Pearls: a literature review

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Abstract:
Pearls occupy a distinguished position among gems due to its unique beauty. Both natural and cultured pearls occur in a wide variety of colors. The most familiar colors are white and cream. Black, gray, and silver are also fairly common, but the palette of pearl colors extends to every hue. Pearl jewelry was used in every civilization such as Egyptian, Chinese, and Roman civilization. It was considered as a symbol of nobility. Pearls also have a key role in modern jewelry as designers tend to use it for its beauty. This paper aims to review the industry of pearls and its importance in jewelry design. it reviews the history of pearls and how the industry was converted from fishing pearls to farming it. Cultured pearls provide solutions for the rareness of natural pearls and its high prices. Pearls types were presented. Pearl grading systems were analysed. The process of pearl treatment was explained for its importance in pearl industry.

Keywords:
Pearl, Formation of Pearl, Pearl Grading, Pearl treatment.

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1. Introduction

The pearl is known for its unique beauty, and it was used throughout history for adornment purposes and as a symbol of richness. In the current civilization, it is known as the only stone that can be made naturally by a human. This type of pearl is called cultured pearl (Zhang & Fang, 2003). The man plays a key role in supplying the oyster with small stones of sand to start making a pearl.

Historical resources show that pearl fishing from the sea was widespread in the old world in various areas such as India, Sri Lanka, the Egyptian Coast of the Red Sea, and the Arabian Gulf in Bahrain and UAE (Matlins, 2001). In some of these countries, the economy was dependent on pearl fishing before discovering oil in the last century (Zhu et al., 2019). For centuries, the Arabian Gulf was the main resource of pearl in the world. According to that fact, the pearl fished from this area was called the oriental pearl to be distinguished from other pearls.

The cultured pearl is not as a modern process as most people think. It began in China in the late thirteen century when pearl fishers used a primitive technique to grow blister pearls on the inner shell surfaces of freshwater mussels (Xie and Min, 2003) but now it is originated in Japan as it was reinvented with its modern shape in 1893. Through time, this technique was used in several countries such as Japan and Indonesia. Now, many countries use produce cultured pearls such as China, Japan, Sri Lanka, India, and Thailand (Southgate, 2007).

Pearl industry now is a sophisticated process that starts with the collection of oysters and preparing the farm. It takes many years to begin the production of pearls as oysters can't produce pearls before reaching a specific age. After harvesting pearls, polishing and other treatments can be applied to enhance the pearl's appearance (Cartier et al., 2012; Haws, 2002).

Evaluation of pearls is a critical process as it determines the value of the pearl. Several grading systems were developed by researchers (Nagata, 1997) and organizations to ease the process of evaluation. GIA's pearl grading system (GIA, 2017) and A-AAA (The Pearl Source, 2020) are the most famous grading systems in the pearl industry. This is because they provide jewelers with clear and detailed standards to grade pearls.

This paper was divided into key five sections. It begins with following the origin of pearls in history. Pearls are one of the oldest gems used by humans. Next to that, it explains how the pearl is formed. Types of pearls are reviewed and their distinctive characteristics were presented. As grading systems are very critical for the industry of pearls, the researchers classified the key standards that are used in grading pearls. Finally, the treating techniques of pearls were explained.

2. History of Pearls

Pearls can be considered one of the oldest gems that humans discovered and used it. Archeologists

suggest that pearls were used long before the written history as ancient people revered them (Strack, 2006). For this reason, pearls can't be attributed to a specific civilization or belonged to a specific geographical region. Many pearls jewelry was found in different places among several civilizations such as the Persian Civilization where archeologists found one of the oldest pearl jewelry dated back to 420 BC.

In old China, people used to present pearls as gifts for royalties as early as 2300 BC. In Rome, pearls were considered the ultimate status symbol. In the 1st century BC, Julius Caesar passed a law limiting the wearing of pears only to the ruling class (Taburiaux, 1985). In the Arabian region, pearls had great importance in the region of the Arabian Gulf (Matlins, 2001), especially in countries such as Bahrain, Kuwait, Qatar, and UAE (Morton, 2020; Alatawi et al., 2019). Pearl fishing was a widespread occupation among local people. Fishing and trading pearls had a big proportion of national income in these countries in the age before the exploration of oil.

