ARTICLE IN PRESS

Composite Structures xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Composite Structures

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

Influence of PU foam reinforcement of I-beam on buckling resistance

Piotr Lacki, Anna Derlatka*

Czestochowa University of Technology, Dąbrowskiego 69, 42-201 Częstochowa, Poland

A R T I C L E I N F O

Keywords:
Composite beam
Aluminum alloys
Refill Friction Stir Spot Welding RFSSW

A B S T R A C T

The paper presents the influence of PU foam on the buckling resistance of an I-beam made with sheets aluminum alloy 6061-T6 sheets and GFRP plates. Four beam types were considered: an aluminum beam, a composite aluminum-fiberglass beam, a composite aluminum-fiberglass-PU beam and a composite aluminum-fiberglass-PU-ribs beam. Each beam was made with two C-profiles connected by webs, with flanges reinforced by flat bars. Channels were made by bending 0.8 mm thick aluminum alloy 6061-T6 sheets. Flat bars were made from aluminum alloy 6061-T6 2.0 mm in thickness. The metal sheets components were connected by Refill Friction Stir Spot Welding RFSSW technology. The composite aluminum-fiberglass beam additionally has GFRP plates glued to the flanges. The 3.0 mm thick GFRP plates were connected by a polyurethane adhesive. The composite aluminum-GFRP-PU and aluminum-GFRP-PU-ribs beams have a rectangular cross-section. The composite aluminum-GFRP-PU beam was made like the composite aluminum-GFRP beam, but with stiffening of the web by polyurethane foam. The aluminum-GFRP-PU-ribs beam was made like the composite aluminum-GFRP beam, but with stiffening of the web by aluminum ribs and polyurethane foam. The PU foam filled up the I-sections in such a way that rectangular cross-sections were obtained. The beams were subjected to three-point bending tests.

1. Introduction

Composite constructions made of aluminum and titanium alloys have increasingly more applications in the transport industry, especially aviation [1]. Due to their advantages like low density, high strength and high corrosion resistance aluminum and titanium alloys are used not only by the transport industry [2–4] but also in civil engineering [5–9].

The highest strength aluminum alloys such as 2xxx, 7xxx and 6xxx series alloys are joined by fasteners. Usually rivets or bolts are used [6]. It is caused by the difficult weldability of these aluminum alloys. Alternative methods of joining aluminum alloy sheets are Resistance Spot Welding (RSW) [10,11] or Electron Beam Welding (EBW) [12,13], Friction Stir Welding (FSW) [14–17], Refill Friction Stir Spot Welding (RFSSW) [18].

The RFSSW process were developed and patented by Helmholtz-Zentrum Geesthacht (formerly GKSS Forschungszentrum) [19,20]. Refill Friction Stir Spot Welding (RFSSW) joints are produced by a special tool showed in Fig. 1. [21–23]. As presented in papers [24–28], the RFSSW process is performed in four main steps (Fig. 2): setting the tool in the base position, plunging the sleeve, retracting the sleeve and returning the tool to the base position. At the beginning, the tool is set in the base position so that a clamping ring is on the upper surface of the top sheet. Afterwards the rotating sleeve is plunged into the workpieces, but the rotating pin is retracted. The plasticized welded material is simultaneously transferred to the pin location. Upon reaching the desired plunge depth the sleeve is retracted and the pin is lowered. At the same time, the pin presses the material into the place of the raising sleeve. Finally, both tool parts return to the base position.

As presented in [24,25,29–31], RFSSW is mainly used to weld aluminum alloy components. However, it is possible to use this technology to join steel with aluminum as well as titanium with aluminum, which were presented in [32–35].

In recent years, researchers have attached importance to the application of Refill Friction Stir Spot Welding in joining airplane constructions. Papers [36,37] present the numerical analysis of aluminum cellular beams. The beam components were joined by RFSSW. I-profile beams with cells of different diameters and arrangement in the webs were analyzed. The beams were made of 6061-T6 aluminum alloy.

Paper [38] presents the experimental and numerical strength evaluation of an aluminum-titanium beam and aluminum-fiberglass beam. Both beams were made with two C-profiles of aluminum alloy 6061-T6 sheets. The aluminum-titanium beam has flanges stiffened by titanium alloy grade 5 sheets (Fig. 3). The aluminum-fiberglass beam has flanges stiffened by GFRP plates. The metal sheets components were connected by RFSSW and RSW technology.

In paper [39], the first-order torsion theory was developed for the restrained torsion of open thin-walled beams on the basis of Vlasov

* Corresponding author.
E-mail address: aderlatka@bud.pcz.czest.pl (A. Derlatka).

https://doi.org/10.1016/j.compstruct.2018.01.050
Received 13 November 2017; Received in revised form 10 January 2018; Accepted 16 January 2018

Please cite this article as: Lacki, P., Composite Structures (2018), https://doi.org/10.1016/j.compstruct.2018.01.050

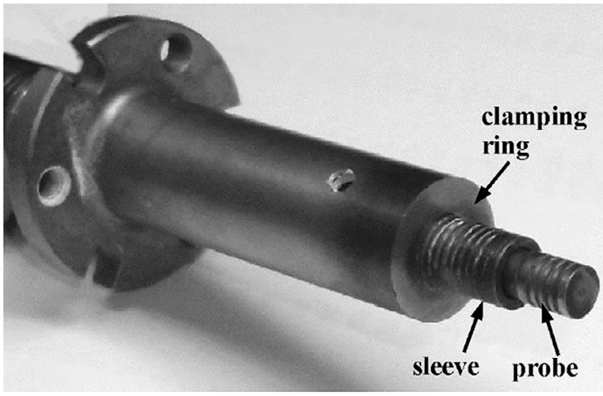

Fig. 1. Tool for Refill Friction Stir Spot Welding process.

theory. The theory considered the effects of both the warping deformation and the restrained shear deformation of a cross section. The authors of paper [39] presented the simplified theory of restrained torsion was.

