EFFECT OF GGBS AND FINE AGGREGATE AS SELF CEMENTINOUS MATERIAL ON FRACTURE PROPERTIES OF SELF COMPACTING CONCRETE

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Abstract - *In the last few decades there is rapid increase in the amount of concrete used in the construction industry and there is great demand for high strength concrete. The high strength concrete should meet the requirements of workability, strength and durability. The flowing properties of concrete are generally improved by using self Compacting concrete (SCC) as the SCC will eliminate the damage induced by vibration. Concrete of higher strength leads to higher shrinkage and heat of hydration. A partial replacement of cement with silica fume, slag, fly ash and other chemical admixtures will reduce the above problems. The effect of mineral admixtures as supplementary cementations material on mechanical properties of Self compacting concrete was studied and compared with conventional concrete. The study focuses on comparison of fresh /hardened properties of self compacting Concrete with varying amount of the fines using ground granulated blast furnace slag (GGBS) and fly ash (FA). This thesis reports the results of an investigation Carried out on 20 and 35 MPa concrete with partial replacement of cement by GGBS and FA. Conventional concrete and SCC mixes with varying percentages of fly ash (20% and 25%) and GGBS (40% and 50%) and combination of fly ash and slag as supplementary cementations materials were investigated.*

***Key Words*: Self Compacting concrete (SCC) , ground granulated blast furnace slag , silica fume, slag, fly ash**.

1. INTRODUCTION

Fracture mechanics is based on the implicit assumption that there exists a crack in the structural component. The crack may be manmade such as a hole, a notch, a slot, reentrant corner etc. The crack may appear due to manufacturing defects like slag inclusion, cracks in a well-meant or heat affected zones due to uneven cooling, presence of foreign particles. Fracture mechanics deals with the question whether a known crack is likely to grow under a certain given loading conditions or not? It is applied even to cracks grown under fatigue loading. Study of Fracture Mechanics enables a designer to use much lower factor of safety, thus reducing cost of structural components. Fracture Mechanics was not studied as a separate discipline for a long time. If we look back, we would find that many bridges, boilers, buildings, ships failed due to fracture in nineteenth century.

During World war II Liberty ships failed in cold temperature of North Atlantic Ocean. With the development of large welded ships and high capacity jet airplanes, new questions arose about their safety. Engineers were forced to find out the causes of failure. And then a new discipline of engineering, “Fracture Mechanics” was developed. In fact, Griffith developed the right ideas for growth of a crack in 1920s. Griffith was not able to invent a convenient parameter that could be used by a practicing Engineer or Designer in predicting the failure load of a component through the growth of a crack under a given Loading condition. For all practical purposes, the modern Fracture Mechanics was born in 1948, when George Irwin formulated the Fracture Mechanics and devised workableParameters like Stress Intensity Factor and Energy release rate. Irwin’s development was mainly for brittle or less ductile materials. The analysis was conservative for commonly used engineering materials such as steel, aluminum, which Are generally ductile. Other parameters like Crack Tip Opening Displacement by Wells and J-integral by Rice in 1968 were developed to account for large plastic zone at thecrack tip. Fracture mechanics is also applied in the fields like nuclear engineering, piping, spaceships, rockets, offshore structures etc.

2. BACKGROUND

A segment of the crack front can be divided into three basic modes as shown in fig.1.

Mode I is the opening mode and the dominant displacement is normal to the crack surface.

Mode II is a sliding mode and the displacement is in the plane of plate, the separation is antisymmetric through relative tangential displacement normal to the crack front.

Mode III also causes sliding motion but the displacement is parallel to the crack front, causing tearing.

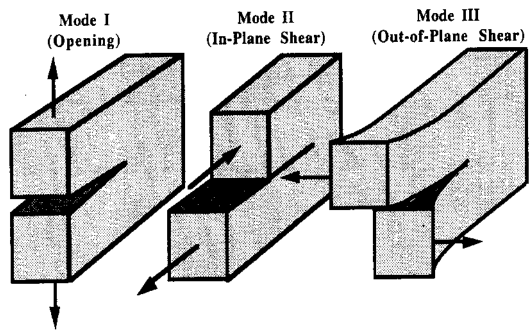


Fig 1. Modes of Fracture

Fracture Mode I can be studied adequately with well-developed experimental methods to find toughness. Codes of practice have been prepared for the experimental methods and they are internationally accepted. However, experimental methods to determine toughness of Mode II and Mode III are still under development and refinement stages.

