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# Effect of Supplementary Materials on Settlement Cracking of Concrete

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**ABSTRACT**

The major sources for cracking in the bridge decks are the settlement cracking. As these cracks continued growth due to the factors effect on the durability of the structures such as chloride and sulfates attacks, corrosion if the reinforcement, freeze-thaw damage and others. So these cracks considered a very severe problem at the life time. The object of this paper is to assess the effect of pozzolanic materials on the settlement cracking of concrete. 85 mixes were cast to explore the aim of this research. The main variables were type of concrete (self-compacted concrete, normal concrete), type of supplementary materials (silica fume, fly ash). 1, 2.5, 5 and 7.5% of silica fume as a replacement of cement content was used. 5, 10, 15, 20, 25 and 30% of fly ash as a replacement of cement content were used. The results clearly that the supplementary materials enhanced the micro-structure of the mixes by reducing the settlement cracking compared with the control mixes. Fly ash reduces the settlement cracks more than silica fume. Settlement cracking didn't observe for the self-compacting concrete mixes. Out of this research; decreasing the settlement cracks yield to get better the durability of the structures, eliminate the abrasion and corrosion of the reinforcement. This yield to decreases the cost needed for maintenance and increases the life time of the structures.



## 1. Introduction

Plastic settlement cracks form while the concrete in the fresh state and it is having not set. The settling concrete is restrained, and cracks form at the surface. The settling concrete is restrictive, and cracks form at the surface. They may be visual while finishing is proceeding, but are oftentimes not observed till several hours after placement. They are distinct from plastic shrinkage cracks by their distinguished pattern which typically mirrors the pattern of the restraining elements such as the reinforcement. The cracks take-place while the concrete is plastic and frequently while bleed water is rising and covers the surface. They can be quite wide at the surface, tend to prolong only to the reinforcement or other restraining element and taper in width to that location. [1] Structural cracks must be evaluated at once and if substantial, a monitoring regime carried out. Structural cracks are commonly caused by the following: 1. Distortion of the structure due to overloading or design insufficiency. 2. Errors in construction. 3. The motion of the ground such as landslide [2, 3]. After the cast the concrete; the plastic concrete may be restricted by reinforcing steel, before concrete placement. As increasing the bar size, increasing the slump and decreasing the cover thickness of the concrete the settlement cracking increasing [4, 5]. Concrete is a brittle material with a low ability for distortion under tensile stress. Mechanical loading, deleterious reactions and environment can result in the enhancement of tensile stresses in concrete. So cracks can perform and effect on the performance of concrete. By suitable precautions in design, materials and construction practices cracks can be reduced. So concrete can be used satisfactorily for a prolonged period of time without any significant loss of service life, safety and serviceability [6]. Michael Thomas (2007) discussed the effect of fly ash on the plastic state of concrete.

The optimum dosage of fly ash was evaluated. 50% of fly ash contents provided the early age strength [7]. Osama Al-Qassag et. al. (2016) studied the effect of rheology modifier on the cracking settlement intensity. The experimental results clear that as increasing the slump of the mixture increasing the cracking settlement. Also, using the modifying admixture minimizes settlement cracking compared to the control mix. This research suggested evaluating the effect of supplementary materials on the cracking settlement [8]. Pendergrass and Darwin (2014) used new materials to get better the properties of light weight concrete. They try to reduce the shrinkage of the concrete. They evaluated the effect of these materials on the concrete durability and cracking [9]. Combrinck and Boshoff (2013) studied how settlement cracking develops. They studied the effect of re-vibration on the consistence of settlement cracks. Two L-shaped molds (deep and shallow sections) were used. Based on that observation, the researchers specified that the plastic cracks forms from the bottom and spreads upward. This observation was approved using numerical analysis. Combrinck and Boshoff (2013) recommended the use of re-vibration before final setting to minimize the settlement around reinforcing bars. To observe the impact of re-vibration on the concrete strength, two groups of concrete cubes were tested. The first group was re-vibrated at initial setting while the second group was re-vibrated at final setting. The results showed that re-vibrating concrete cubes at initial setting increases the strength while re-vibrating at final setting decreases the strength [10]. Mounir M. Kamal et. al. [11, 12] studied the fresh properties of self-compacted concrete.
They reported that the viscosity enhanced agent resists the segregation and bleeding for self-compacted concrete.

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**Research significantly**

The paper illustrates how pozzolanic materials effect on the settlement cracking of concrete in term of slump value, cracks width and cracks length. The steps of manufacture of concrete for developing the settlement cracking were evaluated. Also, the effect of pozzolanic materials (silica fume and fly ash) on the settlement cracking was studied.

## 2. Experimental Program

85 mixes were cast to carry out the aim of this research. Two types of concrete were cast. 22 to 24°C was the temperature of the fresh concrete. 7 mixes considered as a control mixes. 78 mixes were cast to evaluate the effectiveness of supplementary materials on the settlement cracking behavior. Two types of supplementary materials (silica fume and fly ash) were used.1, 2.5, 5, 7.5% of silica fume was used. 5, 10, 15, 20, 25 and 30% of fly ash were used.

