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Introducing Effective Microorganism as Self-curing Agent in Self-cured Concrete

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Abstract. The primary reason for the curing of concrete is to complete the hydration reactions of cement with other materials. However, the problem occurs when required ideal curing becomes challenging due to various anomalous structural elements. To mitigate this issue, a bacterial solution known as Effective Microorganism (EM) has been introduced as a self-curing agent that has favourable surface tension, viscosity and solubility in water. Different percentage of water i.e. 0%, 5%, 10%, 15%, 20%, and 25% were replaced with EM. The optimisation of percentage replacement of EM was based on the compression strength and water loss of concrete. The percentage of EM with 10% water replacing showed better compression strength as compared to other percentage replacements. With the optimum 10% percentage, compression strength was found 42 MPa and 49 MPa compared with 33 MPa and 43 MPa with control samples with air and water curing respectively. The water loss also reduced 2% with 10% EM replacement compared to the control sample. Results showed that 10% of EM is the optimum value to get desirable properties of concrete in air and water curing. EM can be used as a new self-curing agent as a novel approach in the area of self-curing concrete.

1. Introduction

Curing of concrete is an essential factor in all concretes to get their required properties such as strength, durability and other characteristics. Curing is essential, especially in early ages of concrete to enhance the process of hydration of cement, control concrete temperature and moisture movement in and from concrete. The main reason for curing in early ages is to prevent the loss of water from concrete so that it can gain strength in its early days [1, 2]. Conventional curing is practised by external methods, and these methods are performed to keep concrete warm and moist, so the hydration of cement continues until it completes strength gain [3]. First of all, self-curing was proposed to encounter the self-desiccation throughout the concrete [4]. [5, 6]. Recently, the self-curing concrete is a new approach to keep concrete moist and warm for better strength and durability [7]. The primary constituents for self-curing concrete are coarse aggregates, fine aggregates, cement, mixing water and self-curing agent, which are added during mixing [8]. The concept of self-curing concrete is that water is supplied by internal source by using porous aggregates or polymers, which can absorb a large amount of water during mixing[9]. It also has concept of reducing water evaporation from concrete and increases water storage capacity of concrete as compared to conventional concrete [10]. The materials used as self-curing agents are pumice [11, 12], paraffin wax [13], crushed returned concrete aggregates [14], crushed waste ceramic (which has shown better effect on concrete as self-curing agent [15, 16]), biomass-derived waste lightweight aggregates [17], rice husk ash [18], wood-derived materials used as self-curing agents for curing cement-based materials [19], lightweight expanded clay aggregates (LECA) [20], bentonite clay [21], perlite [21], diatomaceous earth[21], polyethylene-glycol which is used in different percentage by weight of cement and improves the concrete properties[22-24], zeolite aggregates [25], rotary kiln expanded shale used with C class fly ash in high volume fly ash concrete [26, 27], and crushed over burnt clay brick [28]. For improving internal curing, some portion of sand is replaced with saturated lightweight aggregates [29].

The Effective Microorganisms (EM) is discovered by Teruo Higa, a Professor of Horticulture at the College of Agriculture, University of Ryukyus in Okinawa, Japan. EM comes in a liquid form and consists of a wide variety of useful, beneficial and non-pathogenic microorganisms of both aerobic and anaerobic types coexisting. It is produced through a natural process of fermentation and not chemically synthesised or genetically engineered. Professor Higa started his development in 1968 with the first batch of what would eventually be called EM which got discovered in 1982 and after that it was further developed and refined [30]. However, its application in cementitious material is rarely reported. Use of EM in the cement-based material as an admixture is a new study. The types of EM which have been used and discovered have the potential to improve the concrete properties. The significant outcomes found in previous studies have initiated curiosity to carry out further investigation to study the effectiveness of EM in cement specimens [31].

It has been noticed in the previous studies that almost self-curing agents are natural aggregates or derived product of natural aggregates. Excess use of natural resources can cause their depletion. So, there is much need for research to find alternative self-curing agents.

