Journal of Manufacturing Science and Mechanical Engineering
Print ISSN: 2959-9881
Online ISSN: 2959-989X
DOI: https://doi.org/10.61784/msme3023

INDUSTRIALIZED PRODUCTION TECHNOLOGY FOR LARGE-SCALE CORRUGATED THREE-DIMENSIONAL ARCHITECTURAL GLASS (LIULI) CURTAIN WALLS

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Abstract: Based on the project background of the China Beijing–Hangzhou Grand Canal Museum, and in response to the novel requirement of transitioning LIULI (traditional Chinese architectural glass) from interior decorative objects to building curtain wall applications, this paper presents a systematic summary of the industrialized manufacturing process for architectural LIULI. The objective is to establish a feasible, full-process, high-quality industrialized production methodology for large-scale corrugated three-dimensional LIULI composite curtain wall products, thereby filling the application gap of LIULI in the field of architectural curtain walls. A complete industrial production–processing–inspection pipeline for such products is established for the first time, covering the entire workflow from "raw material mixing → melting → casting → flipping and demolding → annealing → three-stage inspection → mechanical grinding of the back surface → fine grinding of the corrugated surface → cleaning → laminating → acceptance → packaging → transportation → frame assembly." This work successfully advances LIULI craftsmanship from decorative articles to architectural curtain wall technology, achieving an innovative integration of traditional culture and modern building functions.
Keywords: Large-scale corrugated three-dimensional; LIULI composite curtain wall product; Full-process; Industrialized production

1 INTRODUCTION

Glass, as an artificial material, first appeared in Central Asia and Egypt around 2500 BC. But this material was not applied to architecture until it was used in the stained glass windows of Gothic churches and cathedrals. Glass was gradually and widely used in architecture after the Middle Ages. During the Industrial Revolution of the 19th century, a new technology for producing glass panes was first introduced. The completion of the Crystal Palace in London in 1851 could be regarded as a turning point in the development of architecture. The building constructed for the World's Fair was made of glass on an unprecedented scale [1].

Figure 1 Works of Chinese LIULI (Colored Glaze) Craftsmanship [2]
(a) Lotus Pond Moonlight Series of Works; (b) Chicken Fat Yellow Engraved Snuff Bottle; (c) Lotus Breeze and Clear Rhyme Series of Works; (d) Lunar Colored Glaze Lamp

Colored glaze, as one of the appellations for ancient Chinese glass, was also a variety of artistic glass in modern times. From the discovery of colored glaze precursors in the Western Zhou Dynasty to its peak during the Kangxi and Qianlong periods of the Qing Dynasty, China had a long history of colored glaze manufacturing. At that time, it not only inherited the traditions of ancient colored glaze but also continuously innovated according to modern trends, inheriting from innovation, thus forming the subsequent long-term development [3]. The earliest colored glaze was made by the ancestors using local raw materials, and the formula was somewhat accidental. After accumulating experience and obtaining the mature formula, products with the required performance could be mass produced. With the advancement of science, analytical testing techniques were used to analyze formulas and raw materials, resulting in the formation of experimental components. Up to that era, Boshan-produced colored glaze was the most representative of China, and it was known as the "Hometown of Chinese LIULI (Colored Glaze)". Its series of works gained a high reputation both domestically and internationally (Figure 1) [3]. Its colored glaze firing technique was officially awarded the "National Intangible Cultural Heritage".

In recent decades, glass had been used by architectural engineers in non-traditional forms. In addition to its traditional uses as a window to make the inside and outside of a building visible and to introduce light, glass was increasingly becoming a medium for artistic expression rather than just an architectural material [4-6]. Terms such as "beyond transparency" had been used to describe architectural visions with a more extensive use of glass. The simplest and most widespread use of glass in architecture was as a curtain wall. Typically, transparent glass panels were suspended on aluminum alloy or stainless steel metal frames to form the building facade enclosure structure, but they did not bear the structural loads of the architecture itself. Glass was also used for internal partition walls and architectural decoration. Architectural glass was usually of the safety type. Tempered glass and laminated glass were commonly used in the curtain wall. From the all-glass architectures in New York, Beijing and Shanghai, to the glass facades of iconic architectures and airport terminals around the world (Figure 2), and then to tourist attractions such as the Zhangjiajie Grand Canyon Glass Bridge, glass had witnessed rapid progress in the field of architecture [7]. In addition, in other buildings, such as Apple Stores, glass was also used as a structural load-bearing material in the form of blocks [8].