Pearls have been an important trade commodity science in Roman times. The discovery of pearls in central and south America led to the so-called Pearl Age (Zhou et al., 2017). There was an increasing demand for a pearl as more ladies of nobility and totality wore pearl jewelry to express wealth. By the 19th century, due to this increasing demand for pearl jewelry, the problem appeared as the oyster supplies began to dwindle. Unlike gemstones which are mined from the earth, pearls are produced by a living organism. Nature completely controls the process of pearls production.

A pearl is produced when an irritant, such as a parasite or piece of shell, accidentally entered an oyster's soft inner body causing it to secrete a crystalline substance called nacre. Nacre builds up layers around the irritant until a pearl is formed. In 1893, Kokichi Mikimoto simulated that natural process by introducing an irritant into an oyster manually. Pearls produced from this process were called cultured or cultivated pearls. By 1935, there were around 350 pearl farms in Japan producing 10 million cultured pearls a year. These cultured pearls have the same properties as natural pearls (Nagai, 2013).

3. Formation of Pearls

There are three types of pearls: natural, cultured, and imitation. In this paper, we concentrate on natural and cultured pearls because of their value-added to jewelry pieces and the similarity of their formation process. A natural pearl forms without the need for human intervention when an irritant works its way into a particular species of oyster, mussel, or clam. Due to the defense mechanism of the mollusk, the mollusk secretes a fluid to coat the irritant by building layers around it (Taylor & Strack, 2008). This process of coating the irritant layer upon layer continues until a lustrous pearl is formed. These layers consist of calcium carbonate ($CaCO_3$) in the form of the mineral aragonite or a mixture of aragonite and calcite (polymorphs with the same chemical formula, but different crystal structures) held together by an organic horn-like compound called conchiolin. The combination of aragonite and conchiolin is called nacre, which makes up mother-of-pearl (WADA, 1999).

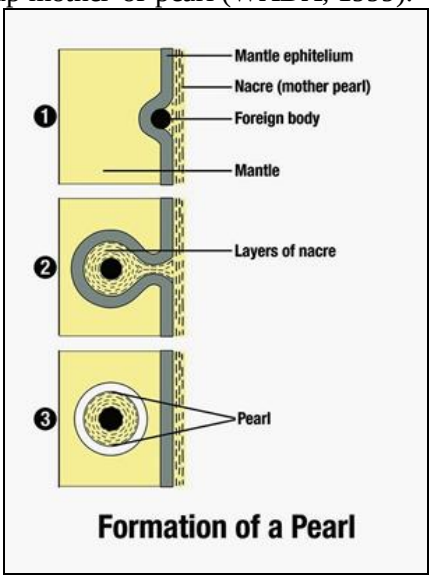

Figure 1shows the formation of a pearl

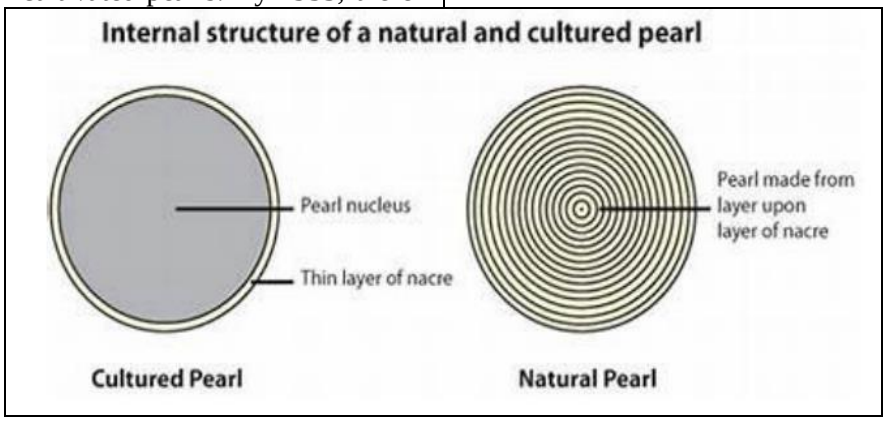

Figure 2shows the difference in narce between natural and cultured pearls

A cultured pearl undergoes the same previous process, but the irritant is surgically implanted inside the mollusk by a human. By examining natural and cultured pearls, it is found that the natural pearls are nearly 100% calcium carbonate and conchiolin. This is because the irritant is very tiny (Gordon et al., 2018). In cultured pearls, calcium carbonate and conchiolin are a thin layer as shown in figure [2].

