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Creation of High Strength Concrete Using Local Materials

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صناعة خرسانة عالية المقاومة من المواد المحلية

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Abstract:
The present study aims to investigate the feasibility of creating high strength concrete (HSC) utilizing local resources. HSC mixture ratios were created with regional resources to increase affordability for a broader range of uses. The practical program was divided into two parts. The objective of the initial section was to create HSC without silica fume by utilizing sand from two different sources, Zliten and Algable Algurby. To enhance the workability of the fresh concrete, various ratios of superplastizer were combined with a low water-cement ratio (w/c). The findings indicated that the greatest compressive strength occurred with w/c ratio of 0.35 and superplasticizer of 1.8, achieving 52.6 and 63.7 MPa at 28 and 90 days, respectively. The objective of the second phase was to produce HSC by utilizing materials found locally along with silica fume, with varying percentages of 15, 20, 25, and 30% utilized as substitutes for cement. The findings showed that the application of silica fume significantly enhanced the compressive strength at later stages. The highest compressive strengths achieved were 93.5 and 97.6 MPa for HSC containing 25% silica fume as cement replacement materials, recorded at 28 and 56 days, respectively.

Keywords: High strength concrete, Compressive strength, Super plasticizer, Silica fume.

الملخص
تهدف هذه الدراسة الى انتاج خرسانة عالية المقاومة باستخدام مواد متوفرة محليا وذلك من اجل تقليل تكاليف صناعة الخرسانة عالية المقاومة. لإنجاز هذا العمل البحثي تم تقسيم البرنامج العملي الى قسمين: الجزء الاول: الهدف منه هو تحديد مدى تأثير نوع الرمل المستخدم والمورد من مصدرين مختلفين على تشغيلية الخرسانة وعلى مقاومة الضغط للخرسانة حيث استخدمت نسب ماء الى اسمنت منخفضة مع نسب متفاوتة من الملذن (0.6%, 1%, 1.4%, 1.8%) وبدون استخدام غبار سيليكا. الجزء الثاني: يدرس تحديد النسبة الأمثل لغبار السليكا التي تنتج خرسانة عالية المقاومة حيث تم استخدام نسبة ماء الى اسمنت ثابتة 0.3 وكذلك نسبة ملذن 1.8% في الخلطات الخرسانية مع نسب متفاوتة من غبار السيليكا (15%, 20%, 25%, 30%) مع عمل خلطة مرجعية والتي لا تحتوي على غبار السليكا (0.0%). النتائج المتحصل عليها اوضحت انه يمكن الحصول على خرسانة ذات مقاومة عالية نسبيا بدون استخدام غبار السيليكا عند نسبة ماء الى اسمنت 0.35 ونسبة ملذن 1.8% حيث بلغت مقاومة الضغط 52.6 و 63.7 ميجا باسكال عند عمر 28 و 90 يوما على التوالي. أما في وجود مادة غبار السيليكا فقد بلغت مقاومة الضغط للخرسانة 93.5 و97.6 ميجا باسكال بعد 28 و56 يوما على التوالي، واوضحت الدراسة البحثية أن نسبة 25% من مادة غبار السليكا هي أفضل نسبة للحصول على خرسانة عالية المقاومة.

الكلمات المفتاحية: خرسانة عالية المقاومة، مقاومة الضغط، ملدن فائق، غبار السيليكا.

1. Introduction

In recent years, HSC has significantly increased in civil engineering uses. There are several advantages to use HSC, especially in tall buildings. This involves a decrease in member size, a decrease in self-weight and super-imposed dead loads, resulting in cost savings due to smaller foundations. A reduction in formwork area and construction expenses for tall buildings leads to lower real estate costs in crowded regions. Supporting the same load magnitude necessitates fewer beams when longer spans are used. Compression members experience reduced axial shortening and require fewer supports and foundations as spans are increased. Reducing the thickness of floor slabs and supporting beam sections, which are major factors in the weight and cost of structures, also decreases. Furthermore, improved long-term performance is observed in static, dynamic, and fatigue loading, as well as low creep and shrinkage.

