Tile Renovation of Exterior Walls for the Taiwan Governor’s Office

Jih-Shong Wu† and Ren-Jye Dzeng

Department of Civil Engineering, National Chiao-Tung University, 1001 Ta Hsueh Road, Hsinchu 300, Taiwan, Republic of China

†Corresponding Author: Tel: 886 937 429090; Fax: 886 2 22484954; E-mail: bill.wu26@msa.hinet.net

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Abstract: Completed in 1919, the Taiwan Governor’s Office has been regarded as the symbol of authority in Taiwan from the colonization by Japan to the present. Its brilliant appearance of intertwined red bricks and white stones, originating from the European Baroque style in the 18th and 19th centuries, has been eroded by the harsh weather for more than 80 years. The exterior wall of red unglazed tiles is the most important material in the renovation project. It was originally manufactured by Shinagawa Shirorenga Co., Ltd. However, tile production ceased completely in Taiwan and Japan in 1935. The end of production resulted in the loss of this traditional manufacturing technology. Research has found that the most important factors for re-making the tiles successfully are: (i) firing temperature, (ii) reconstruction of manufacturing technologies and (iii) firing improvement. This made possible the reemergence of the original beautiful style and features of the Governor’s Office. The conclusions of this research can be shared and referenced by those who are devoted to the renovation and preservation of historical buildings.

Keywords: Brick, Building renovation, Historic buildings, Manufacturing technology, Tiles

Introduction

History catches up with us quickly and many of the buildings of the recent past are now in a state of decay (Winter, 2000). During the last two decades, architectural heritage preservation has gained heightened interest for scientists, architects, engineers and archaeologists, this subject being an interdisciplinary research area (Lo´pez-Arce, Garcia-Guinea, Gracia, M., & Obis, 2003). Damaged historical brick wall masonry needs to be restored with substitute bricks. The aim of the restoration is to preserve as much of the historic materials as possible and to avoid any damage to the structure (Jacob, 2007).

Historic buildings have been repaired in the past in a way that was well intentioned, but which soon turned out to be badly wrong (Jacob, 2007). Brick wall masonry of many historical buildings suffers from rising damp, which is very harmful from a conservation point of view, because water migrating inside the wall is transporting soluble salts of the lagoon (Fassina, Favaro, Naccari, & Pigo, 2002). It is well known that many factors can influence the moisture distribution in brick masonry, such as, for instance, the thickness of wall masonry, the porosity distribution of bricks and exposure to atmospheric agents such as rainwater, relative humidity of the neighboring environment and ventilation (Amoroso & Fassina 1983).

Conservation principles are determined in relation to the spiritual and naturalistic sensibilities of East Asian culture and architecture (Chung, 2005). The basic principle is “the original state cannot be changed during renovation” (Ayala & Wang 2006). New material is used along with original or similar materials and methods (Galan, Carretero, & Mayoral, 1999) to preserve the original beautiful style and features.

Shinagawa Shirorenga Co., Ltd., the original manufacturer of the red unglazed tile used in this exterior wall renovation project, had ceased production in 1935. The traditional manufacturing technology has been lost for years (about 60 years) and there is no current production of this kind of red tile. Furthermore, only 30,000 pieces of red tile are needed in this project, so the volume of tiles is too low to interest any general ceramics producers. Fortunately, due to the committed study and research by an enthusiastic ceramicist together with the project team, difficulties such as the lack of a skillful adobe technique, layout pattern, and temperature control have been ironed out. The initial study working around the clock lasted for more than three months. Although the product defect rate reached 30% in the first batch, after 15 days of modification, the average defect rate dropped to 11.2%, with only 8.72% finished product being below standard after selection. The average water absorption was 2.58% with a modulus of rupture reaching 510 kgf/cm² and the related test results were all in line with the standard criteria. The successful manufacturing of the tile was the most important
factor for accomplishing the renovation project ahead of schedule in December 2004.

Research Aims and Methods

The case study is an extremely flexible and popular method of conducting research. It is considered an important approach for presenting information, describing the problem at hand, and prescribing solutions or treatments (Kirszen & Mandell 1992).

