Cementitious mortar formulation for extrusion-based additive manufacturing using mussel shells and pozzolanic materials to develop artificial reefs and enhance marine ecosystem

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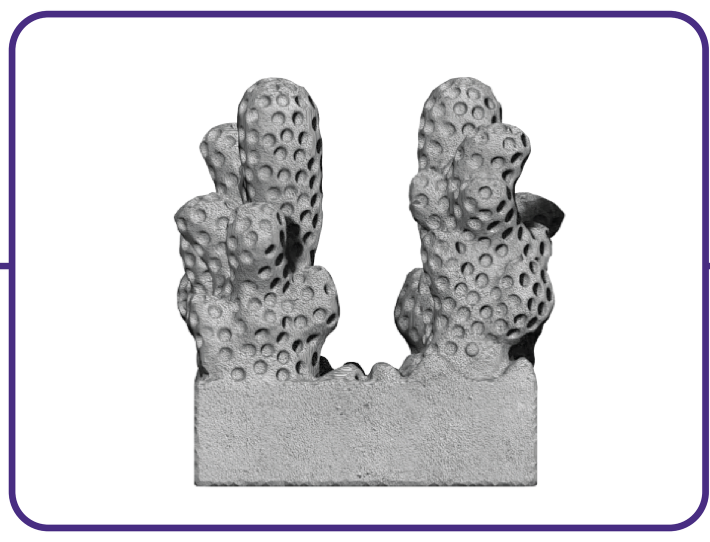
INTRODUCTION

Coral reefs are experiencing significant impacts due to climate change, overfishing, habitat loss, and pollution [1]. This global decline poses serious implications for future marine biodiversity, as coral reefs support a high diversity of marine species [2]. This study explores the potential of cementitious mortar formulations for use as coral propagation substrates and the development of artificial reef through additive manufacturing by extrusion. By examining the physical and chemical properties of the materials employed, the study analyzes seawater parameters, pH variations, and coral growth rates in both horizontal and vertical directions. Following successful results, the data obtained is being applied to develop artificial reefs, including the incorporation of plasticizers and adjustments to the proportion of materials to ensure mechanical resistance and biocompatibility with marine species.

MANUFACTURING PROCESS

SILICONE MOLDS



ARTIFICIAL SUBSTRATE
Coral propagation and growth preferences study.
Aquarium implementation.

ARTIFICIAL REEF
Marine colonization preferences and habitat design diversity.
Seabed implementation.

CEMENT EXTRUSION

CORAL GROWTH PREFERENCE

Coral fragments were placed at the center base of the substrate. Coral growth and preferences were then analyzed and compared across all samples.

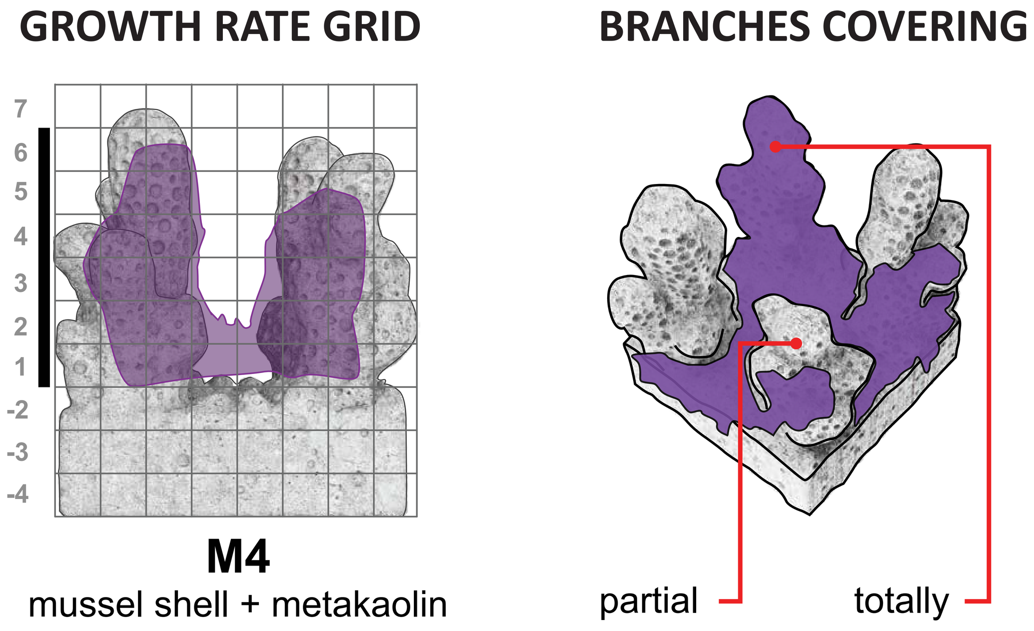


Figure 1. Matrix for qualitative analysis of coral fragment growth rate.

