Transforming Construction: The Role Of Environment-Friendly Materials Like Steel Slag Hydrated Matrix

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Abstract- *Use of more and more environment-friendly materials in any industry in general and construction industry in particular, is of paramount importance. Environment of this 'only living' planet is wary of pollution due to emissions of a host of green house gases from industrial processes. Present day construction industry consumes huge amount of concrete and cement is the binding material used for making concrete. During production of cement huge amount of energy is needed and about 8 % of CO2 is released to atmosphere during cement production. This makes concrete a non eco-friendly material. In consideration of these points, construction industry has devised a substitute for concrete, popularly known as 'Steel Slag Hydrated Matrix'. It consist of steel making slag, ground granulated blast furnace slag, 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.*

In the present study 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 conventional procedure followed to characterize the quality cement is adopted in this phase of tests and best raw material composition was arrived at. The lime content in the lime-fly ash mix was varied as 20, 35, 50, 65, 80 and 100%. Mortar cubes were made with lime- fly ash mix (as mentioned above) and Ground granulated blast furnace slag as fine aggregate in the proportions of 1:2 and 1:3. The compressive strengths of these cubes were determined after 3days, 7days 28 days and 60days of curing period. From the above series of tests the optimum mix was found out. In the second phase of tests, concrete specimens were prepared with taking steel slag as coarse aggregate, ground granulated blast furnace slag as fine aggregate and binder that is found to best performance from the test of phase one. Two compositions of above raw materials were taken that is 1:1.5:3 and 1:2:4 and the compressive strength, flexural strength and tensile strength were determined adopting conventional testing procedure. To find out the effect of curing period on the compressive strength, flexural tensile strength and split tensile strength the samples were cured for 7 days and 28 days and tested.

From the present study following conclusion were drawn: Initial setting time, final setting time and consistency of fly ash and lime powder (binder) are found to be higher than the ordinary Portland cement. 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 15.6 N/mm2 at 28 days and 38.8N/mm2 at 60 days. Whereas, the mortar with proportion (35:65:200) it was 13.53 N/mm2 at 28 days and 35.4 N/mm2 at 60 days of curing. The 28 days compressive strength of concrete of steel slag hydrated matrix is found to be less than the normal cement concrete. The compressive strength of SSHM after 28 days of curing was found to vary from 9N/mm2 to 13N/mm2. However, other researchers have found the compressive strength of SSHM in the range of 20 N/mm2 to 30 N/mm2 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. Steel slag hydrated matrix has the features like made from 100% recycled resources, same strength performance as ordinary concrete. It involves no burning of fossil fuels, which is otherwise used for manufacturing of cement, helps in checking emission of CO2 and protects environmental pollution.

I. 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, utilization of industrial wastes and conservation of natural resources. Preventing the depletion of natural resources and enhancing the usage of waste materials has become a challenge to the scientist and engineers. A number of studies have been conducted concerning the protection of natural resources, prevention of environmental pollution and contribution to the economy by using this waste material. The two major by-products of 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 being 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.

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 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 CO2 is released to atmosphere 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. The steel industry slag having desirable qualities and can be used as coarse aggregates in concrete construction. Graf and Grube have reported that the Ground granulated blast furnace slag cured properly has lower permeability .The incorporation of fly ash and blast furnace slag in concrete leads to many technical advantages. When two mineral admixtures are used together, better results can always achieve. The use of such industrial by-product or waste material having desirable qualities can result in saving of energy and conventional materials. With increase in population, the demand for construction of residential and public buildings is also increasing.

The iron and steel industry produces extremely large amounts of slag as by-product of the iron making and steelmaking processes. As useful recycled materials, iron and steel making slag are mainly used in fields related to civil engineering, for example, in cement, roadbed material, and concrete aggregate. Their recycling ratio is close to 100%, making an important contribution to the creation of a recycling-oriented society. However, public works projects, that is strongly related to recycled fields, tend to be reduced recently and, moreover, other recycled materials, such as reused roadbed materials and fly ash, become competitor of slag in the fields. Thus, the development of new application technologies has become an urgent matter.

