Takeo Ebina

Strategic Development of High-Value-Added Composite Materials

Springer

Strategic Development of High-Value-Added Composite Materials

Takeo Ebina

Strategic Development of High-Value-Added Composite Materials

Springer

Takeo Ebina
AIST Tohoku
Sendai, Japan

ISBN 978-981-97-1706-4 ISBN 978-981-97-1707-1 (eBook)
https://doi.org/10.1007/978-981-97-1707-1

English translation of the original Japanese edition published by National Institute of Advanced Industrial Science and Technology, Tsukuba, 2021

The original submitted manuscript has been translated into English. The translation was done using artificial intelligence. A subsequent revision was performed by the author(s) to further refine the work and to ensure that the translation is appropriate concerning content and scientific correctness. It may, however, read stylistically different from a conventional translation.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface for the English Version

It gives me great pleasure to present the English version of this book approximately three years after its original publication. A decade has passed since the inception of the training course on which it is based.

The English version was created through machine translation and subsequently proofread by the author. Minimal revisions were made while preserving the integrity of the original text. The revisions include updates related to the publication of international standard documents, among other changes.

Since the original book's publication, the global COVID-19 pandemic has continued to impact the world. Local industries have found themselves facing challenging business environments. Simultaneously, the Tohoku region has witnessed advancements in remote meeting infrastructure, reducing in-person interactions and fostering remote meetings as a common communication style.

This marks the third year of the Tohoku Digital Transformation Grand Prize, initiated by the Tohoku Bureau of Economy, Trade, and Industry ahead of the rest of the country. In the inaugural year, small and medium-sized enterprises in the region were still navigating the complexities of digital transformation. Observing the progress in the third year, it is apparent that digital transformation and associated productivity enhancements are gaining traction among small and medium-sized companies in the region.

Specifically, there has been an increase in the utilization of internal IT resources as well as an increase in the number of projects tailored to small and medium-sized enterprises. Notably, more companies are now leveraging external tools to facilitate digital transformation, minimizing the need for substantial investments, costs, or manpower.

Furthermore, an increasing number of companies are transitioning toward a complete digital transformation of their operations, reflecting the growing awareness of managers. Efforts are being made to enhance IoT technology literacy at both the company and community levels, supporting digital transformation in the region.

On a personal note, I have served as the director-general of the AIST Tohoku since the month following the publication of the original book. The AIST Tohoku inaugurated a nanomaterial evaluation and prototyping platform on August 1, 2023. This facility boasts approximately 20 pieces of equipment for designing, prototyping, and evaluating nanomaterials. This approach provides an integrated space for the development of nanomaterials. We aim to encourage small and medium-sized businesses in the region to use this platform to enhance local services and manufacturing capabilities.

The AIST Tohoku operates the Tohoku Activity Panel (TAP), which brings together support organizations from Miyagi Prefecture and Sendai City. Initially, it started with eight organizations, but the number of participants has now expanded to fourteen organizations, including observers. TAP has conducted an analysis of the current state of industry in the Tohoku region, identified issues, and discussed potential solutions. Although many TAP participants initially came from the Miyagi and Sendai areas, the discussions have since broadened their focus to encompass the entire Tohoku region.

Over the course of approximately one year, we reviewed the entirety of these discussions and distilled the proposed solutions into a comprehensible format, resulting in the “Tohoku Innovation Declaration”. We believe that this declaration not only reflects the current state of industry in the region but also offers a vision for the future.

Finally, I would like to thank all the staff who supported the publication of this book, Mr. Shinichi Koizumi and Ms. Taeko Sato of Springer Japan.

