Study on the Pressure Mechanical Properties and Fracture Mechanism of the Meretrix Linnaeus Shell

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Abstract. In order to research the compression performance of the clam shell meretrix Linnaeus, the test was carried out by universal testing machine. A comprehensive analysis is finished based on the relations between bearing load and deformation and the failure state of the pressure shells. The fresh shells had the better pressure performance with the large deformation and the large bearing load. Some microcrack had been produced on the shell, which did not cause fracture failure. The large crack was created directly on the dry shell with the bigger bearing load and that caused easily the dry shell to be destroyed. The conclusions showed that the different state of shell organic matter can directly change the mechanical properties of shells.

Introduction

Shell is very important for the mollusk movement that it can help the mollusk to crawl, jump, swimm and digg holes. And it also plays an important role in protecting the molluscs from other animals. In the long evolutionary process, the shells of marine organisms have the characteristics of light weight and strong ability to withstand impact. There are many species of mollusk. Bivalvia is a typical feature of shellfish. It has two equal shells. Shells have been paid attention to by engineering researchers. The research contents of shells include appearance structure, wear resistance, microstructure, mechanical properties and so on[1-4]. These researches can provides bionic prototype and theoretical support for the the application of biomimetic composites [5-8], that is very important. The researchers have noted that water conditions had some effect on shell mechanical property[9]. But the quantitatively conclusions on the water content and the overall mechanical properties of shells has not been drewed.

In this paper, the mechanical properties were studied of shells meretrix Linnaeus with the different water content. The compression mechanical properties were showed of the dry and fresh shell. The difference between two types shell was found and the reasons were analyzed with the microstructure of the shells. This study provides a theoretical reference for the structural design and application of biomimetic materials.

Testing Samples Preparation and Measurement

Selection and Preparation of Experimental Materials

A typical clam shells Meretrix Linnaeus were used to pressure experiments (as shown in Figure1). The samples were collected from Yantai, Shandong province, May 2017. All samples were collected with the same batch and the uniform size. The average width was 4.64±0.2cm and the average thickness 3.81±0.2mm, so as to ensure the consistency of the experimental samples and reduce the data error.
The fresh clam can be divided into two parts after being washed with a brush. A part ones were directly used to finish the living body experiments, the other part was removed the organic matter and then clean with the ultrasonic equipment. The samples were placed in room for 96 hours and then the test was done.

**Compression Performance Measurement of the Clam Shell**

The electronic universal mechanical test machine was used to test the mechanical parameters. The technical parameters of the machine includes the MTS C43.104, the displacement sensor MTS LPS.103, the pressure range 0~10kN and the motion velocity of the pressure measuring device is 2mm/min. The structure of the testing equipment is shown in Figure 2.

**Experimental Results and Analysis**

**Data and Analysis of the Pressure Test of the Overall Clam Shells**

7 samples were used in each team during the experiment. The minimum and the maximum sets of sample data were eliminated. Then the other data were used to analyzed the shell pressure performance. The pressure characteristic curves of clam shell are shown in Figure 3 in fresh and dry conditions.

The mechanical properties of shells are different in fresh and dry conditions. According to the experimental data, the shell deformation increase with the increasing bearing load. For the fresh clam shells, the deformation becomes larger and larger with the bearing load increasing. The whole curvesof the bearing load fluctuate with increasing and decreasing. But during the process the deformation data of the overall shells arise always. The data of the dry shells varies linearly. With the increase of the deformation, the pressure load rises in a straight line, and the bearing loads suddenly drop obviously after reaching the maximum bearing pressure by the overall shell. The maximum deformation of the dry shell is near 0.004in.
The deformation begins when the compression load is at 100-150N for the fresh shells. The total deformation of shells was increased with the load increase. The maximum bearing load is 350N, when the deformation is about 0.007 in. The fracture crack begins at the deformation of 0.0037 in~0.0050 in. The dry shells start to deform at about 50N and the deformation increased with the increasing bearing load. The fracture cracks will generated until the bearing loads exceed over 250N. At this time the deformation amount is 0.0037 in~0.0050 in. The maximum bearing load of the dry shell is about 250N~330N, and the maximum deformation is 0.004 in~0.0055 in.

The average bearing load of 5 fresh or dry samples was calculated and the Load-deformation curves were plotted as shown in figure 4. From the diagram we can seen, comparison of dry shells and fresh shells, the deformation data of fresh shells are greatly increased than that of the dry shells when the bearing load is the same. The absolute deformation was calculated according to the above diagram when the bearing load is 75N, 100N and 150N. The results were shown in Table 1.

According to the data in Table 1, when the bearing load is at 100 N, the deformation of the fresh shells is 0.00187 in and the dry shell 0.00119 in that the former is 1.6 times that of the latter. And At 175N the former is 1.5 times that of the latter. The macroscopic structure size in the two states did not change significantly. It was shown that the elasticity reduction and the modulus change of the dry shells resulted in the deformation of the dry shells decreased.

