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REVIEW ARTICLE

The Selection of Mother-of-Pearls Shells for Inlay Lacquer Works Characterized from the Qing Dynasty

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ABSTRACT

The application of mother-of-pearl for the traditional Chinese inlay lacquer ware during the Qing Dynasty achieved a high degree of design perfection with absolute unity. This material substantiates the development of art and technology in China. However, the inherent properties such as hardness, thickness, color and textures of the shells have subsequently affected the decorations. This paper systematically examined the physical properties and application methods from the two major shells applied during the era: the *freshwater* and *saltwater* shells. Experimental methods were adopted to reveal the role of materials and their suitability as decorative elements. The results showed that saltwater shells are suitable for intricate inlay patterns due to their higher hardness and lustre, while freshwater shells are more appropriate for large-scale, simple decorations due to their softer texture and thinner width. Hence, the research provides evidence for selecting accurate materials, thus offering new technical references for modern inlay techniques.

Contribution/Originality: This study investigates the role of freshwater and saltwater mother-of-pearl in Qing Dynasty lacquer ware, focusing on their material properties and suitability for decorative applications. By integrating laser cutting as modern technology, it enhances precision and efficiency in traditional craftsmanship. The research offers new insights for modernizing inlay techniques while preserving the artistic essence of historical lacquer ware and opens up new possibilities for future innovation.

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1. Introduction

The craftsmanship of mother-of-pearl inlaying requires exceptional skills and techniques to form products that exhibit the aesthetics of traditional Chinese lacquer art. The ability to delicately inlay the shell into the wood with thematic patterns has evolved over thousands of years. This technique involves embedding the materials into surfaces of functional and non-functional lacquer ware to form intricate patterns. Yang and Sun (2021) described that the craft reached its peak during the Qing Dynasty wherein the selection of perfect shells became essential to justify the quality of decoration. The luxurious appearance is not only associated with the consistency of technique but also the unprecedented aesthetical heights in mastering the perfect shells.

Historically, mother-of-pearl shells are divided into two main categories: *freshwater* and *saltwater*. Pearl and yellow butterflies are the freshwater shells that naturally exist in water source areas such as lakes, rivers, streams and ponds. The shells appear in subdued colors which makes them appropriate for a large-scale lacquer decoration. Saltwater shells on the other hand are from abalone and nacre which originate from marine environments. According to Sonawane (2021), *"both categories are prized for their luster and vibrant textures"* (P. 253). The two distinctive types exhibit significant differences in physical properties which affect not only the crafting process but also the profound influence on the final decoration. The qualities of shells are characterized by their hardness, thickness, and texture and color variations.

Research by Zhang (2009) and Jia (2013) explored the historical development of mother-of-pearl inlay lacquer ware particularly during the Qing Dynasty which focused on craftsmanship and material selection. Li's research outlined the evolution of inlay techniques, while Luo provided a detailed analysis of sourced material and its impact on the final decoration. Both scholars emphasize that the refinement of mother-of-pearl inlay reached its peak during this era due to the advancements in material processing and artistic execution. However, there have been relatively a small number of investigations being made into exploring the physical properties of different shells and their application for lacquer works. Liu (2020) compared the historical lineage of mother-of-pearl inlay lacquer ware in Jishan, Shanxi where she examined and analyzed the mother-of-pearl inlay lacquer ware in terms of production materials, tools, equipment and patterns. The results showed the newly developed products were made at a lower cost by forgoing the inherent qualities and fine craftsmanship of the past works.

Therefore, an in-depth study of the classification and experimental properties of mother-of-pearl from the Qing Dynasty is indeed significant in forming new perspectives for lacquer ware production. The outcome will serve as a reference for innovative designs and materials of modern lacquer ware. This paper aims to systematically classify and analyze the properties of shells, thus revealing the potential capabilities to be applied for the upcoming works.

2. Literature Review

The mother-of-pearl inlay craft is an important component of traditional Chinese handicrafts which has gone through several historical stages and reached its peak during the Qing Dynasty. As described by Frick and Kieser (2018), the Qing Dynasty was acknowledged for numerous advancements not only in agriculture and literature but also in mother-of-pearl inlay works. The level of perfection is highly acknowledged through

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the finest selection of the shell and the inlay techniques in Figure 1. The Qing Dynasty saw a significant advancement in the application of mother-of-pearl shells for lacquer ware (Zhang, 2007). Their research highlights how artisans meticulously selected saltwater and freshwater shells to achieve a balance between durability and aesthetic appeal. The use of abalone and nacre, prized for their vibrant colors and luster was particularly noted in high-end lacquered furniture and ceremonial objects. They explored various attributes of the mother-of-pearl products including artistic styles, cultural background and technical evolution. These studies provide valuable references in illustrating intricate patterns through different shells with complex techniques.

Figure 1: The Finest Selection of the Shell with Inlay Techniques

Source: Shi (2018)

The introduction of saltwater shells greatly enhanced the decorative effects of Qing Dynasty lacquer ware. Especially in the mid to late Qing period where artisans increasingly adopted saltwater shells to produce exquisite lacquer ware. The products showcased more intricate and lavish designs (Figure 2). These materials were commonly used in high-end art pieces like scholar's desk sets and tea wares to demonstrate the superiority of craftsmanship and the aesthetical affluent of the time.

