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Physical and Mechanical Properties of a New Bio-Composite Material Based on Seashells for Use in Furniture Making

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ABSTRACT

This paper explores the possibility of using recycled seashells from marine coasts of the Mali Ston Bay in Dubrovnik-Neretva County, Croatia, to create a novel bio material derived from waste seashells. In this research, two types of waste seashells, mussel (Mytilus galloprovincialis) and oyster (Ostrea edulis), combined with natural, non-toxic binders (bone glue) were investigated experimentally. The goal is to develop a sustainable material, suitable for the production of furniture and decorative objects. The parameters studied, included physical and mechanical properties of this material. The results showed that this bio composite material, derived from recycled seashells, is hygroscopic and has low compression strength. It should be used for making furniture components that don't bear heavy loads and it is suitable only for interior applications. This study presents an eco-friendly and sustainable material option, while optimizing the recycling of food waste materials.

Keywords: waste seashells, bio composite material, recycling, sustainable material, physical and mechanical properties, furniture.

INTRODUCTION

Global warming, the lack of natural sources, and environmental pollution are among the greatest problems in our times. Because of the increasing environmental problems, designers have started to develop ecological design in furniture designing (Yuksel and Kilic, 2015). The main goal of ecological design is to decrease negative environmental effects during the life cycle of the product through careful and responsible material design. The significance of ecological furniture design has grown substantially in 20th and 21st century, particularly in the developed countries, which have widely embraced the concept of ecological furniture design. Advancements in economy and technology resulted in increased manufacturing capabilities with a goal to mitigate the adverse impacts of industrial production on the environment. In ancient China, there was a widespread idea that "nature and human beings share the same root and are brothers and exist as a whole" (Chai at al., 2020). Based on this idea, furniture industry today should promote harmony between human beings and nature through ecological design, replace the use of materials that can cause irreversible harm to the environment, and use sustainable materials instead. To achieve a more sustainable and environmentally conscious society, it is crucial to establish a circular economy that optimizes the efficiency of material resources and reduces waste generation through sustainable design with end-of-life options engagement (such as reuse, recycling, or remanufacturing). Industries based on natural materials have significant potential and tradition in the reuse of materials, or their cascading use.

Promoting reuse and recycling (European Commission, 2016; Husgafvel at al., 2018) aims to increase resource efficiency and mitigate climate change (European Commission, 2014; Thonemann at al., 2018). Cascading is a systematic methodology that involves the sequential use of materials to extract maximum utility and value. This process efficiently manages natural resources by optimizing their value and minimizing waste at every stage of a product's life cycle. This approach is becoming increasingly popular in extending the life cycle of materials and combating climate change. The construction industry, which consumes about half of all materials used by humanity, faces a particular challenge in improving resource efficiency (European Commission, 2011; Ruuska at al., 2014). Demolition and reconstruction processes lead to increased waste production, which is one of the reasons why resource efficiency in the industry needs improvement. Therefore, all new strategies and policies in the European Union emphasize the reuse and recycling of all products based on natural, bio materials.

In many coastal regions around the world, seashells were used in a construction and as a raw material for making pottery (Jovic at al., 2019; Govindhan and Thamizha, 2008; Khamis, 2022). Seashell waste accumulates rapidly, especially in places where a lot of shellfish products are consumed. Comprehensive experimental analysis in literature sources justifies the use of seashell waste as construction material today. The chemical composition of seashells is more than 90% calcium carbonate ($CaCO_3$), therefore this composition is similar to limestone which is used in a production of Portland cement (Lertwattanaruk at al. 2012). As mentioned by Gideon O. Bamigboye at al. (2022), 5% of protein glue which can be found in seashells, is responsible for their toughness. Different authors studied the use of seashells as aggregate for green concrete production (Olivia at al., 2015; Barbachi at al., 2017; Prince at al., 2020). These studies concluded that flat and irregular shape of seashell particles contributes to the decrease of paste–aggregate relation in a concrete, which leads to the increase of closed porosity. Therefore, the compressive strength of a concrete decreases significantly with the higher percentage of shell aggregate (Gonzales at al., 2015), while tensile strength and flexural strength are higher when compared with conventional concrete (Olivia at al., 2015). The experimental results showed that the maximum percentage of replacement of seashell powder in a concrete is 15% (Prince, 2020). The absorption and porosity of a concrete at low percentages of replacement with seashell aggregate are less, when compared with conventional concrete, but these values are increasing with higher percentage of seashell replacement (Tayeh at al., 2019). However, experimentally was proven that decrease in mechanical properties of seashell concrete does not compromise the performance of the material for civil applications (Essalem and Cherradi, 2023). Some authors were studying the use of seashells as aggregate in cemented materials for masonry and plastering. The results obtained showed the reduction in the flexural stress and toughness, and higher water absorption of cement with seashell aggregates. Water absorption depends on the size of the shell crushes and increases with the higher degree of crushing. As the replacement percentage of seashells increases, the free water content in the mix also increases and the compressive strength decreases (Lertwattanaruk at al., 2012; Suarez-Riera at al., 2021). Singamneni at al. (2018) were examining mechanism of bonding in seashell powder based ceramic composites used for 3D printing, while Silva at al. (2019) examined the possibility of using oyster shell waste in artificial stone production. They concluded that the new artificial stone exhibits higher mechanical properties when compared with granite, marble, and Aglostone. Not only from the sustainable perspective, but also from the economic perspective, the effective reuse of these wastes is justified, considering the costs of disposal of waste seashells, which keeps rising in countries around the world (Bamigboye at al., 2022). Waste seashells are a renewable and cheap resource, which can decrease furniture manufacturing costs, and waste disposal cost, while providing a sustainable environment.

