hmax} \qquad (2)$$

Figure (2): L-Box Test.

Table (6): L-Box results – Gate type 1, three group mixtures with different binder contents.

Name Mixture	F.A/S.F ratio	H1	H2	H3	Hm (Mean Height)	H2
350 S1	**15%**	8.5	8	9	8.5	6.5
350 S1.5	**15%**	9	8	8	8.3	6.7
350 S2	**15%**	7	7	8	7.3	7.7
350 F1	**15%**	11	10	10	10.3	4.7
350 F1.5	**15%**	10	9.5	9.5	9.67	5.3
350 F2	**15%**	9	9	9	9	6
400 S1	**15%**	8	7.5	8	7.83	7.17
400 S1.5	**15%**	7.5	7	7	7.17	7.83
400 S2	**15%**	7	6.5	6	6.5	8.5
400 F1	**15%**	10	9	10	9.6	5.4
400 F1.5	**15%**	8	9	9	8.67	6.33
400 F2	**15%**	8	8	8	8	7
450 S1	**15%**	7.4	7.5	7	7.3	7.7
450 S1.5	**15%**	7	6	6.5	6.5	8.5
450 S2	**15%**	6	6	6	6	9
450 F1	**15%**	9	9	10	9.3	5.7
450 F1.5	**15%**	8	8	9	8.3	6.7
450 F2	**15%**	7.5	7	8	7.5	7.5

Table (7): L-Box results – Gate type 1, three group mixtures with different binder contents.

Name Mixture	F.A/S.F ratio	H2	H1	60-H1	PL	BL
350 S1	**15%**	6.5	46	14	0.46	0.54
350 S1.5	**15%**	6.7	48	12	0.55	0.45
350 S2	**15%**	7.7	50	10	0.77	0.33
350 F1	**15%**	4.7	38	22	0.21	0.79
350 F1.5	**15%**	5.3	40	20	0.26	0.74
350 F2	**15%**	6	43	17	0.35	0.65
400 S1	**15%**	7.17	49	11	0.65	0.35
400 S1.5	**15%**	7.83	50	10	0.78	0.22
400 S2	**15%**	8.5	51	9	0.94	0.06
400 F1	**15%**	5.4	43	17	0.29	0.71
400 F1.5	**15%**	6.33	46	14	0.45	0.55
400 F2	**15%**	7	47	13	0.53	.47
450 S1	**15%**	7.7	51	9	0.86	0.14
450 S1.5	**15%**	8.5	51	9	0.94	0.06
450 S2	**15%**	9	51	9	1	0
450 F1	**15%**	5.7	45	15	0.38	0.62
450 F1.5	**15%**	6.7	47	13	0.52	0.49
450 F2	**15%**	7.5	48	12	0.63	0.38

3. RESULTS AND DISCUSSION

All fresh concrete mixture groups are tested for slump test and L-Box test. While hardened concrete cubes, cylinders, and prism specimens are tested for compression, tension, and flexure respectively. Fresh results by using slump flow and L-box test to attain the Dm, T50, and PL, while the hardened results to get the compressive, tensile, and flexural strength. The main objective of this study is to evaluate the mechanical properties and behavior of SCC under different conditions of binder content, VMA ratios, and SA or FA ratios. The main parameters include; the binder content, fly-ash content, silica fume content, and the VMA addition ratios. To achieve this goal an experimental study is performed. 18 concrete mixes are prepared with various binder contents of 350,400, and 450 kg/m3, VMA addition ratios of 1, 1.5, and 2% and 15% replacement of silica fume and fly ash. In addition to the use of three different sizes form crushed dolomite. The mechanical properties were plotted versus the VMA ratios at binder contents of 350, 400, and 450 kg/ m3, at specific ratios of VMA (1%, 1.5%, and 2%) for 15% of SF and FA separately after 28days.

3.1 Effect of Visco Modifying Admixture (VMA) on Filling Ability (Slump Flow DM &T50)

3.1.1 Silica fume (DM & T50)

Figure (3) plots the relationship between the mean diameter (DM) and the VMA additions at different binder contents of 350, 400, and 450 kg/m3, and an SF ratio of 15%. At a binder content of 350 kg/m3, SF ratio of 15%, and a VMA ratio of 1%, the DM of the SCC is 60 mm. As the VMA ratio increases to 1.5%, the DM increases to 68 mm. With the continuous increase in the VMA ratio to 2%, the DM increases to reach 69 mm.

There is also a slight improvement in the DM results by increasing the binder content to 400 kg/m3. In this case, the addition of VMA by 1% raises the DM to 73 mm, thus showing a notable increment compared to the previous case. Raising the VMA ratio to 1.5%; increases to become 75 mm. More substitution of VMA to 2% leads to a further increase in the DM to reach 79 mm.

Again a higher increase in the DM values at a binder content of 450 kg/m3, such that the substitution of VMA by 1% meets the increase in the DM value to 78 mm. The increment in VMA to 1.5%, leads to an increment in the DM of the SCC, meeting a value of 80 mm. More substitution of VMA to 2% leads to the maximum DM value at 82 mm.

