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# The Research of Biology Coupling Characteristics on the Shells of *Haliotis discus hannai* Ino[1]

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**Abstract:** The surface morphologies, structures and materials of *Haliotis discus hannai* Ino shells were qualitatively studied by means of a stereoscopic microscope，a field emission scanning electronic microscopy, energy dispersive spectrometer and X-ray diffractometer, and abrasive particle wear was qualitatively and quantitatively studied by means of a pin-on-disc apparatus. The results showed that the outer layer surface of *Haliotis discus hannai* Ino shells was non-smooth and had some strumae or similar parallel convex wave. The shells of *Haliotis discus hannai* Ino are polycrystalline composites of calcium carbonate and proteins and glycoproteins and consist of the periostracum, prismatic and nacreous layers with calcite in the outer prismatic layer and aragonite in the inner nacreous layer. Nacreous layer is a natural composite comprised of calcium carbonate in the aragonite polymorph with organic macromolecules sandwiched in between, and the coupling of platelet interlocks and organic materials makes nacreous layer to be strong and tough.

The abrasive particle wear tests showed that the abrasion resistance was different on the different parts of the shells, and the left of the shells possessed the highest abrasion

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resistance and the abrasion resistance of the shells was the lowest on the edge of the right. The nacreous layer possessed higher abrasion resistance than prismatic layer because of the coupling of structure and materials of nacreous layer.

**Key words:** *Haliotis discus hannai* Ino shells; morphology; structure; materials; anti-wear; biological character; coupling

# INTRODUCTION

In order to adapt to natural environment and meet the survival needs, the organisms have been optimized with various morphologies, configurations and complicated structures under the law of natural selection for millions of years of evolution, and gradually become a system that has optimal adaptability to the living environment (LU, 2004; Bogatyrev, 2004; REN, 2008). Various functions of the organism are achieved by the mutual couplings of multiple factors in the organism. For example, the biological functions like anti-wear and toughness are achieved by the mutual couplings of different morphologies, structures, materials and constitution of the organism (Edison, 2005; WU et al., 2007; REN et al., 1990; XU et al., 2008).

Man can seek ask for the methods solving a lot of problem based on biological coupling mechanism (REN & LIANG). Evidently, It's important for us to research the coupling characteristics of the organism which are important biological bases for bionic engineering.

Mollusk shells are Layered composite materials possessing particular morphologies, structures and materials. Their strength and toughness are crucial for survival of the individuals. In bionic research, the shells are always the research objectives for anti-wear and toughness (TONG et al.; Heuer et al., 1992; LI et al.). As commercially important mollusks in our country, the shells of Haliotis discus hannai Ino have especial strength and toughness function. These properties depend on structural characteristics, phase (calcite or aragonite), grain morphology and aggregation, etc. Therefore, the research of coupling characteristic about morphologies, structures and materials will provide reference for bionic anti-wear and possess important reality meaning.

# 1. MATERIALS AND METHODS

## 1.1 The selection of *Haliotis discus hannai* Ino shells

*Haliotis discus hannai* Ino used in this experiment were bought from aquatic product market in ChangChun and average weight is 70±2 g, average shell length of length is 7.1±0.3 cm. Carve all the meat out and rinse the inside of the shells in cold water and scrub them with a toothbrush to remove meat particles. Dried at room temperature and stored away.

## 1.2 Stereo microscope observation

The typical parts were selected and incised from *Haliotis discus hannai* Ino shells. The surface morphologies of the samples were observed using a SteREO Discovery.V12 stereo microscope.

## 1.3 SEM observation

The samples possessing regular fracture section were selected. All the samples were sprayed with gold powder using an ion sputter JFC-1600 and observed using a JSM-6700 field emission scanning electronic microscopy.

### 1.4 X-ray diffraction method measurement

A few samples were taken and grinded about 30min at carnelian mortar. The sample powder was put on the glass slice and tested using X-ray diffractometer. The work condition of the X-ray diffractometer is target/filter(monochro):Cu/ graphite；Voltage/Current:40kV/250mA, I(max)=1300.