In the European Union, every year, 600.000 tons of shellfish are produced (Suarez-Riera at al., 2021). In Croatia, which is a member state of the European Union, tones of seashells are produced every year. For example, in 2022, 1.113 tons of seashells were produced in the country (Croatian Ministry of Agriculture, 2023). Even though there are 126 registered seashell farms on Croatian Adriatic coast, 55.7% of seashells are produced in Mali Ston Bay in Dubrovnik-Neretva County (Ministarstvo gospodarstva i održivog razvoja Republike Hrvatske, 2023). Empty seashells are generally disposed in garbage sites, thereby creating unpleasant sight and odor pollution. If left for a long time, microbial decomposition of salts into gases such as hydro-gen sulfide, ammonia and amines, is causing serious environmental impact (Suarez-Riera at al., 2021). The idea for creating the material entirely made of seashell waste came from the tendency to deal with seashell waste problem in Mali Ston Bay in a constructive way. This way, the waste would be eliminated, and a new material, entirely made of natural ingredients, would be a sustainable approach to this ecological problem.

The objective of the research presented in this paper is to develop a new ecological material for furniture production, made of seashell waste and to improve resource efficiency through reuse and recycling of food waste materials. The aim is to examine physical and mechanical properties of the bio composite material made of seashells and bone glue and its capabilities to be used for furniture and decorative objects making.

MATERIALS AND METHODS

Methodology of waste seashell bio composite preparation and testing is shown in Figure 1. Preparation of the seashell bio composite material and sampling were conducted in the workshop of the Department of Art and Restoration, University of Dubrovnik, Croatia. The seashells were conducted from the local restaurants, as a food waste, Figure 2. The seashells were washed well to remove all organic residues, dried in the oven to become softer, and grounded with a blender, until a fine powder was obtained. Additional components in the mixture were alginate, bone glue, lavender essential oil and water. The mix percentages used to obtain this new bio composite material were 18.2% of mussel, 36.4% of oyster, 21.8% of water, 14.5% alginate, 4.5% bone glue, and 4.5% lavender essential oil. All material components were weighted according to the amounts required in the mix design. The seashell bio composite material was prepared by mixing dry materials and water in the pan mixer until a homogeneous paste is obtained. At the end of the mixing phase, mixture was molded manually into prismatic specimens. So far, this material has been used for creating small decorative objects, for interior use.

Testing of physical and mechanical properties of the bio composite material was conducted in the Laboratory for Surface Treatment of the Department of Wood Technology, University of Sarajevo, Mechanical Engineering Faculty, Bosnia and Herzegovina. Physical properties of the bio

Figure 1. Methodology of waste seashell bio composite preparation and testing

Figure 2. Washed and dried mussel and oyster seashells

composite material were determined on the non-uniform-size prismatic samples, Figure 3, that were cut from four bricks of material. Samples were used to determine the density of the material under the different ambient conditions, and to monitor the moisture content in the material.

The density of the tested material was determined using the following equation:

$$\rho = \frac{m}{V} \frac{\mathrm{g}}{\mathrm{cm}^3} \tag{1}$$

where: m – the mass in grams, V – the volume of the sample in cm^3.

The volume of the samples was determined by the stereometric method. The moisture content of the material was determined by the oven and weighing scale method. In order to remove sample residual moisture, samples were placed into the drying chamber (Memmert UF110m) where the dry air temperature was set at 100°C, and they were dried for 48 hours. The percentage of moisture content was calculated using the equation:

$$W = \frac{m_1 - m_2}{m_2} \, 100\% \tag{2}$$

where: m_1 – the mass of the sample before drying in grams, m_2 – the mass of the sample after drying in grams.

Testing of the material's behavior under environmental conditions of air temperature (30–35°C) and elevated relative humidity (not measured) was conducted on four samples. The testing lasted for 24 hours in a humidification chamber. Additionally, six samples were used for testing water absorption after submerging in the water. Samples were submerged in the water at room temperature for 48 hours. The moisture content in the samples before and after the exposure to altered atmospheric conditions was calculated using (2).

