The Innovative Application of Aluminium Alloy Formwork in Construction----A Case Study of the Great Bay University's (Dongguan) Construction Site

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Abstract. As the construction industry developed trends towards high-quality and small-scale, building construction technology also advances to a stage where efficiency and quality coexist. Traditional concrete formwork has disadvantages such as non-reusable systems, lack of precision, and inefficiency, etc. The research objective is to analyse the construction methods using aluminium formwork system, incorporating an innovative method of casting the primary and secondary structures simultaneously within the formwork system. The research will also critically analyse aluminium formwork techniques and conduct a case study of aluminium formwork construction in the apartment building at the Great Bay University (Dongguan) construction site. Aluminium formwork technology aligns with modern construction requirements of efficiency, sustainability, and quality, positioning it as a promising new construction technique with future potential and application prospects in construction projects.

Keywords: Aluminium Alloy Formwork, Construction Technological Innovation, Sustainable Development

1 Introduction

Aluminium formwork is a new formwork system of housing construction that first appeared in the United States in 1962 by Canadian engineer W. J. Malone[1]. Initially, this construction method entered the market to improve construction efficiency. However, the system is only used for some mass housing projects[2]. One of the main reasons for the under adoption was the excessive cost of raw aluminium in the 20th century. According to data from the Chinese aluminium association, compared with less than two million tons of Chinese annual aluminium production in 2001[3], this value increased to 41.6 million tons in 2023[4]. The price of aluminium in China had decreased to 2600 dollars per ton in 2024, making the aluminium formwork economically viable in building construction[5]. China had become the world's largest producer of aluminium since 2004[6]. On the other hand, according to the data provided by the China Population Census in 2010, the total population of China was approximately 1.34

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billion[7]. The high population density results in a high demand for residential buildings. Therefore, a more efficient and sustainable construction method is required to replace the traditional timber framework.

The research objective is to analyse the advantages and disadvantages of the aluminium formwork system, combined with the actual on-site performance of the dormitory building at the Great Bay University (Dongguan). It will also consider the possibility of future development evaluation.

2 Overview of Aluminium Formwork Technology

Aluminium formwork is a new type of formwork system for concrete casting, it has advantages such as high precision, high construction efficiency, sustainability, and cost efficiency, etc. However, the system also contains disadvantages such as high initial investment, only being suitable for mass building, less flexibility, etc. Aluminium formwork production primarily involves the mechanical extrusion, casting, and welding of 6061 T6 or 6063 T6 aluminium materials[8]. The mechanical production process heavily relies on computer modelling to enhance the precision of this concrete casting system.

2.1 The Application of Aluminium Formwork in China

In China, the building that uses the aluminium formwork system was first successfully constructed in Shenzhen in 2008 by Southern Construction Investment Co. Ltd (CSCEC)[9]. Even though there were successful experiences with aluminium formwork in the early 21st century, it did not receive significant spreading in China until 2017 due to its high production costs and less developed construction technology. To meet the regulation for carbon emissions, construction industries began using more environmentally friendly construction materials, which led to a significant increase in the usage of aluminium alloy formwork in China[10].

2.2 Innovations in Construction Methods Brought by Aluminium Formwork

Aluminium formwork dramatically improves construction efficiency by reducing the cutting associated with traditional timber formwork manufacture. However, enhancing efficiency requires more than maintaining existing building methods and pouring techniques. In factories with high-precision equipment, aluminium formwork involves processing high-strength, corrosion-resistant, and weldable aluminium panels through punching, welding, and cutting[11]. High-quality aluminium panels result in extremely precise formwork, achieving finishes suitable for blank concrete facades[12]. As a result, building designers have innovated by allowing for the simultaneous construction of the primary and secondary structures, transforming traditional two-stage pouring into a single-stage process.