Sendai, Japan Takeo Ebina
December 2023

Preface

You may be familiar with the movie "Back to the Future". It is a comedy featuring a duo, Marty and Doc, who use a supercar time machine invented by Doc. The film was also popular in Japan, and a total of three films were made. The two travel 30 years before, 100 years before, and 30 years after the first film's release in 1985. In the places they travel to in time, there are always versions of Doc and Marty from that era, and they learn that problems have arisen for their future selves. They try to resolve the situation by going back in time in the time machine and eliminating the cause of the problem. I think one of the reasons why this film has remained popular is not only because it is a science fiction film but also because it focuses on Marty's tendency to make mistakes and his "do-overs". The theme stated at the end of the trilogy is "the future can be changed". Recently, the effects of aging and population decline have often been felt in various places in Japan. It is thought that the areas where people live are shrinking. As told in the "Tono Monogatari", I think the situation may become such that residential areas are surrounded by nonresidential areas that people cannot control. Popular TV shows reporting on people living in houses in the mountains are a perfect reflection of the current situation. For Japan, where 70% of the land is covered by forests, it is important to maintain and manage the mountains. The population decline rate in Tohoku is 30 years ahead of that in the rest of the country. We still cannot travel in a time machine, but from the perspective of population decline, when you go on a business trip outside of Tohoku and come back, it is like seeing society 30 years in the future. Of course, Tohoku is not completely separated from other regions, and the population decline is progressing under the influence of other regions, so it is unlikely that there will be an independent 30-year period in the future. However, it is clear that working on manufacturing based on collaboration in Tohoku now, making it successful, and meticulously recording it will provide useful information for people now and in the future. There are few large corporations in the manufacturing industry in Tohoku. For small and medium-sized enterprises to continue independent production activities, it is becoming difficult to capture local demand as before. It is urgent to maintain and develop strengths through collaboration with companies outside the region and at the same time to capture markets more actively outside the region than before. In the Tohoku region, there are many hot springs that serve as major tourist attractions. These hot springs also provide us with a mineral resource called bentonite. The National Institute of Advanced Industrial Science and Technology (AIST) is a public research institution with regional centers across the country, and the AIST Tohoku, located in Sendai, proposes manufacturing in Tohoku based on this resource. The AIST Tohoku, established in 1928, has its roots in the Industrial Arts Institute and has contributed to the modernization of crafts by providing guidance in woodworking, metalworking, design, etc., for the industrial promotion of Tohoku. The traditional craft of Miyagi Prefecture, "Tamamushi-nuri", introduced in this book was developed in 1932 by staff member Shun Koiwa as a "new lacquer color method" for export and is still produced and sold using essentially the same process. In 2010, the industry–academia–government consortium "Clayteam" was established, proposing and practicing manufacturing that utilizes natural blessings such as clay-based films. One of the features of the Clayteam is the maintenance of high activity. Approximately 20% of the companies are in the Tohoku region, and they actively collaborate with 80% of companies outside the Tohoku region. Approximately 10% of the companies change every year, and new products are born almost every year. Currently, they are leading efforts to develop and certify international standards for bentonite resource utilization products. This book is a compilation of lectures from the 6th training course of the Clayteam held from March to July 2020. Every year, a one-day training course was held in Sendai for the Clayteam members. Initially, the main content was about clay-based films and gas barrier materials, but gradually, topics such as industry–academia–government collaboration, intellectual property, and standardization were added. The target audience was initially those involved in related research and development, but the content was revised to accommodate the initial training of manufacturing makers. The 5th training session was held in Tokyo and Osaka, and the 6th training session was planned for participants nationwide remotely due to the impact of COVID-19. The same structure as in this book was used for the 8th lecture, and the lecture was divided into eight days. The 7th training course is scheduled to be held in 2021, but to make it easy to unravel at any time or to help those who do not participate in the training course understand, the overview was written as a book. I must confess something embarrassing here, but this book is conscious of "The Chemical History of a Candle". The Chemical History of a Candle is a book compiled by physicist Crookes, who recorded the six Christmas lectures given by the British scientist Michael Faraday in 1861. The Christmas lectures were held at the Royal Institution in London and were attended by people of all ages, similar to a science café event today. From his boyhood, Faraday was interested in the changes in matter, and his endless curiosity led him to study visible and invisible things, namely, matter, gas, and electricity. This is an invitation to science on a grand scale. The content is what we would now call a science class, but many of the scientific discoveries introduced were made in that era, and Faraday himself made some important discoveries, which is different from today's science classes. The participants in the Christmas lecture held 160 years ago had to feel the excitement of science at that time and the essence of chemical history. The lecture notes for this training course were made with the book in mind. Since I cannot compete with the content of the scientific explanation, I decided to approach it from the perspective of industry–academia–government collaboration, which I have been working on for approximately 20 years. I tried to structure the content based on what I had experienced and learned as much as possible. Additionally, I made the content a common theme for the future world, which is currently a key theme in Japan and Tohoku. I wrote this book thinking about how it will be evaluated as a meaningful thing 30 years from now and what it will be like 100 years from now. Although I advocate for the creation of blessings, I have not been able to fully construct its contents, and it remains something like a philosophy. I look forward to the development of future research on this topic.

Among the eight chapters, I think there are some that are too technical to understand. In such cases, it is okay to skip over them. It is rather rare for someone to need all the chapters as information, so I made all the chapters independent to read.

I would be very grateful if those who picked up this book and turned the pages further could receive some kind of hint and if that could be a trigger to produce some effect on future society.

Finally, I would like to express my deep gratitude to the many people who have been involved in the research and development that I used as a motif for writing this book. The explanations of these studies and their development and their generalization are the main story of this book. I would also like to express my deep gratitude to the staff who supported the training course and the writing of this book from March to July 2020 and to those who worked hard to publish it.

