Advances in Concrete Construction, *Vol. 4, No. 2 (2016) 107-121*
DOI: http://dx.doi.org/10.12989/acc.2016.4.2.107

The effect of attack of chloride and sulphate on ground granulated blast furnace slag concrete

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(Received July 15, 2016, Revised October 31, 2016, Accepted November 2, 2016)

Abstract. This concrete is one of the most versatile construction material widely used for almost a century now. It was considered to be very durable material and required a little or no maintenance since long time. The assumption is very true, except when it is subjected to highly aggressive environments. The deterioration of concrete structures day by day due to aggressive environment is compelling engineers to assess the loss in advance so that proper preventive measure can be taken to achieve required durability to concrete structures. The compounds present in cement concrete are attacked by many salt solutions and acids. These chemicals are encountered by almost all concrete structures. The present study has been undertaken to investigate the effect of attack of chlorides and sulphates with varying severity on compressive strength of ground granulated blast furnace slag (GGBFS) concrete after immersion in salt solution for 28 days. The results indicate that the durability of GGBFS concrete increases with the increase in percentage replacement of cement by GGBFS for 20% and then gradually decreases with increases in percentage of GGBFS with cement (as in the study for 40% and 60%). Also there is increase in strength of GGBFS concrete with increase in age. Thus the durability of concrete improves when GGBFS is added as partial replacement of cement. In this study the strength of GGBFS concrete is less affected by chemicals as compared to conventional concrete when exposed to aggressive environment.

Keywords: GGBFS; durability; chloride; slag; sulphate; concrete; chemical; strength

1. Introduction

Concrete is the most widely used construction material today. It is a man-made material and has been extensively used in all types of construction activities due to its better engineering properties. The challenge for civil engineering in the present days is to build projects with the concept of sustainable development involving the use of high strength, environment friendly materials produced at reasonable cost with the lowest possible environmental impact. Concrete has certain disadvantages as well; like low tensile strength, not entirely impervious to moisture and containing soluble salts which may cause efflorescence, alkali and sulphate attack, unstable crack propagation,

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http://www.techno-press.org/?journal=acc&subpage=7 ISSN: 2234-0912 (Print), 2234-179X (Online)

limited durability. It has existence of micro crack and interfacial discontinuities. Creep develops in concrete under sustained load. It is complex material with relatively large degree of physical and chemical complexity.

Most conventional concrete structures deteriorate rapidly and require costly repairs before their expected service life is reached. Four major types of environmental distress affect concrete structures. They are corrosion of the reinforcement, alkali-aggregate reactivity, freeze-thaw deterioration, and attack by sulphates. In each case, water or chemical solutions may penetrate the concrete and initiate or accelerate damages. By using high-performance concrete (HPC), durability and strength can be enhanced resulting in long-lasting and economical structure.

American Concrete Institute (ACI) defined high performance concrete as: "concrete which meets special performance and uniformity requirements that cannot always be achieved routinely by using only conventional materials and normal mixing, placing and curing practices".

Cement concrete structures in highly polluted urban and industrial areas, aggressive seashore environments, harmful subsoil water in coastal areas and many other hostile conditions makes the construction non-durable.

Concrete is being used as a construction material in aggressive environment since long days. The more common form of chemical attack is the leaching out of cement and action of sulphate, seawater and natural slightly acidic water. The main effects of the chemical attack are volume change, cracking of concrete and then the consequent deterioration of concrete occurs. Concrete is not fully resistant to acids. Most acid solution will slowly or rapidly disintegrate concrete depending upon the type and concentration of acids. The most vulnerable part of cement hydrate is $Ca(OH)_2$, but C-S-H gel can also be attacked. As the attack proceeds, all the cement compounds are eventually broken down and leached away. If acids or salts solutions are able to reach the reinforcing steel through cracks or porosity of concrete, corrosion can occur which will cause cracking.

Large number of concrete structures is exposed to seawater. The coastal and offshore structures are exposed to simultaneous action of a number of physical and chemical deterioration processes. The concrete in seawater is subjected to chloride-induced corrosion of steel; freezing and thawing, salt weathering, abrasion by sand held in water and other floating bodies. Seawater generally contains 3.5% of salt by weight. It is commonly observed that deterioration of concrete in seawater is often not characterized by expansion, but takes more the form of erosion or loss of constituents from the parent mass without exhibiting undue expansion. Concrete undergoes several reactions concurrently when subjected to seawater. Also the rate of chemical attack is increases in temperature zones.