Brick wall masonry constitutes a significant part of the construction materials found in historic buildings. The level of decay in bricks varies widely, in many cases requiring partial replacements. The selection of compatible materials for the replacement of original bricks is crucial in order to avoid damage to the historical structure (Elert, Cultrone, Rodriguez Navarro, & Sebastián Pardo, 2003). Studies have examined the influence of manufacture and firing temperature. The feasibility of manufacturing replacement bricks with specific properties suitable for particular conservation requirements has also been assessed (Elert et al., 2003).

Historical research is not just to analyze and preserve objects but also to investigate the knowledge and skills used to produce and use them (Vandiver, 2001). The main goals of building material characterization are preservation and restoration, and aiding archaeological studies, which include:

i. The origin of historical raw materials
ii. Determination of original firing temperature
iii. Reconstruction of firing techniques and manufacturing technologies (Bertelle, Calogero, Oddone, Salerno, Segnan, & Sitevano, 2000).

Historical Review

A Brief History of the Taiwan Governor’s Office

The designer of the Governor’s Office, Matscorejo Moriyama, adopted the Baroque style, which commonly prevailed in the 18th and 19th centuries for European royal buildings, to embody the authority and symbolism of the Taiwan Governor’s Office. Since its establishment in 1919 until the present, it has been regarded as the power center from the colonization of Japan to the democracy of the present time (Figure 1).

It took about eight years to complete, from land acquisition and architectural design, to the construction of buildings. It was actually six years and nine months from when construction commenced officially on June 1, 1912 to the completion in March 1919. In fact, the project was not completed in March 1919 because the construction of related facilities and annexing of neighboring land was not completed until 1923. It cost a total of Yen $2,696,441,397, the currency value at that time (Ministry of Interior, 2003). Located in Taipei, Taiwan, the Governor’s Office was the highest building at the time totaling five ground floors including an 11-floor central tower. The height is about 60m in total, covering a total area of 59,504m$^2$ (architectural area is about 7,157m$^2$) (Ministry of Interior, 2003).

With a brilliant decoration of intertwined red bricks and white stones, the main structure of the Governor’s Office is of reinforced concrete. The red tile was manufactured by a comparatively new technology at the time. The unglazed tile had the same color and texture as facing brick as well as the same look as red bricks (Figure 2). Not only is it attractive to attach the tiles to reinforced concrete but also they protect the main structure from seasonal water erosion.

The main buildings of the Governor’s Office underwent their first renovation for fire damage on the fifth floor in May 1935. However, due to a lack of funds and regulations, the original materials and style were never applied for the next renovation of damage by an air raid during World War II, a blaze that lasted three days in May 1945 and for the last renovation project for structural repairs and leakage in 1973 (Ministry of the Interior, 2003).

When the Governor’s Office was named a “National Historical Treasure” in 1998 by the Ministry of the Interior, it was then

Figure 1: Taiwan Governor’s Office after renovation in 2005 (Courtesy of Ri-hsiang Tsai).

Figure 2: Unglazed tile (finished product).
possible to renovate the exterior wall of the building according to renovation principles for historical buildings. The renovation processes are as shown in Figures 3 and 4.

The Rise and Fall of Unglazed Tiles

The first significant step included the careful examination of historical documents relating to the building and a chronological mapping of the previous restoration efforts (Acun & Aroğlu, 2006). It was found from historical documents that the earliest use of unglazed tile in Japan dated back to about 1912, when they were used on the entrance door and guardroom of Tokyo University. The term “tile” had never been used in Japanese architecture circles when the Taiwan Governor’s Office was constructed. It had been called an “ornamental tile.” Not until the opening of the Tokyo Museum in 1922, was it renamed as a “tile” (Huang, 2004).

Both the entrance door and guardroom of Tokyo University and the Taiwan Governor’s Office adopted the tiles made by Shinagawa Shirorenga Co., Ltd. These red tiles with their diamond trademark with raised “S.S” in the rear center were used in the Taiwan Governor’s Office. S.S had been used as the trademark since the establishment of the company because it was the initials of Shinagawa Shirorenga. Completed in December 1914, the exterior wall of Tokyo Railway Station used 940,000 red unglazed tiles made by Shinagawa Shirorenga (Ministry of Interior, 2003). Taichung Railway Station, completed in 1917, is a reinforced concrete building like the Taiwan Governor’s Office with the same appearance of intertwined red tiles and white stone. The exterior wall tiles were Shinagawa Shirorenga products as well (Huang 2004; Ministry of Interior, 2003).

