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INFLUENCE OF USING EFFECTIVE MICROORGANISMS IN A MOLASSES MEDIUM ON THE COMPRESSIVE STRENGTH, CORROSION RESISTANCE AND PERMEABILITY OF CONCRETE

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Abstract

In this study, we delve into the innovative application of Effective Microorganisms (EM) as a water-replacing concrete admixture. This research is centered on evaluating the impact of EM on enhancing concrete's mechanical properties. We methodically replaced varying percentages of the standard mixing water with an EM solution, specifically 2%, 3%, 5%, 8%, and 10%, to investigate the subsequent effects on concrete's performance.

This study introduces Effective Microorganisms Concrete (EMC), a new concrete variant enhanced with Effective Microorganisms (EM). EMC demonstrates significantly improved properties over traditional concrete. Notably, its compressive strength increased by 36.75% compared to standard concrete, indicating potential for more robust and enduring constructions. EMC's corrosion resistance also saw a remarkable upsurge, rising by 66%. This enhancement is crucial for the structural integrity and safety of concrete in corrosive environments, potentially reducing maintenance costs and prolonging infrastructure lifespan. Another key finding is EMC's enhanced impermeability, being 63% less permeable than control specimens. This reduced permeability is essential for concrete durability, particularly in water-exposed structures, as it helps prevent water intrusion, a major factor in concrete degradation. Overall, EMC's advancements in strength, corrosion resistance, and impermeability mark a significant breakthrough in concrete technology, offering prospects for more durable, sustainable, and resilient construction materials.

Keywords

Bio Concrete; Effective Microorganisms (EM); Compressive Strength; Corrosion Resistance; Permeability of Concrete; Microbial concrete; Corrosion rate; C-S-H; CaCO3; SEM; EDX.

1. Introduction

Concrete is one of the largest producers of carbon dioxide, it's the most widely used construction material in the world. which can be found in swathes of city pavements, bridges that span vast rivers, and the tallest skyscrapers on earth. It is the second most-consumed material after water and it shapes our built environment [1]. In 2009, it was estimated that roughly 25 billion tons of concrete were manufactured globally each year [1]. With nearly 0.9 ton of CO_2 is emitted for each Ton used of Cement [2]. Making it producing nearly 5% of worldwide manmade emissions of CO_2; 50% of which is from the Cement hydration chemical process and 40% from the manufacturing process burning fuel [3]. It's our responsibility to be aware of the climate change situation that's threatening our world and reduce carbon emissions from using cement in particular and from the construction industry overall, or we'll be leaving future generations to face the consequences.

Concrete is a homogenous substance composed of cement, fine aggregate, coarse aggregate, and water in certain quantities. Concrete possesses interconnecting pores, rendering it a porous material that is vulnerable to various forms of degradation such as chloride, carbon dioxide, sulphate, and freezing and thawing cycles. If a material were used as an additive to make concrete more resistant to these attacks, or a mixture with less cement required but has the same mechanical properties compared to control, lowering the amount of cement required to make concrete can be achieved thus lowering carbon dioxide emissions from one of the most used materials all over the planet.

Teruo Higa, a horticulture professor at the University of the Ryukyus in Okinawa, Japan, discovered Effective Microorganisms (EM). EM is a liquid substance that contains a diverse range of efficient, advantageous, and nonpathogenic microorganisms, including both aerobic and anaerobic kinds that coexist. It is produced through a natural process of fermentation and not chemically synthesized or genetically engineered.

Concrete enhancing technology is a life-long research. The research is demanded to discover the best additives and or admixtures that can produce good concrete mixes in terms of physical, chemical, and mechanical properties in a more economical, sustainable, and environmental-friendly. Several studies have been conducted to improve the compressive strength, corrosion resistance, and to reduce the permeability of reinforced concrete structures by modifying cementitious materials in concrete or using pozzolanic or filler materials, or by using chemical additives.

Concrete has played a pivotal role in the creation of numerous architectural marvels and infrastructural advancements. However, due to its inherent limitations, there has been a constant need for the ongoing improvement of construction materials and methodologies. Traditional concrete formulations, although known for their durability, are prone to several types of deterioration as time passes. The main focal points encompass the decline in compressive strength as a result of aging and exposure to the environment, the corrosive effects of aggressive chemicals on steel reinforcements contained inside the concrete, and the degradation of concrete surfaces caused by a range of physical and chemical factors. It is imperative to acknowledge and tackle these concerns in order to prolong the longevity and improve the ecological viability of concrete structures.

The compressive strength of concrete is a fundamental mechanical characteristic that plays a crucial role in determining its structural integrity. Improving this characteristic has the potential to result in structures that are both safer and more sustainable, hence mitigating the necessity for excessive utilization of materials and reducing construction expenses. The utilization of Effective Microorganisms (EM) techniques inside a molasses-based medium has demonstrated potential in enhancing the compressive strength of concrete. This is achieved through the stimulation of calcium carbonate precipitation and the facilitation of more compact concrete matrices. This study investigates the evidence about these impacts and aims to establish a full comprehension of the underlying mechanisms.

Maintaining the structural integrity of reinforced concrete relies heavily on corrosion resistance, which is considered a crucial factor in the overall performance of concrete. If the issue of corrosion affecting embedded steel reinforcements is not effectively addressed, it might result in structural failure. The utilization of EM in a molasses medium has the potential to boost corrosion resistance by facilitating the creation of an alkaline environment through microbial activity and the formation of protective layers on concrete surfaces.

The durability of concrete, which includes its ability to withstand freeze-thaw cycles, chemical exposure, and abrasion, is an important aspect of its overall performance. The examination of the potential of Effective Microorganisms (EM) techniques in a medium containing molasses to enhance the longevity of concrete structures through the mitigation of micro-cracks, reinforcement against frost-induced damage, and safeguarding against diverse types of deterioration is deserving of thorough investigation. This paper critically assesses the current body of information and makes a valuable contribution to the scholarly discussion pertaining to this potential field of research.