In the case of the bio composite material made from the seashells, there are no standards to evaluate its mechanical properties. Therefore, selected mechanical properties (tensile strength, compressive strength, and bending strength) were, due to the limited amount of material, tested on samples whose dimensions and shape are usually used for testing samples of 3D printed materials. The sample sizes for the tensile strength test (a) according to the standard ISO 527-2, the compression strength test (b) according to the standard ASTM D695, and the bending strength test (c) according to the standard EN ISO 178 are shown in Figure 4. Before testing the mechanical properties of the material, the prepared samples were stored for 7 days in the climate chamber (Binder - model KMF 240). The temperature was set to 22°C and relative air humidity (RH) was 55%. The tests were carried out on a universal testing machine (Shimadzu, 10kN), Figure 5. The displacement velocity during tests was maintained at 5.0 mm/min in all cases.

Figure 3. Samples prepared for testing physical properties

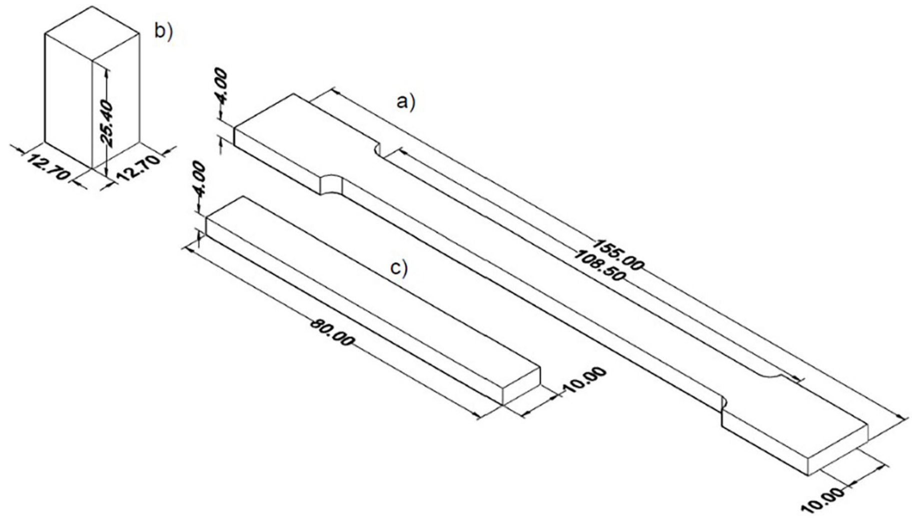

Figure 4. The sample sizes for testing selected mechanical properties in mm

The tensile strength of the bio composite material was tested on five samples, the compressive strength on ten samples, while the bending strength was tested on seven samples, Figure 6.

The tensile/compressive strength (σ_T; σ_C) of the tested material was determined using the following equation:

$$\sigma=\frac{F_{max}}{A_0}\ \text{MPa} \tag{3}$$

where: F_{max} – the maximal (ultimate) force in N, A_0 – the cross-sectional area of the sample in mm^2.

Bending strength σ_b was determined using the following equation:

$$\sigma_b=\frac{3}{2}\frac{F_{max}\cdot l}{b\cdot h^2}\ \text{MPa} \tag{4}$$

where: F_{max} – the maximal (ultimate) force in N, l – the distance between supports (span: 64 mm) in mm, b – the width of the sample in mm, and h – height of the sample in mm.

The main features of a test results datasets were determined by descriptive statistics methods.

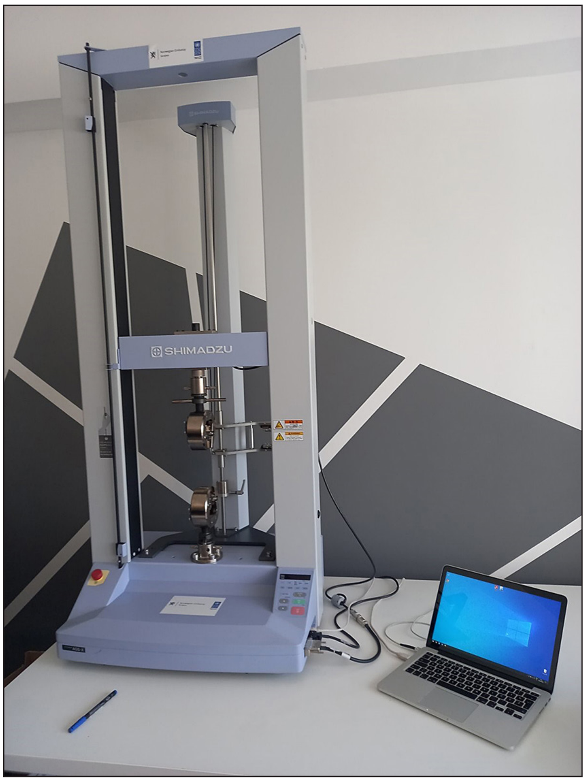

Figure 5. Universal testing machine

RESULTS AND DISCUSSION

The results of the bio composite material density under different ambient conditions are shown in Table 1. The average density of the samples is 1.26 g/cm^3, and the average moisture content in the material is 1.22% at elevated temperature and low relative air humidity and does not differ from the density at absolutely dry material. The density of the tested material is similar to density of the lightweight aggregates (1.2 g/cm^3) used in “light” concretes [15].

