Indian J.Sci.Res. 17(2): 162-167, 2018

ISSN: 0976-2876 (Print)
ISSN: 2250-0138(Online)

EXPERIMENTAL INVESTIGATION ON BEHAVIOUR OF SELF HEALING CONCRETE USING POLYURETHANE

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Abstract - In 21[St] century the reinforced concrete structures have undergone evolution to withstand heavy loads from voluminous vehicular movement, seismic vibrations, cyclones and other catastrophic events, inevitably develops micro cracks. Occurrence of micro cracks reduces the durability and strength of the structure, in addition to the functionality of the structure. In this context, Self Healing Concrete possesses tremendous potential in increasing the longevity of structural members. Polyurethane is used as healing agent in varying proportions (1.5%, 2%, 2.5% and 3% by weight of cement for polyurethane) for grade of M60.Experimental investigation finds mechanical properties of polyurethane for various curing periods (7, 14 and 28days).The results have proved that increase in percentage of healing agents has increased the mechanical properties substantially . This type of cementitious matrix can be used for watertight structures, subways, tunnels etc.

Keywords: Self Healing Concrete, Polyurethane, Mechanical properties

I. Introduction

General

Self-healing materials are no more an illusion and we are not far away from the days when manmade materials can restore their structural integrity in case of a failure. For example, the cracks in buildings can close on their own or the scratches on car bodies can recover their original shiny appearance by itself. Indeed, this is what everyone can see in case of the natural healing of wounds and cuts in living species. Virtually, all materials are susceptible to natural or artificial degradation and deteriorate with time. In the case of structural materials the long-time degradation process leads to microcracks that cause a failure. Thus, repairing is indispensable to enhance reliability and lifetime of materials. Self-healing can be defined as the ability of a material to heal (recover/repair) damages automatically and autonomously. Inception of self-healing properties in manmade materials very often cannot perform the self-healing action without an external trigger. So, self-healing are of two types:

- Autonomic (without any intervention)
- Nonautonomic (needs human intervention/external triggering)

The different types of materials such as plastics/polymers, paints/coatings, metals/alloys, and ceramics/concrete have their own self-healing mechanisms. The different strategies to induce self-healing behaviour are as follows:

- release of healing agent
- reversible cross-links
- miscellaneous technologies
- electrohy drodynamics
- conductivity
- shape memory effect
- nanoparticle migration
- co-deposition.

[1]The natural materials, such as skin, wood, bones and skeletons, grass, etc, often have the special ability that they can, more or less autonomously, heal cracks and other forms of accidental damage. This healing ability is the result of a difference in underlying optimization paradigm for natural materials: damage management. To introduce healing in materials , it is necessary that atoms or molecules flow from their initial position in the vicinity of the damage site to the actual crack and once arrived there restore physical contact between both crack faces. In time, the material newly deposited in the crack will build up proper load bearing ability. The net result is a restoration of the initial mechanical and other physical properties. To obtain such a self healing behaviour the microstructure of biological materials is much more diverse and complex than that of man-made materials, and it is no longer appropriate to regard the material as a material, but it has to be regarded as a system [3].Concrete is made of cement, usually Portland cement, water and other filling materials, like sand and grit. The concrete hardens after mixing with water, which will take about one month, because the cement hydrates with water. Micro cracks in the concrete are an inevitable feature of ordinary concrete, because of the tensile strength. The tensile strength increases when there are a lot of temperature differences. These micro cracks reduce the durability of the concrete structure. Under certain circumstances, small cracks in ordinary concrete can heal themselves. When the mixture hardens,