### 2.1 Materials

Portland cement (CEM I 42.5 N) was used and complied with the requirements of E.S.S. 4765-1/2012 [13]. The specific gravity and Blain fineness of ordinary Portland cement were 3.16 and 3990 $cm^2$/gm., respectively. Well graded siliceous sand was used. 2.55 and 0.81% were the fineness modules and percentage of absorption of sand. Crushed dolomite as a coarse aggregate was used. 10 mm and 2% were the maximum nominal size and the percentage of absorption of dolomite, respectively. The crushing modules was 19%. The used aggregate complies with the requirements of E.S.S. 1109/2008 [14] and ASTM C33 [15]. 2.62 and 2.64 was the specific gravity for the sand and crushed dolomite, respectively. Tap water was used for mixing the concrete. Class (F) fly ash meeting the requirements of ASTM C618 [16] with a specific gravity of 2.2 was used. Silica fume (SF) was used with 170000 $cm^2$/g and 2.2 specific surface area and specific gravity, respectively. The average particle size of silica fume is 0.1μm. The cement content was 350 kg/$m^3$ in all mixes and the water per binder ratio (w/b) was 0.4 for normal and self-compacted concrete mixes, respectively. Tap water was used for mixing the concrete. A high range water reducer (HRWR) for normal concrete and viscosity agent for SCC were used as superplasticizer meeting the requirements of ASTM C494 (Type A and F) [17].

### 2.2 Casting and test procedures

Dolomite as a coarse aggregate and sand was mixed for 1 minute in the dry state. Cement was added to the aggregate for 2 minutes. It is important to control the concrete temperature as needed. 70 percent of the slurry (water and HRWR) was added and mixed for 1 minute. The 30 percent of the slurry with silica-fume or fly ash was added and mixed for five minutes. After full mixing the concrete was allowed to rest for five minutes. It is important to minimize the evaporation by covering the fresh concrete by wet towels during the rest period. After that the concrete was mixed for three minutes. For each mix the slump, temperature and air content will recorded. The air content was within the desired range (7.0-9.0 percent). The desired ranges of temperature and slump for each series of tests were 18°C to 24°C and 50 mm to 205 mm, respectively. A special mold for settlement cracking with 305× 305 ×203 mm was manufactured. This mould was manufactures as reported by O. Al-Qassag et. al. (2016) [8]. Reinforcing bar with (No. 19) and 305 mm in length was used. The nominal clear cove was 15 mm. The ends of the bar were threaded and attached through holes in the molds using machine screws. The specimens were covered by slope acrylic plate as reported by O. Al-Qassag et. al. (2016) [8]. This method tends to eliminate the plastic shrinkage and allow the settlement cracks to occur. The specimens were kept to controlled place with temperature 25°C and relative humidity 50 ± 4 percent. The mixture proportions for normal and self-compacted concrete were identical as shown in the tables [1 to 3]. The fresh properties for self compacted concrete were evaluated by slump, J-ring and V-funnel test. Table [4] shows the fresh properties of self-compacted concrete. To evaluate the settlement cracking for the different mixes, the method was described by Brettmann R. et. al. (2015) [18] and O. Al-Qassag et. al. (2016) [8] was used.

**Table [1]. Mix proportions by weights for normal concrete (without supplementary materials) (kg/$m^3$).**

| code | | cement | Water | Sand | Dolomite | admixture |
|---|---|---|---|---|---|---|
| | 1 | | | 724.0 | 1227.0 | 0 |
| | 2 | | | 722.6 | 1224.7 | 1.75 |
| | 3 | | | 721.1 | 1222.3 | 3.5 |
| Control | 4 | 350 | 140 | 719.5 | 1219.5 | 5.25 |
| | 5 | | | 718.3 | 1217.4 | 7 |
| | 6 | | | 716.9 | 1215.0 | 8.75 |
| | 7 | | | 715.4 | 1212.5 | 10.5 |

**Table [2]. Mix proportions by weights for normal concrete with silica fume as a replacement of cement content (kg/$m^3$).**