Figure 2 Typical Glass Curtain Wall Architectures [7]
(a) Shard, London; (b) Shanghai Central Business District; (c) Shanghai Tower; (d) Jewel Changi Airport, Singapore; (e) Apple Store on Fifth Avenue, New York

In the field of building engineering, LIULI has thus far been used exclusively for roof decoration and interior ornamentation. Representative examples include the glazed tile roofs of the Beijing Cultural Palace of Nationalities and the National Library of China, as well as the Tang tri-color (Sancai) ceramic columns inside the Xi'an Metro Zhonglou Station [9]. For the new Nanjing Porcelain Tower, the outward-cantilevered wing slabs of the tower are encapsulated with ultra-clear (low-iron) glass [10]. The inner glass panels undergo a series of processes—pattern etching, hand glazing, and high-temperature firing—to achieve the tower's distinctive glazed wing appearance, see Figure 3.

(a) Glazed Tile Roof of the Beijing Cultural Palace of Nationalities

(b) Liuli Column Decoration at Xi'an Metro Zhonglou Station

(c) Glazed Tower Wings of the New Nanjing Porcelain Tower

Figure 3 Decorative Applications of Liuli Products in Building Engineering [9-10]

In summary, this paper reviews the origin and evolution of glass materials both domestically and internationally, and conducts a comparative analysis of glass material classifications, casting processes, and mold selection. It is found that glass materials are gradually shifting from traditional decorative crafts to functional products for modern architecture. With the rapid development of contemporary society, glass is achieving an ingenious integration of traditional culture and building functions. However, despite its distinctive cultural and artistic characteristics, Chinese LIULI materials have thus far remained confined to craft artworks, with no involvement in the field of modern building functions. Based on the project background of the China Beijing–Hangzhou Grand Canal Museum, and considering that this LIULI product is applied to a building curtain wall on a large scale for the first time, no domestic or international manufacturer can currently provide off-the-shelf products that meet safety and stability requirements. Therefore, this paper addresses key challenges in outdoor LIULI production processes and assembly techniques, with the aim of establishing a complete and mature industrial production line for LIULI composite curtain wall products, thereby filling the application gap of LIULI in the field of architectural curtain walls.

2 PROJECT OVERVIEW

The Beijing–Hangzhou Grand Canal Museum of China is one of the cultural protection and inheritance projects during the 14th Five Year Plan period of the National Development and Reform Commission. It has been incorporated into the national construction plan of the Grand Canal National Cultural Park, which is of great significance for promoting the culture of the Grand Canal, improving the heritage protection system, enhancing urban cultural construction and comprehensive supporting service capabilities. This project reflects the important heritage level status of the Grand Canal in China's cultural and natural landscapes, with the design concept being "a museum reflecting the canal". Among them, the innovative concept of the "water reflecting facade" is applied to the exhibition hall of the podium building. For the first time, Chinese LIULI (Colored Glaze) is applied as a curtain wall material to the exterior facade of a architecture. The entire curtain wall is ingeniously pieced together from 7240 blue non-uniform thickness water-wave colored glaze composite panels. The total area reaches 17800m², each piece has a size of 1.0×2.5m, and each piece weighs 350kg. It aims to achieve the visual aesthetic image of "water waves shining and reflecting". In addition, large-sized non-uniform thickness water-wave colored glaze has extremely high requirements for the control of the finish texture and the quality of primary forming during the preparation process. (Figure 4)