2. Experimental Work

2.1. Design of concrete mixtures

The concrete grade 30 was designed to achieve 30 MPa compression strength at 28 days, which was according to the Department of the Environment (DOE) method of British specification. So, first of all, the control mixture was prepared, which contained 0% of EM. Other five mixtures were also made which included different percentage of EM replaced with mixing water of concrete. The detail content of concrete mixture for $1m^3$ is given in table 1. The water-cement ratio of control mixture was kept 0.55 and the slump was maintained between 60-180 mm. Portland cement was the primary ingredient of concrete and Type I cement was used. The maximum sizes of fine and coarse aggregates were kept 4.75 mm and 10 mm respectively. The concept of self-curing is that no external curing is applied on the concrete, which is why all the mixtures were subjected to air curing inside the laboratory.

Table 1. Design of concrete mixtures by DOE method.

Concrete mixtures	% of EM	Cement kg/m^3	Water kg/m^3	Fine Aggregates kg/m^3	Coarse Aggregates kg/m^3
Control	0	445	250	875	815
EM1	5	445	237.5	875	815
EM2	10	445	225	875	815
EM3	15	445	212.5	875	815
EM4	20	445	200	875	815
EM5	25	445	187.5	875	815

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2.2. Testing of Materials and Concrete
The physical appearance and solubility of materials were done manually with the help of a glass cylinder as shown in Figure 1. The surface tension of materials was done according to ASTM D1331-14[32] equipment as shown in Figure 2. The viscosity of materials was done according to ASTM D2983-17[33] viscometer used as shown in Figure 3. The workability of concrete mixtures was measured by the slump cone test, according to BS EN 12350-2 (2009)[34]., test setup is shown in Figure 4. Water loss was carried out on the sample by weighing it every day until water loss became constant [13, 24, 32-35]. The compression strength on cubes was tested according to BS EN 12390-3 (2009)[36]. Equipment as shown in Figure 5.

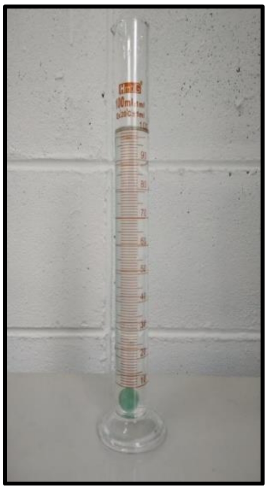

Figure 1. Glass cylinder.

Figure 2. Sigma 703D tensiometer.

Figure 3. Viscometer.

Figure 5. Slump cone test setup.

Figure 6. Universal testing machine (UTM).

3. Results and discussion

3.1. Physical appearance and solubility of materials
Effective microorganism is a new material in the area of concrete. In concrete technology, almost EM is used in liquid form. In general practice, water is colourless. So, concrete achieves grey colour. EM has a reddish-brown colour in its original form as shown in Figure 7. When water is replaced with EM from 0% to 25%, it also gives a different colour as shown in Figure 6. Initially liquid is colourless but when water is replaced with 10 % of EM, it changes into dark yellowish colour. EM is a solution. It is

used in concrete with mixing water of concrete. So, EM must achieve solubility and homogeneity in water. As shown in Figure 8, when 10% of EM is mixed with 90% of water, it produces the same colour and uniformity. Any separation of EM and water is also not found in the glass cylinder. As in previous research, it was noticed that the material such as paraffin wax, used as a self-curing agent having 100% solubility with water gave better performance in concrete [13, 33-37].

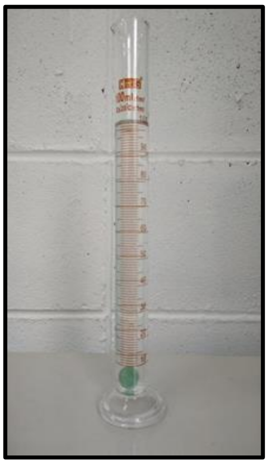

Figure 6. Water in the glass cylinder.

