Effect of Partial Replacement of Cement by Mixture of Glass Powder and Silica Fume Upon Concrete Strength

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Effect of Partial Replacement of Cement by Mixture of Glass Powder and Silica Fume Upon Concrete Strength

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***Abstract*—**All over the world the most common consuming construction material is concrete. It is well know that concrete is the combination of cement, aggregates and water. The production of cement results in the formation of carbon dioxide gas causes the environmental pollution. About 7 percent of carbon dioxide gas is evolved from cement industries to atmosphere. Keeping in view about the environmental pollution which may leads to some serious issues of health, so it is essential to use locally available pozolanic materials as a partial replacement of cement because these materials are economical as compared to Portland cement and also friendly to the environment without compromising on concrete strength.

In concrete cement can be partially replaced by different supplementary cementitious materials. In the recent years pozzolonic materials, glass powder and silica fume are used in concrete as a partial cement replacement to improve the strength of concrete.

In this research work the mixture of glass powder and silica fume were used in concrete as a partial cement replacement, to study its effect upon concrete strength. The mix proportion of 1:2:4 was selected for all the concrete samples with water to binder ratio of 0.55. For comparison, a control sample of concrete was prepared without mixture of glass powder and silica fume to compare it with the various samples containing different percentages of mixture of glass powder and silica fume as a partial replacement of cement in concrete. Results discovered that the usage of mixture of glass powder and silica fume in concrete as a partial replacement of cement increases the concrete strength. Such as compressive strength increases up to 8.64%, tensile strength increases up to 15% and flexural strength increases up to 7.08% at the age of 28 days. It is concluded that maximum strength is achieved at 28 days by 30 percent replacement of cement through mixture of glass powder and silica fume in concrete and the strength was decreased by increasing the mixture of glass powder and silica fume content beyond 30 percent. Therefore 30 percent replacement of cement is the optimum amount to achieve the higher strength. From the SEM analysis of concrete samples it's proved that both the pozzolonic materials contribute in hydration process and further validated the strength test results.

***Keywords*—**Glass Powder, Silica Fume, compressive strength, Tensile strength, Flexure strength, SEM Analysis.

I. Introduction

Concrete is one of the world's most widely used material. It consists of binding material (cement), coarse aggregate, fine aggregate and water (Chandra and Berntsson, 2003; BSI, 1980). In the world there are many different sources for emitting the carbon dioxide gas comprising of cement manufacturing industries, vehicles and burning of fossil fuels. Global warming is the main reason due to the emission of greenhouse gases such as carbon dioxide gas to the atmosphere. Cement act as a binding material to bind fine and coarse aggregate in concrete but cement industries cause an environmental pollution due to the emission of carbon dioxide gas. It is concluded that manufacturing of 1 ton cement produces 1 ton carbon dioxide gas. About 7 percent of carbon dioxide gas is evolved from cement industries to the atmosphere, i.e. fifty percent carbon dioxide gas of all industrial emission (Mehta, 1999). During the manufacturing of cement different harmful gases are produced like Nitrogen Oxide, Sulphur Dioxide, Carbon Dioxide and the dust.(Kampa and Castnas, 2008; Friedrich and Pregger, 2009). Environmental pollution causes due to releasing of dust to air from cement industries. Cement dust created adverse effect on plants, ecosystem and human health. To solve these problems it is required for the cement industries to create some solutions. (Adak et al., 2007; Baby et al., 2008). Fast-growing of industries decrease natural resources, emissions of greenhouse gases and increase in pollution contributing to global warming. The issues related to such depletions and global warming can be overcome by using supplementary cementitious materials i.e. metakaoline, fly ash and silica fume (Mala et al., 2013). Using of cementitious materials as a partial replacement of cement in concrete decreases the amount of cement which in turn reduces the emission of CO2. (Ecosmart, 2012). By utilizing different supplementary cementitious materials as a partial replacement of cement in concrete the compressive strength is positively improved. Cement replaced by minerals has the ability to improve its early strength, which ultimately results in the reduction of the quantity of the cement (Khokhar et al., 2010). The basic properties like strength of concrete mainly depends on the quality of concrete. Different properties like impermeability and durability are dependent on the compressive strength of concrete (Neville and brooks, 2002;

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Taylor, 2002). Usage of ideal quantity of supplementary cementitious material leading to achieve better strength, heat of hydration, permeability, workability and chemical resistance. Reaction between the hydration of OPC and oxides of cementing material results to improve the concrete durability (Perry, 1987).

Keeping in view the worst effects of binding material related to the cement manufacturing on environment it requires to develop alternative binding materials for making concrete. Therefore, extensive research on the use of cement replacement by industrial byproducts and many other waste materials. Usage of these by-products as a binding materials is becoming popular all over the world because of reduction of evolving of many harmful gases in the environment which have good effects on the environment (G.Vijaykumar et al., 2008).

There are many by-products produced by the factories which has been used for the binding material like silica fume which is produced by smelting process of silicon metal and Ferro silicon alloy manufacture, comprising of extensive amount of fine and amorphous silicon dioxide (SiO2) elements. In civil engineering works for stabilization of soil silica fume has been used as a binder in combination with cement gives good result (Taylor et al., 1996).

The most commonly used cementitious material is silica fume. It consists of small particles having surface area from 13,000 m2/kg to 30,000 m2/kg. Size of silica fume is hundred times smaller than cement particles which decreases the permeability of concrete. Reduction in the permeability of concrete decreases the deterioration caused by several factors such as alkali-aggregate reaction, carbonation, chloride attack, freezing and thawing, sulfate attack, etc. (Muhit et al., 2013).

Million tons of waste glass is produced every year in the world due to the improvement of living standards, the rapid population growth, industrialization and urbanization. Therefore it has become a critical problem around the word to utilize the waste glass. Glass waste is considered as non-decaying material that pollutes the surrounding environment. Hence, a requirement of the development of new technologies are necessary for the utilization of waste glass. Thus glass is widely used in aggregates and cement mixes as a pozzolonic material, it contains different chemical varieties such as soda lime glass, alkali- silicate glass and boro- silicate glass.

II. BACKGROUND

Usage of additional cementitious material in concrete have its significance in the past and may follow its significance in the future. Many researchers have been trying to replace the constituents of concrete with cheap and locally available materials because of the rising cost of materials used in concrete and the environmental problems due to the production of cement. Therefore the supplementary cementitious materials (pozzolanic materials) dig up more attention.

In concrete partial replacement of cement through pozzolanic materials have proved to be more favorable from prospective of concrete strength and durability. Tikalsky et al. (1988) stated that the partial replacement of cement by fly ash up to 35 percent in concrete the positive change in strength at later age. Udoeyo et al. (2004) reported that wood ash affected the flexural and compressive strength. Whereas in the start compressive and flexural strength is minimum and improves with the passage of time. Zongjin and Jin (2003) stated that using of mineral admixture in concrete effect the modulus of elasticity of fresh concrete and improved the strength of concrete. Givi et al. (2010) concluded that concrete setting time, strength and workability can be improved by using of rice husk ash in concrete. Yilmaz (2010) stated that the permeability of concrete is decreased and its setting time is increased by using of silica fume in concrete.

