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Influence of Curing Duration on the Ordinary and High Compressive Strength of Concrete Containing Silica Fume

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ABSTRACT

The Impact of silica fume existence and its content with the duration of curing on concrete compressive strength (ordinary and high) has investigated experimentally. Two mixture sets were done in this work to examine the concrete ordinary and high strength. Every set involved four mixtures with varied silica fume proportions as a substitution of cement with (0, 5, 10 and 15 percent). Ninety-six cubes of concrete were prepared and cured by immersion in water to the required age (7, 28, 90 and 150 days). In ordinary concrete and high strength concrete, the results demonstrate that when silica fume used as a substitution with 15 %, the compressive strength of concrete gave the highest value. As compared with concrete having nil content of silica fume, the earned strength for high compressive concrete consisting of silica fume was relatively less than the corresponding ordinary concrete strength. However, continuously curing with water after 28 days produced a considerable increase in the compressive strength of concrete; such an increase in compressive strength was greater in the existence of silica fume.

1. Introduction

Concrete compressive strength is considered as one of the most crucial characteristics of structural materials. Several parameters may influence the progress of concrete strength like curing; which is extremely important for the strength and concrete durability. The prime factors for sufficient curing are the duration of wet curing and the curing temperature. In general, the hydration rate is governed by the cementitious material amounts and the quality of these materials in the mixture; the moisture content of the mixture and the temperature of the surrounding atmosphere (**Tasdemir, 2003**). The strength will increase at an early stage because of the temperature rise during the concrete placing and setting. Later, when it is kept in water curing at about 21°C, then, high temperature will undesirably influence the concrete strength due to the variation of concrete physical and mechanical properties (**Cakir and Akoz, 2008**).

The condensed silica fume can be considered as an effective pozzolan. In the concrete matrix, silica fume is presented to interact together with free lime, and consequently, this will enhance the concrete performance. Silica fume named as silica dust or micro silica, which is a secondary output the silicon manufacturing or alloys ferrosilicon (**Khedr and Abou-Zeid, 1994**). During the production process, the fume of silica will condense on filters that mounted at the gases escaping exit, this done as protection provision of the environment. Silica fume consists of relatively high silicon dioxide (SiO_2) content (85-97%) with a tiny magnitude of magnesium (iron and alkali oxides) (**Yunsheng and Chung, 2000**). The specific surface area of silica fume which varied between 15,000 to 20,000 m^2/kg, is considered a super fine when it's compared to the specific surface area of cement (200-500 m^2/kg). Moreover, the high content of silica dioxide causes an enhancement in the pozzolan activity. Three mechanisms are utilized to blend the silica fume as a substitution of cement in the concrete mixture, these are:

1- directly adding to the cement,
2- partial substitution with an equal weight of cement, and
3- partial substitution with less weight of cement.

The first mechanism is utilized if a high strength of concrete is required. While the second mechanism is utilized to save the content of cement and gain a concrete with high quality. Since a high quality of concrete results by using substitution by 1:1, it is likely to utilize silica fume to minimize the cost of concrete with similar quality by minimizing the content of cement and substituting it with a lower quantity of silica fume; this which demonstrates the third mechanism (**Khedr and Abou-Zeid, 1994**). In this work, the third technique is used.

