Composite Structures 123 (2015) 169–179

Contents lists available at ScienceDirect

Composite Structures

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

Manufacturing and characterization of polyurethane based sandwich composite structures

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ARTICLE INFO

Article history:
Available online 26 December 2014

Keywords:
Polyurethane resin
Trapezoid foam
Composite sandwich structure
VARTM

ABSTRACT

Demand has been growing for structural systems utilizing new materials that are more durable and require less maintenance during the service lifetime. In particular, sandwich composite structures attract attention due to many advantages such as light weight, high strength, corrosion resistance, durability and speedy construction. In this study, three designs of glass reinforced composite sandwich structures, namely boxes (web-core W1), trapezoid and polyurethane rigid foam, are fabricated using new generation of two-part thermoset polyurethane resin systems as matrix materials with vacuum assisted resin transfer molding (VARTM) process. The stiffness, load-carrying capacity and compressive strength were evaluated. Core shear, flatwise and edgewise compression tests were carried out for these three models. The mechanical response of three designs of sandwich structures under flexural loading were analyzed using commercial finite element method (FEM) software ABAQUS. The simulation results of flexural behavior were validated by experimental findings.

1. Introduction

Composite sandwich structures are increasingly used in civil infrastructures due to their many advantages such as light weight, high stiffness to weight ratio, corrosion resistance, good fatigue resistance and high durability. The main advantage of a sandwich construction in civil engineering applications is its ability to provide increased flexural strength without a significant increase in weight.

With the development of composite manufacturing processes, such as resin transfer molding (RTM), pultrusion and VARTM, sandwich structures fabricated using polymer matrix composites have been explored since early 1980s. In particular, VARTM is a low-cost composite manufacturing process that has been employed to manufacture various large components including turbine blades, boats, rail cars and bridge decks [1,2].

Out of many applications of sandwich composite structures in civil infrastructures, using sandwich composite materials in civil infrastructures to replace the conventional materials significantly reduces dead load. Furthermore, in new constructions, lower dead load can translate into savings throughout the structure, as the size of structural members and foundation is reduced accordingly. The other reason for the use of composite materials is their higher corrosion resistance [3].

The necessity to study the structural behavior and failure characteristics of sandwich structures has increased during recent years. Recent applications have demonstrated that fiber reinforced composite sandwich construction can be effectively and economically used in the civil infrastructure and several critical weight applications. A combination of good flexural and compressive strength coupled with high weight savings is critical in these applications. A number of research papers have been presented on experimental and numerical investigation on the mechanical behavior of sandwich composites.

Manalo et al. [4] investigated the flexural behavior of a new generation composite sandwich beams made up of glass fiber reinforced polymer facesheet and modified phenolic core material experimentally and numerically. The results showed that the composite sandwich beams tested in the edgewise position failed at a higher load with less deflection compared to specimens tested in the flatwise position. Finally, the result of the study showed the high potential of this innovative composite sandwich panel for structural laminated beam. Dai et al. [5] investigated the failure behavior of sandwich beams manufactured using VARTM process in static 3-point and in 4-point bending using two different core

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http://dx.doi.org/10.1016/j.compstruct.2014.12.042
0263-8223/

materials. The results showed long beams failed in the face on the tension side when the tensile strength of the face was exceeded. The wood core was predicted to fail laterally in the thickness direction before the face failure because of the relatively high tensile stress in the core. Reisa et al. [6] studied the delamination problems typically faced in traditional glass fiber reinforced polymer (GFRP) sandwich panels. The influence of the panel thickness, through-thickness fiber configuration and density, and other parameters on the tension, compression, flexure and shear behavior of the panels were discussed. The results showed the behavior of the face sheets under tension is bi-linear which could be caused by the presence of the fibers in the perpendicular direction.

A series of analytical and experimental investigations is presented to study the response and failure of truss core sandwich panels. Xiong et al. [7] studied the response of carbon fiber composite pyramidal truss core sandwich panels subjected to axial compression using analytical models and experiments. The results show after initial peak load, the bond strength was one of the main factors in the performance of the panels. Debonding between the facesheet and core were observed, leading to reduction in the load carrying capacity of the structure. The measured peak loads obtained in the experiments showed good agreement with the analytical predictions. Humpreys et al. [8] studied the structural behavior of monocoque fiber composite truss joints. The joints were subjected to static loading of the diagonal tension member. From the results presented, it can be seen that strong monocoque fiber composite trusses can be produced. Canning et al. [9] proposed a hybrid box section consisting of glass fiber reinforced polymer pultruded box with an upper layer of concrete in the compression side. Cartie and Fleck [10] studied the effects of titanium and carbon fiber pins inserted into the polymethacrylimide foam core of a sandwich panel (with carbon fiber face sheets) in order to increase the through-thickness strength. The results show that the compressive strength is governed by elastic buckling of the pins, with the foam core behaving as an elastic Winkler foundation in supporting the pins. The peak strength of the pin-reinforced core is increased. Aref and Alampalli [11] conducted field tests and studied the dynamic response of the first FRP composite bridge built in USA. The same authors also developed a finite element model using MSC-PATRAN and analyzed the dynamic behavior using ABAQUS. The results indicated that the longitudinal joint is performing as intended, and only high degradation of the joint can be detected using the measured vibration characteristic of the sandwich bridge deck.

