PERFORMANCE OF CONFINED FRESH CONCRETE SUBJECTED TO AXIAL LOADING

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ABSTRACT

The search for new techniques to strengthen the bond between the aggregates and mortar at the interfacial zone still remains a challenge. In this study we introduce a new technique of strengthening the inter phase between cement paste mortar and aggregate through confinement of fresh concrete with application of mild load axial loading, this will reflect on developing better bonding within the concrete matrix . Physical and mechanical investigations indicate that, this technique has a strong potential and could double production rate of precast concrete members. Further investigations regarding the microstructure analysis using Scanning electron microscope and (Energy Dispersive X-ray Analyses) were also conducted.

KEYWORDS

Fresh concrete under tri-axial loading, strengthening of fresh concrete matrix, silica fume in concrete under tri-axial loading.

1 INTRODUCTION

Previous studies focused on behavior of the concrete matrix at the interfacial zone between cement mortar paste and coarse aggregate. More recent studies focused on deterioration of fiber reinforced polymers at the interface with concrete [1] other studies considered investigation of interfacial zone between glass fiber reinforced polymers and concrete under various environmental conditions [2]. While other studies focused on molecular behavior of confined molecules inside cement paste pores [3]. More research studies focused on shear and strain behavior using different types of cement [4,5]. Meanwhile more research studies focused on modeling bond at steel- concrete inter facial zone [6,7].

Their main aim was to develop a better understanding of the behavior of coarse aggregate, fiber reinforced polymers, steel at the inter facial zone with cement paste mortar, in order strengthen and enhance the performance of the concrete matrix.

This study focuses on subjecting fresh concrete directly after casting for 24 hours, while still in the forms to axial loading on the exposed concrete surface. This will have a direct impact on interfacial zone performance on all previously mentioned studies. Fresh concrete confinement will develop tri-axial internal stresses and concrete will harden in this state. This confinement will result in better cohesion between the cement paste particles with each other, as well as enhancing the adhesion between the cement paste and the aggregates in all directions. We believe that this technique will be most suitable in precast concrete members. This will also increase the concrete strength remarkably and will speed up the production rate of precast concrete members. The parameters investigated in this study were the load applied on the surface of the concrete matrix directly after casting (No load, 0.25 Kg/cm^2, and 0.75 Kg/cm^2), the quantity of the cement in the concrete mix (350,400,500 and 600 Kg/m^3) and the effect of incorporation of silica fume in the concrete matrix under axial loading (No Silica, 5% silica fume).

The aim in this paper was to study the effect of vicat test needle penetration on fresh cement mortar paste under axial confinement, with respect to time and its effect on initial and final setting time using. Slump testing of concrete with variable cement content and silica fume was also conducted. Mechanical properties of standard concrete cubes under compression and subjected to indirect tensile testing, was also performed. Microstructure of the concrete matrix and the efficiency of the concrete matrix packing were also investigated using the scanning electron microscope.

2 TESTING PROGRAM

The experimental program focused on strengthening the inter phase between cement paste and aggregate through applying an axial load on the fresh concrete directly after casting. The testing program was classified into four main groups G1, G2, G3 and G4 with cement content (350, 400, 500 and 600 Kg/m^3). Each group was further classified into three subgroups with variable axial loading conditions applied on the fresh concrete: No load (reference), 0.25 Kg/cm^2 and 0.75 Kg/cm^2.

The loads were applied directly after casting for 24 hours, while fresh concrete was still confined in the standard concrete molds (15*15*15) cm. Each sub group was further classified into two concrete mixes concrete cubes without silica fume to act as reference specimens and concrete cubes with 5% of the weight of cement silica fume added to the concrete mix. Table 1 shows the testing program of concrete mixes applied in this study.

Table (1) Fresh concrete mixes without silica fume and with 5% silica under loading

Group Type	Water (Kg/m^3)	Cement ((Kg/m^3)	W/C	Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Silica Fume	Applied Axial Load Kg/cm^2
GR1-0	175	350	0.5	815.5	1050	0	0
GS1-0	175	350	0.5	815.5	1050	17.5	0
GR1-1	175	350	0.5	815.5	1050	0	0.25
GS1-1	175	350	0.5	815.5	1050	17.5	0.25
GR1-2	175	350	0.5	815.5	1050	0	0.75
GS1-2	175	350	0.5	815.5	1050	17.5	0.75
GR2-0	200	400	0.5	815.5	1050	0	0
GS2-0	200	400	0.5	815.5	1050	20	0
GR2-1	200	400	0.55	815.5	1050	0	0.25
GS2-1	200	400	0.5	815.5	1050	20	0.25
GR2-2	200	400	0.5	815.5	1050	0	0.75
GS2-2	200	400	0.5	815.5	1050	20	0.75
GR3-0	250	500	0.5	815.5	1050	0	0
GS3-0	250	500	0.5	815.5	1050	25	0
GR3-1	250	500	0.5	815.5	1050	0	0.25
GS3-1	250	500	0.5	815.5	1050	25	0.25
GR3-2	250	500	0.5	815.5	1050	0	0.75
GS3-2	250	500	0.5	815.5	1050	25	0.75
GR4-0	300	600	0.5	815.5	1050	0	0
GS4-0	300	600	0.5	815.5	1050	30	0
GR4-1	300	600	0.5	815.5	1050	0	0.25
GS4-1	300	600	0.5	815.5	1050	30	0.25
GR4-2	300	600	0.5	815.5	1050	0	0.75
GS4-2	300	600	0.5	815.5	1050	30	0.75

3 RESULTS AND ANALYSIS

3.1 Slump Test

Observation of slump test results indicated that, as the cement content increased from 350Kg/m^3 in G1 to 600 Kg/m^3 in G4, the slump value shows a continuous increase. This trend was observed in all groups without silica fume and with silica fume (Reference subgroups and subgroups with 5% silica fume). This was attributed to the continuous increase in the quantity of fine cement particles in the concrete mix accompanied with corresponding increase in the water content, which resulted in a rich highly workable concrete mix. The slump value in concrete mix of group GR4 without silica fume reached 210 mm compared to a slump of 32 mm in corresponding mix in GR1 subgroup without silica fume. Meanwhile the slump value in concrete mix of group GS4 with silica fume reached 210 mm compared to a slump value of 14 mm in corresponding mix in GS1 subgroup with silica fume.

