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A study on assessment of impact resistance characteristics of modified ultra high strength concrete

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Abstract **- Concrete is a homogenous mixture of cement, fine aggregate, coarse aggregate and water. Whereas, in past decades several developments are made in concrete depend upon their applications. Using Ultra High Strength Concrete (UHSC), the durability and resistance capability were achieved in several areas. The impact resistance is essential for concrete where used in bridge, high rise building, marine structures, road sidewalls, etc. In the present study, a detailed review of literature was carried out to study the production of UHSC and properties of Ultra High Strength Concrete (UHSC). Also, basic material properties were evaluated to arrive the mix proportion based on packing density method. Suitable testing methods were identified from literature to assess the impact resistance of Ultra High Strength Concrete (UHSC).**

Key Words: UHSC, Strength Properties, Silica fume, Quartz sand, packing density

I. INTRODUCTION

CONCRETE is a composite material composed of gravels or crushed stones (coarse aggregate), sand (fine aggregate), hydrated cement (binder), water and air. Portland cement has got its name when it was first used in the early 19th century in England, because its product resembled building stone from the isle of Portland off the British coast.

Portland cement is made by grinding calcareous materials such as lime stone or shell, with an argillaceous (clayish) material such as clay, shale or blast furnace slag. These two finely ground materials are heated in giant rotary furnace to the point where they begin to fuse. The resulting product is called a clinker. The clinker is cooled and reground to a fine powder to form Portland cement. While the clinker is being ground, small amounts of additional ingredients are added to produce the various types of cement. When cement is mixed with water the resultant product is referred to as paste. This is if substance that binds all other ingredients together. Aggregate are divided into two categories and comprised of many naturally occurring and manufactured products. The basic distinction is fine aggregate and coarse aggregate.

The addition of fine aggregate to the paste transforms the product to a mortar. The subsequent addition of coarse aggregate results in concrete. Concrete, in the broadest sense, is any product or mass made using a cementing medium. Generally, this medium is the product of reaction between hydraulic cement and water. But, these days, even such a definition would cover a wide range of products, concrete is made with several types of cement and containing pozzolan, fly ash, blast-furnace slag, a 'regulated set' additive, sulphur, admixtures, polymers, fibres, and so on; and these concretes can be heated, steam-cured, autoclaved, vacuum treated, hydraulically pressured, shock-vibrated, extruded, and sprayed.

II. ULTRA HIGH STRENGTH CONCRETE

Concrete having compressive strength more than 150 MPa is known is Ultra-high strength concrete (UHSC). it is one of the most spectacular developments of recent years in Portland cement-based materials. It is a high strength, ductile material formulated by combining portland cement, silica fume, quartz flour, fine silica sand, high-range water reducing admixture, steel or organic fibres and very low water-to-cementitious materials ratios. The trademark of UHSC is known as Ductal concrete.

Increasing the packing density of the cementitious matrix minimizes the interparticle voids and the amount of mixing water. In a more accurate sense, UHSC is not concrete because it is containing no coarse aggregate. The steel fibres provide ductility to UHSC. This material differs from conventional concrete not only in terms of strength, but also in terms of durability. UHSC is more durable because the low water-to-cementitious materials ratio results in very low porosity.

Due to the use of powder-like components and the fluidity, the material has the ability to replicate the macro and micro texture of the formwork. The result is a final product that can have a full range of colours and textures with a high-quality surface. The possibility of achieving high strength, durability and improved ductility with the use of ultra-high strength concrete encourages researchers and engineers to use this modern material in many practical applications like nuclear waste containment structures, high rise structures, long span bridges, and walkways.

The origin of UHSC was first developed by Lafarges and Bouygues in France in 1990s. It is a high strength ductile material formulated from a special combination of constituent materials. The compositions of Ultra High Strength Concrete were first developed by Richard and Cheyrezy in 1994. they developed RPC to overcome the inherent weakness of most high-performance concretes when they reach a compressive strength of about 150-800 MPa.

III. PROPERTIES OF ULTRA HIGH STRENGTH CONCRETE

1. The compressive strength ranges from 200 to 800 MPa, flexural strength 30 to 50 MPa and young's modulus 50 to 60 GPa.
2. Resistance to abrasion is similar to that of rock.
3. It has very high strength and very low porosity which is obtained by optimized particle packing and low water content.
4. The durability properties are those of an impermeable material; there is almost no penetration of chlorides and sulphates and offers high resistance to sulphate attack.
5. It has the capacity to deform and support flexural and tensile loads, even after initial cracking.
6. There is almost no shrinkage or creep, so it makes the material suitable for the applications in prestressed concrete.
7. It also has excellent impact and blast resistance together with high fatigue performance.