Concrete is categorized according to its compressive strength into normal (ordinary) concrete, high-strength concrete, and ultra-high-strength concrete. After a period of 28 days, high-strength concrete shows a compressive strength surpassing 40 MPa, whereas ultra-high-strength concrete displays a compressive strength exceeding 120 MPa. To attain a compressive strength exceeding 40 MPa, it is necessary to decrease porosity by minimizing the water/cement ratio to 0.4 or lower [1,2]. Generally, superplasticizer is utilized to reduce the water-binder ratio, while supplementary cementing materials such as fly ash, silica fume, or natural pozzolan are employed to enhance strength via a pozzolanic reaction, resulting in high-strength concrete. The construction industry has shown an increasing interest in using high strength concrete (HSC) for projects such as dams, bridges, and skyscrapers.

This is due to the significant structural, economic, and architectural advantages that HSC provides when compared to conventional normal strength concrete (NSC). Although high strength concrete is often regarded as a contemporary material, its evolution has taken place slowly over a long duration. The criteria for determining the minimum strength value of high-strength concrete have evolved over the years and vary by location, shaped by the availability of materials, technical knowledge, and market demand [3].

Beginning with a value of 34 MPa in the 1950s in the United States and progressing to higher values, ACI 363, 1999 defines a minimum of 51 MPa for high strength concrete. In 2001, Committee 363 established the definition of HSC as concrete with a defined compressive strength for design of 55 MPa or more. When the initial version of ACI 363R was published in 1992, ACI Committee 363 established the definition of HSC as concrete with a specified compressive strength of 41 MPa or higher. The revised value of 55 MPa by (ACI 363R-10 and modified in 2018) was chosen because it reflects a strength level that necessitates particular attention during the production and testing of the concrete and may require special structural design considerations. The production of HSC might require particular materials, but it certainly requires the finest quality materials and the best properties [4]. Creating HSC that consistently meets the standards for workability and strength growth requires more stringent material selection criteria than those for lower strength concrete. However, numerous trial batches are often needed to gather the data essential for researchers and professionals to identify the optimal mix ratios for HSC.

Careful selection of premium materials and a blend of patterns result in concrete that possesses high strength. Due to the very low water-to-cement ratio of 0.25 to 0.35, this concrete generally has low water-binder ratios, requiring superplasticizers to ensure adequate workability. Usually, mineral additives such as slag, fly ash, natural pozzolans, and silica fume (commonly called microsilica or condensed silica fume) are efficiently employed in making high-strength concrete. Nonetheless, various studies have shown that silica fume excels over other admixtures because of its much smaller particles and a notably greater amount of amorphous silica when compared to other siliceous substances [5, 6]. A study indicated that the addition of 5% and 10% silica fume boosts the compressive strength after 28 days by 9.6% and 24.8%, respectively, whereas a 5% silica fume addition led to a rise of 22.7% [7]. In the experiment, silica fume replaced 10% of the cement while the water-to-cementitious materials ratio remained at 0.5. This adjustment resulted in an approximate increase of 10% in compressive strength and 5% in indirect tensile strength, respectively [8]. In high-performance concrete, the water-to-cement ratio generally ranges from 0.28 to 0.38. For ultra-high-performance concrete, this ratio may be lowered to below 0.2. The maximum compressive strengths observed were 165.6 MPa for UHSC with steel fibers and 161.9 MPa for UHSC without them [9].

Numerous studies [10-17] have indicated that including silica fume in concrete, depending on ratio of w/c and the percentage of silica fume, improves its strength and durability. Weak aggregates restrict strength development, while strength is enhanced by smaller size and robust aggregates. Compressive strength is mostly unchanged by fibers, while flexural and tensile breaking strengths usually rise [18].

In this research, the present study aims to explore the feasibility of creating high-strength concrete utilizing locally sourced materials available in Libya. The ideal proportions of superplasticizer and silica fume will be established to create high-strength concrete locally.