### 1.5 Energy dispersive spectrometer (EDS) measurement

The elements in prismatic layer and nacreous layer of *Haliotis discus hannai* Ino shells were analysed using Energy dispersive spectrometer.

### 1.6 Sliding abrasive particle wear experiment

Sliding abrasive particle wear was tested under a load of 1 N, 3 N and 5N using a pin-on-disc apparatus. Both the left and the right of *Haliotis discus hannai* Ino shells were incised to square 4mm×4mm,and 150,600 and 1000 mesh SiC abrasive papers were used respectively as the counterface. The abrasion value of the shell was tested using JA2300 electronic balance.

## 2. RESULTS AND DISCUSSION

### 2.1 The morphology of *Haliotis discus hannai* Ino shells

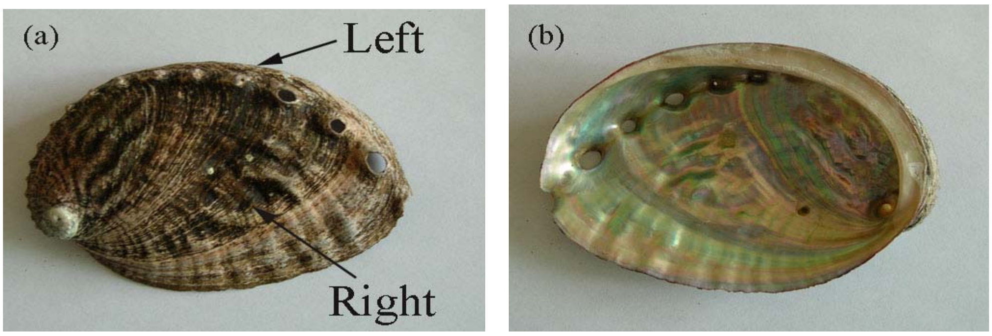
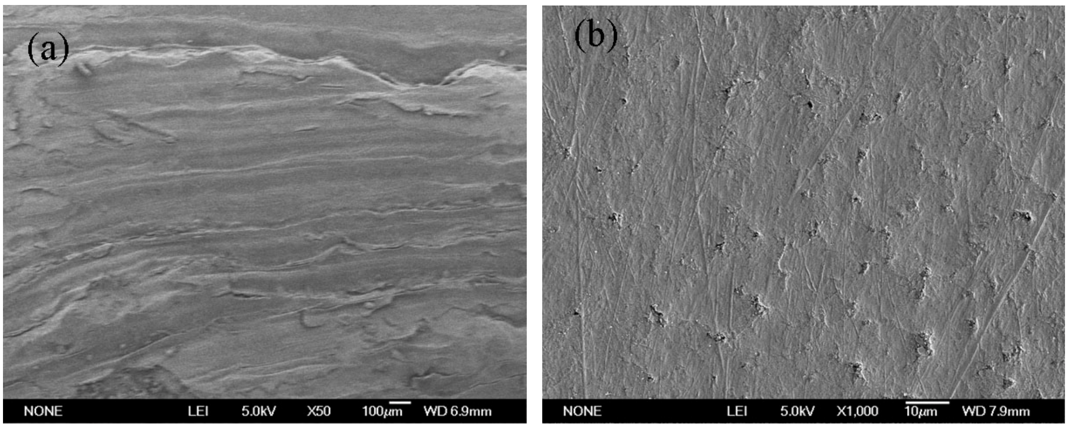