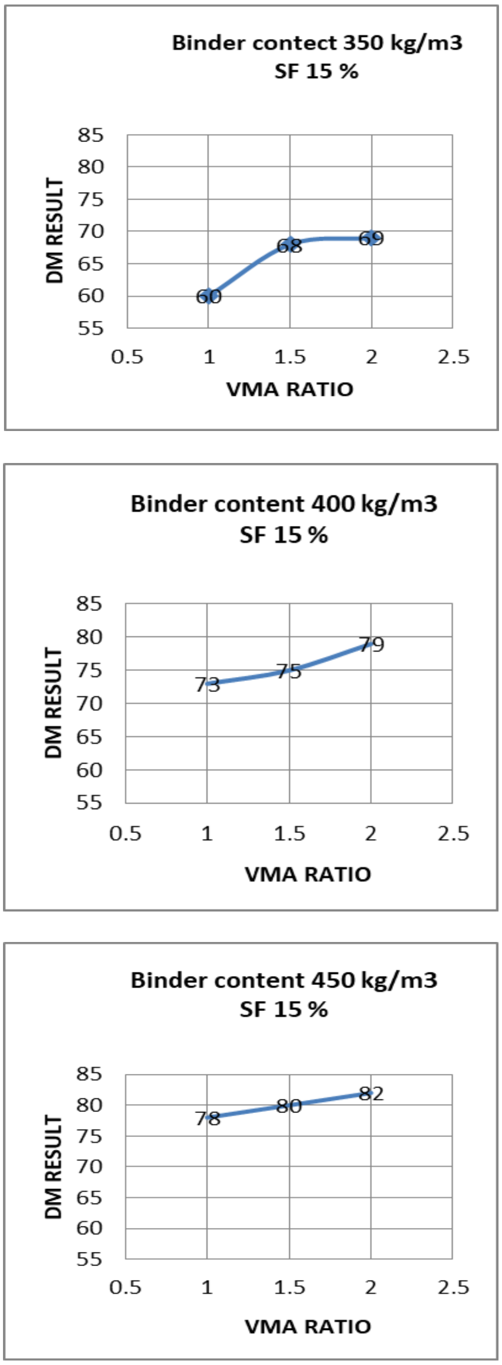


Figure (3): Relationship between DM and the VMA (% cement).

Figure (4) plots the relationship between T50 and the VMA additions at different binder contents of 350 kg/m3, 400 kg/m3, and 450 kg/m3, and an SF ratio of 15%.

At binder contents of 350 kg/m3, SF ratio of 15%, and VMA ratio of 1%, the T50 of the SCC is 5.8 sec. As the VMA ratio increases to 1.5%, the T50 decreases to reach 2.2 sec. With the continuous increase in VMA ratio to 2%, the T50 increases to become 5.9 sec.

There is also a slight improvement in T50 results by increasing the binder contents to 400 kg/m3. In this case, the substitution of VMA by 1% raises the T50 to 2 sec, and increasing the substitution of VMA to 1.5% shows an increase in T50 to 4.9 sec. More substitution of VMA to 2% leads to a further decrease in T50 to reach 4.5 sec.

Again a higher increase in the T50 values at a binder content of 450kg/m3, such that the substitution of VMA by 1% meets the T50 value at 4.5sec. The increment in VMA to 1.5%, leads to a decrease in the T50 of the SCC meeting a value of 4.23sec. With the continuous increase in VMA ratio to 2%, the T50 decreases to become 3.52sec.

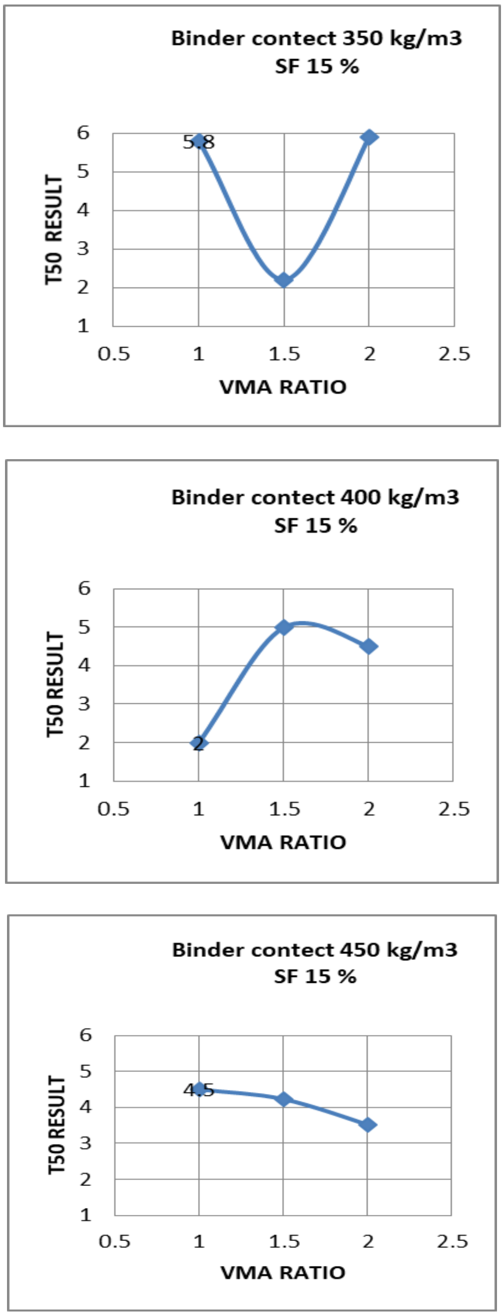


Figure (4): Relationship between T50 and the VMA (% cement).

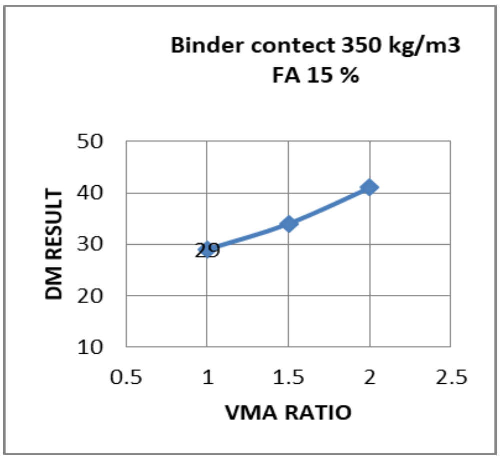
3.1.2 Fly ash (DM & T50)

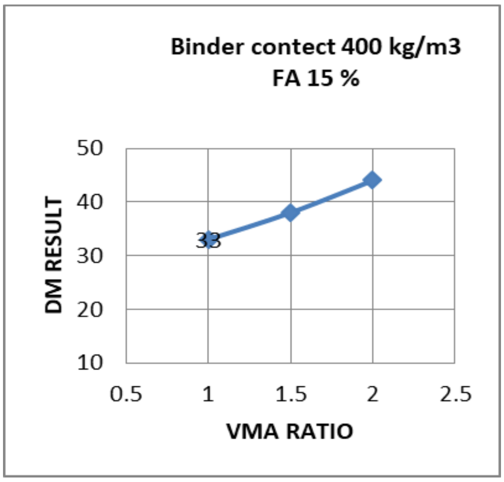
Figure (5) shows the effect of the same factors concerning the FA ratio of 15%. It plots the relationship between the DM and the VMA addition ratios at binder contents of 350, 400, and 450 kg/m3.

