Available online at www.sciencedirect.com

ScienceDirect

Journal of Bionic Engineering 11 (2014) 134–143

Technological Parameters and Design of Bionic Integrated Honeycomb Plates

Chenglong Gu[1], Jianxun Liu[1], Jinxiang Chen[1], Chenglin He[1], Yun Lu[2], Yong Zhao[3]

1. *School of Civil Engineering* & *International Institute for Urban Systems Engineering*, *Southeast University*, *Nanjing* 210096, *P. R. China*

2. *Department of Mechanical Engineering*, *Graduate School* & *Faculty of Engineering*, *Chiba University*, *Chiba* 263-8522, *Japan*

3. *System Consulting Dept. Aimnext Inc.*, *Minato-Ku*, *Tokyo* 105-0013, *Japan*.

Abstract

We investigated an integrated manufacturing method to develop lightweight composite materials. To design the preparation process for the integrated honeycomb plates, the shear and compressive mechanical properties of the corresponding composite materials were also investigated. The results indicate that these composite materials, with two types of resins reinforced by short basalt fibers, exhibit obvious toughness, particularly in their compressive properties. The Epoxy Resin (ER) is denser and has better bonding at the fiber and matrix interface than the vinyl ester resin matrix. Therefore, the ER exhibits better shear and compressive strengths than the vinyl ester resin matrix, thereby providing a design technology of the preparation process of the integrated honeycomb plate. The matrix material of this plate is composed of an epoxy (E51), a curing agent (593), and a thinner (501) at a ratio of 10:3:1; short basalt fibers are added as a reinforcing material at a 30% volume fraction. By increasing the curing temperature and other experimental conditions, we obtained an expected integrated honeycomb plate. This integrated honeycomb plate possesses properties such as a high fiber content, good shear and compressive performance, and high processing efficiency.

Keywords: honeycomb, basalt fiber, bionic material, shear strength, compressive strength

doi: 10.1016/S1672-6529(14)60028-7

1 Introduction

In the development of lightweight composite materials, learning from living creatures is a productive approach[1–4]. Motivated by the fact that the forewings of beetles exhibit high strength and require minimal weight for defense and flight, we have been studying their architecture since 1997[5]. We have also previously investigated the three-dimensional structures and mechanical properties of these forewings[6,7]. These investigations led us to discover a new type of lightweight bionic composite that consists of a completely integrated honeycomb structure and fiber-reinforced trabeculae at the corners of the honeycomb cores. Commercial honeycomb sandwich plates are currently manufactured by adhesively joining the plate and core parts, which are fabricated using different processes[8]. These sandwich plates are easily separated from the side plates and core, and this separation is a factor that limits both the strength and the side sealing of such structures. To overcome these weaknesses of the traditional manufacturing method, we recently developed a set of bionic integrated molding tools, including both trabeculae and honeycombs[9,10]. Additionally, we successfully conducted a trial manufacturing process for the integrated honeycomb product (Fig. 1). The matrix material is Epoxy Resin (ER), and the reinforcing material is Basalt Fibers (BFs). As shown in Fig. 1, the structures of the honeycomb and trabeculae clearly contain short fibers distributed throughout the entire specimen, and long fibers are distributed in the upper and lower laminations. However, this specimen is rather crude, and it requires a