The process of integrating Effective Microorganisms into a molasses medium within concrete is an intricate and diverse undertaking, necessitating a comprehensive comprehension of microbiology, material science, and building technology. The objective of this paper is to examine significant inquiries, corroborate established conclusions, and provide a valuable contribution to an expanding knowledge base. Through a comprehensive investigation of the impact of Effective Microorganisms (EM) forces in a medium including molasses, our objective is to get a deeper understanding of their effects on the compressive strength, corrosion resistance, and durability of concrete. By doing so, we aspire to offer valuable insights that have the potential to revolutionize the field of concrete construction, leading to the development of more sustainable and long-lasting infrastructure.

In this study, the author aims to find if using EM can help reduce the amount of cement required to make concrete; either by making more durable concrete structures in the first place or by lowering the amount of cement required when compared to control specimens while maintaining the same mechanical properties.

2. The Role of Effective Microorganisms

EM was initially developed by Higa and Parr in the 1970s, focusing on around 80 beneficial microorganism species available in the environment, of which five were especially vital for EM's viability. This development was initially for agricultural purposes, enhancing microbial diversity in soils and water [4]- [7]. The first utilization of EM in concrete was marked by the work of Sato et al. in 2003, who experimented with EM1, EM3, and EMx. Since then, research into EM use in concrete has grown, with studies often comparing the performance and mechanisms of EM-based concrete to those involving non-product microorganisms [8]- [14].

The initial hypothesis underlying the use of EM in concrete pertains to the belief that microbial activity can positively affect the concrete matrix. This hypothesis is rooted in the idea that microorganisms can induce biomineralization processes, notably calcium carbonate precipitation, which in turn densifies and strengthens the concrete structure. One of the earliest studies to explore this was by Sato et al., who in their pioneering research, noted an improvement in the compressive strength of concrete with the addition of EM [15]. This improvement was primarily attributed to the microbial activity within the concrete matrix, suggesting a promising avenue for enhancing concrete properties using biogenic methods.

The mechanism behind EM's impact on compressive strength revolves around the microbial synthesis of compounds that contribute to the concrete's matrix densification. For example, lactic acid bacteria, a key component of EM, are known for their ability to produce lactic acid. This acid has been observed to accelerate the hydration of Portland cement, leading to increased strength. In a study, Kastiukas et al. reported a notable increase in compressive strength in a concrete sample containing lactic acid [16]. This finding underscores the potential of EM constituents in altering the concrete's hydration dynamics.

Sam et al. conducted a comparative analysis, revealing that concrete with EM achieved higher compressive strengths at both 7 and 28 days compared to control concrete [17]. Interestingly, the study also observed that as the concentration of EM increased, there was a corresponding increase in strength. However, this trend plateaued and even slightly decreased as the concrete aged, suggesting an optimal concentration range for EM in concrete mixes.

The concentration of microorganisms in EM is a critical factor in determining its effectiveness in enhancing compressive strength. Higher concentrations of EM typically lead to a more pronounced improvement in strength. However, this relationship is not linear, as excessive EM concentrations can lead to diminishing returns, possibly due to the limitation of available nutrients and space within the concrete matrix [17].

3. MATERIALS AND METHODOLOGY

3.1 Properties of Cement

Ordinary Portland Cement (OPC) grade 42.5 was used. It was tested as per American code (ASTM Type I) and its properties are given in **Table (1)**.

Table 1. Physical Properties of Ordinary Portland cement

Physical Properties	Values
Fineness of Cement	0.23 m^2/g
Standard Consistency	31%
Initial Setting Time (min)	40
Final Setting Time (min)	497
Specific gravity	3.25

3.2 Coarse and Fine aggregate properties

Crushed Stone with nominal maximum size (N.M.S.) on 10 mm sieve was used as the coarse aggregate while natural sand of nominal maximum size (N.M.S.) of 4.75mm was used as fine aggregate. The tests were made as per the American code for concrete mix (ASTM-C128) and (ASTM-C127).

3.3 Properties of Mixing Water

Normal tap water was utilized. It was boiled and left to cool down to room temperature before being used. Boiling the water was to make sure it's free of any Microorganisms contaminates and any chlorine added at the water treatment plant as per ASTM D 1193.

3.4 Properties of Effective Microorganisms & Molasses

Effective Microorganisms were supplied by the Department of Micro-Biology of the Egyptian Agricultural Research Center. It was produced through the fermentation process with Molasses - an organic material which is the byproduct of refining sugarcane into sugar - as the growth media. Molasses is relatively cheap and available to use. After fermentation EM was stored in airtight containers because of the anaerobic nature of some of the microorganisms. The EM used contains five families of microorganisms which are lactic acid bacteria, yeast, actinomyces, zymotic eumocetes, and photosynthetic bacterium. Properties of the fermented EM solution are given in **Table (2)**.

Table 2. Physical Properties of the EM solution

Physical Properties	Values
Density	10 g/mm^3
pH	3.87
Color	Light brown
Smell	Sweet-sour
Specific gravity	3.25

3.5 Mix Design

Two main concrete mixes (M1&M2) were made as per the ACI-211-11 standards with six sub-categories. The first main mix of 30 MPa compressive strength were designed and prepared with a cement quantity of 350 kg/m^3 and a water-to-cement ratio (w/c) of 0.46 while the second main mix is of Grade 35MPa with a cement quantity of 450 kg/m^3 and the same (w/c) as the first mix. The sub-categories of each main mix are regarding the percentage of the EM added to each mix. It was **chosen** to examine the effect of adding EM at 2,3,5,8 and

10% as a partial replacement of the mixing water. The Concrete mixes and its proportions are given in **Table (3)**.