Figure 4 Rendering of the Colored Glaze Curtain Wall of the Architecture
(a) Overall Effect; (b) Local Effect; (c) Detailed Effect

3 CONSTRUCTION OF LARGE-SCALE NON-UNIFORM-THICKNESS CORRUGATED LIULI COMPOSITE PANELS

The corrugated Liuli panel features a long edge of 2500mm and a short edge of 1000mm, with the four corner heights measuring 130mm, 110mm, 50mm, and 45mm, respectively. The long edges follow a curved profile dictated by the geometric design. The upper surface exhibits a ripple-textured relief with a characteristic "cat's paw" pattern. The LIULI body is composed of No. 6 borosilicate mixed batch and presents an overall blue hue. Thorough annealing is performed during fabrication to eliminate residual stresses, ensuring smooth and straight edges. A cast flange is integrated on the bottom rear face of the main panel to facilitate mechanical fixing. The lower surface of the LIULI is finished to be perfectly flat, serving as the substrate for laminating with float glass. A double layer of 10 mm thick heat-strengthened glass is bonded to the rear face of the LIULI to ensure outdoor safety. These glass layers are laminated together using PVE-S interlayers with thicknesses of 2.28 mm and 1.52 mm, respectively (Figure 5).

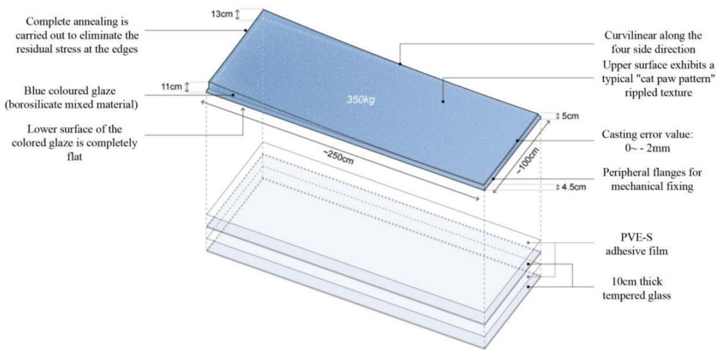

Figure 5 Construction Detail of the Large-Scale Corrugated Three-Dimensional LIULI Composite Panel

The LIULI composite panel is assembled within a precision-fabricated aluminum alloy frame on all four sides. Shims are inserted at the perimeter and sealed with structural silicone sealant to secure the panel within the frame. A bug screen and a backing plate are installed on the rear side of the aluminum frame. Along each long edge, two 16mm thick stainless steel edge protectors are mechanically fixed; along each short edge, one protector is centered. According to the spatial geometry and varying elevation requirements of the LIULI curtain wall, steel hanging-ear connectors are pre-installed onto the aluminum frame (Figure 6).

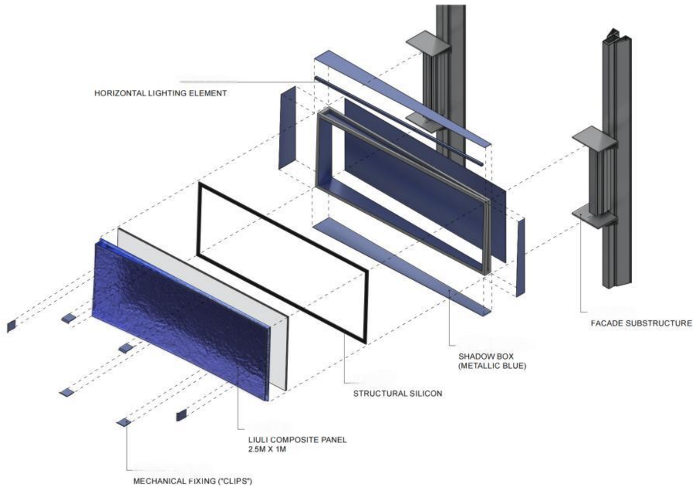

Figure 6 Construction Detail of the Large-Scale Corrugated Three-Dimensional LIULI Composite Curtain Wall Unit