4. Types of pearls

As mentioned above there are three types of pearls: natural, cultured, and imitation. In this section, each type is investigated.

4.1 Natural pearls

Natural pearls are formed as mentioned before without the need for human intervention. Natural pearls are very rare and therefore very expensive. The Arabian Gulf is considered the basic resource for natural pearls as 70-80% of natural pearls was fished in it till the 1950th. Bahrain island was the pearl trading center in the old world (Alatawi et al., 2019). Excavations in the ancient settlement of Dilmun in Bahrain confirmed that pearl fishing began at least 3000 years ago.

The natural saltwater pearls of the Arabian Gulf come from the Pinctada radiata and Pinctada margaritifera oysters (Hänni, 2012). Arabian Gulf pearls range in color from white to darker cream and tend to be more yellow than those of the Red Sea, which are distinguished by their distinctive colors of light yellow, cream, and very light pink. The Red Sea (Then-Obłuska, 2015; Mastaller, 1987) also produces some pearls in dark colors ranging from pink to light p.urple to dark purple.

4.2 Cultured Pearls

Cultured pearls have two categories: Saltwater cultured pearls, and Freshwater cultured pearls.

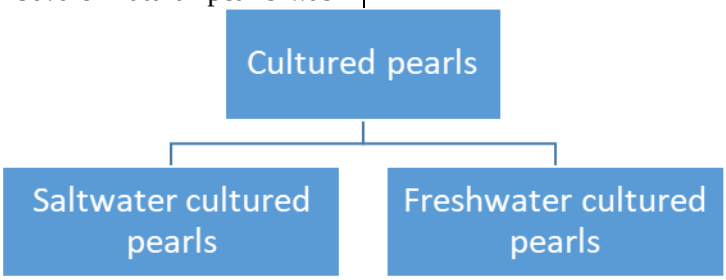

Figure 3 cultured pearls' types

4.2.1 Saltwater Cultured Pearls:

Saltwater cultured pearls are divided into 3 types:

4.2.1.1 Akoya cultured pearls:

Akoya cultured pearls are the most familiar type of saltwater cultured pearl to most people in pearl markets. The Pinctada fucata is a type of oyster that is used to produce akoya cultured pearls. This type was firstly used by the Japanese pioneer of culturing pearls, Kokichi Mikimoto, in the early 1900s (Kiefert et al., 2004; Kripa et al., 2007).

Like other bivalve mollusks, Pinctada fucata is a filter feeder. Water enters the shell through an opening in the mantle, passes over the gills where food particles are filtered out and gas exchange takes place and passes out through another opening (Takeuchi et al., 2012). These pearl oysters feed on infusorians, foraminifers, radiolarians, and other small planktonic organisms.

Akoya cultured pearls are considered one of the smallest pearls produced as their diameter is around 6mm to 9mm. Although the origin of akoya cultured pearl is back in Japan, it is now cultured in various places around the world, such as China, Australia (Otter et al, 2017), India (Kripa et al., 2007), and Mexico (Kiefert et al., 2004). Pearls produced have white or creamy color but, in some cases, they need to be color-treated.

4.2.1.2 Tahitian cultured pearls:

Pinctada margaritifera, is a species of pearl oyster. It is a saltwater mollusk. This type of oyster is used to produce Tahitian cultured pearls. It is also known as the black-lip pearl oyster (Kishore & Southgate, 2016). It lives in various places such as the Arabian Gulf, Red Sea, and New Guinea.

Figure 4 shows the oyster Pinctada margaritifera

Tahitian cultured pearls are available in markets since the 1970s. it comes in a range of colors from white to black with various undertones and overtones of green, pink, silver, and yellow. It also comes in various shapes and sizes. Shapes include a round, semi-round, button, circle, and other geometrical and non-geometrical shapes. sizes range from 8mm to 14mm in diameter (Hänni & Cartier, 2013).

4.2.1.3 South Sea Cultured Pearls:

This type of pearl is produced by one of the largest oysters in the world which are called Pinctada maxima (Zhu et al., 2019). This kind of oyster produced pearls whose diameter reaches 15mm or bigger. it is cultured in regions such as Australia, Burma, the Philippines, and Indonesia (Otter et al., 2017).it also can be found in the south sea but different colors. It comes in various colors but silver, white, and yellow are the most common. The yellow color is called sometimes the golden pearl (Elen, 2001).

