

Strength Behavior of Mortar Using Slag as Supplementary Cementitious Material

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Abstract:- Pozzolanic admixtures are generally being used along with the cement in concrete mixes so as to derive certain benefits like economy, durability, Chemical resistance in permeability etc. The use of high volumes of fly ash has become one of the current topics of research possibility promoted by the availability of a wide range of chemical and mineral admixtures. Test results of the study show that the designed strength was exceeded and that the ductility ratio and the safety margin against brittle failure of concrete containing these industrial by-products were comparable to those of the reference concrete (normal ordinary Portland cement concrete), proving the feasibility of using the waste materials as alternative construction materials. Different water-binder ratios ranging from 0.55 to 0.27 are considered for investigation. From the results, the relationship is developed between Compressive Strength, Split Tensile strength and Flexural Strength of High Volumes of Slag Concrete. Test results show that strength increases with the increase of slag up to an optimum value, beyond which, strength values start decreasing with further addition of slag. Among the seven slag mortars, the optimum amount of cement replacement is about 40%, which provides 19% higher compressive strength and 25% higher tensile strength as compared to OPC mortar.

Keywords— Slag, Cement, Mortar, Compressive Strength, Tensile Strength, Hydration.

1. INTRODUCTION

Cement, mortar and concrete are the most widely used construction material all over the world. The search for any material, which can be used as an alternative or as a supplementary for cement should lead to global sustainable development and lowest possible environmental impact. Concrete is the most widely used construction material worldwide. However, the production of Portland cement, an essential constituent of concrete, releases large amounts of CO₂ which is a major contributor to the greenhouse effect and the global warming of the planet and the developed countries are considering very severe regulations and limitations on CO₂ emissions. In this scenario, the use of supplementary cementing materials (SCMs), such fly ash, slag and silica fume, as a replacement for Portland

cement in concrete presents one viable solution with multiple benefits for the sustainable development of the concrete industry. The most commonly available SCM worldwide is fly ash, a by-product from the combustion of pulverized coal in thermal power stations.

Fly ash, if not utilized has to be disposed of in landfills, ponds or rejected in river systems, which may present serious environmental concerns since it is produced in large volumes. Far from being considered as a "Waste" product, research and development has shown that fly ash actually represents a highly valuable concrete material. In order to considerably increase the utilization of fly ash as replacement for cement, such concrete must meet engineering performance requirements that are comparable to those for

conventional Portland cement concrete, and be cost effective. This is a particularly important issue for India, which currently produces over 100 million tons of Portland cement and 100 million tons of fly ash annually. Disposal of fly ash is a growing problem in India, only about fifteen percent of this amount is currently used; the remainder goes to landfill. Combining GGBFS[1] and OPC at mixer is treated as equivalent to factory made PSC. Concrete with different properties can make by varying the proportions of GGBFS.

The strength values corresponding to „0“ day curing period mean the strength of the specimens after 30 days Plain Water curing. It is clearly demonstrated that the concrete specimens with cement slag proportions 70:30 gives lower strength deterioration for longer curing periods. In case of plain water curing, OPC concrete shows higher strength at initial ages than that for slag concrete. But for relatively longer curing periods, the differences between the results are seen to be decreased [2]. Curing concrete is one of the most important steps in concrete construction and regrettably, one of the most neglected. Effective curing is absolutely essential for surface durability. Economic and environmental considerations have motivated the quest for the use of industrial by-products as alternative to conventional aggregates and binders in cementitious matrix.

Annually, billions of tons of industrial wastes such as fly ash, blast furnace slag and cement kiln dust, to mention but a few, generated world-wide as by-products of industrial processes are disposed off in landfills. This practice, apart from being expensive, places much burden on the limited available landfill facilities. Studies have shown that some of the aforementioned solid wastes contain potentially useful cementitious material that could be used as a full or partial substitute for traditional binders in concrete or mortar. Wimpenny, determined that in general the highest 91-day compressive strength of slag mixes is obtained under 20oC curing, the strength decreasing as the curing temperature is lowered. Increasing the curing temperature to 40o C leads to a drop in strength at longer ages, in the case of OPC control mixes below those recorded at 5oC [4]. A1-Kaisi, also showed that OPC and slag concretes cured under isothermal conditions at temperature of 20o C tend to show a higher strength beyond 28 days than concretes cured isothermally at temperatures between 40-60oC [3].