Figure 7. Pure Effective microorganism.

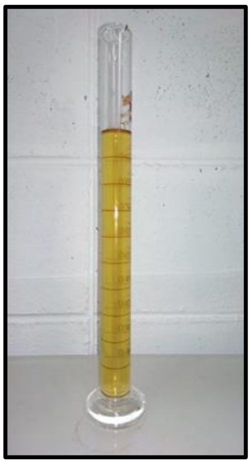

Figure 8. 10% Effective microorganism mixed with water.

3.2. Surface Tension of Materials

Surface tension is the energy, or work, required to increase the surface area of a liquid due to intermolecular forces. These intermolecular forces vary depending on the nature of the fluid [34-38]. Surface Tension of liquid materials plays a vital role inside the concrete. The surface tension of water, EM and EM mixed with water was measured. Surface tension property is related to the drying of concrete and internal pore structure of concrete. There are two primary reasons that drying is terrible for concrete. First, the reactions between cement and water (hydration) continue for many days and weeks after initial mixing. If the water is removed by drying, these reactions stop and the concrete cannot gain any more strength. Second, concrete shrinks when it dries. More specifically, the cement paste component of concrete shrinks, due to its pore system. This shrinkage is related primarily to the surface tension of water. In this research, it was found that EM has low surface tension as compared to water, as shown in Figure 9. Moreover, when 10% EM was mixed with 90% water, it was found that the mixed solution has higher surface tension than original EM and lower than water. The previous study showed that solutions having low surface tension than water reduce the drying, shrinkage and early self-shrinkage deformation by reducing the surface tension of pore water during concrete mixing to achieve concrete crack resistance [35-39].

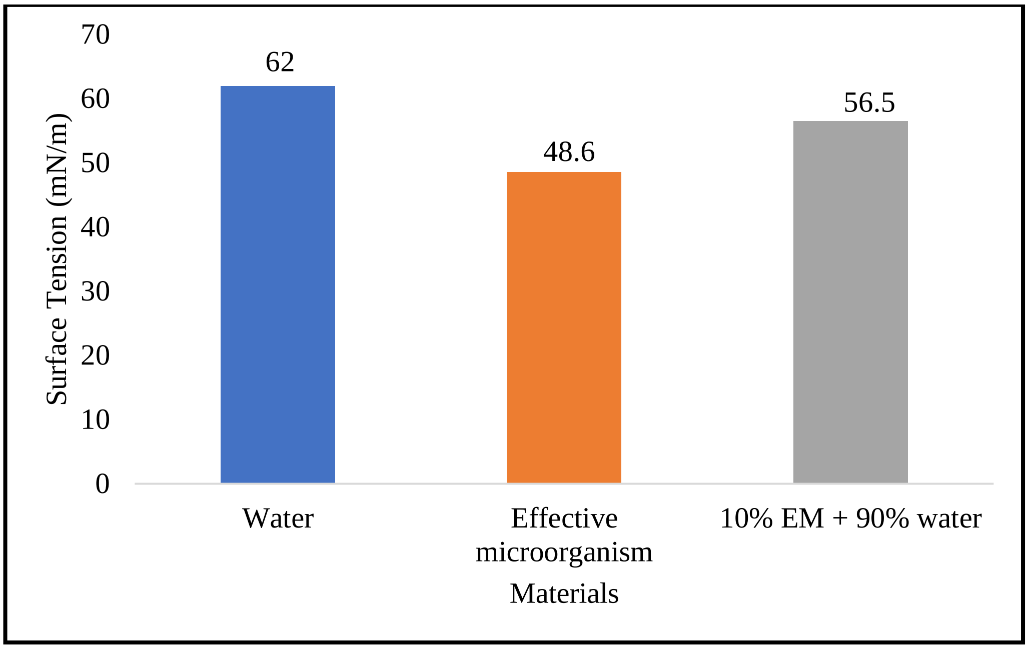

Figure 9. The surface tension of materials.