Figure 2: The Intricate Design from the Saltwater Shells

Source: Shi (2018)

In the early20th century, scholars conducted preliminary studies of the mother-of-pearl inlay techniques by focusing on its historical origins and basic techniques. Guo (2022) indicated that the craft first appeared during the Western Zhou Dynasty, which later grew steadily in the Tang Dynasty and reached its pinnacle during the Qing. Over time, the selection of inlaid materials and the engaged techniques have been diversified significantly. Craftsman began to explore more complex designs by employing a wider range of materials to enhance the techniques for superior artistic value.

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Simultaneously, the interest in the preservation of intangible cultural heritage has risen significantly which encouraged craftsman to enhance their craft works as part of Chinese culture and traditions. The in-depth investigation of the *know-how* will quantify the quality standard for the improved products. As Clark et al. (2020) described, scholars have also researched modern technologies to innovate and enhance traditional techniques. The understanding of the origins and characteristics of the mother-of-pearl shells is particularly useful to relate to the modern approach. Studies by Song et al. (2019) further differentiate the freshwater and saltwater shells through colors and textures which the freshwater shells are usually subtle in colors with simple textures. The study by Chakraborty et al. (2020) analyses the shell characteristics of the two freshwater bivalves (Corbicula bensoni & Lamellidensmarginalis).

The investigation focused on the characteristics of calcium carbonate ($CaCO_3$) content, physical properties and mechanical strength. The results indicate that these shells are suitable for various applications, including large-scale decorations. On the other hand, saltwater shells such as abalone are known for their vibrant and iridescent colors. The hues range from deep blues and greens to purples and pinks. Shells remain a discussion point as nacre, a structure found inside them has such a unique feature of light refraction at different angles, hence this is the cause of a shiny colored visual of pearls in different light sources (Zhong, 2023). A prized optical property for creating challenging foil patterns has made abalone the most typical object incorporated in the design for lacquer ware.

On the technical side, some researchers have focused on the specific processes involved in mother-of-pearl inlay, including material selection, cutting techniques and inlaying methods. Kim (2018) explored the detailed craftsmanship of mother-of-pearl inlay by investigating material selection and cutting methods to provide an in-depth analysis of modern inlay techniques. For instance, advancements in Computer Numerical Control (CNC) technology have made the cutting and shaping of mother-of-pearl more precise. The application has overcome many challenges related to material damage and loss associated with traditional hand techniques. This digital transformation is supported by research that emphasizes the specific requirements for tool selection cutting speed and depth when handling natural shells. Furthermore, the research also points out the complexities of calcium carbonate and organic binders within the shell that make it susceptible to damage during processing. The evidence is indeed important to overcome material loss and breakage that ensued from the traditional manual cutting in earlier periods. Similarly, the introduction of laser cutting has also created new possibilities for precision inlay work, thus significantly improving cutting accuracy and efficiency.

Despite the wealth of literature that contributes to understanding the Qing Dynasty's mother-of-pearl inlay craft, systematic research on the physical properties of mother-of-pearl materials is still relatively scarce. The hardness, thickness, color and practical application of different mother-of-pearl materials remained understudied. Therefore, this paper aims to fill this gap by offering a better understanding of the material applications and the evolution of mother-of-pearl inlay lacquer ware in the Qing Dynasty through experimental analysis and systematic classification. The selection of shells was made in reference to the Qing Dynasty lacquer ware.

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2.1. The Classification of Mother-of-Pearl

The varieties of shells applied in the mother-of-pearl inlay craft directly influence both the artistic expression and technical outcome of the lacquer works. The shells used during the Qing Dynasty were sourced from both *freshwater* and *saltwater* environments. Each type offers distinct physical properties that influence their use in lacquer ware. Freshwater shells, such as pearl and yellow butterfly were commonly used for large-scale background decorations due to their subdued colors and softer texture. In contrast, saltwater shells such as abalone were favored for intricate inlay work due to their hardness and vibrant color spectrum (Lutaenko, 2016). Song et al. (2019) highlights that each category of materials; freshwater and saltwater exhibits significant differences in color, texture, hardness and application. These differences not only influence the range of material used but also impact the final artistic effect of the lacquer ware.

2.1.1. Freshwater Shells

Freshwater shell is primarily sourced from freshwater environments which include pearl shells, yellow butterfly shells and brown river mussels. Missouri Department of Conservation characterized the freshwater shells as follows:

a) Color

Freshwater shells exhibit more subdued shades with light yellow, cream or light brown colors. This natural range of colors is ideal for simple and understated designs that allow for a harmonious visual effect when combined with lacquer ware (Figure3).