Though only a single parameter is required to solve a fracture problem, researchers have proposed four parameters to measure the potency of a crack. They are energy release rate(G) which is energy based and is applied to brittle or less ductile materials. Stress Intensity Factor (K) is stress based also developed for brittle or less ductile materials. J integral(J) has been developed to deal with ductile material. Its formulation is quite general and can be applied to brittle materials also. Crack Tip Opening Displacement(CTOD) parameters were also developed for ductile materials and it is displacement based.

Fracture mechanics problems can be studied by two different approaches:

a) Material science.

b) Applied mechanics.

Problems of Fracture Mechanics are solved with two different approaches. In the first approach, a component geometry including the length, location and orientation of the crack is given along with boundary conditions. The objective is to find the upper limit of applied loads that would not cause catastrophic failure of the component. In the second approach, known as damage tolerance, the maximum loads on a component are known and the objective is to find the longest length of crack that remains dormant.

In current codes of practice, many provisions lack a sound physical basis. Hawkins (1985) identified twenty-nine provisions in the ACI code, alone which could be put on a firm physical footing using the theory of Fracture Mechanics. Various ductility limitations and limits on minimum flexural and shear reinforcement are some of the provisions. ACI committee report (ACI 446.1R-91) advanced five strong arguments in support for the inclusion of the theory of fracture mechanics into the codes of practice. They are as follows: -

Generally crack formation is observed when the stress exceeds the limiting stress. For crack propagation, certain amount of energy is required. The propagation of crack under load can only be explained through an energy based propagation criteria.

In the limit or plastic analysis of a structure, the failure of its various parts occurs simultaneously in proportion to a single load parameter; that is when sufficient plastic hinges have formed. Such failures are characterized by a plateau in the load response diagram. When the Yield plateau is absent the failure is not plastic. It usually implies that material is softening due to fracture or other damage. The failure process in the absence of Yield plateau does not result in the formation of plastic hinges at isolated locations, but it takes place due to the propagation of a fracture zone throughout the structure.

If we load a structure in tension or flexure and record its response right up to the failure, the area under the load-deflection diagram represent the energy absorbed by the structure during the loading up to failure. If we ignore the energy lost in the loading grips and the supports only the elastic part of the energy is recoverable. The bulk of the energy is absorbed by the post peak tension softening range and it determines the ductility of the structure, the greater the energy absorbed, the more ductile will be its response. Limit analysis does not take into account the phenomenon of tension softening. It cannot give us an indication of the energy absorbing capacity of a concrete structure.

The most compelling argument in favour of the theory of Fracture Mechanics is the Size effect. The strength of specimens or structures made of quasi-brittle material such as concrete depends upon their size. Many investigations have shown experimentally that the strength decreases with increase in specimen size and then remain constant. This Size effect is associated with energy being released into the front of any large crack resulting in the redistribution of stress in this frontal zone. It is prevalent in many design situations such as flexural capacity of beams, diagonal tensile failure of beams, punching shear failure of slabs, tension failure of beams and pull out failure of reinforcing bars among others. But it is generally, ignored by the current design practice.

3. NEEDS AND ADVANTAGES

The concept self compacting, "the most revolutionary development in concrete construction for several decades" was introduced to overcome the problem of durability of concrete structures. The major problem posed to engineers for several years to make durable concrete structures using sufficient compaction.

Compaction for conventional concrete is done by vibrating can easily cause segregation. In conventional concrete, it is difficult to ensure uniform quality and good density in heavily reinforced locations. If steel is not properly surrounded by concrete leads to durability problems. The answer to the problem may be type of concrete which can get compacted into every corner of form work and gap between steel, purely by means of its own weight and without the need for compaction.

Self compacting concrete is characterized by

Extreme fluidity as measured by flow, typically between 550-750mm on a flow table, rather than slump (height).

- No need for vibrators to compact the concrete.
- Placement being easier.
- No bleed water, or aggregate segregation.
- To be beneficial to safety and workmanship.
- Objective of the present study.

To develop mix designs for low fines, mid range self compacting concrete by adopting the smart dynamic concrete method of designing mixes.

The study focuses on comparison of fresh/hardened properties of SDC with varying amount of SCM trying out various options amongst the SCM available like slag and fly ash.

Rheological properties and workability of SDC

The Trial mixes for M20 and M35 grade will be carried out with various combinations of OPC+Fly ash and OPC + GGBFS using SDC Concept and the same will compared with TVC. (Traditional Vibrated Concrete)/Normal Concrete.