**Figure 1: The surface of *Haliotis discus hannai* Ino shell**
**(a) the outer surface (b) the inner surface**



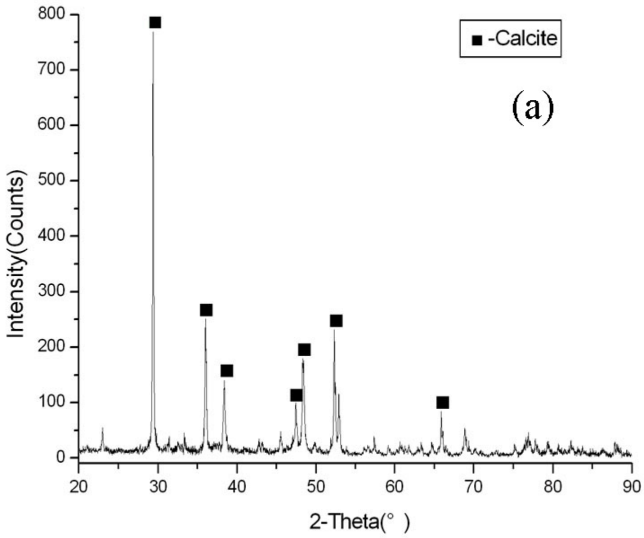

**(a) The outer surface (b) The inner surface**
**Figure 2: SEM surface morphologies of *Haliotis discus hannai* Ino shell**

The shells of *Haliotis discus hannai* Ino has a convex, rounded to oval shape, and the shell may be a little arched. The shells of abalones are ear shaped three whorls and have a low and open spiral structure, and are characterized by several open respiratory pores in a row near the shells' outer edge. The body whorl have a series of holes near the anterior margin and the shells are partitioned to right and left parts by the holes (Figure 1(a)). The left is long and narrow, the right is loose-bodied. The surface of the right is non-smooth and has some strumae or similar parallel convex wave (Figure 1(b)).

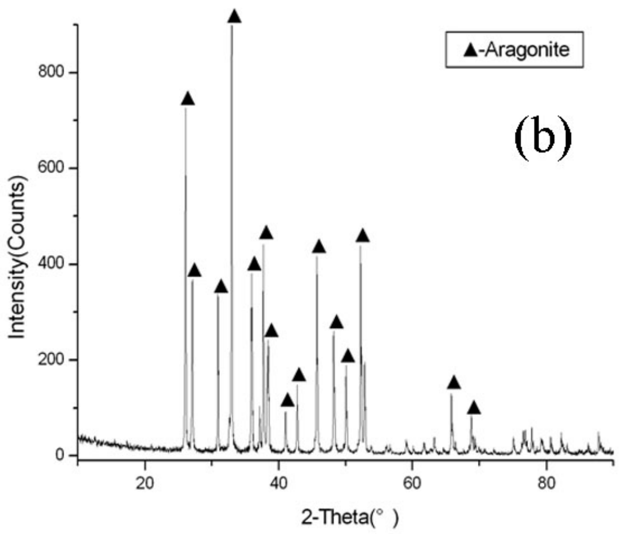
The inner layer of the shells is silvery white having colorized luster and is relative smooth having wondrously tiny sunken (Figure 2).

## 2.2 Materials of *Haliotis discus hannai* Ino shells

The phases of the sample were identified using X–ray diffraction (XRD) and results indicated that aragonite was detected in the nacreous layer, calcite was detected in the prismatic layer (Figure 3).

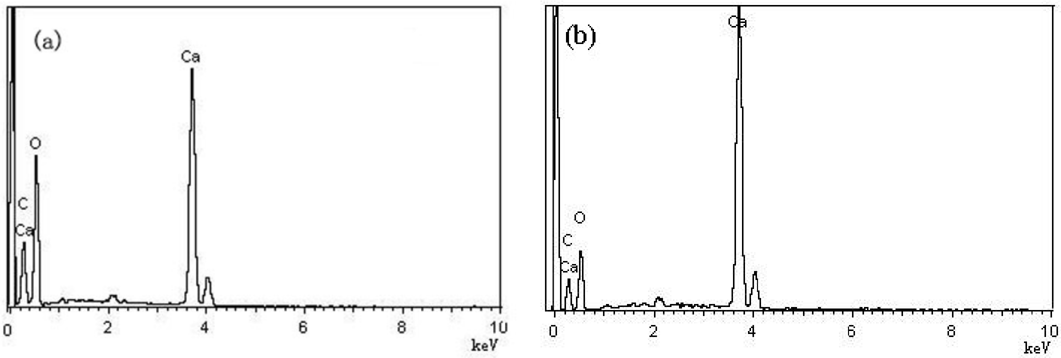



**(a) XRD patterns of the prismatic layer**




**(b) XRD patterns of the nacreous layer**

**Figure 3: XRD patterns of different layer in *Haliotis discus hannai* Ino shell**




**(a) Primary elements in prismatic layer** **(b) Primary elements in nacreous layer**

**Figure 4: Primary elements in different layer**

Energy dispersive spectrometer results were showed in figure 4. The mass percent of each element in prismatic layer and nacreous layer are showed in table 1