2. Experimental Program

In order to fulfill the objectives of this research study, one hundred and fifteen concrete mixtures were created and evaluated. Various types of sand were utilized to examine their influence on workability and compressive strength with differing ratios of chemical admixtures (superplasticizers) ranging from (0.0 - 1.8) and excluding silica fume. For the mixes that included silica fume and superplasticizer, the silica fume powder varied from (0.0 - 30) percent as a substitute for cement content. Water curing was considered until the test specimens were collected.

2.1 MATERIALS

2.1.1 Cement:

In concrete mixtures, cement acts as a binding agent. This research utilizes Ordinary Portland Cement (OPC) and complying with LSS 340/2009 and EN 197-1-2000. The color of the cement is grey and it has a specific gravity of 3.15. The compressive strength of the tested 28-day mortar is 42.5 MPa. The results obtained from the OBC experiment are presented in Table 1.

Table 1: Test results of OBC.

Test	Result		Specification
	hour	minute	
Initial setting time	2	32	Not less than 45 min
Final setting time	4	18	Not more than 10 hours
Com. Strength “3 days”	20 N/mm^2		Not less than 16 N/mm^2
Com. Strength “7 days”	30 N/mm^2		Not less than 24 N/mm^2

2.1.2 Fine aggregate

The dimension of fine aggregate is established to be either equal to or less than 4.75 mm. In simpler terms, all aggregates that can fit through a number 4 sieve with a mesh size of 4.75 mm are categorized as fine aggregates. This group includes substances like clay, silt, and sand. To investigate the impact of fine aggregate on compressive strength, two fine aggregate sources were utilized (Zliten and Algable Algurby) with specific gravities of 2.69 and 2.65, respectively.

2.1.3 Coarse aggregate:

In this research, stones obtained from crushed rocks serve as coarse aggregate and are sourced from nearby quarries in the Al-Azizyah city area. The largest aggregate size was 20 mm and it possesses a specific gravity of 2.67. The aggregates are made up of clean, resilient, and sturdy particles that do not have coatings or absorbed fine material substances, such as clay.

2.1.4 Water

Potable water, which is suitable for human consumption, was employed in this investigation for sample curing and mixing.

2.1.5 Chemical admixtures (super plasticizer)

For this study, a super plasticizer known as sikament-163 M has been utilized to achieve workable concrete with a low water-to-binder ratio, which complies with the standards set by BIS: 9103-1999, BS: 5075-part3, and ASTM C494.

2.1.6 Silica fume

Silica fume, an outcome of producing silicon metal or ferrosilicon alloys, is an extraordinarily fine non-crystalline form of SiO2. It is created at a temperature close to 2000°C and acts as a superb substance for filling pores. The specific gravity of silica fume can vary from 1.3 to 1.4 based on its chemical composition. Table 2 presents the chemical analysis results of silica fume. Compared to regular Portland cement particles, the particles of silica fume are approximately 100 times smaller. Due to its chemical composition and very tiny silica particles, it is an exceptionally reactive pozzolanic material. Cementitious and pozzolanic properties can both be present. The silica fume particles are spherical in shape and very small, averaging 0.1–0.3 µm in size. SF is frequently utilized in high-performance and ultra-high-performance concrete, including blends for bridge decks and high-strength pre-stressed beams.

Table 2: Chemical analysis of silica fume.

Element	Sio_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O	SO_3
%	97	0.5	0.2	0.2	0.5	0.5	0.2	0.15

3. Results and Discussions

The research was carried out in two segments: the first phase consisted of formulating 100 concrete blends to examine the effect of fine aggregate on compressive strength both with and without incorporating silica fume and superplasticizer. The subsequent phase included pouring 15 distinct concrete mixes, created to showcase the effect of silica fume on compressive strength when used with a superplasticizer.

3.1. Effect of fine aggregate

To achieve high strength concrete using local materials, the initial step involved assessing the impact of fine aggregate on compressive strength and workability, utilizing cubic steel molds to conduct compression tests on the samples. In concrete mixtures, two types of sand were utilized: Zliten and Algabl Algurby. Secondly, adjust the water-to-cement ratio in each scenario; the third step involved utilizing varying proportions of chemical additives in the concrete mixtures.