Silica fume is a supplementary cementing material produced from the smelting process of silicon metal and ferrosilicon alloy. It mainly composed of SiO2 more than 85 percent. When Silica fume is mixed with cement in suitable quantity, below than 15 percent, it will increase the durability and strength of concrete. It is very reactive pozzolanic material due to the high amount of amorphous SiO2 content.

Glass is an amorphous material with high silica content, it can be used as a partial replacement of cement when the size of particles of glass powder is less than 75µm. (Federio and Chidiac, 2001, Jin.W, Meyer. and Baxter. 2000). To prevent alkali silica reaction particle size should be less than 75µm (G.Vijaykumar et al., 2008). Glass is manufactured with a mixture of three major components i.e. sand, limestone and silica. When glass powder is mixed with cement in a suitable quantity, increases the durability and strength of concrete. The micro structural analysis shows that glass powder produced a dense matrix which increases the concrete durability. (Ahmad, 2002).

III. MATERIALS

Cement: Ordinary Portland Cement (Type I) was used in the present study. The value of its specific gravity is 3.15.

Fine Aggregate: Sand of Lowerance Pur was used as a fine aggregate, their properties are given in Table 1.

Coarse Aggregates: Dara Adam khel crush was used as a coarse aggregate, their properties are given in Table 2.

Glass Powder: Scrap glass collected from the shops of glass suppliers near to phase 3 Hayatabad Peshawar. Ball mill is used to grind the scrap glass in to powder form, their properties are listed in Table3.

Silica Fume: Silica fume was obtained from Sica Industries Islamabad. Grey colour silica fume was used in this research.

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TABLE. 1 PHYSICAL PROPERTIES OF FINE AGGREGATES

Max particle size (mm)	Fineness modulus	Bulk Specific gravity	Water absorption capacity (%)	Organic impurities
4.75	2.60	2.64	1.01	Nil

TABLE. 2 PHYSICAL PROPERTIES OF FINE AGGREGATES

Max particle size (mm)	Bulk Specific gravity	Dry rodded unit weight (kg/m^3)	Water absorption capacity (%)	Organic impurities
20	2.65	1580.2	0.61	Nil

TABLE. 3 ELEMENTAL AND COMPOUND ANALYSIS OF WASTE GLASS POWDER RESULTS

Elemental Analysis		Compound Analysis	
Element	*Percentage*	*Compound*	*Percentage*
Si	37.5	SiO_2	77.82
Ca	11.2	CaO	16.11
Fe	2.3	Fe_2O_3	3.20
Al	0.9	Al_2O_3	1.64
K	0.6	K_2O	0.62
Zn	0.3	ZnO	0.25
S	0.1	SO_3	0.25
Other	0.29	Total	99.89

IV. TESTING PROCEDURES

MIX PROPORTIONING

Concrete used in this research study is planned to be divided into five sets on the basis of partially cement replacement with mixture of waste powdered glass and silica fume. The concrete mix and their designation are shown in Table 4.

TABLE. 4 MIX PROPORTION DETAILS

Mix	Designation	Percentage Replacement of cement by mixture of glass powder and Silica fume (by weight)		
		Total %age replacement	*GP. 75% of total %age replacement*	*SF. 25% of total %age replacement*
Mix 1	M1	0	0	0
Mix 2	M2	10	7.5	2.5
Mix 3	M3	20	15	5
Mix 4	M4	30	22.5	7.5
Mix 5	M5	40	30	10

Materials used in this research are locally accessible. OPC is used in this research which is partially replaced up to 10%, 20%, 30% and 40% by blended material (mixture of waste powdered glass and silica fume). The maximum particle size of fine aggregate is 4.75mm and the coarse aggregate having maximum particle size is 20 mm. The concrete samples are to be cured for 3,7,14, and 28 days. Concrete mix proportion of 1:2:4 by mass was used in this research. The water binder ratio is 0.55. The concrete mix 1:2:4 signifies the ratio of binding agent (cement), fine aggregate (sand) and course aggregate (crush). Set up of two different types of concrete mix. In one mix only cement was used as a binder called control mix (M1) and in the other concrete mix cement was replaced with the mixture of silica fume and glass powder (pozolanic materials) through weight of different percentages (10%,20%, 30% and 40%). Details of concrete mix types and designation are given in Table 5.

TABLE. 5 QUANTITY OF MATERIALS FOR ONE CYLINDER

S. No	Mix ID	Cement (grams)	Mixture of Glass Powder & Silica Fume			Fine aggregate (grams)	Coarse aggregate (grams)	Water (grams)	W/B
			Total %age replacement	*GP 75% of total % age replacement*	*SF 25% of total % age replacement*				
1	M1	2742.5	0	0	0	5485	10970	1508	0.55
2	M2	2468.2	10	205.7	68.5	5485	10970	1508	0.55
3	M3	2194.0	20	411.4	137.2	5485	10970	1508	0.55
4	M4	1919.5	30	617	205.5	5485	10970	1508	0.55
5	M5	1645.5	40	822.75	274.25	5485	10970	1508	0.55

V. RESULTS AND DISCUSSION

COMPRESSIVE STRENGTH

Concrete samples of 3, 7, 14, and 28 days were tested for its compressive strength having different percentage of mixture of GP and SF as a replacement of cement. The level of replacement of cement by mixture of GP and SF was 10%, 20%, 30% and 40%. Two samples of each replacement were tested for its compressive strength and the average of these two samples is the compressive strength of concrete. In this research the mixing ratio was 1: 2: 4 and have a constant (w/c) ratio of 0.55. Mix M1 contains no replacement of cement with which the other are compared. This mix is commonly used in different structures. Table 6 represents all the results of compressive strength and figures (1—4) shows its graphical representation.

TABLE. 6 COMPRESSIVE STRENGTH OF CONCRETE WITH VARIOUS PERCENTAGE OF MIXTURE OF GP AND SF

Mix type	**Water to binder ratio w/b**	**Compressive strength (psi)**			
		3 days	***7 days***	***14 days***	***28 days***
M1	0.55	1689	2069	2260	2905
M2	0.55	1584	1961	2350	2970
M3	0.55	1513	1913	2380	3125
M4	0.55	1453	1736	2442	3156
M5	0.55	1243	1624	2148	2845