Figure 3: The Selection of Freshwater Pearl Shell

Source: Picture of Freshwater Pearl Shell as the sample material photographed by Author Nuo Xu from Beijing Arts and Crafts Senior Technical School Studio in 2024.

b) Texture

The texture of freshwater shells is generally simple and uniform, hence making them suitable for large background decorations. The texture of freshwater shells complements the delicate surface of lacquer ware when inlaid. As shown in Figure 4, the process creates a balanced and layered visual effect.

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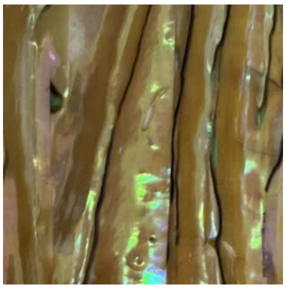
Figure 4: The Layered Visual Effect



Source: The close-up image of the texture from Brown River Mussel Photographed by Author Nuo Xu from Beijing Micron Shared Laboratory in 2024.

c) Hardness and Thickness

Freshwater shell materials tend to have lower hardness and moderate thickness which make them easy to cut and process. While they may not be as suitable for intricate carving as saltwater shells, they hold distinct advantages in large-scale decorations.

d) Application

Freshwater shell materials were widely used in early Qing Dynasty lacquer ware, particularly for simple geometric patterns and decorations. The application was often found in daily-use items and ceremonial objects since it exudes a simple yet elegant style. This appearance reflects a preference for natural beauty and minimalist aesthetics during that time (Figure5).

Figure 5: The Natural Beauty and Minimalist Aesthetics from the Patterns

Source: Shi (2018)

2.1.2. Saltwater Shells

Saltwater shell materials are derived from marine environments and encompass a variety of shells such as abalone, nacre shells and natural rose shells. Research indicates that abalone shells are widely favored for their optical properties. The Duke of Pearl is a well-known supplier that specializes in high-quality mother-of-pearl and abalone (Duke of Pearl, n.d.). The inlaid of those are visible in musical instruments, furniture and other craft products. Additionally, abalone shells have a long history of being used as decorative items and currency. Their unique colors and structures make them significant materials

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in many cultures (The Wandering Bull, LLC, 2023). These materials play a crucial role in inlaying due to their distinctive luster and vibrant colors with the following features:

a) Color

Saltwater shells are known for their diverse and bright colors including shades of purple, blue, green and other vivid hues in Figure 6. This variety in color makes them highly expressive in decorative applications which simultaneously add vibrancy and dynamism to lacquer ware in Figure 7.

Figure 6: The Diverse and Bright Colors of the Australian White Abalone

Source: The close-up image of the color of the Australian White Abalone Photographed by Author Nuo Xu from Beijing Arts and Crafts Senior Technical School Studio in 2024.

Figure 7: The Diverse and Bright Colors of the New Zealand Blue-Green Abalone

Source: The close-up image of the color of the New Zealand Blue-Green Abalone Photographed by Author Nuo Xu from Beijing Arts and Crafts Senior Technical School Studio in 2024.

b) Texture

The texture of saltwater shells is more complex and varied, often featuring unique natural patterns and fine luster (Figure 8). When exposed to light, they can reflect a rich array of colors. This intricate texture provides artisans with greater creative flexibility allowing them to achieve more detailed and refined designs.

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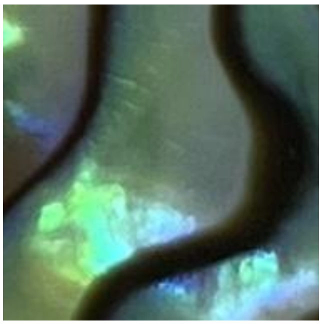
Figure 8: The Texture of the New Zealand Blue-Green Abalone

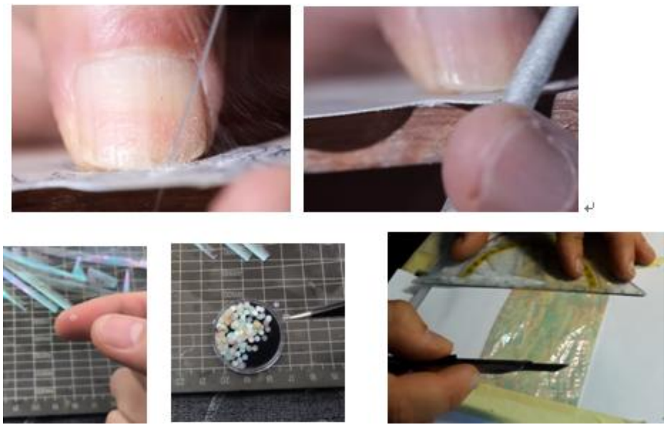


Source: The close-up image of the texture of the New Zealand Blue-Green Abalone Photographed by Author Nuo Xu from Beijing Micron Shared Laboratory in 2024.

c) Hardness and Thickness

Saltwater shells are typically harder than freshwater shells. They can be grounded to a thinner width making them suitable for cutting and carving intricate patterns (Figure 9). These properties make saltwater shells ideal for detailed inlay work allowing greater integrity throughout the process.

Figure 9: The Cutting of the White Abalone



Source: The close-up images of the cutting of the White Abalone shell Photographed by Author Nuo Xu from Own Laboratory in 2024.