4 INDUSTRIALIZED FABRICATION OF LARGE-SCALE CORRUGATED THREE-DIMENSIONAL LIULI COMPOSITE PANELS

The fabrication of large-scale corrugated LIULI panels (panel area: 2.5m²; mass: 35 kg) presents significant challenges, including difficulties in surface texture control, stringent requirements for one-time forming quality, and high safety grade demands. To address these issues, a flow-casting one-time forming process for LIULI firing was adopted. A full-process, high-quality industrialized production and machining workflow was established, covering "raw material mixing → melting → casting → flipping and demolding → annealing → three-stage inspection → mechanical grinding of the back surface → fine grinding of the corrugated surface → cleaning → laminating → acceptance → packaging → transportation" (Figure 7).

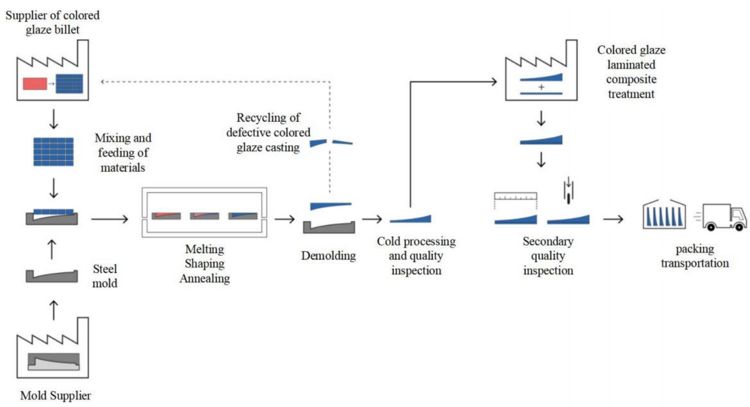

Figure 7 Production Schematic of Large-Sized Non-Uniform Thickness Water-Wave Colored Glaze Composite Panel

4.1 Production Preparation

The industrial production line of water-wave colored glaze composite panel involves a variety of equipment. It mainly includes double acting mixing blender, vertical cold top electric melting furnace, large scale casting and molding equipment, hydraulic turning table, 135m tunnel annealing kiln, full automatic water spraying testing machine, glass stress tester, full automatic glass edging machine, and laminating furnace. The models and performances of various devices are shown in Table 1.

Table 1 Production Line Devices and Performance Parameters

Name	Schematic diagram	Models and specifications	Quantity	Power	Core parameters
Double acting mixing blender		7000L; Gravitational diffusion + shear mixing	2	15kW	Daily output: ≥ 25.5t; Coefficient of variation of mixing uniformity: ≤ 7%
Vertical cold top electric melting furnace		Dodecagon; Vertical melting	2	1080 KVA	Daily melting capacity: 25.5t; Melting temperature: 1680 °C
Large scale casting and molding equipment		Multi-axis linkage of XYZ	2	5kW	X-direction: ±400mm; Y-direction: 9m; Z-direction: 0-500mm
Hydraulic turning table		FZ-10T; Maximum load - bearing capacity: 10t	1	14kW	Flipping speed: 10°/s; Clamping force: 6kN
135m tunnel annealing kiln		34-stage temperature control; Track type trolley	2	450 kW/line	Temperature control accuracy: ±2°C; Speed of track trolley: 0.5m/min
Full automatic water spraying testing machine		MDSS1000	2	0.5kW	Spraying pressure: 0.3MPa; Time: 3min
Glass stress tester		BLY-06	2	0.5kW	Detection range: 0-100MPa; Accuracy: ±0.5MPa
Full automatic glass edging machine		2645×8; 2030×3; 2080×4; 6016×1; 3019×2	18	20kW	Diameter of grinding wheel: 138mm; Flatness: ≤ 0.01mm/m
Laminating furnace		5.6m×2.7m×4; 2.7m×2.7m×1	5	98k W/set	Temperature control accuracy: ±2°C; 135 °C constant temperature: 6h

The raw materials include colored glaze billet, colorant, 10mm thick tempered glass, and PVE-S adhesive film. Among them, the colored glaze billet is a low expansion borosilicate material. The formulation of the colored glaze billet is shown in Table 2.

