

Modeling of ultimate value and kinetic of compressive strength and hydration heat of concrete made with different replacement rates of silica fume and w/b ratios

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Abstract. The objective of this study was to evaluate the influence of silica fume (SF) on the hydration heat and compressive strength of concrete. Portland cement with w/(c+sf) ratios varying between 0.25 to 0.45 was substituted by 10%, 20% and 30% of SF by mass. A superplasticizer was used to maintain a fluid consistency of the concrete. The heat of hydration was monitored continuously by a semi-adiabatic calorimetric method for 10 days at 20°C. Compressive strengths are tested for each mixture until age of 180 days. The results show that silica fume considerably influences the evolution and the ultimate values of the compressive strengths as well as the hydration heat especially for 10% rate. The w/b ratio has a considerable effect where its decrease modifies compressive strength and hydration heat more than silica fume. The correlation of the obtained results allows deducing of ultimate properties as well as the ages to reach half of their values. The correlation coefficients are close to unity and reflect the judicious choice of these relationships to be used to predict compressive strength and hydration heat.

Keywords: cement; compressive strength; half age; hydration heat; relationship; silica fume; ultimate values

1. Introduction

Nowadays, condensed silica fume has been recognized as one of the most effective additions never added to concrete. Its use in combination with superplasticizer and low w/b ratio is a usual way to obtain high-strength concretes. Apart mechanical strength, other properties of high strength concrete such as durability, hydration heat and shrinkage show prominently in this research field. The partial replacement of cement by silica fume increases the strength of mortar and concrete. It was found that for the addition of 8%, 10%, and 15% of silica fume, the compressive strength increased by 33%, 32% and 21% respectively (Toutanji *et al.* 2004). Also, it produced the highest increase in strength when compared to the other supplementary cementitious materials. The positive result due to the addition of silica fume stems from the increase in strength of the cement matrix (Popovics 1987, Xiaofeng *et al.* 1992). Some researchers (Yogendran *et al.* 1987, Duval and Kadri 1998) estimated the optimal content of silica fume about 15%, whereas others (Malhotra

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and Carette 1983, Toutandji and El-Korchi 1995) show the increase in compressive strength may be reached for higher replacement rate. The addition of silica fume to concrete improves the early age strength while reducing its permeability (Xiaofeng *et al.* 1992). Some authors claim that silica fume increases the strength of the bond between the aggregates and the cement matrix (Goldman and Bentur 1989, Cheng-yi and Feldman 1985, Sarkar and Aïcin 1987, Nocun-Wczelik and Czapik 2013). Silica fume can play a dual role; as filler and as pozzolan material (Popovics 1987, Shaikh *et al.* 2015). Due to its small particle size, it can fill the spaces that exist between the cement particles and improves packing. With its pozzolanic activity, it contributes to the formation of others CSH products. However, the reduction of compressive strength in recycled aggregate concrete can be recovered with the incorporation of few amount of silica fume (Mukharjee and Barai 2015).

The analysis of the hydration heat is a very effective way to examine the contribution of mineral additions in cement hydration. The presence of mineral additions modifies the hydration kinetic and the resulting heat by reducing the reactive phase of cement and contributing to hydraulic and pozzolanic reaction. Pane and Hansen (2005) show that the cement with fly ash has less hydration heat than ordinary cement however cements with blast furnace slag have a high final heat due to the latent hydraulic reaction. Cement with silica fume has a high hydration heat at early age because of its fineness and its great reactivity. Hydration heat was studied by Sanches de Rojas and Frias (1996) for several types of additions. The presence of silica fume and opaline clay causes similar acceleration of cement hydration during the first hours. Fly ash addition causes lower heat than ordinary cement due to its weak activity which can not compensate substituted cement. The second peak for cement hydration containing 30% of silica fume is deferred until 10 hours even though the amount of heat is greater than that of ordinary cement (Sanches de Rojas and Frias 1996).

According to the findings in previous research conducted by Sanches de Rojas and Frias (1995), the substitution of cement with 5% of silica fume has no significant effect on the hydration heat where it acts as filler. For 10% of substitution, a large amount of heat is observed due to its high pozzolanicity. For a high rate of 30%, lime liberated by cement hydration is not sufficient to react with silica fume and the hydration heat is reduced. Similarly, Alshami (1997) found that silica fume accelerates the release of heat, but with a reduction of the second peak against blast furnace slag delays its onset in which the temperature variation is less clear. By incorporating 10% of finely ground of different types of supplementary cementitious materials, Kadri and Duval (2002) record the onset of the second peak at 6 hours with limestone powder, 7 hours with aluminum powder, 9 hours with silica fume and 11 hours with quarts powder, yet it appears at 12 hours with ordinary cement.