The samples for testing the mechanical properties of the material were stored for 7 days in the climate chamber at the temperature 22°C and RH 55%. After conditioning, average values of moisture content and density of the samples were 1.64% (stand. dev. 0.096%) and 1.32 g/cm^3

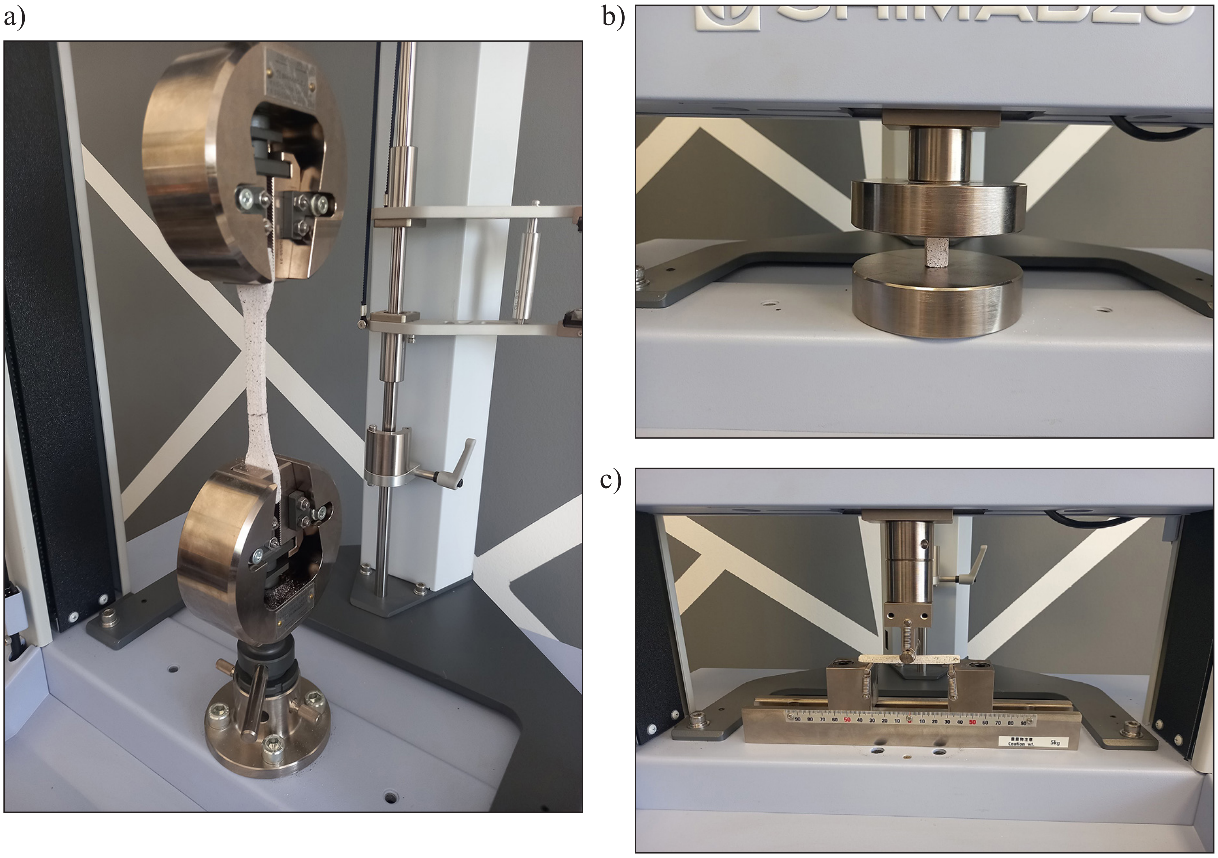

Figure 6. Testing the mechanical properties of bio composite: (a) tensile strength, (b) compression strength, (c) bending strength

Table 1. Density of bio composite material

Sample	Moisture content of material: absolutely dry - 0%			Under laboratory conditions – T=30°C; RH 28%			
	Mass, g	Volume, cm^3	Density, g/cm^3	Mass, g	Volume, cm^3	Density, g/cm^3	Moisture content, %
1	4.34	3.62	1.19	4.38	3.7	0.17	0.92
2	8.83	7.42	1.19	8.95	7.45	0.17	1.36
3	7.15	5.18	1.38	7.24	5.36	0.17	1.26
4	7.01	5.47	1.28	7.1	5.51	0.17	1.28
5	7.08	5.49	1.28	7.17	5.55	0.17	1.27
6	8.12	6.16	1.31	8.22	6.6	0.17	1.23
Total average			1.27	Total average		1.26	1.22
Deviation			0.07	Deviation		0.06	0.15
Total range			0.19	Total range		0.17	0.44

(stand. dev. 0.024 g/cm^3), respectively. The results of testing how the material responds to the environmental condition changes (temperature and relative air humidity) are shown in Table 2. The test results, after 24 hours, showed that there was an increase in the moisture content in the material due to a change of relative air humidity. The material absorbs atmospheric moisture and the difference in moisture content in the material before and after the exposure to altered atmospheric conditions is shown in Table 2.