Pratas found from experiment that the strength loss in high volume slag concrete is more than normal concrete when the curing was not properly done. Curing duration of high volume slag cement concrete must be more than plain concrete [4]. As per Irene K. LaBarca, grade 120 slag cement is a viable material for use in highway pavement concrete design. While variations in mix materials and curing conditions cause changes in the performance of the hardened concrete, many options exist for combinations of materials that are successful with grade 120 slag cement at replacement levels up to 50% [11]. Mohammed Nadeem, Concrete of M20, M30 and M40 grades were considered for a W/C ratio of 0.55, 0.45 and 0.40 respectively for the replacements of 0, 30, 50, 70 and 100% of aggregates (Coarse and Fine) by slag. Whole study was done in two phases, i.e. replacement of normal crushed coarse aggregate with crystallized slag and replacement of natural fine aggregate with granular slag.

The investigation revealed improvement in compressive strength, split tensile and flexure strength over control mixes by 4 to 8 %. The replacement of 100 % slag aggregate (coarse) increased concrete density by about 5 to 7 % compared to control mix. The slag could be effectively utilized as coarse and fine aggregates in all the concrete applications [5]. ASTM C989, adopted in November 1982, provides for three strength grades of slags, depending on their respective mortar strengths when blended with an equal mass of Portland cement. The classifications are Grade-120, Grade-100 and Grade-80, based on the slag-activity index expressed as SP/P X100, where SP is the average compressive strength of slag cement mortar cubes and P is the average compressive strength of reference cement mortar cubes made without slag. Grades 100 and 120 are the most commonly used as admixtures in concrete.

2. HYDRATION CHARACTERISTICS AND STRENGTH DEVELOPMENT OF SLAG MORTAR

When GGBF slag is mixed with water, initial hydration is much slower as compared with Portland cement. Therefore, Portland cement or alkali salts are used to increase the reaction rate. In the hydration process, GGBF slag produces calcium silicate hydrate cement paste. This valuable contribution from GGBF slag

improves the paste-to aggregate bond in concrete. GGBF slag mixtures with Portland cement typically result in greater strength and reduced permeability. The principle constituents of blast furnace slag are silica, alumina, calcium and magnesia (reported as oxide), which comprise 95% of slags total makeup. Minor elements include manganese, iron and sulfur compounds as well as trace quantities of several others. Like Portland cement, most of the calcium oxide (CaO) [6]found in GGBFS is tied up as calcium silicate, calcium aluminates and calcium aluminosilicate. Although these compounds are not identical to those found in Portland cement (i.e., tricalcium silicate, tricalcium aluminate, etc.), they hydrate when activated by calcium hydroxide (lime) which is one of the by-product of Portland cement hydration.

Slag blended cement increases the compressive and flexural strength of conventional concrete and is often a vital component in producing high strength concrete. 28-days concrete strengths generally increase as the percentage of slag content increases up to about 50 percent of cementitious material. When Portland cement reacts with water, it forms calcium silicate hydrate (CSH) and calcium hydroxide (Ca(OH)₂) is a by product of Portland cement hydration that does not contribute to strength. When slag cement is used as part of the cementitious material in a concrete mix, it reacts with water and Ca(OH)₂ to form more CSH. The additional CSH densifies the concrete matrix thereby enhancing strength. High fineness of the slag component did not have a significant effect on the workability. Stutterheim (1968) observed that slag concretes had appreciably better workability than Portland cement concretes allowing for reductions in water content. According to Roy (1982), the effect of slag on workability is less pronounced than that of fly ash.

When slag blended cement and water are mixed, a chemical reaction called hydration initiates, resulting in the creation of calcium-silicate-hydrate (CSH) and calcium hydroxide (CH). CSH is a gel that is responsible for strength development in Portland cement pastes. Also, through Pozzolanic activity, slag combines with free lime to produce the same cementitious compounds formed by the hydration of Portland cement. Hydration rate of slag is slower than that of Portland cement. So the blending of slag and

Portland cement leads to retard the rate of strength development at early ages of curing.

3. EXPERIMENTAL INVESTIGATION

CEMENT:

Locally available 53 grade of Ordinary Portland Cement (Ultratech Brand.) conforming to IS: 12269 was used in the investigations. The cement is tested for various properties like Normal consistency, specific gravity, Fineness, Soundness, Compressive Strength[7] , and Specific Surface area were found to be 28%, 3.10, 4%, 0.5 mm, 53Mpa and 3100 cm²/g in accordance with IS:12269-1987.

