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Original article

Preparation of artificial reeds from natural waste materials for habitat structure of fish breeding and conservation: Experimental and simulation modelling studies

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Abstract Artificial reefs are commonly created with the goal of enhancing fish populations. Currently, the degradation of natural reefs is also causing a decrease in fish productivity. As a result, the marine department is prioritizing the creation of artificial reefs to boost the fisheries. In Palk Bay, artificial reefs that were subject to research were placed in 2019 at Adaikkathevan Seashore (Bay of Bengal), which is located in Thanjavur district, Tamil Nadu, India. Because of a wide range of possible alternative materials and their parameters, research activities involve detailed analysis of all aspects of their influence on the new material's parameters. Durability can be considered one of the most significant parameters of building materials, having a direct impact on the lifetime of the material itself as well as the lifetime of the whole reef. Natural recycled materials used in this research work include fly ash, seashells, rice-husked ash, silica fumes, granite powder, paper pulp, and coconut fiber. The compressive strength of artificial reef concrete was evaluated on various days (7, 14, 28, 56, and 90), and the findings indicated that it surpasses the strength of conventional concrete. It was found that the compressive strength of AR2 and AR3 for 90 days of curing is 0.91% and 3.83% was almost equal to conventional concrete. The purpose of the AR initiative is to enhance the fish population through the establishment of a viable marine ecosystem, thereby ensuring a dependable means of subsistence for indigenous fisher communities. This study demonstrates that the designed artificial reef mimics natural reef properties, fostering algae growth that supports fish breeding. The numerous holes provided in the artificial reef also offer protection for fish against predators.

Keywords artificial reefs, concrete fish, workability, durability

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Introduction

Habitat loss and degradation are major threats to biodiversity, with most terrestrial habitats and seashores have been negatively impacted by the increasing human footprint due to the development of industrialization and tourism [1]. Approximately half of the world's population resides in close proximity to the coast, where fish accommodation modification has been the greatest challenge, due to increased levels of pollution, coastal development and hardening, resource extraction, and the introduction of various hunting systems [2-6]. Seagrass beds, coral reefs, kelp forests, reef habitats, and the species that rely on them are among the marine ecosystems that are being negatively impacted by the fast increase in habitat loss and related changes [7-9].

When protecting or restoring natural habitat is not possible, creating "artificial" habitats can be a viable alternative management strategy, provided that they can replace natural habitats, do not cause further loss of natural habitat, and are resistant to the forces causing environmental change. Artificial reefs are significant structures in the ocean that contribute greatly to the restoration of marine ecologies and economic benefits [14] .In order to achieve management objectives, it is also crucial to understand the factors that influence artificial reef performance. Artificial reefs are rapidly being employed around the world to suit a variety of fisheries management and environmental goals [10]. The design of artificial reefs incorporating more shelter holes has been found to support a higher abundance and diversity of fish species [11,12]. Artificial reefs are commonly constructed from concrete because it is easy to mold and non-toxic. As a result of high pH values and poor biological attachments, traditional artificial reefs are not suitable for use. In recent years, artificial reef studies have focused primarily on the use of waste materials, such as construction solid waste, industrial waste, and agricultural waste, with the objective of increasing concrete's ecological performance and reducing carbon emissions [13]. It's crucial to design artificial reefs in such a way that they function as closely as possible to natural reefs so that habitat loss can be mitigated. Still, it's also essential to use ecological principles when building marine infrastructure (i.e, eco-engineering) so that biodiversity is better. Furthermore, artificial reefs can be used for preventing bottom trawling, improving recreational diving, and as a means of removing hard waste [14-16].

This study's objective was to evaluate a novel type of artificial reef constructed with a variety of holes to maximize fish shelter. The artificial reefs were constructed using natural waste materials and the resulting effects research was carried out on the growth and impacts of fish communities. It also examined how closely the artificial reefs mirrored the communities found in natural reefs. During this experiment investigation, fiber fly ash, sea shell, rice husked ash, silica fumes, granite powder, paper pulp, and coconut fiber are all used as raw materials used to make artificial reef concrete. The mechanical, durability, and physical properties was

Fig. 1. Location of Artificial Reefs setup in the Ocean

also evaluated using a cylindrical and cube shape of artificial reefs concrete. The research, such as on fish diversity, abundance, and community structure, etc, were carried out in Adaikathevan place for more than one year.

Materials and Methods

Study Area

The research was carried out at the Adaikkathevan seashore, Sethubhavachatram Block, Thanjavur District, Tamilnadu, India, which is located at Palk Bay a part of the Bay of Bengal. The latitude and longitude of Adaikkathevan sea shore are 10°11'39" N & 79°15'39" E. The study location was shown in (Fig.1).Artificial Reefs were placed 1.5 km from the coastline at a depth of 12-15 feet. Fish assemblages and breeding are lesser due to sea grasses being more abundant than reefs in Palk Bay Seashore.

Raw Materials

Developing concrete using raw materials with a minimum environmental impact is one of the huge challenges. Artificial Reef (AR) structures are made from raw materials like cement, m-sand, fly ash, rice husk ash, paper pulp, sea shells, granite powder, silica fume, and reinforcement additives. During the preparation of concrete, natural water is used according to the proportions of cement and other materials that are required.

In this experiment, M-sand sizes between 4.75 and 2.75 mm have been used, and all other sizes passing through the sieve have not been taken into account. Likewise, the range of 12.5 mm to 4.75 mm coarse aggregate was utilized in accordance with the standard guidelines. Fly ash was collected from the Neyveli Thermal Power Station, which is located in Tamil Nadu, India. Coconut fiber was obtained from a rope mill in Pattukkottai, which is located in the Indian state of Tamil Nadu. The physical properties of different raw materials for artificial reefs is shown in (Fig.2).

Mix Proportions of Concrete

The concrete mix ratio refers to the proportions of cement, sand, aggregates, and water in concrete. The Table.1 shows the mixing proportion of concrete, with a 0.5 water-cement ratio. The Mixing of raw materials and water was based on the standard ratio. Mix proportions range from AR1 to AR6, where AR1 represents the Conventional Mix Proportion of Cement, M-Sand, and Coarse Aggregates. In OPC (grade 43), the materials used are replaced with pozzolans (fly ash (FA), Rice-husk ash (RHA), Silica fumes (S.F), Paper pulp (P.P), Granite Powder (G.P) and Sea Shell (S.S)) at a ratio of 0-40% based on the total weight of the materials. As a result, the research was carried out to obtain the different Grades of Concrete by adding the materials (Cement: Manufactured Sand (M-Sand): Coarse Aggregate) in different proportions.

Artificial Reef (AR) Structure

Many studies have been conducted on hexagonal, bottle-cube, and ball-shaped artificial reefs, but they are heavier, costlier, less reliability, and are more difficult to transport. As a result, artificial reefs are designed with trapezoidal structures, which are easy to transport and assemble. Here, the specimens are trapezoidal in shape and uniform in thickness.