Another trend was also observed in groups 1, 2 and 3, it was noted that reference concrete specimens GR1, GR2 and GR3 showed higher slump values ranging between (32-110) mm compared to concrete specimens with 5% silica fume(GS1, GS2 and GS3) which showed slump values ranging between (14-95) mm. See Figure 1. This was attributed to the high surface area of the silica fume which increased the absorption capacity of the concrete mix, resulting in more consumption of water in the concrete mix which reflects on decreasing the slump value in concrete mixes with silica fume. It was also noted that as the cement content increases from 350Kg/m^3 in group 1 to 500Kg/m^3 in group 3, the gap in the slump value between reference specimens and concrete specimens with silica fume shows a continuous decrease from 56% to 13.6%. This was attributed to the fact that the continuous increase in the cement content attributed with increase in water content in the concrete mix results in more workable concrete mix, which diminishes the negative effect of introduction of silica fume in the concrete mix. For Concrete specimens in group 4 the slump value in both sub groups GR4 and GS4 was the same which indicates that the negative effect of silica fume on slump value completely vanishes.

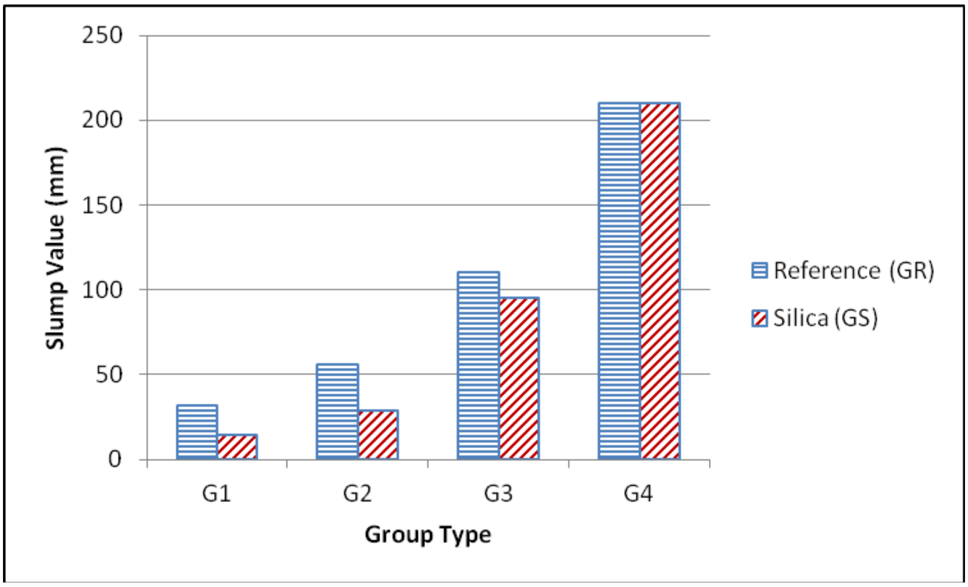

Figure 1: Slump Value for Concrete Mixes with and without Silica Fume

3.2 Vicat Penetration test results

Fresh cement mortar was placed in vicat test set up. Mortar samples were subjected to penetration depth measurement at different time interval using vicat needle, in order to evaluate the rate of hardening of the mortar paste. Penetration test was performed on cement mortar specimens on reference subgroups with no axial load applied (GR1-0, GR2-0, GR3-0 and GR4-0), as shown in Figure 2. The general trend indicates that GR1-0with cement content 350Kg/m^3 showed highest rate of hardening among all groups, with an initial setting time 10 minutes and a final setting time 119 minutes. As the cement content increased to 400Kg/m^3 in GR2-0 cement mortar specimens, accompanied with a corresponding increase in water content, the initial setting time increased to 15 minutes and a final setting time 138 minutes. Further increase in the cement content to 500Kg/m^3 resulted in a very rich mortar paste and resulted in further increase in the initial setting time of GR3-0 to 40 minutes and a final setting time of 150 minutes. The maximum delay in initial setting time among all groups was in GR4-0 subgroup, with an initial setting time 65 minutes and a final setting time 170 minutes.

Penetration test for mortar paste with no silica fume and subjected to axial loading 0.25 Kg/cm^2 in (GR1-1, GR2-1, GR3-1 and GR4-1) indicates lower levels of initial setting time ranging between 4–38 minutes.

Final setting time also decreased to 62-119 minutes. It was also noted that as the cement content increased from 350Kg/m^3 to 600Kg/m^3, the initial setting time increased and the final setting time showed a continuous increase. See Figure 3. This was attributed to the increase in cement paste. These results were compatible with the slump test results discussed in the previous sector.

Penetration test for cement mortar paste with no silica fume and subjected to axial loading 0.75Kg/cm^2 in (GR1-2,GR2-2, GR3-2 and GR4-2), resulted in lowest levels of initial setting time ranging between 2-5 minutes . It was noted that as the cement content increased from 350Kg/m^3 to 600Kg/m^3 , the final setting time also showed a continuous increase from 60 minutes in GR1-2 subgroup to 70 minutes in GR 4-2, which corresponds to a 16% reduction in final setting time compared to GR1-2 and 41% when compared to GR1-0. See Figures 4 and 8). It is believed that increase in axial loading to 0.25Kg/cm^2 and up to 0.75Kg/cm^2, showed a continuous increase in the rate of hardening of the cement mortar paste.