III. IMPACT RESISTANCE

Today, the structural Engineers are facing the problem of ensuring the safe structures which will withstand for the impact loads in addition to static loads. Many concrete structures are often subjected to short duration dynamic loads. These loads originate from sources such as impact from missiles and projectiles, wind gusts, earthquakes and machine vibrations. The need to accurately predict the structural response and reserve capacity under such loading had led researches to investigate the mechanical properties of the component materials at such high rates of strain. Impact is a complex dynamic phenomenon involving crushing shear failure and tensile fracturing. It is also associated with penetration, Perforation, Fragmentation and scaling of the target being hit. The use of fibers was found to be advantageous in both static and impact conditions. One method to improve the resistance of concrete when subjected to impact or impulsive loading is by the incorporation of randomly distributed short fibers. Concrete so reinforced is called Fibre Reinforced Concrete (FRC). Many investigators have shown that addition of fibers greatly increase the energy absorption and cracking resistance characteristics of concrete. The greatest advantage of using fibre reinforced concrete is that fibre additions improve the toughness, so that the fibre addition gives the concrete a considerable amount of apparent ductility. Studies have shown that the shape, volume percentage, aspect ratio, nature of deformation and orientation of fibers are influencing the toughness of FRC. The same parameters that influence the maximum load related to the concept of toughness are the impact resistance of FRC. Many studies have shown that the impact resistance of concrete can increase dramatically with the addition of steel fibers. The American Concrete Institute (ACI Committee 544 on fibre reinforced concrete) recommends a drop weight type test for Impact resistance of Concrete.

In highway bridges, Marine and high rise structures, the concrete faced lots of impact through several factors like sea waves, air flow, etc., So the high impact resistance of the concrete is important in those applications. Several types of impact tests have been used to measure the impact resistance of concrete and similar construction materials. These can be classified broadly, depending upon the impact load application mechanism and parameters monitored during impact, as below.

- Weighted pendulum Charpy -type impact test
- Drop-weight test (single or repeated impact)
- Constant strain-rate test
- Projectile impact test
- Split-Hopkinson pressure bar (SHPB) test
- Explosive test
- Instrumented pendulum impact test

However, none of these tests has been declared to be a standard test, at least in part due to the lack of statistical data on the variation of the results, and comparisons between any of the above tests are very difficult. In addition, some of these tests are relatively difficult to perform and require sophisticated equipment. In this regard, ACI Committee 544 has proposed a drop-weight impact test to evaluate the impact resistance of concrete.

IV. IMPACT STRENGTH

Impact strength is of importance in driving concrete piles, in foundations for machines exerting impulsive loading, and when accidental impact is possible, there is no unique relation between impact strength and static compressive strength. For this reason, impact strength should be assessed, usually by the ability of a concrete specimen to withstand repeated blows and to absorb energy. For instance, the number of bows which the concrete can withstand before reaching the 'no-rebound' condition indicates a definite state of damage. Generally, for a given type of aggregate, the higher the compressive strength of the concrete the lower the energy absorbed per blow before cracking, but the greater the number of blows to reach 'no-rebound'. Hence, the impact strength and the total energy absorbed by concrete increase with its static compressive strength.

V. LITERATURE REVIEW

P.S. Song et.al. (2005) assessed the statistical variations in impact resistance of high-strength concrete and high-strength steel fibre-reinforced concrete. The resistance is assessed through different types of test procedures, such as explosive test, drop-weight test, projectile impact test, constant strain rate test. Among these tests, the drop-weight test is the simplest. This ACI devised test applies repeated blows to a concrete disc and records the number of blows to develop the first visible crack on the top end of the disc and the number to cause the ultimate failure of the disc and indicated that hooked end steel fibers have a good potential for enabling the concretes to withstand more impact loads and that the fibers provide at least a fivefold increase in the impact resistance, compared with straight steel fibers.