At a binder content of 350 kg/m3, FA ratio of 15%, and VMA ratio of 1%, the DM of the SCC reads 29 mm. The DM value is affected by increasing the VMA ratio to 1.5%, reaching 34 mm. Continues increase in VMA ratio to 2%, leads to DM increase to become 41mm.

An improvement is noticed again with a binder content of 400 kg/m3 and a VMA ratio of 1%, showing a DM of 33 mm. Increasing the substitution of VMA to 1.5% shows an increase in the DM to 38 mm. As the VMA ratio increases more to 2%, the DM increases to become 44 mm.

Optimum values of DM exist at a binder content of 450 kg/m3. With adding VMA by 1%, the DM reads 39 mm. By increasing the VMA ratio to 1.5%, the DM increases to 41 mm. Further increase in VMA ratio to 2% induces an increase in DM to reach 47 mm.





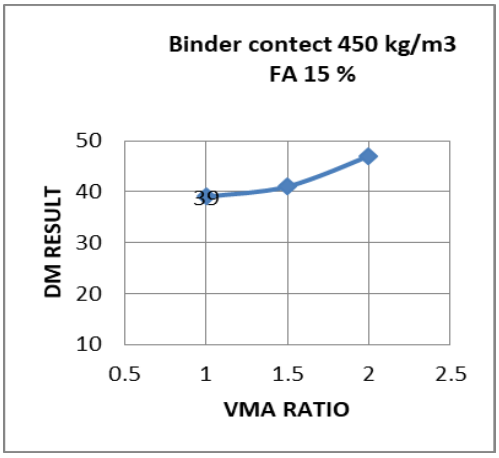
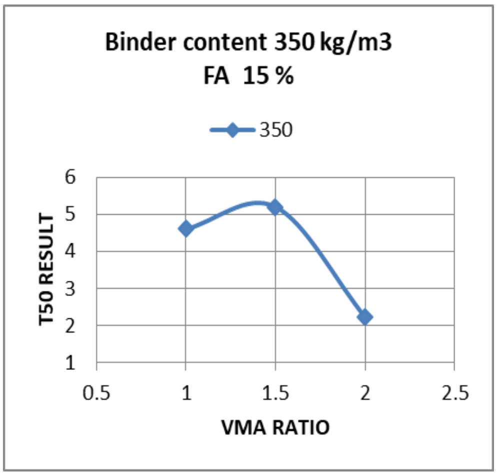


Figure (5): Relationship between DM and the VMA (% cement).

Figure (6) shows the effect of the same factors concerning the FA ratio of 15%. It plots the relationship between the T50 and the VMA addition ratios at binder contents of 350, 400, and 450 kg/m3. At a binder content of 350 kg/m3, FA ratio of 15%, and VMA ratio of 1%, the T50 reads 4.6sec. The value is affected by increasing the VMA ratio to 1.5%, meeting the value of 5.2 sec. The continued increase in the VMA ratio to 2%, leads to a decrease in T50 to become 2.22 sec.

Also, at a binder content of 400kg/m3 and a VMA ratio of 1%, the T50 value is 2.35 sec. Increasing the substitution of VMA to 1.5% shows an increase in the T50 to 4.5 sec. As the VMA ratio increases more to 2%, the T50 decreases and reaches 2.3 sec.

Optimum values of T50 exist at a binder content of 450 kg/m3, and with substituting of VMA by 1%, the T50 reads 2.9sec. By increasing the VMA ratio to 1.5%, the T50 decreases to 1.53sec. Further increase in VMA ratio to 2% induces an increase in T50 to reach 2.32Ssec.



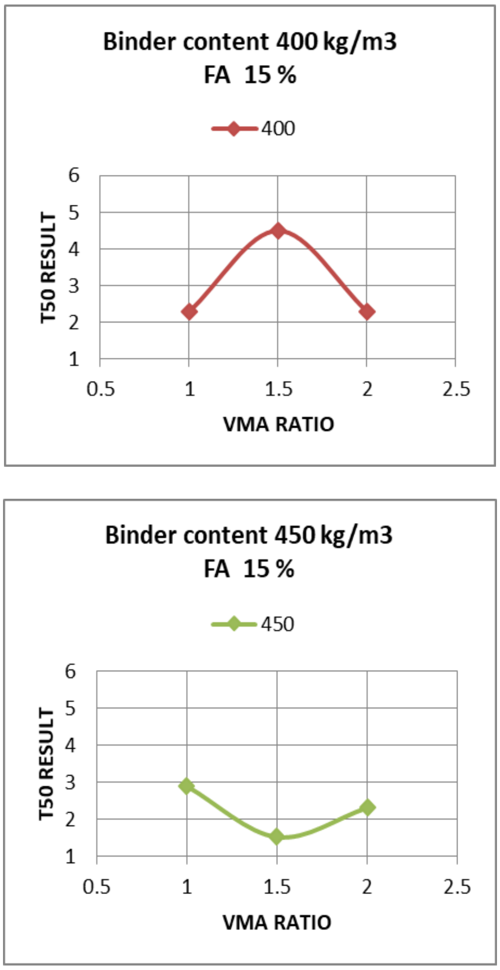


Figure (6): Relationship between T50 and the VMA (% cement).

3.2 Effect of Visco Modifying Admixture (VMA) on Passing Ability (L-Box test PL)

3.2.1 Silica fume (PL)

Figure (7) plots the relationship between PL and the VMA additions at different binder contents of 350 kg/m3, 400 kg/m3, and 450 kg/m3, and an SF ratio of 15%. At a binder content of 350 kg/m3 and a VMA ratio of 1%, the PL of the SCC is 0.46. As the VMA ratio increases to 1.5%, the PL increases to reach 0.55. With the continuous increase in the VMA ratio to 2%, the PL increases to become 0.77.

There is also a slight improvement in PL results by increasing the binder content to 400 kg/m3. In this case, the substitution of VMA by 1% raises the PL to 0.65. Increasing the substitution of VMA to 1.5% shows an increase in PL to 0.78. More substitution of VMA to 2% leads to a further increase in PL to reach 0.94.