In Japan, reinforced concrete structures developed almost concurrently with the tiles. At the early development stage, reinforced concrete architecture was thought to have a rough surface, monotonous and seemingly unfinished. Thus, tiles were adopted for the exterior wall decoration to imitate the appearance of a brick building. Hence, it was very avant-garde and popular for the buildings of the Taiwan Governor’s Office during 1912-1919 to use tiles in the decoration of the exterior wall, reflecting the spirit of the time. Tiles were used in reinforced concrete architecture until 1923 when many brick buildings collapsed during the Great Kanto Earthquake. A feeling of untrustworthiness was triggered in the general population who regarded brick buildings as a symbol of instability. This affected the tile market, and tiles imitating the size and color of bricks became regarded with suspicion. The technique of using tiles for reinforced concrete buildings suddenly ceased and the full-scale production of unglazed tiles stopped in 1935 (Ministry of Interior, 2003).

Raw Materials

The composition of the clay raw materials is important for controlling the production process, since the constituents determine the firing characteristics and properties of the end-product, such as degree of vitrification, porosity and crack development, bloating and black coring (Toledo, dos Santos, Faria, Carrio, Auler, & Vargas, 2004). Raw materials and manufacturing parameters have been found to be of great importance in the quality and durability of bricks (Elert et al., 2003). The first significant step of reviewing the historical documentation gives information about the location of the raw material (Galan et al., 1999).

It was easy to obtain clay, the raw material for bricks and tiles, both in Taiwan and Japan during the colonization of Japan and even in the early period of Retrocession after 1945. At that time, most products were made of good quality clay. However, the

Figure 3: Before renovation and after renovation (Courtesy of Ju-mao Lin).

Figure 4: Laying tiles (Courtesy of Ri-hsiang Tsai).
quality and quantity of present day clay have deteriorated because it is a non-renewable resource and production is limited through environmental protection, and land development.

Clay is usually formed from chemical weathering of granite or quartzite. Clays for ceramic products and tiles are commonly of the clay mineral kaolinite whose main substances are SiO2, Al2O3 and Fe2O3. The high plasticity of clay is due to water acting as a lubricant between particles. This is also the reason for the ease of shaping clay.

At an early stage of developing mimic tiles, clays in Taiwan including Dajia, Guohsing, Miaoli and Huatan tested negative in certain aspects: firing color, surface smoothness and contractibility control. Furthermore, the most important factor to be considered was the pressing project time as it required more than half a year to store, turn over and sun bake the clay. The second factor was the lack of fineness of clays leading to a rough granulated surface. The third factor was the prohibition of mining in Japanese clay areas. The fourth factor was the prohibition of mining in land of comparative economic value; either mining was prohibited in the area or the clay was unsuitable in quality. Therefore, Taiwan imports most of its clay for ceramics, as it cannot afford its own production. After the trial firing, Red Art Clay imported from USA was chosen. After passing through the tile firing trials four times, a committee of specialists, invited by the renovation project, certified the quality of the finished products. The mimic finished products were comparable with the original Governor’s Office tile in color, water absorption and vitrified extent. Hence, it was decided to adopt American Red Art Clay whose main chemical constituents were SiO2, Al2O3 and Fe2O3, with 6% water content. The chemical constituents of American Red Art Clay are as shown in Table 1.

Research and the Manufacture of Glazed Tiles

There was much work involved in the early stage of tile making. Only about twenty pieces were manufactured in each kiln to calculate and control the contractibility, color, water absorption and vitrified extent. Although trial firing was completed within a month with finished products being certified by specialists and experts, many problems remained to be resolved between the trial firing and large-scale production such as black granules on finished products of large-scale manufacturing, and the high defect rate of products. Fortunately, perfect, smooth tiles that could be manufactured on a large scale were finally turned out after more than three months of round-the-clock research.

The process of making a tile can be roughly divided into the following steps: (1) rollover, (2) blank, (3) dry, (4) put into the kiln, (5) kiln-dry, and (6) kiln-done.