The slump flow will be measured at every 30 min Interval till 90 to 120 min.

Hardened/Grey properties of Concrete.

The compressive strength of the concrete will be studied at various age of concrete. (1, 3, 7, 14, 28, 56 and 90 days).

Fracture properties of concrete.

Split Tensile Strength of concrete.

Advantages of Smart Dynamic Concrete.

SDC is a system of low fines self consolidating concrete suitable for everyday use.

SDC matches the flowability of conventional self compacting concrete (slump flow of 550mm-650mm)

SDC is especially applicable for grades 20-40mpa. Since the ranging between 20-40mpa are more than 90% in regular application.

SDC is low cementitious based high flow concrete with a distinct cost advantage over self compacting concrete.

4. LITERATURE REVIEW:

Davis et.al. (1937) conducted an experimental work on FA concrete as early as in 1937 and concluded the following:

(i) The FA concrete mix sets more slowly than corresponding cement mix.

Experimental verification of Lane and Best with modern FA has confirmed this view.

Mehta and Dimond (1995), performed experiments on HPC and investigated that the effect of using FA (high calcium FA) containing soluble sulphates on high alkali Portland cement and they have pointed out that its soluble alkali plays an important role in increasing the alkali-silica reactivity and not the total alkali present in the FA.

Bharat Kumar et.al. (2000) presents the modified mix design procedure based on the experimental study, which utilizes optimum water content and the efficiency factor of mineral admixture. Investigation was carried out using 53 grade cement, crushed granite aggregate, river sand, sulphonated naphthalene formaldehyde type super plasticizer, type F, FA with 15% and 25% of cement replacement by mass of FA and GGBS with 15%, 30% and 50% of cement replacement by mass of slag. The ACI method was adopted for obtaining reference concrete mix. Mix proportions for two extreme Water – binder ratio (W/b) of 0.5 and 0.35 with and without FA or GGBS as cement replacement material were obtained and test specimens were cast. The highlights of their study were as follows:

(i) The early age strength of cement replacement material mixes show lower value for the same w/b because of slower pozzolanic reaction. However, the same early strength can be achieved by increasing the binder content.

(ii) The efficiency factor for cement replacement material, evaluated from the results of two extreme w/b shows increasing trend with the curing period. Therefore, it is essential that the concrete containing cement replacement material may require prolonged curing.

(iii) The efficiency factor for FA mixes showed decreasing trend as the replacement level is increased, whereas slag mixes showed increasing trend (except for high replacement level)

(iv) There is an increase in total binder content as the effective w/b decreases. However, as the cement replacement material content increases, the cement required per unit strength reduces.

(v) The limited durability properties investigated (after 28 days curing) are found to improve by reduction of w/b and further improved by addition of cement replacement material.

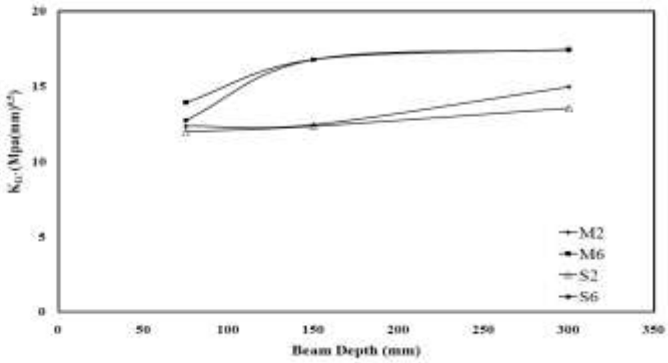
(vi) GGBS mixes up to 50% replacement level showed better performance in terms of mechanical properties and durability characteristics when compared with FA mixes.

Jianxin Ma and Jorg Dietz, (2002) have reported the development of ultra high performance concrete and have found good flowability in concrete with low water powder ratio. Because of the high viscosity of the cement paste, compaction was necessary. To improve the compaction characteristics of the concrete the idea of adding coarse aggregate was developed. The first tests showed a good workability of the fresh concrete and a good self compacting ability. They have attempted to reduce costs while improving workability, shrinkage tendency and the modulus of elasticity.Al-Tammi and M.Sonebi. (2003) Etringite and thaumasite can be found among the deterioration products of cementecious materials exposed to sulfate and hydrochloric acid attack. The results of a test program to investigate the acid resistance of self-compacting concrete(SCC) and conventional concrete(CC),immersed up to 18 weeks at 20^{o}C in sulfuric and hydrochloric acid solutions, are described.