The classification of mother-of-pearl during the Qing Dynasty not only impacted the crafting process but profoundly influenced the design styles of lacquer ware. The selection and application of inlay materials were diversified depending on the evolution of social, cultural and economic conditions of different historical periods. Artisans adapted their designs based on the characteristics of the materials and the desired artistic effects. The engagement has driven continuous innovation and development in lacquer decoration.

Details description from this section provides a foundation for subsequent experimental research and material properties. By gaining a deeper understanding of both freshwater and saltwater shells, we can better assess their application for the inlay process and identify key factors influencing their usage.

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3. Methodology: Experimental Method

A series of experiments was designed to comprehensively evaluate the characteristics of different shells based on the reference from Qing Dynasty lacquer works. These involved microscopic observations and modern laser-cutting techniques. The study observed the physical properties of both freshwater and saltwater shells. The experimental method was divided into four parts: material selection, experimental equipment, and experimental procedures and data analysis.

3.1. Material Selection

The selected mother-of-pearl materials are as follows and they include the six different types of shells covering both freshwater and saltwater varieties. The selection was made based on variety and growth periods in a range of 2 to 20 years in Table 1. The shells pictures in Table 1 were collected by Nuo Xu in 2024 prior to this research which purchased at Giant shell factory.

Table 1: The Material Selection of the Shells

AGE TYPE	A	B	C
Saltwater Shell 1: Australian White Abalone	 5 YEARS	 10 YEARS	 15 YEARS
Saltwater Shell 2: Natural Rose Shell	 5 YEARS	 8 YEARS	 10 YEARS
Saltwater Shell 3: New Zealand Blue-Green Abalone	 5 YEARS	 10 YEARS	 15 YEARS

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Freshwater Shell 1：Freshwater Yellow Butterfly Shell	 8 YEARS	 10 YEARS	 20 YEARS
Freshwater Shell2：Freshwater Pearl Shell	 5 YEARS	 8 YEARS	 10 YEARS
Freshwater Shell3：Brown River Mussel	 2 YEARS	 5 YEARS	 10 YEARS

3.1.1. Saltwater Shells

The Australian White Abalone is renowned for its exceptional hardness and high luster hence making it a preferred material for high-end decorative art. Similarly, the Natural Rose Shell is characterized by its rich coloration and smooth surface which allows for detailed inlay patterns. Additionally, the New Zealand Blue-Green Abalone is valued for its unique color and texture which lends itself well to intricate design works. Together, these shells highlight the diversity and aesthetic appeal of materials used in decorative arts and crafts.

3.1.2. Freshwater Shells

The Freshwater Yellow Butterfly Shell is typically soft in tone and has a gentle texture making it suitable for large-scale decorations. In contrast, the Freshwater Pearl Shell features a smooth surface and delicate texture which lends itself well to simple yet elegant decorative pieces. The Brown River Mussel is relatively common for simpler decorative designs.

3.2. Experimental Equipment

The main equipment used in this experiment includes six kinds equipment. In Table 2, all pictures of experimental equipment and tools were taken during Nuo Xu. And the experiments were provided by the Beijing Micron Shared Lab.

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Table 2: Experimental Equipment

No.	Equipment	Image
1	Zeiss Stemi 508 Stereo Microscope	
2	Laser Cutting Machine	 
3	Cutting Tools	   
4	Experimental Recording Tools	  

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5	Chemical Equipment	       
6	Chemical Materials (Nitric acid and Hydrochloric acid, ethanol)	

3.2.1. Zeiss Stemi 508 Stereo Microscope

The microscope served the function of observing the surface texture, color and thickness of shells. With a magnification range of 0.63x to 5.0x, it provided clear images for detailed analysis. To ensure optimal clarity, the observer can adjust the eyepiece's diaper and eye distance. Adjusting the eyepiece's diaper and the eye distance were among the procedures to be adopted for the sake of attaining the clearest view possible.

3.2.2. Laser Cutting Machine

The CO2 laser cutting machine is known for its high cutting precision and efficiency. It is particularly suitable for handling complex patterns as it reduces material waste and avoids the cracks that are caused by mechanical cutting.

3.2.3. Cutting Tools

Handheld cutters, scissors and saw blades were used for the initial processing and polishing of shell materials to ensure smooth edges after cutting. Additionally, various grades of sandpaper were utilized to polish the edges of the cut shells ensuring the absence of sharp edges or defects.

3.2.4. Chemical Equipment and Materials

The experimental setup included various reagents, such as nitric acid and hydrochloric acid, for mineral analysis, as well as ethanol or other organic solvents for organic extraction. Additionally, beakers, test tubes and titration tubes were essential for

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conducting experiments. A balance was used for weighing samples, while a heating device such as a hot plate aided in heating substances. A centrifuge was also used for separation processes, depending on the requirements of the experiment. A pH meter was employed to measure acidity, whereas spectroscopic analysis instruments, UV-Vis spectrophotometer and infrared spectrometer were utilized to analyze the chemical composition of the samples.