Rollover

A predetermined weight of air-dried clay was mixed with a sufficient amount of water and kept at room temperature to produce the optimum water content for good plasticity (Karaman, Gunal, & Ersahin, 2006). After rocks and impurities had been removed by a No. 200 screen, American Red Art Clay was ground with 1% water added (the original clay has 6% water content) as this was the optimum water content. Then the clay was mixed evenly in a whisk before it was screened by a No. 80 screen to make particles even in size and with a uniform coefficient of expansion. Hence, the chaps and black granules on the surface were avoided.

Blank

Development of mold. After passing through the tile firing trials four times, the shrinkage of the tile was about 25.86%. The dimensions of the original tile used in the Taiwan Governor’s Office were 106mm (length) * 61mm (width) * 15mm (height) (height including pattern of back surface; without 12mm). The panel layout and pressing mold size were deduced to be 116.4 mm (height including pattern of back surface; without 12mm). The process of making a tile can be roughly divided into the following two patterns:

| Table 1: Chemical constituents (%) of American Red Art Clay. |
|---------------------------------|--------|
| SiO2                            | 64.27  |
| Al2O3                           | 16.41  |
| Fe2O3                           | 7.04   |
| MgO                             | 1.55   |
| TiO2                            | 1.06   |
| CaO                             | 0.23   |
| K2O                             | 4.7    |
| Na2O                            | 0.4    |
| others                          | 4.34   |

Note: Water absorption 6%
The defect rate of products reached a high percentage of about 24% in the initial period due to inexperience with the pressing technology. After seven days, the defect rate dropped to less than 10% with improved pressing technology. Now each hydraulic press with double molds can turn out 100 pieces of adobe per hour. (Mold release was used to cut in the adobe in the early stage. However, as the adobe was manufactured in a dry pressing pattern with very little water added, the mold release daubed on the edge would cause a lot of damage to the edges instead. It had to be given up after many trials. It is not as efficient as cleaning the mold after cutting in the adobes.)

**Drying**

Drying was carried out before the firing stage when the moisture content of the clay was high in order to prevent swelling or bloating of the samples at high temperature, caused by the expansion of entrapped water (Karaman et al., 2006). The binder removal process from clay products is very critical and has to be considered for the following reasons:

i. Excess water present in the product may cause firing faults  
ii. The heat of vaporization is enormous when binder removal is carried out in a dryer. The wet products have to be dried to their equilibrium moisture content for the given ambient conditions (Murugesan, Suresh, Seetharamu, Aswatha Narayana, & Sundararajan, 2001).

The finished adobes were sent to the drying room for about 24h. The humidity of the drying room and the drying time should be under strict control as too high water content may result in cracks during firing while too little water content may result in colors in the finished products.

**Selection of Kiln Type**

As only 30,000 pieces of tiles were needed for this renovation project, both gas kiln and electric kiln were adopted for research and manufacturing. The reasons for ultimately selecting the electric kiln are as follows.

The gas kiln uses gas as the fuel to heat from its bottom resulting in dramatic temperature changes and giving unexpected results. In addition, by producing an oxygen shortage, oxidation and reduction results can be achieved. The thermal fluid would rush to the kiln top as the bottom is heated up. The thermal fluid would come down by the chimney effect, forcing the thermal fluid back to the kiln bottom. Hence, the flame will take on a backfire shape with thermal fluid rushing upwards producing good thermal cycling. The inner kiln temperature will be even with a good temperature rise. The thermal cycling is illustrated in Figure 7.

The electric kiln generates heat by “resistors” in a similar layout to an electric stove with more condensed space to make full use of the heat energy. The early type electric kilns used knife-edge contacts to manually control the heat while, nowadays, a microcomputer is used to automatically control the heat. With preset programming, the whole firing process can be automatically controlled. Electric kilns were first used to bake colored flowers on the glaze of bowls, plates and vases. They have been used to bake complex glazes and delicate ceramic products for industrial use due to their high stability and a firing temperature capacity that reaches 1700°C. Because of their simple operation, they have been widely used in ceramic arts circles and ceramic classrooms, thereby making great contributions to the promotion and popularization of the ceramic arts. In addition, the electric kiln uses an electric heating element giving a very high stability to the finished products. Its use for oxidation and reduction is controllable; however, it cannot be used for manufacturing large pieces since it is limited by its volume.