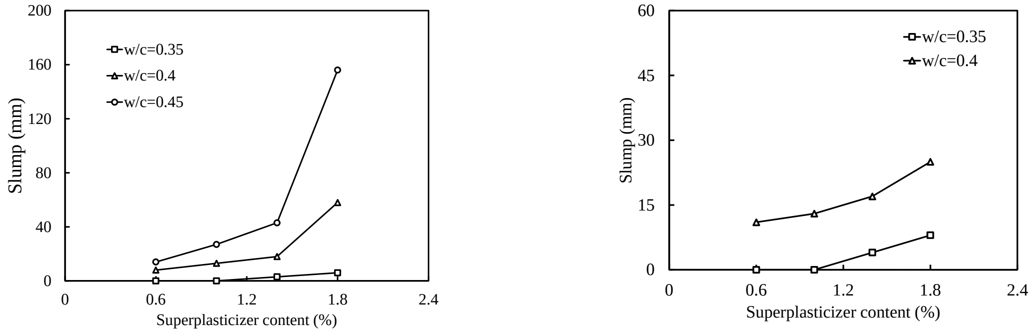
3.1.1 Influence of fine aggregate from Zliten

The experimental program includes three categories of concrete mixtures (A, B, and C), each with varying w/c ratios of (0.35, 0.4, and 0.45). In every instance, the superplasticizer proportions were adjusted for each w/c ratio at (0.0, 0.6, 1.0, 1.4, and 1.8) percent of the cement weight. Table 3 presents the outcomes of cube tests alongside the slump test and compressive strength. Reducing the w/c ratios results in a decrease in workability. A blend lacking superplasticizer and with a w/c ratio of zero results in difficult workability, while all other mixtures have been created with the superplasticizer.

Table 3: Effect of sand (Zlietn) on compressive strength.

Series	w/c	Sample No.	SPZ ratio	Slump mm	Compressive strength (N/mm^2)			
					7 days	28 days	56 days	90 days
A	0.35	A0	0.0	0.0	44.3	56.8	60.3	63.3
		A1	0.6	0.0	40.8	47.1	51.2	54.3
		A2	1	0.0	45.2	51	56.3	59.1
		A3	1.4	3	44	53.1	58.1	61.2
		A4	1.8	6	43	49.2	55	58.6
B	0.4	B1	0.6	8	40.2	46.1	49.2	52.8
		B2	1	13	42.6	50.2	52	53.7
		B3	1.4	18	38.8	44.7	49.4	51.5
		B4	1.8	58	40.2	46.1	47	48.2
C	0.45	C1	0.6	14	38.5	45	47.7	49.5
		C2	1	27	36.7	43.1	48.3	51.2
		C3	1.4	43	33.2	40.1	45.2	47.6
		C4	1.8	156	31.6	37.2	37.9	42.2

Figure 1 illustrates how w/c ratios combined with varying SPZ contents affect fresh concrete, as determined by the slump test, indicating that a ratio of 1.8 provided the optimal percentage for achieving reasonable workability in all mixes. The performance of fresh concrete was largely dependent on the proportion of additives added to the concrete mixes where the values of slum tests were recorded 6, 58, and 156 mm at w/c ratios of 0.35 %, 0.4 %, 0.45 % respectively. On the other hand, the compressive strength was slightly affected by chemical additives.



(a) (b)

Figure 1: Effect of fine aggregate on the workability: a) Zliten, b) Algable Algurby.

The uniaxial compressive strength of concrete, often referred to as "the compressive strength of concrete," is the fundamental property of concrete and is the term most frequently utilized in concrete mechanics. Design relies on a type of concrete, which is evaluated through basic standard tests involving standard-sized cubes or cylindrical samples. The samples are formed in steel molds and go through a designated curing process. And at ages of 7, 28, 56, and 90 days of curing, the specimen is positioned in a testing device and examined under uniaxial compressive load. Figure 2 illustrates the fracture behaviour of cubes subjected to maximum load .Where a displacement-controlled loading approach is utilized to exert a progressively rising compressive load. The loading process continues until damage occurs and advances to the stage of specimen failure. The uniaxial compressive strength of concrete is characterized as the greatest compressive force applied to the specimen.