Taking view of sustainable development it is imperative that the supplementary cementing materials be used to replace large amount of cement in concrete. The high performance concrete mixes designed for low permeability resist this infiltration of aggressive liquids and, therefore, are more durable. One important issue need to be addressed in the use of high performance concrete are the development of the mixes. Low-permeability concretes are made with a low (0.45 and less) water cement ratio (w/c). Pozzolanic material such as fly ash, GGBFS can be used as cementation materials. These modifications to the mixes results in higher compressive strengths than conventional concretes. The structural benefits include increased rigidity because of the increased elastic modulus and increased concrete strength that raise the allowable design stresses. This experimental work is directed mainly to the applications of GGBFS.

In general, use of GGBFS or other mineral admixture causes pore as well as grain refinement that leads to reduced permeability. Performance of GGBFS in concrete depends greatly upon its physical, chemical and mineralogical properties. Some of the significant factors that govern the durability of concrete structures are mix design, structural design, reinforcement detailing, formwork, concrete cover, quality of materials used, compaction, curing and supervision. Inadequate attention to these factors and the presence of chlorides hasten corrosion of reinforcement, moisture, carbonation, sulphate attack, and alkali aggregate reaction leading to the deterioration of structures. Generally, concrete suffers from more than one causes of deterioration, which is generally seen in the form of cracking, spalling, loss of strength etc. It is now accepted the main factors influence the durability of concrete is its permeability to the ingress of oxygen, water, carbon dioxide, chlorides, sulphates etc. Permeability of a concrete mass is therefore, fundamental in determining the rates of concrete deterioration due to destructive chemical action.

(Ramakrishnan *et al*. 1992; Bush *et al*.; Bleszynski *et al*. 2002 and ACI Committee 233R 1995) studied replacement of OPC by GGBFS, It results in lower early strengths, lower chloride ion permeability, greater long term strengths, greater alkali silica reactivity (ASR) durability, less greater sulfate attack resistance enhanced workability, lower heat of hydration, less bleeding and increased steel corrosion resistance. Results are combined of freeze-thaw durability and drying shrinkage somehow the use of slag seems to be non-beneficial. Moreover the hindrances of the GGBFS includes increased salt scaling, increased air entrainment required dosage, increased shrinkage cracking and increased plastic shrinkage cracking.

ACI Committee 233R (1995) confirmed use of GGBFS as cement replacement for temperature reduction in mass concrete. Mostly 50% replacement is done in warm weather by concrete producers. At least 70% replacement is needed to meet required specification while grade 120 (highest reactivity) slag is used. GGBFS mix proportion depends upon the curing temperature, the purpose for which the concrete is used, the characteristics of the cement or activator and the grade the slag. Duos *et al*. (1999) surveyed 20 states in 1995; it was observed that 13 states allows the usage of GGBFS.

MoDOT stated mass concreting is possible when minimum measurement of concrete exceeds five feet and the volume-to-surface area ratio is equal to one. It can be applied effectively by contractor by keeping the temperature differential equal to or less than 22.2˚C between any point deeper than 300 mm in the mass and the surface. When the differential nears 20˚C corrective measures needs to be applied.

Metso *et al*. (1983) and ACI Committee 233R (1995) confirmed the factors that affect slag cement reaction are fineness of the cement, alkali concentration of the reacting system and temperature chemical composition; fineness; glass content and age of the slag.

Metso *et al*. (1983) studied slag preparation in which the glass content plays an important role with granulation resulting in higher glass content than pelletization. Glass content (degree of vitrification) and the structure of the glass are considered a primary factors (Metso *et al*. 1983; Hooton *et al*. 1983 and Regourd 1980). Generally, greater pozzolanic activity is observed on increasing glass content Metso *et al*. (1983) and Hooton *et al*. (1983).

Metso *et al*. (1983) studied the effect of aging on slag reactivity. Slags loose some reactivity has been in the silo for more than a month, thus require more effort at activation. In the activity of slag, alkali content use to assist it. In evaluation of two slags, it was revealed that on increase in alkali content there is significant gain in compressive strength.