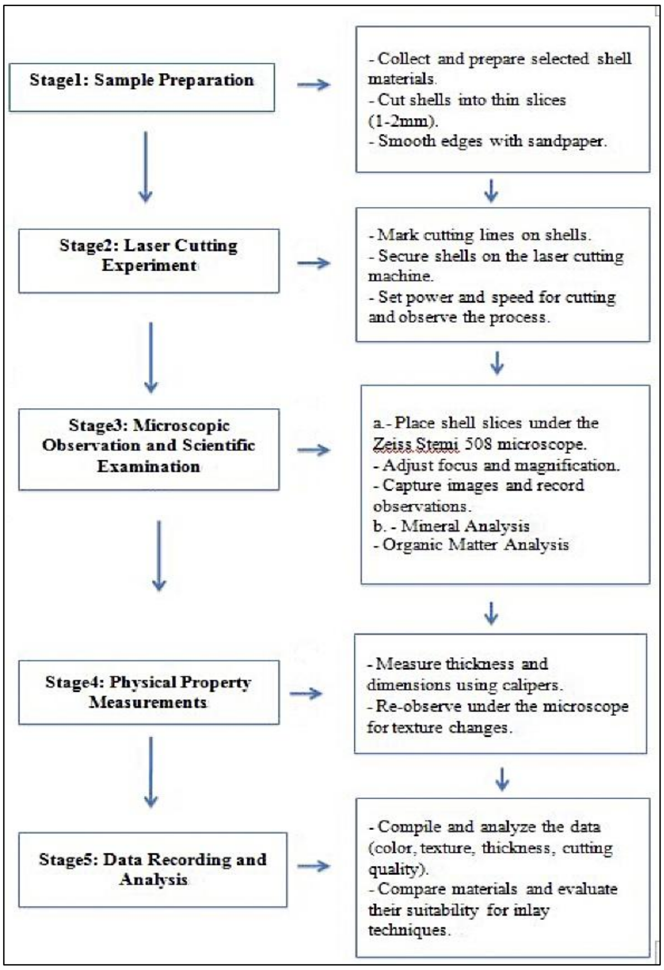
3.2.5. Experimental Recording Tools

A digital camera was utilized to document the experimental process and observation results ensuring data completeness. Additionally, a notebook and pen were used to manually record the observation results and experimental details.

3.3. Experimental Procedures

The experimental steps are mainly divided into several important parts, each of which is crucial to ensure the accuracy and reproducibility of the final results. The figure below is the experimental flowchart which illustrates the experimental process (Figure 10).

Figure 10: Experimental Procedure Flowchart



The sample preparation formed the foundation of the entire experiment. During this phase, the selected samples were organized to ensure each type was represented and uniformed. The chosen shell samples must remain intact, free from any evident cracks or defects to prevent potential influences on the microscopic results. Subsequently, scissors

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and handheld cutting machines were used to slice the shells into thin sections suitable for microscopic examination, typically around 1-2 millimeters thick. This process demands particular care to prevent material breakage which could adversely affect sample quality. Moreover, to enhance observation quality; sandpaper was applied to initially smooth the edges of the samples ensuring they were free from significant defects. The precaution is necessary to avoid interference during both microscopic observation and subsequent cutting.

Following sample preparation, the next step involved conducting the laser cutting experiment. Cutting lines were drawn on the surface of the shells based on a predetermined design to ensure the accuracy and clarity of the pattern. Pencils and water-soluble markers were employed for this purpose. The shell samples were then secured onto the workbench of the laser cutter and adjusted to the power and cutting speed. The laser power was set at a lower level with a moderate cutting speed to prevent the shells from overheating and discoloring. Regular checking was done throughout the process to ensure that the cutting path aligned with expectations. Once the cutting was completed, the smoothness and integrity of the cut edges were meticulously examined. Any damage or defects were recorded to evaluate the effectiveness of the cutting technique.

The next phase relates to microscopic observation. The shell samples were placed under a Zeiss Stemi 508 stereomicroscope where the light source was turned on to ensure sufficient illumination for clear observation of the sample details. Gradual adjustment of the microscope's magnification knob to locate the appropriate focal plane for observation was crucial during this stage. This was to ensure that the images were clear and discernible throughout the observation process. Images of each sample were captured at various magnifications with particular attention to color, texture and thickness. The samples' natural properties were recorded including glossiness, color variation and clarity of texture clarity. The information serves as a critical foundation for subsequent analysis.

The steps involved in analyzing the chemical composition were also crucial. First, the initial step of the experiment was sample preparation. The Australian white abalone was cleaned by using clean water to remove surface dirt and debris.

Next, the shell was air-dried in a cool and ventilated area. Once the shell was completely dried, it was crushed into a fine powder using a mortar and pestle to increase surface area for a more thorough analysis in the following steps which was the mineral analysis. The starting point was about 0.5 g of shell powder that was reacted with 10 ml to 15 ml hydrochloric acid during the reaction. Process in this phase was monitored and documented. This step was geared to facilitate the dissolving of the minerals from the shell, which were in the form of calcium and magnesium ions.