Traditionally, building construction begins with the primary structure (comprising load-bearing elements such as beams, columns, floor slabs, and shear walls) and is followed by secondary structures (the non-load-bearing concrete such as upstand beam and reinforced concrete lintel, etc.) after the completion of primary structure[13]. Traditional timber formwork systems depend highly on manual cutting skills, resulting in precision problems. However, the precision level for the aluminium formwork can achieve millimetre accuracy[14]. This integrated approach allows for the integration of primary and secondary structures to be poured simultaneously, significantly improves construction efficiency, lower the labour costs, and enhances construction quality.

2.3 End of Life Cycle for the Aluminium Alloy Formwork

Aluminium formwork is a sustainable construction material. Meanwhile, aluminium is relatively easier to recycle and reuse than timber, and the energy required of regenerating it is only 5% of its initial production cost[15]. After reaching its 300-use lifespan, aluminium formwork is transported to specialized aluminium recycling facilities, where any solidified concrete and other impurities are removed from the formwork panel's surface. The aluminium is then melted in high-temperature furnaces into liquid aluminium and recast into new aluminium formwork or other aluminium products[16]. Once the recycled aluminium material meets the required standards, it is reintegrated into the appropriate supply chains.

2.4 Future Perspective on the use of aluminium formwork in construction

As the industry prioritizes long life spans, efficiency, high quality, and environmental protection, the aluminium formwork has tremendous potential and advantages for the future. To maximize the reusability of aluminium components, aluminium formwork is ideal for two types of projects: high-rise dense buildings, where its high reuse rate can reduce costs, and communities with uniform designs for each building, where it can be extensively reused. A case study of a 27-story building (high-rise apartment building) in the Great Bay University (Dongguan) will be conducted to demonstrate the practical applications of aluminium formwork. Overall, as the construction sector evolves, aluminium formwork is set to expand its market presence and application prospects significantly.

3 A Case Study of The Great Bay University (Dongguan) Construction Site

3.1 Project Background

To meet the required number of educated talents for the Guangdong-Hong Kong-Macao Greater Bay Area's development and innovation, the Chinese Government introduced the Outline Development Plan of the Central Government and the State Council for the Guangdong-Hong Kong-Macao Greater Bay Area in 2019[17]. Additionally, the expected start date for enrolment at the Great Bay University is September 2024[17]. This short construction schedule has prompted the construction of twenty-eight floors within a 1.5-year construction period, with completion before the school's operations. The school's recruitment office requested the provision of 108 apartments (see Fig. 1). Each floor is designed to accommodate four apartments. Therefore, a construction method and tool capable of quickly completing the main structure of the buildings are required. After considering factors such as economy, environment, and construction efficiency, the architects decided to use aluminium alloy formwork to construct the main structure of the building.

Fig. 1. Design Overall Layout (Source: CSCEC) [18]

3.2 Construction Sequence

3.2.1 Preparation Work

Before construction starts, engineers are required to measure designated locations on each floor and check floor elevations based on the construction designs. It is also mandatory to count and verify the quantities of formwork, connectors, and support systems. Each formwork panel is labelled for easy identification. Finally, the construction workers apply a concrete release agent to facilitate disassembly.

3.2.2 Installation of Aluminium Formwork

Before installing the aluminium formwork, the steel reinforcement structure must be completed, and rebars from the previous floor reinforcement layer must be connected to new rebar positions based on the reinforcement plan. Provisions for cables, internet wires, and water pipes should include reserved holes in the concrete pour areas. Using construction design drawings and pre-drawn ground markings, the formwork is installed and connected to the specified location as the formwork of the concrete (see Figure 2).

Fig. 2. Aluminium Alloy Formwork Installation (Source: Author)

3.2.3 Casting Concrete

The casting step for the aluminium alloy formwork is similar to that of traditional formwork systems. Once the aluminium alloy formwork is installed, the mixed concrete can be transported to the construction site by truck. The concrete pump is required on the higher floor (see Figure 3).

Fig. 3. Pouring Concrete by using concrete pump (Source: Author)

3.2.4 Disassembled Aluminium Formwork

Before disassembling aluminium formwork, it's necessary to check the concrete's strength to ensure it can support its load. The safety check prevents structural instability and damage caused by premature formwork removal. During the disassembled process, non-load-bearing parts and the formwork of secondary structures should be removed first, followed by the disassembled of the load-bearing part formwork. Figure 4 shows the view of the reinforced concrete's final surface after disassembling. Finally, the support bars for the concrete should be removed 28 days after pouring, as the curing time for concrete is typically 28 days to reach its maximum hardness[19].

