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Comparative Study of Mechanical Properties of Self - Healing Concrete Using Industrial Waste Steel Scrap and Polyethylene Fiber

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ABSTRACT
Cracks in concrete are the main reason for a decreased service life of concrete structures. It is therefore more advisable and economical to restrict the development of early age small cracks the moment they appear, than to repair them after they have developed to large cracks. A promising way is to pre-add healing agents (Methyl methacrylate) to the concrete to heal early age cracks when they appear, i.e. the so-called self-healing approach. By this approach, Methyl methacrylate was used as self – healing agent and its self-healing capability was confirmed by UPV test. In that self – healing concrete, Industrial Waste Steel Scrap and Polyethylene fiber were added to evaluate its mechanical properties. The experimental results shown that the self – healing concrete can yield high compressive strength when Polyethylene fiber was added and also yield high tensile strength by adding Industrial waste steel scrap. Also, it is found to be economical by adding steel scrap in self – healing concrete instead of steel fiber.

I. INTRODUCTION

Background of Study

Concrete is exposed to external factors such as extreme heat, cold, stress, during service. Concrete shrinks and expands with variations in moisture and temperature. Cracks can occur when changes to accommodate these factors are not implemented in the Design and development. Other factors that can affect concrete and its lifespan include shrinkage, design flaws or poor quality of construction materials (Mather 1989). Concrete experiences various loading from heavy vehicles, earthquakes and strong winds. Due to these factors in addition to several more it is inevitable that reinforced concrete eventually develop cracks. When cracks originate in concrete structures, a sequence of serious events begins to occur within those structures. Not only do these cracks affect the functionality of the structure, but they also affect the durability and strength of the structure. In order to enhance concrete resistance to these defects and degradations, the innovation of self-healing concrete is promising.

Self-healing concrete can be defined as concrete that possesses self-healing agents, which will 'automatically heal' concrete structures, when cracks occur during their life cycle. Self-healing agents may be transferred through strong core microcapsules, hollow reinforced fibers and even by forms of organic matter (Ming Qiu Zhang et al 2011). All of these methods are currently undergoing testing and analysis in order to test their durability and longevity. This research deals with a number of self-healing chemicals that are used in the micro-encapsulation process.

II. ETHODOLOGY

Introduction:

Self-healing properties in concrete may be obtained by different methodologies, such as secondary hydration of unhydrated cement, addition of fibers, and encapsulation of polymers. The healing agents like expanded additives and polymers, the proposed bio-mineral ($CaCO_3$) is more compatible with the concrete matrix and more environmentally friendly.

Experimental program:

In our project self-healing property is achieved by using self-healing agent (methyl methacrylate) and its mechanical properties can be investigated by adding industrial waste steel scrap and polyethylene fiber. Comparison of mechanical properties of self-healing concrete by adding steel scrap and PE fiber have been done. Silica fume, Hydroxyethyl cellulose and polycarboxylate are used to increase the workability, durability, to block pores and to stabilize them. The specimens were cast and allow it to water curing for 7 and 14 days. The cured specimens can be tested to evaluate its compressive and tensile strength by adding steel scrap and PE fiber in self-healing concrete, and also its self-healing capability was analyzed by Ultrasonic pulse velocity test. Later the mechanical properties of self-healing concrete can be compared by adding different percentages (5% and 10%) of steel scrap and PE fiber.

III. SELECTION OF MATERIALS

Methyl Methacrylate:

Different types of healing agents have already been tested on their efficiency for use in self-healing concrete. Generally, commercial healing agents are used while their properties are adjusted for manual crack repair and not for autonomous crack healing. Consequently, the amount of regain in properties due to self-healing of cracks is limited. In our project, a Methyl methacrylate (MMA)-based healing agent was developed specifically for use in self-healing concrete. Various parameters were optimized including the viscosity, curing time, strength, etc. After the desired properties were obtained, the healing agent was encapsulated and screened for its self-healing efficiency. Various healing agents like polyurethane, epoxy resin, etc. were used. They are capable to reduce the water permeability but can't regain more strength. Methyl methacrylate, a self-healing agent which can restore high strength more than the required after healing of cracks. Methyl methacrylate encapsulated in a microcapsules can be added with the concrete. When the crack reaches the microcapsule, the capsule breaks and the monomer bleeds into the crack, where it can polymerize and mend the crack.

These microcapsules were filled with a liquid monomer (methyl methacrylate). If a micro crack occurs in this concrete, the microcapsule will rupture and the monomer will fill the crack. Subsequently it will polymerize and autogenously heal the cracks.