For high strength concrete with low w/c ratio, the dilution effect may promote hydration heat. Shang *et al.* (2002) reported a heat of 326.4 and 287.1 J/g for ordinary cement and cement containing 10% of fly ash respectively while it increases up to 349.7 J/g for 30% of substitution. It was clearly shown that the hydration heat is proportional to the fineness of the mineral addition, thus for cement with 25% of blast furnace slag, the hydration heat varies from 202 to 226 J/g at 3 days where the fineness of slag changes from 4200 to 4600 cm^2/g (Douglas *et al.* 1990).

The objective of this study is to evaluate the final hydration heat and a long-term compressive strength according to the substitution rate of silica fume and water to binder ratio. This research intended to expand the knowledge concerning the proper use of silica fume in concrete with respect to its hydration heat to obtain high performances and prevent any deterioration of the concrete.

2. Experimental procedure

2.1 Materials

The cement used was ordinary Portland cement CEM I 52.5, having a 28-day compressive strength of 62 MPa and a Blaine specific surface area of 400 m²/kg. Condensed silica fume containing 92% SiO₂ and having a BET specific surface area of 18200 m²/kg was used. Natural river sand and crushed coarse aggregate constitute the basic for concrete formulation. Potable water and a convenient dosage of superplasticizer based on naphthalene sulfonate were used for the mixing. The chemical analysis of the cement and the silica fume is given on Table 1.

2.2 Mix proportions

In order to get homogeneous samples, the superplasticizer dosage was determined by the need for a consistency of concrete corresponding to a slump ranging from 170 to 190 mm. The quantity of silica fume was added by replacing a part of cement with the same mass of silica fume, whose dosage ranged from 0% to 30% of binder (cement + silica fume). The w/b ratio varied from 0.25 to 0.45. The formulation and the properties of 16 distinct concrete mixes are given in Table 2. Cement, silica fume, and aggregates were mixed dry for 1 min, then 2/3 part of mixing water and superplasticizer were added and the mixing continued for 2.5 min. Finally, the remaining mixing water was added and there was 1 additional minute of mixing.

Table 1 Properties of cement and silica fume used

Description	Cement (%)	Silica fume (%)
Chemical composition (%)		
SiO ₂	19.8	92
Al ₂ O ₃	5.14	0.3
Fe ₂ O ₃	2.3	0.8
CaO	64.9	0.3
MgO	0.9	1.1
SO ₃	3.4	0.2
K ₂ O	1.1	1.6
Na ₂ O	0.05	0.7
Loss on ignition	1.1	2.7
Insoluble residue	0.2	-
Mineralogical composition (%)		
C ₂ S	58	
C ₃ S	13	
C ₃ A	10	
C ₄ AF	7	
Mortar compressive strength (MPa) at:		
2 days	35	
7 days	50	
28 days	62	

Table 2 Mix proportions and properties of fresh concrete.

$w/(c+sf)$	$sf/(c+sf)\%$	Quantities kg/m^3				SP%	Slump (mm)
		cement	SF	sand	aggregate		
0.25	0	550	0	638	1192	5.5	160
	10	495	55	640	1200	2.8	170
	20	440	110	620	1190	3.4	160
	30	385	165	610	1172	4	170
0.30	0	460	0	688	1208	2.6	180
	10	414	46	682	1206	1.6	190
	20	368	92	674	1188	2.4	170
	30	322	138	670	1170	2.8	170
0.35	0	400	0	744	1196	1.4	160
	10	360	40	734	1195	1	170
	20	320	80	730	1176	1.6	170
	30	280	120	720	1165	2	170
0.45	0	310	0	760	1152	0.6	170
	10	279	31	754	1147	0.4	180
	20	248	62	748	1137	0.8	170
	30	217	93	740	1129	1	170

2.3 Test methods

For strength test, the concrete was cast in 160×320 mm cylindrical molds filled in two successive stages by needle vibration. One day after casting, the specimens were demolded and cured in lime-saturated water at $20\pm 1^\circ\text{C}$ until testing. The cylinders were tested in compression with a servo-valve hydraulic press. Each strength value was the average of three specimens.