| code | | cement | Water | Sand | Dolomite | admixture | Silica fume | Fly ash |
|---|---|---|---|---|---|---|---|---|
| Silica fume as a replacement of cement content | NS1 | 346.5 | | 722.5 | 1224.6 | 1.75 | 3.5 | |
| | NS2 | | | 721.0 | 1222.2 | 3.5 | | |
| | NS3 | | | 719.7 | 1219.8 | 5.25 | | |
| | NS4 | | | 718.2 | 1217.3 | 7 | | |
| | NS5 | | | 716.8 | 1214.9 | 8.75 | | |
| | NS6 | | | 715.4 | 1212.5 | 10.5 | | |
| | NS7 | 341.25 | | 721.8 | 1223.3 | 1.75 | 8.75 | |
| | NS8 | | | 720.3 | 1220.9 | 3.5 | | |
| | NS9 | | | 718.9 | 1218.4 | 5.25 | | |
| | NS10 | | | 717.4 | 1216.0 | 7 | | |
| | NS11 | | | 716.0 | 1213.6 | 8.75 | | |
| | NS12 | | 140 | 714.6 | 1211.2 | 10.5 | | |
| | NS13 | 332.5 | | 720.6 | 1221.3 | 1.75 | 17.5 | |
| | NS14 | | | 719.2 | 1218.9 | 3.5 | | |
| | NS15 | | | 717.7 | 1216.5 | 5.25 | | |
| | NS16 | | | 716.3 | 1214.0 | 7 | | |
| | NS17 | | | 714.9 | 1211.6 | 8.75 | | |
| | NS18 | | | 713.4 | 1209.2 | 10.5 | | |
| | NS19 | 323.75 | | 719.4 | 1219.4 | 1.75 | 26.25 | |
| | NS20 | | | 718.0 | 1216.9 | 3.5 | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | NS21 | | | 716.6 | 1214.5 | 5.25 | | |
| | NS22 | | | 715.1 | 1212.1 | 7 | | |
| | NS23 | | | 713.7 | 1209.6 | 8.75 | | |
| | NS24 | | | 712.3 | 1207.2 | 10.5 | | |
| Fly ash as a replacement of cement content | NF1 | 332.5 | | 720.6 | 1221.3 | 1.75 | `- | 17.5 |
| | NF2 | | | 719.2 | 1218.9 | 3.5 | | |
| | NF3 | | | 717.7 | 1216.5 | 5.25 | | |
| | NF4 | | | 716.3 | 1214.0 | 7 | | |
| | NF5 | | | 714.9 | 1211.6 | 8.75 | | |
| | NF6 | | | 713.4 | 1209.2 | 10.5 | | |
| | NF7 | 315 | | 714.8 | 1211.5 | 1.75 | | 35 |
| | NF8 | | | 713.4 | 1209.1 | 3.5 | | |
| | NF9 | | | 711.9 | 1206.6 | 5.25 | | |
| | NF10 | | | 710.5 | 1204.2 | 7 | | |
| | NF11 | | | 709.0 | 1201.8 | 8.75 | | |
| | NF12 | | | 707.6 | 1199.3 | 10.5 | | |
| | NF13 | 297.5 | | 715.9 | 1213.5 | 1.75 | | 52.5 |
| | NF14 | | | 714.5 | 1211.0 | 3.5 | | |
| | NF15 | | | 713.1 | 1208.6 | 5.25 | | |
| | NF16 | | | 711.6 | 1206.2 | 7 | | |
| | NF17 | | | 710.2 | 1203.7 | 8.75 | | |
| | NF18 | | | 708.8 | 1201.3 | 10.5 | | |
| | NF19 | 280 | | 713.6 | 1209.5 | 1.75 | | 70 |
| | NF20 | | | 712.2 | 1207.1 | 3.5 | | |
| | NF21 | | | 710.8 | 1204.8 | 5.25 | | |
| | NF22 | | | 709.3 | 1202.2 | 7 | | |
| | NF23 | | | 707.9 | 1199.8 | 8.75 | | |
| | NF24 | | | 706.5 | 1197.4 | 10.5 | | |
| | NF25 | 262.5 | | 711.3 | 1205.6 | 1.75 | | 87.5 |
| | NF26 | | | 709.9 | 1203.2 | 3.5 | | |
| | NF27 | | | 708.4 | 1200.7 | 5.25 | | |
| | NF28 | | | 707.0 | 1198.3 | 7 | | |
| | NF29 | | | 705.6 | 1195.9 | 8.75 | | |
| | NF30 | | | 703.9 | 1193.1 | 10.5 | | |
| | NF31 | 245 | | 709.0 | 1201.7 | 1.75 | | 105 |
| | NF32 | | | 707.5 | 1199.2 | 3.5 | | |
| | NF33 | | | 706.1 | 1196.8 | 5.25 | | |
| | NF34 | | | 704.7 | 1194.4 | 7 | | |
| | NF35 | | | 703.2 | 1191.9 | 8.75 | | |
| | NF36 | | | 701.8 | 1189.5 | 10.5 | | |

**Table [3]. Mix proportions by weights for self-compacted concrete (kg/m$^3$).**

| | Code | cement | Water | Sand | Dolomite | admixture | Silica fume | Fly ash |
|---|---|---|---|---|---|---|---|---|
| Silica fume | SCS1 | 332.5 | 140 | 1078 | 883 | 5.25 | 17.5 | - |
| | SCS2 | | | 1073 | 880 | 8.75 | | |
| | SCS3 | | | 1065 | 873 | 15.75 | | |
| | SCS4 | 323.75 | | 1076 | 882 | 5.25 | 26.25 | - |
| | SCS5 | | | 1072 | 878 | 8.5 | | |
| | SCS6 | | | 1063 | 871 | 15.75 | | |
| Fly ash | SCF1 | 315 | | 1074 | 881 | 5.25 | - | 35 |
| | SCF2 | | | 1070 | 877 | 8.75 | | |
| | SCF3 | | | 1061 | 870 | 15.75 | | |
| | SCF4 | 280 | | 1067 | 875 | 5.25 | - | 70 |
| | SCF5 | | | 1063 | 871 | 8.75 | | |
| | SCF6 | | | 1054 | 864 | 15.75 | | |
| | SCF7 | 245 | | 1060 | 869 | 5.25 | - | 105 |
| | SCF8 | | | 1056 | 866 | 8.75 | | |
| | SCF9 | | | 1047 | 859 | 15.75 | | |