**Table 1: chemistry components in different layer**

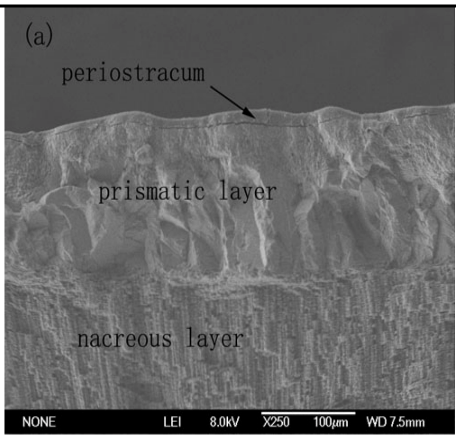
| analyzed parts | chemistry components ( wt.% ) | | |
|---|---|---|---|
| | Ca | C | O |
| prismatic layer | 30.95 | 14.89 | 54.16 |
| nacreous layer | 41.98 | 10.80 | 47.21 |

The results from Figure 4 and Table 1 showed that prismatic and nacreous layer were mainly made up of carbon, oxygen and calcium and relative content of each element had some difference in different layer. Except the three elements, the shells of *Haliotis discus hannai* Ino also include a lot of carbon, hydrogen, oxygen and nitrogen, and the four elements are the primary ingredient in the organism (WANG et al., 2005; TONG et al., 2000).

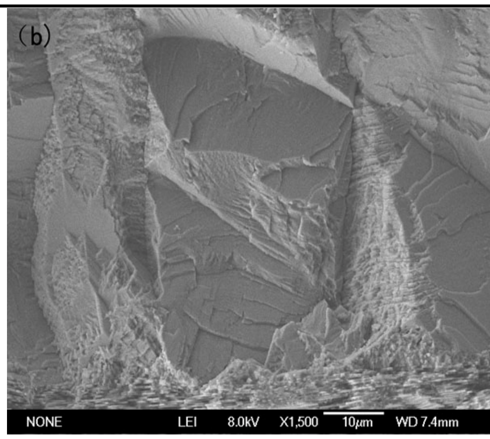
The shells of *Haliotis discus hannai* Ino are polycrystalline composites of calcium carbonate and proteins and glycoproteins, and the successful example of composing multifunctional compound materials. The coupling of calcium carbonate and organic macromolecules makes the nacreous layer's work of fracture is about 3000 times greater than monolithic ceramics, and its capability for substantial inelastic strain, in contrast to aragonite, renders it notch insensitive and can eliminate stress concentrations and catastrophic failure (Currey, 1980; Mann, 2001).