For Subgroups with no axial load and 5% silica fume (GS1-0, GS2-0, GS3-0 and GS4-0), the general trend indicates that, existence of silica fume decreased the initial setting time to 2-55 minutes, this range was lower than that encountered in corresponding reference group mentioned above. This was attributed to the high surface area of silica fume which resulted in higher rate of water absorption. Final setting time in concrete specimens in this subgroup also decreased to 70-120 minutes. It was also noted that as the cement content increased from 350 Kg/m^3 to 600 Kg/m^3, the initial setting time showed a continuous increase. See Figure 5. These results were compatible with previous results obtained from reference specimens with no silica fume.

Penetration test for mortar cement paste with 5% silica fume subjected to an axial load 0.25 Kg/cm^2 in (GS1-1, GS2-1, GS3-1 and GS4-1) indicates lower levels of initial setting time ranging between 2-24 minutes which was lower than corresponding reference specimens with no silica fume mentioned above. It was also noted that, as the cement content increased from 350 Kg/m^3 to 600 Kg/m^3, the initial and final setting time also showed a continuous increase. See Figure 6.

Penetration test for cement mortar paste with 5% silica fume subjected to axial loading 0.75 Kg/cm^2 in (GS1-2, GS2-2, GS3-2 and GS4-2) showed lowest levels of initial setting time among all groups with and without silica fume and decreased to 2-5 minutes and the final setting time also showed lowest levels with respect to corresponding reference specimens with no silica fume and ranged between 60-70 minutes .See Figures 7 and 9. Increase in the cement content from 350 Kg/m^3 to 600 Kg/m^3 resulted in a continuous increase in initial setting and final setting time as it was the case in previous subgroups.

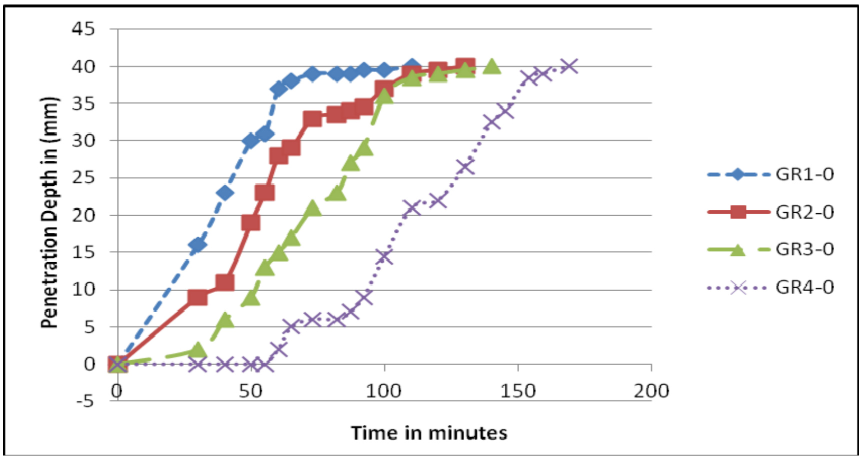

Figure 2: Vicat Needle Penetration for cement mortar with No Silica Fume and No Axial Load

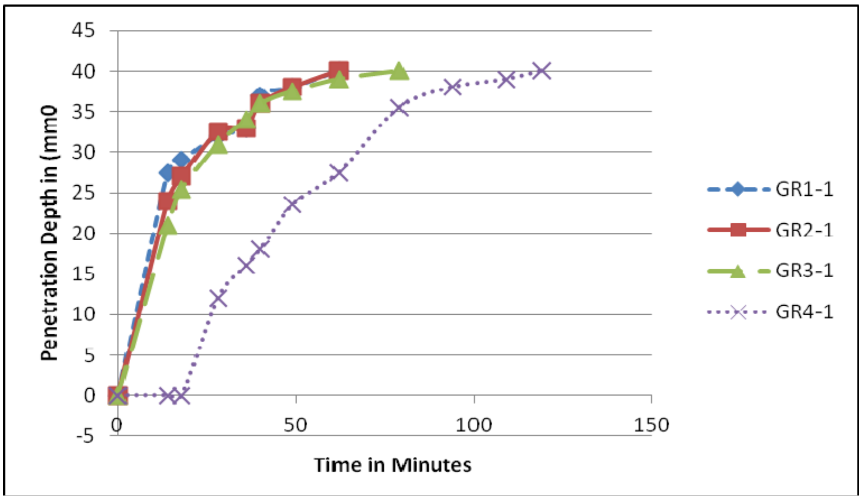

Figure 3: Vicat Needle Penetration for cement mortar with No Silica Fume and 0.25Kg/Cm^2

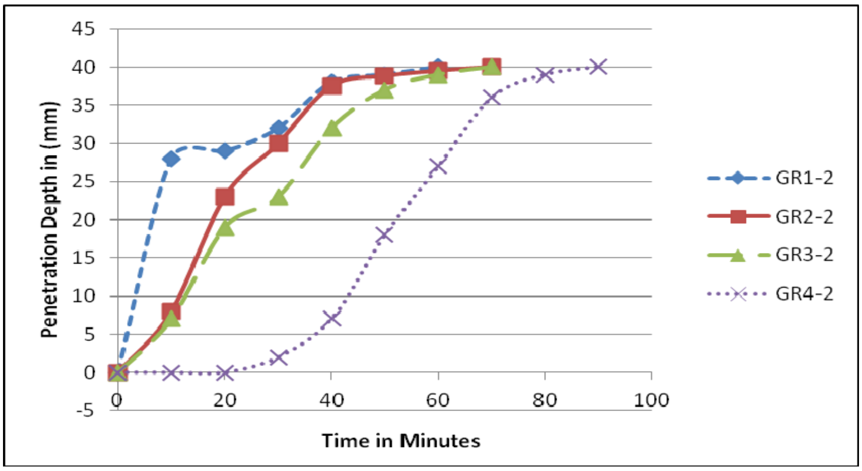

Figure 4: Vicat Needle Penetration for cement mortar with No Silica Fume and 0.75Kg/Cm^2