Figure 5 shows the oyster Pinctada maxima

4.2.2 Freshwater Cultured Pearls:

Freshwater cultured pearls began in Japan at the same time that Akoya pearl was cultured in 1914 in lake Biwa (Wehrmeister et al., 2007). It is the largest lake in Japan and lies near the city of Koyoto. The extensive and successful use of the Biwa Pearl Mussel is reflected in the name Biwa pearls, a phrase which was at one time nearly synonymous with freshwater pearls in general. Over many decades, most freshwater cultured pearls came from Japan, but due to the pollution, the Japanese freshwater cultured pearls industry has died.

Because of the pollution in Japan, Japanese pearl producers also invested in producing cultured pearls with freshwater mussels in the region of Shanghai, China (Soldati et al., 2008). Thus, China has since become the world's largest producer of freshwater pearls. China now is the largest producer of freshwater cultured pearls. Freshwater cultured pearls are similar in size to Akoya pearls. Its size ranges from 2 to 13mm (Kripa et al., 2007).

5 Pearl Grading

Pearl grading is various from one jeweler to another, and from a novice to a professional. Many factors are used to grade pearls. Various grading systems were presented to solve the problem of using different factors in grading such as the GIA (Gemological Institute of America) grading system and the A-AAA grading system. Also, much research was conducted to enhance the quality of these factors. In this section, we tackle the GIA factors in the lighting of evaluation techniques and methods developed by researchers.

GIA's factors are considered the most integrating systems that can evaluate pearls effectively from different sides. GIA's factors include size, shape, luster, surface, color, quality, and matching (Ho & Shih, 2021).

5.1 Size:

Pearls are measured in millimeters, rounded to the nearest 0.5 mm. The diameter of spherical pierced pearls is measured perpendicular to the pierced hole and this measurement is used to denote the size of the pearl. As for pearls of any other shape, length, width, and sometimes depth is measured.

Cultured pearls can range in size from tiny 1.0mm seed pearls up to 21.0mm and rarely, even larger. To date, the largest cultured pearl in the world is an astonishing 29.65mm South Sea baroque. Each type of cultured pearl has its distinctive size guide which helps in measuring and classification pearls (Taylor & Strack, 2008).

Akoya pearls are one of the smallest cultured pearl types and can range in size from tiny 1.0 mm seed pearls up through 9.5 mm, and rarely 10.0 mm at their largest. The most popular and common sizes are 6.0 – 6.5 mm up through 9.0 – 9.5 mm.

Tahitian pearls are one of the largest cultured pearl types available. Average pearl sizes range from 8.0 – 9.0 mm through 15.0 – 16.0 mm and sometimes larger. The most popular pearl sizes range from 8.0 – 9.0 mm through 12.0 – 13.0mm. South Sea pearls are the largest cultured pearls in the world. Pearls range from 8.0 – 9.0 mm up through 16.0 – 17.0 mm, with some giants reaching up to 21 mm.

Freshwater pearls are also a smaller size pearl type, but these pearls can get a bit bigger than the Akoya. The typical Freshwater pearl sizes range from small 2.0 mm seed pearls up to 11.0 – 12.0 mm, and even larger. Some new types of freshwater pearls, sizes reach 15.0 – 16.0 mm and even bigger than that. The most popular Freshwater pearl sizes are generally 6.0 - 7.0 mm, 7.0 – 8.0 mm, and 8.0 – 9.0mm. Figure [6] shows the sizes of pearls.

5.2 Shape:

There are five primary shapes of pearls:

- Round pearls are considered the rarest shape as it is very difficult to be formed naturally. These pearls are perfectly spherical, which is considered the most desirable by pearl experts.