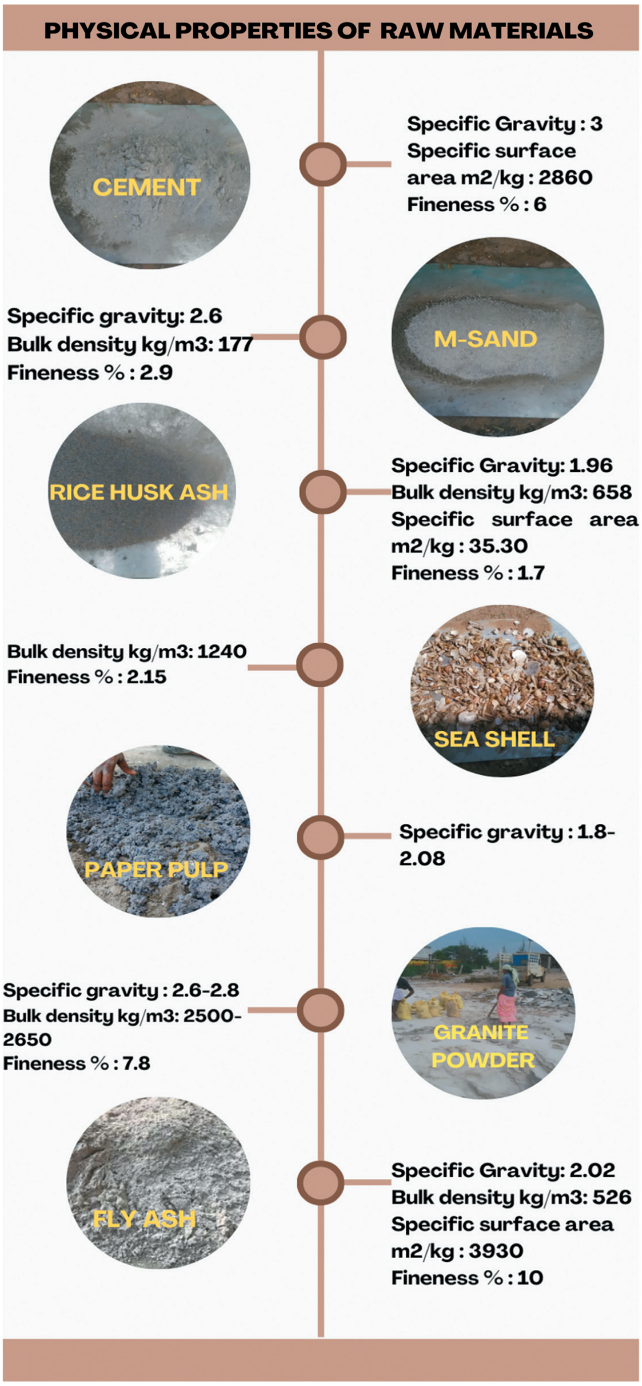

Fig. 2. Physical Properties for Artificial Reefs

Table 1. Classification of mix propositions

Name of Mix Proportions	Grade of Concrete	FA	RHA	S.S	P.P	G.P	S.F (Additive)
AR1	01:1.5:3	-	-	-	-	-	-
AR2	C:M:C.A	5	5	5	5	5	10
AR3	C:M:C.A	10	10	10	10	10	20
AR4	C:M:C.A	15	15	15	15	15	20
AR5	C:M:C.A	20	20	20	20	20	20
AR6	C:M:C.A	25	20	20	20	20	20

Cast specimens are prepared, dried for one day, and then cured for testing. An artificial reef concrete that is used for this research has the dimensions of 1000 mm x 1000 mm x 500 mm. It was designed as a flat slab design with a 50mm thickness throughout the whole structure. The concrete artificial reef was constructed with five circular holes, two of which were 200 mm in diameter and three of which were 100 mm in diameter. As a result of these circular holes, these reefs protect fish, promote reproduction, and provide shelter for them. The CATIA and AutoCAD software have been used to generate the schematic structure and dimensions of reef concrete in (Fig. 3).

Results and Discussion

Various concrete compositions of AR were examined in this research work using microanalysis (SEM, XRD), workability, and durability analysis methods by simulation and experimental. (Fig.4) illustrates that the different method of analysis carried out to study the performance of artificial reefs made from natural waste materials.

AR pH Value Estimation

The pH of concrete plays an important role in determining its alkalinity level. Concrete damage can happen when the alkalinity level drops, so it's very important to measure the concrete pH accurately. Based on the results, artificial reef concrete has a pH value between 11.86 and 12.1. According to these results, AR2 has a lower pH than AR1 and the other mixed proportions. The addition of superplasticizers, altering raw materials, and changing their ratios during concrete formation is responsible for its pH value.The pH value of wet concrete was experimentally measured and shown in (Fig.5).

Concrete Workability and Durability Test Methods

In this work, six specimens were cured for 7,14,28,56, and 90 days in order to determine the compressive strength. In the case of AR2 and AR3, the increase in strength after 28 days was quite significant. As depicted in the graph, the consistence of the given cement samples increases progressively. According to (Fig.6), the consistency of AR 6 is observed to be 26.19% greater than that of conventional concrete (AR1).The (Fig.7) reveals the initial and final setting time of various concrete samples utilized for artificial reefs. Figures AR5 and AR6 show that the compressive strength of the conventional mixer is 21.13% and 23.79% lower after 90 days, respectively. As compared to conventional concrete, the samples given showed a slightly higher strength.

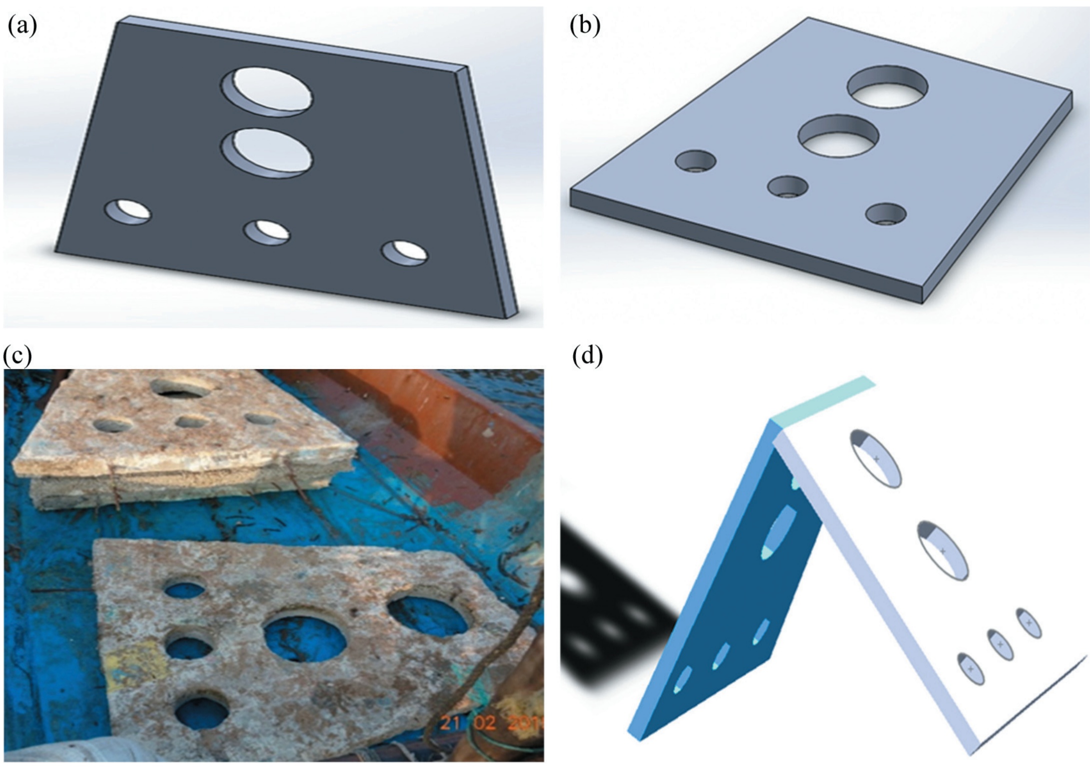

Fig. 3. Schematic Structure view of Artificial Reefs, (a) Stand View, (b) Top View, (c) Concrete Reef, (d) Joint Structure.