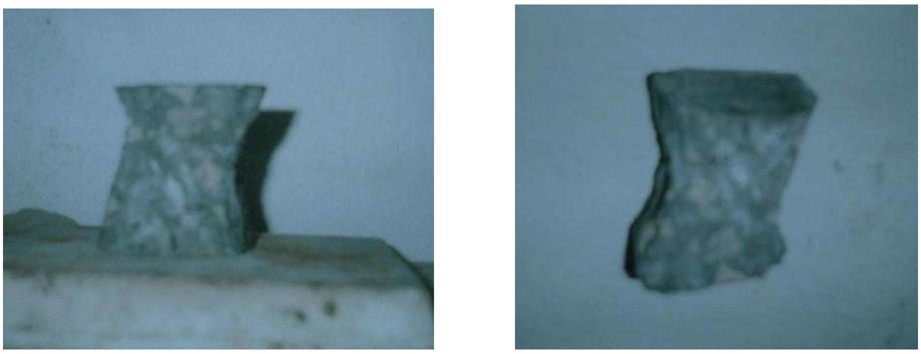
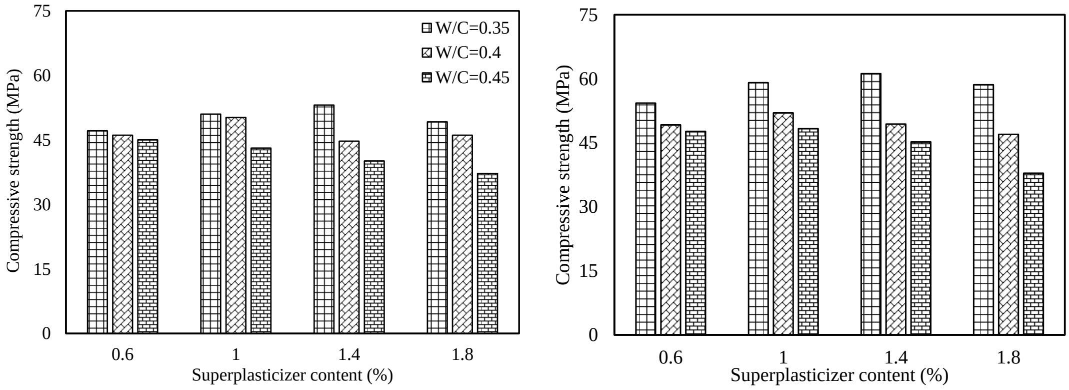


Figure 2: Failure pattern of cubes under the ultimate load.

Figure 3 shows the comparison of compressive strength at (28 and 90 days) for mixtures A, B, and C with water-to-cement ratios of 0.35, 0.4, and 0.45 accordingly. Utilizing this form of fine aggregate resulted in enhanced compressive strength, achieving the high strength concrete category as per the ACI Code, except for mixes C3 and C4, which have a w/c ratio of 0.45 and include superplasticizers of 1.4 and 1.8. The mix results indicated enhancements in compressive strength at (1.4, 1, and 0.6) for w/c ratios of (0.35, 0.4, and 0.45) respectively. The maximum compressive strength of the concrete mix was observed with a w/c ratio of 0.35, achieving 53.1 and 61.2 MPa at 28 and 90 days, respectively.



(a) (b)

Figure 3: Compressive strength using sand (Zliten): a) 28 days, b) 90 days.

