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The Effectiveness of Surface Modification in Steel Slag Using Granite Powder.

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ABSTRACT

Slag is a solid waste from the production of iron and steel which are produced in huge amounts around the globe annually. A major part of this slag is being dumped in landfills which cause serious problems to the environment and natural resources. Therefore a lot of research is being done in utilizing this slag effectively in concrete and cement. The main objective of our investigation is to study the chemical relation between slag and cement using x-ray spectrometry and SEM and also to analyze the behaviour of modified energy optimization furnace slag aggregates in concrete which is used as a replacement for natural stone aggregates in various percentages. The results concluded that the optimal level of replacement of natural stone aggregates by modified slag aggregates to be at 25%.
Keywords: Slag, hydration, particle size, compressive strength, surface modification.

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INTRODUCTION

Concrete starts to attain its strength only after the process of hydration of cement. Due to its property of permeability, concrete is subjected to attack by acids, sulphates, chlorides under various environmental conditions. The presence of chloride and sulphate in the marine environment, deterioration of reinforcement by corrosion proves to be a major problem. Compared to Ordinary Portland Cement, blended cement contain steel slag enhances the durability of concrete and also its overall strength [1]. Slag is a by-product which is obtained during the various extraction processes of metal from its ores. Annually, enormous amounts of slag are being produced which are dumped in landfills which degrades the natural resources and causes environmental pollution [2]. Therefore the construction industry utilizes these slags as a construction material through suitable modifications to meet the purpose. The application of slag is versatile which includes structural concrete, masonry blocks, concrete pavements, concrete pipes, refractory concrete, oil- well cement and much more [3].

Though there are a lot of research study had been done to study the hydration of cement, research studies on the hydration of slag are comparatively scarce which is due to the complexity in understanding the chemical reaction between slag and cement. However, the reaction of slag and cement had been studied both theoretically and by developing computer models of the slag reactions. This study concluded that with these theories and computer-generated models, the microstructure development and the slag cement relation was able to be understood [4]. The influence of particle size on the hydration of slag particle was studied by separating the slag by various sieves and the chemical composition was analysed using X-ray Fluorescence method. Calcium hydroxide was used as an activator and the heat of hydration was measured using isothermal calorimeter. This experimental study concluded that the heat of hydration develops faster with finer particles than coarser particles in slag because of the large surface area and the slag with coarser particles has higher reactivity due to the higher content of CaO compared to the amount of MgO, Al2O3 and SiO2 which indicates that higher the ratio of Ca/Si, higher the reactivity of the slag [5].

The main objective of this investigation was to study the reactivity of the energy optimization slag in concrete. This is relatively a new type of slag obtained as a result of the production of liquid steel as a by-product. The chemical composition of this slag was analysed using EDAX and the microstructure was studied using SEM. This slag was surface modified using quarry dust and used as coarse aggregates in concrete in varying percentages replacements of natural coarse aggregates from 0% to 100%. Three grades of concrete namely M20, M30 and M40 were used and the compressive strength of the concrete cubes cured for 7 days and 28 days were tested. The test results concluded that the optimum level of replacement of coarse aggregates to be 25%.

EXPERIMENTAL PROGRAM

The chemical composition of the slag was obtained using the x-ray spectroscopy and the main components that constitute the slag are given in the Table 1.

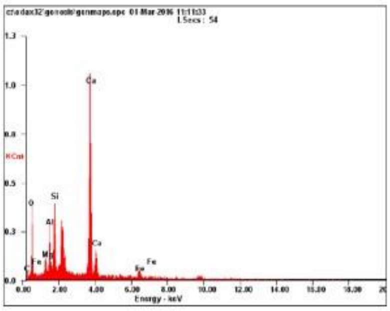
Table 1. Chemical composition of Energy optimization furnace slag

Compounds	CaO	FeO	SiO_2	MgO	Al_2O_3	MnO	P_2O_5	TiO_2	Na_2O	K_2O	LOI
%	36.96	28.93	13.81	7.46	2.53	3.00	1.58	0.60	0.057	0.032	3.70