3.3. Viscosity of materials

The viscosity of the liquid is the property of resistance to the flow of liquid and viscosity means friction between the molecules of the fluid [34-38]. In the concrete, it has a slight effect on the concrete, especially in early ages. In this research, the viscosity of EM was found higher than water, and also the mixed solution of EM and water was slightly higher than water as shown in Figure 10. The high viscous solution was used to prevent segregation and make concrete homogenous. The high viscous solution also resistance internal water to move freely. In this research, it was found that viscosity has low effect on the fresh and hardened properties of concrete because the difference between water and EM-Water solution value is not much different [36-40].

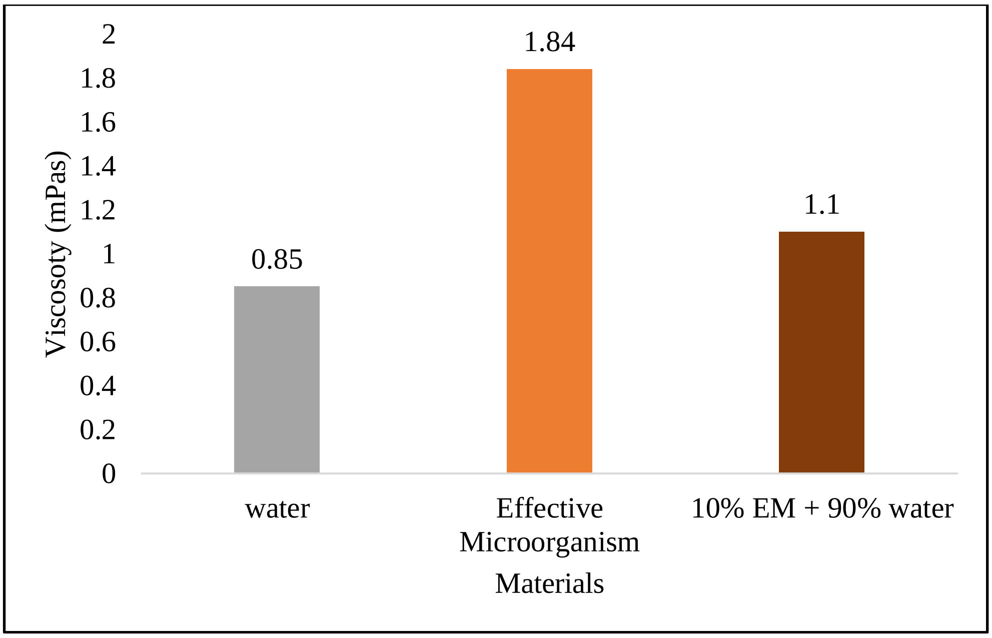

Figure 10. Viscosity of materials.

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3.4. Workability of concrete

Workability is measured to check the ease of concrete mixture. In this research, the slump was designed between 60 – 180 mm. The results showed that workability of concrete increased gradually by replacing the percentage of water with EM. As shown in the Figure 11, workability of control is lower than concrete with the EM replacement. All the concrete mixtures were in the range of designed slump. As water was replaced with the EM in mixing, water caused a reduction of surface tension. It caused the water to disperse easily during the mixing of concrete. It also caused water to wet the particles easily; that is why workability increased by water replacing with EM in mixing water [37-41].

