ECO-FRIENDLY CONCRETE USING BY-PRODUCTS OF STEEL INDUSTRY

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Abstract - This paper outlines the method of preparation, testing procedure and salient results on the eco-friendly concrete that is manufactured using the waste products of steel industries and hydraulic lime. Tests are carried out in two phases. In the first phase of tests, the quantity optimization of raw materials like fly ash and hydraulic lime is made so as to get a best binding material that resembles the conventional binder, the cement. The optimum lime content is determined by testing mortar cubes prepared from lime, fly ash and ground granulated blast furnace slag (GGBFS), mixed in different proportions. The amount of lime in the mixture of lime+ fly ash was varied as 20, 35, 50, 65, 80 and 100 percent. The conventional procedure followed to characterize the quality of cement is adopted in this phase of tests and best raw material composition was arrived at. In the second phase, concrete specimens were prepared with taking steel slag as coarse aggregate, GGBFS as fine aggregate and binder that is found to have best performance from the test of phase one. The compressive strength, flexural strength and tensile strength of specimens were determined adopting conventional testing procedure. The effect of curing period on strength was also studied and reported. The present study indicates that concrete having very high strength can be produced with the above mention waste products of steel industry and hydraulic lime.

Keywords- steel slag, ground granulated blast furnace slag, compressive strength, flexural strength, split tensile strength.

INTRODUCTION:

Global warming and environmental destruction have become the major issue in recent years. Emission of host of green house gases from industrial processes and its adverse impact on climate has changed the mind set of people from the mass-production, mass-consumption, mass-waste society of the past to a zero-emission society with emphasis on utilization of industrial wastes and conservation of natural resources. Use of more and more environment-friendly materials and industrial wastes in any industry in general and construction industry in particular, is of paramount importance. A number of studies have been conducted concerning the protection of natural resources, prevention of environmental pollution and contribution to the economy by using the waste material. The two major by-products of the steel industry are slag and fly ash. In India, the annual production of fly ash is about 170 million tons, but about 35 percent of the total is utilized, which is very low. Owing to its ultra fineness, pozzolanic contribution and other properties, the use of fly ash makes a cost of disposal and to reduce environmental pollution, it is an imperative to increase the quantity of fly ash utilization. Similarly, the Steel industry in India is producing about 24 million tones of blast furnace slag and 12million tones of steel slag annually.

Concrete is the most preferred and the single largest building material used by the construction industry. Concrete is basically made of aggregates, both fine and coarse, glued by a cement paste which is made of cement and water. Each one of these constituents of concrete has a negative environmental impact and gives rise to different sustainability issues. The current concrete construction practice is unsustainable because, not only it consumes enormous quantities of natural stones, sand, and drinking water, but also one billion tons a year of cement, which is not an environment friendly material. For production of cement huge amount of energy is needed and about 8 % of atmospheric CO_2 is contributed during cement production. In fact, many by-products and solid wastes can be used in concrete mixes as aggregates or cement replacement, depending on their chemical and physical characterization, if adequately treated. In consideration of these points, construction industry has devised a substitute for concrete, popularly known as ‘Steel Slag Hydrated Matrix’. It consists of steel making slag, ground granulated blast furnace slag (GGBFS), fly ash, lime and water. The striking feature of this form of concrete is that most of its important ingredients are 100 percent by-products of industries, yet having similar performance record as any other conventional concrete material. Aesthetically also it has good pleasing colour and performance wise it has an excellent resistance to wear and tear. Burning of fossils fuels exclusively for its primary ingredients is not necessary unlike in the cue of cement and also no energy-intensive for cement clinker production. It also utilizes the waste products of industries like fly ash and steel slag which otherwise would pose problem for their safe disposal and sometimes degrades the environment.