The hydration heat was determined using a semi-adiabatic calorimeter. Test samples were 160×320 mm concrete cylinders and they were placed inside an insulated container. Immediately after mixing, the temperature rise in the concrete was continuously monitored by the use of thermocouples and a data acquisition system. For each mixture, the hydration heat was measured for 10 days, given that the heat increase was very low at later ages. The hydration heat of concrete was the sum of the accumulated heat in the calorimeter and the heat dispersed in the environment. It may be written as follow

$$q = \frac{C}{m_c} \Delta\theta + \frac{1}{m_c} \int_0^t \alpha \Delta\theta dt \quad (1)$$

Where C is the total thermal capacity of the apparatus ($\text{J}/^\circ\text{C}$), m_c is the cement or binder mass (g), $\Delta\theta$ is the concrete heating difference to the ambient temperature ($^\circ\text{C}$), and α is the total calorimeter thermal loss coefficient ($\text{J}/\text{h}/^\circ\text{C}$).

3. Results and discussion

The evolution of the compressive strengths of concrete made with w/b ratio of 0.3 is shown in Fig. 1. It is clear from the curves that compressive strength of concrete incorporating 10 and 20%

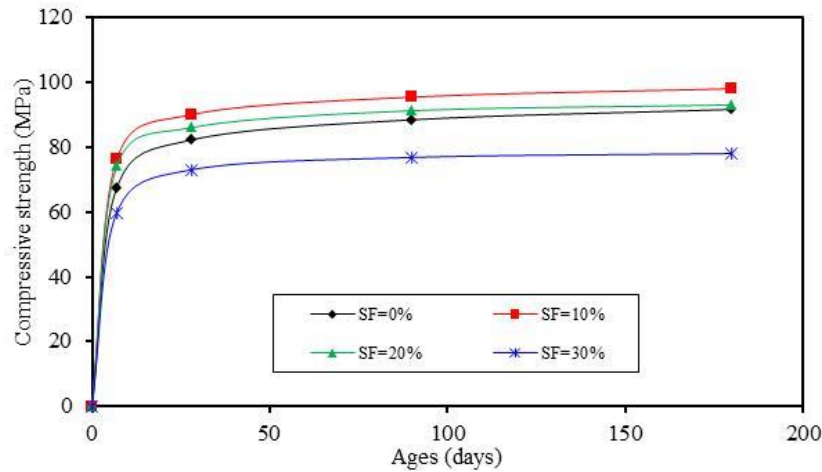


Fig. 1 Development of compressive strength of concrete for different SF content and $w/b=0.3$

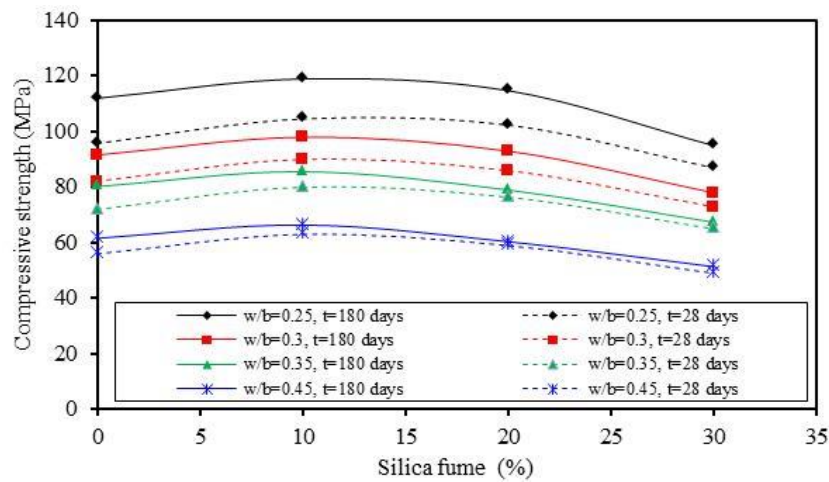


Fig. 2 Variation of compressive strength concrete at 28 and 180 days according to SF content

of silica fume increases compared to that of ordinary cement. However, for 30% SF content, the strength is lower. When SF is added in concrete, the hydration kinetic is activated by a pozzolanic effect that starts early at about 2 days. The variation of the compressive strength as a function of w/b ratios at 28 and 180 days is shown in Fig. 2. It can be observed from the curves that the kinetics of the pozzolanic reaction decrease when the w/b increases. It is obvious that the highest pozzolanic effect is at 10% to 20% of SF content. After 28 days, the development of compressive strength is more important for concretes with low w/b and weak amount of silica fume. For concrete with w/b ratio of 0.25, the compressive strength of the control concrete increases nearly 17% beyond 28 days while the increase is only 10% when mixing with w/b ratio of 0.45. With 10% of silica fume, the increase of compressive strength beyond 28 days reaches 14% and 5% for concrete with w/b ratios of 0.25 and 0.45 respectively. At a very early age, the compressive strength of the reference concrete is always higher than the SF concretes for all w/b ratios. When the pozzolanic effect develops, the compressive strength of 10 and 20% SF concretes becomes