The samples used for testing water absorption were absolutely dry (0%) before submerging. Immediately after placing the samples in the water, air bubbles appeared on their surfaces from the material deposits, followed by a characteristic sound. After two days of submerging in the water, a visual inspection of the samples revealed no change in shape, while the water was muddy and with slight sediment. The material has softened, was of a low strength, and had a tendency to crumble. The average water content that samples absorbed was 28.69%, Table 3. There was no significant change in the volume of the samples. Based on the presented results, it can be concluded that the tested material is hygroscopic and does not swell when absorbing water.

A visual inspection of the dried material's surface was performed under magnification 20x, Figure 7. There are no visible macro and micro voids in the material structure, which suggests that they are mostly removed during the material preparation process. The exceptional hygroscopicity of the material, observed during the testing, is likely due to the binding material used and the presence of entrapped air in micro voids, as noted by Monita Olivia and others [14]. The probable cause of micro voids is due to the aragonite shape of seashell ashes, as mentioned by Bassam A. Tayeh and others [18], which results in higher porosity and water absorption.

The results of tensile strength of the five specimens of the bio composite material are given in Table 4. The average values of tensile strength were 1.9 MPa, sample standard deviation was 0.49 MPa, and the rang of a set of tensile strength data was 1.5 MPa. A stress-strain curves for the bio composite material were linear. Fractures occurred while the deformation was elastic, with a sharp and sudden break, i.e., without zones of

Table 2. Moisture content in the material samples before and after humidification

Sample	Moisture content of the material before humidification, %	Moisture content of the material after humidification, %	Increase of moisture content, %
1	1.45	2.89	1.44
2	1.87	2.35	0.48
3	0.90	2.70	1.8
4	0.80	2.40	1.6

Table 3. Water content and volume of bio composite material after submerging

Sample	Water content after submerging, %	Volume of absolutely dry material, cm^3	Volume of material after submerging, cm^3
1	39.17	3.62	3.63
2	38.95	7.42	7.48
3	16.92	5.18	5.43
4	31.09	5.47	5.54
5	29.24	5.49	5.42
6	16.75	6.16	6.21

a) b)

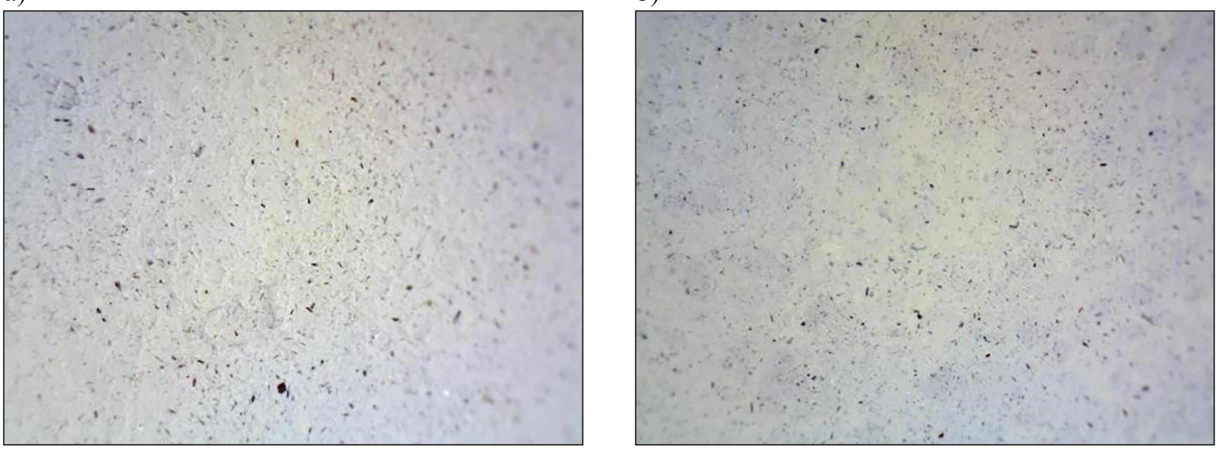

Figure 7. Sample surface of bio composite material at magnification 20×

Table 4. The results of tensile strength of bio composite material

Sample	Max force, N	Max stress, MPa
1	40.7	1.0
2	83.9	2.1
3	80.4	2.0
4	99.5	2.5
5	70.1	1.8
Total average	74.9	1.9
Deviation	19.5	0,49
Total range	58.8	1.5

plastic deformations. The ruptures occurred without any previously noticeable change in the elongation rate. Experimental results of compressive strength of the bio composite material are given in Table 5. The average values of compressive strength were 3.05 MPa, sample standard deviation was 0.43 MPa, and the rang of a set of compressive strength data was 1.41 MPa.