3.1.2 Influence of fine aggregate from Algable Algurby

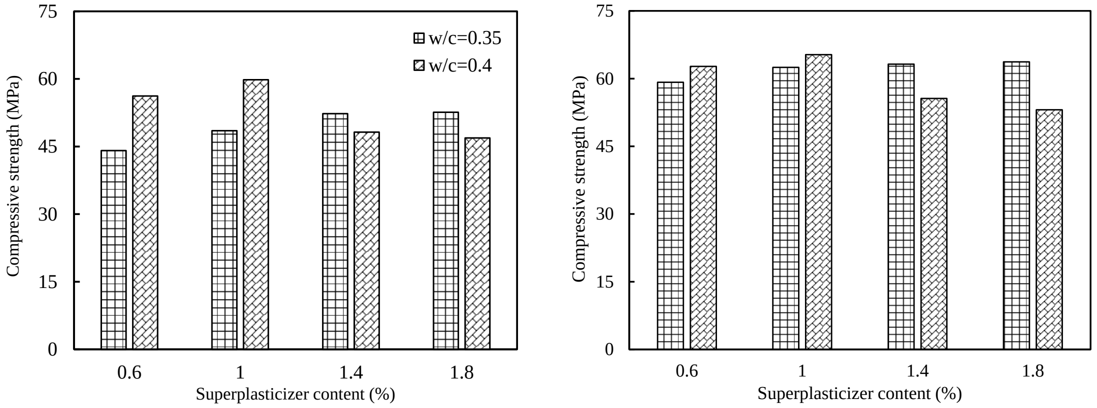
To examine the impact of fine aggregate from Algabe Algurby, the experimental concrete mix program was categorized into two groups (D and E), featuring w/c ratios of 0.35 and 0.4 % as shown in Table 4. The 0.45 percent was nullified because of the feeble resistance shown by the earlier outcomes. The concrete mixtures in this study followed a consistent approach regarding the ratio of superplasticizer, as well as the mixing and curing techniques applied. Figure 1.b illustrates how varying the percentage of superplasticizer impacts workability. The findings matched the outputs of concrete mixes A, B, and C, indicating that raising the w/c ratio and superplasticizer enhanced workability, while it's worth noting that concrete mixtures using Zliten sand achieved superior results with identical mixture components.

Table 4: Effect of sand (Algable Algurby) on compressive strength.

Series	**w/c**	**Sample No.**	**SPZ ratio**	**Slump mm**	**Compressive strength (N/mm^2)**			
					7 days	28 days	56 days	90 days
D	0.35	D1	0.0	0.0	41.8	50.4	63.3	66.2
		D2	0.6	0.0	41.5	44.1	56.2	59.2
		D3	1.0	0.0	41.1	48.5	52.2	62.5
		D4	1.4	4	40.3	52.3	59.6	63.2
		D5	1.8	8	40.8	52.6	59.8	63.7
E	0.4	E1	0.0	9	41.3	51.7	56	59.4
		E2	0.6	11	42.8	56.2	59.3	62.7
		E3	1.0	13	44.8	59.8	62.7	65.3
		E4	1.4	17	39.1	48.2	52.2	55.6
		E5	1.8	25	39.7	46.9	50.8	53.1