Sendai, Japan Takeo Ebina
March 2021

Contents

Chapter 1
Innovation from Component Development

Abstract Clay has been used as a molding material throughout Japan since the Jomon period. Clay with the appropriate water content can be shaped with fingers or a spatula. The molded body is sintered and waterproofed by firing. Fired bodies are used in daily life as vessels and clay figures. As the Jomon period progressed, these products began to feature highly decorative designs, which must have delighted the people of the time. Originally, it is likely that a single creator produced these value-added products from raw materials. Today, the use of clay has diversified, and most products are composed of components made from different materials, with highly specialized production. Therefore, it is important to be aware of the connection between the process of producing value-added products from raw materials. In this chapter, clay, a resource of Megumi Monozukuri, is introduced, and how to use clay to impart various properties to components is explained. Additionally, two cases led to the development of high-value-added components using clay and products that provide a comfortable life. The AIST consortium Clayteam, which was launched in 2010, exhibits at the New Functional Materials Exhibition held at Tokyo Big Sight every winter, but in January 2020, we proposed future manufacturing through the exhibition of a wooden aircraft loaded with high-value-added components.

Keywords Added value · Clay · Flexibility · Self-standing · Synthetic clay · Transparency

1.1 Clay That Becomes a Film

Various types of clay are produced throughout Japan. In Tohoku, a large amount of hydrophilic clay called bentonite is produced. Figure 1.1 is a rather old photo of the Miyagi Kawasaki Mine, a type of open-pit mine that digs from the top. White or slightly bluish surfaces are shown, all of which are clays called bentonite. There is also a method of digging while making a tunnel along the layered ore deposit.

Bentonite has characteristics different from those of other clays. It swells when put in water. Figure 1.2 shows the state of 3 g of a clay called mica in water left for

T. Ebina, *Strategic Development of High-Value-Added Composite Materials*,
https://doi.org/10.1007/978-981-97-1707-1_1

Fig. 1.1 Miyagi Kawasaki Mine

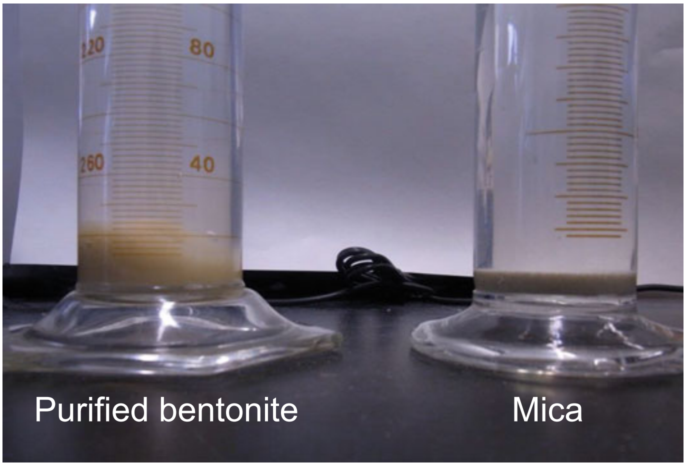

Fig. 1.2 Swelling test

a certain time. The mica powder is lightly accumulated. The transparent part was water. When the same operation is performed with purified bentonite, the interface between the solid and the liquid is greater than that of mica. In this way, purified bentonite has the ability to penetrate water between crystals and swell greatly. This feature is attributed to the hydrophilicity of bentonite.

Furthermore, if water is added and mixed, the clay particles will disperse uniformly in the water. Depending on the need, a water-soluble organic binder is added to this mixture to make a uniform paste, which can be used as a coating liquid. This approach has been applied to various coating materials in various ways. When the sample is dried in an oven, the water is lost, and a thin film remains. However, as the film is weak and can still dissolve in water, the film strength is increased, and the film is waterproofed by heat curing the binder. When thinly coated on a plastic film, for example, it is 0.4 μm in the dry state. In another case, a film with a thickness of 50 μm is prepared for use as a self-standing film by peeling it off from the coated material.

It is possible to create two types of films with different appearances depending on the clay used. The film was made with natural clay and a purified product of natural bentonite and had a light skin color. When synthetic clay without coloring components is used, the material becomes transparent. When transparent plastic is added to this mixture and made into a film, a transparent film is created. Many people may find it strange to say that clay is transparent. The main components of clay are oxygen, hydrogen, silicon, aluminum, magnesium, iron, sodium, calcium, etc., but atoms other than iron do not absorb visible light. The raw material for synthetic smectite is glass dissolved in alkali solution, and synthetic smectite also does not absorb visible light like glass does.

1.2 Design of Components and Clay-Based Films

Clay does not burn, unlike plastic. It also does not degrade at high temperatures. A film mixed with plastic has high-gas barrier properties. While making use of these features of clay, we design what kinds of components to make use of clay-based films.

When making components, there are necessary properties that must always be present. Additionally, there are properties that are not always necessary but are desirable if present. These properties are necessary because they are needed when using the product or because it is preferable to have these properties of the components during the manufacturing process.

Moreover, there are properties that “should not be” or “better not” (Fig. 1.3). We list these properties in advance. When listing, we divided the items into five categories, including “either is fine”. Next, we reinterpreted “should not be” and “better not”. This means that “should not be” is brought to the “necessary” side with the opposite meaning. A “better not” is assigned to the “desirable” side with the opposite meaning.