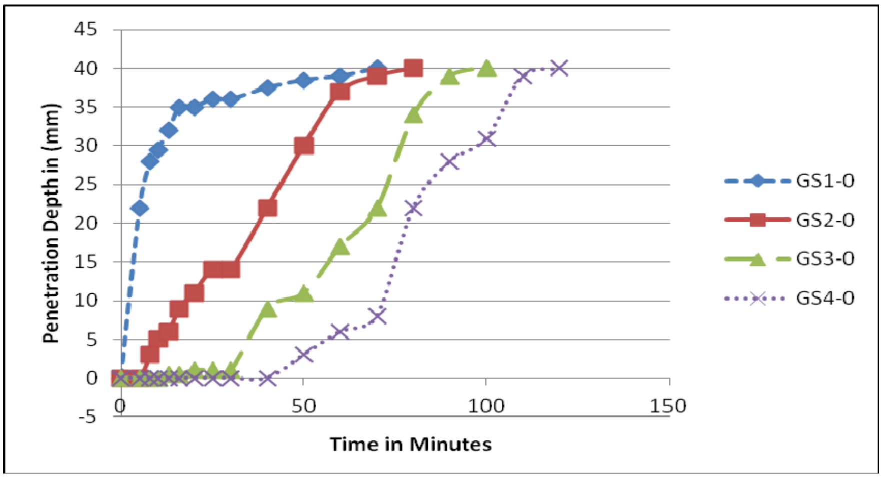

Figure 5: Vicat Needle Penetration for cement mortar with Silica Fume and No Axial Load

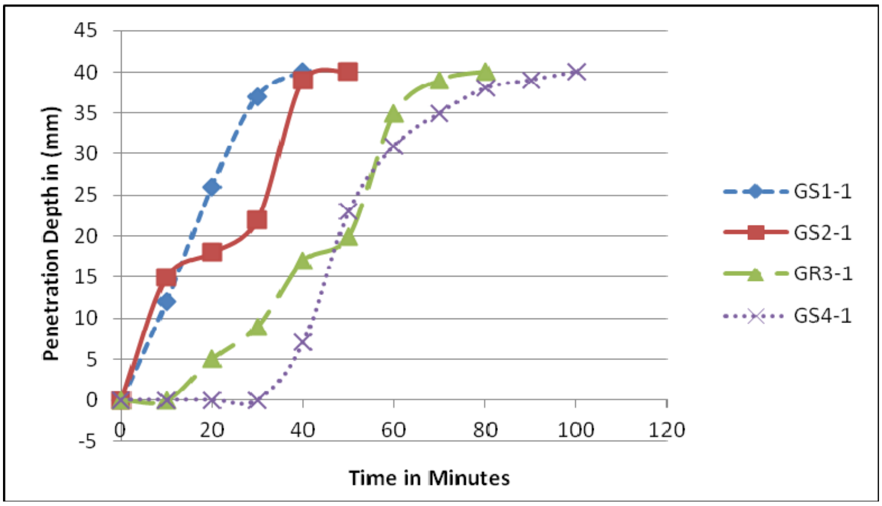

Figure 6: Vicat Needle Penetration for cement mortar with Silica Fume and 0.25Kg/Cm^2

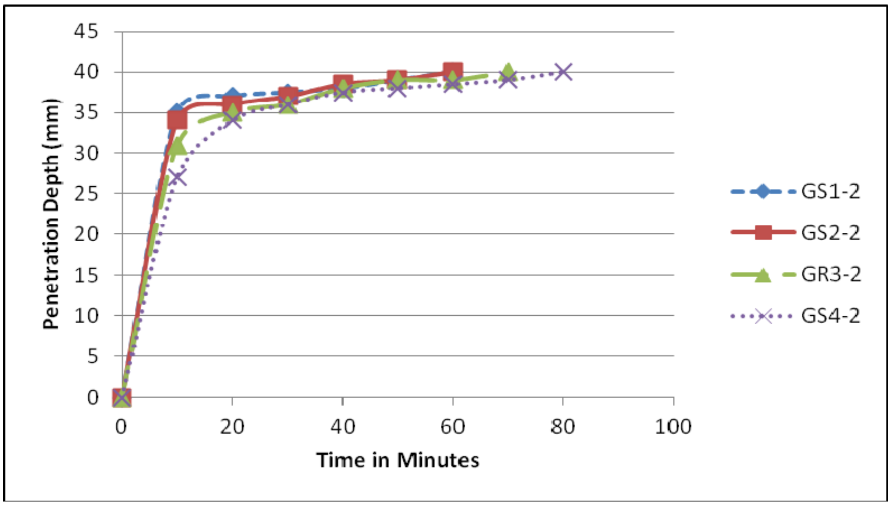

Figure 7: Vicat Needle Penetration for cement mortar with Silica Fume and 0.75Kg/Cm^2