**Table [4]. Fresh properties, settlement cracking results of self-compacted concrete.**

| code | result of fresh properties | | | | | | Concrete temperature, °C | Settlement cracks | Crack length, (mm) | Crack width, (mm) | Crack length/ bar length |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Finial slump test | | J- Ring | | V-Funnel | | | | | | |
| | $D_{av.}$ (mm) | $T_{50cm}$ (sec) | $D_{av.}$ (mm) | $H_1$-$H_2$ (mm) | T (sec) | $T_{5min}$ (sec) | | | | | |
| SCS1 | 555 | 4.56 | 540 | 15 | 3.23 | 5.21 | 22.5 | No | - | - | - |
| SCS2 | 680 | 3.88 | 680 | 5 | 5.99 | 7.28 | 22.9 | | | | |
| SCS3 | 700 | 3.25 | 695 | 5 | 6.38 | 8.0 | 23.0 | | | | |
| SCS4 | 545 | 5.43 | 535 | 10 | 5.78 | 7.39 | 22.8 | | | | |
| SCS5 | 690 | 4.45 | 685 | 5 | 7.84 | 9.27 | 22.4 | | | | |
| SCS6 | 685 | 3.37 | 675 | 5 | 7.99 | 9.34 | 22.7 | | | | |
| SCF1 | 685 | 4.28 | 670 | 15 | 3.18 | 5.05 | 22.5 | | | | |
| SCF2 | 700 | 2.81 | 675 | 5 | 5.62 | 7.25 | 22.6 | | | | |
| SCF3 | 700 | 2.81 | 690 | 15 | 6.03 | 8.0 | 23.0 | | | | |
| SCF4 | 690 | 5.13 | 665 | 10 | 5.35 | 7.68 | 23.2 | | | | |
| SCF5 | 700 | 4.4 | 675 | 10 | 7.35 | 8.88 | 23.1 | | | | |
| SCF6 | 700 | 3.35 | 695 | 10 | 7.88 | 9.27 | 22.7 | | | | |
| SCF7 | 670 | 5.8 | 670 | 15 | 6.74 | 8.16 | 21.9 | | | | |
| SCF8 | 680 | 4.89 | 690 | 10 | 7.94 | 8.99 | 22.0 | | | | |
| SCF9 | 685 | 4.57 | 690 | 5 | 8.35 | 9.6 | 22.4 | | | | |

$D_{av}$: final diameter of the concrete= $[D_1+D_2]/2$, $T_{50cm}$: time for the concrete diameter to reach 50 cm, $H_1$–$H_2$: the difference of the height of the concrete just before and after the ring, T: flow-through time.

**Table [5]. Settlement cracking results of normal concrete.**

| code | Finial slump, mm | Concrete temperature, °C | Settlement cracks | Crack length, mm | Crack width, mm | Crack length/ bar length | code | Finial slump, mm | Concrete temperature, °C | Settlement cracks | Crack length, mm | Crack width, mm | Crack length/ bar length |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 90 | 23.3 | Yes | 159.3 | 0.3 | 0.531 | NF4 | 200 | 22.3 | yes | 30 | 0.35 | 0.1 |
| 2 | 118 | 24.0 | | 138 | 0.3 | 0.46 | NF5 | 220 | 22.7 | | 54 | 0.35 | 0.18 |
| 3 | 132 | 23.8 | | 150 | 0.34 | 0.5 | NF6 | 260 | 22.6 | | 55.2 | 0.4 | 0.184 |
| 4 | 150 | 23.7 | | 210 | 0.45 | 0.7 | NF7 | 80 | 22.4 | | 12 | 0.18 | 0.04 |
| 5 | 170 | 24.2 | | 231 | 0.55 | 0.77 | NF8 | 140 | 22.4 | | 13.5 | 0.16 | 0.045 |
| 6 | 199 | 24.3 | | 208 | 0.9 | 0.693 | NF9 | 170.7 | 22.3 | | 22.8 | 0.19 | 0.076 |
| 7 | 220 | 23.9 | | 201 | 0.97 | .67 | NF10 | 192 | 22.1 | | 44.1 | 0.21 | 0.147 |
| NS1 | 140 | 23.2 | | 67.2 | 0.32 | 0.224 | NF11 | 200 | 21.9 | | 26.1 | 0.23 | 0.087 |
| NS2 | 159 | 22.7 | | 90 | 0.3 | 0.3 | NF12 | 240 | 22.1 | | 59.1 | 0.22 | 0.197 |
| NS3 | 170 | 23.2 | | 105 | 0.32 | 0.35 | NF13 | 100 | 22.1 | No | - | - | - |
| NS4 | 176 | 23.4 | | 104.4 | 0.5 | 0.348 | NF14 | 150 | 22.2 | | | | |
| NS5 | 210 | 22.7 | | 116.1 | 0.67 | 0.387 | NF15 | 170 | 21.8 | | | | |
| NS6 | 230 | 22.9 | | 127.8 | 0.95 | 0.426 | NF16 | 178 | 21.8 | | | | |
| NS7 | 104 | 22.7 | | 64.2 | 0.27 | 0.214 | NF17 | 210 | 22.8 | | | | |
| NS8 | 131 | 23.0 | | 84.6 | 0.26 | 0.282 | NF18 | 240 | 22.4 | | | | |
| NS9 | 150 | 23.1 | | 89.7 | 0.3 | 0.299 | NF19 | 90 | 22.5 | | | | |
| NS10 | 165 | 23.0 | | 90.3 | 0.41 | 0.301 | NF20 | 118 | 22.6 | | | | |
| NS11 | 180 | 22.6 | | 108.9 | 0. 5 | 0.363 | NF21 | 143 | 23.0 | | | | |
| NS12 | 200 | 22.7 | | 116.1 | 0.6 | 0.387 | NF22 | 164 | 23.0 | | | | |
| NS13 | 82 | 22.6 | | 44.4 | 0.28 | 0.148 | NF23 | 175 | 22.7 | | | | |
| NS14 | 93 | 22.9 | | 59.7 | 0.27 | 0.199 | NF24 | 198 | 22.9 | | | | |
| NS15 | 110 | 22.4 | | 82.8 | 0.31 | 0.276 | NF25 | 85 | 22.4 | | | | |
| NS16 | 130 | 22.4 | | 89.4 | 0.5 | 0.298 | NF26 | 106 | 22.6 | | | | |
| NS17 | 167 | 22.6 | | 106.2 | 0.48 | 0.354 | NF27 | 139 | 22.4 | | | | |
| NS18 | 180 | 22.3 | | 113.1 | 0.6 | 0.377 | NF28 | 148 | 22.3 | | | | |
| NS19 | 68 | 22.1 | | 15.3 | 0.3 | 0.051 | NF29 | 160 | 22.1 | | | | |
| NS20 | 70 | 23.0 | | 24.9 | 0.26 | 0.083 | NF30 | 190 | 22.3 | | | | |
| NS21 | 95 | 23.2 | | 54.6 | 0.37 | 0.182 | NF31 | 70 | 22.3 | | | | |
| NS22 | 118 | 23.1 | | 62.1 | 0.4 | 0.207 | NF32 | 89 | 22.4 | | | | |
| NS23 | 123 | 22.7 | | 80.4 | 0.42 | 0.268 | NF33 | 110 | 22.4 | | | | |
| NS24 | 133 | 22.7 | | 90 | 0.5 | 0.3 | NF34 | 132 | 22.3 | | | | |
| NF1 | 112 | 22.5 | | 8.7 | 0.24 | 0.029 | NF35 | 153 | 22.3 | | | | |
| NF2 | 174 | 22.4 | | 28.2 | 0.25 | 0.094 | NF36 | 170 | 22.5 | | | | |
| NF3 | 182 | 22.5 | | 47.4 | 0.29 | 0.158 | | | | | | | |