Let us take electrical insulation as an example. For some components, electricity must pass through. For other components, they must be insulating materials; in other words, electricity must not pass through. The characteristic that electricity must not pass through can be said to be “must be an insulating material” when interpreted in

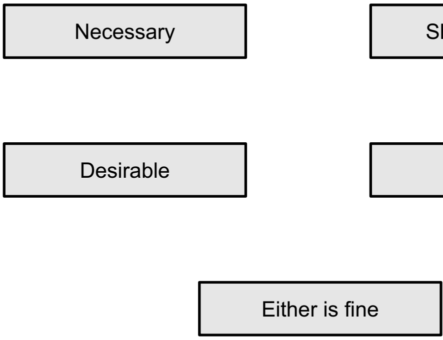

Fig. 1.3 Various requirements for components

the opposite sense. In many cases, it can be brought to the "necessary/desirable" side by interpreting it in the opposite direction.

The listed properties can be divided into additive and nonadditive properties in laminated components (Fig. 1.4). For example, gas barrier properties, electrical insulation, flame retardancy, and radiation heat dissipation can be improved. These properties can be retrofitted to laminated components. The nonadditive properties include heat resistance, dimensional stability, flame retardancy, and adhesion and cannot be retrofitted. Just because something is coated on top, it cannot be made to not melt at 100 °C if it melts at 100 °C, and even if what is coated on the surface is good, what is inside will melt, so it cannot be retrofitted.

For additive properties, the strongest property of the constituent layers appears. Therefore, the design policy is to enhance the strength of the strongest layer among all the layers.

On the other hand, for nonadditive properties, the weakest property of the constituent layers appears. Therefore, the design policy of laminated components is to increase the weakest property to the same level as that of other layers or to eliminate this weakness. In either case, the properties of the material increase, but the policy of which layer to focus on and how to change it differ.

With respect to additive properties, any component layer may possess these properties, such as gas barrier properties and electrical insulation (Fig. 1.5). Therefore, even if the material is placed inside the film, even if it is an independent film itself, or even if it exists on the surface of the substrate, gas barrier properties and electrical

Fig. 1.4 Properties that can and cannot be added

Examples of properties that can be added	Examples of properties that cannot be added
Gas barrier property	Heat resistance
Electrical insulation	Dimensional stability
Flame retardancy	(flame retardancy)
Radiant heat dissipation	Adhesion
→retrofittable	→cannot be retrofitted

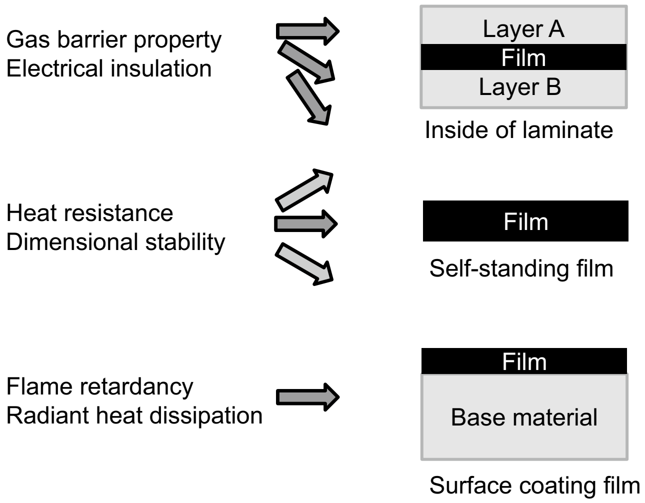

Fig. 1.5 Film position and imparting properties to products (for plastic-based laminates)

insulation will appear. On the other hand, heat resistance and dimensional stability occur at the weakest layer; therefore, the design policy is to improve the weakest layer. For example, clay should be distributed throughout an independent film, and the characteristics of the entire plastic should be improved.

Flame retardancy and radiation heat dissipation are characteristics that do not occur unless they are on the surface. However, as mentioned above, in the case of nonadditive properties, the weakest property of the constituent layers appears; therefore, from the perspective of eliminating weaknesses, the following can be considered. In the case of nonadditive properties, if the middle layer is the weakest, add clay to that layer to match the characteristics of that layer to substrate A or substrate B. If the surface layer is weak, add clay to that layer to match the substrate, which is also a possible measure. Therefore, patterns of placing the film inside and placing the film on the surface were also added. As described above, the design policy of a film can be formulated based on “necessary” or “desirable” properties, “should not have” or “better not” properties.

If further transparency is needed, synthetic clay is used. When high strength is needed, a concept of functional separation is currently considered; that is, a clay-based film is applied to high-strength components because there are currently no high-strength clay-based films. When realizing flexibility by changing the ratio of clay to binder, the heat resistance is also affected by the change. If the proportion of clay becomes too high, it becomes impossible to make a self-standing film, and only a coating can be made. These matters must also be considered. Flexibility and heat resistance are closely related to the mixing ratio of resin and clay. Increasing the amount of clay improves characteristics such as gas barrier properties, heat resistance, flame retardancy, high thermal conductivity, and a low linear expansion coefficient.