Many studies were made to examine the influence of silica fume and

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curing conditions on the compressive strength for different kinds of concrete. At age of 7 days, Detwiler and Mehta obtained that the silica fume effect on the concrete compressive strength might be mainly referred to physical influences, while at the age of 28 days, the chemical and physical influences become considerable (**Detwiler and Mehta, 1989**). Various characteristics of silica fume are experimentally studied on concrete by (**Bayasi and Zhou, 1993**) such as air content, flexural strength, slump, and permeability. The influence of SF replacement, aggregate content and water-binder are discussed. Khayat et al. Claimed that the utilization of blended silica fume cement increases cohesiveness and strength, reduce permeability, and enhances scaling resistance (**Khayat et al., 1997**). Yogendran et al. Found in 28 days, that when 15 percent of cement is substituted by silica fume, a concrete with high-strength (50 to 70 MPa) could be obtained (**Yogendran et al., 1987**). While Bhanja and Sengupta reported that for the strength at 28 days, the substitution with optimum percentage depending on the water-cement ratio in the mixture which is found to be varying from 15 to 25 percent (**Bhanja and Sengupta, 2003**). A comparison is made by (**Ganeshbabu and Suryaprakash, 1995**) for the gained efficiencies from past investigations outcomes on the lower silica fume grade. It has found that the values suggested for efficiency are of lower limits; however, it could be achieved for higher efficiencies by using an adequate mix proportioning. A study designed by (**Cong et al., 1992**) to demonstrate the silica fume function on the concrete strength and its ingredient materials. They found that if a silica fume is utilized as a substitution of cement, the compressive strength is increased. While variation in the interface of paste-aggregate induced by silica fume show to have a minor influence on the concrete compressive uniaxial strength. Salonika and Lamacska modified a general form of Abrams and Bolomey familiarization to anticipate the complexity of the results gained from experimental studies on concrete involving silica fume (**Slanicka and Lamacska, 1991**). The empirical dependences were elaborate graphically into plain holograms. Then, it is easy to evaluate the composition effect on the concrete strength which consisting of silica fume. The moderate formulas of Abrams and Bolomey exhibited the non-linear effect of the silica fume amount on the concrete strength. Kim et al. Presented concrete undergoes to a relatively higher temperature during the early stage of the concrete age. It is found that the concrete earns higher strength (early-age), but lately earns lower strength (later-age), while when the concrete undergoes to a relatively lower temperature during the early age produces to lower strength early-age, but the later-age strength almost the same. (**Kim et al., 1998**). Yazici made a quantitative investigation of silica fume crushed fly ash and crushed granular stove slag with the Portland cement (**Yazici, 2007**). The cement was subrogated with fly ash or furnace slag, while the quartz and basalt powder is employed in the mixture as an aggregate. Three various manners of curing are used (standard, steam and autoclave curing). The outcomes of the test showed that concrete with high strength could be gained in the case of using high mineral volume, and the strength may be reached to 170 MPa. Raheem established that the curing moist sand manner at 28-days made concrete samples in a relatively high compressive strength pursue by the method of burlap curing. On the other hand, air curing manner exhibited a reduction of 15% in strength at 21-days, but unfortunately, the resulting compressive strength at 28 days is the lowest (**Raheem et al., 2013**). Akinwumi and Gbadamosi investigate the influence of curing ages and the manner of curing, using a tropical environment, on the progress of the compressive strength of concrete made by ordinary Portland cement. Cubes of concrete were cured by inundation in lime water, inundation with potable water, wet rug covering, plastic sheets covering and finally air-drying method. Their results discourage the air-drying, curing manner and refer to limiting for using of the other curing manner during only about 28-days (**Akinwumi and Gbadamosi, 2014**).

The prime goal of this study is to examine the trace of the curing period and the content of silica fume on the compressive strength using various amounts of silica fume in concrete mixtures for ordinary and high strength. The development of ordinary and high compressive strength of concrete having different silica fume contents (0, 5, 10 and 15% replacement), and cured by immersion in potable water for 7, 28, 90 and 150 days, is to be investigated.

2. Characteristics of used materials

In this investigation, the curing duration influence and various silica fume contents on the concrete compressive strength was studied in earlier and later ages. Available local materials were used in this work such as gravel, sand, cement and an imported silica fume. The concrete was cured by immersion in potable water for 7, 28, 90 and 150 days to realize the continuous curing effect above 28 days.

2.1 Aggregate

In this work, the (fine and coarse) aggregate were utilized from the available local sand and gravel. The fine and coarse aggregate physical characteristics are shown in Table 1.