LITERATURE REVIEW:

The available literature on Eco-friendly concrete is very limited. JEF Steels developed the concrete using waste material such as steel making slag, GGBFS, fly ash & lime dust and 5 ton type breakwater blocks approximately 2.0 m in height were manufactured. These blocks were exposed in the tidal conditions at Mizushima Port in February 2000. Artificial stones and cover blocks using steel slag concrete (SSC) were manufactured and placed in a shore protection repair project at JFE Steels West Japan Works (Kurashiki) between Sept. 2000 and Sept. 2002 Matsunaga et al, 2000). Matsunaga et al. [1] have prepared SSC with small amount of an alkali activator (calcium hydroxide or lime dust). The compressive strength of these SSC products was reported to exceed 18N/mm^2, which is the general design strength of breakwater blocks. It was also reported that the 91 days compressive strength is approximately 1.3 times greater than 28 days strength. Besher et al.[2] have examined the effect of four types of coarse aggregate namely calcareous, dolomatic, qartzic limestone and steel slag on the compressive strength and elastic modulus of high strength concrete. From their results the highest and lowest compressive strength was obtained in the concrete specimens prepared with steel slag and calcareous aggregates respectively. Takashi Fujii et al. [3] studied the leachate characteristics of SSC prepared with alkali activator. Their work showed that the strength of SSC depend on pH of the matrix after mixing.Tomonari Kimura et al.[4] have developed SSC with steel slag, GGBFS, fly ash and lime dust. The compressive strength of these blocks was comparable to ordinary concrete. Their work show the feasibility of use of SSC as substitute to concrete in RCC structures under chloride attack environment and also the service life of the structure possibly becomes longer. Therefore, it is recommended SSC can be a substitute material in existing RCC structures such as caissons, cellular blocks, quays and mooring-posts, the structures that are highly used in marine environments. Mridul Garg and Manjit Singh [5] have prepared cementious binders by blending 60-70 % fly ash with calcanied phospho-gypsum, hydrated lime sludge, Portland cement and chemical activator in different proportions. They investigated the durability of binder by performance in water and accelerated ageing i.e alternative wetting and drying as well as heating and cooling at temperatures from 27 to 50^0C. Their results indicated that the less compressive strength of binder was obtained at maximum temparture that is 50^0C. Takshi Fujii et al. [6] have developed the concrete using ground granulated blast furnace slag, lime dust, steel making slag, high range water reducing admixture and air entraining agent. Their result indicted that low resistance to freezing and thawing of the steel making slag concrete was due to small amount entrained air by the agent and adequate quantity of fly ash is necessary to consume calcium hydroxide around the aggregate. Wang Chang Long et al. [7] has studied steel slag and slag replacing sand in concrete. The result showed that the compressive strength of concrete with mixture of steel slag is very similar to that of ordinary concrete. Hisham Qasraui et al. [8] studied the effect of waste material of steel plant in concrete. In their investigation local unprocessed steel slag was used in concrete as fine aggregate replacing the sand partly or totally. The compressive strength of concrete was reported to be improved when steel slag is used for low sand replacement ratio (up to 30%). Khidhair et al. [9] has used the steel slag as replacement of aggregate in the concrete. The results showed that the density of concrete, compressive strength, flexural strength after 7 days and 28 days were increased by increasing slag content while water absorption was decreased by increasing slag content. Matsunga Hisahiro et al. [10] investigated the effect of steel slag, ground granulated blast furnace slag, fly ash and alkali activator on mechanical properties, physical properties of the concrete prepared with these raw materials and compared it with the normal concrete. The results indicate that the compressive strength of this recycled concrete is 24 MPa which is equal to conventional concrete used for RCC works.

MATERIAL CHARACTERIZATIONS AND METHODOLOGY:

Fly ash, GGBFS and steel slag used in this investigation were collected from the captive power plant-II, slag granulation unit and steel slag crushing unit of Rourkela Steel Plant respectively. Steel slag brought was 20mm down in size. These raw materials were mixed thoroughly, to bring homogeneity in them, and sun dried. The average moisture content of the sun dried raw materials was determined and these were stored in covered galvanized iron tanks separately for future use. Likewise commercial lime was procured from local market. The specific gravity of fly ash and GGBFS were determined as per IS: 2720 part-III, Section-1, 1980. The particle size distribution of fly ash and GGBFS were determined as per IS: 2720 part-IV, 1975 and is shown in Fig.1.Particle size distribution curve gives an idea about the size range and distribution of particles in the sample. It is found that the fly ash particles are of fine sand to silt size whereas GGBFS particles are of medium sand size. Uniformity coefficient and coefficient of curvature are the measure of the distribution of different size particles in the sample. Uniformity coefficient and coefficient of curvature for fly ash are found to be 2.13 and 1.12 respectively indicating fly ash is uniformly graded. Similarly uniformity coefficient and coefficient of curvature for GGBFS are 3.85 and 1.43 respectively indicating that it is a well graded material within its range having grain size ranging from silt to coarse sand. The physical properties of the fly ash and GGBFS are given in Table.1and particle size distribution curve of fly ash and GGBFS is given in Fig-1.The X-Ray difractogram of fly ash, GGBFS, steel slag and lime are shown in Fig.2 to Fig.5 respectively.

Tests are carried out in two phases. In the first phase of tests, the quantity optimization of raw materials like fly ash and hydraulic lime is made so as to get a best binding material that resembles the conventional binder, the cement. The optimum lime content is determined by testing mortar cubes prepared from lime, fly ash and, ground granulated blast furnace slag (GGBFS), mixed in 1:3(binder : fine aggregate) proportion. The amount of lime in the mixture of lime+ fly ash (binder) was varied as 20, 35, 50, 65, 80 and 100 percent. The mortar cubes were cured in a water tank at an average temperature of 31^0C for3, 7, 28 and 60 days and thereafter the compressive strength of these samples were determined as per I. S 4031 part-7 (1988)[11] and the best raw material composition was arrived at. In the second phase, concrete specimens were prepared with taking steel slag as coarse aggregate, GGBFS as fine aggregate and binder that is found to have best performance from the tests of the first phase. The compressive strength, flexural strength and tensile strength of specimens were determined adopting conventional testing procedure. The effect of curing period on strength was also studied by testing the specimens after curing periods of 7, 14, 28 and 60 day.

Flexural strength is measure the tensile strength of concrete. It is a measure of an unreinforced concrete beam to resists failure in bending. It is measured by loading 100x 100 x500 mm concrete beam called prism. The flexural strength is expressed as Modulus of rupture and is determined by test method referred in IS 516-1959 [12] by using two points loading method. For testing the specimen is placed in the machine and the load is applied and increased continuously at a rate of 180 kg/min until the specimen fails. The maximum load applied to the specimen during the tests are recorded and used to calculate flexural strength of the concrete. For determination of flexural strength of eco friendly concrete, prisms of 100x100x500 mm were prepared for mix of proportion 1:1.5:3. The proportion of lime in the lime + fly ash binder vary from 20 %, 35% , 50% and 65% for different mixes. These were tested for modulus of rupture after 7 days and 28 days of curing and this results are compared with normal cxement concrete. The results are presented in Fig-8. Splitting tensile strength tests were carried out in accordance with IS 5816-1999 [13] standards conducted on concrete cylinders of 150mm diameter and 300 mm length. Each cylinder specimen was placed on its side and loaded in compression along diameter of specimen. The load was continuously applied at a normal rate within the range of 1.2N/mm^2/min to 2.4 N/mm^2/min till the specimens failed. Specimen during the tests are recorded and used to calculate split tensile strength of the eco friendly concrete.

Table1. Physical properties of fly ash and GGBFS

Physical Parameters	Fly ash	GGBFS
Color	Blackish green	Brown
Shape	Rounded	Sub-rounded to angular
<u>Grain size composition (%)</u>		
Silt & clay	13	1.5
Fine sand	87	16
Medium sand	0	72.5
Coarse sand	0	10
Uniformity coefficient ($C_U = D_{60} / D_{10}$)	2.13	3.85
Coefficient of curvature, $C_C = (D_{30})^2 / (D_{10} \times D_{60})$	1.12	1.43
Specific gravity	2.15	2.61
Plasticity index	Non Plastic	Non Plastic

Note: D_{10}, D_{30} or D_{60} represent the sizes, in mm such that 10, 30 or 60 percent (by weight) of the particles are finer than these sizes respectively.