Again a higher increase in the PL values at a binder content of 450 kg/m3. The substitution of VMA by 1% meets the PL value at 0.86. The increment in VMA to 1.5%, leads to an increase in the PL of the SCC meeting a value of 0.94. With the continuous increase in the VMA ratio to 2%, the PL increases to become 1.

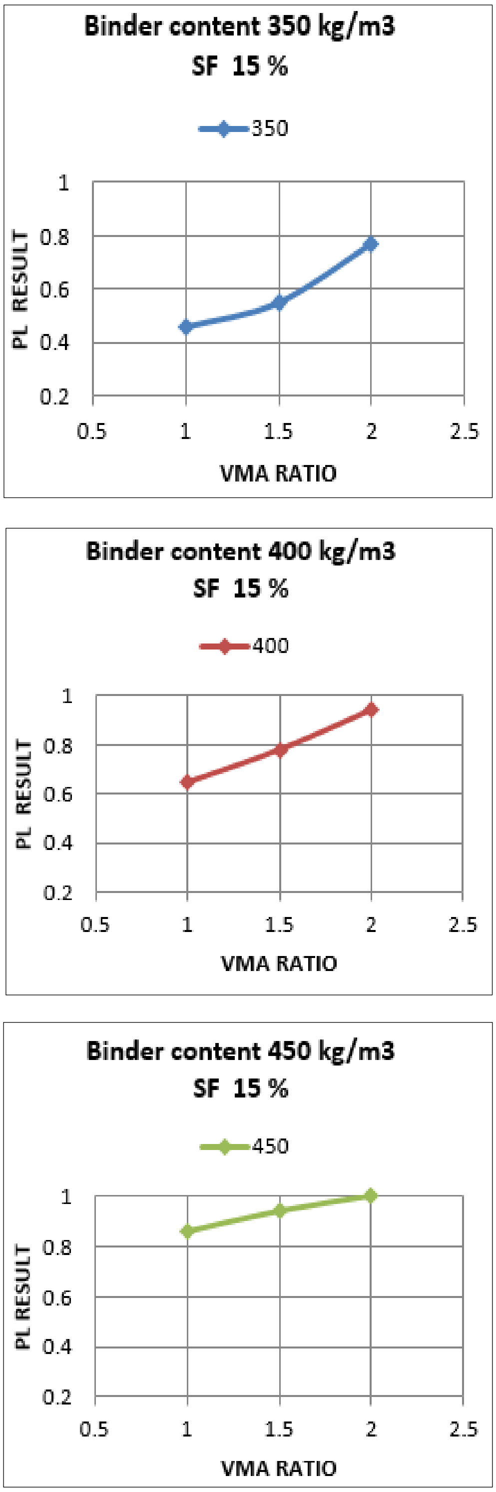


Figure (7): Relationship between PL and the VMA.

3.2.2 Fly ash (PL)

Figure (8) shows the effect of the same factors concerning the FA ratio of 15%. It plots the relationship between the PL and the VMA addition ratios at binder contents of 350, 400, and 450 kg/m3. At a binder content of 350 kg/m3 and a VMA ratio of 1%, the PL of the SCC reads 0.21. The value is affected by increasing the VMA ratio to 1.5%, reaching the value of 0.26 in PL. The continued increase in the VMA ratio to 2% leads to a PL increase to become 0.35. An improvement is noticed again with a binder content of

400 kg/m3. The VMA ratio of 1% gives a PL value of 0.29. Increasing the substitution of VMA to 1.5% shows an increase in the PL to 0.45. As the VMA ratio increases more to 2%, the PL increases and reaches 0.53.

Optimum values of PL exist at a binder content of 450 kg/m3. By substituting VMA by 1%, the PL reads 0.38. Also, increasing the VMA ratio to 1.5% increases PL to 0.52. Further increase in the VMA ratio to 2% induces an increase in PL to reach 0.63.

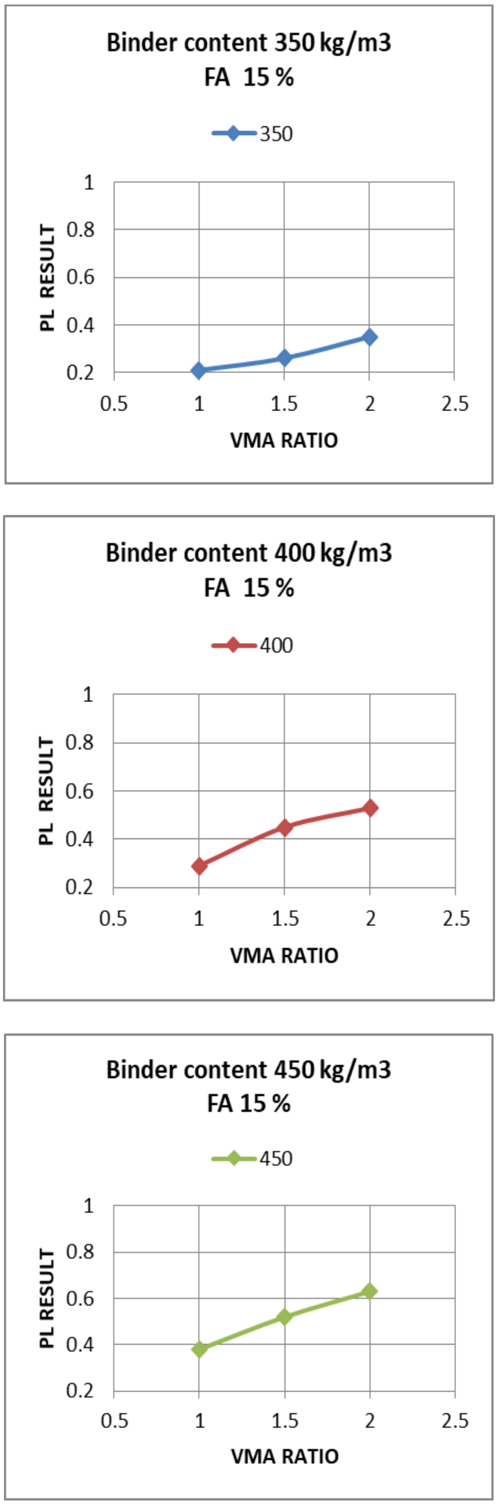


Figure (8): Relationship between PL and the VMA.