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not every cement molecule reacts with water. The non-reacting cement molecules can react with water, which flows in the concrete because of the cracks. Limestone will be produced, which fills the cracks. Ordinary concrete is able to heal cracks of a width of circa 0.20 mm. If cracks become larger, the concrete will not be able to heal these cracks. Recently, in experiments, bacterial spores and nutrients and calcium lactate have been used as self-healing agents. The bacteria and calcium lactate are both embedded in capsules, to prevent interaction before cracks appear. Concrete with added healing agents is called self-healing concrete[4]. To make the material technically and economically competitive, healing agent should be cheap in relation to the low price of concrete, remain potentially active for long periods of time. Self-healing is important to watertight structures and to prolonging service life of infrastructure [3].Self-healing concrete could solve the problem of concrete structures deteriorating well before the end of their service life. Silica fume is an ultrafine material with spherical particles less than 1 µm in diameter, the average being about 0.15 µm. This makes it approximately 100 times smaller than the average cement particle. The bulk density of silica fume depends on the degree of densification in the silo and varies from 130 to 600 kg/m^3. The specific gravity of silica fume is generally in the range of 2.2 to 2.3. The main field of application is as pozzolanic material for high performance concrete. According to ACI Committee 232 [2004] fly ash is the residue that finely divided which results from coal and is transported by flue gases from combustion zone to the particle removal system. Fly ash is relatively higher fineness compared to Portland cement, which range between less than 1 µm and 150 µm. Fly ash utilization has environmental benefits, especially in concrete production industry, viz, better durability, reduction on energy used; lessen the production of greenhouse gases, and reduction of fly ash disposal[18].Simply "aggregate", is a broad category of coarse particulate material used in construction, including sand, gravel, crushed stone, slag, recycled concrete and geosynthetic aggregates. Aggregates are the most mined materials in the world. Aggregates are the base material under foundations, roads, and railroads.

The objective of this study is to investigate the effect of self healing agent polyurethane on mechanical properties of the M60 grade concrete by adding varying quantity of polyurethane (1.5%, 2.0%, 2.5%, and 3.0%) at various curing periods (7,14 and 28days).

II. Experimental Programme

The experimental programme to meet the objectives was carried out with different combinations of materials in the laboratory. M60 grade concrete was designed by using Self healing agents Polyurethane, and other mineral admixtures such as Silica fume, Fly Ash along with ordinary Portland cement. The mixes were designed with Silica fume, Fly ash and Super plasticizers for [1.5%, 2.0%, 2.5%, and 3.0%] of polyurethane has been added by the weight of cement. Various specimens were casted to check different strength at different ages of concrete.

A. Materials Used

To investigate the properties of the materials such as cement, fine aggregate and coarse aggregate used for casting the specimens. Various laboratory tests were performed and the test results obtained were compared with the Indian Standard values. Cement is the essential binding material for the production of concrete. It is incumbent on the part of the user to test the cement to confirm the requirements of the Indian standard specifications with respect to its physical and chemical properties. In this investigation we had used Ordinary Portland cement 53 grade confirming to IS: 12269 - 2013[17]was used. Properties of cement used in the experimental work are tabulated in Table 2.1. The sand used for the experimental was locally available and conformed to Indian Standard Specifications IS: 383-1970[12]. The sand was first sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm. Properties of the fine aggregate used in the experimental work are tabulated in Table 2.1 . The crushed stone aggregate used for the experimental was locally available The coarse aggregate was used in the experimentation were about 20 mm and 10 mm size aggregate and tested as per IS: 2386-1963 (III) [11] specifications. Physical properties of coarse aggregates as determined in a laboratory are tabulated in Table 2.1. Silica fume, which has a similar function as fly ash, is very effective in lowering the water-to-cement ratio needed for workable concrete in conjunction with super plasticizers because its sub-micron particle size allows it to pack between the cement grains. Physical properties of silica fume as determined in a laboratory are tabulated in Table 2.1. Fly ash with suitable spherical morphology can improve the workability and permits lowering the water-to-cement ratio to 0.3 in favorable cases. The super fine fly ash, having a specific surface of 2000-4000sq.m/kg, was found to have a significant improvement on the compressive strength, tensile strength, permeability, acid resistance and chloride resistance compared with the NSC. Recently, it has been found that volcanic ash, which is similar to fly ash but is more abundant in volcanic disaster areas, can also be used as partial cement replacement material to manufacture HPC. Physical properties of flyash as determined in a laboratory are tabulated in Table 2.1. Super plasticizer can increase the workability of concrete mix and reduce the amount of water needed. Therefore, it enables the use of very low water-to-cement ratio and thus produce HPC. The principal active components in super plasticizer are surface-active agents. During mixing, these agents are absorbed on the cement particles, giving them a negative charge which leads to repulsion between the particles and results in a more uniform dispersion of cement grains. With the addition of super plasticizers, concrete can be successfully produced and placed with a water-to cement ratio as low as 0.2. However, this value is not the lowest possible value in concrete. Further lowering of water-to-cement ratio can be achieved by adding other mineral admixtures, like fly ash or silica fume. The super plasticizer used for this project is SP CONPLAST 430. Physical properties of super plasticizer as determined in a laboratory are tabulated in Table 2.1 Polyurethane is a polymer composed of a chain of organic units joined by carbonate links. While most polyurethanes are thermosetting polymers that do not melt when heated, thermoplastic polyurethanes are also available. Polyurethanes are used in the manufacture of flexible, high resilience foam seating; rigid foam insulation panels; microcellular foam seals and gaskets; durable elastomeric wheels and tires; automotive suspension bushings; electrical potting compounds; high performance adhesives; surface coatings and surface sealants; synthetic fibers (e.g., Spandex); carpet underlay; hard plastic parts (e.g., for electronic instruments); hoses and skateboard wheels. Physical properties of polyurethane such specific gravity of polyurethane and test as determined in a laboratory are tabulated in Table 2.1