Industrial Waste Steel Scrap:

Steel scraps are the waste materials which are collected from workshops and other steel industries at very minimum cost. They are similar to the steel fiber but they don't have any regular shape and size. The dimension varies with nature of source which depends upon the type of industries. Scraps considered in this work are 0.5 mm thick, 3 mm in width and 5 mm in length.

Scraps are recyclable and other materials left over from product consumption, such as parts of vehicles, building supplies, and surplus materials. Unlike waste, scrap has significant monetary value. According to research conducted by the US Environmental Protection Agency, recycling scrap metals can be quite beneficial to the environment. Every day about 8 to 10 kg of lathe waste are generated by each lathe industries and dumped in the barren soil there by contaminating the soil and ground water, which creates an environmental issue. Hence by adopting proper management by recycling the lathe scrap with concrete is considered to be one of the best solutions. The test were conducted as per the Indian standard procedure for its mechanical properties such as flexural, split tensile, compressive, and impact strength and compared conventional PCC. The 7 days strength of the Lathe scrap reinforced concrete shows an increase in its compressive strength when compared with PCC, and almost become equal to the strength when tested on 28 days under normal curing. But there is only a considerable increase in the split tensile strength of concrete with lathe scrap when compared with PCC.

When, Steel fibers added to concrete, the behavioral efficiency of this composite material is superior to that of plain concrete and many other construction materials of equal cost (Ganesan*et al*., 2004; and Niranjana *et al*., 2007). Due to this benefit, the use of FRC has increased largely in the recent years and finds its application in many construction areas. However, steel fibers available in market are costly and this makes steel fiber reinforced concrete uneconomical. Lathe scrap, which exhibits the property of steel fiber largely, can be used as an alternate for steel fiber. As the SFRC, the Steel Scrap Reinforced Concrete also reduces the crack width when subjected to loading. The performance of lathe scrap reinforced concrete proves to be better than the normal concrete and very much comparable with steel fiber reinforced concrete regarding its mechanical properties.

Fig - Industrial Waste Steel Scrap

Polyethylene fiber:

Polyethylene fiber have yield strengths as high as 2.4 GPa (350,000 psi) and specific gravity as low as 0.97. High-strength steels have comparable yield strengths, and low-carbon steels have yield strengths much lower (around 0.5 GPa). Since steel has a specific gravity of roughly 7.8, this gives strength-to-weight ratios for these materials in a range from 8 to 15 times higher than steel. Strength-to-weight ratios for Dynamo are about 40% higher than for aramid.

Fig – Polyethylene Fiber

Sand:

Fine aggregate/sand is an accumulation of grains of mineral matter derived from the disintegration of rocks. It is distinguished from gravel only by the size of the grains or particles, but is distinct from clays which contain organic materials. Sands that have been sorted out and separated from the organic material by the action of currents of water or by winds across arid lands are generally quite uniform in size of grains. Sand is used for making mortar and concrete for polishing and sand blasting. The fine aggregate was passing through 4.75mm sieve and had a specific gravity of 2.68. The grading zone of the aggregate was zone 3 as per Indian standard specifications.

Coarse Aggregate:

Coarse aggregate are the crushed stone is used for making concrete. The commercial is quarried, crushed and graded. Much of the crushed stone used is granite, limestone and trap rock. Graded crushed stone usually consist of only one kind of rock and is broken with sharp edged. The sizes are from 0.25 to 2.5 in (0.64 to 6.35cm) although larger sizes may be used for massive concrete aggregate. Machine crushed granite broken stone angular in shape was used as coarse aggregate. The maximum size of coarse aggregate was 20mm and specific gravity of 2.78.

Fig – Coarse Aggregate

Water:

Water fit for drinking is generally considered fit for making concrete. Water should be from as acid, oils, alkalis, vegetables or other organic impurities. Soft water also produced weaker concrete. Water has two function in a concrete mix. Firstly, it reacts chemically with the cement to form a cement paste in which the inert aggregates are held in suspension until the cement paste has hardened. Secondly, it serves as a vehicle or lubricant in the mixture of fine aggregate and cement.

Cement:

Cement is a material generally in powder form that can be made into a paste usually by the addition of water and, when molded or poured, will set into a solid mass. Numerous organic compounds used for adhering, or fastening materials, are called cements, but these are classified as adhesives, and the term cement alone means a construction material. The most widely used of the construction cements is Portland cement. It is a bluish-gray powder obtained by finely grinding the clinker made by strongly heating an intimate mixture of calcareous and argillaceous minerals. The chief raw materials is a mixture of high-calcium limestone, known as cement rock, and clay or shale. Blast-furnace slag may also be used in some cements and the cement is called Portland slag cement (PSC). The color of the cement is due chiefly to iron oxide. In the absence of impurities, the color would be white, but neither the color nor the specific gravity is a test of quality.