Table 2 Formulation of the Colored Glaze Billet (2000kg/batch)

Material Name	Specification requirements	Quantity (kg/batch)
Quartz sand	SiO_2: ≥ 99.5%; Fe_2O_3: ≤ 0.014%; Particle size: 0.1-0.3mm	1306
Aluminum hydroxide	Purity: ≥ 99%; Iron content: ≤ 20ppm; SO_4^{2-}: ≤ 0.01%; Particle size: ≤ 0.1mm	131
Soda ash	Na_2CO_3: ≥ 99.5%; NaCl: ≤ 0.3%; Iron content: ≤ 20ppm; Particle size: ≤ 0.5mm	91
Boric acid	B_2O_3: ≥ 56.2 %; Iron content: ≤ 20ppm; SO_4^{2-}: ≤ 0.01%; Particle size: 0-1mm > 96%	170
Colorant	Purity: ≥ 99%; Particle size: ≤ 10μm	0.1
Minor materials	/	302

4.2 Industrial Production Processes

4.2.1 Mixing and melting materials

The formula weighing of the colored glaze billet is carried out in 2000kg/batch, and the precision is controlled within ±0.05kg. The weighed ingredients are orderly put into the double acting mixing blender. The feeding sequence is quartz sand, boric acid, aluminum hydroxide, soda ash, minor materials, and colorant respectively. The total stirring time is 25min/batch. The liquid level of the blender is controlled at 30-40% to avoid the overflow of raw materials. The stirring should be extended and accelerated for 10-15min when the stirring shown an uneven state. (Figure 8(a))

The furnace should be pre-heated before the formal melting of the material, with rising from room temperature to 1680 °C. The mixture is fed uniformly at a rate of 1000kg/h by an automatic feeder to ensure that the raw materials are in small pile form (diameter: ≤ 1m). The colored glaze liquid is extracted every 2h with a heat resistant steel spoon (500ml) at a furnace temperature of 1680℃. It is necessary to observe whether there are unmelted particles after cooling. The melt is judged to be qualified when the number of bubbles is ≤ 2 per/100ml. At this time, the valve of the liquid flowing groove can be opened to allow the colored glaze liquid to flow into the discharge tank. (Figure 8(b))

Figure 8 Mixing and Melting Materials (a) Mixing Materials; (b) Melting Materials

4.2.2 Discharging and casting, turning over and demolding

Before the colored glaze liquid flows out, the discharge tank is pre-heated to 1400-1500°C, and the launder is pre-heated to 1430°C. At this time, the molten liquid is introduced into the discharge tank through the launder, and the liquid level height is controlled (±2mm) by sensors. The molten liquid is stored at a constant temperature (≤6h) in the discharge tank, and the temperature is controlled at 1430±5°C. The temperature of the colored glaze liquid is detected once every 1h. Auxiliary heating measures should be initiated when the temperature was lower than the constant temperature value. During the discharging process, the feeding valve is controlled to ensure that the discharging and casting speed is controlled at 115kg/min.