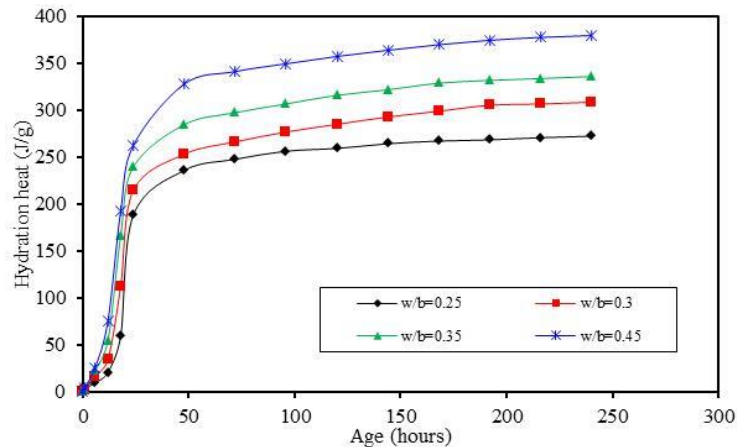


Fig. 3 Development of hydration heat for different w/b ratios without silica fume

greater than that of the control concrete. At later age, the compressive strength of the control concrete was the same as the 20% SF concrete. At this state, only 10% SF concrete remains greater than the control concrete. For 30% SF content, the SF cannot react completely with the free lime available in restricted amounts. The extra part of SF therefore acts as inert filler with no contribution to pozzolanic reaction. Moreover, the influence of the w/b ratio on compressive strength is more important than the incorporation of SF.

The heat evolution curve reflects the physical processes and reactions occurring in the hydrating system and leading to the transformation of plastic cement paste into hardened matrix. It can give an answer about the acceleration or delay due to the additional components introduced to the hydrating system (Nocun-Wczelik and Czapik 2013). For concrete without silica fume, the total heats of hydration curves up to 10 days are shown in Fig. 3. The total heat evolved varies in the same way as the w/b value. The heat released diminishes by 40% when the w/b decreases from 0.45 to 0.25. The reduction in hydration heat comes from the reduction in the quantity of pore water that is available for hydration. As a results, the ultimate degree of hydration decreases with w/b ratio. Fig. 3 reflects the physicochemical process in the hydrating system which leads to the transformation of a plastic concrete to a hardened concrete. Also, it gives some indication about the mechanical strength development and the quality of the matrix porosity. The results presented in Fig. 4 show the hydration heat released after 12 hours of hydration. For low values of w/b , the heat of hydration remains proportional to the substitution rate of silica fume. For concrete containing 30% silica fume, the heat released is 3.8 and 2.8 times that of plain concrete for w/b ratios of 0.25 and 0.3 respectively. On the other hand, when w/b ratio exceeds 0.3, this proportionality remains valid until 20% silica fume beyond which the hydration heat decreases. The positive effects of SF at early age may be attributed to its fine particles that act as heterogeneous nucleation sites on which the first hydrates could precipitate leading to high hydration heat and shorter dormant period as reported by some researchers (Langan *et al.* 2002, Kadri *et al.* 2010). This result is supported by Langan *et al.* (2002) conclusions in which the addition of SF alters the hydration process in the period 2-20 h after the start of hydration. Also, Fig. 4 shows the total heat liberated after 10 days as a function of the SF content. A 10% substitution rate of Portland cement by SF gives a greater total heat released as compared with the concrete without SF. This result matched the conclusions that reported the substitution rate of