Activation of slag in the concrete matrix

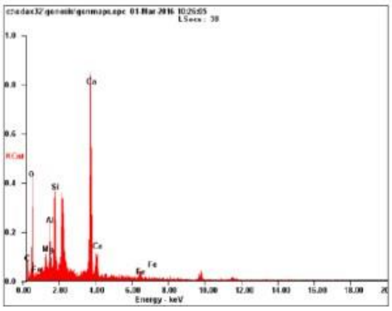
Fig. 1 shows the result of x-ray spectroscopy. The surface analysis of slag by x-ray photoelectron spectrometry shows that there is no activation reaction in slag due to its latent hydraulic properties when it is placed in water. The analysis shows that as soon as the slag gets in contact with water, the surface of the slag was modified which forms a protective glass film preventing the further reaction of Ca2+ ions which causes the slag to dissolve to some extent. The formation of glass film is due to the latent hydraulic properties of slag which can be activated by adding suitable activators. The commonly used methods to activate slag are adding high amounts of calcium sulphate and by alkali activation. The drawback of activation by calcium sulphate is that this method requires longer curing period and also it is sensitive to carbonation and frost attacks while the second method has the problem of excessive shrinkage and efflorescence [6].

a



Element	Wt%	At%
CK	09.60	17.27
OK	37.19	50.25
MgK	02.89	02.57
AlK	06.11	04.90
SiK	07.72	05.95
CaK	32.49	17.52
FeK	03.99	01.54
Matrix	Correction	ZAF

b



Element	Wt%	At%
CK	16.85	27.28
OK	40.34	49.05
MgK	01.73	01.38
AlK	04.55	03.28
SiK	07.69	05.33
CaK	26.51	12.87
FeK	02.33	00.81
Matrix	Correction	ZAF

Fig. 1. (a) EDAX spectrum of raw slag (b) EDAX spectrum of modified slag

Slag has been effectively used in the manufacturing of blended cement due to its hydration property. When blended with cement, slag is activated by a high pH solution which is the result of hydration of CH, which is the main constituent of hydration of alite (C3S) and belite (C2S) respectively. When the water enters the slag cement matrix, cement starts to hydrates which cause the slag to react due to the presence of gypsum in cement. Therefore upon further hydration of cement, more and more alkali is available in the medium which increases the pH up to 13. Following this, the CH proceeds due to the hydration of C3S and C2S which in turn activates the hydration of the slag resulting in the formation of microstructures and strength enhancement of the slag-cement paste. However, the CH content in the blended cement shows an initial increase and the decrease indicating that the CH not only acts as an activator but also a reactant in the process of hydration of slag [6].

The process of hydration of slag

The process of hydration takes place as the result of breaking of the glass film formed when slag reacts with water. The activation of slag is due to the breakage of bond in SiO_2 in which the bond between Si and O is broken by a hydroxyl group breaking the glass film and activating the hydration of slag.

$$\equiv \mathrm{Si} - \mathrm{O} - \mathrm{Si} \equiv + \mathrm{OH}^{--} \rightleftharpoons \equiv \mathrm{Si} - \mathrm{O}^{--} + \equiv \mathrm{Si} - \mathrm{OH}$$

Followed by this, the broken Si-O further reacts with water which completes the breakage of the glass film at the arrival of the hydroxyl ion.

$$\equiv \mathrm{Si} - \mathrm{O}^{--} + \mathrm{H_2O} \rightleftharpoons \equiv \mathrm{Si} - \mathrm{OH} + \mathrm{OH}^{-}$$

While the glass film of the slag breaks as it reacts with water, the cement undergoes hydration as soon as it comes in contact with water. During the hydration of cement, calcium hydroxide is released which enhances the strength of cement in ages. The long-term enhancement of strength of the slag cement is achieved by the activation of slag by the increase in the pH by calcium hydroxide thus releasing the silicon dioxide and aluminium dioxide in large quantities [7]. The mechanism of activation of slag is shown in the Fig. 2.

$$2(\mathrm{3CaO.SiO_2}) + \mathrm{6H_2O} \rightarrow \mathrm{3CaO.2SiO_2.3H_2O} + \mathrm{3Ca(OH)_2}$$