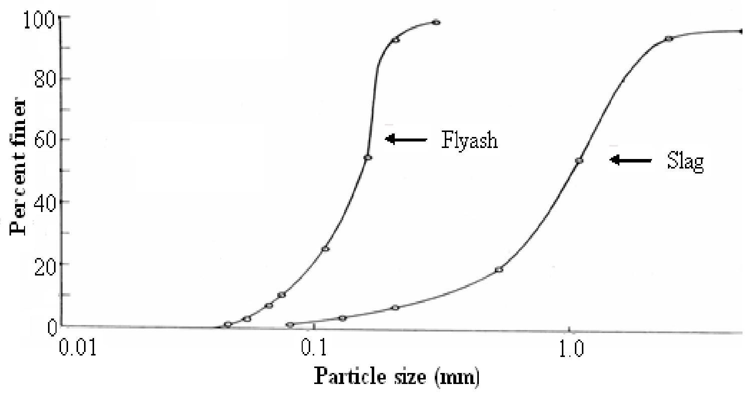

Fig. 1 Particle distribution curves for fly ash and GGBFS

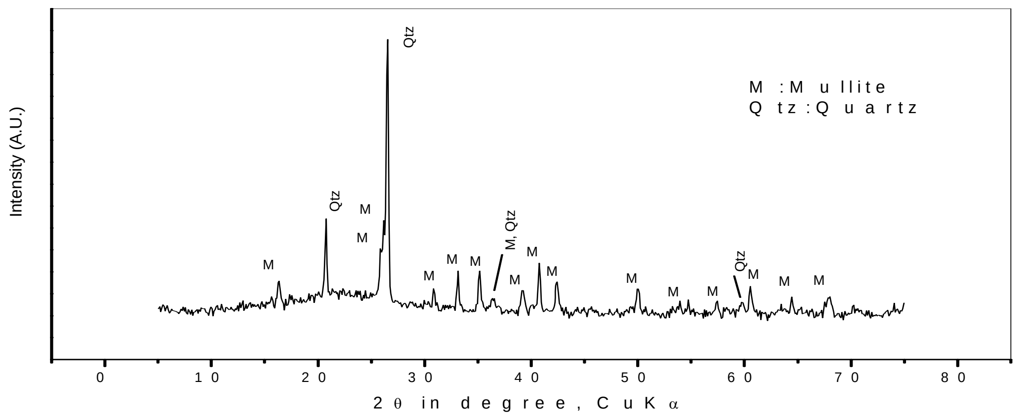

Fig. 2 X-Ray diffractogram of fly ash

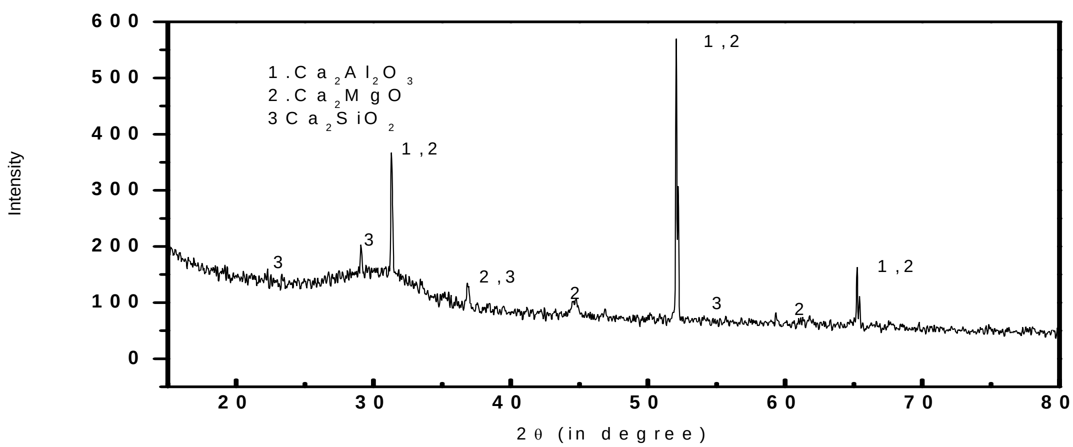