Table 1- Characteristics of fine and coarse aggregate

Property	Value	
	Fine Aggregate	Coarse Aggregate
Maximum aggregate size, mm	2.3	20
Unit weight, kg/m^3	1580	1556
Bulk specific gravity	2.5	2.75
Fineness modulus	2.46	6.5

2.2 Cement

Ordinary Portland cement, Type I (O.P.C), was utilized in the production of the concrete mixture. The chemical compositions of this (O.P.C) are exhibited in Table 2.

2.3 Silica fume (SF)

The silica fume chemical composition is shown in Table 2, while the physical properties for the silica fume are presented in Table 3. Because of its characteristics; silica fume may be considered as the concrete most valuable uses; it is a highly reactive pozzolan. Silica fume is utilized as a substitution (by weight) to the cement with rates of 5, 10, and 15%, respectively.

Table 2- The Chemical composition of cement and silica fume

Component	Cement %	Silica Fume %
SiO_2	19.5	92.4
Al_2O_3	4.8	0.91
Fe_2O_3	2.8	2.0
CaO	64.0	0.89
MgO	1.7	0.95
SO_3	3.3	0.35
Na_2O	0.22	-
K_2O	0.85	1.34
P_2O_5	-	0.02
TiO_2	-	0.26
MnO	-	0.18
C	-	0.05
LOI	2.83	0.65

Table 3- Physical properties of silica fume

Property	Value
Particle size, µm	0.1 - 1
Specific surface area, m^2/kg	23700
specific gravity	2.2
Bulk density, kg/m^3	400

2.4 Water

For concrete mixing and curing potable water was used.

3. Experimental program

3.1 Compositions

Two groups of concrete blends have included in the experimental scheme (ordinary-strength concrete C40 and high strength concrete C60), designed according to ACI mix design method and prepared using silica fume which replaced partially by an equal amount of cement. Four mixtures with four various proportions of 1:1 cement substitution are used for each set. Silica fume potions were 0% (reference blend), 5%, 10%, and 15%, see table 4. The total prepared mixes were eight in number.

Table 4- Mix details

Mix	Details	
Normal strength concrete C40	Proportion (by weight)	1 : 1.46 : 2.29
	W / C ratio	0.36
	Plasticizer (HP 580)	1000 ml per 100 kg of cement
	Silica fume replacement	0, 5, 10 and 15%
	Target mean strength	53 MPa
High strength Concrete C60	Proportion (by weight)	1 : 1.03 : 1.77
	W / C ratio	0.30
	Plasticizer (HP 580)	1000 ml per 100 kg of cement
	Silica fume replacement	0, 5, 10 and 15%
	Target mean strength	73 MPa

3.2 Arrangement of the test specimens

A drum mixer is used for 3 minutes to prepare the samples of concrete. Moulds with dimensions (150mm) were used to cast the concrete cubes. After 24 hours, the moulds were opened, and all concrete specimens have been cured using potable water by immersing in a curing tank for 7, 28, 90 and 150 days until they are ready for testing. The temperature of water used in curing was varied from 20 to 25C°. Three cubes were cast for each proportion of silica fume replacement, and for each curing period. Totally 96 cubes were cast in this study. Figure 1, shows the standard cube moulds for this study.

Fig. 1 Standard cube moulds

3.3 Testing procedures

Compressive strength usually considered as the most crucial characteristics of concrete, it reflects the overall image of concrete quality. Concrete cubes compressive strength were specified by a Digitec (1500 kN) testing machine at the laboratory of construction materials – University of Basrah. Actually; at ages of 7, 28, 90 and 150 days the compressive strengths were determined for each proportion of silica fume replacement. For each rate of silica fume substitution and for every curing duration, an average compressive strength value was determined for every three cubes. The cubes were placed one by one in the (compressive) machine, in which the smooth face of the cast concrete becomes in contact with the loading plates, as shown in Fig. 2.

Fig. 2 Compressive strength test machine

4. Test Results and Discussion

Table 5 listed the values obtained for concrete compressive strength to the whole tested cubes.