However, as the amount of clay increases, the flexibility, crack resistance, and workability decrease; thus, depending on the application, the demand for flexibility must be taken into account, and in some cases, the amount of clay must be reduced, while the amount of resin added increases.

Thus, each characteristic changes according to the ratio of clay to resin, and other characteristics that do not need to be changed are also affected. The addition of clay is expected to result in a combination of characteristics that usually become a trade-off, such as flexibility, gas barrier properties, heat resistance, flame retardancy, high thermal conductivity, and a low linear expansion coefficient. Depending on the product, the requirements for the material change. We consider how to equip all the necessary characteristics accordingly.

Next, I will discuss the development of combinations with base materials. Since the clay-based film itself does not have sufficient strength, when high strength is required for the member, fiber-reinforced composite materials (FRP) are used as the base material, and they are laminated with the clay-based film (Fig. 1.6).

This allows the FRP to be given gas barrier properties and electrical insulation. Specifically, gas barrier properties can be given to FRP gas tanks. Glass fibers have electrical insulation, but carbon fibers have the disadvantage of allowing electricity to flow on the surface. When a clay-based film is applied to a surface, the surface can be electrically insulated. The fibers used in FRP include glass fibers, ceramic fibers, carbon fibers, and organic fibers. When the base material is metal, it can be developed into materials for aircraft and vehicles by providing electrical insulation and preventing corrosion.

When the base material is wood, it can be used as a fire-resistant material for building materials. The above composite materials are guaranteed strength by the

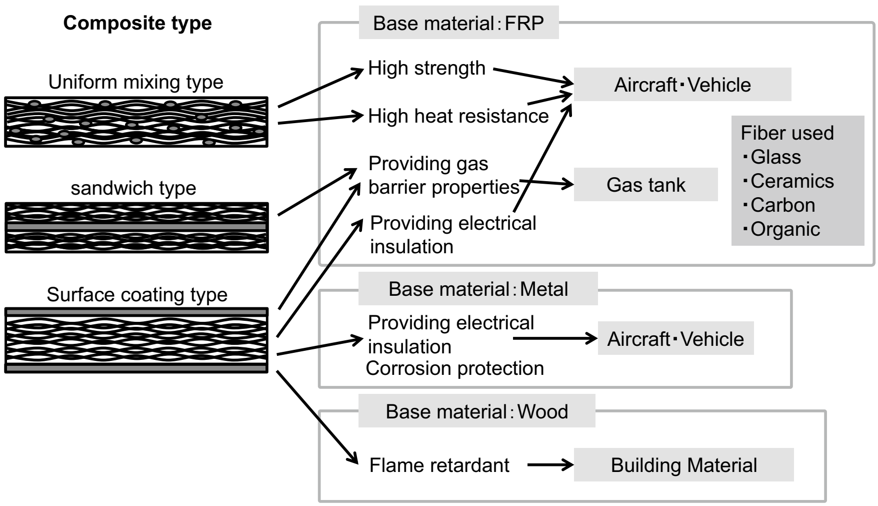

Fig. 1.6 Combination of clay-based film/base material and application

base material, and they are designed to endow the composite material with the unique performance of the clay-based film.

1.3 From Components to Products Supporting Comfortable Lives

In this section, based on the ideas from the previous section, I introduce two examples that have progressed from component development to productization. The first is "Tamamushi-nuri", a traditional craft product that can also be used in dishwashers; this product was codeveloped by Tohoku Kogei Manufacturing Co., Ltd. Tamamushi-nuri was constructed in ancient times and is a traditional craft designated by Miyagi Prefecture. After the Great East Japan Earthquake, in approximately 2012, we began developing highly durable lacquerware with a protective layer containing clay, which we finished as a product in approximately four years. The highly durable lacquerware, a research achievement, was adopted as a commemorative item for the G7 Finance Ministers and Central Bank Governors Meeting held in Sendai in 2016.

The other example I will introduce is a high-resolution, nondirectional tower speaker codeveloped with Ooasa Electronics Co., Ltd. (Hiroshima Prefecture). This speaker has a rocket-shaped design that has won the Good Design Award and uses a film containing clay in the tweeter, a speaker component that generates high frequencies, located at the top of the speaker. Through the AIST Chugoku, the clay film was introduced to Ooasa Electronics, and it was decided to test it as a diaphragm. A company that manufactures the clay-based film also participated, and it was finished as a tower speaker in approximately two years.