Gdoutos and Shah (2003) have reported positive performance of blast furnace slag in a blend with cement kiln dust. Kayali *et al*. (2012) was reported the remarkable role of hydrotalcite, a layered blast furnace slag concrete. Bauchkar *et al*. (2014) investigated rheological properties of double hydroxide in bind chloride ions and protection of corrosion in ground granulated self-consolidating concrete (SCC) with ground granulated blast furnace slag (GGBS) and other mineral admixtures (MA) using an ICAR rheometer. Yang *et al*. (2014) investigated that incorporation of slag as a secondary precursor in fly ash-based geopolymers led to reducing both sorptivity of the pastes, the refinement of the pore structure and the ingress of chloride ions. Jafari *et al*. (2014) inferred that GGBFS of low reactivity can enhance impermeability of high strength concrete and also Chore *et al*. (2015) improve the workability of concrete. Tang *et al*. (2015) concluded that reduced thermal contraction achieved in concrete with no detrimental effect on replacement of cement with GGBS. Darquennes *et al*. (2016) concluded that the structural durability and chloride penetration improves the self-healing limits for mixtures containing blast furnace slag. Zhang *et al*. (2012) evaluated the effect of GGBFS and SF on chloride migration. Ashish *et al*. (2011), Kumar *et al*. (2015), Dar *et al*. (2015), Verma and Ashish (2014), S.F. Wani *et al*. (2015) and Ashish *et al*. (2016) are researchers for industrial bi-products and its usage for construction materials as they provide economical and ecological solution.

2. Experimental program

The aim of the study is to develop concrete of M 35 grade by using key components such as ordinary portland cement of 43 grade, GGBFS, locally available river sand, crushed stone aggregate, GGBFS, super plasticiser and water. The chemical and physical properties of ordinary portland cement and GGBFS are given in Table 1. It includes the comparison of M 35 grade conventional concrete with that of GGBFS concrete of the same grade. In the present experimental programme, OPC has been partially replaced with GGBFS in varying proportions of 20%, 40% and 60%. The scope of present work includes the study of durability parameters in terms of compressive strength in aggressive environment sulphates and chlorides having varying severity levels. The main objectives of present experimental study the effect of attack of chlorides on compressive strength of GGBFS concrete after immersion in salt solution of varying severity of 2.5%. 5% and 7.5% of chlorides for 28 days and the effect of sulphates on compressive strength of GGBFS concrete after immersion in salt solution of varying severity of 2.5%, 5% and 7.5% of sulphates for 28 days.

The broken samples were analysed for the effect of chloride on blended concrete and compared the changes in microstructure by conducting scanning electron micrograph (SEM) analysis.

Table 1 Chemical compositions and physical properties of cement, GGBFS

	CaO (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	SO_3 (%)	LOI (%)	Density (g/cm^3)	Specific surface area M^2/kg
OPC	62.38	20.58	5.35	3.98	1.83	2.54	1.62	3.16	330
GGBFS	43.56	38.84	6.58	0.42	6.81	0.86	2.54	2.96	510

3. Effect of Chloride and Sulphates

For over one and quarter century after inventing OPC, durability of cement concrete was taken for granted in view of higher strengths over that of lime based concretes. It was during 60s the concern for concrete durability surfaced globally by which time the structures built with high-grade cements started yielding to distress. Various factors surfaced questioning the efficiency of high that grade cements for durability surfaced globally by which time the structures built with high-grade cements started yielding to distress. Various factors surfaced questioning the efficiency of high that grade cements for durability.

3.1 Corossive effect of chlorides

The mast important concern for seashore concrete structure is reinforcement corrosions caused by penetration of chlorides to the level of the reinforcement. Chlorides initiated corrosion can be divided into separate stages: Initiation and growth.

Steel reinforcement in concrete is normally protected from corrosion by the oxide layer that forms on the steel in highly alkaline conditions. External influences such as chlorides, can break down the passive layer, over large or small areas. Chloride initiated corrosion take place when chloride penetrating through the concrete covers encounters defects in the passive film. Then pitting corrosion will initiate. Corrosion occurs when the average chloride concentration at the steel exceeds the threshold value. This value appears to have a complex dependence on a number of factors, and it is still and important subject of study.

3.2 Sulphate attack

Concrete buried in soils or groundwater containing high levels of sulphate salts particularly in the form of sodium, potassium or magnesium salt, may be subjected to sulfate attack under damp conditions. An expansive reaction occurs between the sulphates and the C_3A phase to form calcium sulfo aluminate (ettringite) with consequent disruption to the matrix. Past experience has shown that true sulfate attack is rare in concrete, only occurring with very low cement content concretes, with less than about 300 kg/m^3 of cement. As a guide, levels of sulphate above about 4% of cement (expressed as SO_3) may indicate the possibility of sulphate attack, provided sufficient moisture is present. Sulphate attack requires prolonged exposure todamp conditions.

However, there has been recent concern with another form of sulphate attack, as follows: Thaumasite Attack - A Form of Sulfate Attack This has hit the news recently, in 1998, when the foundations to a number of bridges on were found to be suffering from serious erosion and crumbling of the outer part of the concrete in the foundations. The problem was diagnosed as being due to unusual form of sulphate attack, known as thaumasite attack.