### 3. Settlement Cracking Reading

After 24 hours; the specimens were inspected visually without magnifications to obtain the settlement cracking. The cracks which were parallel and above the reinforcing bar were considered settlement cracks. Some short and random cracks were seen nearly at the perimeter of the mold. The width of theses cracks was less than 0.035mm. These cracks were not considered as settlement cracking. The ratio of the total length of settlement cracks to total length of reinforcing bar (305mm) is defined as the intensity of cracking. For each mixture three reading was recording and calculating the intensity of settlement cracking. The average of these results was illustrated the crack intensity for the mix. For each mix; Crack length, width, and intensity of settlement crack were recorded. Figure (1) shows magnifications for the settlement cracks for the different normal concrete mixes.

### 4. Results and discussion

#### 4.1 Settlement crack intensity for normal concrete

##### 4.1.1 Control mix

Figure (2) illustrates the relation between the slump and the crack length/bar length for the control mix to show the settlement cracking which is occurring. This figure illustrates the slump front side the settlement crack intensity. It is clear that, as slump increased as the crack length/bar length increased. This means that settlement crack intensity increased. From the figure the slump values ranged from 90 to 220 mm and the crack length to bar length ratio ranged from 0.531 to 0.77. The average of crack length to bar length ratio increased from 0.473 at slump value 92 mm to 0.733 at the slump value 222 mm. The figure shows that the diffraction in the results about 2% of the average trend line. The imperial equation for the settlement crack intensity and the slump was formulated in the figure.

##### 4.1.2 Effect of fly ash

At the same degree of the workability the fly ash enhance the workability of concrete by reducing the water content. Mahesh. V. Raut and Shirish V. Deo (2015, 2017) [20,21] checked on the pervious literatures review on the effect of pozzolanic materials such as fly ash on the shrinkage and durability of concrete. They could that the workability and strength and durability increasing by using fly ash. In the other hand a reduction in the heat hydration was occurred. Profale et. al. (2010) [22] and K. Holschemacher et.al. (2010) [23] studied the effect of fly ash on the workability of the concrete. They investigated that the workability for the mixes with fly ash increased by 25% compared with the control mixes. Figure (3) shows the relationship between the slump and the crack length to bar length ratio to evaluate the effect of fly ash percent on the settlement crack intensity. Thirty-six mixes with different percent of fly ash as a replacement of cement content (5, 10, 15, 20, 25 and 30%) were cast and tested. Figure (3-a) shows the slump value and the crack length to bar length ratio for the mixes containing 5% of fly ash as a replacement of cement content. The slump value ranged from 112 to 260 mm and the crack length/bar length ranged from 0.029 to 0.184. The average of crack length to bar length ratio increased from 0.04 at slump value 111 mm to 0.2 at the slump value 259 mm. The average value of slump increases by 23.1% and settlement crack intensity reduced by 78.5% compared with the control mix. The figure shows that the diffraction in the results about 26% of the average trend line. Figure (3-b) shows the slump value and the crack length to bar length ratio for the mixes containing 10% of fly ash as a replacement of cement content. The slump value ranged from 80 to 240 mm and the crack length/bar length ranged from 0.04 to 0.197. The average of crack length to bar length ratio increased from 0.01 at slump value 81 mm to 0.153 at the slump value 239 mm. The average value of slump increases by 9.7% and settlement crack intensity reduced by 82.9% compared with the control mix. The figure shows that the diffraction in the results about 32% of the average trend line. There are no settlement cracks at different values of the slump for the mixes with 15, 20, 25 and 30 % of fly ash as a replacement of cement content as illustrated in figures (3-C) to (6-f). So the reduction in the settlement crack intensity was 100% at different values of the slump compared with the control mix. The imperial equation for the settlement crack intensity and the slump was formulated in this figure.