Figure 8 shows the curves of stress-strain diagrams of the compressive strength of the tested specimens. The diagrams show noticeable differences among the values of ultimate compressive stress of ten material samples. The average compressive strength curve of the bio composite material has a defined elastic region, and at higher stress, the behavior is inelastic. The final breaking material occurs at a lower stress than the ultimate stress. The results of bending strength of the bio composite material are given in Table 6. The average values of bending strength were 3.63

Table 5. The results of compression strength of bio composite material

Sample	Max force, N	Max stress, MPa
1	558.85	3.42
2	403.56	2.47
3	633.28	3.88
4	519.14	3.18
5	462.99	2.84
6	413.93	2.54
7	503.59	3.08
8	525.20	3.22
9	443.76	2.72
10	521.70	3.20
Total average	498.60	3.05
Deviation	69.87	0.43
Total range	229.72	1.41

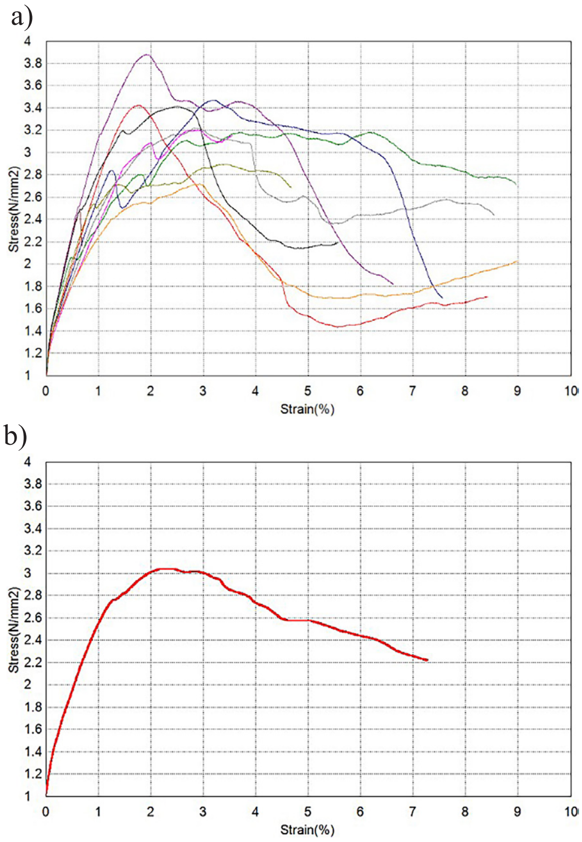

Figure 8. The stress-strain diagrams of compressive strength test: samples curves (a), average (b)

MPa, sample standard deviation was 0.73 MPa, and the rang of set of bending strength data was 1.83 MPa. The curves of stress-strain diagrams of the bending strength of the tested specimens are shown in Figure 9. Two different groups of curves are noticeable, which indicates a significant variation of the modulus of elasticity of seven material samples. The average bending strength curve of the bio composite material has a dominant elastic region and does not have a noticeable yield point.

Table 6. The results of bending strength of bio composite material

Sample	Max force, N	Max stress, N/mm^2
1	10.14	3.92
2	9.56	3.70
3	10.29	3.94
4	6.88	2.66
5	6.60	2.55
6	10.86	4.20
7	11.33	4.38
Total average	9.38	3.62
Deviation	1.89	0.73
Total range	4.73	1.83