Presently, limited literature is available on the mechanical properties of VARTM thermoset PU sandwich structures. In this study, the main objective is performance evaluation of thermoset polyurethane sandwich structure manufactured with low cost VARTM process. The failure mechanisms of VARTM thermoset polyurethane (PU) composite sandwich beams were studied. Three different models of all-fiber reinforced polymer composite sandwich structures utilizing various core designs, namely box, trapezoid and polyurethane (PU) rectangular rigid foam, were fabricated using VARTM process. Woven glass fiber and new generation of two-part thermoset polyurethane resin systems were used for fabrication. Core shear, flatwise compression and edgewise compression tests were performed accordance to ASTM standards C393, C365 and C364 respectively. In addition, finite element analysis was conducted to model the flexural behavior for all three types of sandwich structures.

2. Materials

Three different models were constructed with woven E-glass fiber face sheets. The E-glass fiber, obtained from Owens Corning, OH, was compatible with PU resin. A new generation two-part thermoset polyurethane resin system from Bayer MaterialScience was used as the matrix material. The two-part thermoset resin system (RTM NB #840871) consists of two components. The “A” component is Isocyanate NB#840859 ISO, Diphenylmethane Diisocyanate (MDI-Aromatic). The “B” component is a Polyol (RTM NB#840871), of low viscosity (approx. 350 cPs). The components react rapidly after mixing, forming a highly cross-linked thermoset with good mechanical properties.

Three different materials comprised the sandwich’s foam core.

- Type-1: high density (6 lb/ft^3) PU rigid foam with closed cell (Fig. 1a).
- Type-2: low density (2 lb/ft^3) polyurethane foam of a trapezoid shape (Prisma) with a combination of two plies and a knitted E-glass biaxial (+/−45°) matted reinforcement encompassing a single cell (Fig. 1b).
- Type-3: web-core boxes with a low density (2 lb/ft^3) polyurethane foam and matted reinforcement. It had one additional layer mesh mat of glass fiber between each cell of the core (Fig. 1c). The core cells had grooves on their sides to facilitate resin flow across shear webs.

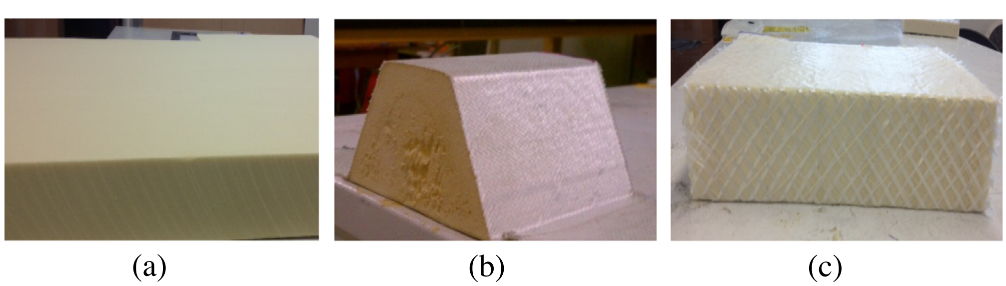

Fig. 1. Three types of foam cores. (a) Type-1 high density PU foam, (b) Type-2 trapezoidal low density foam with mat reinforcement, (c) Type-3 web-core foam with mat reinforcement.

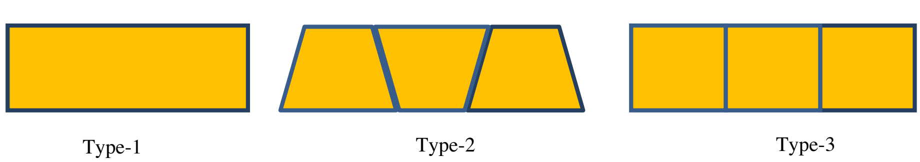

Fig. 2. Sandwich structure models.