After the reaction, the solution was filtered to remove any insoluble substances resulting in a clear liquid. A precipitating agent (sodium hydroxide) was added if required to cause the ions to precipitate during the process. Following this, the concentration of metal ions in the solution was measured using spectroscopic instruments (such as atomic absorption spectrometry) and data was recorded.

The experiment also involved the extraction of organic compounds. 0.5 grams of shell powder was poured into a beaker and a range of 10 ml to 15 ml ethanol organic solvent was added for a solution. The mixture was heated and stirred to promote the dissolution

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of the organic components in the shell. After dissolution, the mixture was subjected to centrifugation to separate the liquid from the solid and obtain the extracted organic phase. The organic components were then separated and analyzed using gas chromatography-mass spectrometry (GC-MS) or high-performance liquid chromatography (HPLC) with the results recorded. This thorough work of sequential steps resulted in determining the mineral and organic levels in the shell of the Australian white abalone. Thus, this work became a source of valuable information for the next scientific research.

This detailed series of steps enabled full analysis of the mineral and organic components of the Australian white abalone shell, hence providing valuable data for subsequent research.

Physical properties measurement constitutes an important aspect of the experiment. High-precision calipers were employed to measure the thickness and dimensions of the cut shell samples and meticulously recorded specific data for each sample. The process was applied to facilitate a subsequent comparative analysis in determining the material samples. Special attention was directed towards changes in thickness during the cutting process as variations revealed differences in material properties. Furthermore, the cut samples were observed once again under the microscope to document any changes in texture, cut shapes and gloss levels during the post-cutting. The process was equally vital to identify whether any new textures emerged during the cutting.

Finally, data recording and analyzing were the crucial steps to ensure the reliability of the experimental results. In this phase, the outcomes of microscopic observations and cutting experiments, data from samples characterized by color, thickness, texture and cutting effects were systematically organized to create a comprehensive experimental record. Through comparative analysis of the performance of different materials across various indicators, identifying physical properties was the most critical departure to the inlaying process. The evaluation summarized the suitability of shells and their practical applications in inlay techniques. This series of experimental steps not only facilitated a deeper understanding of the characteristics of the inlaying process but also provided invaluable data support for future research and applications.

4. Data Analysis

After compiling the experimental data, the research team used statistical software (such as SPSS or Excel) to systematically analyze and compare the performance of different materials across various metrics. The steps included:

4.1. Data Compilation

4.1.1. Raw Data Recording

After each experiment, the results of the microscopic observations and laser cutting were recorded in the experimental log including sample numbers, colors, thicknesses, textures and cutting effects.

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4.1.2. Data Input

The recorded data was entered into a spreadsheet, after which it was sorted into a specific structure for analysis. This inspection was critically important to ensure data quality and accuracy.

4.2. Statistical Analysis

4.2.1. Descriptive Statistics

Descriptive statistics deals with the analysis of the main characteristics of the materials, including means, standard deviations, minimums, and maximums, so that one can understand the basic properties of the various materials.

4.2.2. Analysis of Variance (ANOVA)

ANOVA was applied to test the differences in stuffiness, hardness, and hue of the two mediums. This was done to find any significant differences between the two mediums. The significance was generally set at a p-value equal to or less than 0.05 levels. Thus, it was concluded that a statistically significant difference was present when the p-value was less than 0.05.

4.2.3. Correlation Analysis

Pearson correlation coefficients were calculated to evaluate the relationship between different physical properties (e.g., hardness, thickness, color) to determine which characteristics most strongly influence the mother-of-pearl inlay process.

4.3. Data Visualization

Use charting tools to visualize the analysis results (Table 3).

Table 3: Comparison of the Key Components

Component	**Australian White Abalone Shell**	**Freshwater Pearl Mussel**
Calcium Carbonate (CaCO3)	95% - 99% (primarily aragonite)	90% - 95% (primarily aragonite)
Magnesium (Mg)	1% - 2%	1% - 3%
Proteins	0.5% - 2%	1% - 3%
Polysaccharides	0.1% - 0.5%	0.5% - 1%
Trace Elements (e.g., Strontium, Iron)	< 0.1%	< 0.1%

Note: A comparison of the proportions of the main components of these two types of shells was obtained after chemical experiments, and the table was done by researcher Nuo Xu from Beijing Micron Shared Laboratory in 2024in 2024

4.3.1. Microscopic Image Presentation

Organized and labeled the images observed under the microscope to create comparison charts and facilitate an intuitive presentation of the characteristics of different materials.

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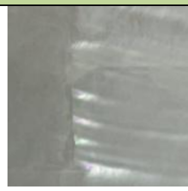
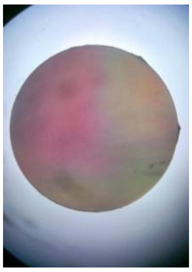
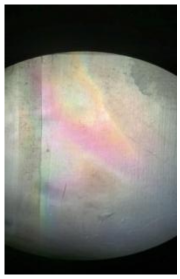
Based on the chemical composition of the two shell types (Australian white abalone shell and freshwater pearl mussel) from Table 4, a comparative data analysis regarding their key components facilitated to determine of the physical properties; hardness, toughness and coloration.