B. Mix Design M60 Grade Concrete

The mix design was carried out for 8 mix proportions with Silica fume, and Fly ash along with Polyurethane. Mix design was calculated as per AITCIN-1998[8]. The Mix design was arrived by calculations based on the material properties and tested values of the ingredients. Polyurethane was used in the four mixes Silica fume and Fly ash. The quantities of materials are tabulated for M60 concrete using Polyurethane. They are presented in Table 2.2

Table 2.1 Physical Properties of Materials

Material Property	Value
Specific Gravity of Cement	3.14
Fineness of Cement	3%
Specific Gravity of Fine Aggregate	2.6
Fineness modulus of Sand	2.76
Water Absorption	0.917%
Specific Gravity of Coarse Aggregate	2.5
Fineness modulus of Coarse Aggregate	5.195
Water Absorption	0.4%
Specific Gravity of Silica fume	2.22
Specific Gravity of Fly Ash	2.10
Specific Gravity of Super Plasticizers	1.20
Specific Gravity of Polyurethane	1.07

C. Specimen Preparation

To determine strength, specimens were casted and tested at various curing period. The specimens were casted as per the test requirement in the laboratory. All the specimens were cast on mechanical vibration table. For compressive strength test 150×150×150 mm cubes were cast. For testing flexural strength 100×100×500 mm beams were cast. For split tensile strength cylindrical specimen of 150 mm diameter and 300 mm length were cast. The specimens were demoulded after 24 hours of casting and were cured in water until the testing

Table 2.2 Quantity of materials for M60 grade concrete using Polyurethane

Ingredients	Polyurethane , %				
	0	1.5	2.0	2.5	3.0
Cement - Kg/m3	422	422	422	422	422
Coarse aggregate - Kg/m3	1075	1075	1075	1075	1075
Fine aggregate - Kg/m3	647	631	626	621	617
Silica fume - Kg/m3	23	23	23	23	23
Fly ash - Kg/m3	23	23	23	23	23
Water - Kg/m3	146	137	134	131	127
Super plasticizer - Kg/m3	4.9	4.9	4.9	4.9	4.9
Polyurethane - Kg/m3	-	14.8	19.8	24.7	29.6