For the problem to occur, a number of factors have to be present. A source of sulphate water (usually plenty of moisture). A source of limestone (as aggregate or filler) low temperatures (<15°C). The combination of these factors can cause an unusual reaction between the cement, the lime and the sulphate, to form thaumasite, a sulphate mineral. The effect is to cause serious damage and softening of the exposed outer surface of the concrete (assuming an external source of sulphate). The plates below show one of the affected foundation and also a damaged road in North Texas which showed serious heaving of the road surface over a gypsum rich soil, when a lime soil stabilizer was used under the roadway. It should be noted that sulfate resisting cement has not proved to be any more resistant to normal portland cement in resisting this type of attack. A huge amount of research has gone into documentation of the properties of GGBFS concrete, documentation generated both in the laboratory and in field testing. Now information from actual structures and from large, structure-like field trials becomes available, and this confirms the good

Fig. 1 Heaving due to thaumasite/ettringite attack

Fig. 2 Heaving due to thaumasite/ettringite attack

performance of GGBFS concrete in the seashore environment.

GGBFS concrete is excellently suited for use in seashore concrete structures. The use of this material on its own, or together with other supplementary cementing materials, provides benefit in a number of areas: For constructability because of fresh properties, for design because of high strength and for service life because of the excellent chloride resistance and high resistivity.

3.3 Chemical resistance

Concrete is resistant to most natural environments and many chemicals. Concrete is virtually the only material used for the construction of wastewater transportation and treatment facilities because of its ability to resist corrosion caused by the highly aggressive contaminants in the wastewater stream as well as the chemicals added to treat these waste products.

However concrete is sometimes exposed to substances that can attack and cause deterioration. Concrete in chemical manufacturing and storage facilities is specially prone to chemical attack.

(a) Testing of cube specimen (b) Testing of cylinder specimen

Fig. 3 Compressive strength test

Acids attack concrete by dissolving the cement paste and calcareous aggregates. In addition to using concrete with a low permeability, surface treatments can be used to keep aggressive substances from coming in contact with concrete.

3.4 Resistance to Sulphate attack

Excessive amounts of sulphates in soil or water can attack and destroy a concrete that is not properly designed. Sulphates (for example calcium sulphate, sodium sulphate, and magnesium sulphate) can attack concrete by reacting with hydrated compounds in the hardened cement paste. These reactions can induce sufficient pressure to cause disintegration of the concrete. For the best defense against external sulphate attack, design concrete with a low water to cement material ratio (around 0.40) and use cements specially formulated for sulphate environments.

4. Results

The present chapter contains the results of test conducted on GGBFS concrete specimens immersed in salts with varying percentages. Total number of 72 cube specimen and 48 cylinder specimens were cast and then water cured for 28 days. Then the specimens were immersed in magnesium sulphate ($MgSO_4$) and magnesium chloride ($Mgcl_2$) solutions. The percentages of these salt solutions were taken as 2.5%, 5%, and 7.5% and following aspect was studied the effect on compressive strength of concrete with GGBFS in 0%, 20%, 40%, and 60% replacement of cement, after immersing it in magnesium sulphate, and magnesium chloride with different dilution for 28 days (after 28 days of moist curing).

4.1 Compressive strength test

According to Indian standard procedure laid down in IS: 516-1959. Specimens were taken out

Fig. 4 Cube and cylinder specimens

from the salt solution tank after immersion of 28 days and then tested. The experimental set up for the test is shown in Fig. 3. The specimen were tested on 2000 kN capacity UTM. The position of the specimen when tested was at right angles of that as cast. The axis of specimens was carefully aligned with the centre of the thrust of the spherically seated plate.

The load was applied gradually and without shock and increased continuously at the rate of approximately 5 kN/second till the failure of the specimen and thus the compressive strength was found out.

4.1.1 Effect of Chloride ions on cube compressive strength

Higher the concentrations of magnesium chloride greater is the detrimental effect on the compressive strength of concrete and also with the addition of GGBFS to cement, there is increase in compressive strength of concrete as compared to concrete without GGBFS. After 28 days of immersion in 2.5% magnesium chloride solution the compressive strength is first increased from 55.6 N/mm^2 to 63.4 N/mm^2 for 0% and 20% after gradually decreased to 62.2 N/mm^2 and 59.2 N/mm^2 for 40% and 60%. Similarly after 28 days of immersion in 5% magnesium chloride solution the compressive strength is first increased from 54.2 N/mm^2 to 61.2 N/mm^2 for 0% and 20% after gradually decreased to 59.6 N/mm^2 and 57.3 N/mm^2 for 40% and 60%.