Table 3. Concrete mixes' proportions

Mix	Cement (kg/m³)	C.Agg (kg/m³)	F.Agg (kg/m³)	Water (kg/m³)	EM (kg/m³)
M1C	350	1177.6	801.5	161.0	-
M1E2	350	1177.6	801.5	157.78	3.22
M1E3	350	1177.6	801.5	156.17	4.83
M1E5	350	1177.6	801.5	152.95	8.05
M1E8	350	1177.6	801.5	148.12	12.88
M1E10	350	1177.6	801.5	144.90	16.10
M2C	450	1177.6	801.5	207.0	-
M2E2	450	1177.6	801.5	202.86	4.14
M2E3	450	1177.6	801.5	200.79	6.21
M2E5	450	1177.6	801.5	196.65	10.35
M2E8	450	1177.6	801.5	190.44	16.56
M2E10	450	1177.6	801.5	186.30	20.70

3.6 Compressive strength

The compressive strength of concrete was examined at 3, 7, 28, 56, 180 and 365 days in accordance with the ASTM C39. The specimens used for testing were standard cubes having dimensions of 100x100x100 mm.

3.7 Corrosion resistance

The corrosion resistance of concrete was determined after 365 days. The specimens used for testing were standard cylinders having a diameter of 100 mm and a height of 200 mm. A series of standardized tests were conducted. The tests involved subjecting reinforced concrete specimens, both with and without EM, to aggressive environmental conditions, simulating conditions typically encountered in practical applications. The specimens were exposed to chloride ions rich environments - which are known to accelerate corrosion process.

Electrochemical impedance spectroscopy testing method was used, the computer-controlled Potentiostat-Galvanostat Model 273A and the analyzer of HF Frequency Response SI 1255 were used for frequency response. The test uses a three-electrode system including a working electrode (steel reinforced), an auxiliary electrode (316 stainless steel), and the reference electrode (SCE). Before each test, 30 min were allowed for each sample to reach steady state. To investigate the properties of concrete and reinforcement simultaneously, the full frequency range (high, medium and low) was applied in the 1–10 MHz range with a voltage range of 10 mV and simulated seawater electrolyte (3.5% NaCl) was used.

3.8 Permeability

The water permeability of concrete was evaluated in accordance with the test described in ASTM C1585 which consists of applying water under pressure to the hardened concrete specimen which has been water cured, then splitting the specimen and measuring the depth of penetration of the water front. Standard cubes with dimensions of 150×150×150 mm were casted and curing. Two main concrete mixes (M1&M2) were made as per the ACI-211-11 standards with six sub-categories. The first main mix of 30 MPa compressive strength were designed and prepared with a cement quantity of 350 kg/m³ and a water-to-cement ratio (w/c) of 0.46 while the second main mix is of Grade 35 with a cement quantity of 450 kg/m³ and the same (w/c) as the first mix. The sub-categories of each main mix are regarding the percentage of the EM added to each mix. It was chosen to examine the effect of adding EM at 2,3,5,8 and 10% as a partial replacement of the mixing water as shown in **Table (3)**.

4. RESULTS

4.1 Compression test results

The compressive strength of concrete enhanced with Effective Microorganisms (EM) have been measured over an extended period.The results were obtained at 3, 7, 28, 56, 180 and 365 days and shown in **Table (4)** and **Fig.1** for Mix no.1 and in **Table (5)** and **Fig.2** for Mix no.2. The values shown are the average of 3 specimens.

Table 4. Development of Compressive Strength for Mix 1

Mix (N/mm²)	3 (days)	7 (days)	14 (days)	28 (days)	56 (days)	180 (days)	365 (days)
M1C	8.4	15.6	21.1	25.3	27.4	28.8	29.0
M1E2	18.4	22.0	30	34.6	36.1	37.8	38.3
M1E3	14.8	19.1	24.4	28.1	30.0	31.7	32.4
M1E5	13.0	16.9	22.4	26.9	28.4	29.8	30.3
M1E8	7.9	14.1	19.7	23.4	25.1	25.9	26.3
M1E10	5.7	11.2	16.1	20.0	22.1	22.9	23.4

Table 5. Development of Compressive Strength for Mix 2

Mix (N/mm²)	3 (days)	7 (days)	14 (days)	28 (days)	56 (days)	180 (days)	365 (days)
M1C	18.9	26.1	31.6	35.7	37.2	37.9	38.2
M1E2	23.5	28.7	33.8	38.1	39.2	39.9	40.3
M1E3	26.7	33.1	38.4	42.3	44.9	45.7	46.2
M1E5	20.5	27.4	32.8	37	38.1	38.8	39.2
M1E8	17.9	24.8	30	34.1	35.8	36.5	36.9
M1E10	14.5	20.7	25.6	30	31.8	32.6	32.9