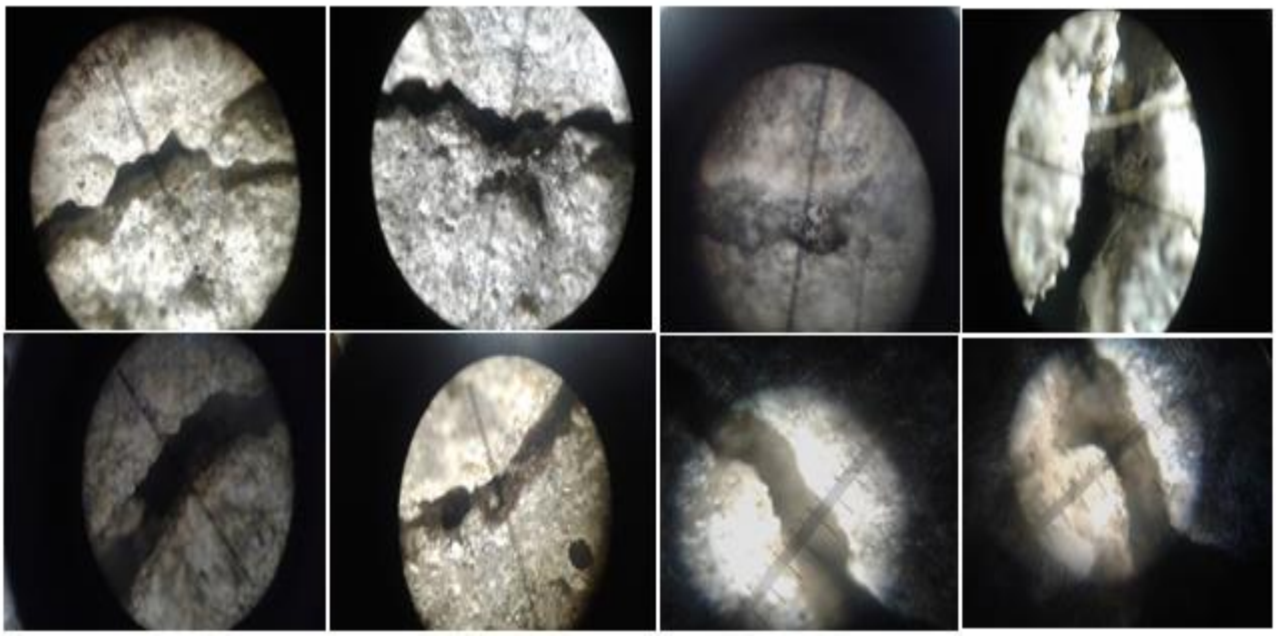


**Figure (1). Magnifications for the settlement cracks for the different normal concrete mixes.**

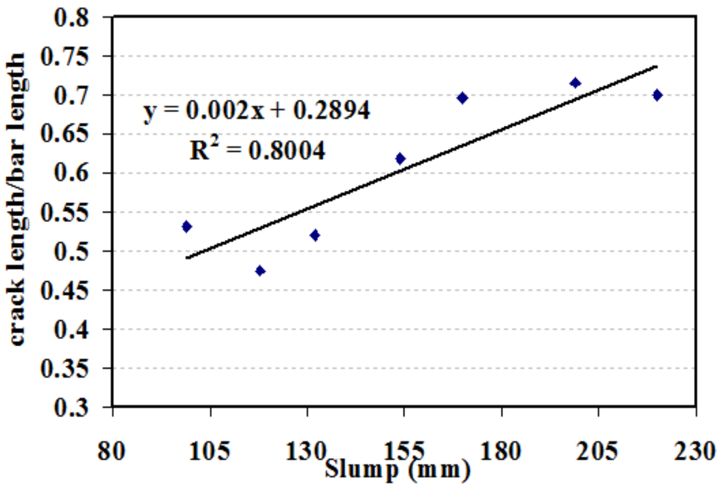
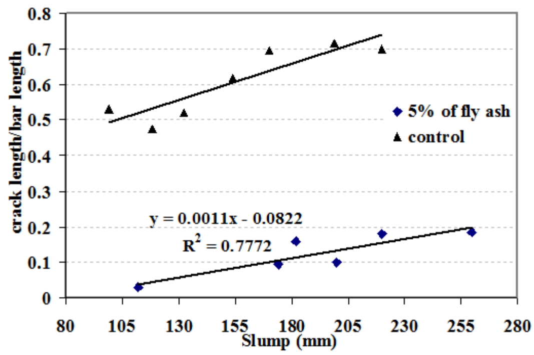
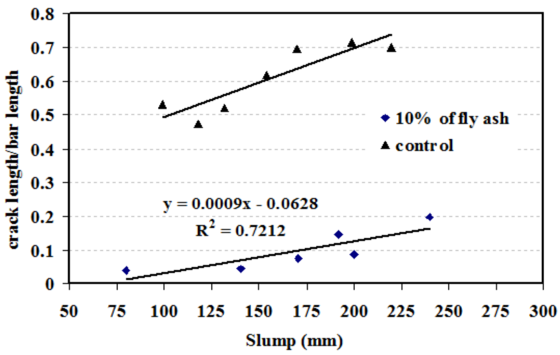