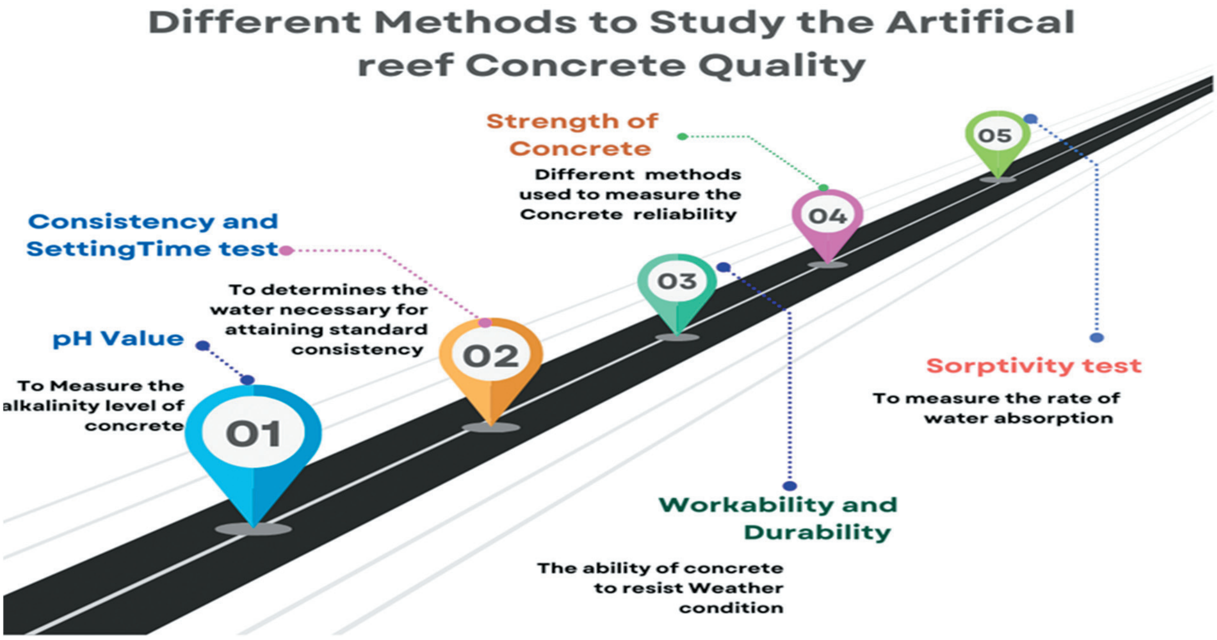

Fig. 4. Different methods to analysis of Artificial Reefs made from natural waste materials.