Table 4: Microscopic Images

Name	Australian White Abalone	Fresh Water Pearl Shell
Cutting State		
Microscope State		
Shell Age	5Years	5Years
Main Components	Calcite, Aragonite, Spherulitic Calcite, Amorphous $CaCO_3$, Organic Matter	Calcite, Aragonite, Spherulitic Calcite, Amorphous $CaCO_3$, Organic Matter
Size	Diameter: 8 mm	7*12mm
Shape	Circular	Rectangular
Thickness	0.8mm	0.3mm
Texture	- Surface: Smooth -Texture Variation: Has transitional texture	-Surface: Smooth -Texture Variation: Texture is distinctly defined
Color	White, light gray texture, high luster	Displays pearlescent colors, high luster, with pink and yellow flecks

Note: The state of these two shells under microscopic observation, when compared, presents a contrast of different forms and states. And the table was done by researcher Nuo Xu from Beijing Micron Shared Laboratory in 2024.

a) Calcium Carbonate (CaCO3)

Calcium carbonate is the primary component in both materials and its crystalline form (aragonite) contributes to the shells' overall strength and hardness (Table 5). Since the Australian white abalone shell has a higher concentration of calcium carbonate, it is likely to be slightly harder and more durable than the freshwater pearl mussel shell. The high proportion of aragonite in both types of shells indicates their ability to withstand wear and tear, though the abalone may have an edge due to the higher CaCO3 percentage.

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Table 5: Calcium carbonate content of the two shells

Name	Percentage	Manifestation
Australian White Abalone Shell	95% - 99%	Aragonite
Freshwater Pearl Mussel	90% - 95%	Aragonite

Note: This is a table comparing the calcium content in these two types of shells. And the table was done by researcher Nuo Xu from Beijing Micron Shared Laboratory in 2024.

b) Magnesium (Mg)

Magnesium content contributes to the flexibility and fracture resistance of the shells (Table 6). Since freshwater pearl mussels tend to have a slightly higher magnesium range (up to 3%). This suggests they may exhibit better toughness or resistance to cracking under stress compared to the abalone shell. However, the variation is small, and differences might not be highly significant unless the upper threshold is reached in freshwater pearls.

Table 6: Magnesium (Mg) content of the two shells

Name	Percentage
Australian White Abalone Shell	1% - 2%
Freshwater Pearl Mussel	1% - 3%

Note: This is a table comparing the magnesium content in these two types of shells. And the table was done by researcher Nuo Xu from Beijing Micron Shared Laboratory in 2024.

c) Proteins

Proteins play a crucial role in the organic matrix of the shells, aiding in shell formation and contributing to their mechanical properties, especially their toughness (Table 7). Freshwater pearl mussels have a higher protein range which may suggest they have a better capacity for energy absorption and toughness compared to the abalone shell. This could make the pearl mussel shells more resilient under impact or pressure, although abalone shells still retain significant protein content.

Table 7: Protein content of the two shells

Name	Percentage
Australian White Abalone Shell	0.5% - 2%
Freshwater Pearl Mussel	1% - 3%

Note. This is a table comparing the protein content in these two types of shells. And the table was done by researcher Nuo Xu from Beijing Micron Shared Laboratory in 2024.

d) Polysaccharides

Polysaccharides, though present in small amounts have influenced the mechanical properties by contributing to shell flexibility and assisting in binding the mineral components (Table 8). Freshwater pearl mussels contain a higher concentration of polysaccharides which could suggest a better capacity for plastic deformation making them less brittle compared to abalone shells.

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Table 8: Polysaccharides content of the two shells

Name	Polysaccharides
Australian White Abalone Shell	0.1% - 0.5%
Freshwater Pearl Mussel	0.5% - 1%

Note: This is a table comparing the polysaccharides content in these two types of shells. And the table was done by researcher Nuo Xu from Beijing Micron Shared Laboratory in 2024.

e) Trace Elements (e.g., Strontium, Iron, etc.)

Both shell types contain less than 0.1% of the specified component. Trace elements like strontium and iron may influence color and slight variations in mechanical properties but are presented in such small amounts that do not have a significant effect on overall shell performance. However, these elements may contribute to slight differences in the coloration and surface sheen.

f) Coloration and Luster

The iridescent sheen in both abalone and freshwater pearl mussels is primarily due to their aragonite structure which interacts with light to produce a nacreous or "mother-of-pearl" appearance. The concentration and patterning of such organic elements, as proteins and polysaccharides, together with the presence of some trace elements, would cause the differences in color between the two types of shells. For instance, the inclusion of metal ions like magnesium and the protein content in freshwater pearl mussels continue to create a misrepresentation of the abalone color that is slightly different.

g) Conclusion on Hardness and Toughness

Australian white abalone shell is likely to be slightly harder because of its higher calcium carbonate content. This condition primarily contributes to its rigidity and structural integrity. In contrast, freshwater pearl mussels may exhibit better toughness and flexibility, largely due to their higher levels of magnesium, protein and polysaccharides which enable them to absorb more energy without cracking.