GGBFS:

GGBFS which is available in local market, brought from Steel Plant, Visakhapatnam (Dt.), Andhra Pradesh. The physical requirements in accordance with IS 1727- 1967 (Reaffirmed2008) and chemical requirements in accordance with IS: 12089 – 1987 (Reaffirmed 2008). The GGBFS is tested for various properties like Specific gravity and Fineness were found to be 2.2 and 3500 cm²/g.

SUPER PLASTICIZER:

The Super plasticizer utilized was supplied by internationally reputed admixture manufactures. Endure flowcon04 was manufactured by Johnson. Endure flowcon04 is dark brown colored liquid and it is based as sulphonated naphthalene formaldehyde (SNF) super plasticizer. It complies with IS:9103-1999, BS5075, ASTM C-494 was used. The super plasticizer is tested for properties like density and pH were found to be 1.2 and minimum 6.

FINE AGGREGATE:

The locally available river sand is used as fine aggregate in the present investigation. The sand is free from clay, silt, and organic impurities. The sand is tested for various properties like specific gravity, water absorption and fineness modulus of fine aggregate were found to be 2.55,1.72 and 2.74 in accordance with IS:2386-1963.

COARSE AGGREGATE:

Machine crushed angular granite metal of 20mm nominal size from the local source is used as coarse aggregate. It is free from impurities such as dust, clay particles and organic matter etc., The coarse aggregate is also tested for its various properties. The specific gravity, water absorption and bulk density and fineness modulus of coarse aggregate were found to be 2.65, 0.38, 1490 kg/m³ and 7.16 respectively.

WATER:

Locally available water used for mixing and curing which is potable, shall be clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to concrete or steel.

4.VARIABLES STUDIED

(a) Mortar quality:

Seven different mix proportions of cement: slag (90:10, 80:20, 70:30,60:40, 50:50, 40:60, 30:70) were used as cementitious material. Cement slag mix ratio of 100:0 i.e. plain cement mortar specimens were also cast as reference mortar for comparing the properties of slag mortars.

(b) Exposure period:

Specimens were tested periodically after the specified curing periods of 3, 7, 14, 28, 60, 90 and 180 days.

(c) Size of specimens:

50 mm x 50 mm x 50 mm cube specimens for compressive strength and briquette specimens of standard size for tensile strength tests were prepared as per ASTM standard.

(d) Mortar mix ratios:

The mix ratio of cementitious material and sand was 1:2.75 for compressive strength and 1:3 for tensile strength test specimens.

(e) Curing environment and testing:

A total of 400 mortar specimens were cast in the laboratory. After casting, the specimens were kept at

27°C temperature and 90% relative humidity for 24 hours. After demoulding, all the specimens were cured in water in a curing tank at room temperature. After specific exposure period, specimen was tested for compressive strength and tensile strength in accordance with test procedure ASTM C190-85 and C190-87.

5. RESULTS AND DISCUSSION

5.1 Compressive Strength

Test results showed that the 3 days compressive strength for OPC mortar is 12%,14%, 20%, 21%, 31%, 51% and 58% higher than slag mortar of replacement level 10%, 20%, 30%, 40%, 50%, 60% and 70% respectively. The percentage increase in compressive strength in ordinary concrete is in between 10% to 15% for w/c 0.55 to 0.40. For lesser w/b ratios the high volume fly ash concrete have better strength compared to ordinary concrete. Up to curing period of 14 days, compressive strength is seen to decrease with the increase in slag content when compared with no slag mortar[8]. Test results for 28 days compressive strength of the specimens up to 50% replacement level were very similar with OPC[14] mortar strength. Compressive strength are slightly higher by 1%,4%, 9% and 10% for slag mortar of cement slag ratio 80:20, 70:30,60:40 and 50:50 respectively. 28 days strength for the 60% and 70% slag replaced mortar was lower by 14% and 25% respectively when compared with no slag mortar.

90 days compressive strength data obtained for 10%, 20%, 30%, 40% and 50% slag replaced mortar were respectively 3%, 4%, 14%, 16% and 8% higher than no slag mortar and almost same for slag mortar of cement slag ratio of 90:10. 60% and 70% replacement level mortar strength were lower than no slag mortar by 7% and 15%. After 180 days, maximum compressive strengths were obtained for 30%, 40% and 50% slag replaced mortar specimens with an increase in strength of 17%, 19% and 12% respectively as compared to OPC mortar. Also 10% and 50% replacement level provided an increase in strength of 4% and 5% respectively when compared with no slag mortar. In the presence of slag, C3S hydration is slightly delayed, while hydration at later ages is accelerated (Ogawa, 1980). Slag also acts as a retarder to the hydration of C3A[9] (Uchikawa and Uchida, 1980).The setting time of slag-blended cement

is delayed as compared to ordinary Portland cement by 10 to 20 minutes per 10% addition of slag (Hogan and Meisel, 1981).