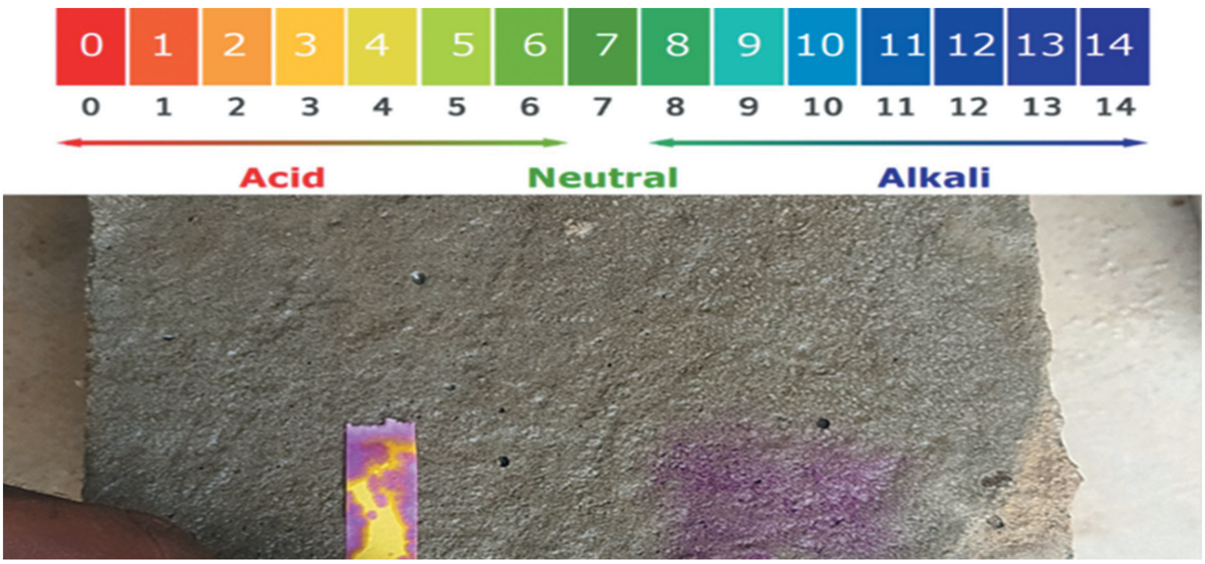

Fig. 5. pH values for Different Concrete Specimens

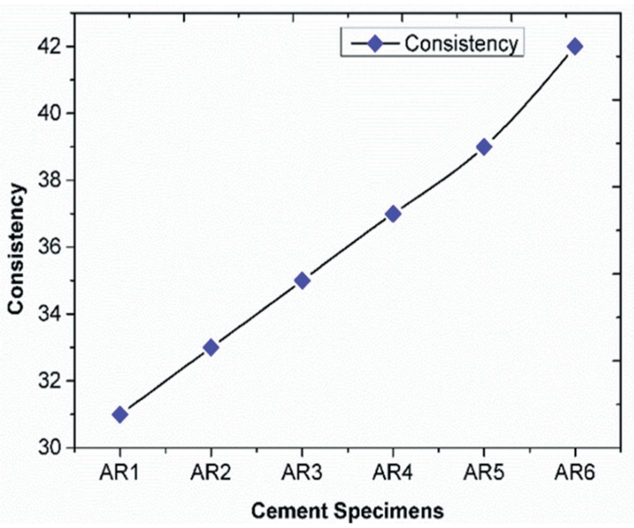

Fig. 6. Consistency values of concrete specimens

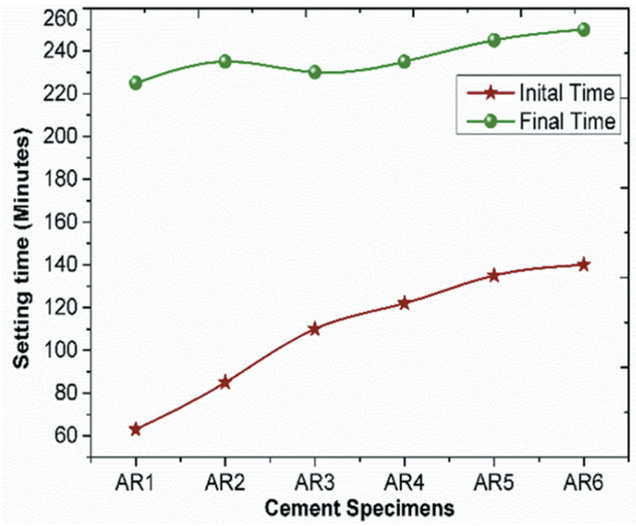

Fig. 7. Setting time of concrete specimens

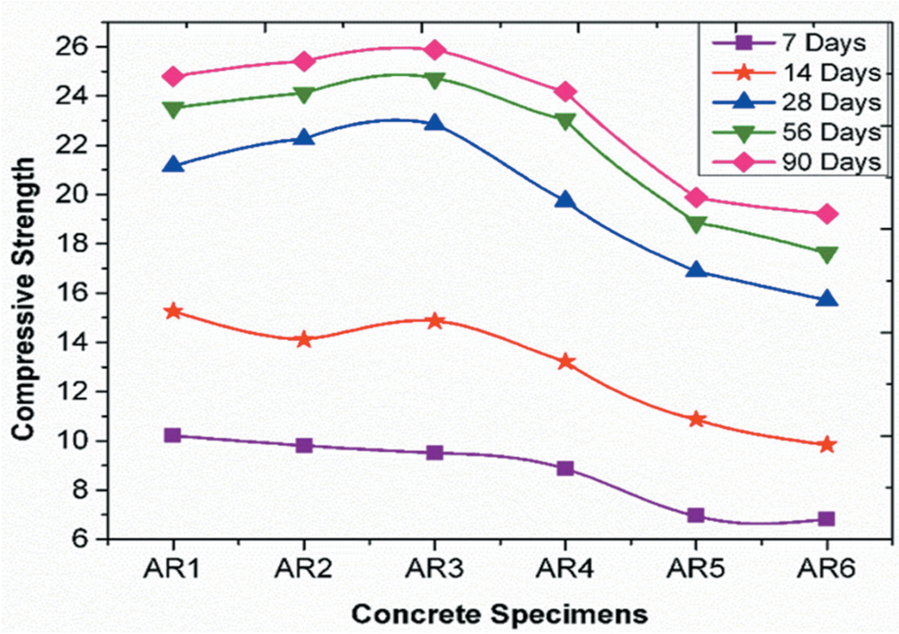

Fig. 8. Compressive Strength of concrete specimens

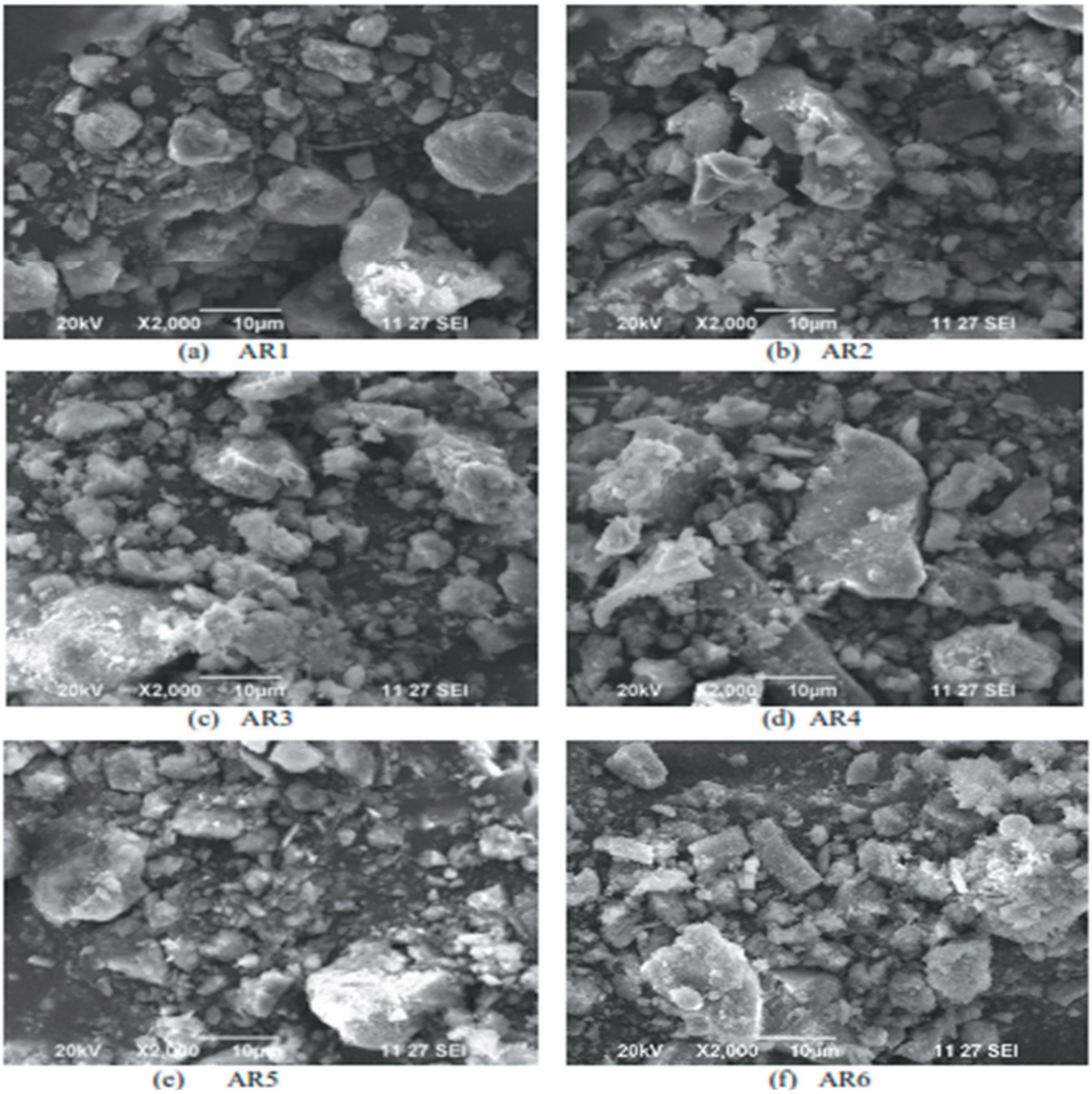

Fig. 9. SEM Analysis for different concrete specimen

Compressive Strength Analysis

The intention of this study was to investigate the compressive strength of six specimens using various curing methods over different time periods, specifically 7, 14, 28, 56, and 90 days, in accordance with the IS 516-1959 standards. The graphical representation of the consistency test is depicted in (Fig. 8). The provided samples exhibited a marginally greater level of strength in comparison to traditional concrete. The presence of paper pulp in concrete has the potential to negatively impact its compressive strength, leading to a decrease in early strength. N. Kress et.al [17] conducted an experimental study on incorporating coal fly ash (CFA) in concrete to create marine artificial reefs in the south-eastern Mediterranean. They investigated various properties, including compressive strength, the presence of sessile biota, and the chemical composition of the concrete. To explore the feasibility of using CFA in artificial reefs, concrete blocks with 0%, 40%, 60%, and 80% CFA replacing sand were submerged at a depth of 18.5 meters off the coast of Israel for 33 months. The results showed that blocks with 40% and 60% CFA had 1.5 times the compressive strength of those with 0% and 80% CFA.

According to the data presented in (Fig.8), it can be observed that the AR5 and AR6 mixtures exhibit a reduction in compressive strength of 21.13% and 23.79% respectively, compared to the conventional mixer, over a period of 90 days. The compressive strength of AR2 and AR3, after a 90-day curing period, is observed to be 0.91% and 3.83% lower than that of conventional concrete. Therefore, it is highly advantageous to develop a concrete design that incurs lower costs compared to traditional methods.