Fig – Cement

Polycarboxylate:

Polycarboxylate, a pale amber colored liquid, with a specific gravity of 1.1, chloride content < 0.1 wt. % and sulphate content < 3.0%. It is a Chemical admixtures are materials that are added to the constituents of a concrete mixture, in most cases, specified as a volume in relation to the mass of the cement or total cementations materials. The admixtures interact with the hydrating cementations system by physical and chemical actions, modifying one or more of the properties of concrete in the fresh and/or hardened states. It is used to increase the mobility and workability of concrete, and to reduce segregation. It does not allow air entrainment and improve the pump ability of concrete. Polycarboxylate super plasticizer increase dispersion because of its superior performance in dispersing cement particles at smaller dosages and retaining concrete slump without prolonging setting times.

Fig – Polycarboxylate

Hydroxyethyl Cellulose:

Hydroxyethyl cellulose is a nonionic water-soluble polymer derived from cellulose. It can be able to dissolves readily in cold or hot water. It has very good flow properties which enable the fibers to spread over the area of concrete. It serves as a viscous agent. It is also used as a binder, stabilizer in concrete to promote better bonding between cement paste and aggregates. It also serves as protective colloid during polymerization of Methyl methacrylate.

Fig– Hydroxyethyl Cellulose

Silica Fume:

Silica fume, also known as **micro silica**, is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. The main field of application is as pozzolanic material for high performance concrete. Silica fume is added to Portland cement concrete to improve its properties, in particular its compressive strength, bond strength, and abrasion resistance. Addition of silica fume also reduces the permeability of concrete to chloride ions, which protects the reinforcing steel of concrete from corrosion. Silica fume also blocks the pores in the fresh concrete so water within the concrete is not allowed to come to the surface and reduces bleeding. It had shown that Portland cement-based-concretes containing silica fumes had very high strengths and low porosities. Since then the research and development of silica fume made it one of the world's most valuable and versatile admixtures for concrete and cementations products.

Table– Properties Of Silica Fume

PROPERTY	VALUES
SiO_2 content	85% – 97%
CaO content	< 1
Fineness as surface area	15,000 – 30,000 m^2/kg
Specific gravity	2.22
General use in concrete	Property Enhancer

Fig– Silica Fume

Mix Design

A mix was designed as per IS 10262 – 1982 to achieve a minimum target strength of 40 N/mm^2 . The mix proportion was 1**: 1.65: 2.92.** A constant water cement ratio of 0.4 was used. Ordinary Portland cement is used with a specific gravity of 3.15. The particle size of a fine aggregate and coarse aggregate are 1.5mm and 20mm having specific gravity of 2.61 and 2.65. The quantities of different ingredients of concrete mix were given in Table

Table– Quantities Of Different Ingredients

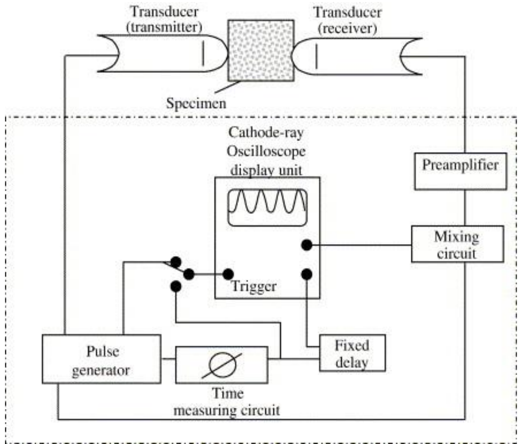
MIX	CEMENT	F.A	C.A	STEEL SCRAP	PE FIBER	W/C RATIO	REMARKS
SHC	400	660	701	-	-	0.4	Control mix
SCH1	400	660	701	20	-	0.4	Addition of 5% steel waste in self – healing concrete
SCH2	400	660	701	40	-	0.4	Addition of 10% steel waste in self – healing concrete
SCH3	400	660	701	-	20	0.4	Addition of 5% PE fibre in self – healing concrete
SCH4	400	660	701	-	40	0.4	Addition of 10% PE fibre in self – healing concrete

Table– No of cubes for Ultrasonic Pulse Velocity Test

Specimen	Ultrasonic Pulse Velocity Test
Normal Concrete	3
Self – Healing Concrete	3

Fig – Ultrasonic Pulse Velocity Test

Pulse velocity = (Path length/Travel time)



Fig– Ultrasonic Pulse Velocity Test

Fig– Compressive Strength Test

Fig– Split Tensile Strength Test

Results and Discussion

Table– Test Result for Ultrasonic Pulse Velocity Test

Specimen	Avg.Specimen weight	Grade of concrete	Avg.Time taken
Control Mix	8.2 Kg	M40	32 m.sec
Self – Healingconcrte	8.86 kg	M40	38 m.sec