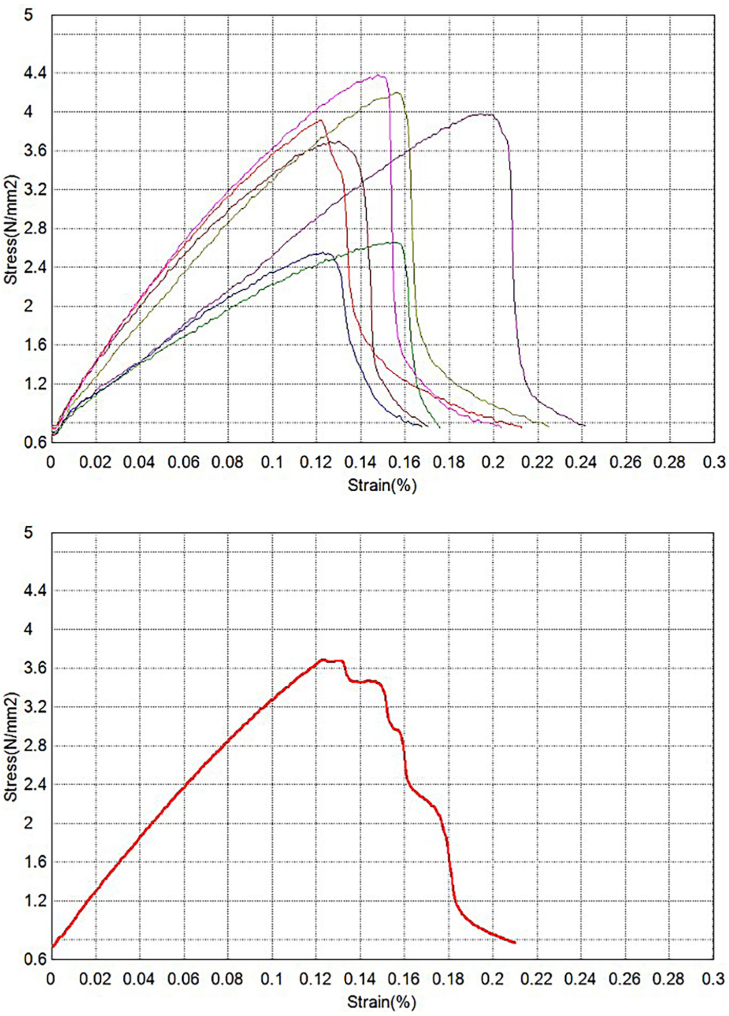

Figure 9. The stress-strain diagrams of bending strength test: samples curves (left), average (right)

The comparison of tensile, compressive, and bending strength of seashell composite material is shown in Figure 10. The mean value of tensile strength was remarkably lower (37.7%) than the mean value of compressive strength which, together with fracture analysis, indicates that the bio-composite material has the characteristics of a brittle material, such as concrete.

The obtained results of the bio composite material, examined in this paper, were compared

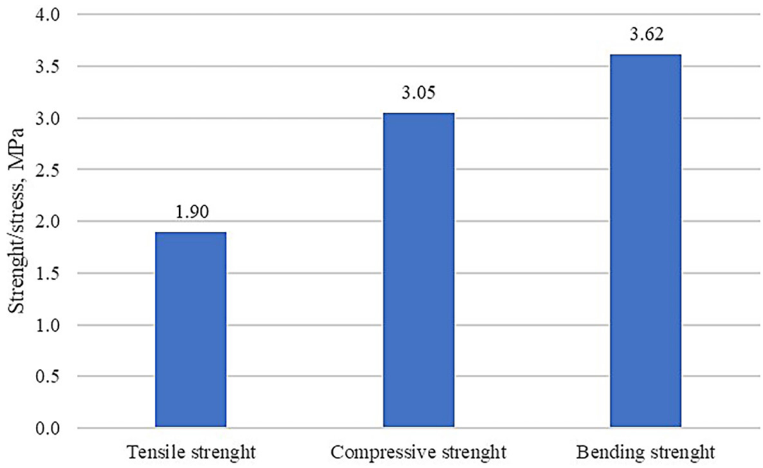

Figure 10. Comparison of maximal strength/stress of seashell composite material

with literature testing results of a concrete material, where seashells were used as partial cement replacement (Prince at al., 2020). The seashell powder was added in various percentages such as 5%, 10%, 15% and 20%. The results obtained for concrete with maximum percentage of seashell powder added (20%), after 28 days of drying, has higher compressive strength (7.77 MPa), but lower values of tensile strength (1.26 MPa) and bending strength (3.04 MPa). In addition, the results showed that the compressive strength decreases significantly, as the percentage of shell aggregate grows in a concrete.

CONCLUSIONS

Based on the laboratory test results, the following conclusions can be drawn. The average density of the tested material is 1.26 g/cm^3, and it is similar to density of the lightweight aggregates (1.2 g /cm^3) used in "light" concretes. The average moisture content in the material is 1.22%. The mean value of tensile strength was 37.7% lower than the mean value of compressive strength. This indicates that the tested material has the characteristics of a brittle material, such as concrete.

This material can be used for making furniture components that don't bear heavy loads and it is suitable only for interior applications. The material absorbs atmospheric moisture. It is hygroscopic and does not swell when absorbing water. The compressive and bending strength were higher than tensile strength. The average values of tensile strength were 1.9 MPa, the average values of compressive strength were 3.05 MPa, and the average values of bending strength were 3.63 MPa. Tested material yielded better bending properties, but little lower compressive strength. Further research, based on the data obtained from the analysis presented in this paper, will focus on creating a prototype of a side table with tabletop made of seashell bio composite material obtained by 3D printing.