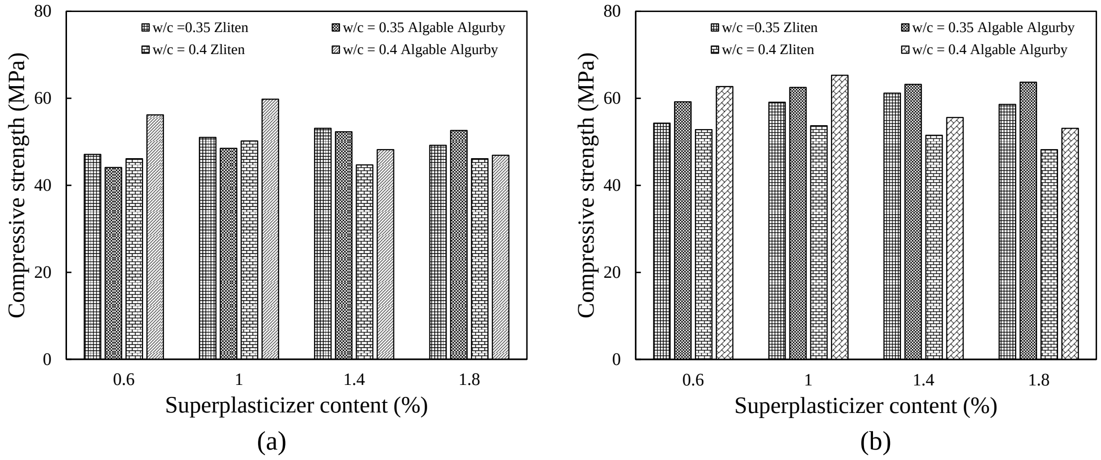
Figure 4 illustrates the impact of fine aggregate sourced from the Algable Algurby area on the compressive strength at both 28 and 90 days, with water-to-cement ratios of 0.35 and 0.4 designated as (D and E) respectively. All concrete mixtures include plasticizers (sikament-163 M) and exclude silica fume. The compressive strength obtained from these local materials was within the designated range according to the ACI Code for high-strength concrete. The findings indicated that the maximum compressive strength occurred at a w/c ratio of 0.35 and a superplasticizer dosage of 1.8, achieving 52.6 and 63.7 MPa at 28 and 90 days, respectively. Conversely, the minimum compressive strength was noted at a water-cement ratio of 0.4 with a plasticizer content of 1.8 percent. Thus, raising the water content in the concrete mixture results in concrete that has low compressive strength.

The earlier study indicates that minor variations are observed based on the type of sand utilized, as demonstrated in Figure 5. With a w/c ratio of 0.35, the compressive strength achieved with Zliten sand at superplastizer ratios of 0.6 %, 1 %, and 1.4 % exceeded that of Algable Algurby sand; however, at a 1.8 % superplastizer ratio, the compressive strength for Algable Algurby sand experienced a slight enhancement as illustrated in Figure 5 (a). At 90 days, the compressive strengths with Algable Algurby sand demonstrated favorable results for all scenarios involving superplasticizer and w/c ratios, as shown in Figure 5 (b), with the concrete's compressive strength attaining 66.2 MPa. The variation in compressive strength between the two sand types, expressed as a percentage, is between 3 and 7%. This difference may be disregarded based on the sand supply costs and its proximity to the construction site.



(a) (b)

Figure 4: Compressive strength using sand (Algable Algurby): a) 28 days. b) 90 days



(a) (b)

Figure 5: Compressive strength depending on the sand used: a) 28 days. b) 90 days

3.2 Effect of silica fume

In this section of the study, the ideal amount of silica fume is examined with a fixed superplasticizer percentage of 1.8 relative to the weight of cement, and w/c equals 0.3. Several concrete mixtures were formulated using silica fume as a substitute for cement at percentages of 15%, 20%, 25%, and 30% by weight, with strength testing performed at 7, 28, and 56 days, as shown in Table 5. During mixing, it was noted that silica fume enhances the workability of concrete mixtures. All mixes containing silica fume exhibited relatively improved workability and easier casting capabilities compared to mix (F), which lacked silica fume. Figure 6 illustrates the influence of silica fume content on workability, with the greatest recorded slump of 135 mm occurring at 20% silica content.

The results show that incorporating silica fume in mortar to substitute a portion of cement greatly improves the bond strength between the cement paste and aggregate by boosting compressive strength. The strength of mortar is improved by partially substituting cement with silica fume and incorporating superplasticizer; whereas the strength of cement paste stays unchanged. Figure 7 demonstrates the compressive strength at 7, 28, and 56 days with silica fume replacing cement at different proportions of 15%, 20%, 25%, and 30% by weight.