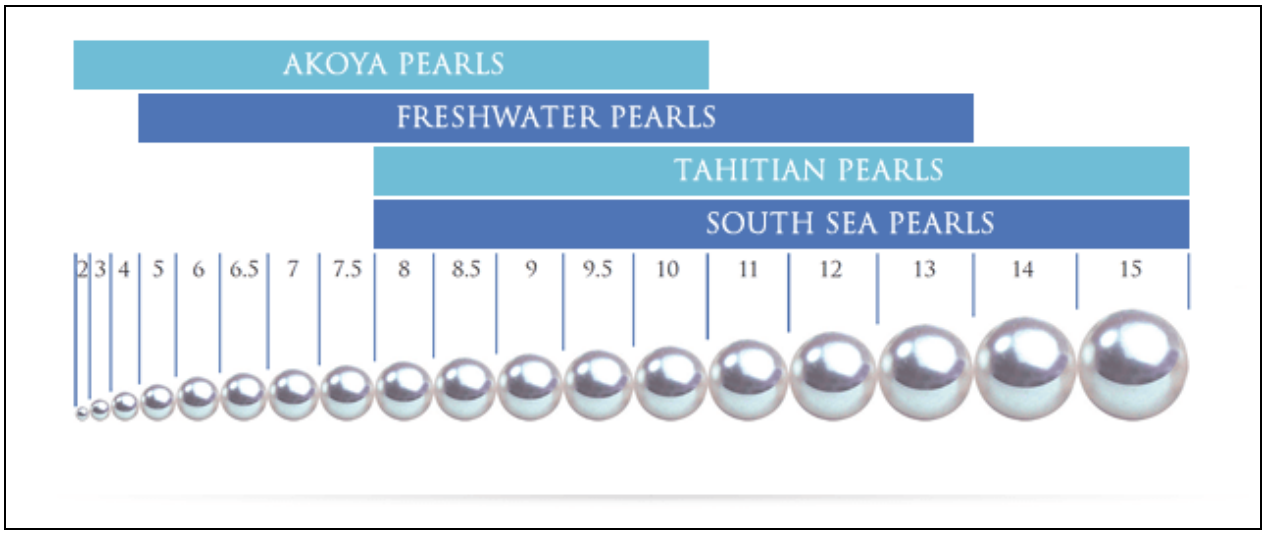

Figure 6 shows the sizes of pearls

- Semi-round or near-round pearls are very close in shape to round pearls and for an unexpert eye, it seems round. Microscopes are used to investigate the shape perfectly.
- Drop-shaped pearls get their name from their uncanny resemblance to teardrops. These pearls are symmetrically extended and can be extremely valuable if they possess a flawless pear shape.
- Baroque pearls are irregular in shape, with no two being the same.
- Semi-baroque pearls are a subset of baroque-shaped pearls. They feature rings around the pearl which makes them easily distinguishable and extremely unique.

Figure [7] shows the different shapes of pearl.

Figure 7 shows the different shapes of pearl

5.3 Color:

Pearl color has three main factors: bodycolor, overtone, and orient. Bodycolor is the main color of the pearl. It takes into account hue, tone, and saturation. Overtone is a noticeable translucent color that appears to overlie the bodycolor. Orient is a mixture of colors shimmering just below the surface of the pearl (Snow et al., 2004).

All pearls have a primary color which is mainly caused by the natural pigments found in conchiolin. These pigments are different from one type of mollusk to another. Other factors that can help determine a pearl's body color include the color of the implant used to grow the pearls, the materials in the water, and the nature of the food the mollusks eat. Some pearls show an overtone secondary color that appears above the primary color. It usually appears on the whole pearl or on a large part of it. The most common colors are green, blue, and pink (Dixon, 2017).

Pearls' colors can be classified into three categories:

- Neutral colors: white, gray, and black
- Semi-neutral colors: silver, cream, and brown
- Other colors: all other colors

Gemological Institute of America (GIA) presented a color classification system for pearl colors. This system defines 19 colors of pearls. These colors are divided into cold and hot colors. It is important to use a very detailed description of pearls' colors to give no space for misunderstanding (Yazawa & Zhou, 2018). Figure [8] shows the GIA color classification system for pearls.

5.4 Luster:

Luster is the visible phenomenon that occurs when light strikes the surface of the pearl and also penetrates through the various layers of aragonite platelets and is reflected back at the viewer (Taylor & Strack, 2008). The tighter and more compact the layers of nacre are, the more intense the pearl's luster will appear. Pearl Luster is the measurement of the quality and quantity of light that reflects from the surface and just under the surface of a pearl. The word comes from the Latin Lux which translates into "Light". There are three grades of luster: low, medium, and high. Figure [9] shows these 3 grades.