The JFE Steel Group has developed and sells the following as new use technologies for iron and steel making slag: (1) an environment-friendly block, “Ferroform,” which can be used as a substitute for concrete, (2) materials for restoration of coastal and marine environments, “Marine Block” and “Marine Base,” and (3) a water retaining pavement material which reduces the urban heat island phenomenon. This report introduces these new application technologies of iron and steel making slag which are contributing to a recycling-oriented soci- steel slag was considered a waste material having no economic asset, but nowadays it is known that 100 percent of blast furnace slag and 75-80 percent of steel slag can be reused. A large amount of steel slag was deposited in slag storing yards which occupied farmland, silted rivers and polluted the environment for many years. Steel slag is produced as a by-product during the oxidation of steel pellets in an electric arc furnace. This by-product that mainly consists of calcium carbonate is broken down into smaller sizes. One way to utilize the steel slag is to incorporate it into hot mix asphalt (HMA). Steel slag aggregate has been used in asphaltic mixtures since the early 1970's in Canada. This process has been used successfully in the Midwestern and eastern United States with reported improvement in pavement performance. Their experiences indicate that the addition of steel slag may enhance the performance characteristics of the pavement. Since the slag is rough, the material improves the skid resistance of the pavement. Also, because of the high specific gravity and angular, interlocking features of the crushed steel slag, the resulting HMA is more stable and resistant to rutting. Steel slag has been used to construct pavements for nearly one hundred years. Since it was discovered that the residue from the manufacture of steel could be crushed and processed into a product that looked like crushed rock, other testing was performed to determine the usefulness of this “waste” product. It was discovered that the highly angular, rough textured, vesicular, pitted surfaces provide the particle interlock. Now days it is used as coarse aggregate in concrete. The present work aims at developing a cementation material that can replace the conventional cement in concrete work using the waste product like fly ash, granulated blast furnace slag with hydrated lime without involving the burning process and manufacture, quality assessment of eco-friendly concrete that is made out of the above material and steel slag as coarse aggregate. This will solve the problem of waste disposal side by side preserving our natural resources.

STEEL SLAG

Extraction of 'iron' from ores is a complex process requiring a number of other materials which are added as flux or catalysts. After making steel these ingredients forming a matrix are to be periodically cleaned up. Removed in bulk, it is known as steel –slag. It consists of silicates and oxides. Modern integrated steel plants produce steel through basic oxygen process. Some steel plants use electric arc furnace smelting to their size. In the case of former using oxygen process, lime (CaO) and dolomite (CaO.Mgo) are charged into the converter or furnace as flux. Lowering the launce, injection of higher pressurized oxygen is accomplished. This oxygen combines with the impurities of the charge which are finally separated. The impurities are silicon, manganese, phosphorous, some liquid iron oxides and gases like CO2 and CO. Combined with lime and dolomite, they form steel slag. At the end of the operation liquid steel is poured into a ladle. The remaining slag in the vessel is transferred to a separate slag pot. For industrial use, different grades of steel are required. With varying grades of steel produced, the resulting slags also assume various characteristics and hence strength properties. Grades of steel are classified from high to medium and low depending on their carbon content. Higher grades of steel have higher carbon contents. Low carbon steel is made by use of greater volume of oxygen so that good amount carbon goes into combination with oxygen in producing CO2 which escapes into atmosphere. This also necessitates use of higher amount of lime and dolomite as flux. These varying quantities of slag known as furnace slag or tap slag, raker slag, synthetic or ladle slag and pit or clean out slag. Fig-2.1 presents a flow chart for the operations required in steel and slag making.