## 2.3 Structures of *Haliotis discus hannai* Ino shells

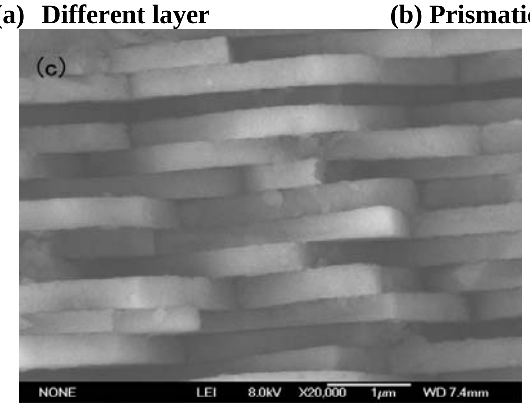
The shells of Haliotis discus hannai Ino consist of 95-99% calcium carbonate and l-5% organic material by weight (LIANG et al.). The internal shell structure was studied using scanning electron microscopy. The shell consists of the periostracum, prismatic and nacreous layers with calcite in the outer prismatic layer and aragonite in the inner nacreous layer (Figure 5). The periostracum is thin and one of the albuminoid, having the function of segregating deleterious substance from outer environment. Nacreous layer, the internal iridescent layer of Haliotis discus hannai Ino shells, is a natural ceramic composite comprised of calcium carbonate in the aragonite polymorph with organic macromolecules sandwiched in between (Figure 5(c)). Calcium carbonate tiles in nacreous layer stacked like bricks and protein substance between the layers of shells like mortar. The coupling of the "bricks" and "mortar" makes the shells to be strong and tough (Jackson et al., 1998; Currey, 1997). When the shells are struck, the tiles slide instead of shattering and the protein stretches to absorb the energy of the blow (LIN & Meyers).




**(a) Different layer**




**(b) Prismatic layer**




**(c) Nacreous layer**

**Figure 5: SEM Experiment results of *Haliotis discus hannai* Ino shell**

## 2.4 The anti-wear function of *Haliotis discus hannai* Ino shells

### 2.4.1 Wear test on the left of *Haliotis discus hannai* Ino shells

Sliding abrasive particle wear on the left of shells was tested under a load of 1 N, 3 N and 5N using a pin-on-disc apparatus. The results showed that wear loss were all increased along with the increase of abrasive particle size under a load of 1 N,3 N and 5N,and the loss was more obvious when the load increased (Figure 6).

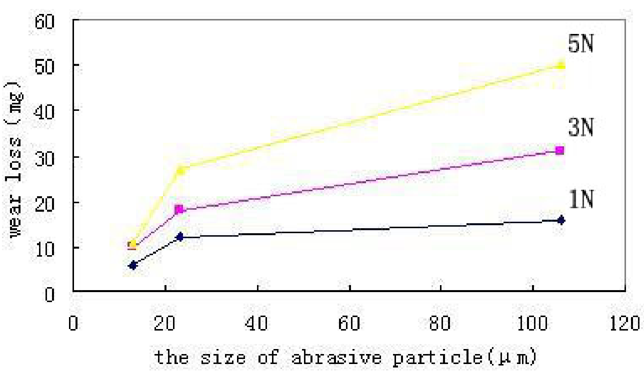



**Figure 6: Wear of *Haliotis discus hannai* Ino shells under different loads**

### 2.4.2 Wear test on the different parts of *Haliotis discus hannai* Ino shells

Sliding abrasive particle wear on different parts of shells was tested when the load was 3 N and abrasive size is 600 mesh. The results showed that the abrasion resistance was different on the different parts of the shells. The left of the shells possesses the highest abrasion resistance; the abrasion resistance of the shells is the lowest on the edge of the right, and intervenient on the middle of the right (Figure 7).