3.3 *Compressive Strength*

Table (8) shows the results of the compressive strength test for 7 and 28 days at binder contents of 350, 400, and 450 kg/m3, SF or FA ratio of 15%, and VMA ratios of 1%, 1.5%, and 2%.

Table (8): Compressive strength results.

Group	**Name mixture**	**Binder content (kg/m3)**	**S.F / F.A ratio**	**Compressive strength (MPa)**	
				7 days	**28 days**
Group (1)	G1S1	350	15%	35.50	38.50
	G1S1.5	350	15%	34.50	37.50
	G1S2	350	15%	31.00	34.00
	G1F1	350	15%	29.50	32.00
	G1F1.5	350	15%	27.00	29.50
	G1F2	350	15%	26.00	28.00
Group (2)	G1S1	400	15%	39.00	42.50
	G1S1.5	400	15%	38.50	42.00
	G1S2	400	15%	38.00	41.00
	G1F1	400	15%	29.50	32.00
	G1F1.5	400	15%	29.50	32.50
	G1F2	400	15%	28.50	31.00
Group (3)	G1S1	450	15%	41.00	44.50
	G1S1.5	450	15%	40.50	44.00
	G1S2	450	15%	39.50	44.00
	G1F1	450	15%	34.50	37.50
	G1F1.5	450	15%	34.00	36.50
	G1F2	450	15%	31.00	33.50

3.3.1 *Silica fume*

Figure (9) plots the relationship between the compressive strength and the VMA addition ratios (1%, 1.5%, and 2%) at different binder contents of 350, 400, and 450 kg/m3, and an SF ratio of 15%. At a binder content of 350 kg/m3 and a VMA ratio of 1%, the compressive strength of the SCC is 38.5 MPa. As the VMA ratio increases to 1.5%, the compressive strength decreases by 2.6% to 37.5 MPa. With the continuous increase in the VMA ratio to 2%, the compressive strength decreases by 11.7% to become 34 MPa.

There is also a slight improvement in the compressive strength results by increasing the binder content to 400 kg/m3. In this case, the substitution of VMA by 1% raises the compressive strength to 42.5 MPa showing a notable increment compared to the previous case. Raising the VMA ratio to 1.5%; decreases the compressive strength by 1.2% to become 42 MPa. More substitution of VMA to 2% leads to a further decrease of 3.5% in the compressive strength to reach 41 MPa.

Again a higher increase in the compressive strength values at a binder content of 450 kg/m3, such that the substitution of VMA by 1% meets the maximum compressive strength value at 44.5 MPa. The increment in VMA to 1.5%, leads to a 1.2% decrement in the compressive strength of the SCC meeting a value of 44 MPa, which remains stable despite raising the VMA to 2%.

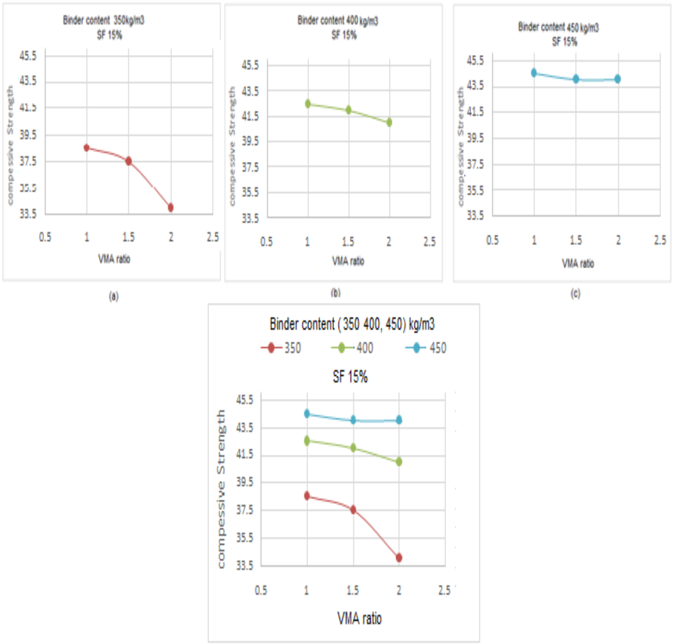


Figure (9): Compressive Strength at VMA Addition Ratios (1%, 1.5%, 2%), SF (15%) and Binder Contents of (350, 400, 450) kg/ m3 for 28 days.

3.3.2 *Fly ash*

Figure (10) shows the effect of the same factors concerning the FA ratio of 15%. It plots the relationship between the compressive strength and the VMA additions ratios at binder contents of (350, 400, and 450) kg/ m3. At a binder content of 350 kg/ m3, FA ratio of 15%, and VMA ratio of 1%, the compressive strength of the SCC reads 32 MPa. The value is affected by increasing the VMA ratio to 1.5%, and a decrement (7.8%) is observed meeting the value of 29.5 MPa in compressive strength. The continued increase in the VMA ratio to 2%, leads to compressive strength decrement (12.5%) to become 28 MPa. An improvement is noticed again with binder contents of 400 kg/m3 and a VMA ratio of 1% showing compressive strength of 32 MPa. Increasing the substitution of VMA to 1.5% shows a slight increase in the compressive strength to 32.5 MPa by (1.01%). As the VMA ratio increases more to 2%, the compressive strength decreases (3.1%) and reaches 31 MPa. Better values of compressive strength exist at a binder content of 450 kg/m3, and with the substitution of VMA by 1% the compressive strength reads 37.5 MPa. By increasing the VMA ratio to1.5%, the compressive strength decreases to 36.5MPa with a decrement (2.66%). Further increase in the VMA ratio to 2% induces decrement (10.66%) in the compressive strength to 33.5 MPa. These results show that the optimum case is at binder contents of 450 kg/ m3, VMA of 1%, and SF of 15%.