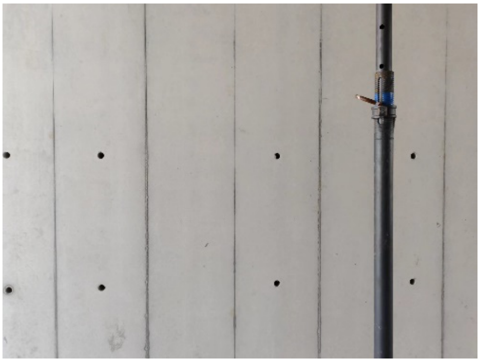

Fig. 4. Concrete Surface after Disassembly (Source: Author)

3.2.5 Pre-positioning of Holes before Casting

Finally, concrete structures built using aluminium formwork are required to have a hole reserved on the slab of each floor that facilitates the upward transfer of the aluminium components (see Figure 5). This hole allows workers to pass the disassembled aluminium formwork to the upward floor. This design reduces the over-dependence on construction equipment and lifts.

Fig. 5. Reserved Hole (Source: Author)

3.3 The Application of Aluminium Formwork on Construction

3.3.1 The Aluminium Formwork Improving the Construction Efficiency

The assembled and disassembled steps of aluminium formwork are efficient. Only construction workers who have undergone professional training need to install the formwork according to the design, which reduces the complexity at the construction site and transforms the building process into a systematic and standardized construction procedure. This approach saves 42% of the time in the concrete casting phases. Table 1 records the comparison between the construction time required for the floor 21st utilized the aluminium formwork system and the simulated construction log by using the timber formwork for the same amount of construction workload.

Table 1. Construction Log

Date	Construction Log Utilize Aluminium Formwork	Simulated Construction Log Utilize Timber Formwork
2023/6/1	**Floor 20th** Casting Completed **Floor 21st** Slab Marking Completed **Floor 21st** Vertical Steel Reinforcement Connection Completed	**Floor 20th** Casting Completed **Floor 21st** Slab Marking Completed **Floor 21st** Vertical Steel Reinforcement Connection Completed
2023/6/2	**Floor 21st** Wall and Column Steel Reinforcement Completed **Floor 20th** Aluminium Formwork Disassembled	**Floor 21st** Wall and Column Steel Reinforcement Completed **Floor 21st** Wooden Formwork Start Manufactured
2023/6/3	**Floor 21st** Aluminium Formwork Assembled 70% **Floor 21st** Beam Steel Reinforcement Completed	**Floor 21st** Beam Steel Reinforcement Completed **Floor 21st** Primary Structure Wooden Formwork Manufactured 50%
2023/6/4	**Floor 21st** Aluminium Formwork Assembled 90% **Floor 21st** Steel Reinforcement Trapped Beam 60%	**Floor 21st** Steel Reinforcement Trapped Beam 60% **Floor 21st** Primary Structure Wooden Formwork Manufactured 80%
2023/6/5	**Floor 21st** Steel Reinforcement Completed **Floor 21st** Aluminium Formwork Completed	**Floor 21st** Steel Reinforcement Completed **Floor 21st** Wooden Formwork for Primary Structure Cutting Completed
2023/6/6	**Floor 21st** Slab Steel Reinforcement Completed	**Floor 21st** Primary Structure Wooden Formwork Assembled 30% **Floor 21st** Slab Steel Reinforcement Completed **Floor 21st** Wooden Formwork Start Assembled
2023/6/7	**Floor 21st** Concrete Pouring Completed	**Floor 21st** Secondary Structure Wooden Formwork Cut 40% **Floor 21st** Wooden Formwork Assembled 60%
2023/6/8	The Attached Scaffolds Rise 3100 Millimetres	**Floor 21st** Secondary Structure Wooden Formwork Cut 80% **Floor 21st** Primary Structure Wooden Formwork Assembled Completed
2023/6/9	N/A	**Floor 21st** Primary Structure Concrete Pouring Completed **Floor 21st** Secondary Structure Wooden Formwork Cutting Completed