Table 5- Outcomes of concrete compressive strength

Mix	SF Replacement %	Concrete Compressive strength, MPa			
		7 days	28 days	90 days	150 days
Normal strength concrete C40	0	28.3	41.0	49.0	51.2
	5	30.9	44.5	56.3	70.0
	10	33.1	47.0	63.8	77.0
	15	37.2	50.0	67.5	83.0
High strength concrete C60	0	38.8	56.0	74.0	78.0
	5	40.2	58.5	80.0	85.0
	10	42.8	62.0	82.0	89.0
	15	46.7	65.3	87.0	94.0

Table 6- Relative compressive strength references to SF 0% strength

Mix	SF Replacement %	Relative Compressive strength (to SF 0%), %			
		7 days	28 days	90 days	150 days
Normal strength concrete C40	0	100	100	100	100
	5	109	109	115	137
	10	117	115	130	150
	15	131	122	138	162
High strength concrete C60	0	100	100	100	100
	5	104	104	108	109
	10	110	111	111	114
	15	120	117	118	121

4.1 The influence of silica fume replacement

The gained compressive strength outcomes of concrete versus different rates of silica fume substitutions for C40 and C60 are shown in Figures 3 and 4, respectively. While Table 6 displays the relative compressive strength of concrete with respect to zero content of silica fume.

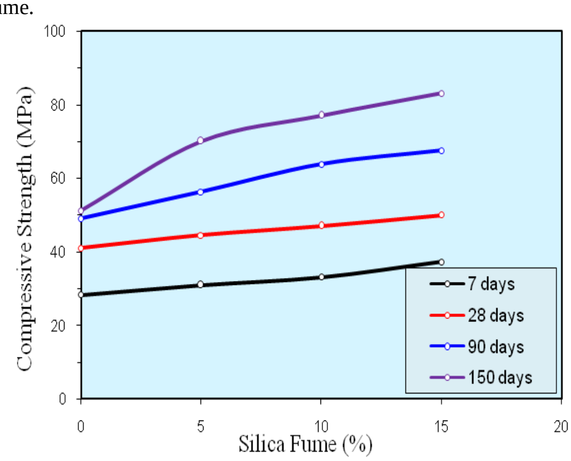

Fig. 3 Variation of compressive strength with different contents of silica fume (C40 mix)

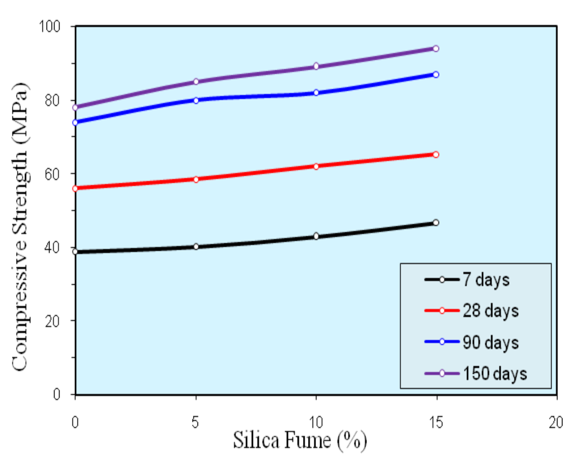

Fig. 4 Variation of compressive strength with different contents of silica fume (C60 mix)

For ordinary concrete strength, this is shown in Fig. 3, the compressive strength of concrete increased by using the silica fume. Moreover, when the silica fume content raised, the compressive strength will consequently increase (within the used range of SF substitution from 0 to 15%). For 7 and 28 days, a significance small compressive strength difference with approximately 9% is observed when comparing concretes with 0% and 5% silica fume content. However, for the content of silica fume with 10% and 15%, the difference increased by approximately 15% and 25%, respectively. While, for cubes with 90 days in age, this difference increases to moderate values as the SF content increases. For content of silica fume with 5%, 10% and 15%, it becomes 15, 30 and 38%, respectively. While for cubes in 150 days age, this difference becomes significant as the SF content increases. It becomes 37, 50 and 62% when substitution of silica fume is used with rates of 5%, 10% and 15%, respectively.