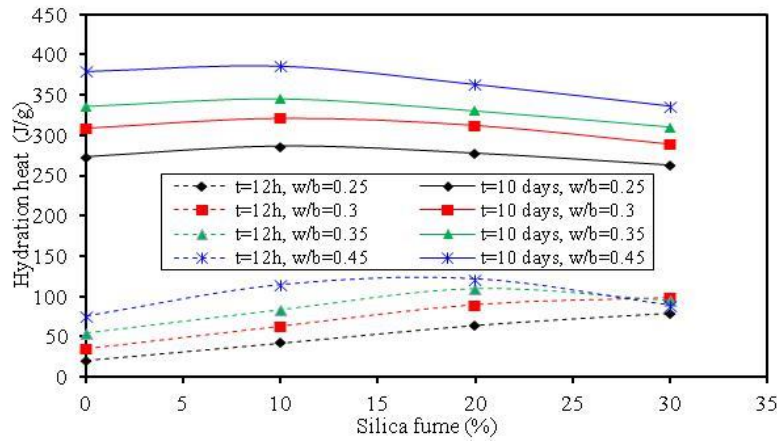


Fig. 4 Variation of hydration heat released at 12 hours and 10 days according to the substitution rate of silica fume and w/b ratios

7.5% (Ma *et al.* 1994) and 10% (Mostafa and Brown 2005) and 15% (Sobolev 2004) of SF increases the hydration heat liberation. In contrary, a 30% substitution of cement gives a lower accumulated heat. This finding is supported with result that the heat liberation over 45 hours diminishes for the mixes containing 20% to 30% of silica fume (Mostafa and Brown 2005). It will be concluded that the effects of SF hydration heat evolution may be attributed to its chemical and physical effects on the cement hydration process.

The beneficial effect of SF is caused by its reaction with the lime liberated by cement hydration that contributes to the formation of other CSH products. The addition of SF, create a heterogeneous environment that causes the appearance of other nucleation sites which promotes cement hydration (Ma *et al.* 1994, Kadri *et al.* 2011). Also, their fine particles fill the void between the cement grains and make denser the matrix. In concrete, its presence improve paste aggregates bond which plays a fundamental effect on the development of mechanical strength. This is due to the conversion of calcium hydroxide, which tends to form on the surface of aggregate particles to calcium silicate hydrate (Toutandji *et al.* 2004). However, when the dosage of silica fume increases beyond 10%, the compressive strength starts to decrease. This reduction in strength may be a result of the lack of water in the mix since self-desiccation of the specimens may have taken place. This limits the pozzolanic effect and thereby reduces the strength and the hydration heat of the SF concrete (Kadri *et al.* 2010).

4. Correlation and analysis results

To analyze the obtained results, an approach recommended by ASTM Standard C107422 (ASTM 1993) to analyze propriety-age data under isothermal curing was used. It was assumed that the kinetics of the propriety development at a constant temperature can be represented by the following hyperbolic equation

$$X(t) = X_u \frac{t - t_0}{(t - t_0) + t_{50}} \quad (2)$$

Table 3 Results of ultimate values of compressive strength and hydration heat correlation

w/b & SF(%)		Compressive strength				Hydration heat			
		0	10	20	30	0	10	20	30
Ultimate values (MPa & J/g)	0.25	105.4	116.0	112.2	93.4	339.9	333.8	315.4	295.6
	0.30	88.5	96.9	93.0	78.8	368.1	365.3	344.9	321.0
	0.35	76.7	85.5	80.3	68.8	392.2	390.5	367.7	344.0
	0.45	61.1	67.1	61.6	52.3	440.3	433.2	400.5	368.3
Half age (hours)	0.25	32.7	36.1	40.0	41.7	37.5	24.2	20.8	19.7
	0.30	34.6	40.0	43.0	51.8	32.7	22.7	19.4	18.7
	0.35	38.4	45.6	46.4	58.9	27.3	21.3	19.3	18.8
	0.45	50.2	50.8	54.8	65.0	25.5	19.8	18.6	18.3

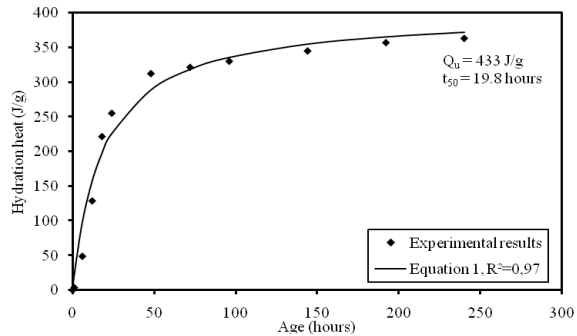
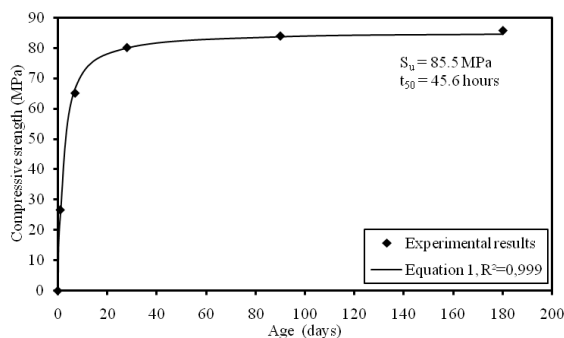