Table 5: Effect of silica fume on the compressive strength

Mix	Silica fume %	Slump mm	Compressive strength (MPa)		
			7 days	28 days	56 days
F	0	5	55.1	65.1	68.5
G	15	108	62.2	73.6	75.4
H	20	135	68.2	77.8	82.2
I	25	95	75.3	93.5	97.6
J	30	68	66.5	93	95.3

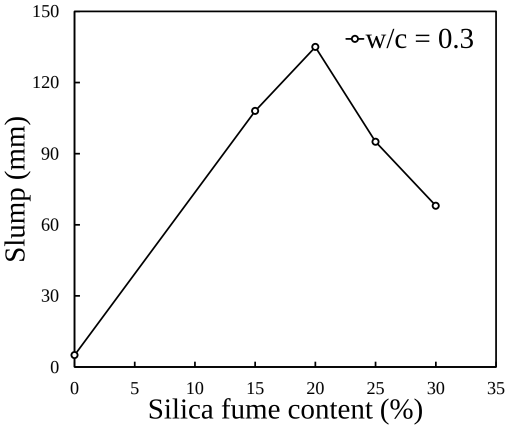


Figure 6: Effect of silica fume content on the workability

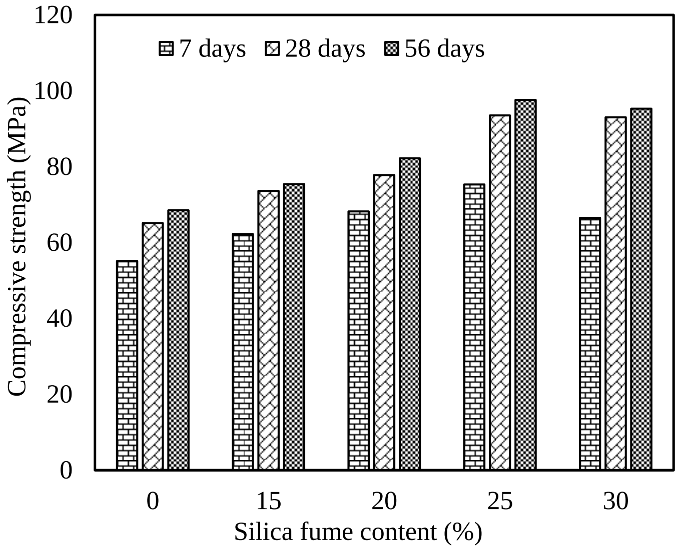


Figure 7: Effect of silica fume content on compressive strength.

The findings showed that incorporating silica fume significantly enhanced the compressive strength at later ages. It is evident that the compressive strength of concrete mixtures enhanced with an increase in silica fume content up to 25%, after which it began to decline for all mixes. At 7, 28, and 56 days, the compressive strength improved, incorporating 25% as cement replacement materials, with the maximum compressive strength noted. After 7 days, the compressive strength attained values of 62.2, 64.1, and 75.3 MPa when substituting 15 %, 20 %, and 25 % of the cement content, respectively. This strength kept rising and registered 73.6, 77.8, and 93.5 MPa at the same prior ratios of silica fume content following 28 days of curing, respectively. The compressive strength of concrete mixtures at 56 days was noted to be 75.4, 82.2, and 97.6 MPa with identical proportions of silica fume content, respectively. The blend lacking silica fume demonstrated the lowest levels of compressive strength. Thus, utilizing higher amounts of silica fume may result in an ineffective and costly method, as employing 30% silica fume caused a reduction in compressive strength, which was measured at 66.5, 93, and 95.3 MPa at 7, 28, and 56 days, respectively.

4. Conclusion

Based on the findings of this study, the following conclusions can be made:

- The compressive strength of concrete varies depending on the amount of water content and chemical admixtures; therefore, trial concrete mixes should be made to determine the ratio of water to cement and superplastizer to obtain the required resistance.
- The fine aggregate supplied from Zliten gives good workability and improving the compressive strength.
- It is possible to obtain high strength concrete using local materials and without silica fume.
- Silica fume enhances the workability of fresh concrete and 20% as replacement of cement content produces the highest slump.
- Using 25 % silica fume as a replacement of cement content and water-cement ratio of 0.3 creates the highest compressive strength of concrete where reached 93.5 and 97.6 MPa at ages of 28, and 56 days respectively.
- The possibility of producing high strength concrete using locally available materials in Libya; therefore, lowering the expenses associated with manufacturing high strength concrete.
- The technique for producing this type of concrete includes eliminating coarse aggregates and using coarse fine aggregate.

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