In same manner immersion in 7.5% magnesium chloride solution the compressive strength is first increased from 52.4 N/mm^2 to 58.9 N/mm^2 for 0% and 20% after gradually decreased to 56.7 N/mm^2 and 54.2 N/mm^2 for 40% and 60%.

Fig. 5 depicts after 28 days of immersion in 2.5% magnesium chloride solution, the compressive strength is increased by 14.02%, 11.69%, and 6.47% for 20%, 40%, and 60% GGBFS concrete respectively. In the same manner after 28 days of immersion in 5% magnesium chloride solution, the compressive strength is increased by 12.90%, 9.96%, and 5.71% for 20%, 40%, and 60% GGBFS concrete respectively. Similarly after 28 days of immersion in 7.5% magnesium chloride solution, the compressive strength is increased by 12.40%, 8.26%, and 3.32% for 20%, 40%, and 60% GGBFS concrete respectively.

The above results shows that the durability of concrete increases with replacement of GGBFS with cement. The addition of GGBFS to cement, there is increase in compressive strength of concrete as compared to concrete without GGBFS.

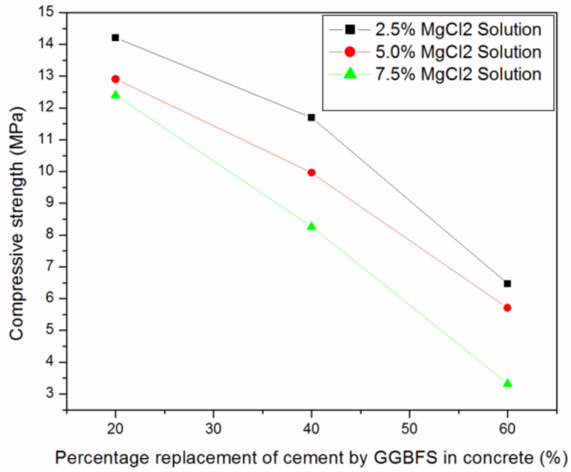

Fig. 5 Effect of chloride ions on cube compressive strength

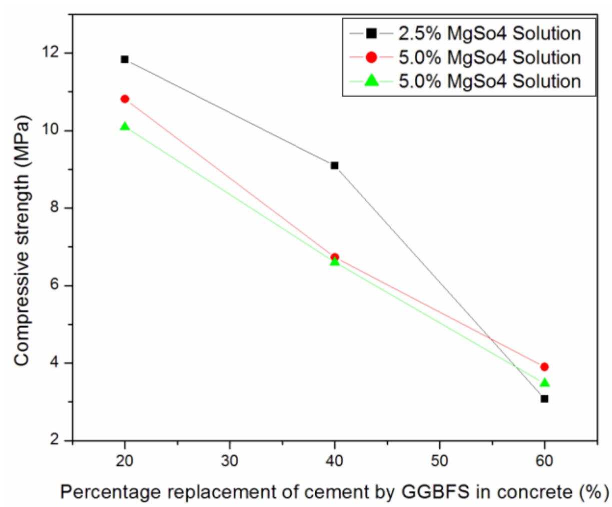

Fig. 6 Effect of sulphate ions on cube compressive strength

4.1.2 Effect of sulphate ions on cube compressive strength

Higher the concentrations of magnesium sulphate greater is the detrimental effect on the compressive strength of concrete and also with the addition of GGBFS to cement, there is increase in compressive strength of concrete as compared to concrete without GGBFS. After 28 days of immersion in 2.5% magnesium sulphate solution the compressive strength is first increased from 58.3 N/mm^2 to 65.2 N/mm^2 for 0% and 20% after gradually decreased to 63.3 N/mm^2 and 60.1 N/mm^2 for 40% and 60%. Similarly after 28 days of immersion in 5% magnesium sulphate solution the compressive strength is first increased from 56.4 N/mm^2 to 62.5 N/mm^2 for 0% and 20% after gradually decreased to 60.2 N/mm^2 and 58.6 N/mm^2 for 40% and 60%. In same manner immersion in 7.5% magnesium sulphate solution the compressive strength is first increased from 54.5 N/mm^2 to 60.1 N/mm^2 for 0% and 20% after gradually decreased to 58.1 N/mm^2 and 56.4 N/mm^2 for 40% and 60%.

Fig. 6 depicts after 28 days of immersion in 2.5% magnesium sulphate solution, the compressive strength is increased by 11.83%, 9.09%, and 3.08% for 20%, 40%, and 60% GGBFS concrete respectively. In the same manner after 28 days of immersion in 5% magnesium sulphate solution, the compressive strength is increased by 10.81%, 6.73%, and 3.90% for 20%, 40%, and 60% GGBFS concrete respectively. Similarly after 28 days of immersion in 7.5% magnesium sulphate solution, the compressive strength is increased by 10.09%, 6.60%, and 3.48% for 20%, 40%, and 60% GGBFS concrete respectively.

