ARTICLE IN PRESS
EFA-02847; No of Pages 14
Engineering Failure Analysis xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Engineering Failure Analysis

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

Train passenger car floor panel testing using digital image correlation and strain gauges and comparison with finite element modelling

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ARTICLE INFO

Article history:
Received 30 November 2015
Received in revised form 7 March 2016
Accepted 14 March 2016
Available online xxxx

Keywords:
Digital image correlation
Laser beam welding
Finite element method

ABSTRACT

Weight reduction of passenger railway cars is a recurrent concern, driven by increasing efficiency objectives. The work presented here is part of a project aiming at developing a new solution for a train passenger car floor panel. A design was proposed and an experimental programme sets forth to evaluate its feasibility. Small coupon testing was performed to assess the selected joining processes. A structural detail was also studied for static and fatigue loading in order to evaluate failure modes and locations. A prototype of the structure was built and tested in 3-point bending using electrical strain gauges and digital image correlation. A numerical model of the prototype was built in order to estimate loads during testing and for benchmarking purposes.

1. Introduction

In the context of light-weighting of railway cars, corrugated floors were discussed in the middle of the last century [1]. Later, honeycomb panels have been used as flooring for aircraft and railway cars due to high stiffness and lightness, but may suffer from drawbacks caused by the adhesive used to glue honeycomb core and skins [2]. Avoiding adhesives, truss core panel may be an alternative to honeycomb panel, open to a variety of geometrical solutions, e.g. [2–4]. Welded connections in orthotropic plates may be prone to fatigue damage, as in civil engineering structures [5,6]. Currently, lightweight floors of passenger railway cars are typically made of welded extruded panels [7].

Cost savings may be possible using an Al-alloy sandwich panel composed of two flat skins welded to a grid made of straight beams, provided compliance with design requirements concerning weight and stiffness are met. Aluminium alloys are extensively used in structural design of transport solutions, from shipbuilding [8] to aeronautics [9], but the joining operation may limit their applicability. In the 1999 Ladbroke Grove accident report [10], the authors state that although aluminium presents several advantages over steel in train car structures, it is recommended that consideration should be given to the following points, when developing new vehicles constructed in aluminium:

(i) '…*the use of alternatives to fusion welding*;
(ii) *the use of improved grades of aluminium which are less susceptible to fusion weld weakening, and*;
(iii) *the further development of analytical techniques to increase confidence in the crashworthiness of rail vehicle structures, particularly those constructed of aluminium*…'.

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http://dx.doi.org/10.1016/j.engfailanal.2016.03.015
1350-6307/© 2016 Published by Elsevier Ltd.

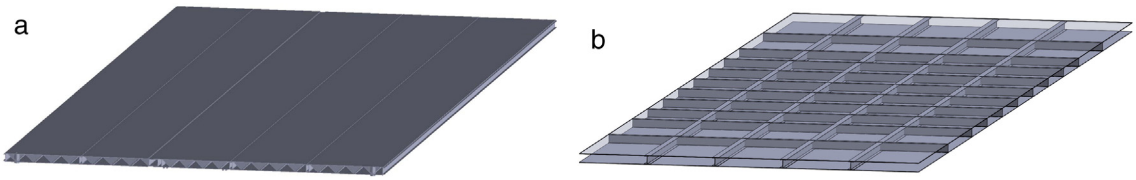

Fig. 1. 3D scheme of a) original and b) new design for the car floor panel (in b upper sheet is set as transparent for better visualization).

As stated in [11], aluminium cars, such as those of the German ICE 3 train, are usually assembled from extruded aluminium panels which are MIG (metal inert gas) welded together. In this work, an alternative design for a train passenger car floor panel was studied using welded subcomponents instead of extruded panels. Two welding technologies were proposed for the fabrication of the panel and used in the assembly of the prototype: CO_2 laser beam welding (LBW) and friction stir welding (FSW).

Laser beam welding is a well-established thermo-mechanical joining process for aluminium structures, which uses radiant energy to produce the heat required to melt the materials to be joined [12]. An extensive review on aluminium welds using laser beam welding may be found in [13]. CO_2 lasers have been more extensively used in welding as they generally produce better quality weld beams [14] and are cost competitive [15]. Yonetani in [16] studied the use of a hybrid LBW MIG welding process for railway car body panels, demonstrating the potential of this process for the application studied.

FSW is a solid-state welding process developed at TWI in the early 1990's [17] and is capable of producing sound joints and in certain conditions with fatigue strength similar or better than base materials [18]. As a solid phase, purely mechanical process, all the problems from the melted material solidification are circumvented [18,19]. The process thermal efficiency is above 90% [20] and compared to other joining technologies it has the advantage of allowing the complete recycling of the welded structure. The process is applicable to butt, T [21] and other types of joints, and has received much attention from the research community and technology integrators [22]. Although initially developed for lightweight alloys such as aluminium, industries such as shipbuilding have pushed FSW for steel joints [23]. The concept has also expanded onto fields other than welding, such as friction stir processing [24] and friction stir channelling variants [19]. LBW and FSW are both highly automatable processes which produce reliable and sound welds and, as such, comparisons of both technologies can be found on the literature [25]. The use of either of these two techniques to manufacture integral structures has generated interest and comparisons between them may be found in the literature, such as in [26].

Digital image correlation (DIC) was employed in this study to assess displacement fields. DIC is a non-contact, full-field, optical technic to measure displacement fields in both in-plane (2D) or out-of-plane (3D) loading [27,28]. It consists of recording images in different stages of specimen loading, dividing them in small sections, or subsets, and tracks the displacements of each subset along the entire set of captured images. Despite the fact that this technique is commonly used with small test specimens, it can also be employed for large structures, accuracy being essentially tied to the recorded image resolution.

Test of solutions for floor panels involves typically three- or four-point bending of a representative part of the floor, as in [2,11] respectively. The structural solution proposed in this work was tested under three-point bending, as discussed later.

2. Proposed floor panel design

The floor panel studied in its original application rests on a steel frame and as such the contribution of the floor panel towards the global car rigidity is minor, although it has an important role of supporting the passenger weight and transmits these loads to the steel frame. The steel frame also includes the coupler-buffer section and as such it was not considered in this analysis.

Original design of the floor panel consists of long extruded profiles which are welded together along the longitudinal direction as exemplified by Fig. 1a. The proposed new design for the floor panel is composed of a welded core of extruded aluminium profiles welded together and to an upper and lower skin (aluminium sheet), as in Fig. 1b.

This solution was studied through FEM analysis and met the design requirements with a weight saving of approximately 40%, when compared with the original extruded panels' solution.

3. Small scale coupon testing

Prior to prototype production and testing, small scale coupons were tested in order to assess the mechanical properties of the material in welded form and compare the two proposed welding methods for the prototype (LBW and FSW). The material used for prototype and coupon manufacture in this study was 2 mm thick AA6082 in T6 condition (see Table 1). The choice of material was due to its current application in rail car structural panels and its availability.

Table 1
AA6082-T6 mechanical properties [29].

Material	Yield strength [MPa]	Ultimate tensile strength [MPa]	Elongation [%]
AA6082-T6	>260	>310	7

Please cite this article as: D.F.O. Braga, et al., Train passenger car floor panel testing using digital image correlation and strain gauges and comparison with finite element model..., Engineering Failure Analysis (2016), http://dx.doi.org/10.1016/j.engfailanal.2016.03.015