2023/6/10		**Floor 21st** Primary Structure Wooden Formwork Disassembled 60%
2023/6/11		**Floor 21st** Primary Structure Wooden Formwork Disassembling Completed **Floor 21st** Secondary Structure Wooden Formwork Assembled 50%
2023/6/12		**Floor 21st** Secondary Structure Wooden Formwork Assembling Completed **Floor 21st** Secondary Structure Concrete Pouring Completed
2023/6/13		**Floor 21st** Wooden Formwork Disassembling Completed
2023/6/14		The Attached Scaffolds Rise 3100 Millimetres

A shorter construction timeline can reduce the required labour hours for construction workers, thereby lowering labour costs. For instance, according to the construction logs for the apartment building at Great Bay University (Dongguan), the average number of construction workers on-site at the same time was 80s. More specifically, using aluminium formwork significantly enhances efficiency, particularly in constructing the loading structure of the building. This dramatically reduces the labour hours for technical supervisors, framework construction workers, steelwork workers, concrete workers, safety inspectors and quality inspectors involved in the loading structure. According to recorded data from the construction logs, 48s people were responsible for the main structure construction. In contrast, the estimated number of construction workers dedicated to the main structure might reach about 70s for a building of the same size using traditional formwork. Using aluminium formwork eliminates the dependence on on-site timber formwork manufacturing workers and significantly reduces the number of concrete finishers.

According to the construction log in Table 1, using aluminium formwork reduced the construction time by six days, saving 6(days)*22(NO. Workers) = 132 working days salary unit. The average labour cost per day is ¥800 (RMB). Therefore, the reduced labour cost of implementing the aluminium formwork for one story of the building is ¥800*132(Working Days) = ¥105,600 RMB (13.5% less).

3.3.2 High Precision

Aluminium formwork systems are precise and stable. The production of the aluminium panels, which have been cut and welded with high-precision instruments, results in a smooth surface that meets the standards of a blank concrete façade (see Fig. 6).

Fig. 6. Building after Disassembled all Aluminium Formwork (Source: Author)

3.3.3 Environmentally and Economical Effectively

Each aluminium formwork panel was used 27 times in the Great Bay University project. After construction, the aluminium formwork can be returned to the factory and reused for related projects. This reduces reliance on timber during construction and may decrease construction waste associated with the use of disposable materials.

3.4 Innovated Implication

The project's construction requirements emphasise high quality and high construction efficiency. Although the conventional aluminium formwork improved construction efficiency in assembling and manufacturing panels, it still involves two stages of concrete pouring separating the primary and secondary structures. This approach requires that the installation and pouring for secondary structures only commence after the primary structure is completed, suggesting significant potential for enhancing the efficient construction process. However, the innovation of The Great Bay University Project is using aluminium formwork by simultaneously casting both the primary and secondary structures. This method not only utilises the benefits of aluminium formwork but also introduces an innovative approach to its application.

Fig. 7. Secondary Structure (Source: Author)

This innovation demonstrates that the single pouring of concrete can also ensure stability. As shown in Fig. 7, casting the secondary and primary structures had no discontinuity problems between the junctions. Such innovative construction methods can significantly accelerate construction efficiency, finally achieving a construction period of one floor completion per week.

4 Conclusion

The completion of the apartment building of the Great Bay University project demonstrates a shift from traditional construction methods to more innovative and precise techniques. This approach allows for the one-time casting of concrete structures, reducing material waste, labour and maintenance costs, and construction time while improving efficiency and reusability. These benefits make aluminium formwork cost-effective and environmentally friendly, aligning with the government's sustainable development goals. However, the disadvantages of aluminium formwork are high initial costs, limited construction flexibility, etc. Although there exist some problems in the system, the significant advantages of aluminium formwork make the potential for growth in aluminium formwork remain substantial, indicating its likely increased adoption in the future construction projects.

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