The same increase pattern is found in the progress of the compressive strength, for concrete high strength is also noticed when the comparison is made of concrete of different silica fume contents with the reference concrete. However, the values of the difference in compressive strengths are smaller than those of ordinary strength concrete. From Fig. 4, it can be remarked an increase in the concrete compressive strength when using the silica fume. When the content of silica rises, an increase in the compressive strength will remark (within the used range of SF replacement 0 – 15%). For early age (7 days), a marginal difference in compressive strengths, approximately 4%, can be observed when comparing concretes with 0% and 5% silica fume content. However, for 10% and 15% silica fume content, the difference increases by approximately 10% and 20%, respectively. For concrete cubes with an age of 90 days, this difference becomes 8, 11 and 18% when the silica fume content varied from 5% to 15%. For concrete cubes with an age of 150 days, this differs slightly increases as the SF content increases. While for silica fume content with 5%, 10% and 15%, it becomes 9, 14 and 21%, respectively. The noticed rising in compressive strength may cause by the continued pozzolanic reaction in concrete which enhances the its strength.

A conclusion can be drawn for both concrete strengths (ordinary and high), that the optimum compressive strength value is earned when using 15% of silica fume substitution. However, for concrete with high strength, the gain in compressive strength is relatively less than that of ordinary strength pattern. For concrete with an ordinary strength pattern, when using the silica fume content with 15% in 28, 90 and 150 days, the compressive strength progress for concrete will be rising by 22, 38 and

62%, respectively, as compared with the reference specimens of no silica fume replacement. While for high strength concrete, there is an increase of 17, 18 and 21% in compressive strength development of concrete with 15% silica fume contents after 28, 90 and 150 days, respectively, when compared with the reference concrete of no silica fume replacement. This conclusion invalidates the previous experimental results of (**Mazloom et al., 2004**) which stated that there is no increase in the compressive strength of concrete (high strength pattern) that including silica fume after 90 days.

4.2 Effect of curing period

Good curing usually maintains a suitable moist and warm environment required to develop the hydration products that reduce the cement paste porosity and increase the density of concrete microstructure. The variation of obtaining compressive strength with duration of water curing for a concrete mix of (ordinary and high) strength shown in Figs. 5 and 6, respectively. Table 7 listed the compressive strength gained at various ages for the design strength target at 28 days.

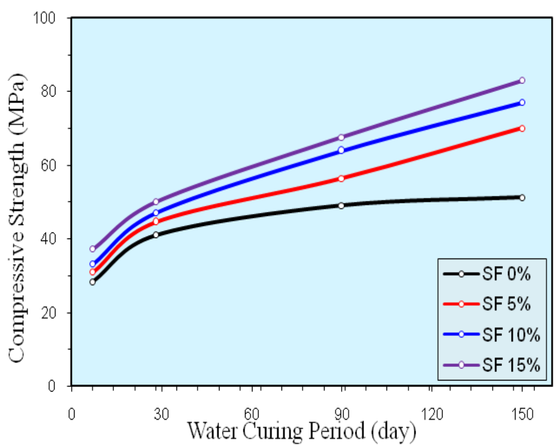

Fig. 5 The compressive strength variation with water curing period (C40 mix)

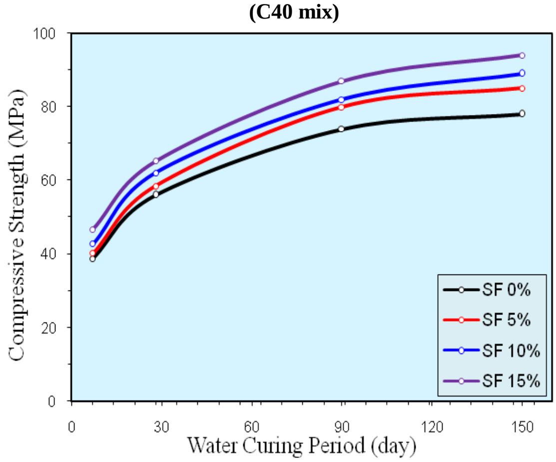

Fig. 6 The compressive strength variation with water curing period (C60 mix)