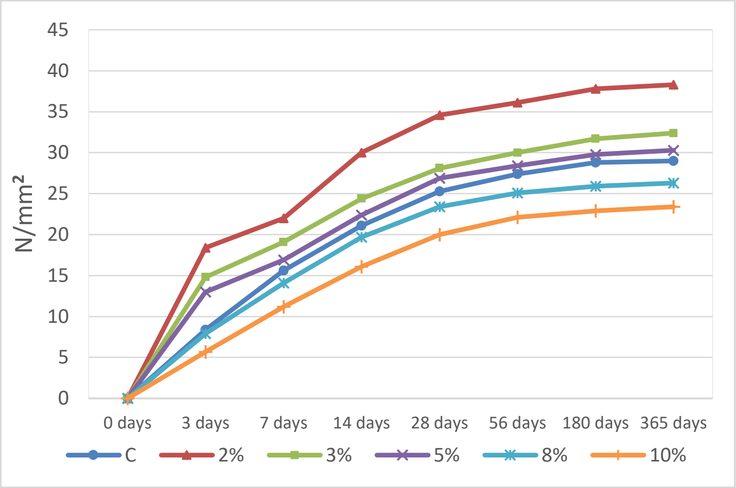

Fig.1 Mix No.1 Relation between the compressive strength and time

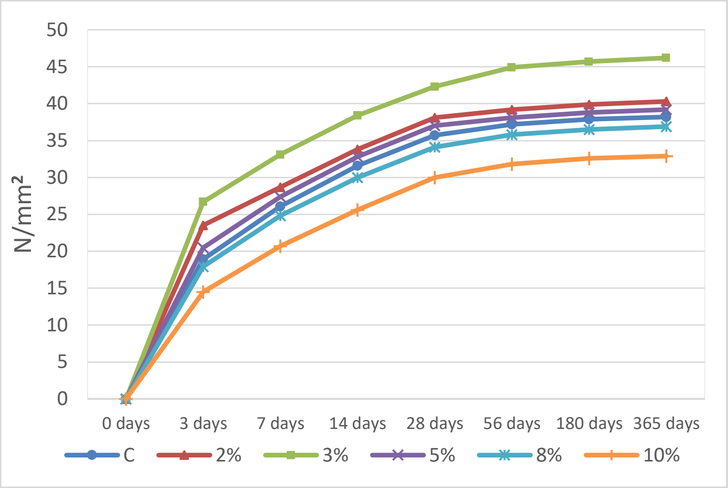

Fig.3 Mix No.2 Relation between the compressive strength and time

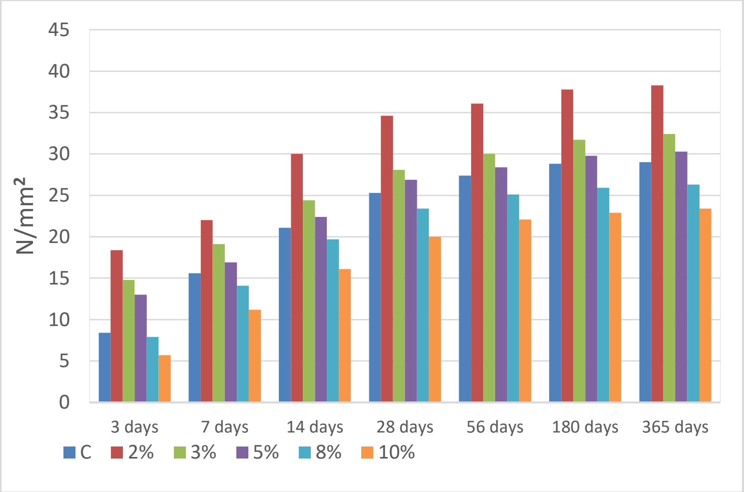

Fig.2 Mix No.1 Relation between the compressive strength and time

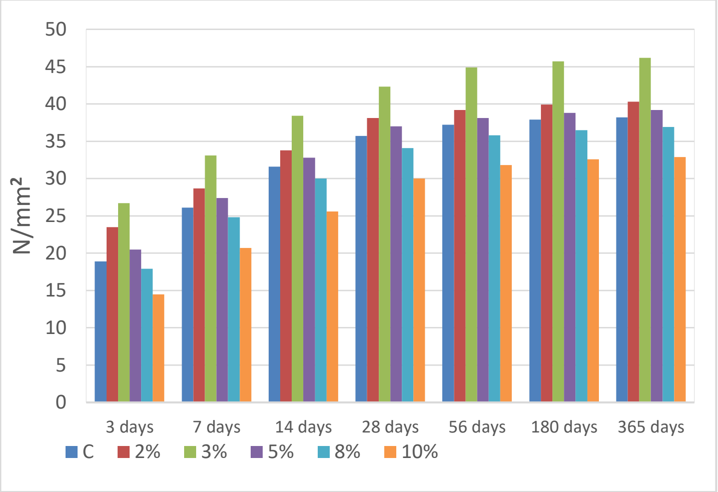

Fig.4 Mix No.2 Relation between the compressive strength and time

4.2 Corrosion test results

The test results are for 3 standard cylinders for each percentage and the test results are shown in **Table (6)** and **Fig 6.** The control specimens, which did not contain EM, exhibited the expected corrosion progression over the testing period. Visual inspection and electrochemical measurements revealed the presence of corrosion products on the surface of reinforcing steel, indicative of ongoing corrosion activity. These control specimens experienced significant mass loss due to the corrosion of steel reinforcement, ultimately leading to a decrease in the structural integrity of the concrete. In contrast, concrete Mix 1 specimens incorporating EM exhibited an improvement of 8.6% up to a remarkable 66.4% in corrosion resistance and 25.8 - 65.5% for Mix 2. Visual examination of these specimens revealed minimal or no visible signs of corrosion on the reinforcing steel surfaces. Electrochemical measurements confirmed the highly positive impact, as the polarization resistance increased significantly, indicating a substantially reduced corrosion rate. The formation of a protective layer on the concrete surface due to the alkaline environment created by microbial activity was evident in the EM-infused specimens.