Fig. 5 Correlation of compressive strength results versus age with Eq. (1) ($w/b=0.35$, $SF=10\%$, $R^2=0.999$)

Fig. 6 Correlation of hydration heat results versus age with Eq. (1) ($w/b=0.45$, $SF=20\%$, $R^2=0.97$)

where $X(t)$ is the concrete property at t age; X_u is the ultimate value property measured after an infinitely long time; t_0 is the age when the concrete property development is assumed to start and can be assumed to equal final setting time (5 hours) for compressive strength and zero for hydration heat, which gives the smaller squared sum of errors as reported by some researchers (Eren 2002, Eziane *et al.* 2010); and t_{50} is the time beyond t_0 where the concrete reaches 50% of its ultimate value property. A least-squares regression analysis for Eq. (1) was used to determine the best-fit values of X_u and t_{50} for each set of data. The values of the age t_{50} and the final values X_u founded for each mixture are summarized in Table 3. Curves drawn in Figs. 5 and 6 are representative samples for the resulting best-fit hyperbolic curves. It is seen that Eq. (1) fits the data quite well.

4.1 Ultimate strengths

The ultimate strengths shown in Fig. 7 vary with the replacement rate of silica fume and the w/b ratio. For low w/b ratio equal to 0.25, high compressive strength was observed that exceeds 100 MPa. Contrary, high w/b ratio leads to a noticeable decrease in compressive strength where the ultimate value just reaches 60 MPa. When silica fume substitutes a part of cement improved ultimate strengths are observed around a substitution rate of 10%. Beyond this optimum amount,

the compressive strength decreases with the increase of silica fume content.

From Fig. 7, it is clear that the evolution of the ultimate strength according to the substitution rate of silica fume follows a polynomial law. From this, a correlation has been applied to the results to find the best possible fit. The following relationship was obtained with a correlation coefficient very close to the unit which justifies this correlation choice.

$$S_u = K S_{c28} (1 + 1.6 p - 6.6 p^2) \frac{1}{w/b} \quad (3)$$

where K is a coefficient that depends on the properties of aggregates measured by the calibration of the results without silica fume ($K=0.43$), S_{c28} represents the compressive strength of the standardized mortar equal to 62 MPa, p is the substitution rate of silica fume, w and c designate the weight of mixing water and binder respectively.

4.2 Ultimate hydration heat

The generated ultimate hydration heat shown in Fig. 8 varies with silica fume content and w/b ratio. For high w/b ratio equal to 0.45, the hydration heat reaches 408 J/g when cement contains 10% of silica fume. Close to this substitution rate an increase in hydration heat is observed for all w/b ratios. For silica fume higher than 10% and a low w/b ratio a significant decrease of hydration heat is observed in which hydration heat reaches its lower value for 30% of silica fume and w/b ratio of 0.45. The excessive mixing water offers the possibility to a maximum cement grain to hydrate and participate in an increased release hydration heat. The presence of silica fume with an optimal rate contributes to the formation of other hydration products and produces additional heat. When this substitution rate is exceeded, the dilution effect becomes more important as well resulting in a reduction of total heat.

The ultimate hydration heat can be predicted as a function of w/b ratio and the substitution rate silica fume. From Fig. 8, the ultimate heat reaches its highest value near the rate of 10% of silica fume which increases with w/b ratio. By applying the least squares method, a relationship giving the ultimate hydration heat for each mixture is obtained.

$$Q_u = 600 (1 - 0.1 p - 1.2 p^2) \left(\frac{w}{b}\right)^{0.4} \quad (4)$$

where b , w and p represent the weight of binder, mixing water and the substitution rate of silica fume respectively. Fig. 8 shows the relationship between the results found and those predicted by Eq. (4). The choice of this relationship is supported by its high correlation coefficient ($R^2=0.996$). This relationship is a generalization of the formula presented by Person (1997) to include the combined effect of SF and w/b ratio.