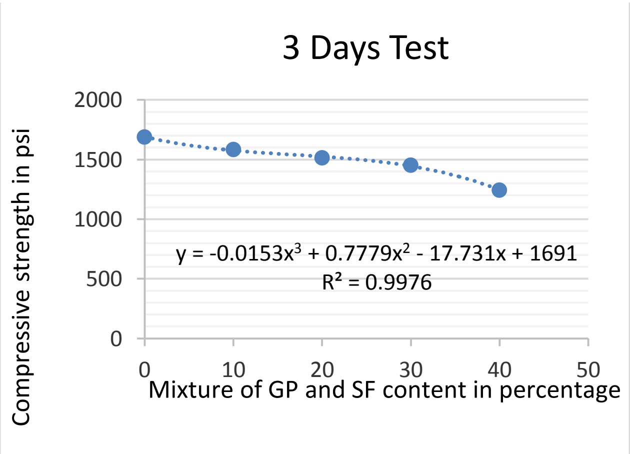

Figure. 1 Compressive strength of 3 days cylinder

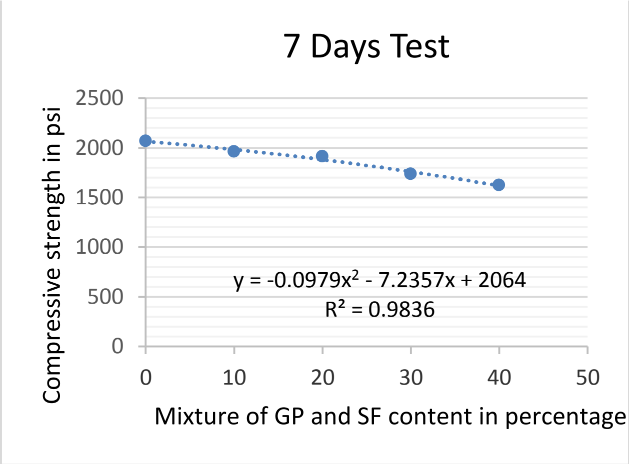

Figure. 2 Compressive strength of 7 days cylinder

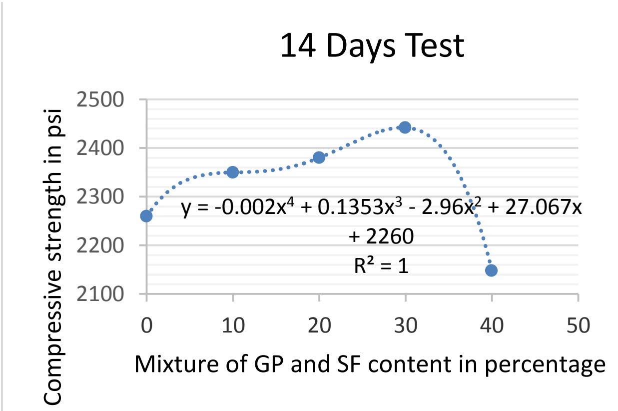

Figure. 3 Compressive strength of 14 days cylinder

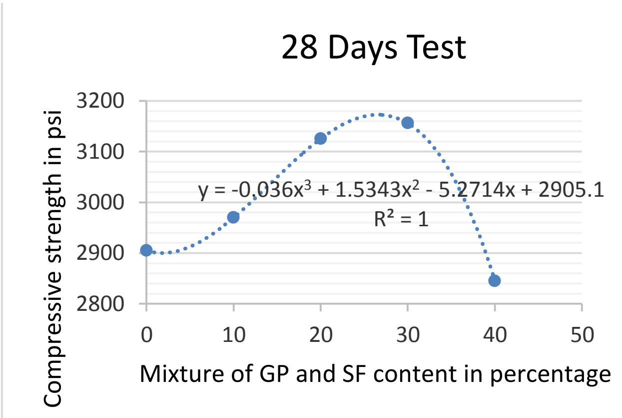

Figure. 4 Compressive strength of 28 days cylinder

TENSILE STRENGTH

Concrete samples (cylinders) of 28 days were tested for its tensile strength having different percentages of mixture of GP and SF as a replacement of cement. The level of replacement of cement by mixture of GP and SF was 0%, 10%, 20%, 30% and 40%. Ten cylinders were tested for blended and control mix. Two samples of each replacement were tested and the average strength of these two cylinders are taken as the final result. Table 7 represents all the results of tensile strengths and Figure 5 shows its graphical representation.

Table. 7 TENSILE STRENGTH OF CONCRETE

Mix Type	Water binder ratio W/B	Tensile strength of concrete(psi)
M 1	0.55	282.8
M 2	0.55	298.6
M 3	0.55	320.14
M 4	0.55	326.16
M 5	0.55	236.05

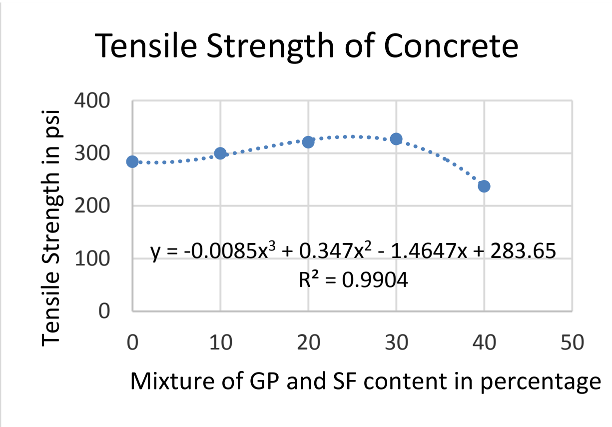

Figure. 5 Tensile strength of concrete

FLEXURAL STRENGTH

Concrete samples (Beams) of 28 days were tested for its flexural strength having different percentages of mixture of GP and SF as a replacement of cement. The level of replacement of cement by mixture of GP and SF was 0%, 10%, 20%, 30% and 40%. Ten samples of beams were tested for blended and control mix. Two samples of each replacement were tested, the average strength of these two beams are taken as the final result. Table 8 represents all the results of flexural strengths and Figure 6 shows its graphical representation.

Table. 8 FLEXURAL STRENGTH OF CONCRETE

Mix Type	Water to Binder Ratio (W/B)	Flexural Strength of concrete (Psi)
M 1	0.55	628.4
M 2	0.55	605.8
M 3	0.55	643.2
M 4	0.55	672.9
M 5	0.55	537.1

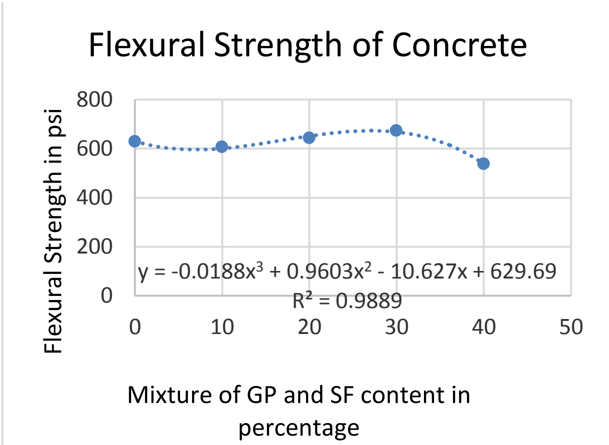

Figure. 6 Flexural strength of concrete

SCANNING ELECTRON MICROSCOPE ANALYSIS OF GLASS POWDER AND SILICA FUME

SEM images of glass powder and silica fume are shown in figures (7—13).