In the early stages, only a few tiles were needed for tests and trials. Thus, the electric kiln was adopted; large-scale production was put on hold until the quality of the samples was recognized by experts because the electric kiln could not produce large quantities of tiles due to its limited capacity. Large-scale production had to use a gas kiln. However, the defect rate of products was poor in quality with the gas kiln, and reached as high as 95% for the first trial batch, and 90% for the second batch. The defect rate dropped to nearly 50% in the third and fourth batches by reducing the number of adobes, thereby reducing the output of each kiln. It was found after many trials and tests that the heat source comes from the bottom of the gas kiln. Although, the temperature rises smoothly, the internal heat is not even or stable, giving finished products in different colors especially in the temperature range between 1120 and 1170°C, which is the most important stage for deciding the color. Shrinkage of the tiles also occurs and the tiles are vitreous. Therefore, unevenly distributed heat is the major reason for the high defect rate in the finished products.

It was finally decided to install resistors on five facets of the electric kiln (only the top of the kiln had no resistor installation), giving even heat radiation resulting in even and stable temperatures, and easy temperature control in the kiln. Adobes placed in the center of the electric kiln were heated evenly. The disadvantage is the limited capacity. The evenly
it imparts the final properties to the product. Rapid firing causes bloating of the clay to occur since the formation of an impermeable vitrified outer skin prevents the loss of gases such as water vapor and carbon dioxide from the interior of the clay (Karaman et al., 2006). Apart from the characteristics and firing process, the size of the finished products will be influenced by the temperature rise ratio. Usually, a slower ratio is preferred for larger or thicker adobes.

The results revealed significant differences in the evolution of degree of vitrification, porosity and pore size distribution. Such evolution depends mostly on the raw clay composition and firing temperature (Eleret et al., 2003). High firing temperatures (>900°C) impart high compression strengths (Karaman et al., 2006; Lopez-Arce et al., 2004). At 1000°C, the phyllosilicate surfaces become smoother and the pores become ellipsoid with smooth edges (Cultrone, Sebastian, Elerta, de la Tone, Cazallaa, & Rodriguez-Navarro, 2004). The best hydric parameters occur at 1100°C, which is used as an indicator of technical quality and durability (Vos, 1978).

Vitrification is present at high firing temperatures of 1100°C (Cultrone et al., 2004; Karaman et al., 2006; Maniatis Simpoulos, & Kostiakas, 1981). The high degree of vitrification at 1100°C counters the expansion force exerted by the portlandite. Furthermore, calcium silicates form a reaction ring that replaces the CaO (or CaO+MgO) aggregates (Cultrone et al., 2001).

Firing temperature was tested many times in the initial stages. At the beginning of May 2004, a large-scale production test was carried out. Not until the middle of July was the first batch of trial products manufactured. The defect rate of the first batch reached as high as 30%. However, it dropped by about 10% after fifteen days of layout pattern improvement and temperature control. The control of firing temperature is shown in Table 3 and the curve based on records of temperature is shown in Figure 9.

**Table 2: Shrinkage of tiles.**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Dimension (mm)</th>
<th>Length (mm)</th>
<th>Width (mm)</th>
<th>Height (mm)</th>
<th>Volume (mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adobe (a)</td>
<td></td>
<td>116.4</td>
<td>66.6</td>
<td>13.5</td>
<td>104,655</td>
</tr>
<tr>
<td>Product (b)</td>
<td></td>
<td>106</td>
<td>61</td>
<td>12</td>
<td>77,592</td>
</tr>
<tr>
<td>Difference</td>
<td></td>
<td>10.4</td>
<td>5.6</td>
<td>1.5</td>
<td>27,063</td>
</tr>
<tr>
<td>Shrinkage (%)</td>
<td></td>
<td>8.93%</td>
<td>8.41%</td>
<td>11.11%</td>
<td>25.36%</td>
</tr>
<tr>
<td>Time (h)</td>
<td></td>
<td>1.098</td>
<td>1.092</td>
<td>1.125</td>
<td>1.349</td>
</tr>
</tbody>
</table>

* The height of the tile is its thickness, excluding the pattern on the back surface.