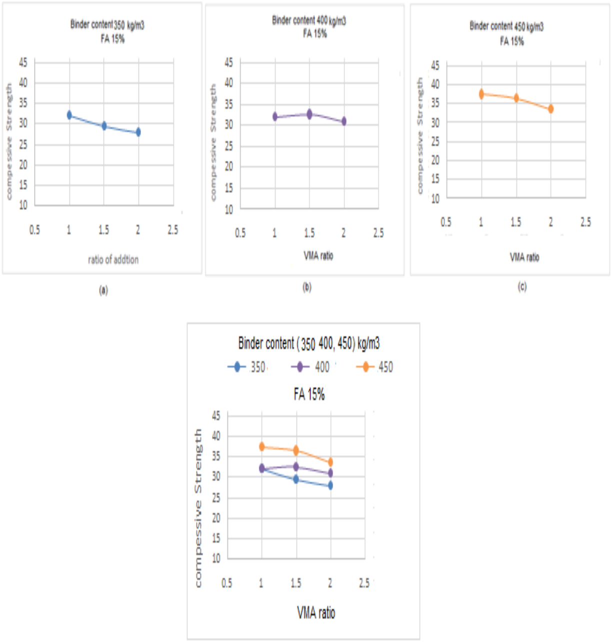


Figure (10): Compressive Strength at VMA Addition Ratios (1%, 1.5%, 2%), FA (15%) and Binder Contents of (350, 400, 450) kg/ m3 for 28 days.

3.4 *Tensile Strength*

A total of 54 cylindrical specimens of diameter 100 mm and height 200 mm are cast with different binder contents and VMA addition ratios. Table (9) shows the effect of binder contents (350, 400, 450 kg/m3), (SF or FA) ratio (15%), and VMA ratios (1%, 1.5%, 2%) on the tensile strength at an age of 28 days.

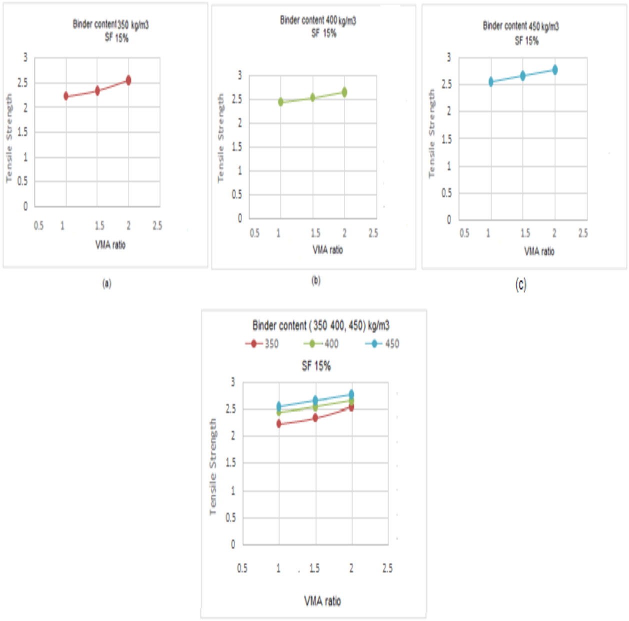
Table (9): Tensile strength results.

Group	**Name mixture**	**Binder content (kg/m3)**	**S.F / F.A ratio**	**Tensile strength (MPa)**
Group (1)	G1S1	350	15%	2.23
	G1S1.5	350	15%	2.336
	G1S2	350	15%	2.548
	G1F1	350	15%	1.699
	G1F1.5	350	15%	1.805
	G1F2	350	15%	1.911
Group (2)	G1S1	400	15%	2.442
	G1S1.5	400	15%	2.548
	G1S2	400	15%	2.654
	G1F1	400	15%	2.017
	G1F1.5	400	15%	2.23
	G1F2	400	15%	2.336
Group (3)	G1S1	450	15%	2.548
	G1S1.5	450	15%	2.654
	G1S2	450	15%	2.761
	G1F1	450	15%	2.124
	G1F1.5	450	15%	2.336
	G1F2	450	15%	2.336

3.4.1 Silica fume

Figure (11) plots the relationship between the tensile strength and the VMA additions at different binder contents of 350 kg/ m3, 400 kg/ m3, and 450 kg/ m3, and an SF ratio of 15%.

At binder contents of 350 kg/ m3, SF ratio of 15%, and VMA of 1%, the tensile strength is found to be 2.23 MPa. The increment in the VMA by 1.5%, leads to a tensile strength increment of (1.04%) and becomes 2.336 MPa. The addition of VMA by 2%, drives the tensile strength to increase by (1.14%) to become 2.548 MPa. A higher value of tensile strength 2.442 MPa is observed by increasing the binder contents to 400 kg/m3 and substitution of VMA by 1%. An increment in VMA ratio by 1.5% is associated with an increment in the tensile strength by (1.04%) to become 2.548 MPa. Further increment in the VMA ratio by 2% increases the tensile strength by 1.08% to 2.654 MPa. A tensile strength value of 2.548 MPa is obtained at a binder content of 450 kg/m3 and VMA of 1%. As VMA increases to 1.5%, the tensile strength increases to 2.654MPa by a ratio of 1.04%. Further increase in the VMA to 2% is associated with an increase in tensile strength by 1.08% to 2.761 MPa.



(a) (b) (c)

Figure (11): Tensile Strength at VMA Addition Ratios (1%, 1.5%, 2%), SF (15%) and Binder Contents of (350, 400, 450) kg/ m3 for 28 days.

3.4.2 Fly ash

Figure (12) shows the relationship between the tensile strength and the VMA additions at different binder contents of (a) 350 kg/ m3, (b) 400 kg/ m3, (c) 450 kg/ m3, and the FA ratio of 15%. The figure shows a value of tensile strength as 1.699 MPa at binder contents of 350kg/m3, SF ratio of 15%, and VMA of 1%. This value increases by (1.06%) to 1.805 MPa as VMA increases to 1.5%. The increment reaches (1.12%) to 1.911 MPa as VMA rises to 2%. In the same figure, the tensile strength meets a value of 2.017 MPa at a binder content of 400 kg/m3; and a VMA ratio of 1%. As the VMA ratio increase to 1.5%, the tensile strength increases also to 2.23 MPa by a ratio of 1.1%. This value increases to 2.336 MPa by a ratio of 1.16% as VMA increases by 2%. At a binder content of 450 kg/m3, and a VMA ratio of 1% the tensile strength reads 2.124MPa. The increment in VMA to 1.5% drives the tensile strength to increase to 2.336 MPa by a ratio of 1.1%. The tensile strength shows stability as the VMA increases to 2%.