Table 6. Concrete mixes' Corrosion rate

Mix	Rate (μm/year)
M1C	522
M1E2	477.1
M1E3	381.2
M1E5	175.3
M1E8	651.3
M1E10	903.1
M2C	487.2
M2E2	361.5
M2E3	238.1
M2E5	167.6
M2E8	713.9
M2E10	877.4

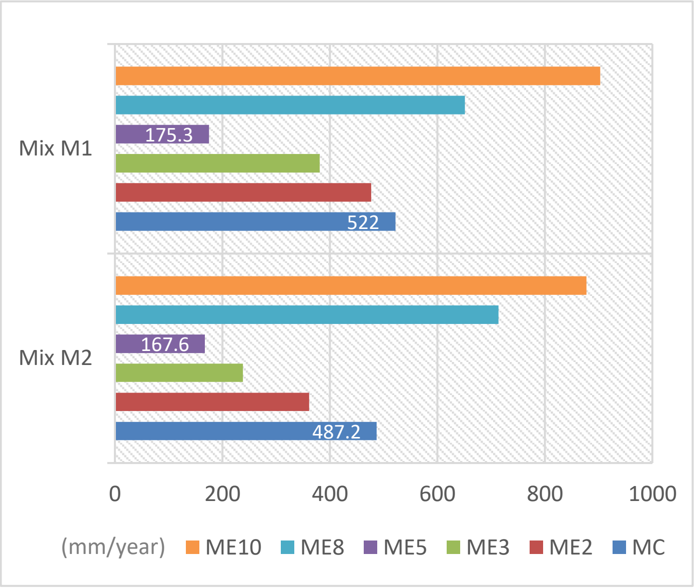

Fig 6. Concrete mixes' Corrosion rate

4.3 Permeability test results

The depth of water penetration was measured at 28 days and the test results are shown in **Table (7)** and **Fig.7**. These results represent the average values of 3 Specimens. From these test results, the following observations can be made:

- The initial depth of water penetration of M1C was (19 mm).
- By adding EM of 8% into the mix M1E8, the depth of water penetration decreased from 19 mm to 11 mm.
- The water permeability test results have shown that using EM with a percentage of 8% gave the best result in reducing the depth of penetration of water Concrete.

Table 7. Concrete mixes' Water propagation

Mix	Depth (cm)
M1C	19
M1E2	19
M1E3	18.5
M1E5	14.3
M1E8	12
M1E10	13
M2C	18
M2E2	17.5
M2E3	16.7
M2E5	13.5
M2E8	11
M2E10	12.8

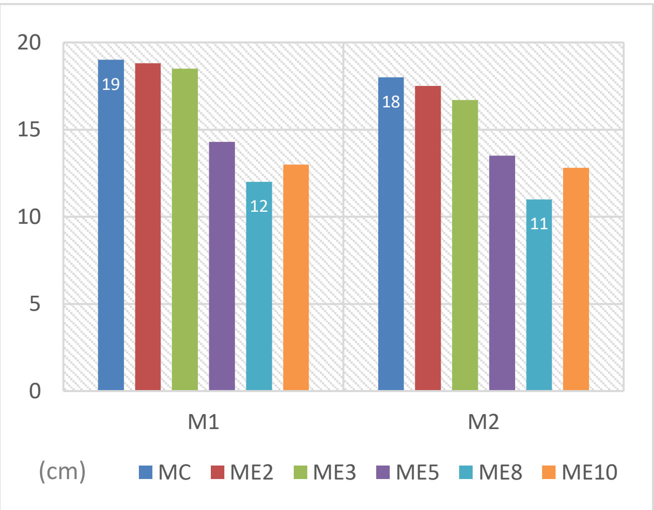

Fig 7. Concrete mixes' Water propagation

4.4 SEM analysis

The SEM micrographs of the control sample and samples with different EM percentages are depicted in Figures (8), (9), (10), and (11), revealing a well-defined and uniform microstructure along with a substantial increase in the size of calcite crystals. The crystals are of spherical, cubical, and rhombohedral shapes, as it has been discussed by Muynck et al. [18] and Sam et al. [17]. Due to this densification incident, higher mechanical strengths, lower corrosion rates and less permeability were acquired, as presented earlier. It could be explained that the cells of EM's bacteria enhanced the calcite precipitation; first by accelerating the carbonation process [2]. It should be pointed out not to pay attention to cracks shown in the SEM micrographs; it is generated either from compression testing or preparation of specimen's chip.

More crystalline growth of calcites was detected in the M1E2 matrix **Figure (9)** compared to the M1C one **Figure (8)**. The impact of EM on the concrete matrix can be summurized, focusing on C-S-H production rate, $Ca(OH)_2$ reduction, and $CaCO_3$ formation:

- Microstructure density: A denser microstructure with fewer voids and cracks could indicate improved binding and potentially higher strength due to the influence of EM.