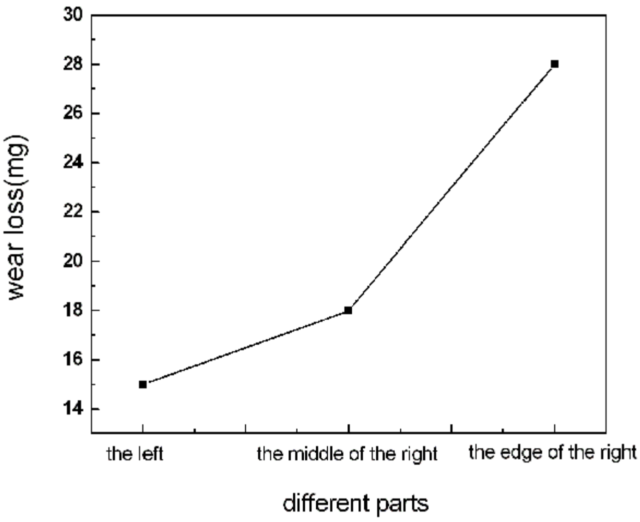
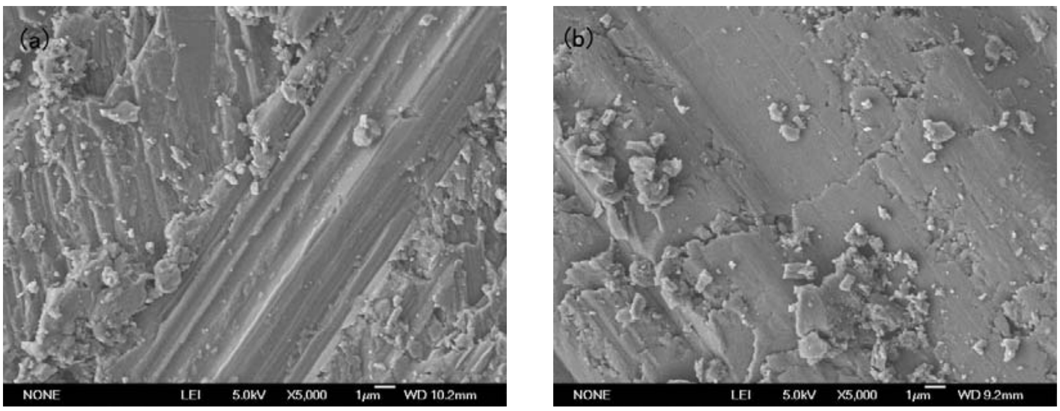



**Figure 7: Wear of *Haliotis discus hannai* Ino shell on the different parts**

### 2.4.3 Wear test in the different structures of *Haliotis discus hannai* Ino shells

The research of microscopic friction showed that the surface of the shell presented the lower coefficient of friction under the conditions of the lower load (TONG et al.). Figure 8 illustrates SEM photographs of the resultantly abraded surfaces of different structures in *Haliotis discus hannai* Ino shells, and the results showed that the nacreous layer possessed higher abrasion resistance than prismatic layer because of microstructural features of nacreous layer. Platelet interlocks have a significant role on deformation in nacreous layer (HOU et al.). Organic materials between platelets have the excellent plasticity and form the organic film on the interface of friction during the abrasive wear. Therefore, the coupling of a simple “brick” and “mortar” has an important effect on protecting and lubricating the friction interface, and important contribution for the strength and toughness of nacreous layer.




**(a) Prismatic layer** **(b) Nacreous layer**

**Figure 8: SEM Wear Experiment results of *Haliotis discus hannai* Ino shell**

## CONCLUSION

The outer layer surface of *Haliotis discus hannai* Ino shells is non-smooth and has some strumae or similar parallel convex wave. The inner layer of the shell is silvery white having colorized luster and is relative smooth having wondrously tiny sunken. The shell of *Haliotis discus hannai* Ino is polycrystalline composites of calcium carbonate and proteins and glycoproteins and consists of the periostracum, prismatic and nacreous layers with calcite in the outer prismatic layer and aragonite in the inner nacreous layer. Nacreous layer is a natural ceramic composite comprised of calcium carbonate in the aragonite polymorph with organic macromolecules sandwiched in between. Calcium carbonate tiles in nacreous layer stacked like bricks and protein substance between the layers of shells like mortar. The coupling of the “bricks” and “mortar” made the shells to be strong and tough.

The abrasive particle wear tests showed that wear loss were all increased along with the increase of abrasive particle size under a load of 1 N,3 N and 5N,and the loss was more obvious when the load increased. The abrasion resistance was different on the different parts of the shell, and the left of the shell possessed the highest abrasion resistance; the abrasion resistance of the shell was the lowest on the edge of the right, and intervenient on the middle of the right. The nacreous layer possessed higher abrasion resistance than prismatic layer because of micro-structural features of nacreous layer. The coupling of platelet interlocks and organic materials has an important effect on protecting and lubricating the friction interface, and important contribution for the strength and toughness of nacreous layer.

The research of morphologies, structures and materials about the *Haliotis discus hannai* Ino shells establishes important biological foundation for the research of bionic anti-wear.

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