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Material characterization of a multi-cavity composite structure for the bogie frame of urban maglev train

Kai Yao [a, e], Ying Yang [b], Huimin Li [c, **], Xiaobo Liu [b], Hongshuai Lei [a, *], Hualin Fan [d, ***], Daining Fang [a, c, ****]

[a] College of Engineering, Peking University, Beijing 100871, China
[b] CRRC Zhuzhou Electric Locomotive Co., Ltd., Zhuzhou 412001, China
[c] Research Institute of Advanced Structure Technology, Beijing Institute of Technology, Beijing 100081, China
[d] State Key Laboratory of Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China
[e] School of Civil Engineering, Beijing Jiaotong University, Beijing 100044, China

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ABSTRACT

Lightweight composite structure has been widely used in various applications such as aerospace, transportation, and marine. The aim of present paper was to design and fabricate a bogie frame composite element of urban maglev train. It was an attempt to use lightweight composite as the primary load carrying structure in rail transit. A combined mold which can be used in autoclave molding process was developed and a multi-cavity composite casting block was manufactured. Three-point bending test and finite element analysis (FEA) were respectively conducted to evaluate the static strength of this structure. The experimental results revealed that the glass fiber reinforced casting block could satisfy the load bearing requirement for application and the weight reduction was approximately 30.9% in contrast with the traditional metal material. Therefore, it was found that the lightweight composite has a significant potential as the load bearing structure for the rail transportation application.

1. Introduction

Lightweight composites have been widely used in many engineering fields for their advantages of high specific stiffness, high specific strength, corrosion resistance and easy manufacturing [1–9]. In comparison with aerospace, marine and automotive, the railway transit is perceived to have been slow in the adoption of composite materials. Meanwhile, weight reduction is a permanent issue in transport applications [10–13]. Using lightweight composite in transportation can help to reduce the overall weight and improve the fuel efficiency, which translates to long-term cost saving [13]. Therefore, it is urgently necessary to focus on the design and application of lightweight composite in railway transit.

In the past decade, lightweight composites have been adopted as secondary load bearing structure in transportation [12,14]. A recent report [15] showed that composite has been increasingly used as the main material in train as well as railway infrastructure constructions, including railway bridges [16], platforms, and sleepers. NPSP, a Dutch company, claimed that it has fabricated a new nose plated using glass fiber and foam, making it lighter and cheaper than the traditional steel noses. Belingardi et al. [17] designed a glass fiber reinforced composite polymeric foam sandwich structure which can be used as the front shield of high speed train. Fan et al. [18,19] fabricated an ultra-light hierarchical wind deflector by using woven lattice sandwich composites to replace the solid composite laminate, and achieved a significant weight reduction. The novel structure has been applied in China Railway High-speed (CRH) train. Kim et al. [20–22] developed a large scale sandwich composite carbody of trains which has been adopted in Korean Tilting Train eXpress (TTX). They systematically studied the natural frequency and deformational behavior of the composite train carbody. Wennberg [23] proposed a multi-function concept for the application of sandwich composite in train carbody. In addition, there are some other researchers exploring to employ

* Corresponding author.
** Corresponding author.
*** Corresponding author.
**** Corresponding author. College of Engineering, Peking University, Beijing 100871, China.
E-mail addresses: fengyun327@163.com (H. Li), leihongshuai@pku.edu.cn (H. Lei), fhl02@mails.tsinghua.edu.cn (H. Fan), fangdn@pku.edu.cn (D. Fang).

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composite materials in rail vehicle floor and energy-absorbing structure [24,25].

The investigation on the design and application of lightweight composite as the primary load carrying structure in rail transit is extremely rare. This is mainly due to the extreme loading requirement and complex manufacturing process. Geuenich et al. [26], Maurin et al. [27], Kim et al. [28,29], and Chvojana et al. [30] respectively designed and manufactured glass fiber reinforced composite bogie frames that a primary structure to support the weight of car body and passengers for urban subway trains. The experimental results exhibited that the use of composite element for the bogie frame could result in a weight reduction of approximately 25% [28]. Recently, a new rolling stock bogie was developed by Kawasaki Heavy Industries of Japan, which was named as efWING [31,32]. The new bogie frame contained two carbon fiber composite side-beams similar to the leaf spring. Although the above mentioned efforts on the composite bogies were all the significant break-through in the application of lightweight composite, but the fabricated composite bogie frame elements were simple beams or foam filled box beams. In fact, there are some complex cavities structures exist in train bogie, especially for urban maglev train.