The impact resistance variability of HSFRC statistically commanded this study in comparison with that of HSC, thus enabling understanding the impact-resistance improving potential of steel fibres in HSC. Moreover, for both concretes, two reliable regression models were developed to predict the failure strength through the first crack strength. The 3.5-mm long hooked-end steel fibres register an aspect ratio of 40; the fibre volume fraction was 1%. The freshly mixed steel fibre-reinforced concrete was placed in moulds to cast 150 x 300 mm cylinders and discs. The moulds were filled in two equal layers; each layer was consolidated using a vibrating table. After consolidation, the specimens were kept in the moulds for 24 hours, then removed from the moulds and cured at approximately 25^0 C in water until the test age of 28 days. For each concrete, was subject to the drop-weight test following the ACI committee 544 Report "Measurement of Properties of Fibre Reinforced Concrete". In the test, the number of blows to cause the first visible crack on the disc is recorded as the first-crack strength, and the number of blows to cause ultimate failure of the disc is recorded as the failure strength. The two regression models enabled point and interval estimates for the number of blows to ultimate failure in the concretes, providing insight into the potential impact resistance of the concretes to ultimate failure. The impact resistance of HSFRC was superior to that of HSC. The first-crack strength of HSFRC was about 3.9 times that of HSC, with the failure strength about 4.2 times.

M.H. Zhang et.al. (2005) investigated the impact resistance of concrete with compressive strengths of 45-235 MPa. Specimens were subjected to impact by 12.6 mm give-nosed projectile at velocities ranging from 620 to 700 m/s. The mix proportion has Cement, Silica fume, Water, Coarse aggregate, Fine aggregate, Fibres and Granite specimens. In testing, the experimental arrangement has a gas gun with a 12.7 mm bore, and the give-nosed projectiles with a calibre radius head of 2.5, diameter of 12.6 mm and 15 g weight. The investigation revealed that high-strength fibre-reinforced concrete with a compressive strength of 100MPa appears to be most efficient in protection against projectile impact. The results indicated that the penetration depth and crater diameter in target specimens exhibit an overall reduction with an increase in the compressive strength of the concrete.

Atef Badr et al. (2006) studied the Statistical variations in impact resistance of polypropylene fibre-reinforced concrete. The impact resistance of polypropylene fibre-reinforced concrete (FRC) was investigated using the repeated drop-weight impact test recommended by ACI Committee 544. The variation in results was examined within the same batch and between different batches. Statistical parameters were compared with reported variations in impact resistance of concrete composites reinforced with other types of fibres such as carbon and steel fibres. Ordinary Portland cement (OPC), conforming to BS 12: 1996, was used in this study. The coarse aggregate was quartzite natural gravel of 10mm nominal maximum size. It had a specific gravity of 2.63 and bulk density of 1588 kg/m3. The fine aggregate was quartzite sand with a specific gravity and water absorption of 2.66 and 0.17%, respectively. Sieve analysis of this sand showed that it has grading which complies with zone M of BS 882, 1992. A super plasticiser based on naphthalene sulfonate polymer, which has a powerful dispersing effect on the cement particles, was used as a water-reducing admixture. Five standard cylinders with a diameter of 150mm and a height of 300mm were cast from each batch to prepare specimens for the impact test. Ten cubes (100 mm) were prepared from each batch according to BS 1881: Part 108: 1983 for the compressive strength test.

The test was carried out by dropping a hammer weighing 4.47 kg from a height of 457mm repeatedly on a 64mm diameter hardened steel ball, which is placed on the top of the centre of the cylindrical specimen. Compressive strength was determined at the age of 28 days, as a means of quality control. The average 28-day compressive strength was 41.3MPa and the standard deviation was 4.17 MPa. The coefficient of variation was 10.09%. The mean compressive strengths within batches were 38.6 and 44.1MPa with standard deviations of 2.80 and 3.46 MPa, the corresponding coefficients of variation within batches were 7.26% and 7.85%. Impact resistance of PPFRC, as determined from the ACI repeated drop-weight impact test, has a large standard deviation and coefficient of variation. The observed coefficients of variation were about four-fold the recommended value for compressive strength. The values were about 60% and 50% for first-crack and ultimate impact resistance, respectively. If this test is to be considered as a standard test it is necessary to increase the number of replications to at least 40 specimens per each test or concrete mix to assure an error below 10%. This, however, is neither practical nor economical and goes entirely against the intention of this test, which is to provide an easy, simple and economic impact test.

Mahmoud Nili, et.al. (2010) evaluated the impact resistance and mechanical properties of steel fibre-reinforced concrete with water cement ratios of 0.46 and 0.36, with addition of silica fume and hooked steel fibers with 60mm length and 0.75mm diameter. The experimental results show that incorporation steel fibres improve the strength performance of concrete, particularly the splitting tensile and the flexural strengths. Compressive strength tests were performed after 7,28 and 91 days on 100 x 100 x 100 mm cube specimens and flexural strength testing was also performed on 80 x 100 x 400 mm specimens. split tensile strength was performed at 28 days on 100 x 200 mm cylindrical specimens. the impact resistance of the specimens was also determined in drop weight loading according with procedure proposed by ACI Committee 544. The result of under impact loading, a ductile failure was observed in fibrous and silica fume–fibrous specimens.