Pulse velocity = path length / travel time

Control mix: Pulse velocity = 0.15 / 32 = 4.68 x 10^{-3} m/sec

Self-healing concrete: Pulse velocity = 0.15 / 38 = 3.94 x 10^{-3} m/sec

Table- 7 days compressive strength

Specimen	Compressive Strength (N/mm^2)
SHC	**24**
SHC1	**25.55**
SHC2	**26.23**
SHC3	**26.67**
SHC4	**29.53**

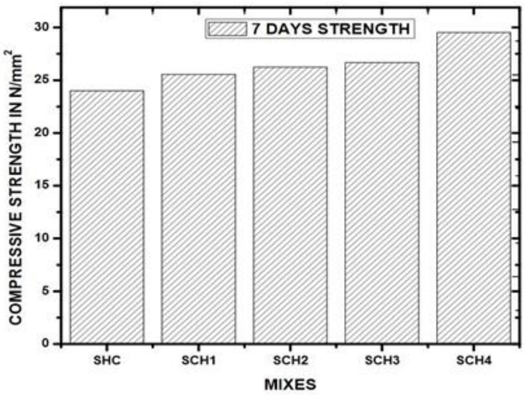


Fig - 7 days compressive strength

Table - 14 days compressive strength

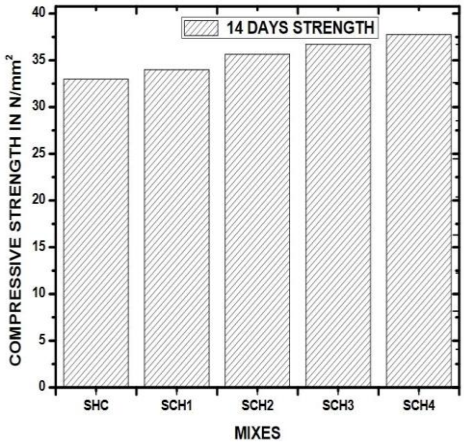
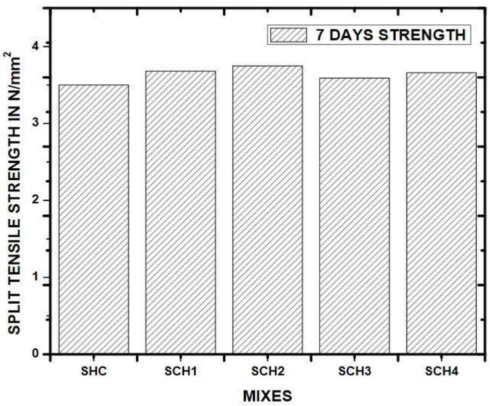


Fig - 14 days compressive strength

Table – 7 Days Tensile Strength

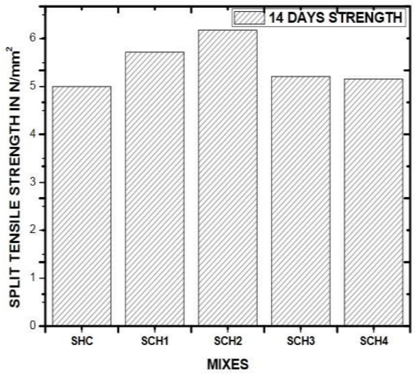
SPECIMEN	Tensile Strength (N/mm^2)
SHC	**3.5**
SHC1	**3.68**
SHC2	**3.75**
SHC3	**3.59**
SHC4	**3.66**



Fig– 7 Days Tensile Strength

Table 4.5 – 14 Days Tensile Strength:

SPECIMEN	Tensile Strength (N/mm2)
SHC	**5**
SHC1	**5.72**
SHC2	**6.18**
SHC3	**5.21**
SHC4	**5.16**



Fig– 14 Days Tensile Strength

II. CONCLUSIONS

By ultrasonic pulse velocity test, self-healing capability of concrete can be confirmed by adding methyl methacrylate as self-healing agent. And, further tests has to be carried to evaluate the mechanical properties of self – healing concrete by adding industrial waste steel scrap and polyethylene fiber.

Addition of steel scrap in the percentages of 5% and 10% to the self-healing concrete leads to a considerable increase in the tensile strength of concrete, because it has the property similar to the steel fiber.

Compressive strength was increased in the self-healing concrete by adding 5% and 10% of polyethylene fiber than steel scrap.

From the investigation, self-healing concrete with polyethylene fiber shows considerable increase in the compressive strength, but steel scrap is found to be more economical compared with PE fiber and can yield high tensile strength.

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