As seen from Figs. 5 and 6, for all specimens, the compressive strength rises as the curing period becomes more. Table 7 shows that, at early ages, both of the concrete normal and high strength mixes (with no silica fume) gain 53% and 77%, respectively, of the target strength (53 and 73 MPa, respectively) at age of 28 days, while they gain full target strength within approximately 150 and 90 days, respectively. In the presence of 15% SF replacement, the ordinary strength concrete mix gains 94% of the target strength at age of 28 days, while it gains 127% and 157% of target strength at 90 and 150 days continuous curing, respectively. For high strength concrete mix, with 15% SF replacement, the strength gained 89% of the target strength at age of 28 days, while it gains 119% and 129% of strength target at 90 and 150 days, respectively. This rapid rise in compressive strength probably caused due to the continuous curing resulting in a general rising in the relative humidity which is fundamental for continuing the reaction of pozzolana in concrete that accelerates the strength development.

Table 7- Compressive strength gains for the designed target strength

Mix	SF Replacement %	Compressive strength gain, % 7 days	28 days	90 days	150 days
Normal strength concrete C40	0	53	77	92	97
	5	58	84	106	132
	10	62	87	120	145
	15	70	94	127	157
High strength concrete C60	0	53	77	101	107
	5	55	80	110	116
	10	57	85	112	122
	15	88	89	119	129

As seen from Figs. 5 and 6, for all specimens, the compressive strength rises as increasing of the curing period. Table 7 shows that, at early ages, both concrete normal and high strength mixes (with no silica fume) gain 53% and 77%, respectively, of the target strength (53 and 73 MPa, respectively) at age of 28 days, while they gain full target strength within approximately 150 and 90 days, respectively. In the presence of 15% SF replacement, the ordinary strength concrete mix gains 94% of the target strength at age of 28 days, while it gains 127% and 157% of target strength at 90 and 150 days continuous curing, respectively. For high strength concrete mix, with 15% SF replacement, the strength gained 89% of the strength target at age of 28 days, while it gains 119% and 129% of strength target at 90 and 150 days, respectively. This rapid rise in compressive strength probably causes due to the continuous curing resulting in a general rising in the relative humidity which is essential to keep the reaction of pozzolana in concrete that accelerates the strength progress.

Figures 7 and 8 showed progressive increments in the compressive strength of ordinary and high strength concrete mix, respectively, with increasing curing period relative to the 28 days. While Table 8 shows the compressive strength related to the concrete strength at 28 days for all specimens. From figure (7) and table (8), it can show that the gain compressive strength percentage (compared to the strength at 28 days) for the 7 days curing period is approximately 70% of all specimens of both ordinary and high concrete strength and concrete with nil SF content and concrete that containing SF. For concrete cubes that cured with water immersion, it can be shown that the concrete with 7 days age gain 73% of the compressive strength at 28 days, (**Raheem et al., 2013**). While (**Akinwumi and Gbadamosi, 2014**) stated to gain only 52% in the same period. Therefore, the current outcome is relatively compatible with the finding of (**Raheem et al., 2013**).

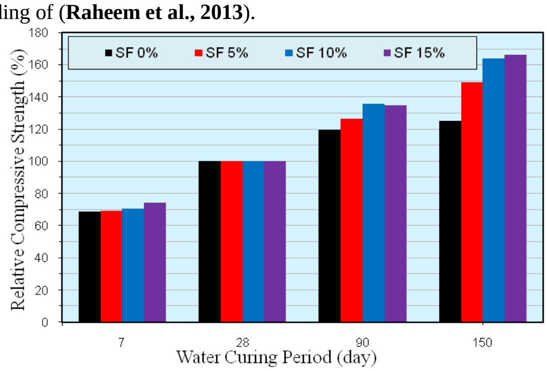

Fig. 7 Water curing duration with relative compressive strength (C40)