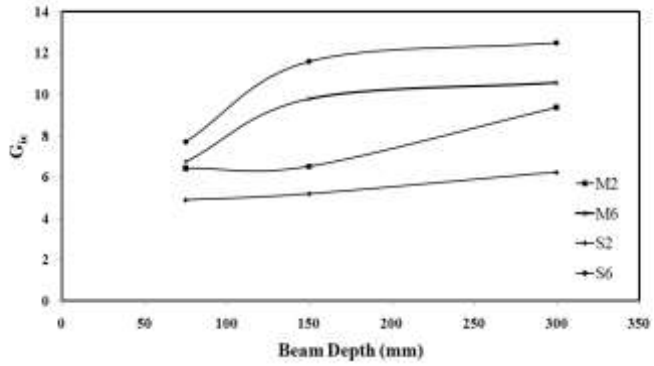
Janie Peter et. al,(2004) have reported self compacting concrete(SCC) made from almost the same ingredients as that of conventionally vibrated concrete(CVC) expect that relative proportions of these ingredients are to be carefully selected to impart self leveling and self compacting property to fresh concrete without a need for any external compacting and vibrating equipment. SCC have generally higher content of fines (cement and fine aggregate) and chemical admixtures so that enhanced cohesiveness with no tendency for segregation is achieved. Thus, CVCs and SCCs are designed to have different characteristics when the concrete is fresh. In order to understand the structural behavior of these two concretes in hardened stage, reinforced concrete(RC) beams of size 150mm*400mm*3000mm with similar concrete strength and identical reinforcement were cast and tested in flexure. The paper compares the structural behavior such as number of cracks, crack pattern, ultimate load carrying capacity, moment curvature relationship, longitudinal strain in both concrete and steel for SCC and CVC.

Praveen Kumar et. al. (2004) has shown that self-compacting concrete generally possesses a high powder content which keeps the concrete cohesive with high flowability. For achieving economy, a substantial part of this powder could contain fly ash. In such cases, early age strength development may prove to be a decisive factor, particularly when the formwork has to be reused. Test results of an experimental study are presented in this paper, which involved fly ash contents of more than 50 percent of the total powdered material. Compressive strength and split tensile strength test results are reported at the ages of 3, 7,28 and 56 days. Compressive strength of the order of 20 and 30 Mpa are obtained with SCC at the ages of 3 and 7 days, respectively.

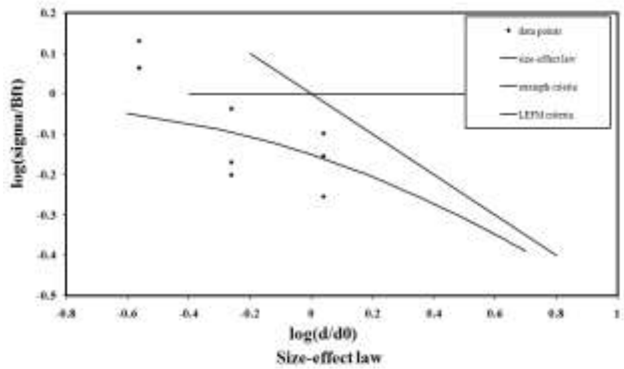
5. RESULTS & DISCUSSIONS:



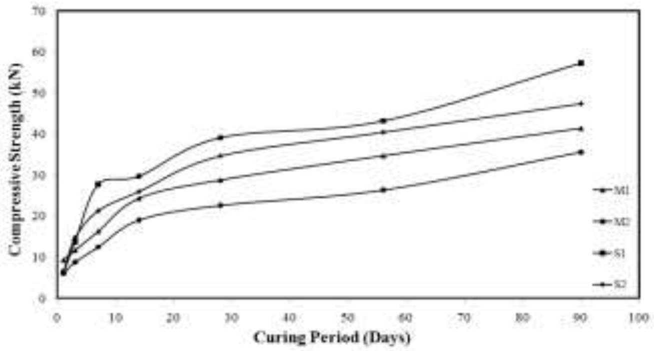
Variation of critical stress intensity factor with beam depth for $a_0/d=0.5$.