REFERENCES

1. Yüksel E., Kiliç M. 2015. Eco-Friendly Approach in Furniture Design. Proc. 27 Intenational Conference, 357–368.
2. Chai L., Wang X., Chen Z. 2020. Research of furniture design based on Chinese traditional sustainable ideology. E3S Web Conference, 179, 1–5. doi: 10.1051/e3sconf/202017902090
3. European Commission. 2016. Circular economy implementation of the circular economy action plan. http://ec.europa.eu/environment/circular-economy/index_en.htm (accessed 2023 June 13)
4. Husgafvel R., Linkosalmi L., Hughes M., Kanerva J., Dahl O. 2018. Forest sector circular economy development in Finland: A regional study on sustainability driven competitive advantage and an assessment of the potential for cascading recovered solid wood. Journal of Cleaner Production, 181, 483–497. doi: 10.1016/j.jclepro.2017.12.176
5. European Commission, EC. 2014. Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions towards a circular economy: a zero waste programme for Europe. COM/2014/0398 final. http://eur-lex.europa.eu/legal-ontent/EN/TXT/?uri=celex%3A52014DC0398 (accessed 2023 May 15)
6. Thonemann, N., Schumann, M. 2018. Environmental impacts of wood-based products under consideration of cascade utilization: a systematic literature review. Journal of Cleaner Production, 172, 4181-4188. doi:10.1016/j.jclepro.2016.12.069
7. European Commission. 2011. Roadmap to a Resource Efficient Europe. Eur. Comm. https://www.eea.europa.eu/policy-documents/com-2011-571-roadmap-to (accessed 2023 May 15)
8. Ruuska A. and Häkkinen T. 2014. Material efficiency of building construction. Buildings, 4(3) 266–294. doi: 10.3390/buildings4030266
9. Jović M., Mandić M., Šljivić-Ivanović M., Smičiklas I. 2019. Recent trends in application of shell waste from mariculture. Studia Marina, 32(1), 47–62. doi: 10.5281/zenodo.3274471
10. Govindhan S., Thamizha S. 2008. Experimental Study of Concrete Using Seashell and Flyash. International Research Journal of Engineering and Technology, 6(3), 403–411.
11. Khamis Z. 2022. Seashell and Snails in Egypt During Prehistoric Times. Egyptian Journal of Archaeological and Restoration Studies, 12(2), 233–247. doi: 10.21608/ejars.2022.276170
12. Lertwattanaruk P., Makul N., Siripattarapravat C. 2012. Utilization of ground waste seashells in cement mortars for masonry and plastering. Journal of Environmental Management, 111, 133–141. doi: 10.1016/j.jenvman.2012.06.032
13. Bamigboye G.O., Okecuhukwu U.E., Olukanni D.O., Bassey D.E., Okorie U.E., Adebesin J., Jolayemi K.J. 2022. Effective Economic Combination of Waste Seashell and River Sand as Fine Aggregate in Green Concrete. Sustainability. 14(19). doi: 10.3390/su141912822

14. Olivia M., Mifshella A.A., Darmayanti L. 2015. Mechanical properties of seashell concrete. Procedia Engineering, 125, 760–764. doi: 10.1016/j.proeng.2015.11.127
15. Barbachi M., Imad A., Jeffali F., Boudjellal K., Bouabaz M. 2017. Physical characterization of sea shell for a concrete formulation. Journal of Materials and Environmental Sciences, 8(1), 332–337.
16. Prince J.R., Sreekumar S., Sudhakaran S.2020. Experimental Investigation of Concrete Using Seashell. International Journal of Innovative Research in Science, Engineering and Technology, 9(7), 5823-5831.
17. Gonzalez B., Carro-Lopez D., Martinez-Abella F., Martinez C., Seara-Paz S. 2015. Effects of seashell aggregates in concrete properties. First International Conference on Bio-based Building Materials, 33(2), 376–382.
18. Tayeh B.A., Hasaniyah M.W, Zeyad A.M., Yusuf M.O. 2019. Properties of concrete containing recycled seashells as cement partial replacement: A review. Journal of Cleaner Production, 237. doi: 10.1016/j.jclepro.2019.117723
19. Essalem M.L.M., T. Cherradi T. 2023. Seashell as Aggregate in Cemented Materials: A Review. Civil Engineering and Architecture, 11(3,) 1337–1345. doi: 10.13189/cea.2023.110318
20. Suarez-Riera D., Merlo A., Lavagna L., Nistico R., Pavese M. 2021. Mechanical Properties of Mortar Containing Recycled Acanthocardia Tuberculata Seashells as Aggregate Partial Replacement. Boletín de la Sociedad Española de Cerámica y Vidrio, 60, 206–210. https://doi.org/10.1016/j.bsecv.2020.03.011
21. Singamneni, Behera M.P., Le Guen M., Zeidler H. 2018. Mechanism of Bonding in Seashell Powder Based Ceramic Composites Used for Binder-Jet 3D Printing. Bioceramics Development and Applications, 8(1), 1–7. doi: 10.4172/2090-5025.1000108
22. Silva T.H., Mesquita-Guimarães J., Henriques B., Silva F.S., Fredel M.C. 2019. The potential use of oyster shell waste in new value-added by-product. Resources, 8(1), 1–15. doi: 10.3390/resources8010013
23. Croatian Ministry of Agriculture: Marine aquaculture. 2023. https://ribarstvo.mps.hr/default.aspx?id=14 (accessed 2023 September 21)
24. Ministarstvo gospodarstva i održivog razvoja Republike Hrvatske. 2023. Plan upravljanja zaštićenim područjem Malostonski zaljev i Malo more. 6146. https://mingor.gov.hr/UserDocsImages//UPRAVA%20ZA%20ZA%C5%A0TITU%20PRIRODE/NATURA%202000//PU%206146%20Malostonski%20zaljev%20i%20Malo%20more.pdf