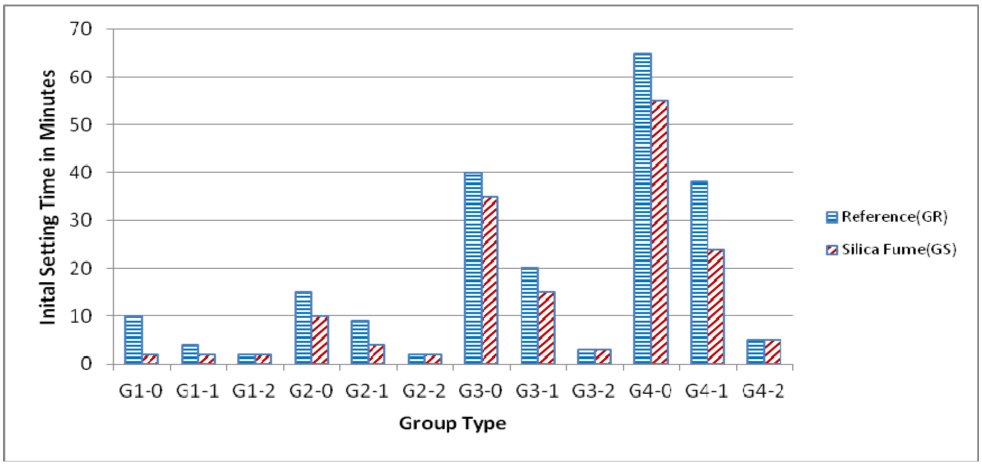

Figure 8: Initial Setting Time for cement mortar with and without Silica Fume

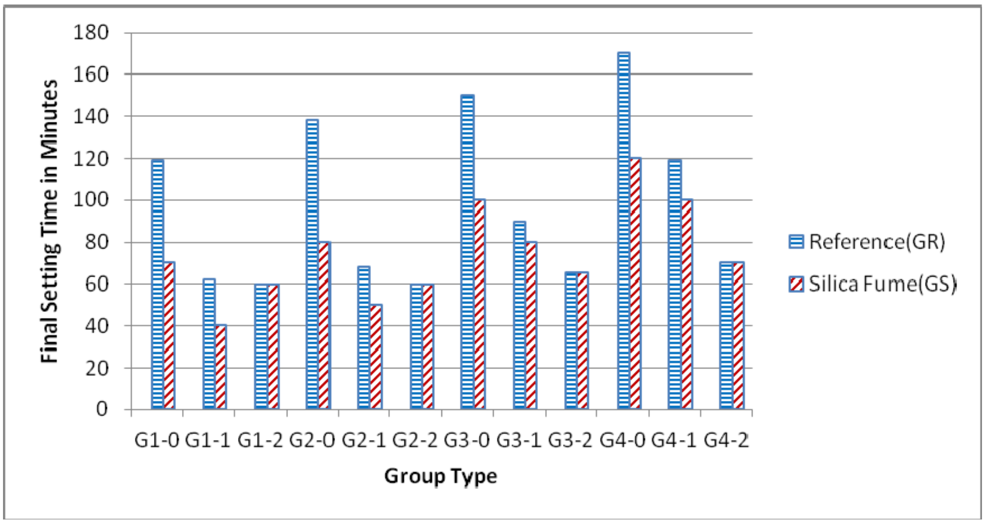

Figure 9: Final Setting Time for cement mortar with and without Silica Fume

3.3 Compressive Strength

Compressive strength test was performed of all concrete specimens using standard cubes (15*15*15) cm. under same lab conditions. The general trend regarding the compressive strength results indicates that subgroups with 5% silica fume (GS) showed higher compressive strength results compared to corresponding reference (GR) specimens within each subgroup after 28 days by 3.4-23.2%. This trend was observed in all groups G1, G2 G3 and G4 with cement content (350, 400, 500 and 600) Kg/m^3. This was attributed to the effect of the silica fume in increasing C-S-H gel, which is the effective binding material. See Figure 10. For Reference specimens, it was noted that the confinement of fresh concrete under axial loading of 0.25Kg/cm^2, resulted in further increase in the compressive strength in subgroups GR1-1, GR2-1, GR3-1 and GR4-1 by 4.51-11.46%, compared to corresponding reference specimens GR1-0, GR2-0, GR3-0 and GR4-0 subgroups. The same trend was also observed in concrete specimens with 5% silica fume, GS1-1, GS2-1, GS3-1 and GS4-1 subgroups, subjected to 0.25 Kg/cm^2, which showed an increase in the compressive strength by 7.38-10.59% compared to corresponding reference specimens with 5% silica fume under no axial loading. This affirms the theory that confined fresh concrete under axial loading improves the adhesion between the aggregates and the mortar paste and increases the cohesion between cement particles and provides better confinement for the aggregates. Further increase applied axial loading from 0.25Kg/cm^2 up to 0.75Kg/cm^2 results in further increase in the compressive strength. For Reference specimens, it was noted that the confinement of fresh concrete under axial loading of 0.75Kg/cm^2, resulted in increase in the compressive strength in GR1-2, GR2-2, GR3-2 and GR4-2 subgroups by 5.25-32.77%, compared to corresponding reference specimens GR1-0 subgroup. The same trend was also observed in concrete specimens with 5% silica fume, subjected to 0.75Kg/cm^2, GS1-2, GS2-2, GS3-2 and GS4-2 subgroups, showed an increase in the compressive strength by 11.4-25.1 % compared to corresponding reference specimens with 5% silica fume under no axial loading GS1-0, GS2-0, GS3-0 and GS4-0 subgroups. As evident from Figure 10, as the cement content increased from 350 Kg/m^3 to 600 Kg/m^3, the compressive strength showed a continuous increase reaching highest compressive strength levels among all groups in GR4 and even higher levels in GS4 subgroups.