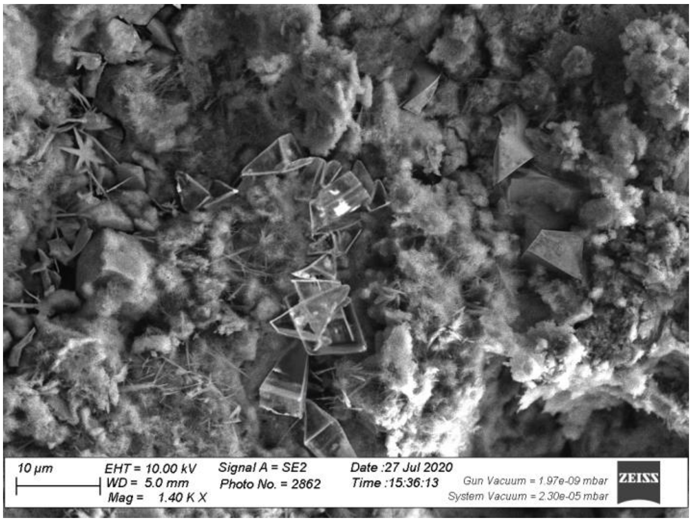

Fig 8. SEM Micrograph of M1C

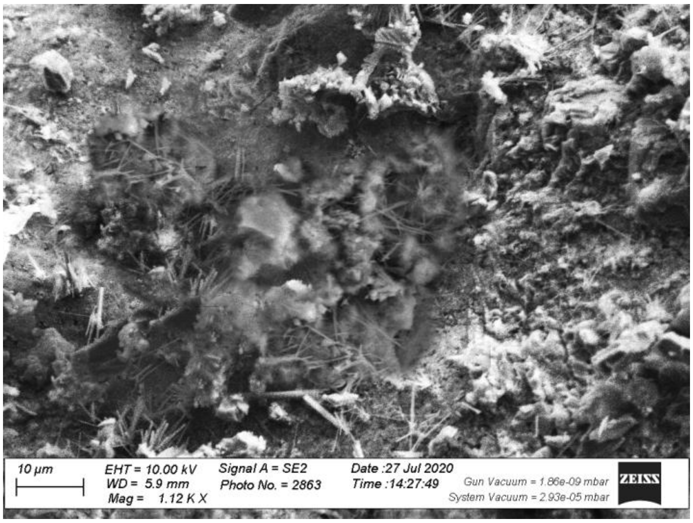

Fig 9. SEM Micrograph of M1E2

- C-S-H morphology: The presence of well-developed, dense C-S-H gel with a low porosity-to-solid ratio suggests good hydration and enhanced mechanical properties, The crystals in the image that are densely packed and seem to form a continuous matrix are likely indicative of C-S-H.
- The presence of EM have influenced the nucleation and growth of C-S-H crystals. It's opvious that EM facilitated a more homogeneous distribution or altered the morphology of the C-S-H, which led to changes in the strength and durability of the concrete.

In E1M5 **Figure (10)** less Calcium Hydroxide and more Calcium Carbonate is found compared to the M1C **Figure (8)**.

- $Ca(OH)_2$ distribution: the absence of hexagonal plates which is the characteristic of $Ca(OH)_2$. A decrease in the quantity or size of these plates as compared to control samples without EM indicate a reduction in $Ca(OH)_2$. A more evenly distributed and reduced concentration of $Ca(OH)_2$ crystals imply effective pozzolanic activity.
- Presence of $CaCO_3$: Identifying rhombohedral calcite crystals, especially around aggregate particles or filling voids, could be evidence of microbial-induced carbonate precipitation (MICP) activity.

In E1M8 **Figure (11)** more Calcium Carbonate and less C-S-H is found compared to the M1C **Figure (8)**.

- Presence of a denser CaCO3 matrix: Identifying more rhombohedral calcite crystals, especially when compared to M1E5 **Figure (10)**, could be evidence of less permeable concrete.
- C-S-H reduced production: The higher concentration of EM might have influenced the nucleation and growth of C-S-H in a negative way resulting in less C-S-H Crystals which is the primary source of strength in concrete.

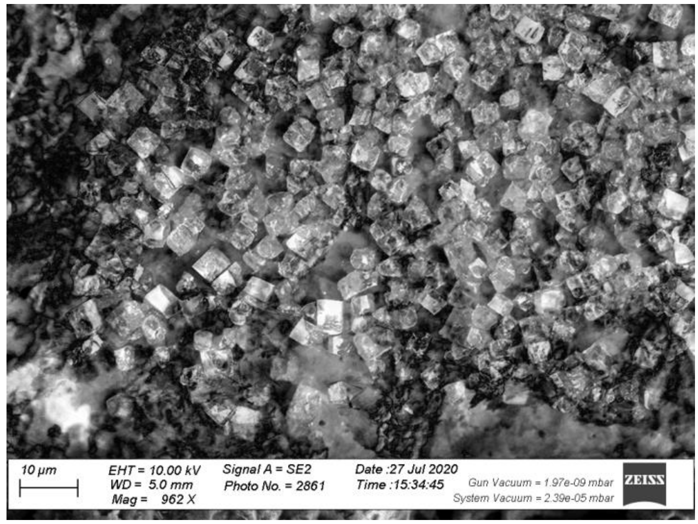

Fig 10. SEM Micrograph of M1E5

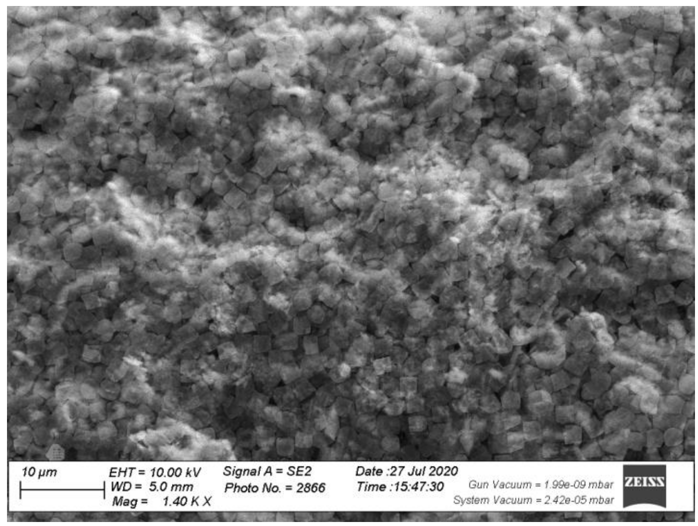

Fig 11. SEM Micrograph of M1E8

4.5 EDX analysis

The Energy-Dispersive X-ray Spectroscopy (EDX) test was conducted as part of the comprehensive analysis to explore the influence of using Effective Microorganisms (EM) in a molasses medium on the compressive strength, corrosion resistance, and permeability of concrete. The EDX analysis provided valuable insights into the elemental composition of the concrete specimens, shedding light on potential chemical changes induced by the incorporation of EM and molasses.

