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Failure mechanism of woven natural silk/epoxy rectangular composite tubes under axial quasi-static crushing test using trigger mechanism

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A R T I C L E I N F O

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A B S T R A C T

This study investigates the energy absorption response of rectangular woven natural silk/epoxy composite tubes when subjected to an axial quasi-static crushing test using a trigger mechanism. The resulting deformation morphology of each failure region was captured using high resolution photography. The rectangular composite tubes were prepared through the hand lay-up technique, in which 24 layers of silk fabric were used, each with a thickness of 3.4 mm and tube lengths of 50, 80, and 120 mm. The parameters measured were peak load, energy absorption, and specific energy absorption as functions of the tube lengths. Specific energy absorption values decreased with increased length of the composite specimen, whereas total energy absorption increased with the increased length of the composite specimen. The deformation morphology showed that the failure mechanism proceeded in two stages, namely, (i) onset of tear and (ii) propagation of tear, which included progressive buckling and delamination. The composite tubes only exhibited progressive but not catastrophic failure.

1. Introduction

In the past few decades, wide-ranging research efforts on fiber-reinforced composite materials have shown the advantages of these materials, such as high specific strength, specific stiffness, design flexibility with which to tailor the materials according to specifications, production of improved properties, weight reduction, low fabrication costs and potential for lightweight energy absorption, compared with more conventional isotropic materials [1]. This awareness has increased the use of fiber-reinforced composite materials in energy absorber and crashworthiness applications for the automobile, aerospace, and even sport industries. The use of fiber-reinforced composite materials in automotive applications has resulted in significant purposeful and economic gains such as increased strength, durability, weight reduction, and lower fuel consumption [2]. Numerous studies that have focused on improving vehicle structural crashworthiness involve the use of reinforced fiber composites in designing collapsible absorbers of crash energy. The composites are utilized as structural members that are able to absorb large amounts of impact energy while collapsing progressively in a controlled manner.

However, previous works have reported that a drawback in the utilization of these composites is that most thin-walled fiber-reinforced composite structures deform catastrophically when subjected to compressive axial loading, that is, the composites collapse at various modes marked by extensive micro-cracking. Mamalis et al. [3] reported the failure mechanism of glass and carbon fibers in the epoxy matrix due to brittleness. This global brittle failure mode has been identified as a major setback associated with composite energy absorbers, because the failure is tantamount to absorbing a negligible amount of energy [4–6]. According to the Hull classification, other modes by which a fiber-reinforced composite tube fails lie on the Euler overall column buckling, which is usually observed when compressing long thin tubes, and progressive folding with a hinge formation similar to the behavior of ductile metal and plastic tubes [7].

Given these drawbacks, various types of composite structures in the form of fiber-reinforced composites tubes, sandwich panels, and hybrids have been investigated in an effort to achieve improved levels of crashworthiness [6–15]. In the current study, we present a novel composite structure with great capabilities in absorbing energy while collapsing progressively in a controlled manner. The Bombyx mori natural silk fiber is an ideal candidate for energy-absorbing applications because of the fiber's mechanical and environmental properties. The Bombyx mori natural silk fiber is among the strongest fibers produced in nature because of its high

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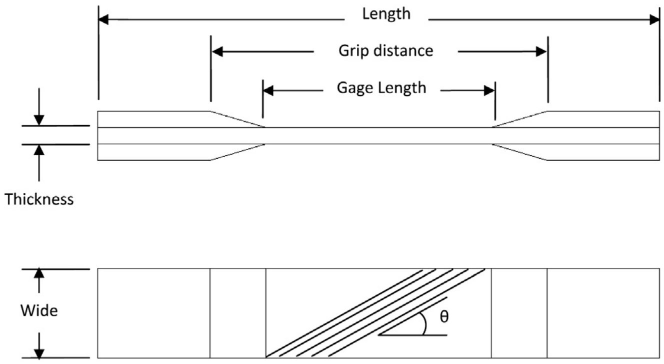

Fig. 1. Schematic views of tensile test specimen and dimensions.

specific strength and high specific stiffness, making it extremely elastic and resilient [14]. The fiber has been reported to be better than Kevlar, carbon, and glass fibers because of its elongation at failure [15–17]. Perez-Riguerio et al. [16] also reported that the Bombyx mori natural silk fiber has the capacity to absorb and dissipate energy in a very controlled manner as it deforms. Given these properties, the silk composite absorber is expected to display different failure behaviors under axial compression loading using a trigger mechanism. In our recent study on the silk composite tube energy absorber under axial loading, without a trigger mechanism [18], we proposed two different types of failure modes, namely, local buckling from top and mid-length buckling. Information on natural silk composites is very rare, and the findings of this study could aid in forming a guide for designing natural silk composite energy absorbers.

2. Materials and methods

2.1. Materials

Three main materials were used in preparing the experimental specimen. These materials included the following: woven silk fiber from the Makassar fabrics Indonesia, measuring 30 × 40 yarns per centimeter and weighing 66 g/m^2; Epoxy type (DER 331); and Jointmine Hardener, type (905–35), to be used as resin.