Decorative textures are imparted to the surface of the colored glaze panel by using the Maya ocean simulation system. The large panel model is milled at full scale ratio (1:1) using 3D printing technology. Furthermore, nodular cast iron is adopted to prepare a corrugated three dimensional mold (HT300 with water-wave texture, and the error is ≤ 0.3mm). The steel mold is heated to 400°C (temperature difference at three points is ≤ ±1℃) before formal casting. The position of the mold is adjusted by the XYZ multi-axis linkage in the large scale casting and molding equipment, and is aligned with the discharge port, with a positioning error ≤ 0.08mm. The colored glaze liquid (at 1430℃) is injected into the steel mold at a uniform speed of 115kg/min, and the casting sequence is from deep to shallow. The upper cover plate is closed for die casting when the molten solution has cooled down to 600℃. The mold is hoisted to the hydraulic turning table, turned over 180° at a speed of 10°/s, and stays for 15s. Subsequently, the turning table is reset and the fixture is released. The colored glaze panel is demolded and transferred to the inlet of the annealing furnace (580℃). (Figure 9)

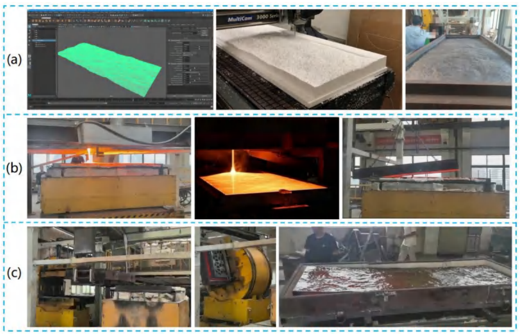

Figure 9 Discharging and Casting, Turning Over and Demolding

(a) Preparation of Steel Mold; (b) Discharging and Casting; (c) Turning Over and Demolding

4.2.3 Annealing and three stage inspection

The colored glaze panels are centrally placed on the track type trolley of the 135m tunnel annealing kiln through the driving track (0.5m/min), and the plate to plate distance is ≥ 5m. The annealing kiln is divided into 34 levels for temperature control. The temperature gradually and steadily decreases from 580℃ to 50℃, with a cooling rate of ≤ 5℃/h and a temperature difference in the kiln of ≤ ±2℃. (Figure 10(a))

After the annealing cooling of the colored glaze panel to 50℃, the product is first placed in a full automatic water spraying testing machine and spray it with a pressure of 0.3MPa for 180s. If the colored glaze has no leakage, no cracks, and the surface moisture content is ≤ 0.1%, the water spraying test of the product shall be judged as qualified. Furthermore, six measuring points are selected at the four corners and the center of the colored glaze panel by using a stress meter, and the internal stress is detected by laser. The stress test of the product is determined to be qualified when the stress at each point was ≤ 2MPa and the deviation of a single point was ≤ ±0.5MPa. Finally, the colored glaze panel is fixed on the shaking table and vibrated and vibrate it for 10min with a frequency of 50Hz and a vibration force of 55kg. If the colored glaze panel has no cracks and no deformation, the product is determined to be qualified in the seismic resistance test. (Figure 10(b))

Figure 10 Annealing and Three Stage Inspection
(a) Annealing; (b) Three Stage Inspection

4.2.4 Machine grinding back surface and fine grinding corrugated surface

First, an 80# diamond grinding wheel (3000r/min) is used to grind the back of the qualified products by 0.8mm to remove the mold residues. Secondly, a 120# diamond grinding wheel (2500r/min) is used to grind continuously by 0.2-0.3mm to improve the flatness. Three diagonals on the colored glaze panel are randomly selected. If the flatness is all ≤ 0.1mm/m, the machine grinding shall be regarded as qualified. For the corrugated surface of the colored glaze panel, 40# emery is first used for sand blasting and rough grinding. Then, manual fine grinding is carried out using a 240# emery. (Figure 11)

Figure 11 Machine Grinding Back Surface and Fine Grinding Corrugated Surface
(a) Machine Grinding Back Surface; (b) Fine Grinding Corrugated Surface

4.2.5 Cleaning and laminating

The cleaning process of the colored glaze panel is divided into pre-washing, main washing, rinsing and drying. Among them, both pre-washing and rinsing are carried out by flushing with a high pressure water gun. The cleaning solution (98% alcohol) is sprayed on the surface of the product for main washing and is cleaned by manual scrubbing. (Figure 12(a))