Table 1. The Relations of mean bearing load and deformations of shell.

<table>
<thead>
<tr>
<th>Bearing load(N)</th>
<th>Shell Deformation(inch)</th>
<th>Fresh</th>
<th>Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.00187</td>
<td>0.00119</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>0.00296</td>
<td>0.00203</td>
<td></td>
</tr>
<tr>
<td>175</td>
<td>0.00371</td>
<td>0.00248</td>
<td></td>
</tr>
</tbody>
</table>
Analysis of Fracture Cracks in Shells

The samples were shown in Figure 5 after the compression test. The failure mode of clam shells is to produce crack. The crack position on the shells is basically same and it produced near the pressure points. The size and distribution characteristic of the crack are not exactly same.

The crack is produced at the pressure point as the center on the fresh shell body after compression. Then the crack is extended in many directions. The features are shown in Figure 5, a and b. The main crack length is longer along the outer ring surface of the shell and the micro ones are shorter along other directions. These micro cracks will be a constraint on the main crack growth and they help the fresh shell to weak the extrusion effect and impact damage. Restricting the crack propagation and shorting the crack length also means that the serious structure fracture of the fresh shell is reduced.

![a. external cracks of fresh shell](image1)
![b. internal cracks of fresh shell](image2)
![c. external cracks of dry shell](image3)
![d. internal cracks of dry shell](image4)

Figure 5. External and internal cracks of different states Scapharca subcrenata shells.

The dry sample produced cracks also with the pressure point as the center. The crack direction has a stronger orientation, and the length of the main crack is longer than that one of fresh shell. At the same time, there is no micro crack on the dry shell. It shows that the rapid expansion of the crack in the dry shell caused the structure of the sample completely and quickly destroyed (shown in figure 5, c and d).

![Figure 6. Scanning electron microscope(SEM) images of shell sections.](image5)

The conclusion has been drawn that the main components of clam shell are calcium carbonate and that exists as the microstructure of aragonite crystals. Calcium carbonate accounts for 97.82% of total quality of the shell, organic matter accounts for 1.78% and water is 0.4%. Although the proportion of organic matter in shells is small, but it has the key effect on the excellent mechanical properties of shells. And the change of the state of organic matter affects the bearing pressure and the mechanical properties of the shell [10-11]. From SEM photograph in figure 6, we can see that the clam shell is composed of three layers, and there is an obvious boundary between the three
layers. Under the conditions of fresh and dry, water content is different in shell and the state of organic matter is different in the three layers also. The organic matter exists in liquid state in fresh shell. When the shell is subjected to compression, the micro crack are first produced along the combination of organic matter and spread. The liquid organic matter helps to reduce the stress concentration, so that the load pressure is distributed evenly between the lamellar crystals, so that more micro cracks are produced. The formation of micro cracks consumes a certain bearing load energy, and the existence of liquid organic matter also enhances the deflection of the crack propagation between the lamellar crystals. The crack propagation increase greatly and the expansion resistance is enhanced. So the pressure fracture consumed more energy. We can see that the shell toughness is enhanced. This mechanical features are be shown from the load-deformation diagram of fresh shell. The curves of the fresh shell rise in a series of zigzags. When the micro crack is produced in the shell, the pressure load decreases and then increases, and the deformation becomes bigger and the shell do not produce the serious structural damage. With the bearing load becoming more and more, until the shell bearing limit is reached. Compared with dried clam shell, the deformation of fresh shell increased significantly. The organic matter has dried up in dry clam shell. The dry organic matter makes the shell layer tightly combined to enhance the pressure load of the shell. So the bearing load of the dry shell rise rapidly and straightly. Once the stress concentration is produced in shell, the micro cracks between the layers can expand rapidly and produce large cracks. The large cracks result in the structural destruction of the dry clam shell.

Conclusions

The compression test was carried out with the fresh shell and the dry ones. The bearing performance of the fresh samples was the better than that of dry ones. Several micro cracks produced in the fresh shell. The production of the micro crack consumed the loading energy. So it cause the bearing load and deformation of the fresh shell to significantly increase before the serious damage of the shell. But the bearing capacity of the dried samples gradually decreased, which indicating that the biological activity of the organic matter and water content in the clam shell had a significant effect on the mechanical properties of the samples.

The fracture positions of different samples are near the pressure point, but the crack growth of the fresh samples has no significant orientation and the crack length is shorter in fresh shell than that of the dry shell. But the crack orientation of dry specimens is more obvious than that of the fresh shell and the crack length increased rapidly, the structure damage degree of the same load to the dry shells is more destructive than to the fresh ones.

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References