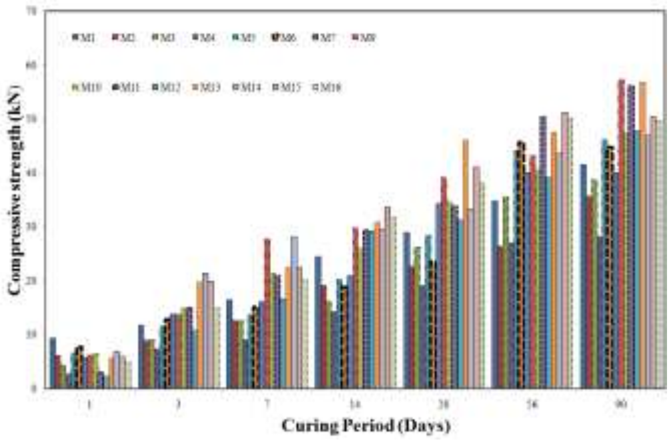
Variation of energy release rate Vs beam depth for $a_0/d=0.5$ at 28 days



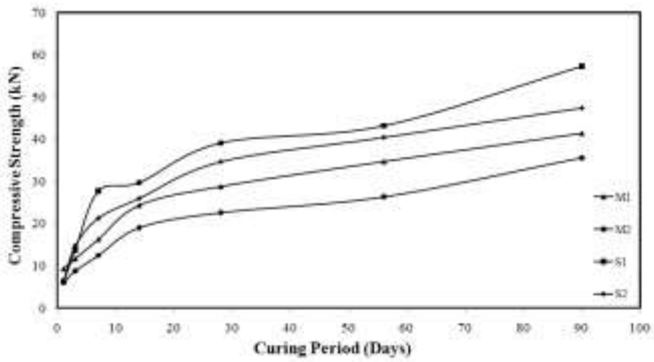
Size effect plot for TVC ($a_0/d=0.5$, Mix M2, 28 days)



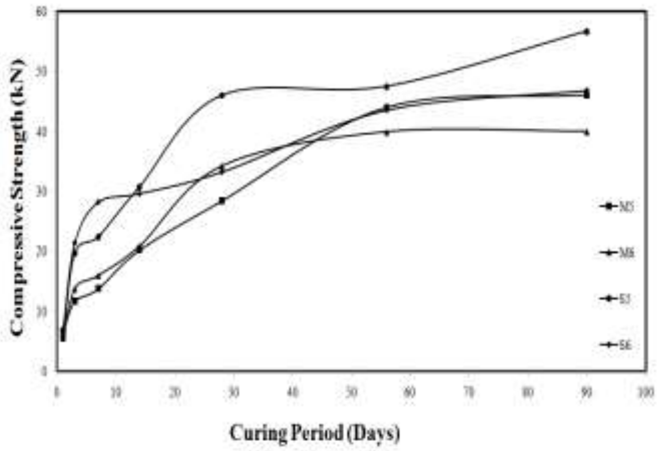
Plot of compressive strength v/s different percentage of fly ash replacement at different ages for M20



Plot of compressive strength at different ages for the different concrete mixtures.



Plot of compressive strength v/s different percentage of GGBS replacement at different ages for M20



Plot of compressive strength at different ages for different percentage of GGBS replacement for M35

6. CONCLUSIONS:

This experimental study fly ash and ground granulated slag furnace has been used as a replacement material in varying percentages from 20 to 50% (20%, 25%, 40% and 50%) for water cement ratio 0.48 and 0.52. In each of these grades, compressive strength and split tensile strength tests have been carried out as per IS standards. Two series of fracture tests have been carried out as per RILEM recommendations. The experimental results have captured all the features of the fracture behavior of concrete beam specimens. From the present study, following concluding remarks have been drawn:

1) Fly ash and Ground granulated blast furnace slag can be made use in the concrete as cement replacement material, which in turn helps in the reduction of environmental hazards.

2) Experimental results show that as the there is an increase in compressive strength of smart dynamic concrete compare to traditional vibrating concrete.

3) The relation between compressive strength and split tensile strength for GGBS and Fly ash replaced concrete is given by $f_t = 0.45\sqrt{f_{ck}}$

4) The results have shown that by measuring the peak loads it is possible to obtain the fracture parameters without resorting to sophisticated measurements.

5) Both TVC and SDC mixes show a strong size effect law. The experimental data is close to Bezant's size effect law.

6) The results show that as the beam depth increases critical stress intensity factor and energy release rate also increases.

Relation between Tensile & Compressive strengths

ACKNOWLEDGEMENT

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