To enhance the safety and stability of the water-wave colored glaze for architectural curtain wall, double layer 10mm tempered glass is attached to back side of panel and bonded and compounded through PVE-S adhesive film. Before the formal lamination, the back side of panel and lamination surface of the tempered glass are wiped and cleaned with alcohol (surface cleanliness: Class 10000) and dried with a high pressure air gun. The product is stacked in the order of "colored glaze panel→three layer PVE-S adhesive film (2.28mm)→10mm tempered glass (tin free side)→two layer PVE-S adhesive film (1.52mm)→10mm tempered glass (tin free side)". And 3cm perforated adhesive tape is used to fix the edges. The laminated product is placed in a 1.1×2.7m vacuum bag for encapsulation. It is evacuated to 0.1MPa and maintains the pressure for 180min without leakage. Furthermore, the laminated product is placed into the laminating furnace. The tempered glass surface faces upward, and the colored glaze panel faces downward, and the vacuum state (-0.1MPa) should be continuously maintained. The lamination process is carried out for thermo forming strictly in accordance with the heating procedure of "35℃ (= 2h)→60℃ (↑2h)→90℃ (↑2h)→110℃ (↑3h)→135℃ (↑2h)→135℃ (= 6h)→30℃ (↓8h)". The colored glaze composite panel is taken out under pressure relief after the lamination was completed. Whether there are bubbles and delamination phenomena between layers is checked (illuminance for out of oven detection: 5000±500lux; peel strength: ≥ 45N/cm). Furthermore, the residual PVE-S adhesive film at the edge is removed. The dust on the product surface is cleaned by spraying alcohol (surface cleanliness: Class 100). (Figure 12(b))

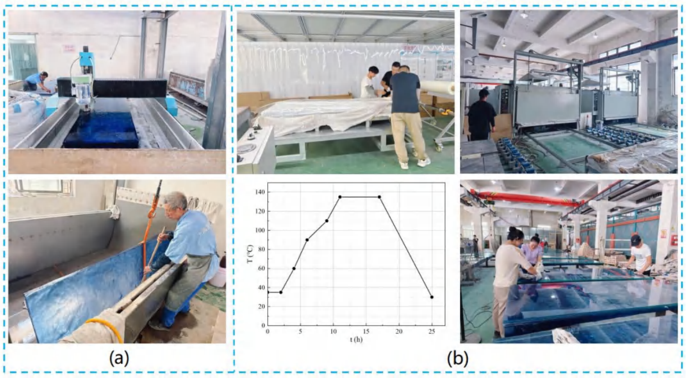

Figure 12 Cleaning and Laminating
(a) Cleaning; (b) Laminating

4.2.6 Acceptance inspection, packing and transportation

Its dimensions, appearance, and properties are tested after the colored glaze composite board was formed. It is required that the thickness deviation should be within the range of ±3mm, and the length deviation should be within the range of +5~-7mm. The compressive strength shall be ≥ 100MPa, and there shall be no cracking under the heat shock condition from 75℃ to 25℃. The number of bubbles with a diameter of 0.5-3mm inside the glazed composite board should be ≤ 15 per/m². It shall be wrapped with two layers of 0.05mm bubble wrap for internal protection after the product had been inspected and found to be qualified. And 5mm triangular cardboard is used for the protection of the outer edges. Finally, every five pieces of products are placed on a prefabricated shelf for off site transportation. (Figure 13)

Figure 13 Acceptance Inspection, Packing and Transportation

4.3 Industrialized Fabrication of LIULI Composite Curtain Wall Units

Upon passing acceptance inspection, the LIULI composite panels proceed to the framing stage. The workflow includes: aluminum profile frame processing and assembly → panel-to-frame alignment and fixation → structural sealant application → accessory installation (stainless steel edge protectors, bug screens, backing plates) → self-inspection and re-inspection → finished product handover.