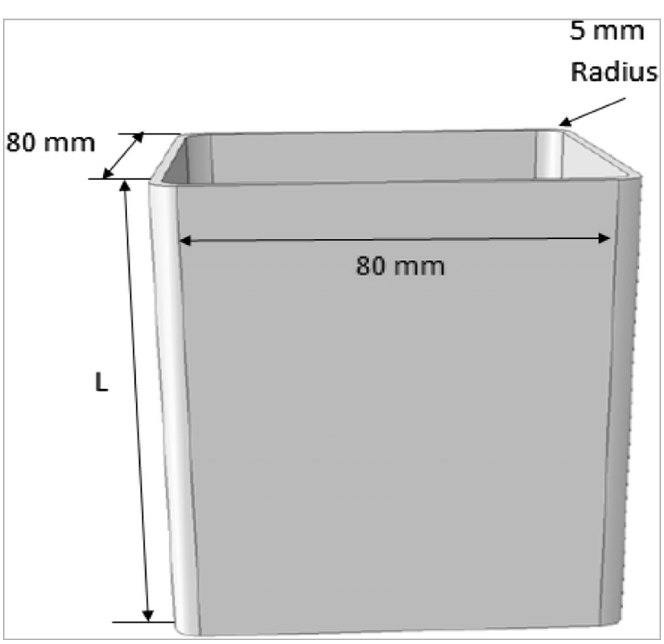

Fig. 2. Schematic diagram of the specimen.

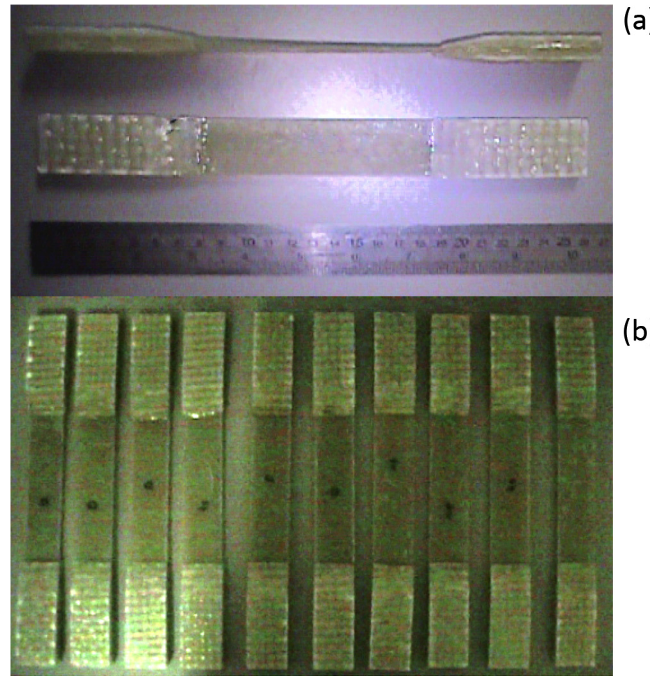

Fig. 3. Top and side view of tensile test specimen (a), tensile specimens with 0° and 90° (b).

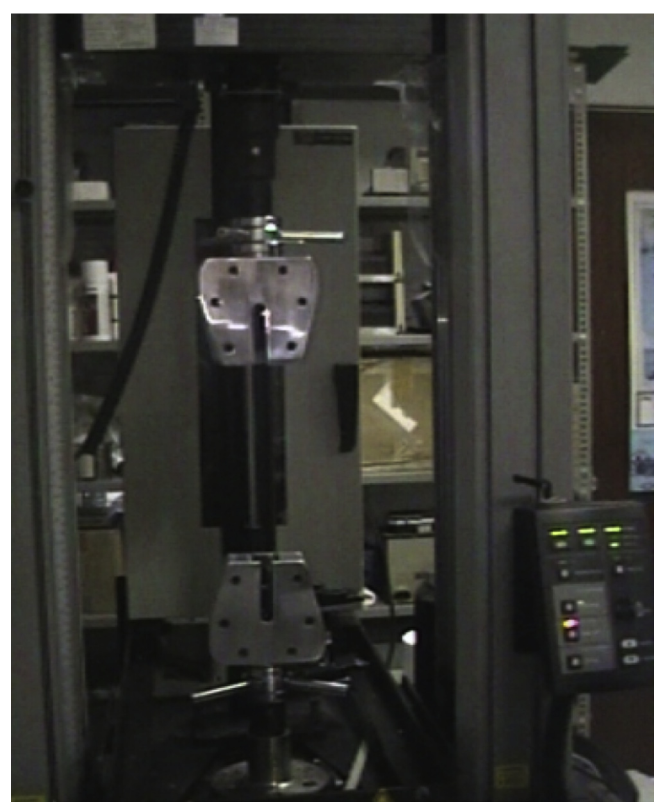

Fig. 4. INSTRON 5567 universal test machine.