Three factors interact to help determine a pearl's luster: thickness, quality, and composition of the nacre, the velocity of sedimentation of the nacre, and the types of mollusks and their health. Thick nacre does not necessarily produce a high-quality pearl, But the nacre should be thick enough and have enough layers to interact with the light well. The thickness needed varies because it is affected by other factors. The quality of the nacre is mostly

determined by the regularity of its layers. The tight, uniform construction usually results in high-quality nacre.

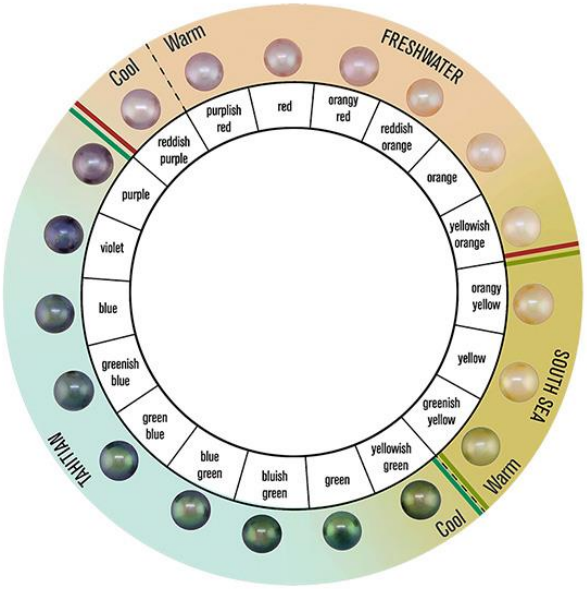

Figure 8 shows the GIA color classification system for pearls

Figure 9 shows the grades of pearl luster

Nacre consists of aragonite, calcite, and conchiolin, but when nacre is aragonite only or predominantly aragonite, luster is higher, other factors being equal. Conversely, as the calcite content increases, the luster decreases. In general, a slowly deposited nacre has a better luster than a rapidly deposited nacre. Coldwater slows down the rate of nacre deposition, so pearl farmers usually harvest cultured pearls during or after periods when the water is cold.

Some types of mollusks also produce seashells that are much brighter than others. For example, Akoya slugs naturally produce nacre with a higher luster than the South Sea slugs. The cooler water in Akoya's habitat may also be a factor. Healthy mollusks produce cultured pearls of higher luster. For mollusks to be healthy, they need water that is free of pollution, plenty of dissolved oxygen, and a large number of types of microorganisms as food.

5.5 Surface:

In the pearl industry, the term "blemish" has the same meaning as "flaw". Some other terms used are imperfection and spot. All of these terms describe the characteristics of the pearl surface that determine the quality of the pearl. The quality of the pearl's surface is classified into four grades: clean, lightly spotted, moderately spotted, and heavily spotted. The clean surface is spotless. Pearls with spotless surfaces are pure and have a high value in the jewelry industry. The lightly spotted surface has slight flaws that can be discovered by a very trained expert. The moderately spotted surface has a medium amount of flaws, but most of them may not be seen with the eye. The heavily spotted has flaws that can be easily noticeable by the eye and may affect the reliability of the pearl. Figure [10] shows the four grades of pearl surface quality.

Figure 10 shows the grades of pearl surface quality

Pearl flaws can be classified as follows:

- Scratches: Scratched lines on the surface of the pearl, usually fine straight or crooked lines. This is acceptable if the pearl is not heavily scratched and affects the luster of the surface.
- Pinpoints / Pits: These are tiny bumps and holes or pits that are usually not that visible from a distance.
- Dull spots: Very low luster in areas of poor nacre quality. This can also be due to contact of the pearl with chemicals or cosmetics.
- Bumps: Raised areas or welts, either alone or in groups. When the raised areas occur in groups, they can cover most of the pearl's surface and affect the pearl's shape. Sometimes wrinkles appear due to the grouping of bumps.
- Dimples: Pearl dimples look like circular depressions on the surface, usually occurring in groups.
- Cracks: Internal cracks may not be visible or sometimes look like fine hairs caught in the pearl. Again, these cracks usually do not affect the beauty of the pearl, but can threaten its durability.
- Chipping and Gaps: These occur when some layers of the nacre flake off and are very common in pearls with thin nacre.
- Discoloration: Uneven hues on the pearl surface due to the concentration of protein substance that holds the nacre together.

