THE EFFECT OF USING SILICA FUME IN HIGH STRENGTH CONCRETE ON WORKABILITY AND COMPRESSIVE STRENGTH: REVIEW

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Abstract

Supplementary Cementitious Materials (SCMs) are widely used to replace Ordinary Portland Cement (OPC) in High Strength Concrete (HSC). The addition of SCMs to HSC mixes generally results in altering the properties of the resulted HSC. This study focuses on reviewing the effect of a common SCM – Silica fume (SF)– as a partial cement replacement at different replacement levels by weight on workability and compressive strength of HSC. First, the researchers reviewed the chemical reactivity and particle characterization of SF. They also reviewed several research papers on the fresh and hardened properties of HSC mixes containing SF.

The review showed a significant enhancement in the compressive strength of HSC when OPC was partially replaced with SF. It also demonstrated the disagreement among researchers about the effect of SF on the workability of HSC.

While reviewing the research papers, the authors identified the optimum weight replacement of SF indicated in the reviewed papers. The researchers concluded that there are differences in the chemical composition, particle shape and size, and surface area of SF as compared to OPC. These differences in the characteristics of SF influence water demand, packing ability, and reactivity of the HSC mix, which could explain the change in the workability and compressive strength of the resulted HSC.

Keywords: High Strength Concrete; Supplementary Cementitious Materials; Workability; Compressive Strength.

Introduction

High Strength Concrete (HSC) is a relatively old concept. However, it has been gradually developed over many years. While its development has continued, the definition of HSC has changed over time (ACI 363, 1997). In the 1950s, concrete with a compressive strength of 34 MPa was recognized as a High Strength Concrete (ACI 363, 1997). Meanwhile, through the 1970s, compressive strength of 62 MPa was produced. Currently, compressive strength exceeding 140 MPa has been utilized in many projects. According to Peterman, HSC is a special type of concrete that has greater compressive strength than the typical ordinary concrete in a county (Peterman et al., 1987). This definition was early acknowledged because of the variation in the maximum compressive strength of concrete from one region to another.

While the HSC was developed, researchers have studied and used SCMs in HSC for decades. However, the effect of adding some types of SCMs on concrete properties was not fully understood in some aspects. The chemistry and physical properties of the SCMs are a few factors that could influence the properties of HSC. Silica Fume (SF) is a popular SCM, which is a by-product of the production of elemental silicon or ally containing silicon (ACI 116R-00). In general, adding SF to HSC mixes results in better properties of fresh and hardened HSC. This paper aims to review the effect of SF on the workability and compressive strength of HSC.

Chemical Composition of SF

The addition of SF generally changes the properties of both fresh and hardened HSC. Factors such as chemical composition, particle's shape and size, and surface area of SF affect the properties of High Strength Concrete (HSC) because these factors influence water demand, packing ability, and reactivity of the HSC mix. Table 1 shows the typical composition and properties of SF and OPC.

Table (1): Typical Composition and Properties of SF and OPC (Illston and Domone, 2001).

Oxides (% by wt)	SF	OPC
SiO_2	97	20
CaO	<1	64
Al_2O_3	<1	5
Fe_2O_3	<1	4
MgO	<1	1
Pozzolan reactivity (mg CH/gm)	427	
Particle size range (microns, μm)	0.03-0.3	0.5-100
Specific surface area (m^2/kg)	20000	350
Particle relative density	2.2	3.15
Particle shape	Spherical	angular

Physically, SF has extremely fine particles that have a spherical shape as shown on Figure (1). It also has a relatively high surface area. In terms of chemical reactivity, SF is classified as a highly reactive pozzolan because of its high level of silicon dioxide (SiO_2) (Peterman et al., 1987).

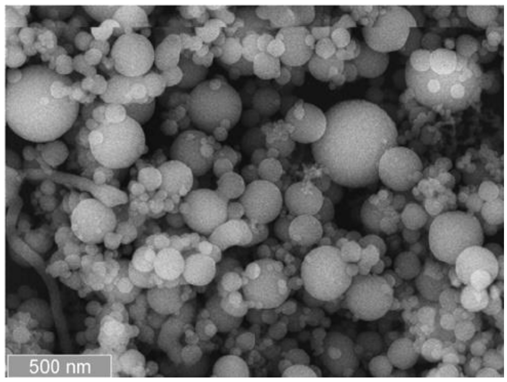

Figure (1): Scanning Electron Microscope picture of a typical silica fume (Snellings et al., 2012).

Effect of SF on Workability and Compressive Strength of HSC

The effect of SF on the workability and compressive strength of HSC is discussed below.**Workability**

There is debate among researchers about the effect of adding SF to HSC mixes on workability. Many researchers (Elbasir et al., 2019; Wong and Abdul Razak, 2005; Jagan et al., 2021; and Bhikshma et al., 2009) agree that partial replacement of OPC with SF in HSC mixes decreases concrete workability. Some researchers (Elbasha, 2019; Srivastava et al., 2015) have concluded that SF increases the workability of the resulted mix, meanwhile others (Johari et al., 2011; Duval and Kadri, 1998) have found that small replacement doses of SF increase workability and higher replacement doses of SF decreases workability of the resulted mix.

