Thin-Walled Structures 131 (2018) 151–164

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Full length article

Harmonised method for impact resistance requirements of E-glass fibre/unsaturated polyester resin composite railway car bodies

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ARTICLE INFO

Keywords:
Composite materials
FRP
Railway vehicle
Flying ballast
Impact modelling
Strain rate

ABSTRACT

This paper shows for the first time an approach to harmonise and unify various railway standards into a single method for small object strike against rail vehicles. Emerging composite materials applications for structural parts of railway vehicles highlight the need for assessment of impact response. The objective of this work is to provide a practical and cost-effective approach for rail vehicle car bodies affected by object strikes such as flying ballast, which is a concern and restricting phenomenon for high speed rail operation. A static destructive test method combined with numerical models has been developed. High velocity impact (HVI) simulations are performed with E-glass/polyester laminates based on experiments and similarities between the two cases are highlighted. Validated numerical models are used to simulate three railway standards that are relevant to object strike in order to unify them into the proposed single method. The analysis of the energy transfer characteristics, contact forces, and impact velocity change of the projectile showed that the proposed method can be used alone instead of various existing standards, providing a significant decrease in sample size as well as avoiding the costly high-velocity impact experiments, hence resulting in substantial cost savings.

1. Introduction

The response and assessment of composite materials to impact loading are quite complex not only due to the various number of failure modes and interactions between the constituents, but also due to the rapid occurrence of the event itself. In addition, experimental testing methods for high energy/velocity impact events require specialised and expensive equipment such as gas gun, high-speed cameras, and fast data acquisition systems.

Using composite materials as the primary load bearing structures is a relatively new challenge for the rail industry [1–9], therefore it will most likely require an assessment of the rail specific impact events as these types of materials are sensitive to impact loading. One of the requirements of a passenger rail vehicle is to resist the strike from a flying solid object, and with the introduction of high-speed rail lines, small-sized object strike such as flying ballast phenomenon (Fig. 1) has become an important issue. Flying ballast phenomenon is the displacement of ballast particles on the track, which become airborne by various forces such as train aerodynamic forces, wind forces, mechanical induction, vibration, and icefall under the train floor structure. This phenomenon can cause significant damage to the rail vehicle and is considered a hot topic [10]. Previous research [11–16] has been focusing on the risk assessment and movement analysis of the ballast particles by mechanical and aerodynamic forces, but very few studies were found concerning the results of the aftermath of this phenomenon such as [17] and the recent work of the authors [18]. Furthermore, in the rail industry there are various national/international standards which identifies specific object impact requirements for car bodies. There is no harmony between these methods and the requirements are case specific, therefore a more flexible and unifying assessment method is needed. This paper presents a rapid and low-cost method to predict the response of a composite train car body impacted by a flying object without the need of high-velocity testing, and evaluates this approach by comparing it with relevant standards to decide whether it can be preferred over existing ones.

Impact on composite materials has been researched widely over the years in many aspects, such as analytical modelling of ballistic limit and damage prediction, numerical modelling, size-shape effects, and strain rate effects [19–26]. Among the techniques in past research, quasi-static punch testing (QSPT) emerged as a simpler and useful method to analyse impact related failure and damage mechanisms of fibre reinforced composites [27–35]. Lee and Sun investigated the damage behaviour of graphite/epoxy laminates under high velocity impact loading, using the displacement levels of the punch as failure criteria

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https://doi.org/10.1016/j.tws.2018.06.041
Received 21 March 2018; Received in revised form 26 June 2018; Accepted 28 June 2018
0263-8231/