SEM and EDAX Analysis

A scanning electron microscopy (SEM) image has been provided for the purpose of examining the cementitious material, microstructure, and morphology of Artificial Reef Concrete. The provided illustration depicts scanning electron microscope (SEM) images of the artificial reef, captured at a magnification level of X2,000. Energy Dispersive X-ray analysis (EDAX) is employed for the purpose of determining the elemental composition of the specimen and analyzing the surface of concrete.

SEM analysis of six different proportions of Artificial Reefs Concrete is illustrated in (Fig.9). The (Fig.10) shows the predominant elements are potassium (k), calcium (Ca), silicon (Si), alumina (Al) and oxygen (O), but iron (Fe) and sodium (Na) are also present at lesser concentrations. The presence of sodium (Na) leads to an enhancement in compressive strength and a reduction in the corrosive impact.

Determination Strength of Concrete using Splitting Tensile

The splitting tensile strength (*f* spt) holds considerable importance in the design of concrete structures and plays a crucial role in ensuring the resilience of reinforced concrete structures in the face of natural disasters. (Fig.11), illustrates the splitting tensile strength of each individual specimen. The values depicted in the figure illustrate the outcomes of the concrete tests conducted on days 7 and 28, specifically in relation to the splitting tensile strength. The splitting tensile strength of the traditional mixer after 28 days is measured to be 2.94 MPa, which is found to be 2.11%, 4.79%, 4.68%, 23.81%, and 28.78% higher than the corresponding values observed in the other specimens.

The AR1 specimen exhibits a higher split tensile strength compared to the other specimens, attributed to the specific grade of M20 Concrete, which has a higher design strength.

Coefficient of Water Absorption

The process of water absorption by concrete commonly results in alterations to its strength, ultimately resulting in structural failure. The water absorption coefficient was measured as a significant performance parameter for the process of setting and hardening. The various specimens were immersed in water for the purpose of curing, and the experimental measurements were conducted at the 28-day and 90-days. (Fig.12) illustrates the experimental setup used to examine the water absorption of concrete. The graph depicts the coefficient of water absorption of concrete at two different time intervals, specifically 28 and 90 days, as given in (Fig.13). The data indicates that the water absorption coefficient of AR3 exhibits a lesser at both the 28 and 90 days.

Sorptivity Test Method for Concrete Specimens

The utilization of sorptivity as a metric for assessing the durability of concrete in the face of aggressive environmental conditions is progressively becoming popularity. The sorptivity of concrete samples was tested at 28 and 90 days of curing, as shown in (Fig.14). The graph depicts the sorptivity analysis of concrete at 28 and 90 days, as revealed in (Fig.15). Following the 28-day curing period, the sorptivity values for concrete samples AR2 and AR3 were determined to be 2.75% and 9.85% respectively. Similarly, after 90 days, the curing of concrete samples AR2 and AR3 is 6.49 and 13.38 percent, respectively. A reduced absorption characteristic of materials is thought to be responsible for this phenomenon.

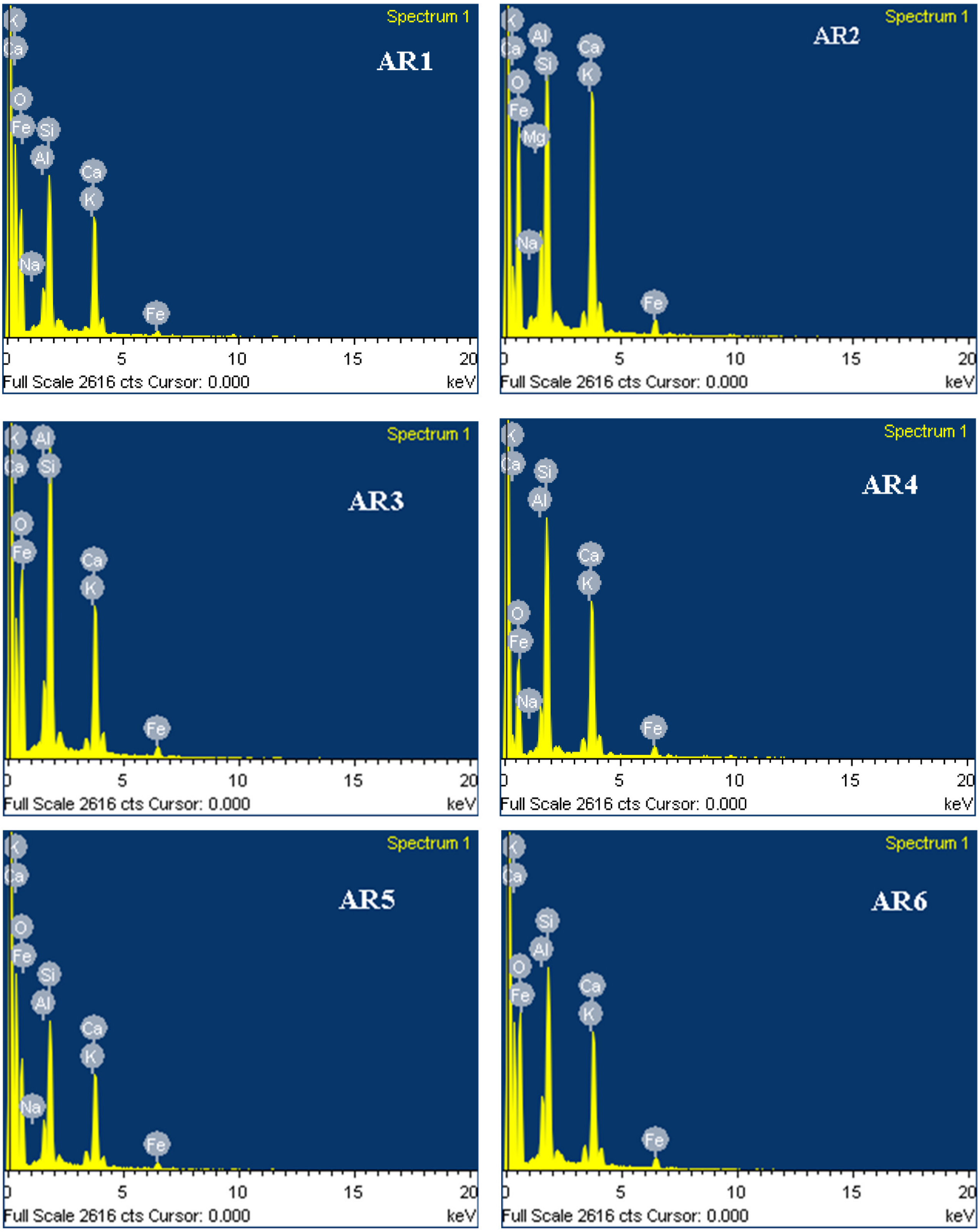

Fig. 10. EDAX Analysis for different concrete specimen

Finite Element Analysis of Artificial Reefs

Recent years have seen an increase in the use of the finite element method as a method of numerical calculation. Predictions of the response of experimental specimens were made using Finite Element Analysis. The fundamental concept involves the process of discretizing a continuous structure into a finite number of cells and establishing a finite number of nodes within each cell. This approach considers the continuum as a composite of numerous cells that are interconnected at the nodes. Subsequently, stress, strength, mesh, and static displacement were analyzed.