The above results shows that the durability of concrete increases with replacement of GGBFS with cement. The addition of GGBFS to cement, there is increase in compressive strength of concrete as compared to concrete without GGBFS.

4.1.3 Effect of Cloride ions on cylinder compressive strength

Higher the concentrations of magnesium chloride greater is the detrimental effect on the compressive strength of concrete and also with the addition of GGBFS to cement, there is increase in compressive strength of concrete as compared to concrete without GGBFS. After 28 days of immersion in 2.5% magnesium chloride solution the compressive strength is first increased from 43.95 N/mm^2 to 50 N/mm^2 for 0% and 20% after gradually decreased to 46.8 N/mm^2 and 45.9 N/mm^2 for 40% and 60%. Similarly after 28 days of immersion in 5% magnesium chloride solution the compressive strength is first increased from 42.4 N/mm^2 to 46.3 N/mm^2 for 0% and 20% after gradually decreased to 45 N/mm^2 and 43.6 N/mm^2 for 40% and 60%. In same manner immersion in 7.5% magnesium chloride solution the compressive strength is first increased from 36.4 N/mm^2 to 43.3 N/mm^2 for 0% and 20% after gradually decreased to 41.6 N/mm^2 and 40.2 N/mm^2 for 40% and 60%.

Fig. 7 depicts after 28 days of immersion in 2.5% magnesium chloride solution, the compressive strength is increased by 13.89%, 6.60%, and 4.55% for 20%, 40%, and 60% GGBFS concrete respectively. In the same manner after 28 days of immersion in 5% magnesium chloride solution, the compressive strength is increased by 9.19%, 6.13%, and 2.83% for 20%,

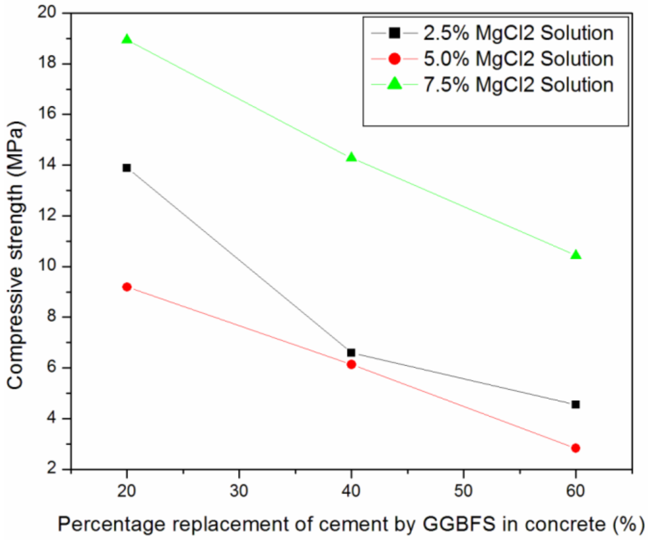

Fig. 7 Effect of chloride ions on cylinder compressive strength

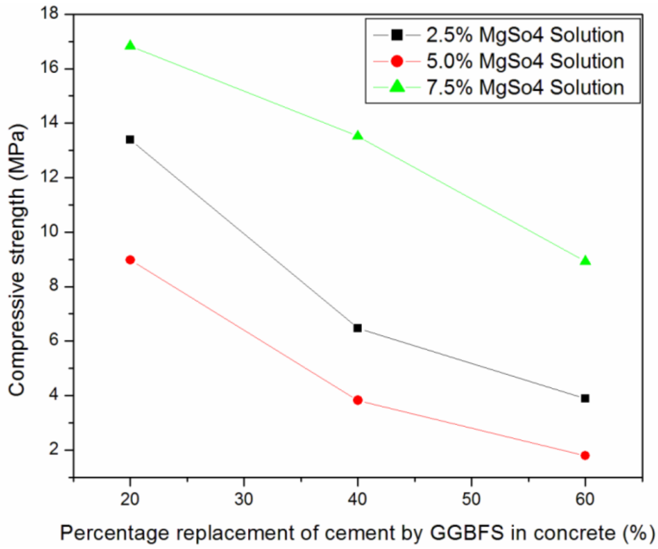

Fig. 8 Effect of sulphate ions on cylinder compressive strength

40%, and 60% GGBFS concrete respectively. Similarly after 28 days of immersion in 7.5% magnesium chloride solution, the compressive strength is increased by 18.95%, 14.28%, and 10.43% for 20%, 40%, and 60% GGBFS concrete respectively.