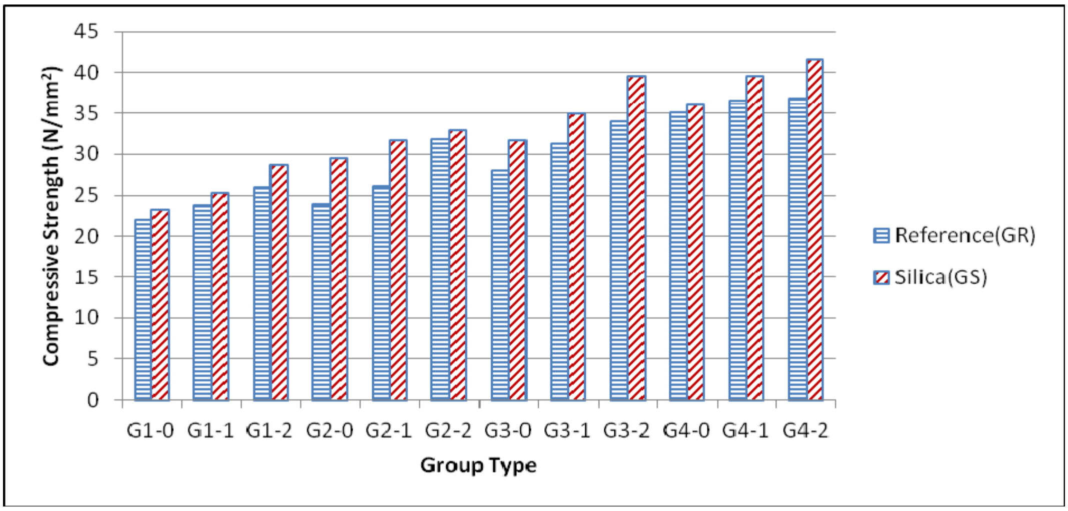

Figure 10: Compressive Strength for Various Groups

3.4 Splitting Tensile Testing

The general trend observed in the compressive strength results was reflected in the tensile strength results. Two trends were registered in the splitting tensile test. The first trend indicates that the splitting tensile strength in concrete specimens with silica fume were higher than the splitting tensile strength results of corresponding reference specimens in groups 1, 2 and 3 ranging between 5% and 16.1% . It was also noted that as the cement content increased from 350 Kg/m^3 to 600 Kg/m^3 the splitting tensile strength showed a continuous increase, reaching maximum levels of splitting tensile strength in GR4 subgroups with no silica fume, ranging between 2.9 and 3.9 N/mm^2. For concrete specimens in subgroup GS4 with silica fume, the splitting tensile strength ranged between 3.61-5.9 N/mm^2 which was higher by 24.5-51.28% compared to corresponding reference subgroups in GR4. It should be noted that concrete specimens in subgroup 4-2 with cement content 600 Kg/m^3 and subjected to axial loading 0.75 Kg/cm^2, showed significant splitting tensile strength resistance compared to groups G1, 2 and 3. GR4-2 subgroup with 600 Kg/m^3 showed an increase by 25.8-77.27% compared to corresponding specimens in groups 1, 2 and 3 subjected to 0.75 Kg/cm^2. In GS4-2 concrete specimens with 5% silica fume, cement content 600 Kg/m^3 and subjected to axial loading 0.75 Kg/cm^2, the splitting tensile strength showed an increase by 63.8-136%, compared to corresponding specimens in group GS1-2, GS2-2 and GS3-2.

This was attributed to the high workability of concrete specimens of group 4 as evident from the slump test results as well as the high cement content. Existence of silica fume in GS4-2 subgroup resulted in further increase in the splitting tensile by 51.28%, compared to corresponding reference concrete specimen GR4-2.

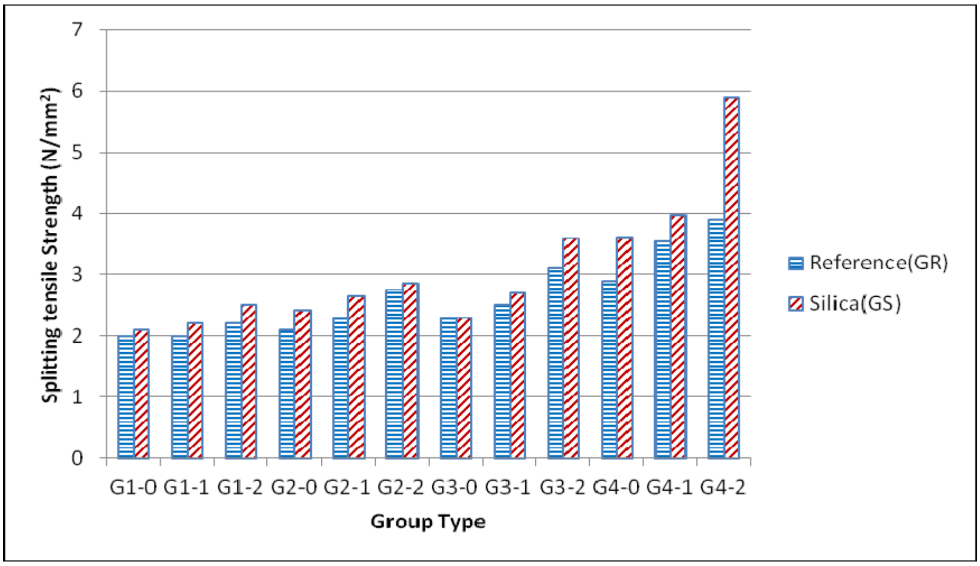

Figure 11: Ultimate Splitting Failure Load for Various Groups

3.5 Micro structural Behavior

Microstructure was performed using a Scanning electron microscope (SEM), model type QUANTA FEG 250 with a (Field Emission Gun) attached to an EDX Unit (Energy Dispersive X-ray Analyzer), with an accelerating voltage of 30 K.V. and a magnification of 14X up to 1000000, resolution. The investigation was performed at the Egyptian Mineral Resources Authority Laboratories. Samples were taken from reference concrete cubes with aggregate particles integrated within mortar paste.