Mesh Analysis

Mesh analyses of the artificial reefs specimens were carried out by utilising Solid work simulation software version 19. The finite element model employed in the analysis is clearly illustrated in (Fig.16). As a result of mesh analysis of artificial reefs, it has been found that relatively accurate results were obtained and the yield strength is 4.600e+8.

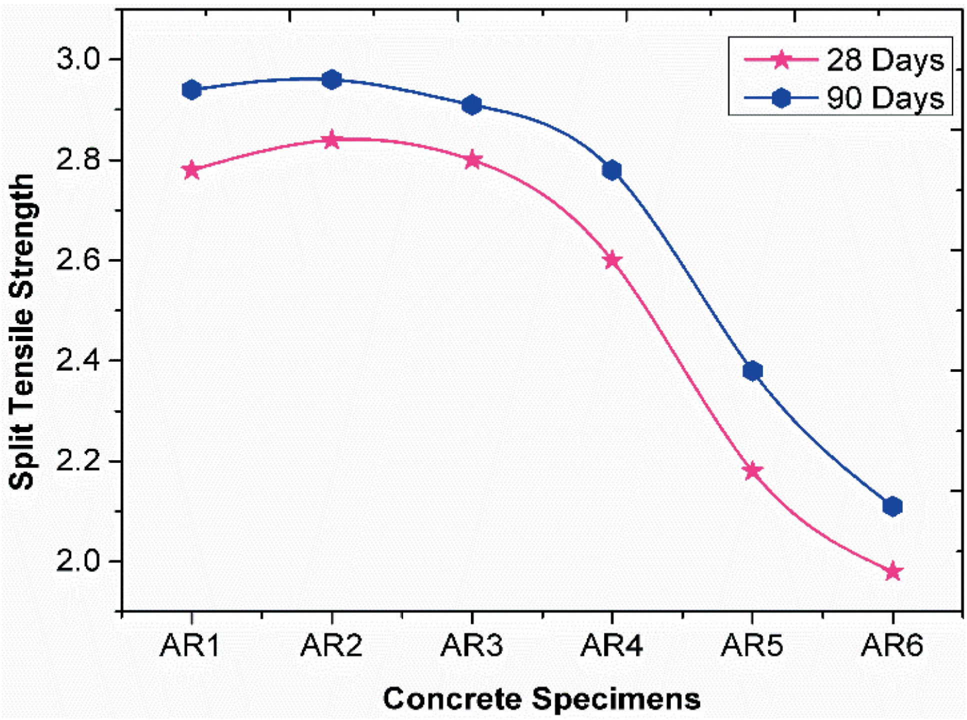

Fig. 11.Splitting tensile strength values of Concrete for 28 and 90 days

Fig. 12. Water absorption of Concrete for 28 and 90 days

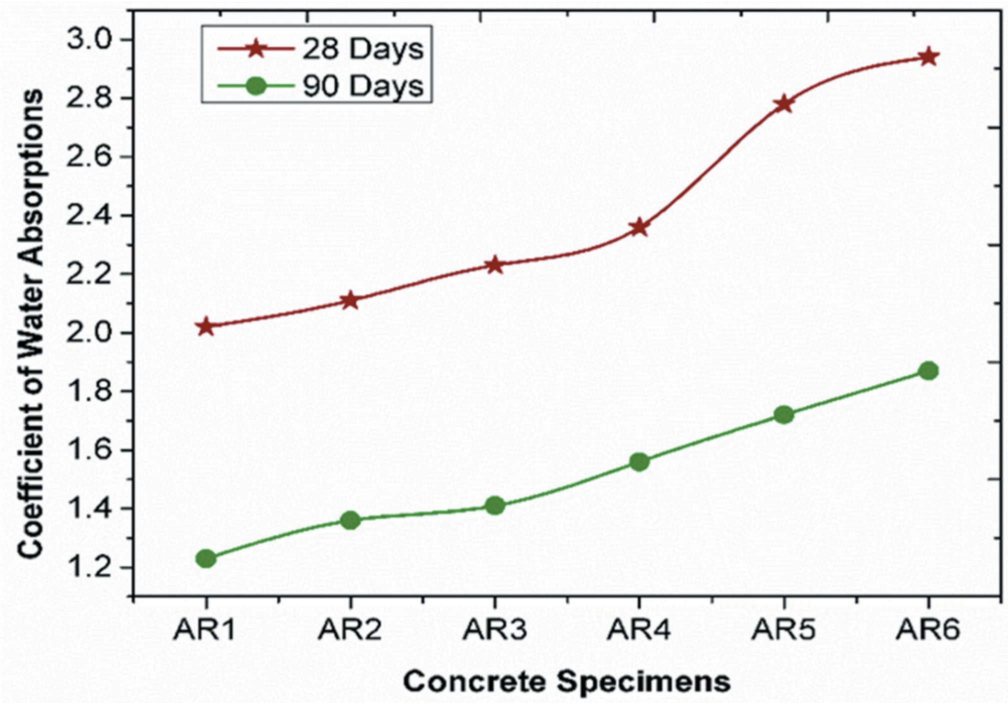

Fig. 13. Coefficient of water absorption values of Concrete for 28 and 90 days

Fig. 14. Concrete Specimen Sorptivity test

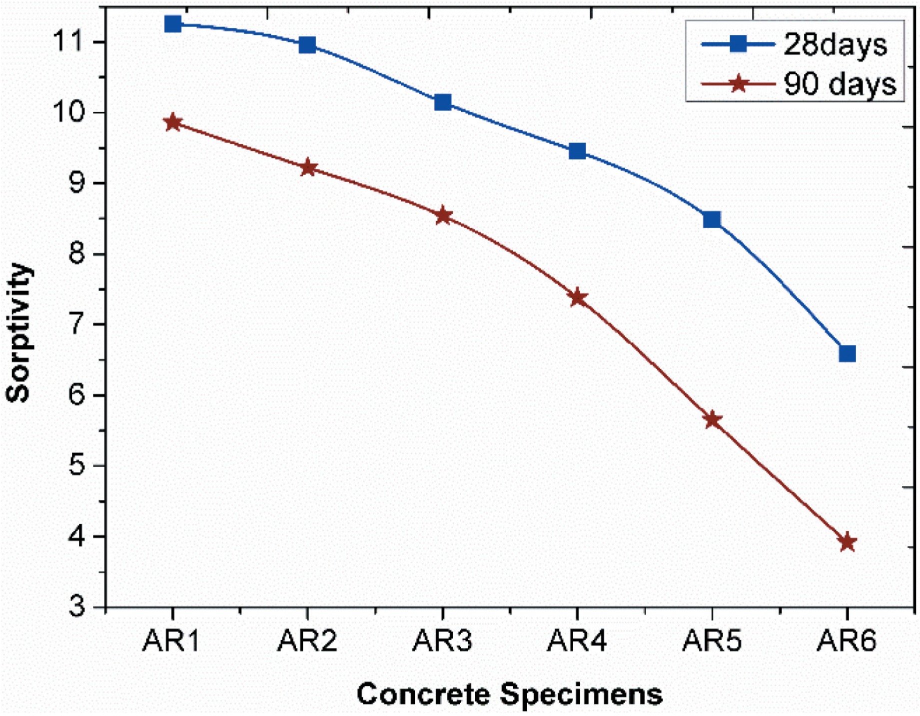

Fig. 15. Graphical representation of Sorptivity test

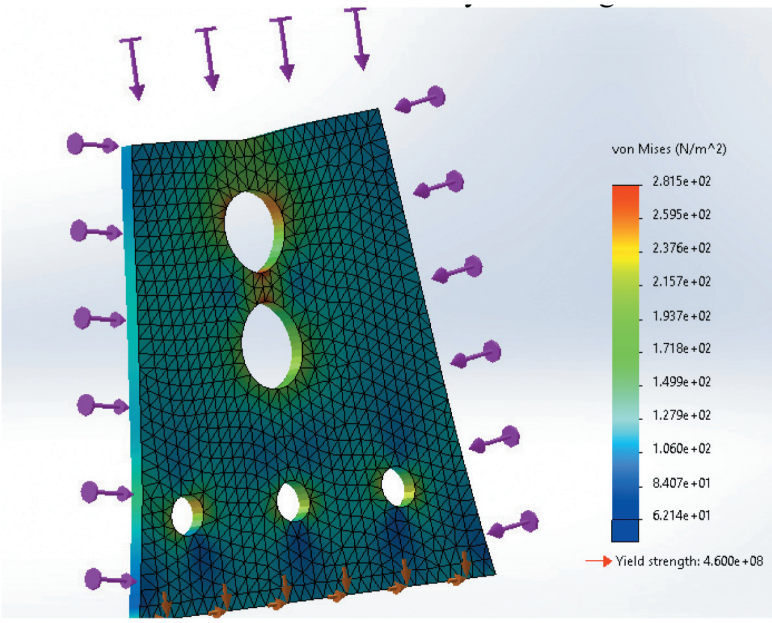

Fig. 16. Mesh representation of Artificial Reefs

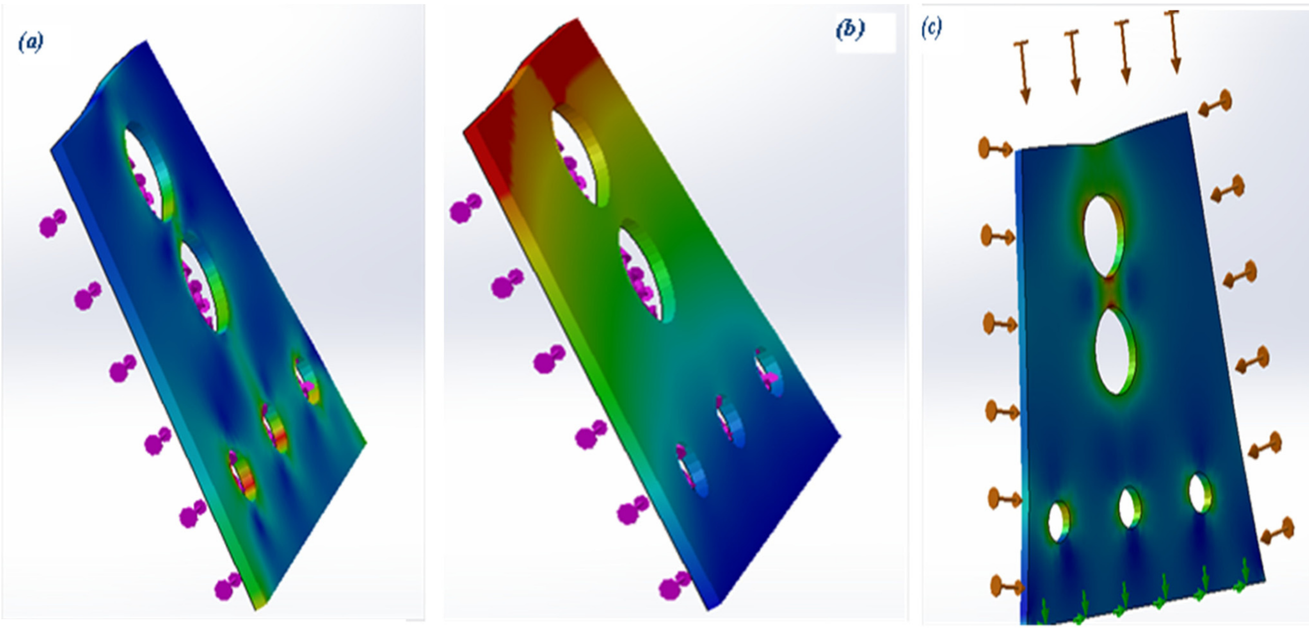

Fig. 17. Stress analysis of artificial reefs, (a) less stress, (b) displacement stress, (c) higher stress

Fig. 18. Adaikkathevan seashore artificial reefs. (a) Artificial Reef in boat (b) Reef step down from boat (c) Placed in Ocean (d) Growth of algae in reef

Stress Analysis

Simulations were conducted to determine the static displacement strength of specimens under a variety of water pressures as shown in (Fig.17). According to the results, the artificial reefs specimen is strong and stable enough to withstand the increase in water pressure. In this analysis, blue color shows that it has the strength to withstand the pressure of sea currents as shown in the (Fig.17b and (Fig.17c). It