The EDX analysis revealed several noteworthy findings:

Calcium and Silicon Content: The EM-treated specimens showed a higher concentration of calcium and silicon compared to the control specimens. This suggests that the incorporation of EM have led to enhanced cement hydration and the formation of a denser, more compact calcium silicate hydrate matrix. This improvement in the cementitious matrix likely contributed to the observed increase in compressive strength and impermeability.

Iron Content: The iron content in the EM-treated specimens was lower than in the control specimens. This reduction in iron content is an encouraging sign, as it indicates a lower susceptibility to corrosion of the steel reinforcement. The enhanced corrosion resistance observed in the study aligns with this finding.

Chlorine Content: A significant reduction in chlorine content was observed in the EM-treated specimens. This reduction is highly significant as it points to a diminished presence of chloride ions within the concrete. The lower chlorine content is in line with the remarkable improvement in corrosion resistance demonstrated in the study, as reduced chloride exposure inhibits the corrosion process.

Sulfur Content: The sulfur content in the EM-treated specimens was also notably lower. A lower sulfur content suggests a reduced risk of sulfate attack on the concrete, contributing to its increased durability.

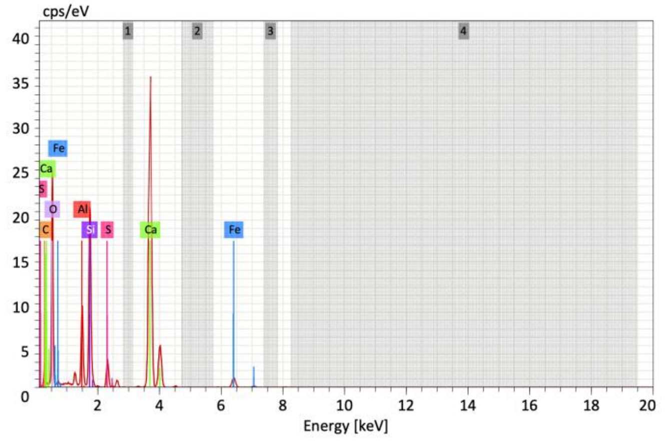

Fig 12. EDx Graph of M1C

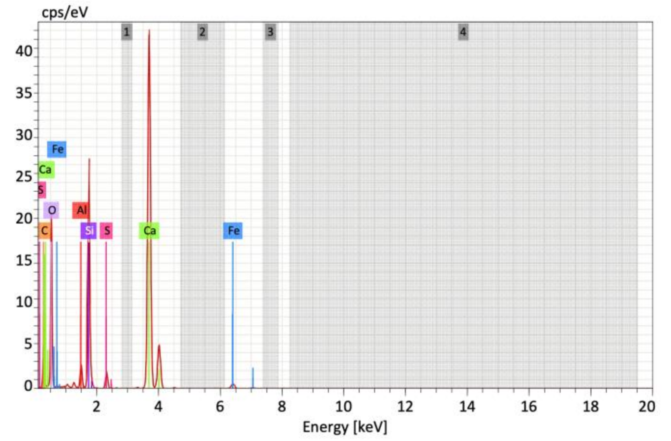

Fig 13. EDx Graph of M1E2

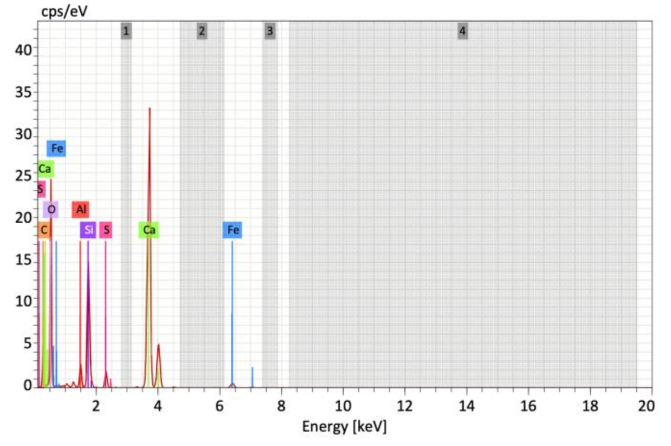

Fig 14. EDx Graph of M1E5

4.6 EM/Cement ratio

Based on the findings, it has been determined that various EM/Cement ratios can be employed for various purposes, as indicated in **Table (8)** below.

Table 8. Effective Microorganisms/Cement Ratio

Aim	EM/C Ratio
Compressive Strength	0.92/100
Corrosion Ressistance	2.3/100
Impermiability	3.68/100

5. Conclusion

The influence of using Effective Microorganisms (EM) in a molasses medium on the compressive strength, corrosion resistance, and permiabilty of concrete has been a central focus of this paper. Our investigation has sought to shed light on the potential benefits and challenges associated with this innovative approach, with the aim of contributing to the advancement of sustainable and resilient concrete construction practices.

Studies on the introduction of EM into concrete have improved the conventional mechanical and permeation properties chiefly. The impact of such microorganisms on the corrosion of rebar for the reinforced concrete application was less civilized. This research presents a comparison between ordinary concrete mixes and the effect of adding EM on the compressive strength, and durability ones (corrosion protection and permeability) of concrete. Thus, from the results found the following is drawn:

- Specimens of Mix 1 with 2% EM showed 36.75% inrease in the compressive strength at age of 29 days compared to the control.

- It's noted that Mix 2 with higher cement content required higher EM percentage to achive similar gains in compressive strength, Testing Mix 2 with 3% EM showed 20.9% gains in the compressive strength.

- The increment gain of concrete mechanical strengths after 3 and 7 days of cured EM specimens in fresh-water were higher than those after 28 days.