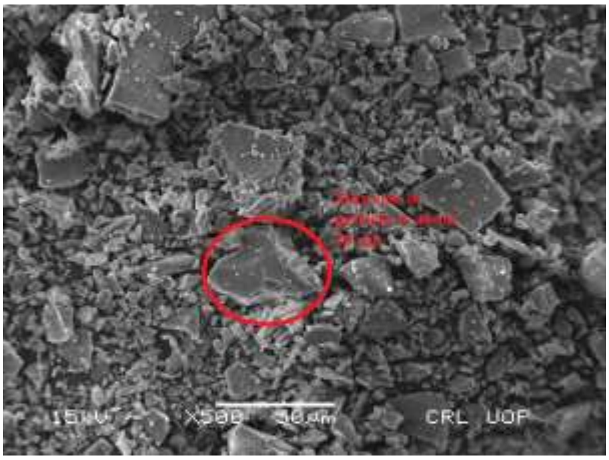

Figure. 7 SEM of glass powder at 50 µm

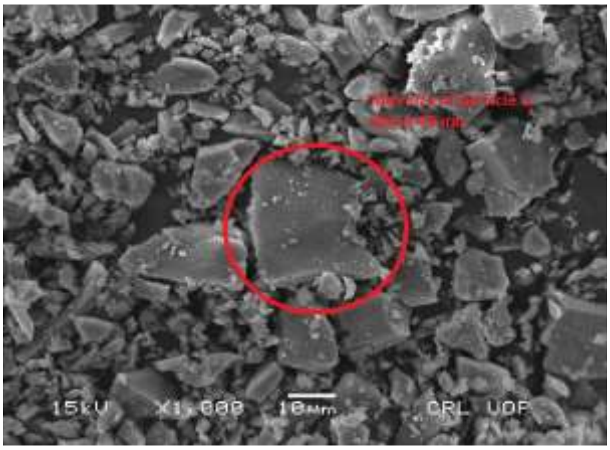

Figure. 8 SEM of glass powder at 10 µm

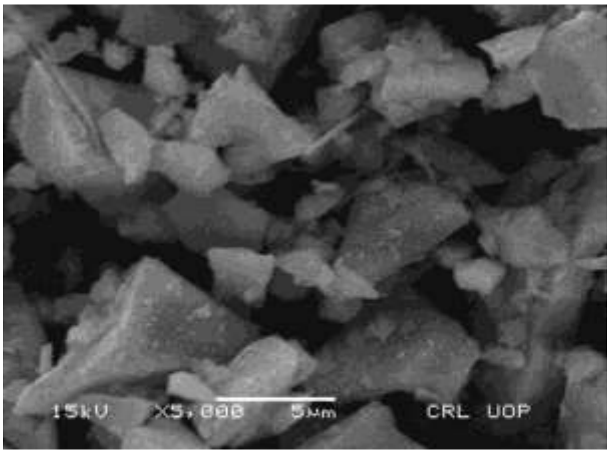

Figure. 9 SEM of glass powder at 5 µm

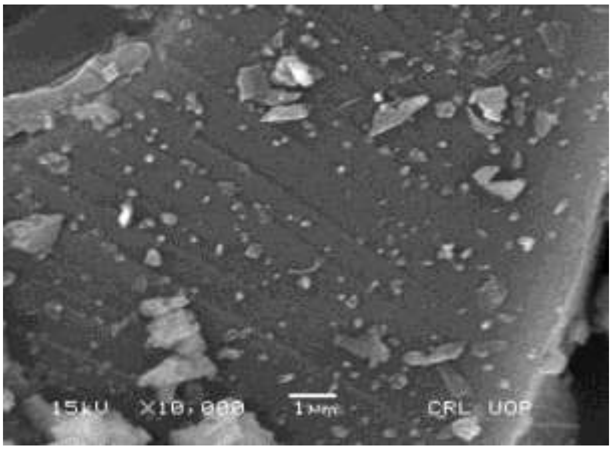

Figure. 10 SEM of glass powder at 1 µm

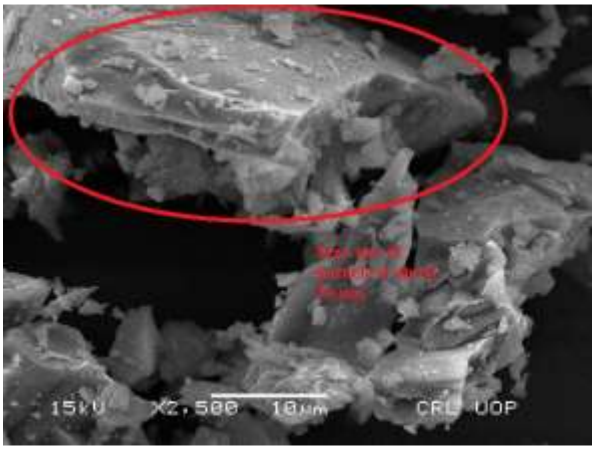

Figure. 11 SEM of silica fume at 10 µm

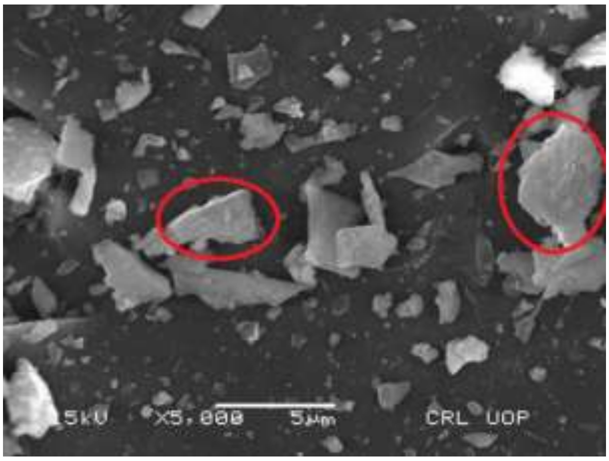

Figure. 12 SEM of silica fume at 5 µm

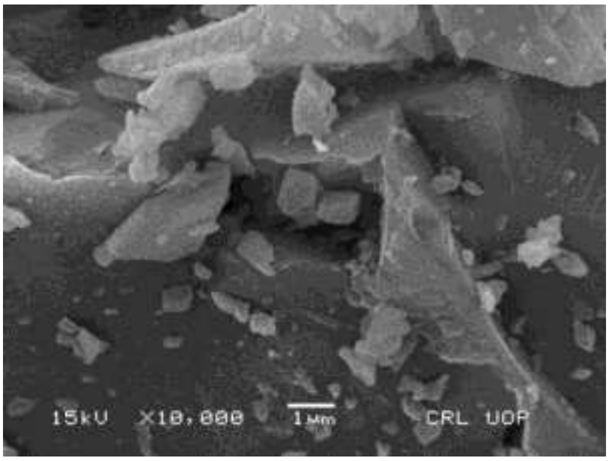

Figure. 13 SEM of silica fume at 1 µm

SCANNING ELECTRON MICROSCOPE ANALYSIS OF BLENDED CONCRETE

From the SEM analysis of blended concrete samples (M2, M3, M4, M5) it is evident that no clear particles of silica fume and glass powder are seen, hence it’s prove that both the pozzolonic materials contribute in hydration process. The bigger black spots show the aggregate particles. SEM images of blended concrete samples at the age of 28 days are shown in figures (14⎯40).