has been observed from the (Fig.17c) that the pressure occurs when the seawater passes through the holes in the artificial reef. It has been revealed that the simulation model of artificial reefs shows that it is well suited in the ocean for fish breeding and algae growth.

Settling of Artificial Reefs in ocean

The present study involved the deployment of concrete artificial reefs at a depth of 18 feet within the marine environment, with the objective of investigating their impact on the aquatic ecosystem. The construction of this artificial reef involves the use of concrete and incorporates a trapezoidal shape, as depicted in (Fig.18a-18d). Additionally, the reef

(a)

(b)

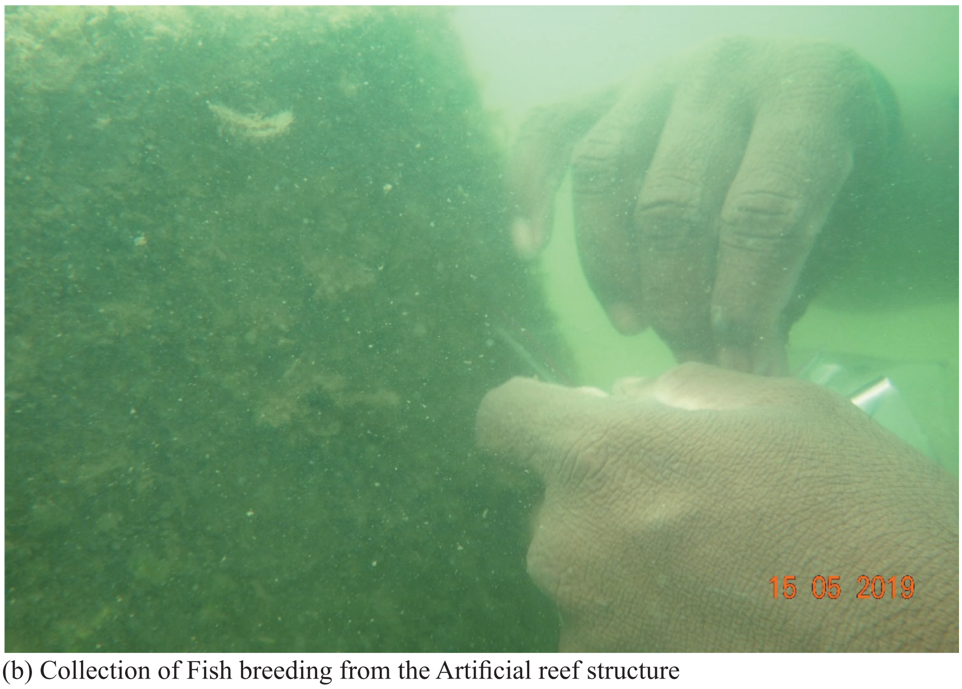

Fig. 19. (a) and (b) Collection of Fish breeding from the Artificial reef structure

features five circular holes located at its center. The artificial reef that has been designed exhibits stability and durability, owing to its composition of aggregate building materials that are biodegradable. This composition serves the purpose of attracting a diverse range of species. As depicted in (Fig.18d), it is evident that a significant proliferation of algae has occurred within the artificial reef. The influence of artificial reef (AR) habitat structure on fish assemblage composition off the southern coast of Brazil is reported in reference [18]. Their results show that it is effective and safe for fish breeding due to the number of holes, and it also enhances the biodiversity and biomass of some species. The collection of fish breeding from the artifical reef was shown in the (Fig.19a and b).