Microstructure analysis was performed on reference concrete samples subjected to no axial load as shown in Figure (12-A) with a magnification of 200 times naked eye view. Large mild gray aggregate particles appear integrated with light gray mortar paste adhering to its surface. At the interface between aggregate and mortar paste (C-S-H gel) is solidified into an irregular surface. Further enhancement with a magnification of 1000 X on the cement paste zone as shown in Figure (12-B), clearly shows a high intensity of black spots of air voids entrapped within the cement paste matrix, which explains low compressive strength values registered in concrete cubes subjected to no axial load.

Investigation of a concrete sample subjected to 0.25 Kg/cm^2 axial load, indicates as shown in Figure 13 lower levels of black spots (air voids) compared to reference specimens discussed above, which seems to reflect on higher levels of compressive and splitting tensile strength values compared to corresponding reference groups subjected to no axial load.

Cement mortar paste sample taken from a concrete specimen subjected to 0.75 Kg/cm^2 axial load, shows almost no black spots (voids) within the cement mortar paste. See Figure 14. Cement mortar paste sample in this case was under a magnification of 1000X. There is a distinct difference in the intensity of the black spots or air voids between, reference cement mortar paste sample in Figure (12-B) and the very low number of voids in cement mortar paste sample subjected to 0.75 Kg/cm^2 in Figure 14. We believe that this is the primary cause for the high compressive and splitting strength results achieved in concrete specimens subjected to 0.75 Kg/cm^2 (G1-2, G2-2, G3-2 and G4-2), which was the highest among all corresponding subgroups.

EDX Unit (Energy Dispersive X-ray Analyzer), results shown in Figure 15 indicates typical high levels of Ca and Si as well mild traces of Fe, Al and Mg which exist in nature within cement components. This is a typical EDX spectrum for cement mortar paste in all concrete samples.

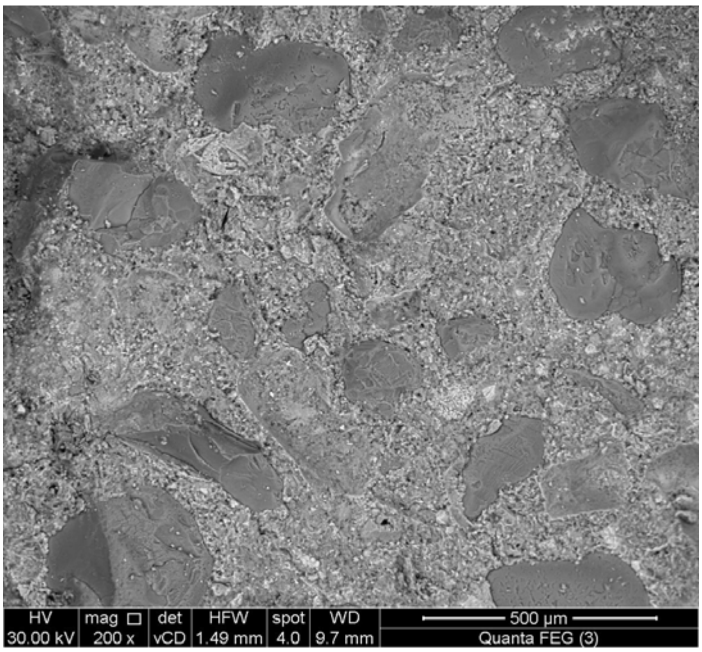

Figure 12-A: Reference concrete sample under 1000X magnification

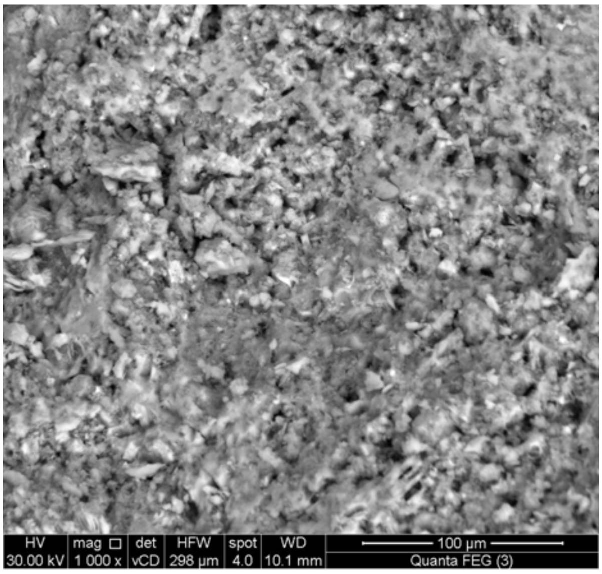

Figure 12-B: Reference cement mortar paste sample with no axial load under 1000X magnification

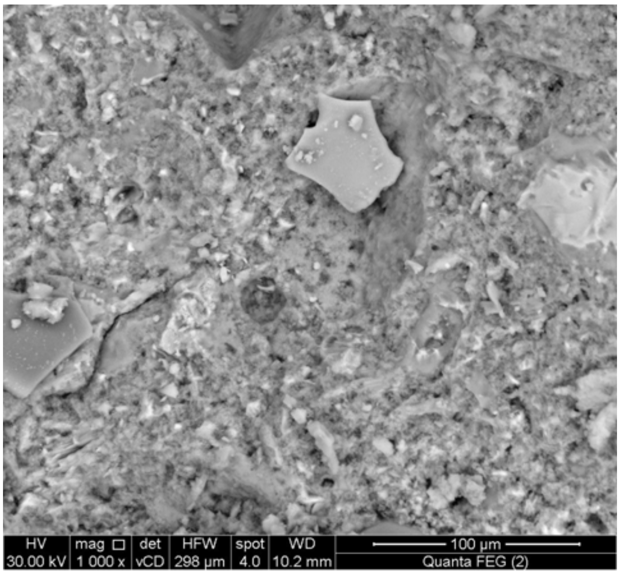

Figure 13: Cement mortar sample subjected to 0.25Kg/Cm^2 axial load and 1000X magnification