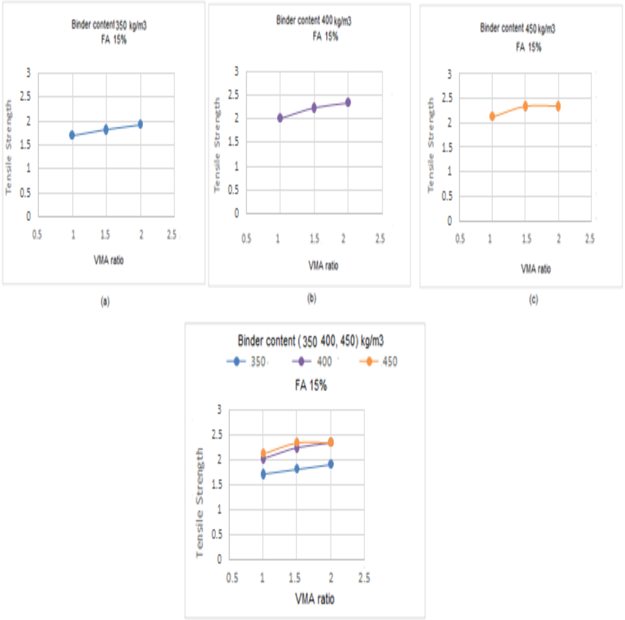
These results show that the optimum case is at binder contents of 450 kg/ m3, VMA of 2%, and SF of 15%. It is also observed that the tensile strength is proportional to the compressive strength according to equation (3) as follows:

$$Ft=0.08Fcu \quad (3)$$

Where:

Ft: tensile strength in MPa, and

Fcu: cube comp. strength in MPa.



(a) (b) (c)

Figure (12): Tensile Strength at VMA Addition Ratios (1%, 1.5%, 2%), FA (15%), and Binder Contents of (350, 400, 450) kg/ m3 for 28 days.

3.5 Flexural Strength

The effect of binder contents (350, 400, 450kg/m3), SF or FA ratio (15%), and VMA ratios (1%, 1.5%, 2%), on the flexural strength at an age of 28 days are shown in Table (10).

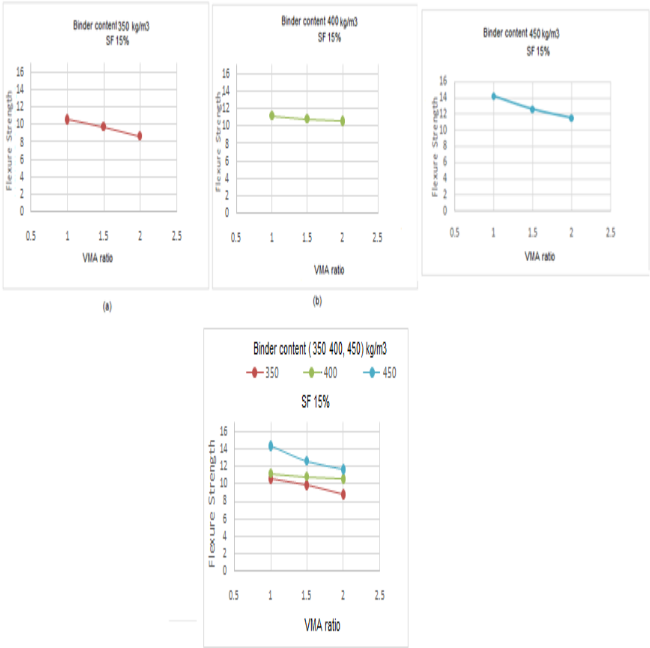
Table (10): Results of flexural strength.

Group	Name mixture	Binder content (kg/m3)	S.F / F.A ratio	Flexural strength (MPa)
Group (1)	G1S1	350	15%	10.50
	G1S1.5	350	15%	9.75
	G1S2	350	15%	8.70
	G1F1	350	15%	9.30
	G1F1.5	350	15%	8.40
	G1F2	350	15%	7.50
	G1S1	400	15%	11.10
	G1S1.5	400	15%	10.80

Group (2)	G1S2	400	15%	10.50
	G1F1	400	15%	12.60
	G1F1.5	400	15%	11.85
	G1F2	400	15%	10.20
Group (3)	G1S1	450	15%	14.25
	G1S1.5	450	15%	12.60
	G1S2	450	15%	11.55
	G1F1	450	15%	13.20
	G1F1.5	450	15%	12.30
	G1F2	450	15%	11.70

3.5.1 Silica fume

Figure (13) describes the relationship between the flexural strength at different binder contents of 350 kg/ m3, 400 kg/ m3 and 450 kg/ m3, SF ratio of 15%, and VMA additions (1%, 1.5%, 2%). At binder contents of 350 kg/ m3, SF ratio of 15%, and VMA of 1%, the flexure strength reads 10.50 MPa. When VMA increases by 1.5%, the flexure strength decreases by (7.14%) and meets 9.75 MPa. More decrement is achieved by (17.14%) to reach 8.70 MPa at a VMA of 2%. The figure shows also a flexure strength value of 11.10 MPa at binder contents of 400 kg/m3 and a VMA of 1%. With the increment in VMA ratio by 1.5%, the flexure strength decreases to 10.80 MPa by (2.7%). Further decrement in the flexure strength by (5.4%) to 10.50 MPa as the VMA ratio rises to 2%. It also displays the flexure strength value of 14.25 MPa at a binder content of 450 kg/m3 and VMA of 1%. As VMA increases to 1.5%, the flexure strength decreases to 12.60 MPa by a ratio of 11.57%. Further decrement in the flexure strength to 11.55 MPa by (18.94%) occurs as VMA rises to 2%.