MATERIAL BIOCOMPATIBILITY

Macronutrients, microelements, and contaminants were analyzed through Inductively coupled plasma optical emission spectrometry (ICP-OES) testing and periodic pH measurements.

- Calcium Carbonate Composition
- Chemical Stability
- Trace Elements and Contaminants
- pH Compatibility

EXTRUDABILITY MORTAR

The mortar formulation was adapted to ensure extrudability and mechanical resistance. A superplasticizer was included.

Figure 2. Testing mortar proportions for the extrusion process. Gabriel Monteiro and Ilse Matus images, 2024.

RESULTS

All substrates demonstrated success in terms of survival, attachment, and expansion. The formulation composed of mussel shell, metakaolin, and brick powder exhibited the highest rate of horizontal and vertical growth.
The Weber 3D cement exhibited a high initial sedimentation rate in saltwater compared to the developed mortars. The substrates should be conditioned in saltwater before colonization begins.

Figure 3. Evolution of Montipora Danae growth on the substrates.

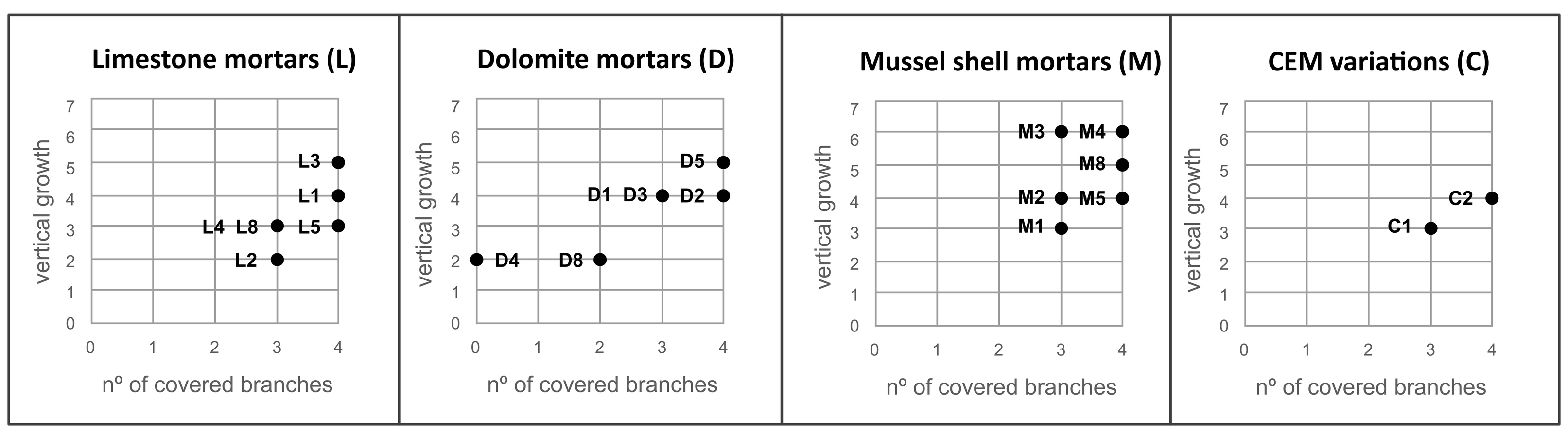


Figure 4. Results of matrix evaluation to determine growth rates in all mortars developed. Variant nomenclature(L-D-M): (1) fly ash; (2) Silica fume; (3) Brick dust; (4) Metakaolin; (5) CEM IV; (8)Rice husk ash. CEM variations: (1) CEM I; (2) CEM IV.

CONCLUSION

The study demonstrated the efficiency of Additive Manufacturing to produce substrates for marine colonization and the integration of sustainable materials derived from waste. Mussel shell, metakaolin, and brick powder, combined with CEM I, showed the highest growth rates. Adjusting proportions and particle sizes below 1mm is crucial for the extrusion mix in the Delta WASP 40100. Metakaolin requires higher water percentages, which reduces the mixture's strength. A superplasticizer is used to decrease water content and enhance the performance of the extrusion.

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