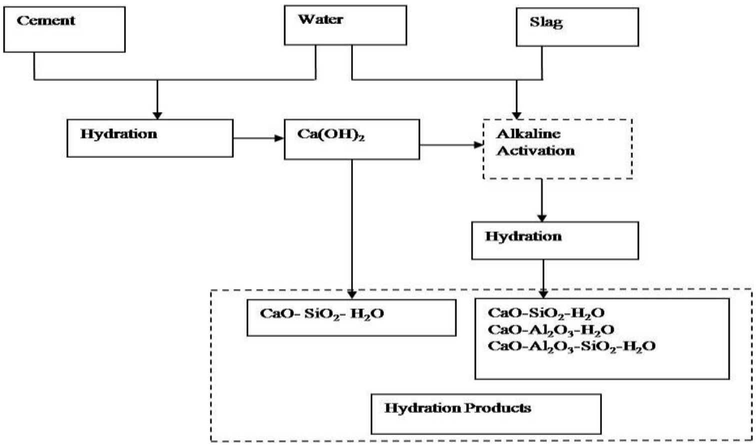


Fig. 2. Flowchart representing the mechanism of activation of slag

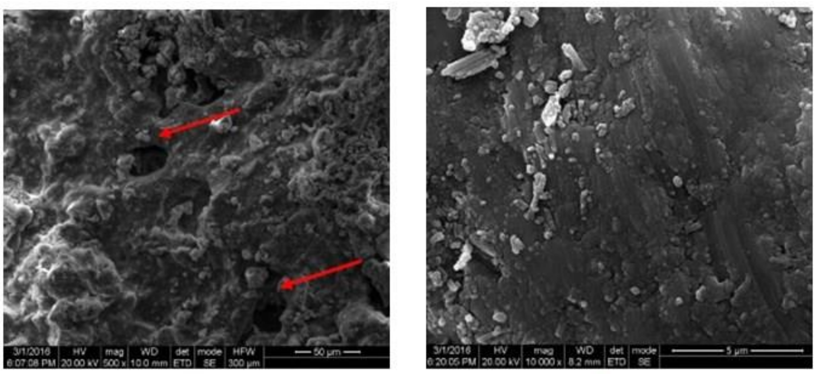
Factors affecting the reactivity of slag

The three major factors affecting the reactivity of slag are fineness, glass content and its chemical composition. The surface area of the slag influences the reactivity of slag. Increase in surface area enhances the strength development which in turn depends on the economic factors, shrinkage and setting time. The glass content of the slag is formed during the quenching process and it depends on the cooling rate. In general rapid cooling process results in higher glass content in slag which is an important factor contributing to its latent hydraulic properties. Studies show that the slag with a glass content of more than 90% can produce satisfactory properties when used in the manufacturing of cement. The third factor which influences the reactivity of slag is its chemical constituents. The four major chemical constituents include CaO, SiO2, Al2O3 and MgO. It is believed that the ratio of the mass of MgO to CaO+SiO2 should exceed 1.0 which results in a high alkaline environment otherwise the slag becomes hydraulically inactive [8].

Therefore the strength of slag can be increased with increase in the CaO/SiO_2 ratio and Al_2O_3 compensates the deficiency of CaO. Experimental studies show that an increase in Al_2O_3 by 13% is said to influence the sulphate resisting capacity of slag concrete. The replacement of CaO by MgO seems to be dependent on the basicity of slag and is reported that the MgO of 11%is significantly equivalent to CaO. Many research studies have been made to quantify the slag reactivity comprising the four major constituents and the ratio $(CaO+MgO+Al_2O_3)/SiO_2$ is the simplest and most widely used. It was observed from the ratio that the reactivity of slag increases with increase in CaO, MgO and Al_2O_3 but decreases with increase in SiO_2 [6].

Analysis of microstructure using SEM

The microscopic structure of slag was analysed using the images from Scanning Electron Microscope. The SEM images of raw and modified slag are shown in the Fig. 3 (A) and (B).