Composite and sandwich plates are one of the most significant composite materials applied in industry [40–42]. The authors of the papers [43,44] emphasize that sandwich structures have widespread use particularly in transportation, where weight minimization is of great importance. In recent years, sandwich structures have also gained a noteworthy role in civil engineering constructions, not only as cladding elements [45], but also in structural elements, such as roofs or bridge decks. In civil engineering structural applications, sandwich panels are often subjected to permanent loads. As presented in [46], GFRP profiles and sandwich panels can be used as the floor module in emergency houses.

In the beam presented in [38], lateral-torsional buckling appears in the web. Therefore, there is a need for web stiffening. One of the ways is to fill the I-beam with a polyurethane foam (PU), which is analyzed in this paper. PU foam has good thermal insulation properties, which was shown in [47,48]. As presented in [49–51], PU foams are the most commonly used noise-controlling materials in the automotive and aerospace industry due to their high sound absorption, light weight and ease of production.

According to papers [52–54], the transport industry uses PU foams to fill thin-walled structures. Thin-walled structures are preferable in vehicles because they are excellent at dissipating impact energy by stable progressive deformation when subjected to axial compressive loads.

Thin-walled metal tubes have been widely used in almost all vehicle collision energy dissipation systems [52]. However, thin-walled metal tubes have a weaker ability to withstand non-axial load. The solution is a foam-filled structure. For example, an aluminum foam-filled structure has been widely used in automotive front bumpers and front beams. The analysis of aluminum and CFRP tubes filled with PU foam was presented in [52–54].

The authors of [55] investigated the crushing behavior of hexagonal metallic honeycomb subjected to axial impact loads. On the other hand, the authors of paper [56] presented the crushing response of a more complex structure consisting of square aluminum tubes filled with an aluminum honeycomb and polyurethane foam.

2. Goal and scope of work

The aim of this study was to determine the influence of PU foam on the buckling resistance of an I-beam made with aluminum alloy 6061-T6 sheets and GFRP plates. The load bearing capacity of four thin-walled beams were considered: an aluminum (AA) beam, a composite aluminum-fiberglass (AA-GFRP) beam, a composite aluminum-fiberglass-PU (AA-GFRP-PU) beam and a composite aluminum-fiberglass-PU-ribs (AA-GFRP-PU-ribs) beam. Additionally, tests of the static tensile/shear load bearing capacity of the RFSSW lap joints were conducted.

2.1. RFSSW lap joints

Two types of lap joints made with aluminum alloy 6061-T6 sheets were prepared (Fig. 4). The first type of lap joints was made with two sheets 0.8 mm in thickness, like in the beam webs. The second type of lap joints was made with two sheets 2.0 mm and 0.8 mm thick, like in the beam flanges. In each thickness combination, three arrangements of RFSSW spot welds were analyzed: with only one spot weld, with two spot welds parallel to the stretching direction, with two spot welds perpendicular to the stretching direction. Three samples of each joint geometry were made.

All the RFSSW spots were 9.0 mm in diameter.

The RFSSW joints were stretched/sheared. Tests were carried out using a testing machine and Aramis system. Aramis is a non-contact and material-independent measuring system based on Digital Image Correlation (DIC) [57,58]. Aramis uses a stereo camera system which delivers precise 3D coordinates based on triangulation and using stochastic patterns. The Aramis provides information on the properties of the materials used and the behavior of the products under load.

The obverse and reverse sides are distinguished in the joints. The obverse was the side where the tool worked. The reverse was on the opposite side.

2.2. Beams

The aluminum beam has an I-profile cross-section (Figs. 5 and 6). It

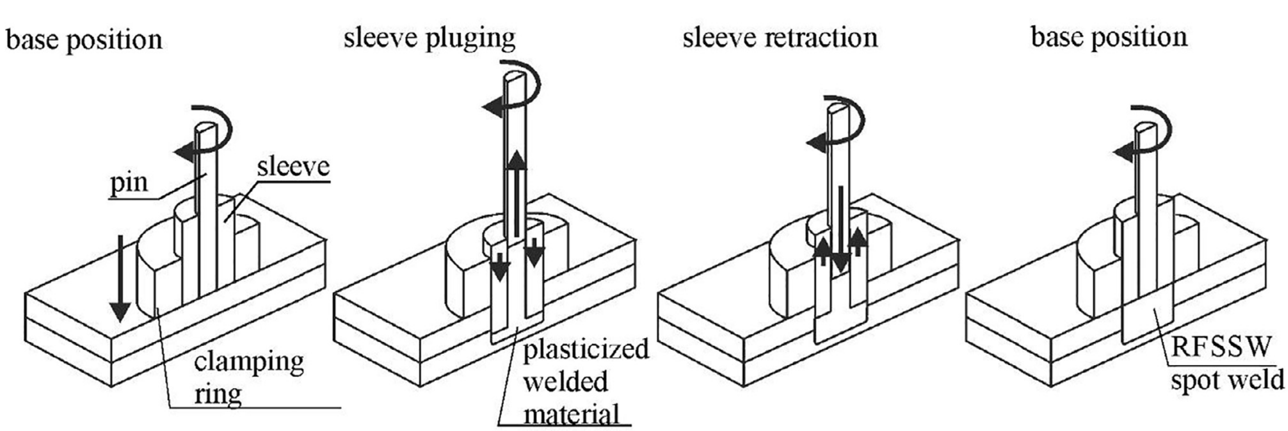

Fig. 2. Scheme of RFSSW process execution.