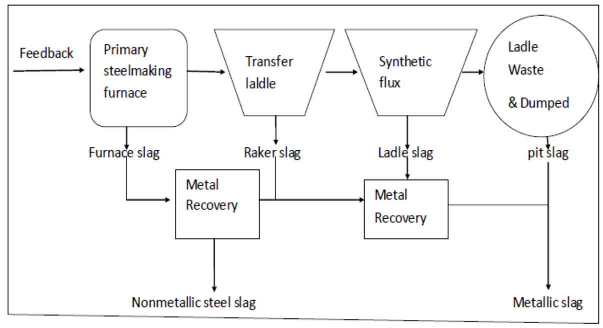

Fig-Flow chart of steel slag production

The steel slag produced during the primary stage of steel making is known as furnace slag or tap slag which is the major share of the total slag produced in the operation. After the first operation, when molten steel is poured into ladle, additional; flux is charged for further refining. This produces some more slag which is combined with any carryover slag from first operation. It helps the in absorbing of deoxidation products, simultaneously providing heat insulation and protection of ladle refractories. Slag produced on this operation is known as raker and ladle slag.

Utilization of slag:

The steel slag is used as aggregates. Natural aggregate resources are becoming more difficult to develop or remove aggregate from the ground when slag can be used as a substitute which reduce waste and conserve resources. It protects and preserves our environment. Benefit from technical advantages offered by many of the steel making slags. High performance products not necessarily low grade applications

GGBS

Blast furnace slag is a by-product from the manufacture of iron in a blast furnace. The liquid iron blast furnace is lighter in weight than the main product which is iron in a molten state. The blast furnace will naturally separate from the iron where it is collected and cooled with large amount of cold water. This quenching process results in the transformation of liquid into small sized particles having amorphous particles' structure. Following an efficient drying process, the particles are ground to the desired fineness and the material gain a cementitious property. The main chemical composition of GGBFS is SiO2 Al2O3 and CaO. When GGBFS is added to concrete in powered form it accelerates the pozzolanic reaction. The benefits of adding powered GGBFS in concrete can be grouped as follows:

Improvement of fresh concrete properties

The impacts of GGBS addition on the behavior of fresh concrete are as follows:

- Increased cohesion
- Reduced internal and external bleeding
- Reduced risk of segregation
- Reduced washout for under water concrete
- Enables the production of self compacting concrete.

Improvement of hardened concrete properties:

The impacts GGBS addition on hardened concrete performance is as follows:

- Increased tensile and flexure strength
- Enables production of high performance concrete
- Enhanced resistance to chloride attack, sulphate attack,
- Acid attack and various other external chemical attacks
- Enhanced resistance to internal chemical attacks such as
- Alkali silica reaction and alkali carbonate reaction
- Improved impermeability to liquids, gases and ions
- Improved bonding between concrete and steel reinforcement
- Reduced risk of cracking due to thermal stresses.

FLY ASH

In many disposal areas, fly ash is hauled from the plant and disposed loose by tailgating over the edge of fly ash slope. The resulting embankment is often unsightly and costly to remain steep fly ash slopes and lack of adequate drainage often result in slides, which encroach upon resulting properties, cause erosions and silts up nearby streams. In wet disposal system, ten fly ash and bottom ash are mixed with sufficientter and the ash slurry is sluiced into large sized ponds called ash ponds. This ash is called pond ash or Fly ash.

USE OF FLY ASH

- Fly ash can be used for multifarious applications Some of the application areas are the following Brick manufacturing
- Cement manufacturing Part replacement in mortar and concrete.
- Road and embankment construction
- Dyke rising.
- Structural fill for reclaiming low areas.
- Stowing material for mines.
- Agriculture and Forestry.

LIME

The most common form of commercial lime used in concrete is slaked lime and unsliced lime also used. Quick lime is higher lime (CaO or CaO.MgO) content than hydrated lime but it is much more dangerous than hydrated lime and strict safety precautions are necessary when it is used.