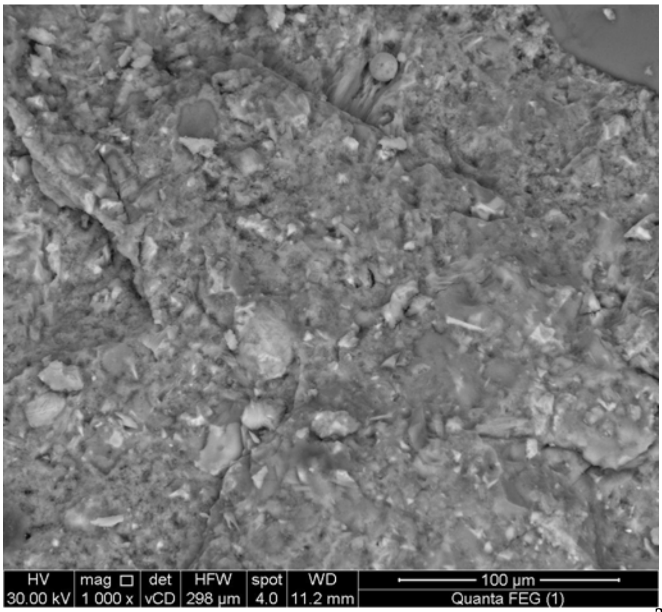

Figure 14: Cement mortar paste sample under 0.75Kg/Cm^2 axial load and 1000X magnification

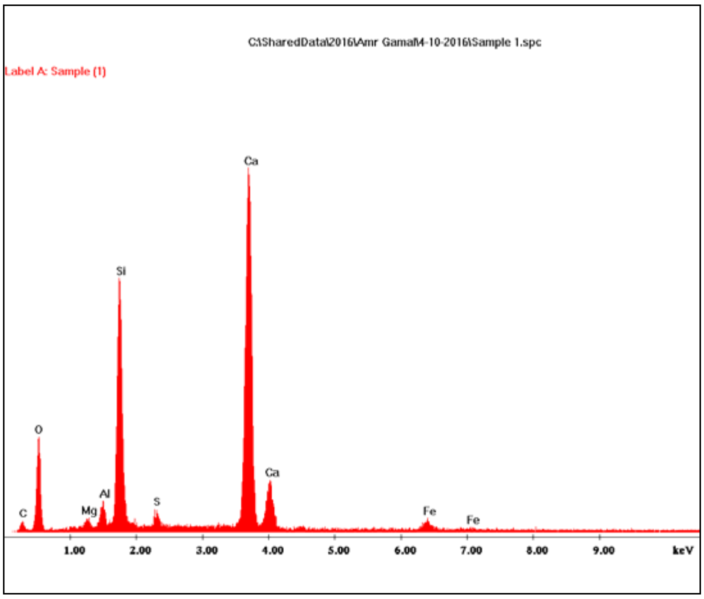

Figure 15: Typical EDX spectrum for cement mortar paste sample

4 CONCLUSION

1- Increase in axial loading from 0 to 0.75Kg/cm^2, increases the rate of concrete hardening of the concrete matrix. Penetration tests for cement mortar paste samples with and without silica fume and subjected to axial loading 0.75Kg/cm^2 , showed decrease in the final setting time by 41% compared to reference specimens subjected to no load.

2- Increase in the cement content from 350Kg/m^3 to 600Kg/m^3, resulted in a continuous increase the slump value, while introduction of 5% silica fume resulted in a decrease in the slump value. These trends were observed in all groups in this study and had a direct effect on penetration test results.

3- Increase in axial loading on fresh concrete from 0 to 0.75Kg/cm^2 in reference concrete cubes with no silica fume, resulted in increase in the compressive strength after 28 days by 67.91 %.

4- Increase in axial loading on fresh concrete in standard concrete cubes with 5% silica fume from 0 to 0.75Kg/cm^2, resulted in increase in the compressive strength after 28 days by 79.12%. They also showed increase in compressive strength compared to reference concrete cubes with no silica fume by 89.65%.

5- Fresh concrete in standard concrete cubes subjected to 0.75 Kg/cm^2 showed highest splitting tensile strengths compared to corresponding concrete specimens subjected to no axial load and concrete specimens with 0.25 Kg/cm^2 , this trend was observed in all groups.

6- As the cement content increased from 350 Kg/m^3 to 600 Kg/m^3 , the splitting tensile strength showed a continuous increase, reaching maximum levels of splitting tensile strength in GR4 subgroups with no silica fume, ranging between 2.9 and 3.9N/mm^2 and ranging between 3.96 and 5.9N/mm^2 in GS4 subgroups with 5% silica fume.

7- Micro structural analysis showed evidence of denser packing and a severe decrease in the number of voids within the cement mortar paste samples subjected to 0.75Kg/cm^2, to almost no voids, compared to corresponding reference specimens under no axial load and cement mortar specimens with 0.25 Kg/cm^2.

5 RECOMMENDATIONS

1- It is recommended to introduce higher levels of axial loading; this will further speed up production rate of precast concrete members.

2- Introduction of higher level of silica fume 10-15% of the weight of cement will have positive impact on compressive and tensile strength and production rate of precast members.

3- Addition of super-plasticizers will help in reduction of water/cement ratio, which will lead to increase in compressive and tensile strength characteristics.

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