Alavi Nia. A et.al, (2012) studied that impact loading results from numerical simulations of plain concrete and fibre reinforced concrete. The arrived theoretical values are compared with experimental results. Material specification, concrete specimen prepared with water cement ratio 0.36 and 0.46. hooked - end steel fibres 60 mm in length and 0.75 mm diameter at 0.5% and 1% by volume, polypropylene fibres – 0.2%, 0.3% and 0.5% by volume. Compression test, splitting tensile test and Impact test are conducted. Analytical procedure was carried on version 971 LS-DYNA explicit software. Hence, it is concluded that the impact resistance increase was greater for normal strength concrete than for high strength concrete. Also, demonstrated that steel fibres are more effective at increasing impact resistance than polypropylene fibres. The reactive powder concrete specimens had higher static load capacity and impact resistance compared to high strength specimens. The higher impact resistance of reactive powder concrete specimens was demonstrated by larger number of impacts required to induce failure.

Wai Hoe Kwan, et.al. (2014) studied the performance of marine structures subjected to seismic and impact loads resulting from waves, impact with solid objects, water transports and explored the effects of simulated aggressive environments on flexural strength and impact resistance of fibre reinforced concrete, to identify the relationship between the two parameters. The Coconut fibre, Bar – chip fibre and Alkali- resistant glass fibre were used in this study. These fibre dosage ranged from 0.6% to 2.4% of the binder volume and its water /binder ratio of 0.37 and their compressive strengths were all exceeding 60 MPa. And specimens were prepared and exposed in Tropical climate, Cyclic air and Seawater conditions and seawater environment for up to 180 days. Results indicate that flexural strength and impact resistance of fibre reinforced concrete have a direct relationship with fibre content.

Trilok Gupta, et.al. (2015) assessed the effect of replacement of aggregates by waste rubber fibres on the impact resistance of concrete with silica fume as partial replacement for cement. Three techniques were used to find out impact resistance, (i) Drop weight test (ii) Flexural loading test and (iii) Rebound test. In addition of natural fibres in the form of coir, sisal, jute, and hibiscus cannabinus has also used to increase the impact resistance of concrete. These waste rubber are obtained from grinding of waste rubber tyres, its dimensions about 2-5 mm width and up to 20 mm length, and its specific gravity of 1.07. In this experimental study, the compressive strength, impact resistance under drop weight test, flexural loading and rebound test, micro-structural properties of hardened concrete were analysed as per relevant standards. A good correlation exists between the results of drop weight test, flexural loading, rebound test.

VI. MATERIAL TESTING

- In this study, quartz sand has been used as fine aggregate, is confirmed to zone II of table 4 of IS 383–1970. Specific gravity of the fine aggregate is 2.535 and Fineness modulus is 2.927
- Specific Gravity of Silica fume is 2.272
- Specific Gravity of Quartz powder is 2.717
- Bulk density of Quartz sand 1.4463
- Fibres are added to enhance the tensile strength and to improve its ductility in UHSC. The straight steel fibres are used in the production of UHSC. The fibres introduced into the mix at a ratio of 2% by volume.
- To improve the workability, a high range water reducer – super plasticizer may be used is most recommended instead of adding excess water in the mix.

VII. DESIGN OF CONCRETE MIX USING PACKING DENSITY METHOD

The packing density of individual aggregate in a volume fraction of total aggregate or over all aggregate is determined from its maximum bulk density of mixture and specific gravity from the following relation.

Packing density = (Bulk density X weight fraction) / Specific gravity

Mix Ratio Concrete (Packing Density Method)

1	1.4	0.25	0.2	0.2
Cement	Quartz Sand	Silica Fume	Quartz Powder	W/C Ratio

VI. SUMMARY

In the present study, a detailed review of literature was carried out to study the production of UHSC and properties of Ultra High Strength Concrete (UHSC). Also, basic material properties were evaluated to arrive the mix proportion based on packing density method. Suitable testing methods were identified from literature to assess the impact resistance of Ultra High Strength Concrete (UHSC). In this review, maximum researchers identified impact resistance by using drop weight test with various dropping conditions.

It is proposed to conduct an experimental study on mechanical properties and impact resistance characteristics of Ultra-High Strength Concrete incorporating steel fibers, bagasse ash and rise husk ash.

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