The object of this paper is to develop a lightweight composite multi-cavity element for the bogie frame of urban maglev train. The specific mold design and manufacturing process will be presented. To evaluate the deformation resistant capability of the element under an extreme load condition, a static three-point bending test was performed. Finite element analysis (FEA) was conducted using the commercial Abaqus software. The experimental results of local strain of element were compared with theoretical and FEA results.

2. Design background

The first medium-low urban maglev train in China, which was designed and manufactured by CRRC (as shown in Fig. 1), was put into operation in 2015. This maglev express with the length of 18.55 km was the longest medium-low commercial maglev to date. The designed maximum passenger capability was 363 persons, and the maximum speed was 100 km/h. The system of train was composed of five metal bogies per car, and the metal material consisted of aluminum and iron. Because the drive power was magnetic levitation, thus weight reduction was the most urgent issue in contrast with the traditional train.

The metal bogie frame of urban maglev train was mainly composed of four casting blocks, four anti-rolling sills, two side beams and electromagnet (as shown in Fig. 2a). The frame undertook the load of a car, and separated the rail and carbody. The casting block, a multi-cavity structure made of aluminum material, was the main load carrying component and it accounted for approximately 60% of the total weight of bogie frame. In the case of suspended parking condition, the casting block will undertake about 20 kN vertical load without undergoing any local failure or critical deformation to guarantee safety. Considering it takes the large component of the overall weight, we chose it as the lightweight design target (as seen in Fig. 2b). A new lightweight composite coasting block was designed taking into account the assembly relationship between all components, as seen in Fig. 2c. In fact, the main load bearing part of casting block was the upper half (as seen in Fig. 2d) which was a multi-cavity complex structure. To evaluate the feasibility of lightweight design, the simplify coasting block was as the research object in present study. The trial of manufacturing and mechanical test will be performed.

3. Experimental details

3.1. Design of mold

The casting block used was a high stiffness structure which included one rectangular structure with seven cavities. The shape and cross sectional geometry of its cavities cannot be considered as variables for the structural design process. This characteristic implied a high technical requirement in the preparation. In this paper, the component was manufactured successfully after selecting mold, preforming process and autoclave molding process based on the requirements of design.

Autoclave molding process has been verified to be the preferred method to fabricate a high performance composite structure [33], thus we also consider adopting this technique. Subsequently, the primary task was to design and manufacture an appropriate mold to prepare the desired composite bogie element. The mold was assembled using the simulation in CATIA (as shown in Fig. 3), which would be ideal for implementation in industry for its ease of access. Because of the particular geometry of the structure, the mold must be made of such a material that the thermal expansion coefficient was compatible with that of the composite material. The traditional metals were not considered while red oak was preferred in order to present a thermal behavior. It was a relatively inexpensive material with good mechanical properties. Moreover, its auto-ignition temperature was well above the maximum curing temperature of the composite material used in autoclave molding.

Because of the size and geometrical complexity of the bogie, the mold was constituted by mold core, outer mold and substructure, which could be removed at the end of the forming processed, as shown in Fig. 4. The mold core was comprised of seven components

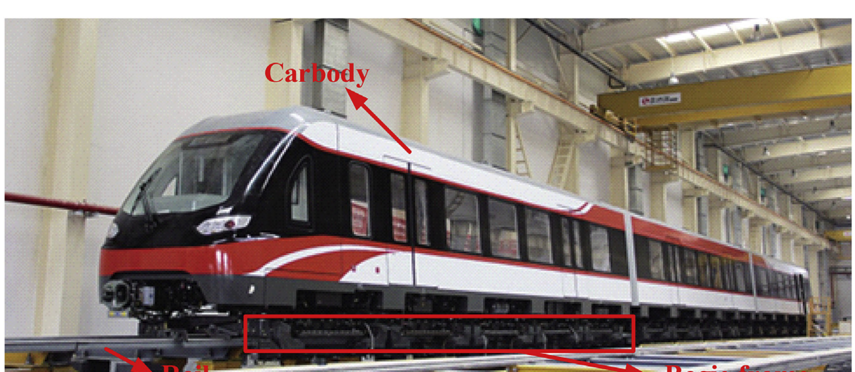

Fig. 1. Medium-low maglev train produced by CRRC Zhuzhou Electric Locomotive Co., Ltd.