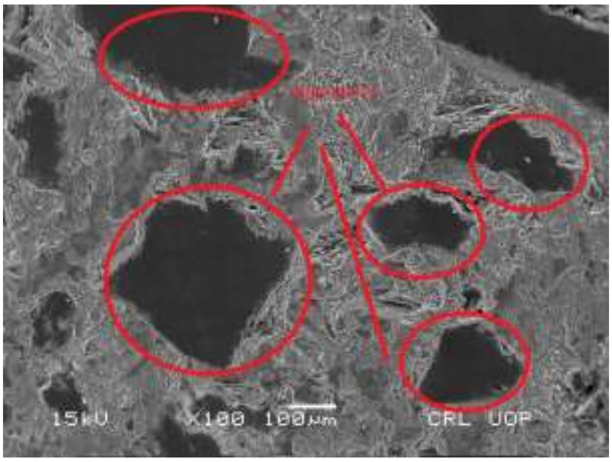

Figure. 14 SEM of sample M2, X100 at 100 µm

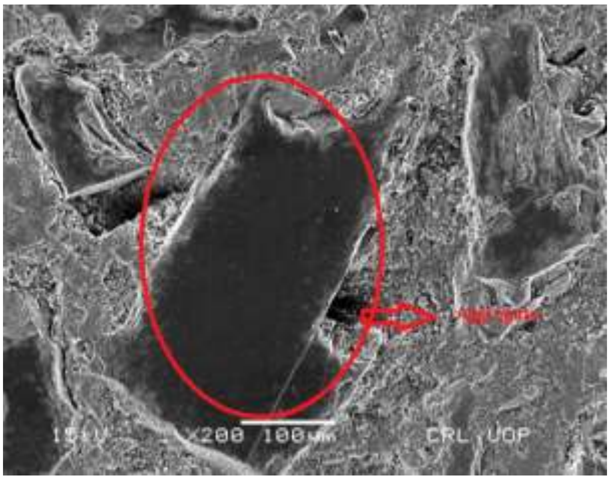

Figure. 15 SEM of sample M2, X200 at 100 µm

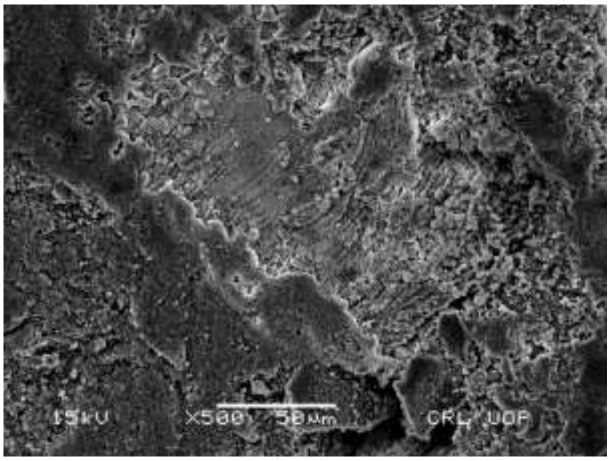

Figure. 16 SEM of sample M2, X500 at 50 µm

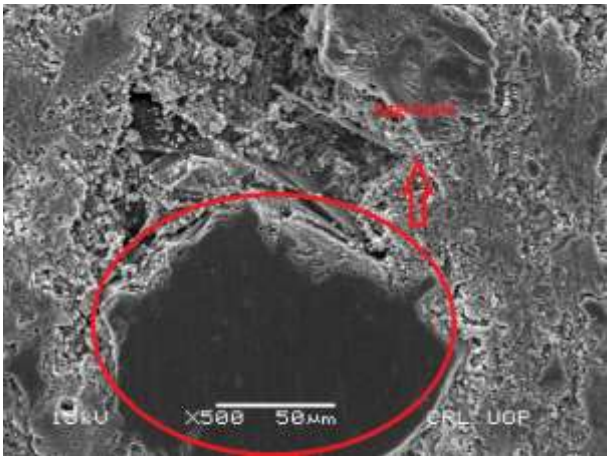

Figure. 17 SEM of sample M2, X500 at 50 µm

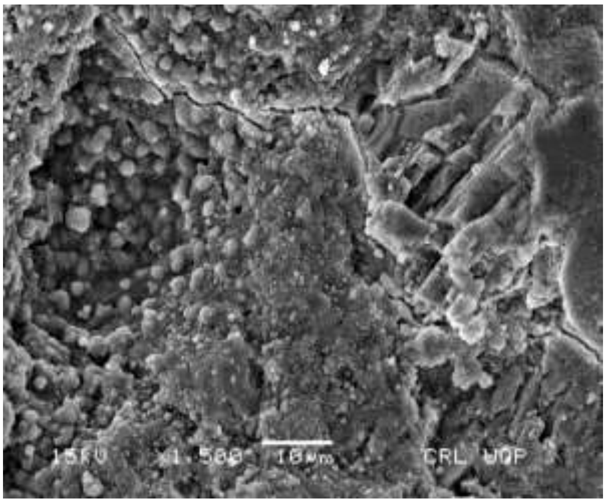

Figure. 18 SEM of sample M2, X500 at 10 µm

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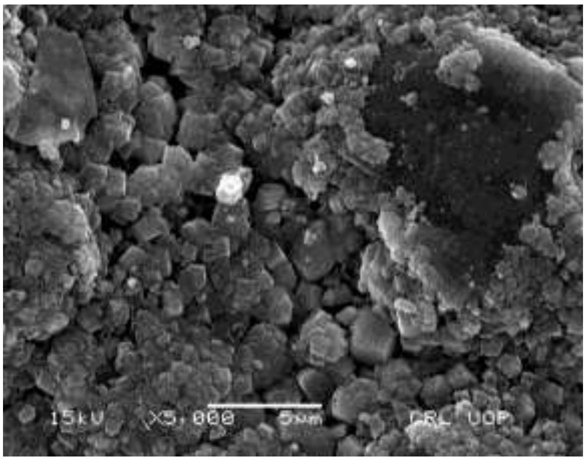