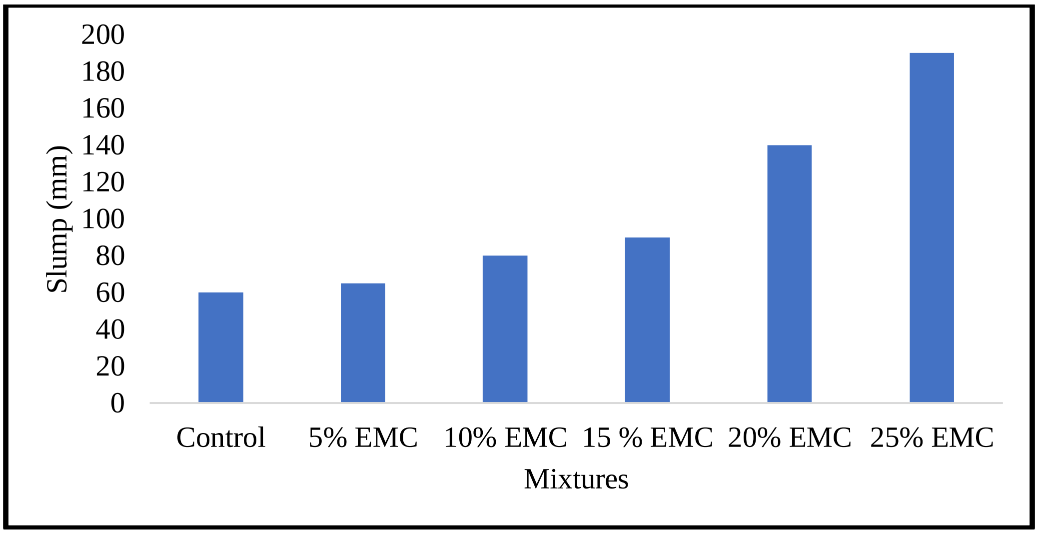

Figure 11. Workability of different concrete mixtures.

3.5. Water loss of concrete

The water content of concrete and curing of concrete are essentials in the early ages of concrete. In early ages, there is a high chance of water loss from concrete. That is the early age of concrete when the hydration of cement takes place. The water loss from self-cured concrete decreases as shown in Figure 12. The lowest water loss accrues, with the 5% water replaced with EM. 10% water replacement with EM is slightly high. Further, increasing from 15% to 25% of EM resulted in rising water loss. It was noticed that water loss occurred in the early age of concrete that is four days, after that it became constant. The reduction in water loss or less evaporation is due to lower surface tension of EM solution mixed with water. Generally, concrete with surface tension reduction exhibits slower drying, resulting in less mass loss at equal drying times than the corresponding material without low surface tension solution addition [38-42]. Another reason for the reduction in evaporation is due to less internal stress in the pore of concrete. The stress in the pore solution is directly proportional to its surface tension [39-43]. Water loss reduced due to slightly high viscosity water mixed with EM solution, which resisted the movement of water inside the pores.

3.6. The compression strength of concrete

There is no compromise on the durability and strength properties of concrete. Curing is an essential element in concrete technology to achieve its designed strength. In this research, the optimum strength was gained, while replacing 10% of water with EM that is 42 MPa at 28 days and the normal concrete with EM achieved the compression strength 33 MPa at 26 days as shown in Figure 13. It was noticed that the difference between the compression strength of 5%, 10% and 15% was not too much, as shown in Figure 13. The compression strength of 25% water replaced with EM was the lowest strength among all mixtures that was 31 MPa at 28 days, which was also lower than compression strength of normal concrete. The compression strength of concrete is based on water content and inter voids. Larger pores have less strength as compared with small pores concrete. Due to the low surface tension of mixing water with the EM, less diving force inside the pores was developed. The less driving force also made small size of pores and discontinued the voids [35-39, 38-42]. As mentioned above, water loss also reduced with EM. It means water is available for hydration of cement to achieve designed strength.