Some researchers claim that partial replacement of OPC with SF increases workability. Srivastava (2015) concluded that the workability of resulted mix improves by increasing SF replacement levels from 5% to 35%. Elbasha (2019) noticed similar results when OPC was partially replaced with SF – an increase in workability by 160%, 90%, and 70% at 10%, 15%, and 20% replacement levels, respectively although, there was a decreasing effect as the replacement level of SF increases from 10% to 20%.

Others argue that small replacement doses of SF increase the workability of HSC mixes, then as the replacement dose increases, the workability of HSC mix decreases. According to Johari (2011), replacing 5% to 10% of OPC by weight with SF increases the workability of the mix. However, there is a decreasing effect as the replacement level of SF increases from 5% to 10%. Meanwhile, at a 15% replacement level, the researcher noticed a reduction in workability. Similarly, Duval (1998) reported a slight increase in concrete workability at a 10% replacement level at different levels of water to cement ratios. However, this increase changes to a decrease in workability at a 20% replacement level.

On the other hand, many researchers (Patil et al., 2017; Bhikshma et al., 2009; Elbasir et al., 2019; Mazloom et al., 2004; Wong and Abdul Razzak, 2005; Jagan and Neelakantan, 2021) have noticed a decrease in concrete workability when OPC was partially replaced with SF at all replacement levels. Bhikshma (2009) reported a decrease in workability at all tested replacement levels (from 3% to 15%), and this reduction intensifies as the SF dose increases. Similarly, Elbasir (2019) noticed 20%, 29%, and 49% reduction in the workability at 5%, 10% and 15% replacement levels. Also Mazloom (2004) concluded that high SF levels in HSC mixes require higher doses of superplasticizer.

Data related to the workability (slump) of HSC mixes containing SF at different replacement levels from several reviewed papers were collected and plotted on Figure (2) as relative workability (percentage) based on the workability of the control mix –HSC mix without SF.

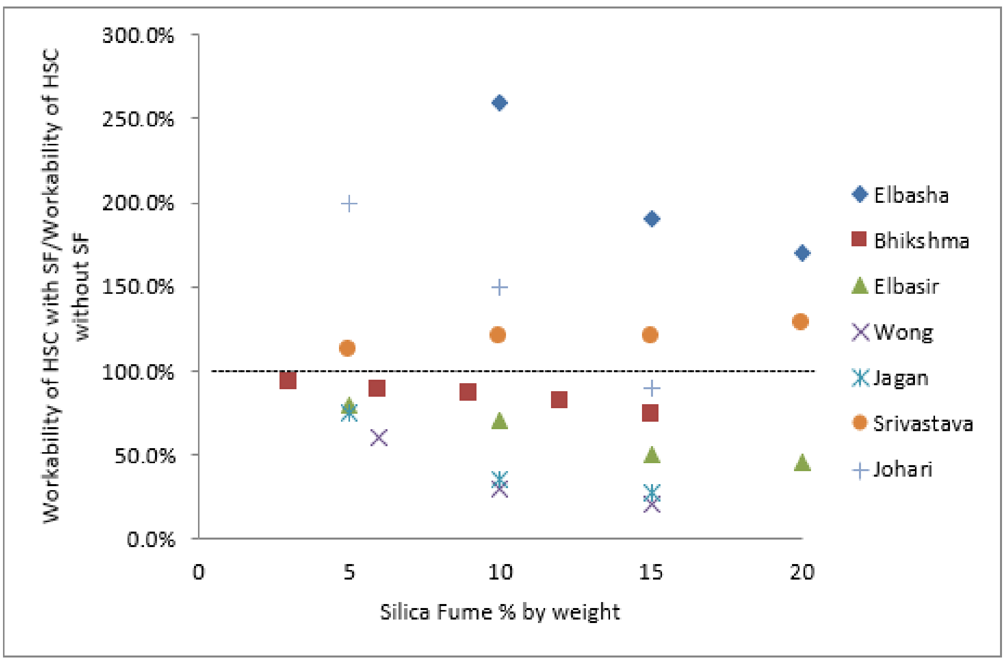

Figure (2): Summarizes the Effect of Partially Replacing OPC with SF on the Workability of HSC (the Data were Collected from the Reviewed Paper).

The cause of the increase of workability of HSE mixes at low contents of SF is the particle characteristic of SF. The spherical shape of SF's particles reduces water demand, which increases the workability of HSC (Johari et al., 2011). On the other hand, the decrease in workability of HSC mixes when adding SF can be explained due to the huge surface area and extreme fineness of SF. The authors conclude that there could be an optimum level of SF at which optimum water reduction and high workability can be achieved.

