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Structural Behaviors of a GFRP Composite Bogie Frame for Urban Subway Trains under Critical Load Conditions

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Abstract

In order to replace a conventional steel bogie to a composite one, in this study, a GFRP composite bogie frame has been designed and manufactured to be applied to the bogie of urban subway trains. To evaluate the structural behavior, the composite bogie frame was manufactured using the autoclave curing method and tested under the critical load conditions; vertical loads and twisting load. Through the test, the stresses at the connection region between a cross beam and a side beam and deflection were measured and used to assess the structural safety. Moreover, the stress and strain distribution for the whole bogie frame was evaluated through finite element analysis and compared with the experimental results.

Keywords: Composites; bogie frame; subway; Goodman; GFRP

1. Introduction

The bogie of a railway vehicle sustains the weight of the car body, controls the wheel sets on straight and curved track, and absorbs the vibrations [1]. The weight of the bogie makes up approximately 37% of the total vehicle weight. Therefore, reducing the weight of the components making up the bogie system is essential for lightweight railway vehicle design. In particular, a bogie frame, which accounts for approximately 20% of the bogie weight, is intended to support heavy static and dynamic loads, such as the vertical load by the body of the vehicle, braking and accelerating load, twisting load induced by track twisting, and traction load. This is why it is common to produce bogie frames with solid steel (especially a freight bogie) or welded structures. Such bogie frames are rigid and heavy, weighing from 1 to 2 tons. They have to be equipped with suspension and damping systems to safeguard the comfort of passengers and to absorb vibrations due to the unevenness of the railway track on which the vehicles run.

Usually, the bogie of urban subway trains is subjected to much more load variation than passenger trains due to passenger weight difference between the full weight condition during rush hour and the tare weight condition. The passenger weight difference of the urban subway train is in the range of 25tones to 30tones while in case of the

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passenger train, it ranges from 6tones to 10tones. Therefore, the bogie frame of the urban subway train has to sustain a severe load condition although its speed ranging from 80 km/h to 100 km/h is lower than the passenger train.

In order to evaluate the structural behavior of a composite bogie frame, in this study, it was tested under the critical load conditions; vertical loads and twisting load. From the test, the stresses at the stress concentration areas such as the connection region between the side beams and the cross beams were measured. Moreover, the stress distribution for the whole bogie frame was evaluated through the finite element analysis.

1.1. Composite bogie frame

The conventional bogie frame of a urban subway train is manufactured as a welded steel box format (like a hollow tube) to reduce the weight (Fig. 1(a)). The SM490A steel is usually used as the base material of the bogie frame. In case of the composite bogie frame, its external shape is similar to the conventional one as in Fig. 1(b). It also has two side beams and two cross beams. It is 2970 mm long and 2170 mm wide. In order to meet the structural requirements, the inside of the side beams of the proposed composite bogie frame was filled with the following structural parts; composite chords, ribs, and foam cores. The glass/epoxy prepregs were stacked up on the inner structural part to form the skin, as seen in Fig. 1(b).

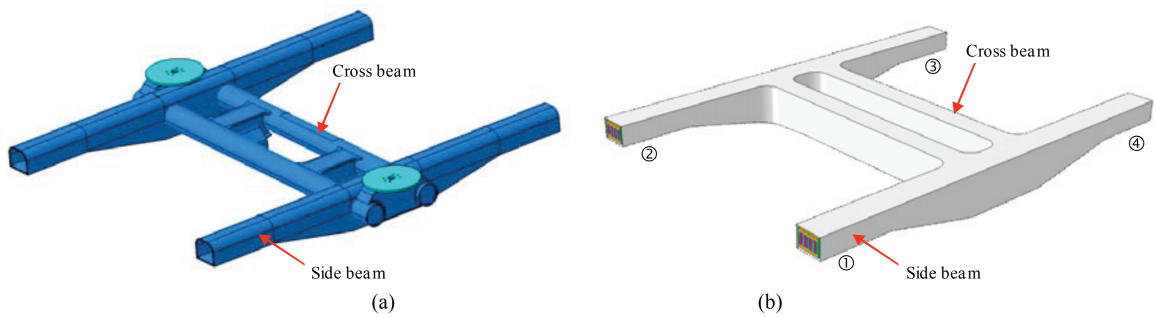

Fig. 1 The conventional steel bogie frame and the composite bogie frame for the urban subway train.

1.2. Manufacturing process

In order to manufacture the composite bogie frame, first, the plates for ribs were manufactured using the resin infusion process. For this process, eleven quadaxial glass fiber perform (QGFP, Owens corning, USA) sheets with a thickness of 0.91mm were laid up. The QGFP sheet was composed of four layers of 0^o, 90^o, 45^o and -45^o unidirectional glass fiber. After the completion of the layup, the resin was infused into the stacked QGFP sheets by vacuum. After completion of the resin infusion, the plate was cured in an oven for 2 hours at 80^oC, and finally, the plate for ribs was completed. The cured plate was cut using a diamond cutting machine and bonded with the foam cores (Airex® foam, Alcan Composites), which were already trimmed, using FM73 adhesive film (Cytec, USA). The bonded parts were vacuum-packed and then cured in the oven for one and half hours at 80^oC. In order to make the composite chords, 4-harness satin fabric glass/epoxy prepregs (GEP224, SK Chem., Korea) were laid up between the ribs and the foam cores to the required thickness. The composite chord increases the bending stiffness and sustains the compressive force imposed on the width direction. After the completion of the layup, the part was vacuum-packed and then cured in the oven. After the manufacturing of the inner structural part, the two cross beams and the two side beams were assembled by adhesively bonded method using fixing jig. Then, the GEP224 prepregs were laid up on the surface of the assembled structure to form the skin. The totally stacked composite frame was vacuum bagged and cured in the autoclave. The final product weighed 145kg.

1.3. Material property evaluation

The static and fatigue material properties of the 4-harness satin fabric glass/epoxy were evaluated according to ASTM and ISO standards [2-6]. In case of the static mechanical properties, both of the in-plane and out-of plane properties were measured because the skin and the composite rib parts were composed of thick composites. Fig. 2 (a) and (b) show the pictures of the out-of plane tensile modulus and the interlaminar shear strength measuring test.