Figure. 19 SEM of sample M2, X5000 at 5 µm

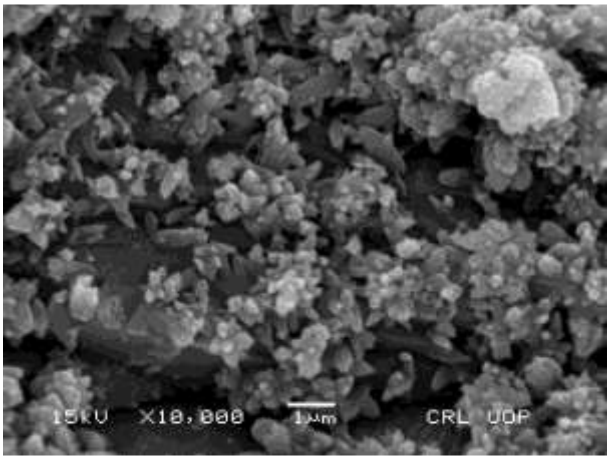

Figure. 20 SEM of sample M2, X10000 at 1 µm

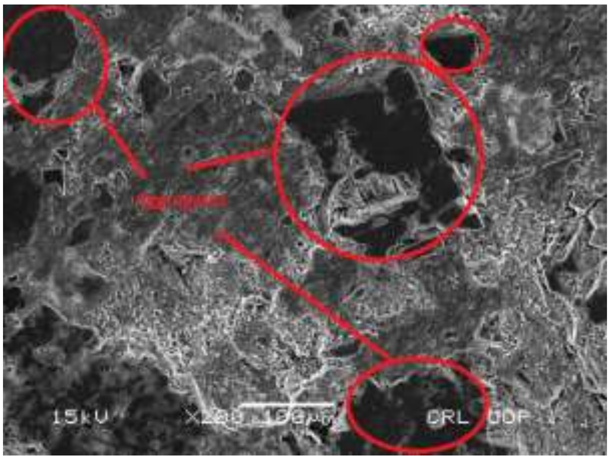

Figure. 21 SEM of sample M3, X200 at 100 µm

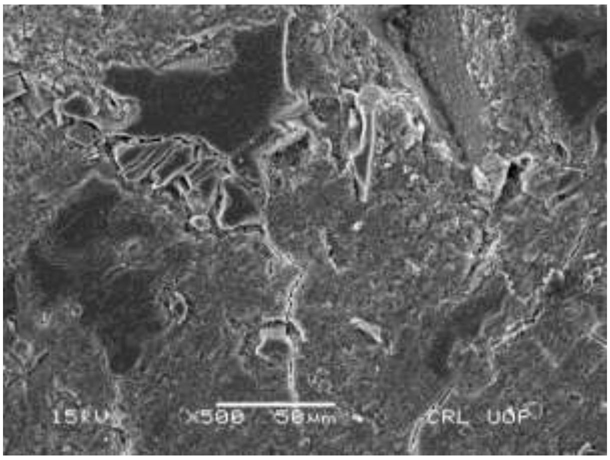

Figure. 22 SEM of sample M3, X500 at 50 µm

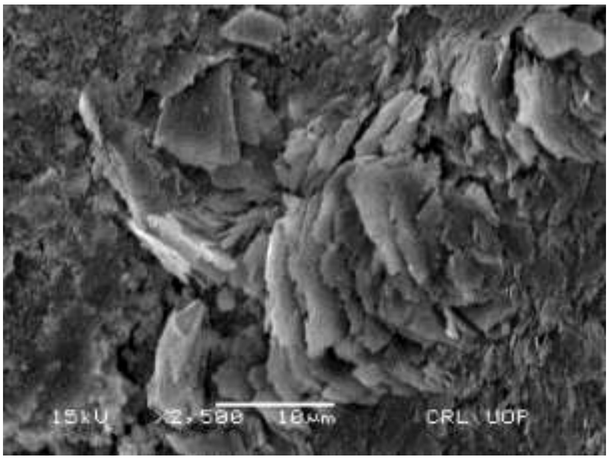

Figure. 23 SEM of sample M3, X2500 at 10 µm

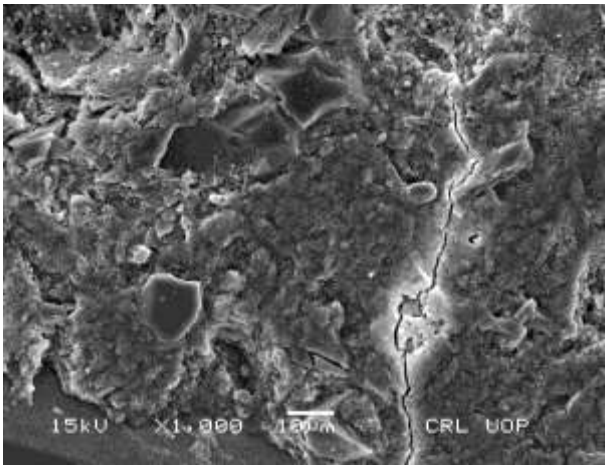

Figure. 24 SEM of sample M3, X1000 at 10 µm

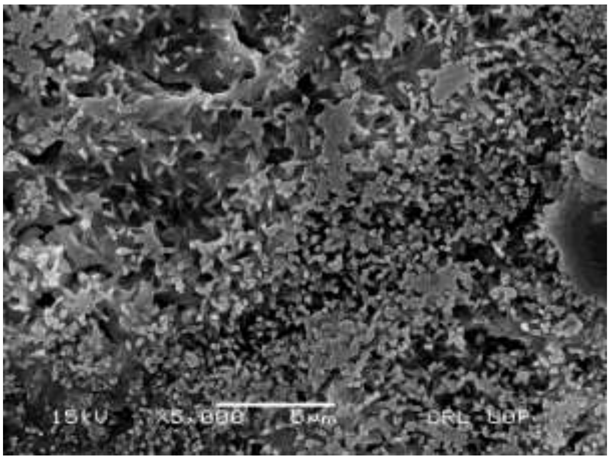

Figure. 25 SEM of sample M3, X5000 at 5 µm

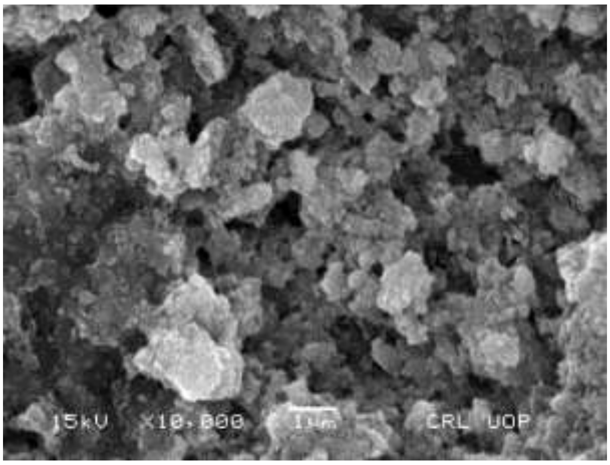

Figure. 26 SEM of sample M3, X10000 at 1 µm

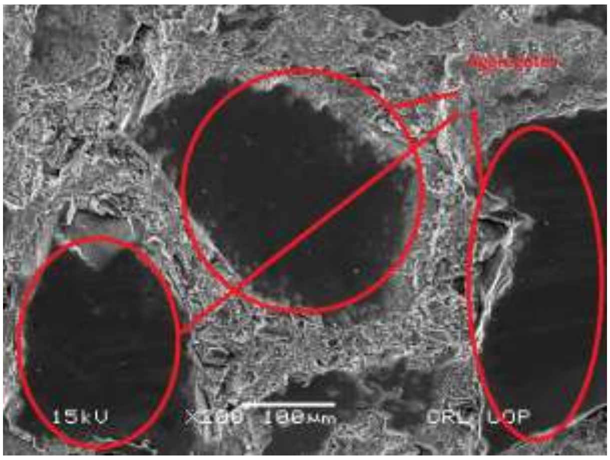

Figure. 27 SEM of sample M4, X200 at 100 µm

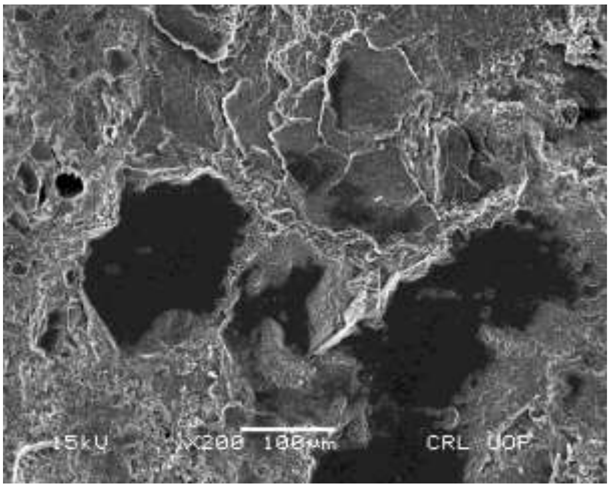

Figure .28 SEM of sample M4, X200 at 100 µm

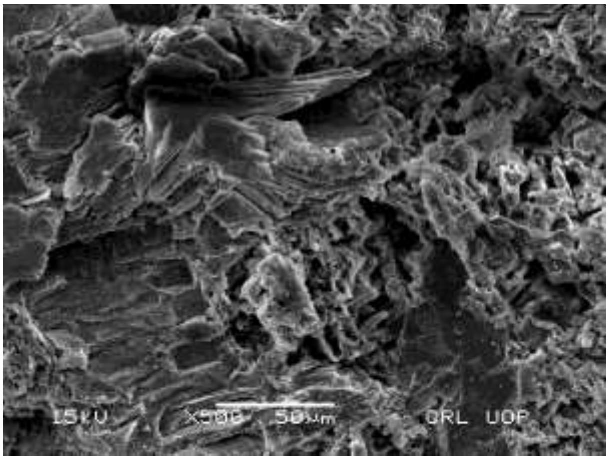

Figure. 29 SEM of sample M4, X500 at 50 µm

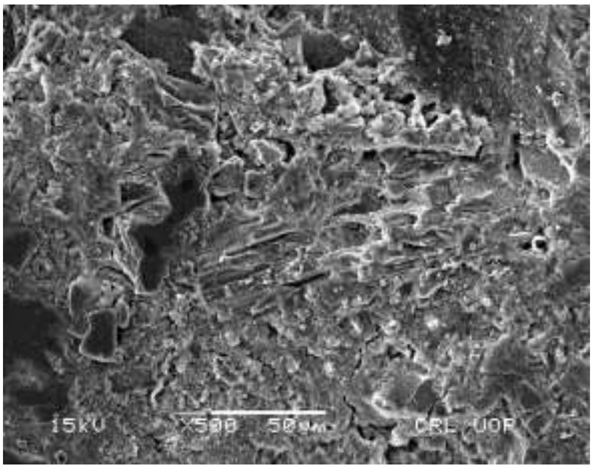

Figure. 30 SEM of sample M4, X500 at 50 µm

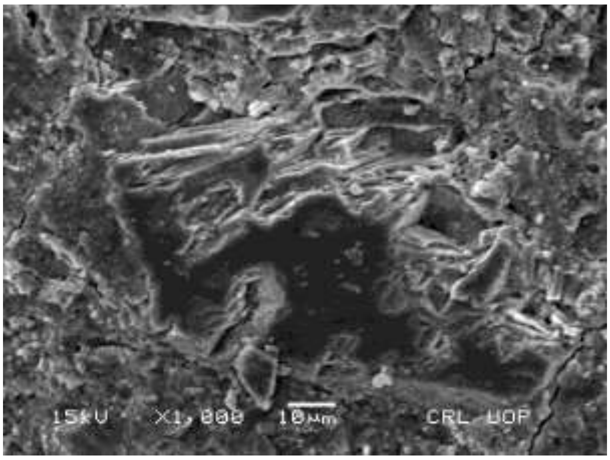

Figure 31: SEM of sample M4, X1000 at 10 µm

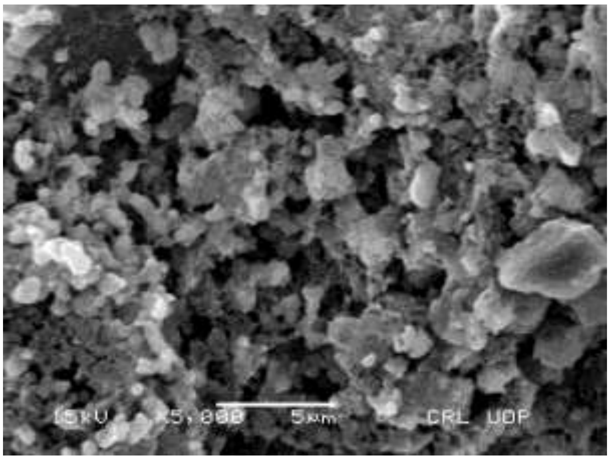

Figure 32: SEM of sample M4, X5000 at 5 µm

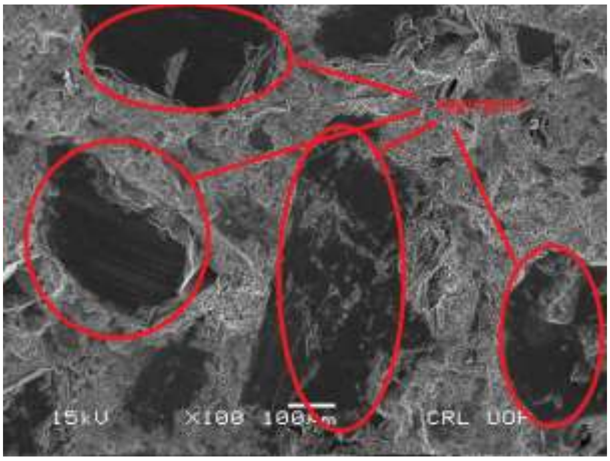

Figure 33: SEM of sample M5, X100 at 100 µm

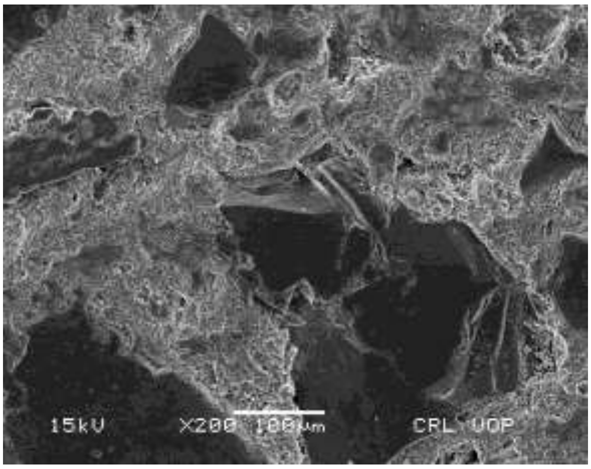

Figure 34: SEM of sample M5, X200 at 100 µm

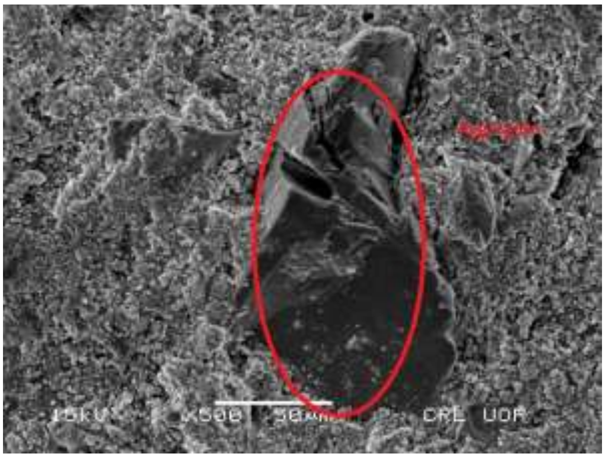

Figure 35: SEM of sample M5, X500 at 50 µm

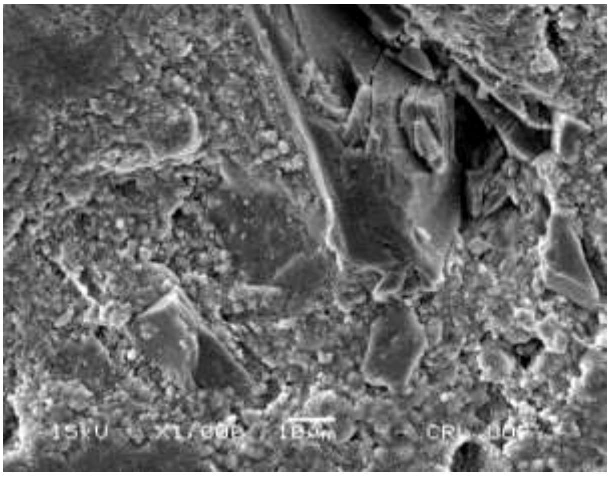

Figure 36: SEM of sample M5, X1000 at 10 µm

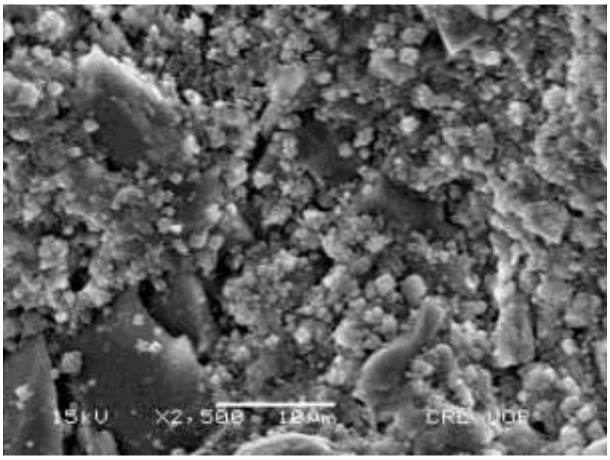

Figure 37: SEM of sample M5, X2500 at 10 µm

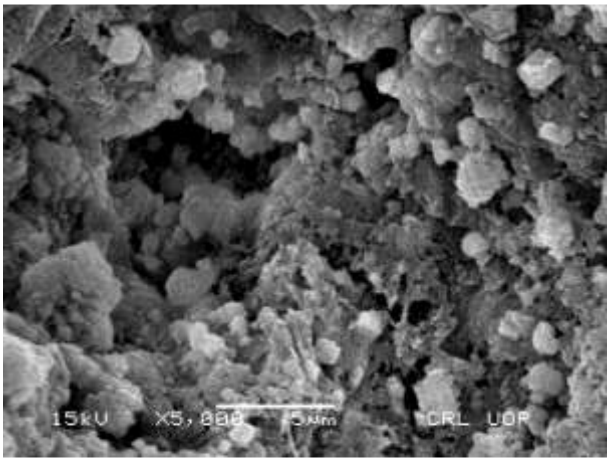

Figure 38: SEM of sample M5, X5000 at 5 µm

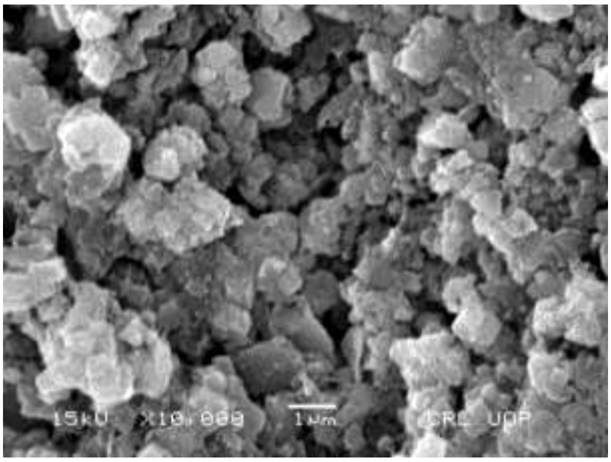