Now, both products have a common point of creating a comfortable living space (Fig. 1.7). Crafts are used according to each person's preferences, leading to a comfortable sensation. Comfort is common to people and is something individual; for example, as many people experience it when staying at a business hotel, the rooms of chain business hotels are generally the same specification. These rooms are basically made comfortable, but many people make rooms with just enough space for most people to feel comfortable. At the same time, no matter how comfortable it is, if you are told to live here for a month, you will need your own preference for curtains, ornaments, music, etc. The amount of money you can spend on individual comfort is relatively high, and people tend to spend extra money on their preferences. Business-to-customer B-to-C added value is closely related to such preferences.

Researchers in the materials R&D field often conduct research and development with material manufacturers. Then, the target is mostly business-to-business; B-to-B products, which are slightly different from the final product. In the B-to-B relationship, users make demands on suppliers such as "Can you supply us with this characteristic at this price"? In response, it becomes a difficult task to say, "Buy this material at a high price because it has added value". On the other hand, as seen in consumer electronics stores, the final product allows direct interaction with

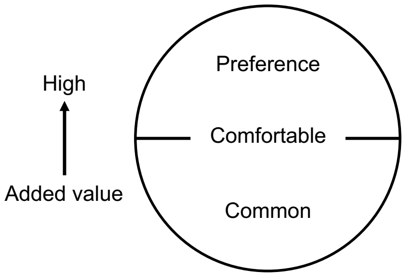

Fig. 1.7 Relationship between preference and added value

the customer, making it possible to convince them by asking, "Why is this electrical product expensive, and how will your life improve if you buy this electrical product"? As a result of this persuasion, if the customer is willing to pay, for example, 20% more, the added value has been transferred to the price. Even if what the material manufacturer has developed does not become the final product, the closer it is to the final product through collaboration with downstream companies, the more likely it is that the added value can be transferred to the price. From this perspective, let us look at two examples.

1.3.1 Development of High Durability Lacquerware

At the Vienna World Exposition in Meiji 6 (1873), several traditional Japanese crafts were exhibited and received high international acclaim. However, these traditional crafts were essentially one-of-a-kind items at the time. When trying to export them, productivity became an issue. In addition, industrial design technology was considered important. There was a need to strengthen the industry in Tohoku, and in Showa 3 (1928), the Industrial Arts Institute was established in Sendai [1]. The Industrial Arts Institute aimed to modernize and develop Japanese crafts, promoting exports and industrial development in Tohoku simultaneously. The tallest person in the photo in Fig. 1.8 is Bruno Taut, a German architect who was staying in Sendai at the time, and to his right is the first director-general, Kitaro Kunii.

The history of Tohoku Kogei Co., Ltd. is as follows: In Showa 7 (1932), Takashi Koiwa, a member of the Industrial Arts Institute, succeeded in developing Tamamushi lacquer, and in Showa 8 (1933), he applied for a patent for Tamamushi lacquer. In the same year, with the support of the Research Institute for Iron, Steel, and Other Metals; Tohoku Imperial University; and the Industrial Arts Institute, Tohoku Kogei Co., Ltd., was established. Figure 1.9 is a photo of early Tohoku Kogei Co., Ltd., and the sign reads "Manufacturing and selling products using KS magnet steel, invented by Professor Kotaro Honda, President of Tohoku Imperial University". At the same time, as a manufacturer and seller of crafts using the world's strongest KS magnet at the time, they also manufactured and sold Tamamushi lacquer developed at the Industrial Arts Institute. Tohoku Craft Manufacturing Co., Ltd. can be considered a

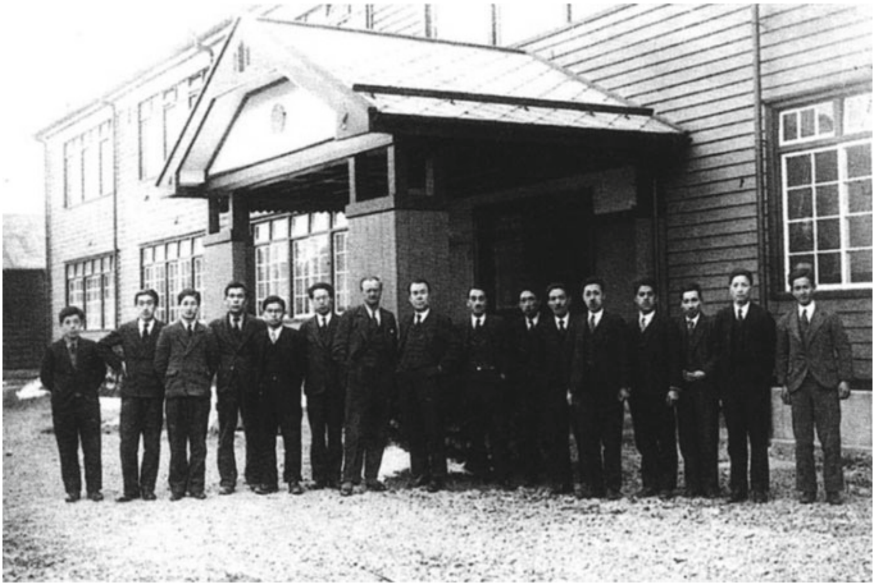

Fig. 1.8 Bruno Taut and members of the Industrial Arts Institute. *Photo* Courtesy of National Institute of Advanced Industrial Science and Technology

precursor to venture companies that productize the latest materials. Two years later, in Showa 10 (1935), the Industrial Arts Institute's patent application for Tamamushi lacquer, Patent No. 110460 "New Lacquer Painting Method for Lacquerware", was registered. This patent was licensed to Tohoku Kogei Co., Ltd., in Showa 14 (1939).