5.6 Nacre quality:

Nacre is the substance from which pearls are made. As nacre determines luster, nacre quality is an important factor when determining a pearl's value. Generally, the thicker the nacre, the more valuable the pearl. Thick nacre not only looks better than thin, but it also is much more durable.

Nacre quality is divided into three categories:

- Acceptable: In this category, the pearl is not chalky. The nacre is uniformly thick enough that the nucleus cannot be seen. A slight "blink" or glimpse of the nucleus is permissible.
- Nucleus Visible: the pearl shows strong blinking, a flickering of darker and lighter when it is rotated. The flicker of the dark is the nucleus, which can be quite noticeable in thin-nacre pearls.
- Chalky Appearance: this type of pearl is a dull and whitish pearl. The thin nacre on these gems never developed that glow that makes a pearl special.

5.7 Matching:

This standard applies only when two or more pearls are sorted for uniformity and used in a necklace or other piece of jewelry. As for gradual necklaces, it applies to the consistency of volume. The GIA Pearl Descriptive System provides five classifications of conformance:

- Excellent: pearls are uniform in appearance and pierced in the center
- Very good: very slight differences in matching
- Good: Slight differences in matching
- Acceptable: Noticeable differences in incongruence
- Poor: Very noticeable differences in incongruence

6 Pearl Treatment

Pearl treatment is defined as any action other than polishing that enhances a pearl's appearance. This may include dyeing, irradiation, and luster treatment. Pearl treatment happens after the harvesting of pearls.

6.1 Dyeing:

- Dyeing is darkening the nacre of the pearl by using silver nitrate which has been used for many decades to darken the appearance of pearls. Silver nitrate penetrates the layers of nacre and has a chemical reaction with light and hydrogen sulfide gas to create a very dark, black color.
  Colors other than black can be produced by using organic or inorganic. This is a very popular treatment done to freshwater pearls, as the lower values give producers more opportunity to experiment. Akoya pearls are also routinely "pinked" to enhance a more desirable rose overtone. This is done after drilling and bleaching have taken place, and then the pearls are placed in a solution with Aniline or other red dyes and left there until the color is absorbed through the drill hole.

6.2 Irradiation:

Irradiation is the use of gamma rays to darken the nucleus of the pearl in akoya pearls and the nacre layers in freshwater. The gamma rays do not affect the nacre of saltwater cultured pearls but darken the nucleus of the pearl. An irradiated saltwater pearl will look gray or blue colored. This is because saltwater pearls do not contain Manganese, since salt makes it insoluble, and it is this element that is altered with this process. So, the color altering is done only on the nucleus.

The nacre of freshwater pearls, on the other hand, when affected by gamma rays can become very dark. Some of these freshwater treated pearls will also have an intense metallic sheen and iridescent orientation over their surface. This is because manganese is freshwater soluble and ends up being a normal component in freshwater nacre.

6.3 Luster Treatment:

Luster treatment aims to increase the luster of a pearl. There are many methods to make this process. The common method is to give a thermal

treatment to the pearl by first being heated and then cooled, this is referred to as "maeshori". Another method is to apply a "coating" of lacquer to enhance its luster artificially. This method has gone out of fashion recently.

Maeshori is a treatment used on all akoya, freshwater, and some South Sea. Maeshori treatments vary from factory to factory, but it tightens nacre crystals and pulls moisture out, which will enhance the pearl's luster; but it has the issue of turning the pearl's nacre brittle. In freshwater pearls that have been over-treated, the pearls will turn "chalky" in short order.

7 Conclusion

Pearls are considered a key factor in the jewelry industry for their unique appearance and value. It was used for a long time in old civilizations till now in jewelry pieces such as Egyptian, Roman, and Persian civilizations. It is the only gem that is generated by a live creature. In this paper, we investigated the way that mollusk creates pearls and how it is formed. Also, the process of culturing pearls was explained. We concentrated on the cultured pearls as they simulate the natural pearls' formation and appearance. They are commonly used in jewelry design and manufacturing at the moment.

Pearl types were reviewed and treatment methods were explained. Treatment is used for cultured pearls to enhance the appearance of the pearl by treating pearls' flows, correcting their color, or changing the color of the pearl. Future works target to investigate the development of pearl jewelry design throughout history to find out new and creative approaches for pearl jewelry design. This may help designers and the jewelry industry to compete in the contemporary jewelry market that changes fast.

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