This comparative analysis provides valuable insight into the structural properties of both shells that are crucial for applications in inlay techniques where durability and visual aesthetics are important.

5. Summary of Results

The data analysis revealed several key findings:

5.1. Hardness Differences between Freshwater and Saltwater Shells

Saltwater shells generally exhibit higher hardness than freshwater shells which indicates that saltwater shells are more durable during cutting, thus making them suitable for creating intricate inlay designs. For example, the hardness test results revealed that Australian white abalone had an average hardness of 5.5, while freshwater yellow butterfly shell had an average hardness of only 3.2. The result suggested that saltwater shells are better suited for high-end lacquer ware decoration.

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5.2. Impact of Thickness

The experimental results indicated that freshwater shells generally have a greater average thickness than saltwater shells, a characteristic that makes freshwater shells advantageous for large-scale decorations. The thickness may limit their use in intricate carvings. For instance, New Zealand blue-green abalone had an average thickness of 1.2 mm, while freshwater pearl shells averaged 2.5 mm, providing valuable reference points for designers when selecting materials.

5.3. Color Expression and Decorative Effect

Data analysis revealed that saltwater shell materials performed significantly better in terms of color expression as their rich and varied hues provide more possibilities for lacquer ware decoration. Notably, the natural rose shell when exposed to different lighting conditions reflected a variety of colors, thus enhancing the visual impact of the artwork

5.4. Cutting Effect Comparison

The cutting experiment results indicated that saltwater shell materials had smoother cut surfaces with fewer cracks making them more suitable for high-precision inlay work. On the contrary, some of the freshwater shells were cut into cracks. For example, instead of having smooth cut surfaces, nacre shell cuts had no visible damage signs after laser cutting, while the brown river mussel was demonstrated to have some serious edge breakage during the laser cutting. These findings provide valuable insights into the selection and application of mother-of-pearl materials in lacquer inlay processes.

To further verify the specific performance of these materials in lacquer inlay, this study conducted experimental research on six different shell materials using microscopic observation and laser cutting technology. The experimental results showed that saltwater shell materials (such as Australian white abalone and New Zealand blue-green abalone) are suitable for intricate inlay patterns due to their higher hardness and luster, while freshwater shell materials (such as freshwater yellow butterfly shell and brown river mussel) are more appropriate for large-scale, simple decorations due to their softer texture and thinner thickness. The experiments also revealed that modern laser cutting technology significantly improves cutting precision and material utilization, preventing the common breakage and fragmentation issues found in traditional manual cutting.

6. Conclusion

This paper provides a systematic classification and experimental analysis of different mother-of-pearl shells used in lacquer ware during the Qing Dynasty. The purpose is to select suitable shells and explore in-depth the physical properties, chemical composition and performance of freshwater and saltwater for craft applications. By combining microscopic observation with modern laser cutting technology and chemical composition analysis, a series of important conclusions were drawn from the research.

Firstly, the research indicates that the selection of mother-of-pearl materials is crucial for the decorative effects of Qing Dynasty lacquer ware. The experimental results show that saltwater materials, such as Australian white abalone and New Zealand blue-green abalone excel in hardness, thickness and luster. These attributes make them suitable for

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intricate inlay techniques and for creating complex and exquisite artworks. In contrast, while freshwater materials have advantages in large-scale decoration, their limitations in hardness and thickness make them relatively insufficient for detailed carving. This finding provides a valuable reference for craftsmen when choosing materials and emphasizes the importance of selecting materials according to design requirements.

Secondly, this study highlights the potential application of modern cutting technologies in traditional craftsmanship. By introducing laser cutting technology, the research team successfully improved precision and efficiency in cutting while reducing material waste. Laser cutting effectively avoids the cracks and damage that may occur during traditional hand cutting while providing new ideas for optimizing the materials. This achievement is not only significant for improving mother-of-pearl cutting techniques but also offers insights into the modernization of other traditional crafts.

The expressive power of color is fully demonstrated in this study. The rich colors and natural textures of saltwater materials add more layers and dynamism to the decorative arts of Qing Dynasty lacquer ware, especially under different lighting conditions. The condition exhibits a variety of visual effects. The color variation provides designers with broader creative space enabling them to better express the themes and emotions of their artworks.

Finally, the research findings provide an important theoretical basis for understanding Qing Dynasty mother-of-pearl inlay techniques and have also opened new directions for innovation and practice in modern art design. Future research could consider expanding to other types of shells and exploring their applications within different cultural contexts. Hence, the application will further enrich the understanding of mother-of-pearl in various other art directions.

Ethics Approval and Consent to Participate

The researchers used the research ethics provided by the Research Ethics Committee of Universiti TeknologiMARA (RECUiTM). All procedures performed in this study involving human participants were conducted in accordance with the ethical standards of the institutional research committee. Informed consent was obtained from all participants according to the Declaration of Helsinki.

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Conflict of Interest

The authors reported no conflicts of interest for this work and declare that there is no potential conflict of interest with respect to the research, authorship, or publication of this article.

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