Classification of Lime by I.S.I

Indian Standards institute has classified the lime into 3 parts i.e., Class A, B & C. Class A is used for masonry work and can be obtained only in the form of slaked lime. Slaked lime must be the form of powder. Class B is used for mortar where as class C is used for plaster & white washing. Class C is infecting pure lime. Class B & C can be obtained in the form of slaked or unsliced lime Unsliced lime may contain calcium oxide and little amount of magnesium oxide.

BRIEF REVIEW OF VARIOUS STEL SLAG HYDRATED MATRIX

In this section a brief review of the available literature regarding steel slag hydrated matrix are presented.

In Dec. 1999, JEF Steel's developed the concrete using waste material such as steel making slag, ground granulated blast furnace slag, fly ash &lime dust and 5 t type breakwater blocks approximately 2.0 m in height were manufactured from steel slag hydrated matrix and concrete. These blocks were exposed in the tidal at Mizushima Port, Okayama Pref. in Seto - Inland Sea in Feb. 2000. Square sections of biofouling organisms with an area of 20 cm x 20 cm were cut respectively from four locations on the wave-dissipating blocks and dried at 60°C for 24 h. The biomass of the specimens was then measured.

Mathur et al. (1999) looked at the physical properties of blastfurnace slag and steel slag and concluded that both materials were suitable to replace natural stone aggregates in base and sub base road layers, as long as the steel slag was adequately weathered. The study also mixed various slogs together and determined that a mixture of ACBF slag (50%), steel slag (20%), granulate blast furnace slag (20%), fly ash (6%), and lime (4%) would self-stabilize over time and form an adequate bound base or sub base road layer. They have got that the concrete containing above these material better corrosion resistances.

Artificial stones and cover blocks using steel slag hydrated matrix were manufactured and placed in a shore protection repair project at JFE Steel's West Japan Works

(Kurashiki) between Sept. 2000 and Sept. 2002. H. MOOSBERG-BUSTNES (2004) has studied on properties of steel slag and investigate if it is possible to improve the steel-slags properties, by selective screening, fine wet grinding or remelting, so that the steel-slags can be used as mineral-addition/filler material in concrete.

Three different studies were conducted:

1 .The effect of the fines of disintegrating AOD-slag on concrete strength was examined.
2. The effect of wet ground EAF- and AOD-slogs on cement pastes' heat development, concrete strength and shrinkage/expansion were examined.
3. Re melting and granulation of AOD-, EAF- and ladles lags and their effects on cement hydration were examined (part of a joint MiMeR-project).

They found the result; the compressive strength for mortar containing fines of disintegrating AOD-slag obtains a slightly increased strength compared with the reference samples containing quartz. This effect may be due to the filler effect or because a positive chemical effect takes place.

Kyong Yun Yeaua, Eun Kyum Kimb(2005) have presented the experimental test results on corrosion resistance of concrete containing ground granulate blast-furnace slag (GGBS) and ASTM Type I or ASTM Type V cement. To investigate the problem, a series of tests were performed. They First, rapid chloride permeability tests were carried out in accordance with ASTM C 1202 to determine the qualitative terms of chloride-ion penetrability, accelerated chloride-ion diffusion tests were done to calculate diffusion coefficients of chloride-ions permeated through concrete specimens. Steel corrosion tests were carried out by using the repeated wetting and drying technique, half-cell potential tests were implemented in accordance with ASTM C 876 to evaluate the probability of steel corrosion. Finally, the surface area of corrosion on embedded steel in concrete specimens was measured to confirm half-cell test results. Test results shown that the coefficient of permeability of Type I cement concrete was lower than that of Type V cement concrete. All the concrete mixed with GGBS exhibited lower diffusion coefficient, compared to GGBS-free concrete. Moreover, the corrosion probability of steel bar in Type V cement concrete was higher than that of steel bar in Type I cement concrete. Based on the test results, it is suggested the compressive strength of all compressive specimens exceeded design strength of 35 MPa before 28 days. Their results indicated that GGBS mixture specimens showed lower compressive strength than B1 mixture ones at the early age, the compressive strengths of GGBS mixtures were stronger than that of B1 mixture after 28 days. The permeability of Type I cement blended with GGBS was lower than that of Type V cement. The chloride-ion concentrations of Type I cement are lower than that of Type V cement, compared for the same amount of GGBS.