4.3 Half-strength age

Fig. 9 shows the variation of the half-strength age t_{50} for concrete according to w/b ratio and substitution rate of silica fume. The age, to reach half of the ultimate strength (t_{50}), increases with w/b ratio and SF content. The replacement of cement with silica fume causes a dilution effect that gives half-strength age a linear evolution. This change becomes more important with increasing of w/b ratio. For low w/b ratio of 0.25, the presence of 30% of silica fume in concrete increases the half-strength age by 10 hours compared to that of concrete without silica fume. This variation reaches 33 hours for w/b ratio of 0.45. It is obvious that increasing of mixing water causes a

greater dispersion of cement grains and managed to keep them away as long before their hydration. When silica fume replacing a more active phase such as cement, the second generation formation of hydration products is deferred and half-strength age is increased.

Half-strength age is an increasing function of w/b ratio and decreasing one of the substitution rates of silica fume. By adjusting the results with the least squares method, a simple relationship is obtained and may represented as follows

$$t_{50} = (6 + 2p + 22p^2) \left(0.5 \frac{w}{b} + 0.1\right) \quad (5)$$

where b , w and p represent the weight of binder, mixing water and the substitution rate of silica fume respectively. Fig. 9 shows a comparison between measured values and those predicted by Eq. (5), where the highest value of correlation coefficient supports the choice of this relationship.

4.4 Half-hydration heat age

Half-hydration age t_{50} is the time required to reach half of the total hydration heat represented in Fig. 10. For concrete without silica fume, the half-hydration age takes a decreasing function of w/b ratio and SF content. When the cement is replaced by silica fume, this time decreases and becomes independent of w/b ratio. For w/b ratio of 0.45, half-hydration age decreases slightly for high substitution rate of silica fume. For concrete containing more than 10% silica fume, the half-hydration age is less than one day for all w/b ratios. With w/b ratio of 0.25, half-hydration age decreases from 37.5 to 24.2, 20.8, 19.7 hours, for silica fume content of 0%, 10%, 20% and 30% respectively. It will be concluded that silica fume accelerates cement hydration in the same way as w/b ratio. For concrete with w/b ratio of 0.25, 30% silica fume reduces half-hydration age about 47% while an increase of w/b ratio to 0.45 leads to 32% decrease. The hydration heat is accelerated by increasing mixing water which gives the possibility to greater amount early hydration of cement grains. The presence of silica fume promotes the appearance of new nucleation sites which leads to further hydration of cement grains and results in a reduction of the half-hydration age.

The kinetic of hydration heat can be expressed by the age required to reach half of its final value (t_{50}). Half-hydration age increases with increasing w/b ratio, which gives a possibility of

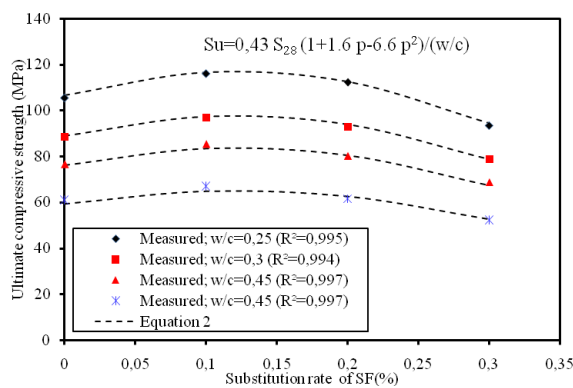


Fig. 7 Variation of ultimate strength results according to replacement level of silica fume and w/b ratios

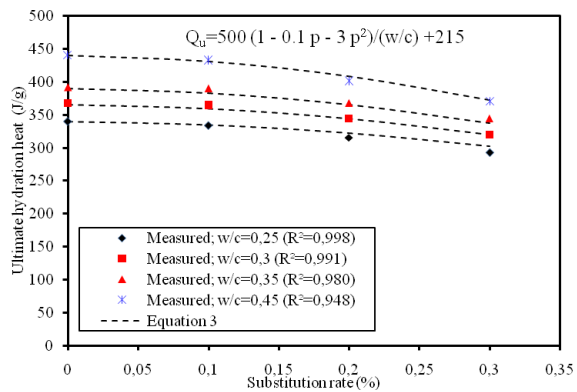


Fig. 8 Variation of hydration heat results according to replacement level of silica fume and w/b ratios