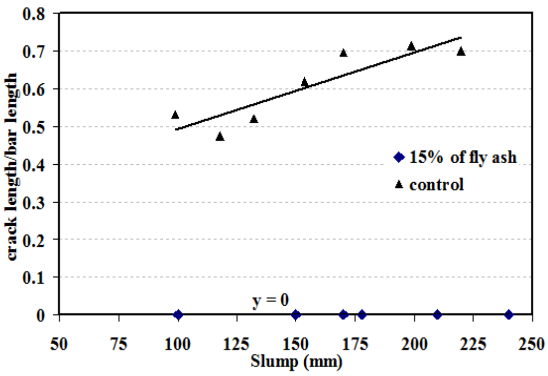

**Figure (2). Relationship between slump and the crack length/bar length for Control mixtures.**



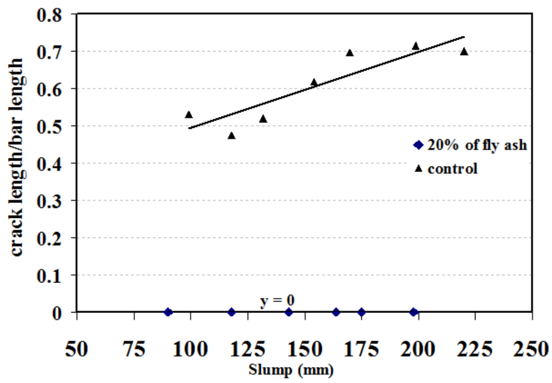

(a) 5 % of fly ash



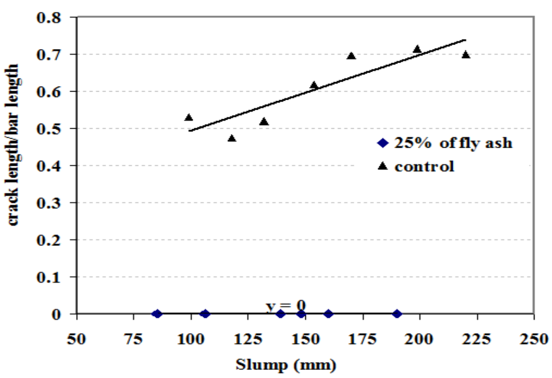

(b) 10 % of fly ash



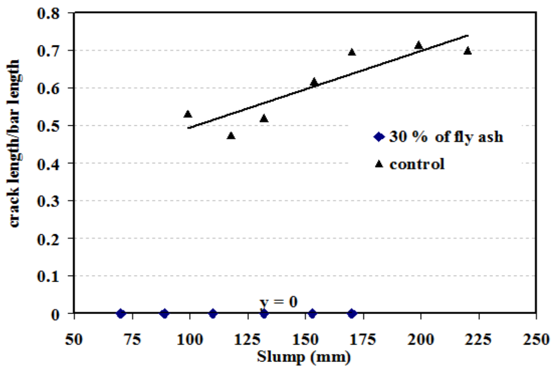

(c) 15 % of fly ash




(d) 20 % of fly ash

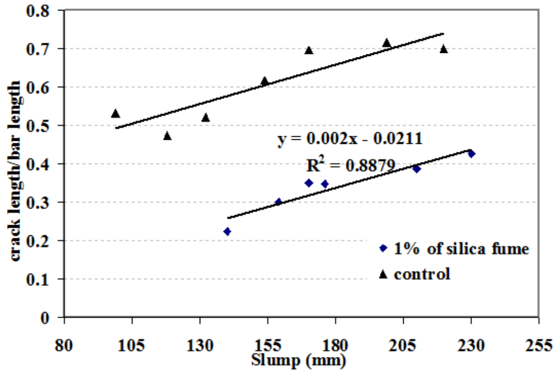



(e) 25 % of fly ash

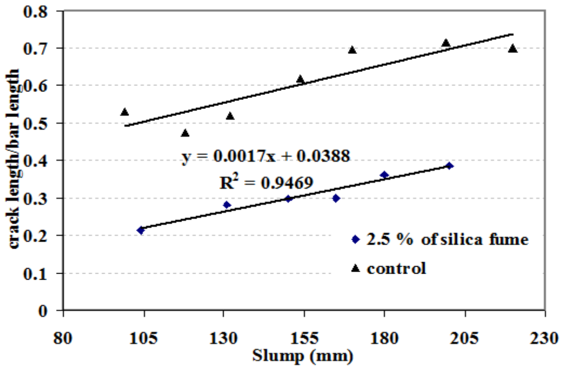



(f) 30 % of fly ash

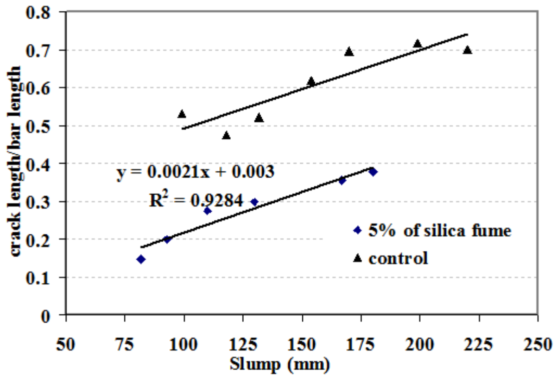
**Figure (3). Relationship between slump and the crack length\ bar length the mix with different percent of fly ash as a replacement of cement content.**