Conclusions

The Adaikkathevan seashore in the Thanjavur district of Tamilnadu has been the location of artificial reef research. This initiative aims to study the fish assemblages and breeding patterns of various species. Similarly, the purposes of artificial reef research include investigating the true relationship between fish and habitat structures. This study involved the partial modification of conventional concrete construction through the incorporation of biodegradable materials derived from natural waste. The present study employed an experimental investigation method to examine the mechanical and physical properties of each individual specimen utilized in the construction of the reef. The results indicate that AR2 and AR3 concrete exhibit alkalinity in terms of their pH values, making them suitable for the construction of artificial reefs. The X-ray diffraction analysis (EXRD) indicates that the composition of the concrete does not include any harmful substances that have the potential to contaminate water sources or have adverse effects on living organisms. Furthermore, it can be observed that the sorptivity of concrete specimens AR2 and AR3 is nearly identical to that of conventional concrete specimen AR1, in comparison to the remaining specimens. The findings of this study demonstrate that the presence of artificial reefs has a substantial positive impact on the reproduction of fish, the proliferation of algae, and the overall well-being of various marine organisms. Furthermore, these artificial structures contribute to the overall health and stability of the marine ecosystem.

Conflict of interest

The authors declare that they have no conflicts of interest.

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References

1. Komyakova V, Chamberlain V, Jones GP, Swearer SE. Assessing the performance of artificial reefs as substitute habitat for temperate reef fishes: Implications for reef design and placement", Science of The Total Environment. 2019;668:139-152. ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2019.02.357.
2. Halpern BS, Walbridge S, Selkoe KA, Kappel CV, Micheli F, D'Agrosa C, Bruno JF, Casey KS, Ebert C, Fox HE, Fujita R, Heinemann D, Lenihan HS, Madin EMP, Perry MT, Seli, ER, Spalding M, Steneck R, Watson R. A global map of human impact on marine ecosystems. Science. 2008;319 (5865):948–952.
3. Sih A, Ferrari MCO, Harris DJ. Evolution and behavioural responses to human induced rapid environmental change. Evol. Appl. 2011;4(2):367–387.
4. Seto KC, Güneralp B, Hutyra LR. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proc. Natl. Acad. Sci. 2012;109 (40):16083–16088.
5. Dafforn KA, Mayer-Pinto M, Morris RL, Waltham NJ. Application of management tools to integrate ecological principles with the design of marine infrastructure. J. Environ. Manag. 2015;158:61–73.
6. Strain EMA, Alexander KA, Kienker S, Morris R, Jarvis R, Coleman R, Bollard B, Firth LB, Knights AM, Grabowski JH, Airoldi L, Chan BKK, Chee SY, Cheng Z, Coutinho R, de Menezes RG, Ding M, Dong Y, Fraser CML, Gómez AG, Juanes JA, Mancuso P, Messano LVR, Naval-Xavier LPD, Scyphers S, Steinberg P, Swearer S, Valdor PF, Wong JXY, Yee J, Bishop MJ. Urban blue: a global analysis of the factors shaping people's perceptions of the marine environment and ecological engineering in harbours. Sci. Total Environ. 2019;158:1293–1305.
7. Jackson JBC, Kirby MX, Berger WH, Bjornda, KA, Botsford LW, Bourque BJ, Bradbury RH, Cooke R, Erlandson J, Estes JA, Hughes TP, Kidwell S, Lange CB, Lenihan HS, Pandolfi JM, Peterson CH, Steneck RS, Tegner MJ, Warner RR. Historical overfishing and the recent collapse of coastal ecosystems. Science. 2001;293(5530):629–637.
8. Halpern BS, Walbridge S, Selkoe KA, Kappel CV, Micheli F, D'Agrosa C, Bruno, J.F, Casey, K.S, Ebert, C, Fox, H.E, Fujita, R, Heinemann, D, Lenihan, H.S, Madin EMP, Perry MT, Selig ER, Spalding M, Steneck R, Watson R. A global map of human impact on marine ecosystems. Science. 2008;319 (5865):948–952.
9. McCauley DJ, Pinsky ML, Palumbi SR, Estes JA, Joyce FH, Warner RR. Marine defaunation: animal loss in the global ocean. Science. 2015;347(6219).

10. Bortone SA. Introduction to the role artificial reefs play in fisheries management.In: Bortone SA, Brandini FP, Fabi G, Otake S (Eds.). Artificial Reefs in Fisheries Management. CRC Press, Boca Raton. 2011a.
11. Hixon MA, Beets JP. Shelter characteristics and caribbean fish assemblages: experiments with artificial reefs. Bull. Mar. Sci. 1989;44(2):666–680.
12. Hackradt CW, Félix-Hackradt FC, García-Charton JA. Influence of habitat structure on fish assemblage of an artificial reef in southern Brazil. Mar. Environ. Res. 2011;72(5):235–247.
13. Kong J, Cong G, Ni S, Sun J, Guo C, Chen M, Quan H. Recycling of waste oyster shell and recycled aggregate in the porous ecological concrete used for artificial reefs. Construction and Building Materials. 2022;323. 126447,ISSN 0950-0618, https://doi.org/10.1016/j.conbuildmat.2022.126447.
14. Grove RS, Sonu CJ, Nakamura M. Design and engineering of manufactured habitats for fisheries enhancement. In: Seaman, W.J, Sprague, L.M. (Eds.), Artificial Habitats for Marine and Freshwater Fisheries. Academic Press, Inc, San Diego, California, 1991:109–152.
15. Collins KJ, Jensen AC, Albert S. A review of waste tyre utilisation in the marine environment. Chem. Ecol. 1995;10(3–4):205–216.
16. Baine M. Artificial reefs: a review of their design, application, management and performance. Ocean Coast. Manag. 2001;44 (3–4):241–259.
17. Kress N, Tom M, Spanier E. The use of coal fly ash in concrete for marine artificial reefs in the southeastern Mediterranean: compressive strength, sessile biota, and chemical composition, ICES Journal of Marine Science. 2001;59:S231–S237,_https://doi.org/10.1006/jmsc.2001.1164.
18. Hackradt CW, Félix-Hackradt FC, García-Charton JA, Influence of habitat structure on fish assemblage of an artificial reef in southern Brazil. Marine Environmental Research. 2011;72 (5):235-247, ISSN 0141-1136, https://doi.org/10.1016/j.marenvres.2011.09.006.