5.2 Tensile Strength

The tensile strength of the specimens is seen to increase with age. At early ages of curing (3 days and 7 days), the tensile strength decreases with increase in slag content in mortar. However, the rate of decrease diminished with the increasing age of curing. The slag mortar specimens shows that tensile strength results are almost identical with that of reference mortar up to cement replacement of 50% at 28 days. Tensile strength values are 101%, 102%, 107%, 109% and 106% for slag mortar [13] of replacement level of 10%, 20%, 30%, 40% and 50% for the curing age of 28 days. 60% and 70% replaced slag mortar achieved 85% and 70% strength of OPC mortar. After 90 days, a maximum tensile strength of 6.1 MPa was achieved for the slag mortar of 40% replacement level with an increase of 18% higher than the no slag mortar. Even 30% and 50% slag replaced mortar showed 19% and 18% higher strength. However, 60% and 70% slag mortar provides a decrease in strength of about 8% and 15% respectively. According to Mehta (1986), pozzolan cements are generally somewhat slower to develop strength than slag cements. Given long-term continuous curing, the ultimate strengths of slag cement mortar will be higher than that of Portland cement. According to Gee (1979), early strength development in slag cement is affected by the chemistry of the clinker, since the manner in which it releases calcium and alkali cations affects the rate of hydration of the slag.

5.3 Flexural strength

It can be seen that the strength varies from 3.80Mpa to 4.76Mpa, 4.12Mpa to 5.25Mpa, 4.22Mpa to 5.45Mpa and 4.32Mpa to 5.50Mpa for High Volumes of Slag Concrete, with water/binder ratios varying from 0.55 to 0.27 respectively. It is observed that an increment in Flexural strength [10] 5 to 10 percent for 90 days, 10 to 19 percent for 180 days and 14 to 20 percent for 360 days with respect to 28 days. Because of the phenomenon of pozzolanic activity, the strength of HVSC increases with increase in age.

6. HEAT OF HYDRATION

The hydration of cement is an exothermic reaction. High amount of heat is generally developed during this reaction. The generated heat causes the rise in temperature and accelerates the setting time and strength gain of mortar. In many structures, the rapid heat gain of cement increases the chances of thermal cracking leading to reduce concrete strength and durability. The applications of replacing cement by high percentage of slag can reduce the damaging effects of thermal cracking [11].

The hydration mechanism of slag is different from that of cement. When cement comes into contact with water, the dissolution of some phases takes place quite rapidly. But when slag is mixed with water, initial hydration is much slower than cement mixed with water. Hydration of slag in the presence of cement depends upon the breakdown and dissolution of the glassy slag structure by hydroxylions released during the hydration of cement and also the alkali content in cement. The hydration of slag consumes calcium hydroxide and uses it for additional CSH formation.

According to Regourd (1980), Vanden Bosch (1980) and Roy and Idorn (1982), hydration of slag, in combination with cement, at normal stage, in general, is a two stage reaction. Initially and during the early hydration, the predominant reaction is with alkali hydroxide [12], but subsequent reaction is predominantly with calcium hydroxide. As a result the rate of heat liberation is correspondingly slow.

7. CONCLUSION

Based on the results of the investigation conducted on different slag mortars made with various level of cement replacement and cured for various curing period up to 180 days. Slag mortar mix having various cement replacement level up to 50% exhibited satisfactory results for both compressive and tensile strength. The optimum use of slag in the mortar is observed to be 40% of cement. Slag mortars with 40% cement replacement shows 19% higher compressive strength than OPC mortar after 180 days curing. The corresponding increase in tensile strength is reported to be 25%. Use of high volume slag as a replacement of cement, in any construction work, provides lower impact on environment. Use of slag reduces the amount of cement content as well as heat of hydration in a mortar mix. Thus, the construction work with slag concrete becomes economical and also environmentally

safe. Slower Rate of hydration in case of slag cement concrete/mortar lower the risk of thermal cracking.

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