**Table 3: Firing temperature record.**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Time (h)</th>
<th>Temperature (°C)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rise</td>
<td>12</td>
<td>Room temperature</td>
<td>80</td>
</tr>
<tr>
<td>Rise</td>
<td>6</td>
<td>80-200</td>
<td></td>
</tr>
<tr>
<td>Rise</td>
<td>4</td>
<td>200</td>
<td>400</td>
</tr>
<tr>
<td>Rise</td>
<td>6</td>
<td>400</td>
<td>600</td>
</tr>
<tr>
<td>Rise</td>
<td>4.5</td>
<td>600</td>
<td>1170</td>
</tr>
<tr>
<td>Stable</td>
<td>1.5</td>
<td>1170</td>
<td>Tiles are vitreous</td>
</tr>
<tr>
<td>Cooling down</td>
<td>24</td>
<td>1170-273</td>
<td></td>
</tr>
<tr>
<td>Open the kiln gate by stage*</td>
<td>12</td>
<td>273-120</td>
<td>120°C kiln gate fully open</td>
</tr>
</tbody>
</table>

* The kiln gate gradually opens during the stage 273-120°C. The door can be opened fully when the temperature drops to 120°C and leads to natural cooling at room temperature. Sudden opening of the kiln gate may result in cracks.

**Firing Improvement (Firing Twice)**

For large-scale production, the firing process was improved by firing twice, first with a gas kiln of large capacity for nearly 21 h, from room temperature to about 1000°C, then, using an electric kiln to heat to 600°C in a very short time followed by heating to 1170°C. The finished products were similar in quality to that of the one time firing products but more suitable for large-scale production. The control of firing temperature is shown in Figure 10.

To conclude, altogether nearly 24,000 pieces of tile were manufactured and used in the renovation project to accomplish successfully the exterior wall renovation project of the Taiwan Governor’s Office, renewing and restoring its original beautiful style and features.

**The Quality of Tiles**

**Water Absorption**

Tiles can be roughly divided into fine earthenware tiles, stone tiles and ceramic tiles, mainly determined by water absorption. According to Chinese National Standards (CNS), water absorption of fine earthenware tiles should be below 18%, stone tiles below 6% and ceramic tiles below 1%.

However, exterior wall tiles exposed to the ravages of
weather and excessive absorption should be avoided to prevent chaps and breakages. Therefore, it is better to choose material of low water absorption for exterior wall tiles. The production of unglazed tiles in Japan and Taiwan has long been replaced by glazed multi-color tile production. Hence, mimic tiles follow CNS 10631 R2172 with average water absorption less than 6% and Japanese Industrial Standards (JIS) A5209 with average water absorption less than 5%. Above 1000°C, the open porosity (as well as the water absorption) abruptly decreases from 39.4% to 2.6% (Toledo et al., 2004). The average water absorption for finished tile products is 2.58% with test data shown in Table 4.

**Color**

Regardless of its natural color, clay rich in iron burns red when exposed to an oxidizing flame, due to the formation of ferrous oxide, and due to the valence state of iron influenced by the firing conditions (Khan, 1998). The color is essentially the result of reactions of minerals present in a particular clay blend, when fired at high temperatures (Borchelt, 2002). Murad and Wagner (1998) detected red color of clay material up to a firing temperature of 800°C. Brick makers can influence the color by changing the atmosphere in the kiln; by reducing the oxygen content, a darker brick is produced which under normal conditions turns to a light red brick. Creating a reducing atmosphere in the kiln is known as “flashing” (Karaman et al., 2006). Color is considered more important in this case. The mimic finished products are in line with the original Governor’s Office tile in color.

**Other Major Standards**

Firing temperature is an important factor affecting the strength of the bricks. The compressive strength slightly increased with increasing temperature as the firing temperature gradually increased from 700 to 1050°C, and the increase became more pronounced as the temperature further increased. The increase in compressive strength against rising temperature was relatively slow up to around 950°C, due to vitrification of the clay material (Table 5) (Karaman et al., 2006).

The main minerals virtually fused after the adobes had been baked at a high temperature of 1170°C. The water absorption of the finished products can be consequently reduced with no influence on quality due to weather change. Its modulus of rupture is in line with the standard 204 kgf/cm² of CNS 10631 R2172 with the test results reaching 510 kgf/cm².