III. Results And Discussion

A. Compressive Strength for Polyurethane

The main aim is to determine the compressive strength of concrete specimen. Compression tests are made at the age of the test specimens. Specimens were removed from curing. The bearing surfaces of the testing machine are wiped clean and the cubes are placed in the compression testing machine in such a manner that the load is applied to opposite sides of the cubes as cast. The axis of the specimen is carefully aligned with the centre of thrust of the spherically seated block is brought to bear on the specimen and the load is applied without shock and continuously at a rate approximately 140 kg/cm2/minute until the failure of the specimen. The specimens have been subjected to an applied load to induce initial crack. The cracking is minor and internal only. These specimens have been retested to found the strength regained after one week. The compressive strength test for cube samples containing polyurethane as self healing agent with the dosage of (1.5%, 2.0%, 2.5%, and 3.0%) added by the weight of cement was carried out as per IS 516:1959. The tests were conducted on 7th, 14th and 28th day test results are tabulated in 3.1. The graph showing the increase in compressive strength for various proportions of polyurethane is shown in Figure 3.1. It is evident from the table that the compressive strength has been achieved well above the target strength of 73.49 N/mm2 . As a result the compressive strength is increased up to 73.49% with the addition of 2.5 % of polyurethane when compared to all other proportions at 28 days.

Table 3.1 Compressive strength values of M60 grade concrete with Polyurethane

S. No	% of Polyurethane	Days	Compressive Strength in N/mm^2		% increase in Compressive strength
			BH	AH	
1	0	7	41.76	-	-
		14	54	-	-
		28	64.74	-	-
2	1.5	7	32.27	41.96	29.62
		14	36.57	49.03	34.07
		28	39.82	60.35	51.55
3	2	7	32.99	42.87	42.07
		14	37.98	49.89	31.35
		28	41.03	64.51	57.22
4	2.5	7	33.47	55.62	66.17
		14	39.73	58.81	48.02
		28	42.3	73.39	73.49
5	3	7	29.04	37.53	29.23
		14	33.53	39.17	16.82
		28	35.47	47.03	32.59

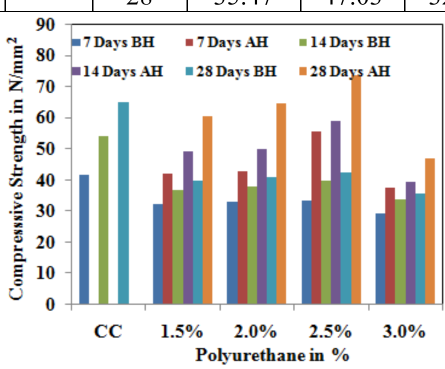

Fig 3.1 Compressive strength of cube 7 Days, 14 Days and 28 Days of healed concrete using Polyurethane

B. Split Tensile Strength for Polyurethane

The test is carried out by placing a cylinder by placing a cylinder out by placing a cylinder specimen horizontally between the loading surfaces of a compression testing machine. The load is applied until failure of the cylinder, along the vertical diameter. When the load is applied along the generators, an element on the vertical diameter of the cylinder is subjected to a vertical compressive stress, The loading condition produces a high compressive stress immediately below the two generators to which the load is applied. The specimens have been subjected to an applied load to induce initial crack. The cracking is minor and internal only. The Split Tensile strength test for cylinder samples containing polyurethane as self healing agent with the dosage of (1.5%, 2.0%, 2.5%, and 3.0%) added by the weight of cement was carried out as per IS 5816:1999. The tests were conducted on 7th, 14th and 28th day test results are tabulated in 3.2 .The graph showing the increase in split tensile strength for various proportions of polyurethane is shown in Figure 3.2. It is evident from the table that the compressive strength has been achieved well above the target strength of 8.32 N/mm2 . As a result the Split tensile strength is increased up to 76.53% with the addition of 2.5 % of polyurethane when compared to all other proportions at 28 days.

Table 3.2 Split Tensile Strength values of M60 grade concrete with Polyurethane

S.No	% of Polyurethane	Days	Split Tensile Strength in N/mm^2		% increase in split tensile strength
			BH	AH	
1	0	7	4.39	-	-
		14	5.73	-	-
		28	6.87	-	-
2	1.5	7	3.15	5.00	58.30
		14	3.56	6.57	84.5
		28	4.34	7.44	71.42
3	2	7	3.44	5.42	57.28
		14	3.98	7.38	85.15
		28	4.60	7.83	70.30
4	2.5	7	3.72	6.43	72.4
		14	4.34	8.10	86.80
		28	5.74	8.32	76.53
5	3	7	3.02	4.04	33.59
		14	2.89	4.40	52.14
		28	3.58	6.04	68.71