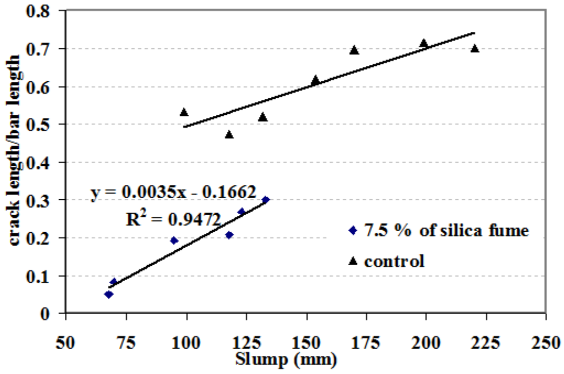

**(a) 1 % of silica fume**




**(b) 2.5 % of silica fume**




**(c) 5 % of silica fume**




**(d) 7.5 % of silica fume**

**Figure (4). Relationship between slump and the crack length\ bar length the mix with different percent of silica fume as a replacement of cement content.**

### 4.1.3 Effect of silica fume

As quantity of Silica fume increases, the workability of the concrete decreases. At lower quantities of silica fume, workability of concrete can improve. Figure (4) shows the relationship between the slump and the crack length to bar length ratio to evaluate the effect of silica fume percent on the settlement crack intensity. Twenty-four mixes with different percent of silica fume as a replacement of cement content (1, 2.5, 5 and 7.5%) were cast and tested. Figure (4-a) shows the slump value and the crack length to bar length ratio for the mixes containing 1% of silica fume as a replacement of cement content. The slump value ranged from 140 to 230 mm and the crack length/bar length ranged from 0.224 to 0.426. The average of crack length to bar length ratio increased from 0.26 at slump value 142 mm to 0.44 at the slump value 230 mm. The average value of slump increases by 15.8% and settlement crack intensity reduced by 41.3% compared with the control mix. The figure shows that the diffraction in the results about 18% of the average trend line. Figure (4-b) shows the slump value and the crack length to bar length ratio for the mixes containing 2.5% of silica fume as a replacement of cement content. The slump value ranged from 104 to 200 mm and the crack length/bar length ranged from 0.214 to 0.387. The average of crack length to bar length ratio increased from 0.22 at slump value 104 mm to 0.379 at the slump value 200 mm. 10.3% and 46.7% were the reduction in the average slump value and settlement crack intensity compared with the control mix. The figure shows that the diffraction in the results about 22% of the average trend line. Figure (4-c) shows the slump value and the crack length to bar length ratio for the mixes containing 5% of silica fume as a replacement of cement content. The slump value ranged from 82 to 180 mm and the crack length/bar length ranged from 0.148 to 0.377. The average of crack length to bar length ratio increased from 0.184 at slump value 86 mm to 0.381 at the slump value 180 mm. 18.3% and 52.4% were the reduction in the average slump value and settlement crack intensity compared with the control mix. The figure shows that the diffraction in the results about 31% of the average trend line. Figure (4-d) shows the slump value and the crack length to bar length ratio for the mixes containing 7.5% of silica fume as a replacement of cement content. The slump value ranged from 68 to133 mm and the crack length/bar length ranged from 0.051 to 0.30. The average of crack length to bar length ratio increased from 0.079 at slump value 70 mm to 0.29 at the slump value 131 mm. 34.9% and 68.25% were the reduction in the average slump value and settlement crack intensity compared with the control mix. The figure shows that the diffraction in the results about 28% of the average trend line. The imperial equation for the settlement crack intensity and the slump was formulated in this figure.

### 4.2 Settlement crack intensity for self-compacted concrete

Table [5] shows the settlement cracking results of self-compacted concrete. The effect of fly ash and silica fume percent on the settlement crack intensity was observed. Fifteen mixes were cast and tested. It is clear there is no settlement cracks for all the self-compacted concrete mixes. This is due to the segregation and bleeding resistance in fresh properties for self-compacted concrete. This property achieved by viscosity enhanced agent which is increase the viscosity of fresh concrete as reported by the requirements of Technical Specification for SCC [19] and Mounir M. Kamal et.al [11, 12].

## 5. Conclusions

Based on the results of the experimental program, the following results can be drawn:

1) As increases the slump the settlement cracking increases.
2) Using self-compacted concrete prevent settlement cracking occurs.

3)Using fly ash as supplementary materials reduces the settlement cracking more than silica fume.

4)More than 10% of fly ash prevents the settlement cracking occurs.

5)The average value of settlement cracks intensity reduced by 41.3, 46.7, 52.4 and 68.3% at 1, 2.5,5 and 7.5% of silica fume as a replacement of cement content, respectively compared with the control mix.

6)The average value of settlement cracks intensity reduced by 78.5 and 82.9% at 5 and 10% of fly ash as a replacement of cement content, respectively compared with the control mix.

7)The imperial equation for the settlement crack intensity and the slump was formulated

8) Out of this research; the major sources for cracking in the bridge decks are the settlement cracking. As Theses cracks continued growth due to the factors effect on the durability of the structures such as chloride and sulfates attacks, corrosion if the reinforcement, freeze-thaw damage and others. So theses crack considered very severe problem on the life time. Decreasing the settlement cracks yield to get better the durability of the structures, eliminate the abrasion and corrosion of the reinforcement. This yield to decreases the cost needed for maintenance and increases the life time of the structures.

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