4.3.1 Aluminum profile frame processing and assembly

The primary frame utilizes 60×60×5mm aluminum square tubes, while the auxiliary frame consists of L50×5 equal-leg angle steel. The aluminum profiles are stamped into shape using a punch press according to specified dimensions. For each LIULI composite curtain wall unit with a unique identification code, stainless steel hanging-ear connectors are stamped to match the architectural geometry and varying elevation requirements at the four corners. These connectors are then bolted to designated positions on the aluminum frame. The bolt strength grade is required to be ≥ Grade 8.8, and the flatness tolerance of the hanging-ear connectors must be ≤0.5 mm (Figure 14).

(a) Stamping of the Aluminum Profile Frame

(b) Stamping of the Stainless Steel Hanging-Ear Connector

(c) Installation of the Stainless Steel Hanging-Ear Connector

(d) Assembled Aluminum Profile Frame (with QR Code Identification)

Figure 14 Processing and Assembly of the Aluminum Profile Frame

4.3.2 Panel-to-frame alignment and fixation, structural sealant application

After the aluminum alloy frame is assembled, xylene/MEK cleaning agents are used to effectively remove oil stains and dust from the profile surfaces. The LIULI composite panel is secured to the frame using 8 mm T-shaped stainless steel plates. Along the perimeter, EPDM rubber strips are cut to match the profile lengths (the strip length is ≤100mm shorter than the profile to accommodate shrinkage). The strips are pressed into the profile grooves to ensure gap-free contact. Waterproof sealant is applied to the end faces of horizontal members and screw holes (sealant layer thickness: 2–3mm). With the LIULI decorative face oriented outward, the panel is aligned with the frame hanging points. Its position is adjusted to maintain a hole-position deviation of ≤1mm, ensuring proper texture alignment. A pneumatic caulking gun is then used to apply structural sealant along the joints. The sealant bead width is controlled at 5–6mm (in compliance with a +1.0/0mm tolerance). A finishing tool is used to smooth the bead, ensuring no voids or discontinuities (Figure 15).

(a) Alignment and Fixation

(b) Structural Sealant Application

Figure 15 Panel-to-Frame Alignment and Fixation, Structural Sealant Application

4.3.3 Accessory installation (stainless steel edge protectors, bug screens, backing plates)

The 16mm thick stainless steel edge protectors are fastened to the aluminum frame using six M8 stainless steel blind rivets per protector. Rubber gaskets are placed between the LIULI panel and the edge protectors to prevent edge spalling or cracking caused by compressive stress. The bug screen is first bonded to the backing plate, which is then secured to the bottom of the aluminum frame with screws, with the screen facing inward (Figure 16).

(a) Installation of Stainless Steel Edge Protectors

(b) Installation of Backing Plates

Figure 16 Accessory Installation (Stainless Steel Edge Protectors, Bug Screens, Backing Plates)

4.3.4 Self-inspection, re-inspection, and finished product handover

Self-inspection covers frame dimensions, sealant beads, and accessory positions. Upon passing self-inspection, re-inspection is conducted on hanging-point accuracy (deviation $\leq \pm 1.0$mm) and sealant integrity (confirmed by water spray testing with no leakage). After re-inspection approval, the Liuli composite curtain wall units are packaged (with the unique identification code verified), horizontally placed on dedicated transport racks, and prepared for handover and transportation (Figure 17).

(a)

(b)

Figure 17 Finished Product Stacking

5 CONCLUSION

Based on the project background of the China Beijing–Hangzhou Grand Canal Museum, and in response to the novel requirement of transitioning LIULI from interior decorative objects to building curtain wall applications, this paper presents a systematic summary of the industrialized manufacturing process for architectural LIULI. The study successfully establishes the world's first complete industrial production–processing–inspection pipeline for LIULI composite curtain wall units, and develops a full-process, high-quality manufacturing workflow covering "batch preparation → melting → discharging → casting → shaping → annealing → inspection → grinding → laminating → acceptance → framing". This work advances LIULI craftsmanship from decorative articles to architectural products, achieving an innovative integration of traditional culture and modern building functions.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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