The above results shows that the durability of concrete increases with replacement of GGBFS with cement. The addition of GGBFS to cement, there is increase in compressive strength of concrete as compared to concrete without GGBFS.

4.1.4 Effect of sulphate ions on cylinder compressive strength

Higher the concentrations of magnesium sulphate greater is the detrimental effect on the compressive strength of concrete and also with the addition of GGBFS to cement, there is increase in compressive strength of concrete as compared to concrete without GGBFS. After 28 days of immersion in 2.5% magnesium sulphate solution the compressive strength is first increased from 46.3 N/mm^2 to 52.5 N/mm^2 for 0% and 20% after gradually decreased to 49.3 N/mm^2 and 48.1 N/mm^2 for 40% and 60%. Similarly after 28 days of immersion in 5% magnesium sulphate solution the compressive strength is first increased from 44.5 N/mm^2 to 48.5 N/mm^2 for 0% and 20% after gradually decreased to 46.2 N/mm^2 and 45.3 N/mm^2 for 40% and 60%. In same manner immersion in 7.5% magnesium sulphate solution the compressive strength is first increased from 39.9 N/mm^2 to 45.8 N/mm^2 for 0% and 20% after gradually decreased to 44.5 N/mm^2 and 42.7 N/mm^2 for 40% and 60%.

Fig. 8 depicts after 28 days of immersion in 2.5% magnesium sulphate solution, the compressive strength is increased by 13.39%, 6.47%, and 3.88% for 20%, 40%, and 60% GGBFS concrete respectively. In the same manner after 28 days of immersion in 5% magnesium sulphate solution, the compressive strength is increased by 8.98%, 3.82%, and 1.79% for 20%, 40%, and 60% GGBFS concrete respectively. Similarly after 28 days of immersion in 7.5% magnesium sulphate solution, the compressive strength is increased by 16.83%, 13.52%, and 8.92% for 20%, 40%, and 60% GGBFS concrete respectively.

The above results shows that the durability of concrete increases with replacement of GGBFS