Tomonari Kimura and Nobuaki Otskui (2006) have developed, Steel Slag Hydrated Matrix (SSHM) as a construction material for reducing environmental problems. They have investigated on pre-treatment slag and blast-furnace slag powder which are by-products of steel making process. In SSHM, the corresponding substitute material for cement is the mix of blastfurnace slag powder, fly ash and slaked lime whiles the corresponding substitute material for the fine and coarse aggregate is pre treatment slag. They discussed the prediction of deterioration due to chloride attack when SSHM is used as material with reinforcing steel under marine environment. In order to predict the deterioration of steel reinforced members due to chloride attack, it is basic to determine the length of time for each deterioration stage: the incubation period, the propagation period, the acceleration period, and the deterioration period. Their results indicated that ,the incubation period was calculated using the chloride ion diffusion coefficient of the specimens cured for four weeks , the generalized equation of the Flick's second law and the chloride concentration limit of 1.2kg/m3 around the steel bar (JSCE) While the propagation period was calculated by using results of mass reduction due to corrosion, the equation from JCI-SC1 for mass loss in mg/m2/day and the corrosion mass limit of 10mg/cm2 which is generally used as the quantity of corroded mass of steel at the occurrence of crack (JSCE), shows the calculation result of the average ratio of deterioration periods between SSHM and normal concrete. The results show that SSHM had longer periods of incubation and propagation compared with concrete. This shows that the use of SSHM as substitute to concrete in steel-reinforced structures under chloride attack is quite feasible and also the service life of the structure possibly becomes longer.

Takshi Fujii ,Toshiki Ayanond and Kenji Sakta (2007) have developed the concrete using steel making slag which is reducing environmental load. They have made the concrete using Ground granulated blast furnace slag (GGBS),lime dust(LD),steel making slag(SS),high range water reducing admixture (HRWRA) and Air entraining agent (AE).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.

Hanifi Binice et al. (2007) The aim of this research work is to investigate the seawater resistance of the concrete incorporating ground blast furnace slag (GBS) and ground basaltic pumice (GBP) each separately or both together. The variable investigated in this study is the level of fine aggregate replacement by GBS and GBP and normal concrete Compressive strength measured on 150 mm cubes was used to assess the changes in the mechanical properties of concrete specimens exposed to seawater attack for 3 years. From this study, they observations were found , GBP concrete presented an excellent behavior in both short and long-term compressive strength in seawater, higher compressive strengths and lower permeabilities. Abrasion resistance of concrete was strongly influenced by its compressive strength and GBS and GBP content then the normal concrete

Nobuaki et.al (2006), have developed a new construction material called “steel slag hydrated matrix”, hereafter this term will be abbreviated as SSHM, produced from steel making slag, ground blast furnace slag powder without using portland cement and natural gravel. However, its application has been limited to non-steel reinforcement material when used in structures under marine environment. They applied SSHM for steel reinforced structures and their results showed that the resistance to chloride ion penetration, oxygen permeability, resistance of steel bar to corrosion in SSHM were equal to or even better than that of steel reinforced concrete material under marine environment.

II. SCOPE OF THE PRESENT STUDY

Thus, through the appraisal of the literature review it is observed that several attempts have already been made by researchers to understand the mechanism of Steel slag hydrated matrix or steel making slag concrete. However, in the present study an attempt has been made to concrete which is containing full of waste material.