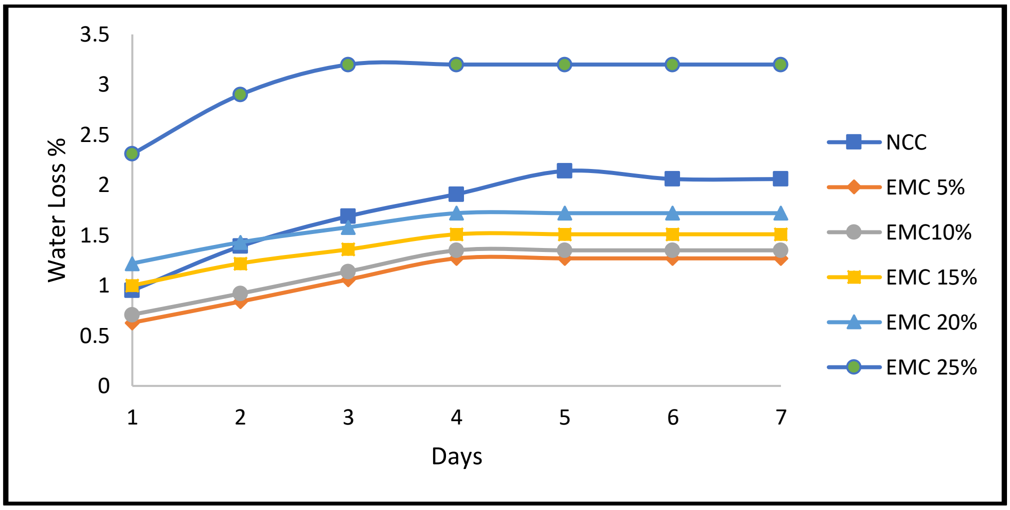

Figure 12. Water loss percentage of different concrete mixtures.

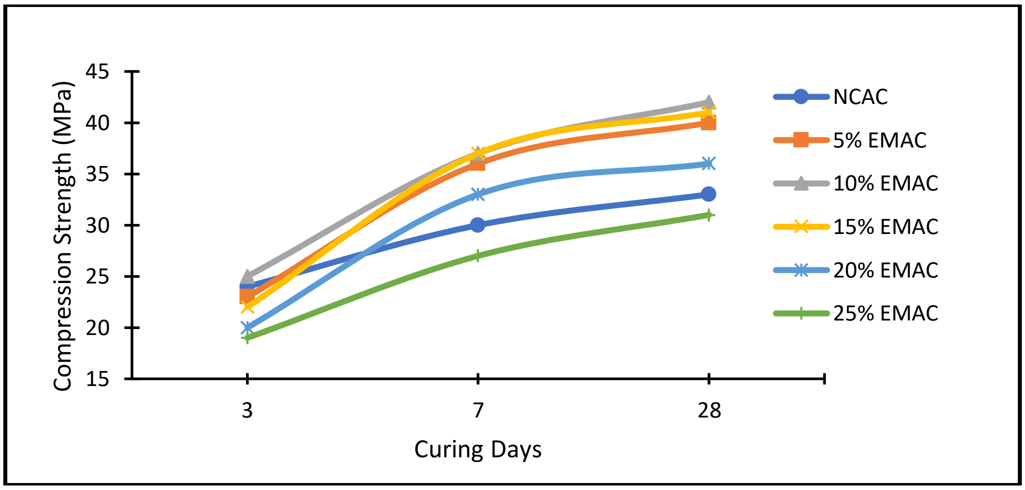

Figure 13. Compression Strength of different concrete mixtures.

4. Conclusion

Self-curing concrete technology improves the properties of concrete to produce more durable and strength concrete product. In this research, a new self-curing agent was introduced known as Effective microorganism (EM). It is in reddish-brown colour having low surface tension and slightly high viscosity than water. This enables EM to be a self-curing agent in the area of self-curing concrete. The workability of self-cured concrete with EM is also higher than normal concrete. The water loss of self-cured concrete is less as compared with normal concrete that is 1.35% and 3.5%, respectively. The optimum value of water replaced with EM was found with replacement of 10% EM. The compression strength of self-cured concrete was achieved at 10% of EM replaced with water. Self-cured concrete increased 21.5% as compared with normal concrete in air curing. The results indicate that effective microorganism can be used as a self-curing agent.

5.Acknowledgments
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