Fig. 3 X-Ray diffractogram of ground granulated blast furnace slag

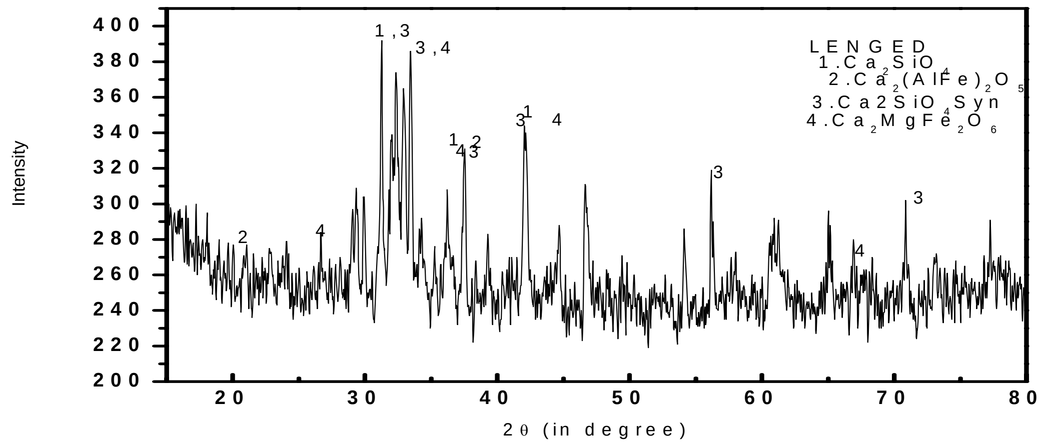

Fig. 4 X-Ray diffractogram of steel slag

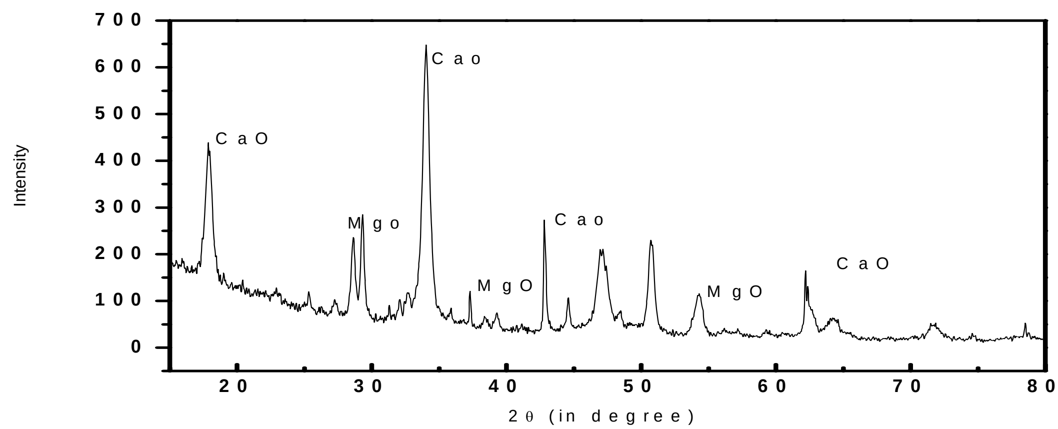

Fig. 5 X-Ray diffractogram of lime

RESULT AND DISCUSSION:

COMPRESSIVE STRENGTH OF MORTAR:

The optimum lime content in the mixture of lime, fly ash and GGBFS were determined by conducting the compression tests on mortar specimens as per I. S Code of practice 4031 part-7 (1988)[11]. In this test lime and fly ash is treated as binder material and GGBFS as fine aggregate. The lime content in the mixture of lime, fly ash was varied as 20, 35, 50, 65, 80 and 100 percent. The ratio of binder to fine aggregate was taken that is 1:3. The samples were prepared keeping their normal consistencies in consideration and were tested after curing periods of 3, 7, 28 and 60 days. The test results are presented in Fig. 6. It is observed that a lime content of 35% in the mixture of lime, fly ash gives the maximum compressive strength. The strength of the mortar cubes increases with curing period and it reaches the value almost same as the ordinary Portland cement after 28 days of curing. The compressive strength of mortar prepared from lime, fly ash and GGBFS was low during early stages of curing, but it achieved almost the same strength as of normal cement mortar after 56 days. The compressive strength of mortar cubes made from lime, fly ash, GGBFS in the proportion of (35:65:300) was found to be 29 N/mm^2 at 28 days and 38.8N/mm^2 at 60 days. A comparison is made with the compressive strength of mortar prepared by using cementious binders of 60-70% fly ash with calcined phospogypsum, hydrated lime sludge and binder to fine aggregate ratio was taken 1:3 (Garg & Singh). However, river sand was used as fine aggregate and the samples were tested after curing period of 3,7,28 and 90 days. It is observed that the variation of compressive strength with curing period shows similar trend with the present test results with the later having comparably higher magnitudes.

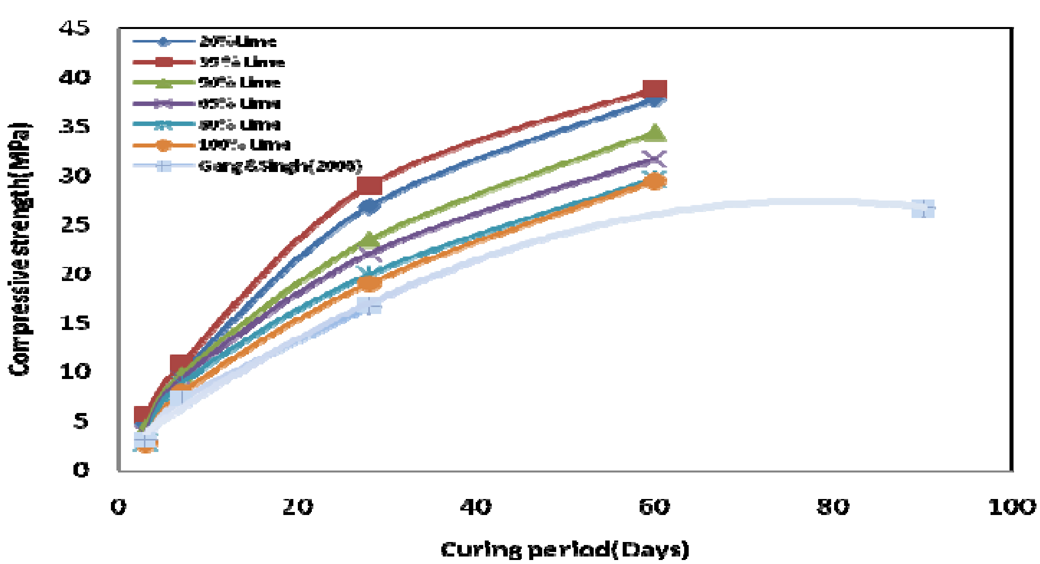

Fig. 6 Compressive strength of mortar

COMPRESSIVE STRENGTH OF CONCRETE:

Eco-friendly concrete cubes were prepared taking lime+ fly ash, GGBFS and steel slag in the ratio of 1:1.5:3. The lime content in lime, fly ash mix was varied as 20, 35, 50, 65 and 80%. The cubes were cured at an average temperature of 31^0C in a water tank and tested after 7, 14, 28 and 60 days of curing. The test results are shown in Fig-7. It is seen that the cubes that contain 35% lime gives the highest strength that is 16N/mm^2 compared to 20N/mm^2 of normal concrete but in 60 days it was 21.1N/mm^2. Moreover it is observed that minor hair cracks are present in the cured samples before testing. This may be due to the presence of excess lime in the steel slag which might have caused swelling and crack in the specimen during curing. Similar observations are also available in the literature and sufficient weathering of steel slag is recommended before it can be used in concrete.