Thermal shock-resistance test results are in line with the no-crack standards of CNS 3299 R3071. The chemical resistance of glaze acid and chemical resistance of glaze alkaline test results is in line with no falling off and no fading of color. Therefore, the mimic tile is fully in accordance with relevant materials with a smooth surface and can be applied on exterior and interior walls.

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**Figure 9:** Curve of temperature.

**Figure 10:** Curve of temperature by firing twice.
Table 4: Water absorption.

<table>
<thead>
<tr>
<th>No.</th>
<th>Water absorption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.60</td>
</tr>
<tr>
<td>2</td>
<td>2.71</td>
</tr>
<tr>
<td>3</td>
<td>2.39</td>
</tr>
<tr>
<td>4</td>
<td>2.42</td>
</tr>
<tr>
<td>5</td>
<td>2.75</td>
</tr>
<tr>
<td>6</td>
<td>2.63</td>
</tr>
<tr>
<td>Average</td>
<td>2.58</td>
</tr>
</tbody>
</table>

Tile Production Defect Rate

The defect rate in the first batch reached as high as 30% and was finally reduced to nearly 10% after 15 days of improvement and tests with an average defect rate of 11.2%. Responsible personnel in the construction field eliminate those finished products with discordant colors, damage during transport, granulated and rough surfaces through selection and testing. The defect rates for applied finished products are shown in Table 6.

Conclusions

The red unglazed tiles on the exterior walls are the most important material in this renovation project. Tile production had ceased in 1935. The traditional manufacturing technology has been lost for years in Taiwan and Japan. The replacement tiles ceased in 1935. The traditional manufacturing technology

Table 5: Compressive strength values obtained at various firing temperatures (Karaman et al., 2006)

<table>
<thead>
<tr>
<th>Firing temperature (°C)</th>
<th>Min. (kg/cm²)</th>
<th>Max. (kg/cm²)</th>
<th>Mean (kg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>700</td>
<td>87.94</td>
<td>106.89</td>
<td>96.91</td>
</tr>
<tr>
<td>750</td>
<td>94.97</td>
<td>106.69</td>
<td>104.86</td>
</tr>
<tr>
<td>800</td>
<td>99.97</td>
<td>123.91</td>
<td>113.93</td>
</tr>
<tr>
<td>850</td>
<td>118.92</td>
<td>143.88</td>
<td>129.92</td>
</tr>
<tr>
<td>900</td>
<td>144.90</td>
<td>155.91</td>
<td>149.90</td>
</tr>
<tr>
<td>950</td>
<td>182.91</td>
<td>231.83</td>
<td>203.90</td>
</tr>
<tr>
<td>1000</td>
<td>294.80</td>
<td>325.78</td>
<td>308.96</td>
</tr>
<tr>
<td>1050</td>
<td>417.69</td>
<td>551.59</td>
<td>453.66</td>
</tr>
</tbody>
</table>

Table 6: Tile defect rate.

<table>
<thead>
<tr>
<th>Adobe (pieces) (a)</th>
<th>Qualified products out of the kiln (pieces) (b)</th>
<th>Defect rate of kiln-dry (%) (c)=100 (a-b)/a</th>
<th>Finished products for application (pieces) (d)</th>
<th>Unqualified finished product (pieces) (e)</th>
<th>Defect rate for applied products (%) (f)=(e/d)*100</th>
</tr>
</thead>
<tbody>
<tr>
<td>29,803</td>
<td>26,465</td>
<td>11.2%</td>
<td>26,400</td>
<td>2,302</td>
<td>8.72%</td>
</tr>
</tbody>
</table>

The research found that the most important factors for remaking the tiles successfully were:

i. Firing temperature
ii. Reconstruction of manufacturing technologies
iii. Firing improvement (firing twice)

Due to the unevenly distributed heat sources within the kiln in the tile firing process, adobes in various areas of the kiln may be heated unevenly. To make the heating more even and to reduce the number in each kiln production, the following improvements can be adopted based on the initial studies:

- Improve the layout pattern of resistors in the kiln and enlarge the resistor to make the heat sources even
- Search for a new clay source to lower the cost and water absorption of finished tiles

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References