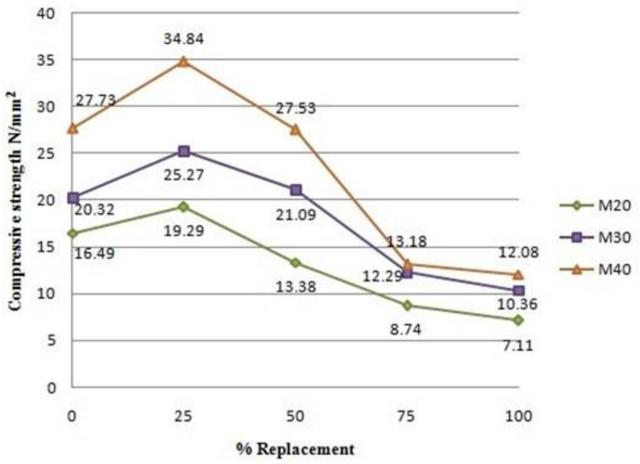
A B

Fig. 3. SEM images of (A) Raw slag (B) Modified slag

Upon analysing the SEM image of the raw slag it was found that the surface of the slag is highly porous. The arrow marks indicate the presence of pores which causes volume expansion in the concrete matrix thereby deteriorating the overall strength. In order to overcome this problem, the raw slag was modified using finely sieved quarry dust and dried for 7 days. The optimum amount of quarry dust to be added to the slag was found to be 1:6:14 which was found by trial and error method. Silicon dioxide and aluminium oxide are the main constituents of quarry dust. Therefore, when quarry dust is added to slag it not only acts as a surface modification material but also acts as an activator. The amount of Al_2O_3 acts as an activator when there is a deficiency in the amount of calcium to make the solution alkaline and increase the pH which will intensify the reactivity of slag [6].

Compressive strength of concrete

Compressive tests were carried out to evaluate the impact of raw modified slag as aggregates in concrete. Compressive strength is one of the most important characteristics of concrete. 15 cubes of standard dimensions 150mm x 150mm were cast and cured for 7 days and 28 days. Three different grades of concrete namely M20, M30 and M40 with varying percentages of replacement of stone aggregates by the slag aggregates from 0% to 100% were tested. Fig shows the graphs of 7 days and 28 days compressive strength of concrete.



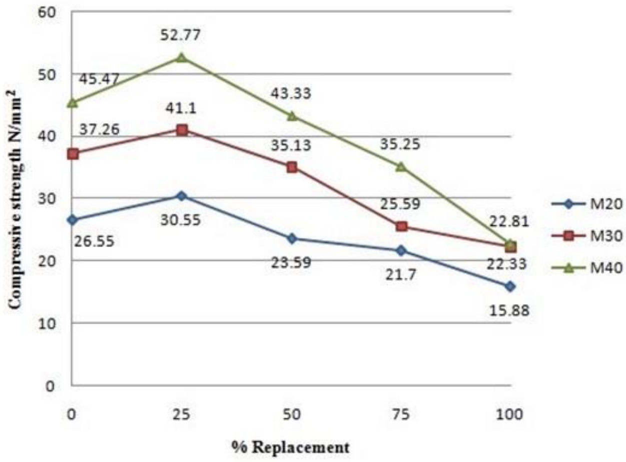


Fig. 4. (A) 7 day Compressive Strength **(B) 28 day Compressive Strength**

From Fig. 4 (A) and (B), it can be observed that for both 7 days and 28 days compressive strength peaks at 25% replacement of natural aggregates and declines beyond 25% for all the three grades of concrete namely M20, M30 and M40. The 75% and 100% replacement with modified slag shows much lesser value compared to plain concrete without the modified slag aggregates. This indicates that the compressive strength decreases for higher percentages of replacements with modified slag aggregates. The low sharpness edge and lower angularity of the modified slag reduced the compressive strength for higher percentages of replacements.

CONCLUSION

From this study, the following conclusions were made.

- The reactivity of slag greatly depends upon the ratio of CaO/SiO_2 i.e. higher the content of CaO higher the reactivity of slag.
- The quarry dust used in this study proves to be a suitable surface modification material, effective in filling up the voids on the surface of slag preventing the problem of volume expansion.
- The replacement of natural coarse aggregates by modified slag aggregate was found to be ideal at 25% replacement for all the three grades of concrete tested in this study.

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