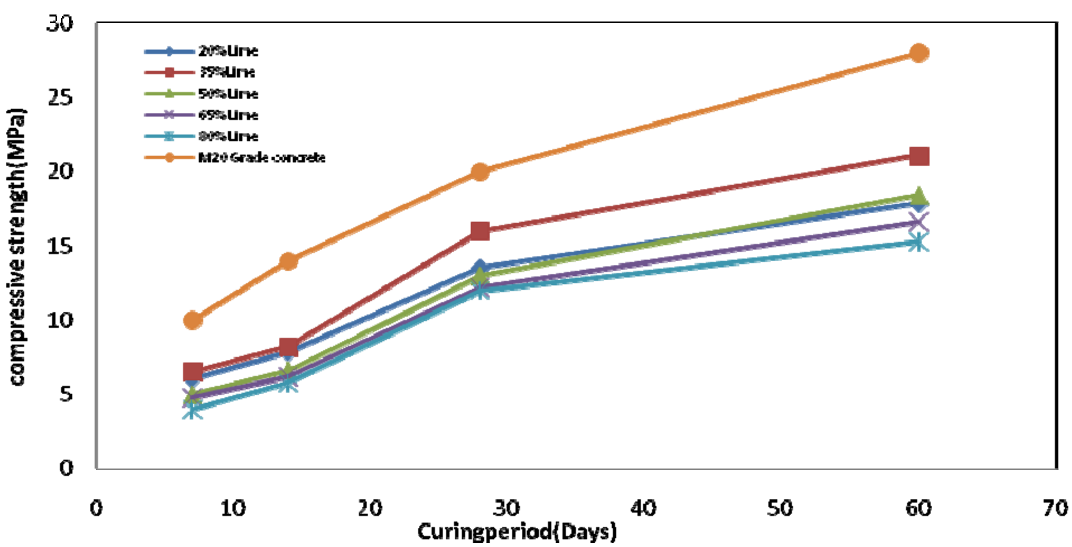

Fig. 7 Compressive strength of eco-friendly concrete

FLEXURAL & SPLIT TENSILE STRENGTH:

Flexural strength is measure the tensile strength of concrete. It is a measure of an unreinforced concrete beam to resists failure in bending. The flexural strength is expressed as modulus of rupture and is determined by test method referred in IS 516-1959 by using two points loading method. The prism specimens prepared in the mix propertions of 1:1.5:3 were tested for modulus of rupture after 7 days and 28 days of curing and this results are compared with normal M_{20} grade cement concrete. The results are presented in Fig-8. It is observed that the specimen containing 35% lime gave the highest strength after 7 days and 28 day of curing. The flexural strength of ecofriendly concrete is 2.5N/mm^2 compared to 3 N/mm^2 of normal concrete at 28 day curing period.