Figure 39: SEM of sample M5, X10000 at 1 µm

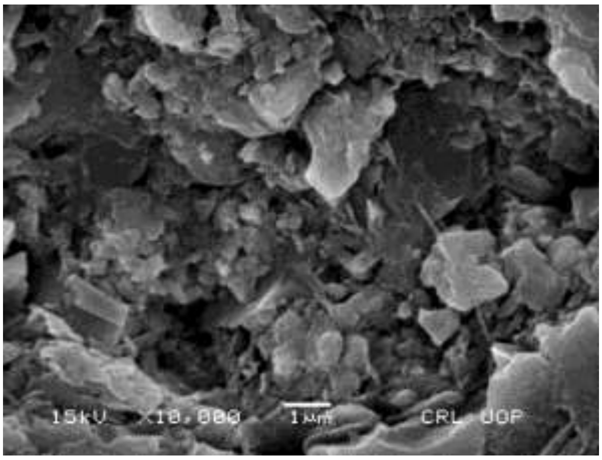

Figure 40: SEM of sample M5, X10000 at 1 µm

DISCUSSION

From the Table 6 and Figures (1—4) it is clear that the concrete in which replacement of cement by mixture of silica fume and glass powder its compressive strength is less than the control sample at 3 and 7 days curing and then increases its strength at 14 and 28 days curing. Because glass powder and silica fume are pozolanic materials and the pozolanic reactions starts later. Maximum compressive strength of concrete is achieved by 30 percent replacement of cement by mixture of silica fume and glass powder at 28 days curing. Replacing of cement by mixture of silica fume and glass powder beyond 30 percent reduces the concrete compressive strength. Therefore 30 percent of cement replacement by the mixture of silica fume and glass powder is the optimum quantity to achieve the higher strength. From the tables and graphs of tensile and flexural it is also clear that maximum tensile and flexural strength of concrete is reached by 30 percent replacement of cement by mixture of glass powder and silica fume at 28 days curing. Replacing of cement by mixture of glass powder and silica fume beyond 30 percent also reduces the concrete tensile and flexural strengths. The increase in strength is due to the reaction of silica fume and glass powder with $Ca(OH)_2$ .This $Ca(OH)_2$ is a by-product which is produced during the cement hydration process and about 25 percent $Ca(OH)_2$ is formed. Glass powder and silica fume are pozolanic materials which will react with $Ca(OH)_2$ but at later stages and produce C-S-H an extra binding materials to bind fine and coarse aggregates which provides additional