Corresponding author: Jinxiang Chen
E-mail: chenjpaper@yahoo.co.jp

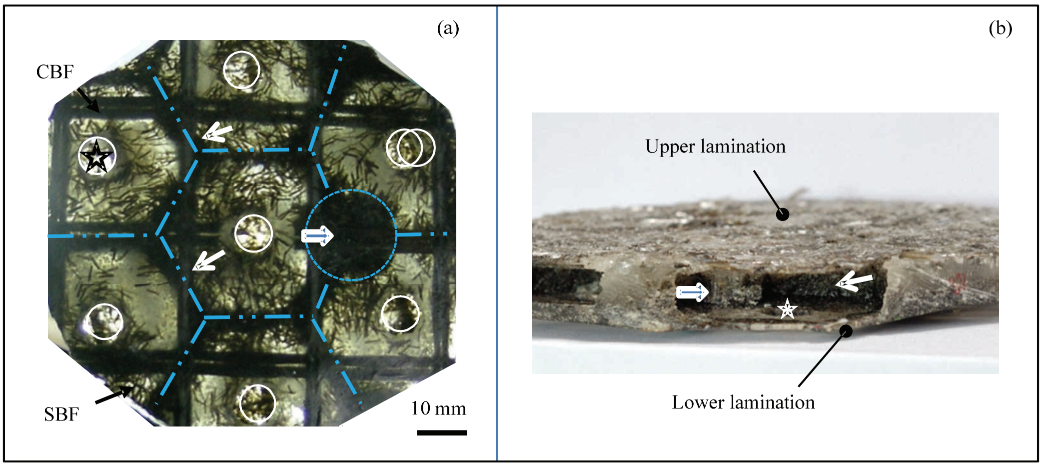

Fig. 1 Example of a composite made by integrated molding: (a) top view (lower surface), (b) side view[9]. CBF: Continuous BF, SBF: Short BF; the thick and white arrows indicate a trabecula and honeycomb wall, respectively; star symbols show a positioning hole.

long forming time. Moreover, the BF ratio was low, and the distribution of BFs was uneven. Therefore, improvements were required for several aspects of the material constitution, preparation process, and production techniques, among others[9]. Although the most effective, reliable method for designing the aforementioned processing parameters is to perform experiments on the integrated honeycomb plates, to simplify these complicated issues, we selected the trabeculae as the experimental subjects. First, the trabecular composite materials were prepared, and then their shear and compressive properties were tested. Consequently, we explored how the fiber volume fraction and type of resin matrix influence the molding process and the mechanical properties of these composite materials. Accordingly, we conducted a preliminary design for the material selection and constitution and molding process conditions of the integrated honeycomb plates. The preparation and mechanical properties of the integrated honeycomb plate itself will be reported in a future publication.

2 Materials and methods

2.1 Material selection

Reinforcing materials Commonly use reinforcing fibers include glass fibers, carbon fibers and BFs. BF is a new type of fiber prepared by melting at a high temperature and through a platinum-rhodium alloy. Although the mechanical properties of BF are not as good as those of carbon fiber, their properties are superior to those of glass fiber[11–13]. BF has numerous advantages, including a broad range of raw material sources, lower cost than carbon fiber, high-temperature resistance, acid and alkali resistance, and good resistance to ultraviolet radiation[11]. Therefore, in this study, we only selected BF as the reinforcing material (Zhejiang Stone Gold Basalt Fiber Co., Ltd., Jinhua, China). The fiber diameter is 13 μm, and its density is 2.65 $g \cdot cm^{-3}$.

Matrix materials: The properties and molding method (process) of the composite materials are closely related to the matrix materials. In this study, we compare vinyl ester epoxy resin, a type of thermosetting resin, with the ERs that are currently widely used, that possess good heat resistance, and that are easily cured. ER[14] contains a unique epoxy group, a hydroxy group, an ether, other reactive groups, and polar groups. Additionally, this material has a strong bond force, good wettability on the surfaces of the reinforcing fibers, and minimal curing shrinkage[15]. Vinyl ester resin has a low density and excellent impact, cracking, and corrosion resistance.

Materials list: E51 ER (Xing-Chen Chemical New Materials Co., Ltd., Wuxi Resin Factory), curing agent 593 (Wuxi Shuo-Hua Environmental Protection and New Materials Co., Ltd.), activated thinner 501 (Wuxi Pin-Hua Chemical Co., Ltd.), and bisphenol A epoxy Vinyl Ester Resin (VER) (Shanghai Fu-Chen Chemical Co., Ltd) were used. The two-component curing agents were Tert-Butyl Peroxy Benzoate (TBPB) and Benzoyl Peroxide (BPO).

2.2 Design and preparation of specimens

The fiber volume fractions used in this experiment