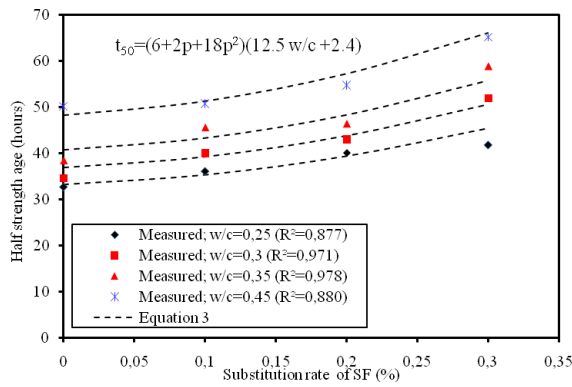


Fig. 9 Variation of half-strength age results according to replacement level of silica fume and w/b ratios

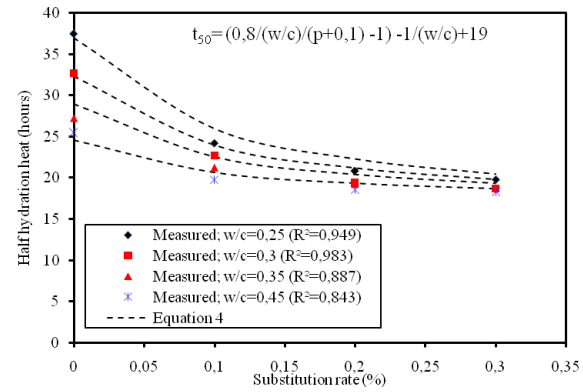


Fig. 10 Variation of half-hydration heat age results according to replacement level of silica fume and w/b ratios

hydration to many cement grains that generate more heat. The presence of silica fume causes additional heat after activation of its pozzolanic reaction. After analyzing the results found by adjusting the heat generated by Eq. (6), we opted for the following relationship giving half-hydration age according to the substitution rate of silica fume and w/b ratio.

$$t_{50} = \left(\frac{0.8}{\frac{w}{b}} - 1 \right) \frac{1}{p + 0.1} - \frac{1}{\frac{w}{b}} + 19 \quad (6)$$

where c , w and p represent the weight of cement, mixing water and the substitution rate of silica fume respectively. Fig. 10 shows the relationship between the results found and those predicted by Eq. (6). The correlation coefficient is higher than 0.9 with a variation less than 5%.

5. Conclusions

Based on an experimental study on the effects of SF and w/b ratio on compressive strength and hydration heat of concrete, an analysis and a modeling of the obtained results, the following conclusions can be drawn

1. It can be observed that the pozzolanic effect of SF decrease when the w/b increases. It is obvious that the highest pozzolanic effect is between 10% and 20% of SF content. With 10% of silica fume, the increase of compressive strength beyond 28 days reaches 14% and 5% for concrete with w/b ratios of 0.25 and 0.45 respectively.
2. The total hydration heat evolved varies in the same way as the w/b value. At 12 hours, the hydration heat remains proportional to the substitution rate of SF with low w/b ratio. For concrete containing 30% SF, the heat released is 3.8 and 2.8 times that of plain concrete for w/b ratios of 0.25 and 0.3 respectively. On the other hand, when w/b ratio exceeds 0.3, this proportionality remains valid until 20% SF beyond which the hydration heat decreases.
3. The replacement of cement with silica fume causes a dilution effect that gives half-strength

age a linear evolution. This change becomes more important with increasing of w/b ratio. For low w/b ratio of 0.25, the presence of 30% of silica fume in concrete increases the half-strength age by 27% compared to that of concrete without silica fume. This variation reaches 100% for w/b ratio of 0.45.

4. For concrete containing more than 10% silica fume, the half-hydration age is less than one day for all w/b ratios. With w/b ratio of 0.25, half-hydration age decreases from 37.5 to 24.2, 20.8 and 19.7 hours, for silica fume content of 0%, 10%, 20% and 30% respectively. It will be concluded that silica fume accelerates cement hydration in the same way as w/b ratio. For concrete with w/b ratio of 0.25, 30% silica fume reduces half-hydration age about 47% while an increase of w/b ratio to 0.45 leads to 32% decrease.

5. The relationships obtained by the correlations of the obtained results made it possible to identify compressive strength and hydration heat of concrete according to its composition. These characteristics are simply identified by their ultimate values and the ages to reach the corresponding half-value. Correlation coefficients are acceptable and support the right choice of these expressions.

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