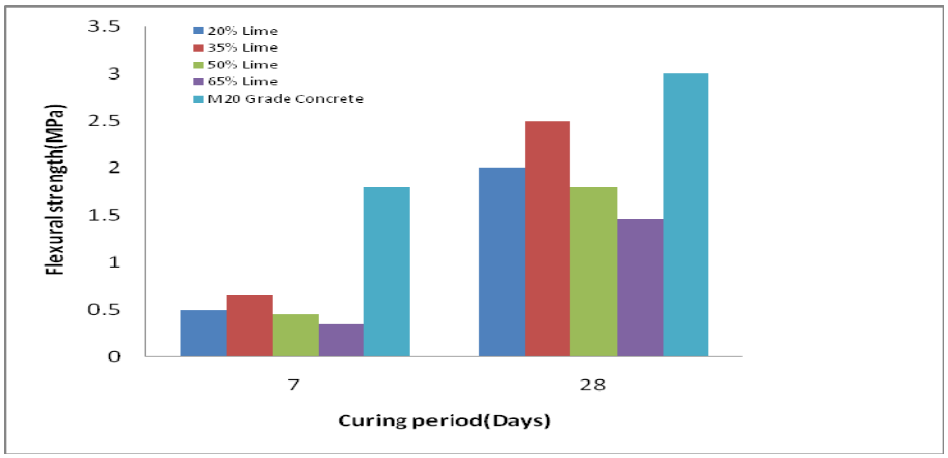

Fig. 8 Flexural strength of eco-friendly concrete

Splitting tensile strength tests were carried out in accordance with IS 5816-1999 with cylindrical specimens of size 150mm diameter and 300 mm length. The proportion of lime in fly ash-lime mixes were varied as 35, 50 and 65% of total binder mass. The samples were tested for tensile strength after 7 days and 28 days after curing. The test results are presented in Fig. 9 and compared with M_{20} grade ordinary concrete. At 35 and 50% lime content the eco-friendly concrete gives split tensile strength values slightly more than the normal M_{20} grade concrete. The split tensile strength of the normal concrete was 2.0MPa while it was in the range of 2.1 to 2.13MPa in the steel slag concrete.

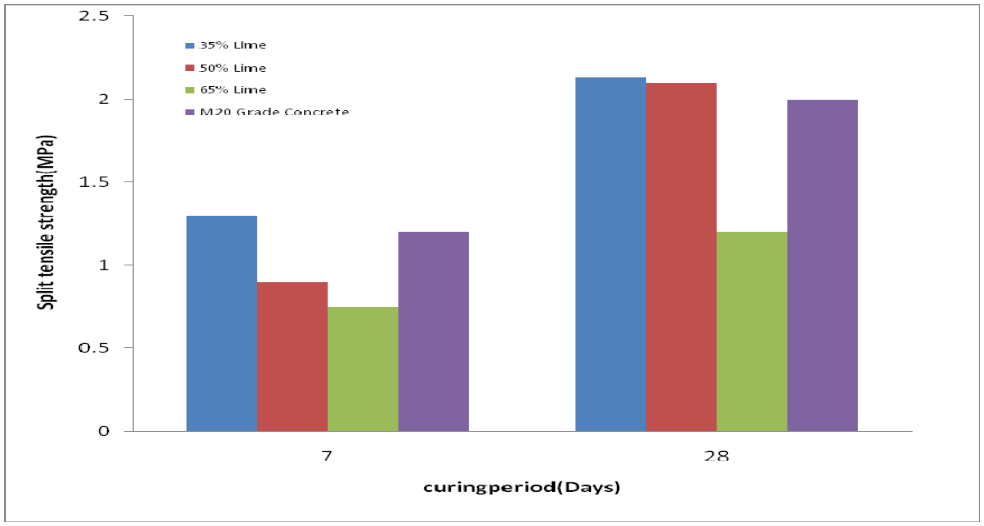

Fig. 9 Split tensile strength of eco-friendly concrete

CONCLUSION:

The compressive strength of mortar prepared from lime, fly ash and GGBFS was low during early stages of curing, but it achieved almost the same strength as of normal cement mortar after 60 days of curing. The compressive strength of mortar cubes made from lime, fly ash, GGBFS in the proportion of (35:65:300) was found to be 29 N/mm^2 at 28 days and 38.8N/mm^2 at 60 days. The 28 days compressive strength of eco-friendly concrete is found to be less than the normal cement concrete. The compressive strength of eco-friendly concrete with 35% lime as binder was found to 16N/mm^2 after 28 days of curing but at 60 days it was 21.1 MPa. However, other researchers have found the compressive strength of eco-friendly concrete in the range of 20 N/mm^2 to 30 N/mm^2 after 28 days of curing. Flexural strength of steel slag hydrated matrix is lower than the normal concrete. However, the split tensile strength is approximately same as the normal concrete. The environmental friendly concrete can be used as a substitute for concrete blocks and semi hard natural stones in various construction works. Thus the by-products of steel industry can be used in making concrete that have technical, economical and ecological advantages for sustainable development.

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