Compressive Strength

As shown in Figure (3), adding SF as a partial replacement of OPC at different replacement levels to HSC mixes significantly increases the compressive strength at 28 days (Johari etal., 2011; Elbasha, 2019; Bhikshma et al., 2009; Elbasir et al., 2019; Amudhavalli and Mathew, 2012). For instance, it was reported that relative strengths of 112%, 131%, and 136% at 28 days were obtained using 5%, 10%, and 15% SF replacement levels, respectively (Johari et al., 2011). Another report showed that a 15% replacement level increased the strength of concrete by 17.7% and 28.3% at 28 days and 56 days, respectively (Elbasha, 2019). Several other researchers reported an increase of compressive strength at 28 as the replacement level increases from 3% to 12%, then the increase of compressive strength slightly decreases when the replacement level exceeds 15% (Bhanja and Sengupta, 2003; Wild et al., 2003; Amudavalli and Mathew, 2012; Elbashir et al., 2019; and Elbasha, 2019). This enhancement in the compressive strength of HSC is due to the high pozzolanic nature of SF and its void filling ability (Bhikshma et al., 2009). All reviewed papers concluded that a replacement level between 12% and 15% is the optimal percentage for HSC compressive strength at 28 days.

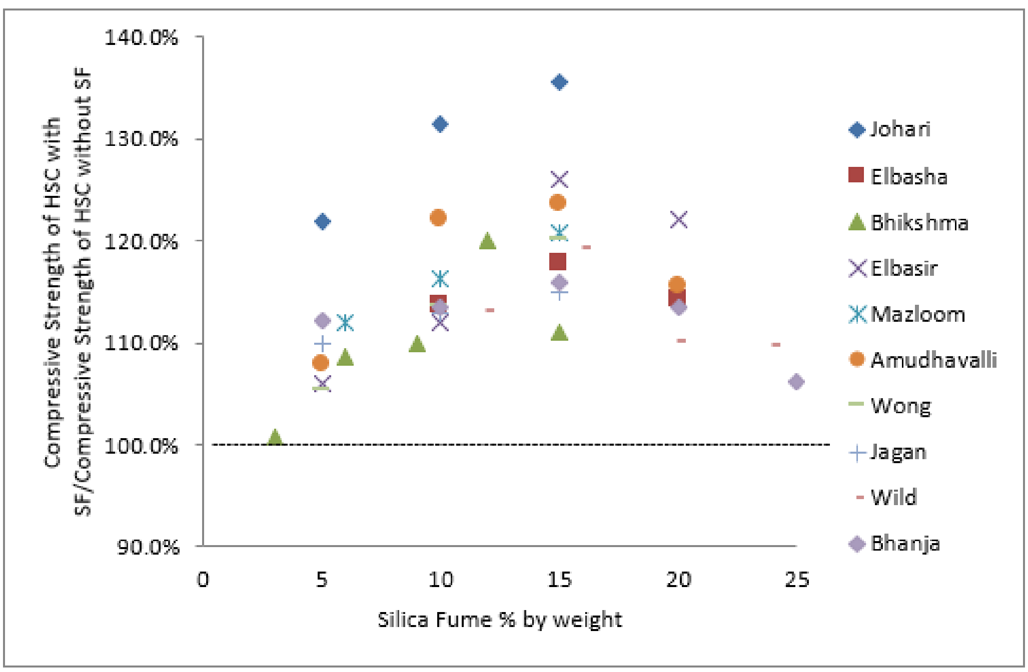

Figure (3): Shows Effect of SF on the 28-day Compressive Strength of HSC (the Data were Collected from the Reviewed Paper).

In addition to the long-term strength gain, the early compressive strength of HSC increases with the addition of SF (Johari et al., 2011; Elbasir et al., 2019). At the age of 1 day, it was found that the relative strength of the HSC mix that contains SF is 109%, 108.6% ,and 107.4% for replacement levels of 5%, 10%, and 15%, respectively (Johari et al., 2011). Another report showed that there is an increase in the compressive strength at 3 days by 0.652%, 2.69%, 8.02% , and 4.20% due to cement replacement of 5%, 10%, 15%, and 20% by SF, respectively (Elbasir et al., 2019). This early strength improvement could be attributed to the influences of the acceleration in OPC hydration and to the micro filler effect resulted from the extreme fineness of SF particles (Johari et al., 2011).

Conclusion

Based on the review of the effect of SF on the workability and compressive strength of HSC, we can conclude that:

1. The additive of SF to HSC mix as a cement replacement from 5% to 15% by weight increases early and long-term compressive strength at 3 days and 28 days. The enhancement can be attributed to the filling ability and high reactivity of SF.
2. The effect of SF on workability varies. SF could increase workability due to the spherical particle, which helps the flow of the mix. On the other hand, SF could decrease workability because of its relatively high surface area.
3. It is observed that the optimum SF partial cement replacement for the 28 days compressive strength for HSC is between 12% and 15% of weight.

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