Tamamushi-nuri is still made today using essentially the same process as in the past (Fig. 1.10). In the construction of the Tamamushi-nuri layer, assuming that the base material is wood, a primer layer and a middle layer are first applied to the wood. A silver powder layer was then applied on top of the sample. Next, aluminum powder was sprinkled on the plants. Further on top of that, a semitransparent top layer, in this case, a red top layer, is painted. When this process is complete, the incident light first passes through the semitransparent top layer, and the light is scattered in the silver powder layer. This scattered light passes through the semitransparent top layer again. Because this light is reflected, the metallic luster, especially at the rounded surface, becomes a characteristic of Tamamushi-nuri. It was named Tamamushi-nuri because its appearance resembles that of a jewel beetle. The main component of lacquer is urushiol, the discovery of which and the total synthesis of urushiol were performed by Dr. Toshiyuki Majima of the Chemistry Department of Tohoku Imperial University. However, lacquerware dating back to approximately 7,000 BC was excavated from the Kainoshima B site in Hakodate city. Since then, it has been used as a red lacquer mixed with Bengal. Today, not only wood but also various materials are used as the base material for lacquerware, and paints other than genuine lacquers are widely used. Materials harder than wood, such as glass and porcelain, are also

Fig. 1.9 Photo of the early Tohoku Kogei Co., Ltd. *Photo* Courtesy of Tohoku Kogei Co., Ltd.

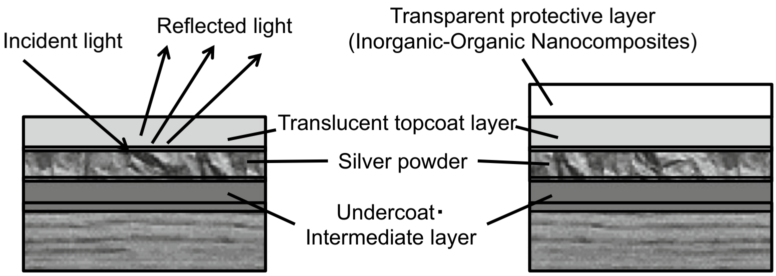

Fig. 1.10 Structures of conventional Tamamushi-nuri (left) and the proposed one (right)

used as base materials for lacquerware. Currently, dishwashers are widespread. It was assumed that the surface of the lacquerware would be scratched using them, and it was problematic that the surface hardness of the coating material was soft and lacked dishwasher resistance and light resistance. To solve this problem, a transparent protective layer with abrasion resistance was applied to the outermost surface. Next, this protective layer was designed. The protective layer must have an abrasion resistance (hard coating property) and high transparency. In addition, because of the need to improve UV resistance, the assumed structure of this protective film layer is considered to be the configuration shown in Fig. 1.11 [2]. The clay distributed in the protective layer is chosen to be composed of small particles of approximately 50 nm,

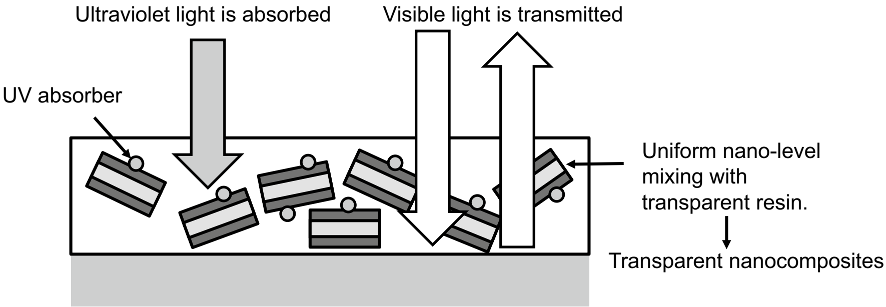

Fig. 1.11 Assumed internal structure and optical properties of the protective layer. Excerpt from [3]