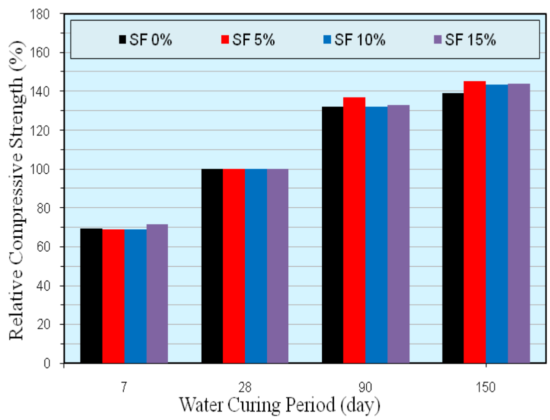

Fig. 8 Water curing duration with relative compressive strength (C60)

Table 8- Compressive strength at 28 days for C40 and C6)

Mix	SF Replacement %	Relative Compressive strength (to 28 days strength), %			
		7 days	28 days	90 days	150 days
Normal strength concrete C40	0	69	100	120	125
	5	69	100	127	149
	10	70	100	136	164
	15	74	100	135	166
High strength concrete C60	0	69	100	132	139
	5	69	100	137	145
	10	69	100	132	144
	15	72	100	127	144

For concrete mixing of ordinary compressive strength with no silica fume that cured in water in 90 and 150 days, the compressive strength will increase by approximately 20 and 25 per cent, respectively. (Akinwumi and Gbadamosi, 2014) have shown that 90 days, the compressive strength will rise by 15% relative to the strength at 28 days. Moreover, in the existence of SF substitution by 15%, the concrete compressive strength which is cured in water for a duration of 90 and 150 days will increase at a rate of 35% and 66%, respectively. For mixtures of high concrete strength with nil silica fume content, the concrete compressive strength which is cured in water for 90 and 150 days, the strength will be increased by a rate of 32% and 39%, respectively. However, with 15% SF replacement, the compressive strength increases by 27% and 44% for a period curing with 90 and 150 days, respectively. Therefore, the increase in compressive strength of high concrete strength at later ages relative to the 28 days strength, is significantly less than the concrete ordinary strength. According to the mentioned outcomes, the continuous curing with water after 28 days will produce a worthy rise in compressive strength. In the meantime, the existence of silica fume in the mixture will maximize the compressive strength much more.

5. Conclusions

Experimental work is done to demonstrate the impact of silica fume content and curing duration on the concrete compressive ordinary and high strength. From the gain outcomes, following conclusions can be remarked:

- Using of silica fume increases the concrete compressive ordinary and high strength. As the content of silica fume increases from 0 to 15 %, the gained compressive strength will consequently rise. Thus, the values of concrete compressive strength with 15 % silica fume substitution will be the highest of the other rates.
- For concrete containing nil silica fume the obtained strength for C60 will be more than the concrete compressive strength including silica fume.
- For ordinary strength which contains 15% of silica fume substitution, there is an increase of 22, 38 and 62% in compressive strength, relative to the reference concrete of no silica fume replacement, after 28, 90 and 150 days, respectively.
- For high concrete strength with the substitution of 15% for silica fume, there is a growing in compressive strength of 17, 18 and 21%, relative to the reference concrete of no silica fume substitution, after 28, 90 and 150 days, respectively.
- In contrast with what has been shown in some previous studies; the current study shows that the mixtures of high compressive concrete strength which consisting of silica fume will display an increase of strength after 90 days.
- The rising in concrete (high) compressive strength (with nil or containing silica fume) during later ages, relative to the strength of 28 days, is relatively less than that of corresponding ordinary concrete.
- Continuous water curing after the age of 28 days leads to a considerable compressive strength increase. This gained rising in strength will be much higher in the silica fume presence.

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