Hence, the experimental programme undertaken investigates:

1. To determine the mix proportion of fly ash, lime, ground granulated blast furnace slag and water to achieve the aim study
2. To determine the water/ (lime fly ash) ratio so that design mix adequate proper workability.
3. To determine the mix proportion of fly ash, lime, ground granulated blast furnace slag, steel slag and water to achieve the required strength.
4. To investigate different basic properties such as compressive strength, flexural strength etc. of Steel Slag Hydrated Matrix in comparison with ordinary concrete.
5. To study the effect of curing period of the strength characteristics of SSHM.

From the present studies following conclusions were drawn-

- The compressive strength of mortar that is lime: fly ash: GGBFS in the proportion of (35:65:300) was found to be 15.6 N/mm^2 at 28 days, 38.8N/mm^2 at 56 days.
- The mortar proportion (35:65:200) it was found to be 13.53 N/mm^2 at 28 days, 35.4 N/mm^2 at 56 days.
- Initial setting time, final setting time and consistency of fly ash and lime powder (binder) is approximately 30% , 25% and 46% more than the cement.
- The compressive strength of mortar Steel slag hydrated matrix was less during earlier stages of curing, but it has achieved almost same strength as normal cement mortar after 56 days.
- The 28 days compressive strength of concrete of Steel slag hydrated matrix is found to be less than the normal cement concrete.
- The compressive strength of SSHM after 28 days of curing was found to vary from 9N/mm^2 to 13N/mm^2. However, other researchers have found the compressive strength of SSHM in the range of 20 N/mm^2 to 30 N/mm^2 after 28 days of curing.
- Flexural strength after 28days of Steel slag hydrated matrix is lower than normal concrete.
- Split Tensile strength after 28 days of Steel Slag hydrated Matrix is approximately same as the normal concrete.
- The material which is used as coarse aggregate, steel slag procured from RSP contains lot of unborn carbon particle in addition to that over burnt lay lumps which could not be separated during sample preparation .During curing of specimen is found that hair cracks starts from the burnt at that clay lumps. This might have reduce the compressive strength, flexural strength of steel slag hydrated matrix.
- Steel slag hydrated matrix has the features like made from 100% recycled resources, same strength performance as ordinary concrete, excellent wear resistance, low alkaline dissolution, and excellent growth habitat for befouling organisms in marine environments. In this project work, all attempts have been made to get an alternative material to concrete using mostly waste products of steel industry. It involves no burning of fossil fuels, which is

otherwise used for manufacturing of cement, helps in emission of CO_2 and protects environmental pollution

III. SETTING TIME OF LIME+FLY ASH

The initial setting and final setting times of various mixes of lime-fly ash is given in Table 4.1.In general it is observed that both the initial and final setting times of fly ash lime mixes are comparably higher than the conventional cement.

IV. COMPRESSIVE STRENGTH OF CONCRETE

The compressive strength of steel slag aggregate concrete decreased with the proportion of lime content. The compressive strength varied from 12.5MPa, for concrete with 20% lime content10MPa, to 12.5MPa for concrete with 35% lime content. The Steel slag Hydrated Matrix Concrete was compared with Normal concrete and the compressive strength of Normal concrete was 24.2MPa. The compressive strength of steel slag aggregate concrete is less than the normal concrete. The steel slag was full of impurities particles like coal, burnt soil lumps and some other materials and also presences of excess lime .These have swelled after coming in contact with water and consequently creating cracks in the Steel slag hydrated matrix. The crack pattern in the cube was shown below the Figure-4.6. Therefore, the compressive strength of concrete was less than the normal concrete.

Figure crack pattern in Cube

Further for steel slag hydrated matrix and normal concrete compressive strength at 7 days and 28 days were calculated given in table4.6 and 4.7 respectively. The comparison between compressive strength of steel slag hydrated matrix and normal concrete is in Fig (4.8).

Figure: loading arrangement for determination of the compressive strength.

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