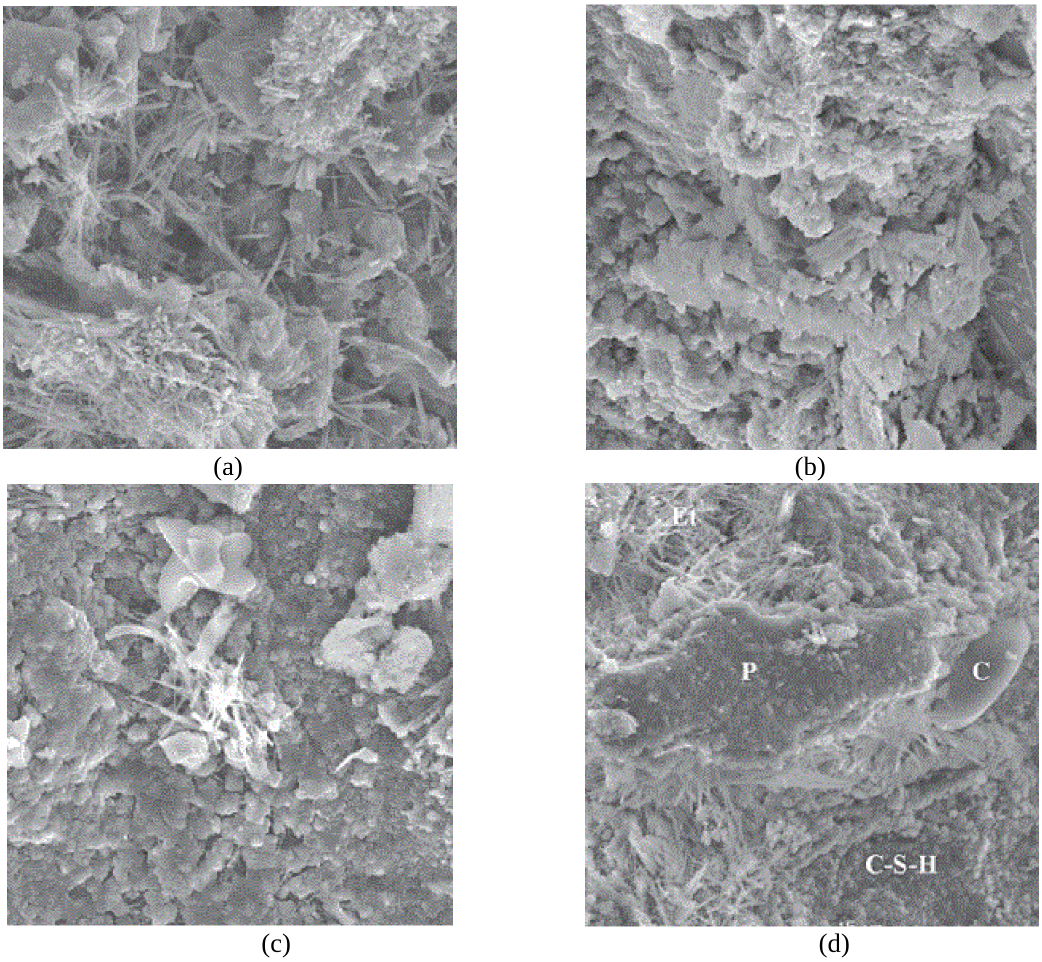

Fig. 9 Scanning electron morphology of blended concrete immersion in 2.5% $Mgcl_2$ solution

with cement. The addition of GGBFS to cement, there is increase in compressive strength of concrete as compared to concrete without GGBFS.

4.1.5 Microstructure

The concrete sample investigated by SEM presents a microstructure with slight pores. In general it was compact and uniform. The concrete microstructure consist of calcium silicate hydrate gel, calcium sulfoaluminate hydrate (ettringite and monosulfate), calcium hydroxide, coarse and fine aggregates, and the interfacial transition zone between cement hydration products and aggregate. The fractured pieces of marble powder concrete generated from compressive strength tests were used for observing micrographs. Before placing on the SEM, the samples were made electrically conductive by coating thin layer of gold.

The Fig. 9(a) depicts cement hydration such as some ettringite agglomerates and Fig. 9(b) represents C-S-H particles mixed with portlandite and calcium silicate. Fig. 9(c) depicts presense of carbonates and Fig. 9(d) was identified with carbonates (C), ettringite (Et), portlandite (P) and calcium silicate hydtrate (C-S-H).

5. Discussion

Poupard *et al*. (2004) observed, when the concentration of chloride at the steel surface in concrete exceeds critical value than it becomes susceptible to corrosion. The structures exposed to sulphate and chlorides are investigated to predict service life of structures for sulphate and chloride migration.

The concrete structure is tested for transport number of chloride and sulphate migration for 28 days. It can be observed that GGBFS had considerable effect on the transport number of chloride and sulphate migration through the concretes. On comparison with control concrete, compressive strength increased from 0% to 20% due to decrease in transport number of chloride and sulphate migration through concrete. Detwiler *et al*. (1994), Jau and Tsay (1998), Basheer *et al*. (2002), Bohác and Gregerová (2009), Song and Saraswathy (2006) observed considerable decrease due to C-S-H gel and $3CaO \cdot Al_2O_3$, formed during pozzolanic reaction of GGBFS in concrete at early ages which can reduce the pore sizes and cumulative pore volume. Moreover, C-S-H gel can reduce permeability of concrete by binding more chloride ions and blocking the diffusing path. In GGBFS concrete, the number of total ions Ca^{2+}, Al^{3+}, Si^{4+} and $AlOH^{2+}$ is greater than ordinary portland cement concrete, ion concentration of control concrete is lower than GGBFS concrete. Leng *et al*. (2000), Luo *et al*. (2003), Dhir *et al*. (1996) concluded that the movement of chloride ions may be restricted due to lower diffusing ions. In comparison to control concrete, compressive strength decreased from 40% to 60% due to increase in transport number of chlorides and sulphates in blended concrete. This is due to low calcium hydroxide provided by cement which is not sufficient for full pozzolanic reaction at high level slag replacement by Jau and Tsay (1998), Dehghanian and Arjemandi (1997).

6. Conclusions

From the results obtained in this work the following conclusions can be drawn.

• 20% GGBFS replacement had a considerablyy positive effect on the cube and cylinder compressive strength but 40% and 60% GGBFS replacements reduced the strength at the age of 28 days.

• The transport number of magnesium chloride through concrete containing 20% GGBFS replacements was lower than that of the control concrete, but 40% GGBFS replacement increased the transport number of chloride.

• The transport number of magnesium sulphate through concrete containing 20% GGBFS replacement was lower than that of the control concrete, but 40% and 60% GGBFS replacements increased the transport number of chloride.

• The durability of GGBFS concrete increases with 20% replacement of GGBFS with cement and then started decreasing gradually for 40% and 60%.

• The maximum loss of strength of 0%, 20%, 40%, and 60% GGBFS concrete is due to the effect of magnesium chloride followed by magnesium sulphate.

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