- A correlation between the concentration of EM and Concrete strength have been found, indicating that as the concentration of EM raised, strength also increased. Interestingly, this pattern reached a point of stability and even experienced a decline in concrete strength as the EM percentage used increased.

- The bigger diameter size of concrete pores (at early stages of curing) compared to the smaller ones (after semi-total hydration of cement) accommodate that EM cells produced calcite minerals resulting in a denser concrete matrix and reduced spores.

- Specimens with 5% EM exhibited a better and pronounced corrosion resistance than the control mix and other EM mixes' with different percentage under the same curing conditions. Concrete Mix 1 specimens incorporating 5% EM exhibited an improvement of 8.6% up to a remarkable 66.4% in cor-rosion resistance and 25.8 - 65.5% for Mix 2. Visual ex-amination of these specimens revealed minimal or no visible signs of corrosion on the reinforcing steel surfaces.

- The corrosion rate of the control specimens is increased under the effect of chloride ions in seawater but decreased significantly in the EM ones, which candidates the implementation of EM in the marine medium.

- The improvement in corrosion resistance observed in the EM specimens' can be attributed to several key mechanisms. The beneficial microorganisms in the EM consortium facilitated an alkaline environment by consuming Calcium Chloride and producing metabolic byproducts that elevated the pH levels. This alkaline environment acted as a deterrent to the corrosion of steel reinforcement by reducing the availability of chloride ions and increasing the passivation of steel surfaces. Furthermore, the microbial activity also contributed to the formation of a protective layer on the concrete surface, effectively shielding it from the corrosive environment.

- The higher the EM concentration -up to 5%- the lower the maximum anodic current is, the better the quality of the passive layer is, and the lower the corrosion rate is. The reason for the increased higher corrosion resistivity is that the EM concrete possesses blocked pores with calcites and thus low permeability.

- After accelerating the rebar's corrosion of the EM specimens contributed to the reduction of the corrosion rate. The accelerated specimens prepared with 5% EM decreased the corrosion rate from 522 mm/year to 175.3 mm/year.

- The EDX analysis indicated that the EM2, 5 and 8 specimens showed 65.46%, 66.89 and 68.34% of precipitated calcite minerals, respectively, while the control showed 61.18%.

- The SEM investigated has shown significant CaCO3 crystal growth in the EM5 mix more than Control resulting in less pores and more corrosion restistance. Rhombohedral calcite crystals, especially filling voids, could be evidence of microbial-induced carbonate precipitation (MICP) activity.

- In the EM8 mix, there is a noticeable growth of CaCO3 (calcium carbonate) crystals, particularly in the form of rhombohedral calcite crystals. These crystals were observed to be more densely packed around aggregate particles or filling voids, which is indicative of microbial-induced carbonate precipitation (MICP) activity. This increased presence of CaCO3 in the EM8 mix, as compared to the EM5 mix and the control, suggests a denser concrete matrix. However, this densification and increase in CaCO3 crystals in the EM8 mix coincides with a reduced production of C-S-H (calcium silicate hydrate) crystals. Since C-S-H is the primary source of strength in concrete, this reduced production negatively impacts the overall strength of the concrete. The higher concentration of EM in the EM8 mix is thought to influence the nucleation and growth of C-S-H crystals adversely. As a result, the EM8 mix exhibits a denser and less permeable concrete structure but with lower overall strength compared to mixes with lower EM concentrations or the control mix.

- Calcite precipitation has been determined to serve a role in strengthening the passive layer protection and inhibiting corrosion of the rebar, in addition to improving other attributes that are desired.

- The EDX analysis offers support for the observed improvements in compressive strength, corrosion resistance, and permeability in EM-treated concrete specimens. The higher calcium and silicon content in the EM-treated specimens indicates improved cement hydration and a denser cementitious matrix, contributing to enhanced compressive strength and impermeability.

- The reduction in iron and chlorine content is particularly significant. The lower iron content suggests a decreased susceptibility to corrosion of the reinforcing steel, aligning with the improved corrosion resistance. The substantial decrease in chlorine content indicates a reduced presence of chloride ions, which is a key factor in inhibiting the corrosion process.

- In conclusion, the SEM and EDX analysis supports the findings of the study, indicating that the incorporation of Effective Microorganisms in a molasses medium has a positive influence on the elemental composition of concrete. This, in turn, contributes to the improvements observed in compressive strength, corrosion resistance, and impermeability. The reduced presence of iron and chlorine, as well as the lower sulfur content, suggests a more durable and sustainable concrete mix, aligning with the research objectives of this study.

- The findings underscore the potential of EM as a transformative admixture for concrete, suggesting its viability as a sustainable solution for enhancing the durability and longevity of concrete structures. The results from this study open new avenues in the field of construction materials, indicating that EM can play a pivotal role in developing more resilient and sustainable building materials.

6. Future Work

- Exploring Varying EM Concentrations: This study showed different effects at various EM concentrations. Future work could focus on optimizing EM concentration in concrete mixes to balance strength, corrosion resistance, and impermeability.

- Long-Term Performance Analysis: Investigating the long-term durability and performance of EMC under various environmental conditions could provide valuable insights into its practical applications.

- Different Types of Cement: Since different types of cement have varying chemical compositions, studying the effects of EM on these could yield interesting results.

- Scaling Up Experiments: Conducting larger scale experiments or real-world pilot projects could validate the laboratory findings and assess the practicality of EMC in construction.

- Economic and Environmental Impact Analysis: Understanding the cost implications and environmental benefits of using EMC on a larger scale is crucial for its adoption in the industry.

- Mechanistic Studies: Further research into the biochemical interactions between EM and concrete components could provide deeper insights into the observed improvements.

- Comparative Studies with Other Additives: Comparing EMC with concrete containing other microbial or chemical additives could highlight the unique benefits or drawbacks of EM.

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