ABSTRACT

Steel slag is an industrial by-product of steel industries. The disposal of this solid waste material in dump yards is usually associated with high cost along with negative impact on the environment. Concrete is a widely used construction material in the world. More than ten billion tonnes of concrete are consumed annually. Conventional concrete is a versatile material and it is a mixture of cement, natural aggregate and water. Aggregate occupy 70% to 80% of the total volume of concrete and affect the fresh and hardened properties of concrete. In most parts of the world, conventional cement concrete consists of river sand as fine aggregate and gravel/limestone/granite as coarse aggregate. Increase in demand and decrease in supply of aggregates for the production of concrete, results in the need to identify new sources of concrete aggregates. Steel slag is considered as potential alternative to natural aggregates.

The advancement of concrete technology, as well as the development of new materials and components, has resulted in increased performance and strength requirements, which are not adequately satisfied by conventional materials. Maintenance, repair and rehabilitation of existing cement concrete structures are cause significant increase in expenditures. Hence, there is an urgent need to pay more attention to improve the properties of concrete with respect to strength, durability and structural behaviour.

Most of the previous research works were done by using conventional aggregates in concrete. In this research work, an effort has been made to focus on the complete replacement of Natural Coarse Aggregate (NCA) with Steel Slag Aggregate (SSA) in concrete. High Performance Concrete (HPC)
of M60 Grade is attempted in this investigation. Ordinary Portland Cement (OPC) of grade 53 conforming to IS 12269-1987, River Sand (RS) of grading zone II (conventional fine aggregate) obtained from Cauvery river bed at Karur and 20mm down blended, well graded, Hard Blue Granite (HBG) stone aggregate (conventional coarse aggregate) are used for the investigation. Class F Fly Ash (FA) of specific gravity 2.15, obtained from Mettur Thermal Power Station and Silica Fume (SF) of specific gravity 2.25, obtained from ELKEM, Mumbai are used as mineral admixtures. Sulphonated naphthalene based Superplasticizer (SP) confirming to IS 9103-1999 is used as chemical admixture. The steel slag is obtained from a private steel industry at Coimbatore, India. Potable water is used for mixing concrete and curing of specimens. The physical and mechanical properties of cement are tested according to IS 4031-1988. Physical and mechanical properties of conventional aggregates are determined according to IS 2386-1963 and are found to confirm with IS 383-1970.

The mix design is carried out as per ACI 211.4 R-93. The absolute volume method is used in the calculation of concrete mixtures to obtain denser concrete. Conventional Concrete (CC) using OPC and natural aggregates is prepared as control mix. After extensive trials, the water cement ratio (W/C) and cement content (C) are established as 0.32 and 584 kg/m³ respectively. The major difference between conventional cement concrete and high performance concrete is essentially the use of chemical and mineral admixtures. Therefore, the combined use of chemical and mineral admixtures leads to economical concrete with enhanced properties. In order to determine the optimum replacement level of mineral admixtures (such as fly ash and silica fume) to produce HPC, trial mixes are prepared as per the guidelines given in ACI 211.1-91 and ACI 211.4 R-93. From the test results of trial mixes, the optimum replacement level of fly ash and silica fume are determined as 25% and 10% of weight of cement respectively.
Superplasticizer is used at the rate of 2% of weight of cement, as per the guidelines given in IS 456-2000. HPC mixes are prepared using conventional aggregates along with fly ash/ silica fume and superplasticizer. Steel slag is obtained in the form of boulders. SSA is prepared by crushing the steel slag boulders and sorting into two groups by sieving. Fraction 1-passing through 20 mm and retained on 10 mm (F1), and fraction 2-passing through 10 mm and retained on 4.75 mm (F2) are considered in this study. Physical and mechanical properties of SSA are determined as mentioned in the case of conventional aggregate.

Test results showed that SSA have properties similar to NCA. Hence, it is decided to completely replace the NCA with SSA. But SSA is found to be contaminated with free lime. The space in which the free lime presents in steel slag is known as lime pockets. This free lime is in uncombined and unstable form in the lime pockets. This contaminated steel slag produce some serious problems by volume expansion in concrete, due to the delayed hydration of free lime. From literatures it is observed that steel slag must be allowed to aging, before it is used as aggregates. However, there are different opinions about the aging period of steel slag and research papers on the effect of steel slag aging on the properties of concrete are also found rare. Hence, a detailed study has been made to evaluate the effect of different aging periods of steel slag on strength and durability of high performance concrete. There are several methods of aging, namely air aging, hot water aging and steam aging. In this research air aging method (SSA is left out in the open for weathering in air) which is easier and cost effective was used. There are several kinds of slag obtained after different processes of steel making such as, basic oxygen slag, electric arc furnace slag, electric induction furnace slag, ladle slag, etc. This study focuses only on the use of locally available electric induction furnace slag in concrete.
SSA are stocked on a hard, dry and level patch of ground according to their nominal size in stockpiles and used as coarse aggregate after every six months to produce HPC mixes. Sampling of the aggregates is carried out as per IS 2340-1986. The aggregate types HBG and SSA are composed of 60% of fraction 1 and 40% of fraction 2 particles. In order to evaluate the effect of aging period of steel slag, concrete containing steel slag aggregate (HPC1, HPC2, HPC3, HPC4, HPC5, HPC6, and HPC7) after different aging periods (6, 12, 18, 24, 30, 36 and 42 months respectively) with fly ash/silica fume are prepared and investigated.

The workability of concrete mixes is determined by conducting slump test and compaction factor test. Strength properties such as compressive strength, flexural strength, Young’s modulus, impact strength and bond strength are studied at different curing periods. The durability properties such as water absorption, porosity, acid resistance, fire resistance, abrasion resistance and rapid chloride permeability are investigated. Equations are developed to obtain flexural, Young’s modulus, impact strength, bond strength and durability properties in terms of compressive strength of concrete.

From the experimental and analytical studies conducted, it is concluded that steel slag (after sufficient aging) can be used as concrete aggregate along with chemical and mineral admixtures, to produce concrete of better quality. Aging of steel slag have a greater influence on the strength and durability of concrete. By considering strength and durability test results, the optimum aging period of steel slag aggregate is determined as 24 to 36 months.

An experimental study is carried out to study the behaviour of beams in flexure. The flexural behaviour of reinforced concrete beams
with natural aggregate (CC, HPCF, HPCS) and with SSA after optimum aging (HPC7F and HPC7S) is studied with respect to load carrying capacity and deflection. Beams made with SSA showed a better performance than the beams made with natural aggregate. Analytical (ANSYS) models are developed for beams in flexure. The results obtained from experimental investigation are compared with analytical results and found to be satisfactory.

In general, the HPC prepared with steel slag aggregate and admixtures have performed much better in comparison to those cast with conventional aggregate. Hence, the use of steel slag aggregate (after sufficient aging) in concrete is recommended. Use of steel slag aggregate in construction, simultaneously reduces the disposal problem and environmental pollution.