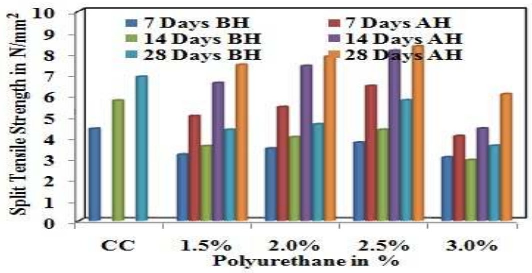

Fig 3.2 Split Tensile strength of cube 7 Days, 14 Days and 28 Days of healed concrete using Polyurethane

C. Flexural Strength for Polyurethane

The surface of the supporting and loading rolled is wiped and cleaned. The specimen is then placed in the machine in such manner that the load is applied to the upper most surface as cast in the mould. The axis of the specimen is carefully aligned within the axis of the leading device. No packing is used between the bearing surface of the specimen and rollers. The load is applied without shock and increasing continuously at a rate of specimen. The load is increased until the specimen fails and the maximum load applied to the specimen during the test is recorded. The specimens have been subjected to an applied load to induce initial crack. The cracking is minor and internal only. The Flexural Strength test for prism samples containing polyurethane as self healing agent with the dosage of (1.5%, 2.0%, 2.5%, and 3.0%) added by the weight of cement was carried out as per IS 516:1959. The tests were conducted on 7th, 14th and 28th day test results are tabulated in 3.3. The graph showing the increase in split tensile strength for various proportions of polyurethane is shown in Figure 3.3

Table 3.3 Flexural Strength values of M60 grade concrete with Polyurethane

Sl. No	% of Polyurethane	Days	Flexural Strength in N/mm²		% increase in flexural strength
			BH	AH	
1	0	7	4.41	-	-
		14	5.72	-	-
		28	6.88	-	-
2	1.5	7	3.15	5.00	25.83
		14	3.56	6.57	44.80
		28	4.34	7.44	66.58
3	2	7	3.41	4.93	44.4
		14	3.81	6.16	61.5
		28	4.61	7.20	56.08
4	2.5	7	3.72	6.43	60.6
		14	4.34	8.10	69.26
		28	5.74	8.32	85.04
5	3	7	3.02	4.04	18.60
		14	2.89	4.40	26.82
		28	3.5	6.04	32.14

It is evident from the table that the compressive strength has been achieved well above the target strength of 8.32 N/mm². As a result the Split tensile strength is increased up to 85.04% with the addition of 2.5 % of polyurethane when compared to all other proportions at 28 days.

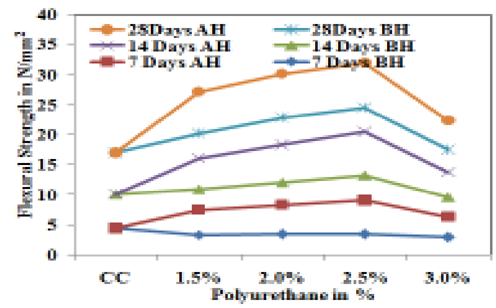

Fig 3.3 Flexural strength of cube 7 Days, 14 Days and 28 Days of healed concrete using Polyurethane

IV. Conclusions

Based on the experiments conducted in this study, the following conclusions were drawn.

1. The compressive strength arrived at 28 days are 73.49N/mm² for polyurethane. It indicates that, the usage of polyurethane is increasing the compressive strength by 13.51% than control concrete. Similar results were observed in flexural and split tensile strength and concrete with polyurethane was 20.9% and 21.1% more than control concrete
2. 2.5% of polyurethane are the optimum dosage for increasing the compressive strength, split tensile strength test and flexural strength.
3. This type of self healing concrete can be used for water retaining structures and tunnel structures. It reduces the direct cost for maintenance and repair.
4. The self healing agents polyurethane have an influence on compressive strength, split tensile strength and flexural strength on concrete in a larger scale.
5. Further this investigation may be extended to compare the various agents.

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