(a)

(b)

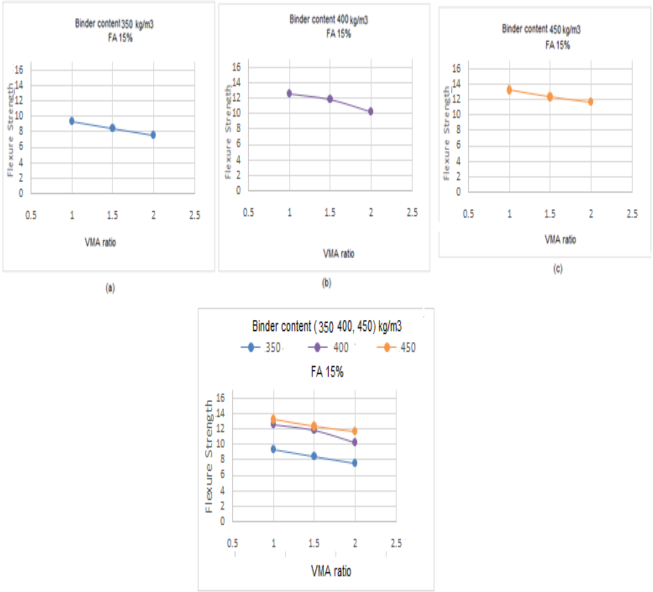
Figure (13): Flexural Strength at VMA Addition Ratios (1%, 1.5%, 2%), SF (15%) and Binder Contents of (350, 400, 450) kg/ m3 for 28 days.

3.5.2 Fly ash

Figure (14) plots the relationship between the flexural strength at the binder contents of 350 kg/ m3, 400 kg/ m3 and 450 kg/ m3, SF ratio of 15%, and VMA additions (1%, 1.5%, 2%). In the figure, with binder contents of 350 kg/m3, SF 15%, and VMA 1%, the flexure strength is 9.30 MPa. As VMA rises to 1.5%, the flexure strength decreases by (9.67%) and meets 8.40 MPa. More decrement is achieved by (19.35%) to reach 7.50 MPa at a VMA of 2%. Flexure strength of 12.60 MPa is observed at binder contents of 400 kg/m3 and VMA of 1%. With the increment of the VMA ratio by 1.5%, the flexure strength decreased by (5.95%) to 11.85 MPa. Further decrement in the flexure strength to 10.20 MPa by (19.04%) occurs at a VMA ratio of 2%. Moreover, a flexure strength of 13.20 MPa exists at a binder content of 450 kg/m3 and VMA of 1%. As VMA increases to 1.5%, the flexure strength decreases to 12.30 MPa by a ratio of 6.81%. Further decrement in the flexure strength to 11.70 MPa by (11.36%) occurs as VMA rises to 2%. These results show that the optimum case is at binder contents of 450 kg/ m3, VMA of 1%, and SF of 15%. It is also observed that the relation between flexure strength and compressive strength can be represented by equation (4) as follows:

$$Fb = 0.2\ Fcu \qquad (4)$$

Where:
Fb: flexural strength in MPa, and
Fcu: cube compressive strength in MPa.



(a)

(b)

(c)

Figure (14): Flexural Strength at VMA Addition Ratios (1%, 1.5%, 2%), FA (15%) and Binder Contents of (350, 400, 450) kg/ m3 for 28 days.

4. CONCLUSIONS

The obtained results and observations of this study drew the following conclusions:

1. The ratio of fine aggregate to total aggregate in the mix design should be between 0.45-0.50 to get a perfect flow for SCC and avoid the accumulation of concrete behind the reinforcement.
2. The directly proportional between VMA and DM with increasing the binder content lead to an increase in the flow of SCC inside the formwork.
3. The directly proportional between the binder content and DM lead to an increase in the workability of SCC in the case of adding silica fume and fly ash.
4. There was an improvement in values of T50 when the binder content increased.
5. With increasing the binder content, PL is increasing.
6. L-Box test stated improvements in the properties of concrete by adding silica fume and fly ash in the concrete mix design.
7. The mechanical properties optimum cases for compressive strength at binder contents of 450 kg/ m3, VMA of 1%, and SF of 15%, and tensile strength at binder contents of 450 kg/ m3, VMA of 2%, and SF of 15%, and flexure strength at binder contents of 450 kg/ m3, VMA of 1%, and SF of 15%.
8. A relation could be derived between the compressive and tensile strength, and between the compressive and flexure strength.

References

[1] ElGawady M. A., "Shear behavior of reinforced fly ash-based geopolymer concrete", Journal of Construction and Building Materials, 2016.

[2] Sooriyaarachchi v., "Influence of Fine Aggregate Types on the Performance of Self - Compacting Concrete", Journal of the Institution of Engineers, Sri Lanka, pp. 9-20 ،2016.

[3] Nehemiya K. and Rao T., "Experimental investigation on studying the flexure behavior of geopolymer concrete slab under fixed Boundary condition", IJRET Vol. 5, pp. 2321-7308, 2016.

[4] Lokuge W., Wilson A., Gunasekara C., Law D.W., and Setunge S., "Design of fly ash geopolymer concrete mix proportion using multivariate adaptive regression spline model", Construction and Building Materials, Australia, pp. 472-481,2018.

[5] Annamalai S., Thirugnanasambandam S., and Muthumani K., "Flexural behavior of geopolymer concrete beams cured under ambient temperature", Asian journal of civil engineering, India, pp. 621-631, 2016.

[6] Shehab H. K., Eisa A. S., and Wahba A. M., "Mechanical properties of fly ash based geopolymer concrete with full and partial cement replacement", construction and building materials, pp. 560-565, 2016.

[7] Maghsoudi A., Mohamadpour S., and Maghsoudi M., "Mix design and mechanical properties of self-compacting lightweight concrete ", International Journal of Civil Engineering, may 2011.

[8] Davidovits J., "Chemistry of geopolymseric systems, terminology." in: The Proceedings of Geopolymere ‘99, St. Quentin, France, pp. 9-39, 1999.

[9] ACI Committee, American Concrete Institute and International Organization for Standardization, 2008. Building code requirements for structural concrete (ACI 318-08) and commentary. American Concrete Institute.

[10] Sarker P. K., Haque R., and Ramgolam K.V., "Fracture behaviour of heat cured fly ash based geopolymer concrete", Materials & Design, vol. 44, pp. 580-586, 2013.

[11] Bažant Z.P., and Becq-Giraudon E., "Statistical prediction of fracture parameters of concrete and implications for choice of testing standard", Cement and Concrete Research, 32(4), pp. 529-556, 2002.

[12] Buchwald A., and Schulz M., "Alkali-activated binders by use of industrial by-products", Cement and Concrete Research, 35(5), pp. 968-973, 2005.