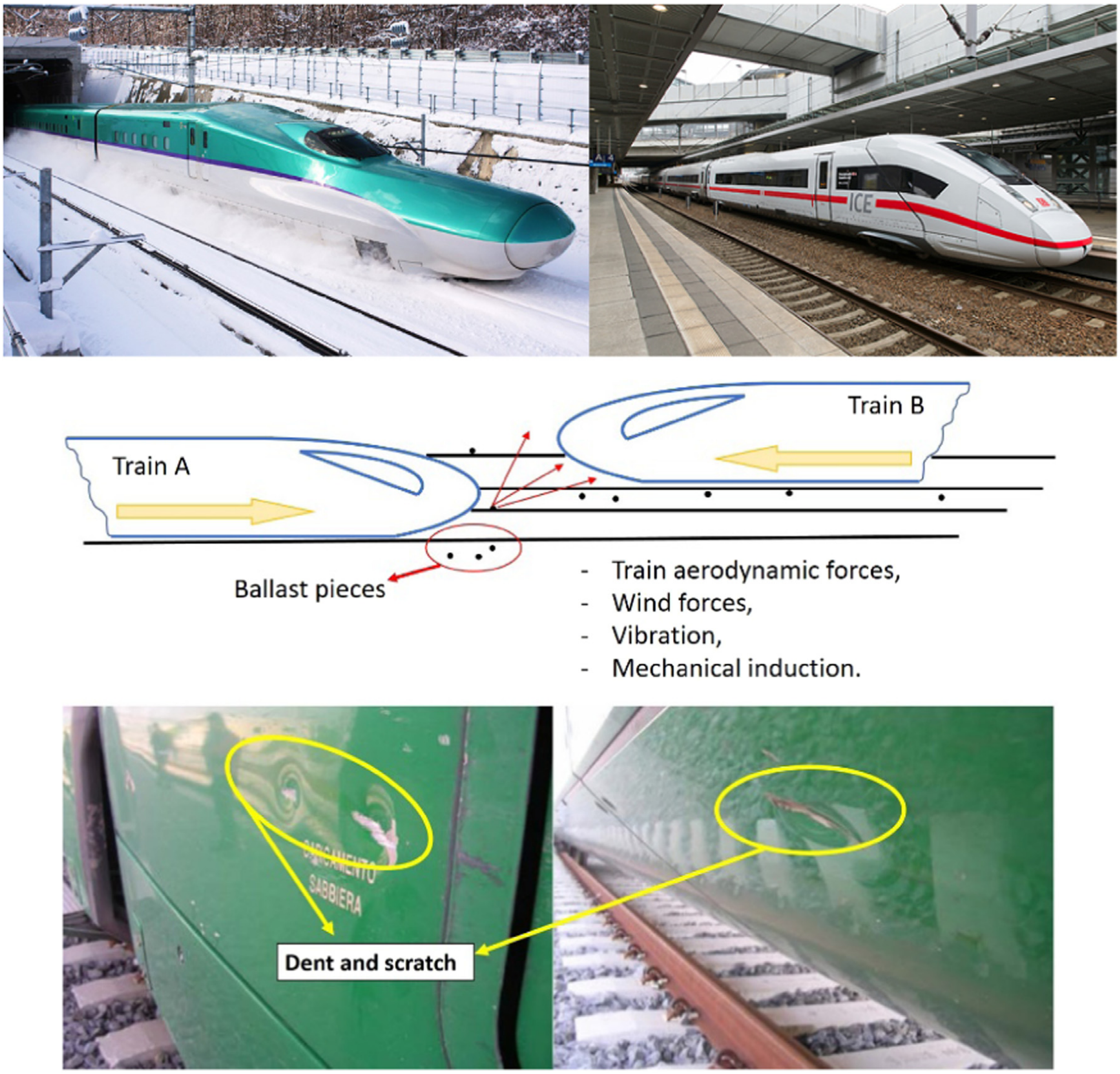

Fig. 1. High speed train car bodies ((top): Hokkaido Shinkansen on the left and DB Siemens ICE4 on the right). Flying ballast phenomenon; causes (middle) and outcomes (bottom figure reference: [10]).

[27]. They pointed out that when all the boundary conditions are the same there is a similarity of damage in graphite/epoxy laminates between dynamic perforation and quasi-static punch. Zhou and Davies investigated the low-velocity and static impact response of thin and thick glass fibre/epoxy laminates [29]. The strain rate effect in maximum force for failure was observed to be 36% for thin laminates and 22% for thick laminates. Supporting the findings of Zhou and Davies, Sun and Potti reported that energy consumed by specimens in dynamic penetration was higher than as it was in static penetration [30]. Gama and Gillespie developed a methodology for calculating the ballistic limit of glass fibre laminated composites by using quasi-static punch shear testing (QS-PST) [33]. The failure sequence of laminates under high-velocity impact was captured in quasi-static testing by using fixtures with a different span length. Consequently, the energy absorption value was found to be quite close in both types of loading, along with the same failure sequence. In a subsequent paper [34] Gama and Gillespie achieved a reliable level of validation between ballistic experiments and numerical modelling by incorporating strain-rate effects which influence the material properties of glass fibre laminates. Sutherland and Guedes Soares [35] carried out quasi-static testing in order to compare the failure modes and energy absorbing behaviour of glass fibre composite laminates for marine applications using the drop-weight impact test method. They achieved good agreement in terms of delamination onset in both test cases, however for the onset of fibre failure they observed a considerable difference. The fibre failure happened earlier in static cases than it did in the dynamic tests which can be explained by the influence of the strain rate effects in GFRP.

In more recent publications, Ansari and co-workers studied the ballistic performance of woven glass fibre reinforced polymer with two different thicknesses (3.12 mm and 6.24 mm) [36,37]. Various parameters including projectile nose shape, fixture span aspect ratio, boundary conditions, and damage patterns were studies experimentally and validated numerically with AUTODYN software. It has been observed that the aspect ratio of the sample-holder span has an increasing effect on the ballistic performance of GFRPs for both thicknesses. In addition, the boundary conditions incorporating non-clamped conditions (i.e. free edges or simply supported edges) also increases the ballistic limit of the samples. The authors observed that as the nose shape changes from conical to blunt followed by ogival and spherical, the damage in the target increases. This can be explained by the overall contact characteristics of the projectiles as sharper tips have better penetration ability, thus resulting in a more localised material failure. Zhikharev and Sapozhnikov analysed two different numerical modelling approaches on penetration of GFRP plates [38]. A continuum