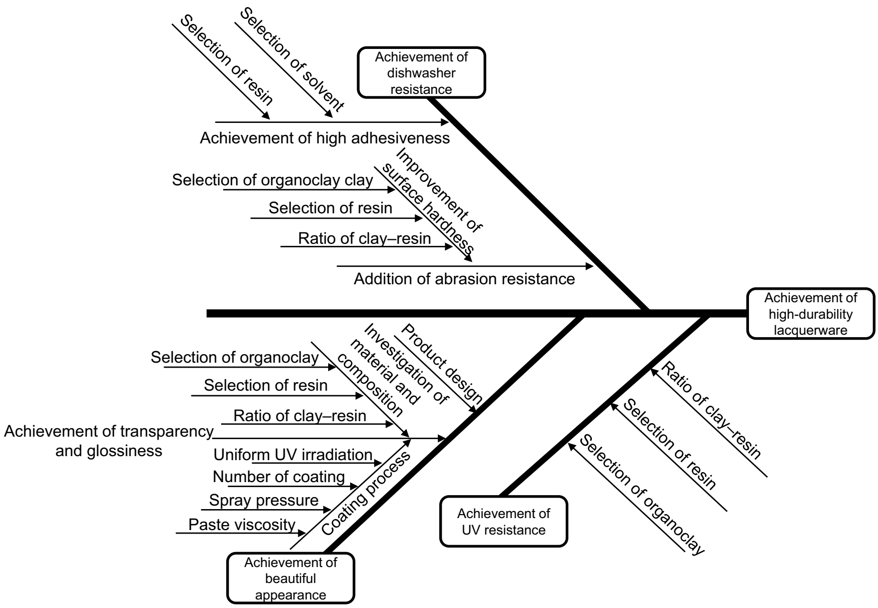

Fig. 1.12 Fish bone diagram in development of high-durability lacquerware

which prevents scattering and refraction of light, and visible light passes straight through. This requires a transparent resin and a finely and uniformly mixed clay structure. Another problem was the prevention of fading due to ultraviolet rays, so it was decided that the protective layer would absorb ultraviolet rays. Since clay itself does not absorb ultraviolet rays, a UV absorber was added to stabilize the material by binding it to the clay. The factors necessary to realize high-durability lacquerware were listed with the above configuration. Figure 1.12 [2] is a characteristic factor diagram, also known as a fishbone model, where the most important factor is drawn horizontally in the middle, and other factors directly connected to it are drawn as lines connected to the middle line. The factors of children and grandchildren are drawn to hit that line, and the whole relationship is "visualized". It is possible to check whether the necessary development has been done without omission and whether the progress of each development is well balanced toward the final goal. The development was divided between the painting process handled by Tohoku Kogei and the composite material development handled by AIST. The product proposal is what ultimately equips the product with added value, so product design was also carried out in collaboration. For example, researchers and B-to-C companies were able to complement each other. Clay, solvent, and hard coat resins were chosen for their mutual affinity. We used a UV-curing resin and further mixed it with components that play the role of photopolymerization initiators and UV absorbers to create a coating paste. This material was applied to glass and cured with a small UV light source to form a protective layer, after which various evaluations were conducted. As shown in Figs. 1.10 and 1.11, the protective layer must be transparent. Especially for lacquerware, Tamamushi-nuri plants require a particularly high gloss, so we also thoroughly evaluated the transparency of the coating formed on the glass (Fig. 1.13). We aimed for transparency identical to glass and for light to pass straight through, i.e., low haze. For the abrasion resistance test, we conducted a commonly used pencil hardness test (Fig. 1.14). This test uses a series of pencils of different hardnesses to examine the hardness of the pencil that scratches were made, and the hardness of the protective film was one step lower than that of the softest pencil that gave rise to scratches. Normally, 2H or more is called a hard coating, but in this case, it was scratched at 6H, so a hardness of 5H was recognized. The weather resistance test was conducted as follows. UV light was applied to the sample for a certain period of time, and the color was quantified using a device called a color difference meter. This value expresses the difference in color as a distance in color space. If the distance is long, it is judged that the color has changed significantly. We evaluated how much discoloration could be reduced with and without the protective layer and confirmed the effect of improving UV resistance by applying the protective layer. In addition, we adopted a measurement equivalent to gloss, called the G value, as an aesthetic evaluation. Especially in the case of Tamamushi-nuri, glossiness is a characteristic; therefore, we proceeded with development while checking this value to keep the G value high. The development of high-durability Tamamushi-nuri requires the fusion of four unique technologies (Fig. 1.15). The first is the invention of Tamamushi-nuri made at the Industrial Arts Institute. The second is the industrialization of transparent synthetic clay and synthetic smectite conducted at the Tohoku National Industrial Research Institute, the predecessor of the AIST Tohoku, from the Showa 40 s–50 s (1965–1984) [3, 4]. The third is the use of transparent polymer clay nanocomposites of clay-based films, which was conducted at the AIST Tohoku in the Heisei era (1989–2019); the fourth is spray coating, a traditional technique. In the Reiwa era (2019–), these were fused together to create a traditional craft that can be proposed anew, even after passing through the three eras of Showa, Heisei, and Reiwa. This is due to the press release issued on January 24, 2020. The local professional baseball team, Tohoku Rakuten Golden Eagles, has adopted helmets coated with a nanocomposite of Tamamushi-nyuri from the 2020 to 2023 seasons