strength. Pozolanic reaction is slow reaction and may start at later ages due to which it offers lower strength at start ages and then increase the strength of concrete with the passage of time. From the scanning electron microscopy (SEM) analysis of blended concrete samples it is evident that no clear particles of silica fume and glass powder are seen, so its prove that both the pozolanic materials (glass powder and silica fume) react with $Ca(OH)_2$ and produce (C-S-H) an extra binding material which provides additional strength to concrete.

CONCLUSIONS

The following conclusions are drawn from the research based on the experimental investigation of using mixture of glass powder and silica fume as a partial cement replacement.

- Flexure, tensile, and compressive strength of concrete is effected by incorporation of mixture of silica fume and glass powder in concrete.
- In concrete mixture of silica fume and glass powder can be used effectively and efficiently as a partial cement replacement.
- From experimental work it is observed that 3 and 7 days strength are decreased by using mixture of silica fume and glass powder as a partial cement replacement and then increased after curing at 14, and 28 days. 30 percent mixture of silica fume and glass powder as a cement replacement give maximum strength at 28 days.
- Therefore in concrete 30% mixture of silica fume and glass powder can be used is recommended as the best amount for higher strength.
- It is concluded from the SEM analysis of blended concrete samples that no clear particles of silica fume and glass powder are seen, hence it's prove that both the pozzolonic materials contribute in hydration process.

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