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Research paper

The investigation of quasi-static indentation effect on laminated hybrid composite plates

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ABSTRACT

Present study aims to investigate quasi-static indentation (QSI) behavior of fiber reinforced hybrid composites in order to develop basic understanding of low velocity impact events. The goal of QSI tests from this study is to explore energy absorption, and load carrying capacity incorporating two and three different combinations of fibers. Major reinforcing fibers were selected as Kevlar with twill weave, carbon and S-glass fibers with plain weave for designing of hybrid composites. Failure modes and extension of damage mechanisms were characterized by observing the surfaces of the indented samples, and damage assessment was identified through the thickness by the cutting of test samples. The results from this study showed that failure mechanisms in hybrid samples were significantly affected by stacking sequence of the fibers as well as fiber types.

1. Introduction

The use of hybrid composite materials has been increasing in structural and engineering applications in which strength to weight considerations are the major design requirements. It is well known that composite materials are vulnerable to damage resulting from foreign objects due to the inherent brittleness of both the fiber and the matrix. During the impact loading, soft and hard materials result in different failure modes in the impacted materials. When the object is significantly rigid and small, extensive damages reveal around the contact region within the shorter contact time. Hence, the damage extension through the composites strictly depends on the contact force between target and object (Yang and Sun, 1982).

The influence of foreign object impact needs to be predicted as the component may be subjected to a low velocity impact like a dropped tool during the service life. This localized loading generally causes to propagate a damaged area resulting in strength and stiffness reductions. In most cases, these types of impacts reveal the failure that is hardly detectable by visual inspections, leading to significant reduction of the structural performance under service loads (Kaw, 2006; Vasiliev and Morozov, 2001; Bunsell and Renard, 2005; Harris, 1999). It should be noted here that amount of impact damage is effected by many parameters like geometry of support and projectile parameters such as material, size, shape, and angle of incidence, stacking sequence, thickness of the plate and shape of the impactor (Abrate, 1998; Herb et al., 2010).

The measurement of dynamic contact force during the impact event is not easy due to wide range of impact velocities and limitation of experimental technique. During the modelling and evaluation of low velocity impact, static test methods provide much more data with high accuracy compared with impact tests (Nettles and Douglas, 2000). The several researchers (Lee and Zahuta, 1991; Jackson and Poe, 1992; Hongkarnjanakul et al., 2014; Kwon and Sankar, 1991; Kaczmarek and Maison, 1994; Aoki et al., 2007) showed the similarities between low velocity impact and QSI tests, while others (Bull et al., 2015; Lagace et al., 1993) showed the disadvantages and limitations of quasi static tests for impact events.

It is possible to get desired impact resistance and damage tolerance by arranging different property of fibers along with the hybridization. One of most promising properties in hybridization is ‘synergy effect’ which is called ‘hybrid effect’ (Szeluga et al., 2015). In the view of hybrid effect concept, combination of two or more different fibers provides a high structural performance utilizing with each fiber structure helping to get high property of toughness with impact strength and load carrying capacity. A positive or negative hybrid effect may be occurred as a result of hybridization effect. Positive hybrid effect can be explained the resulting value of the composite property which is greater than the value obtained from rule of mixture. Researchers have shown the hybridization effect to improve mechanical properties and damage resistance of composite laminates (Kim et al., 2001; Park and Jang, 1998; Tjong et al., 2003; Salehi-Khojin et al., 2006; Sreekala et al., 2002; Sayer et al., 2010; Gustin et al., 2005; Naik et al.,

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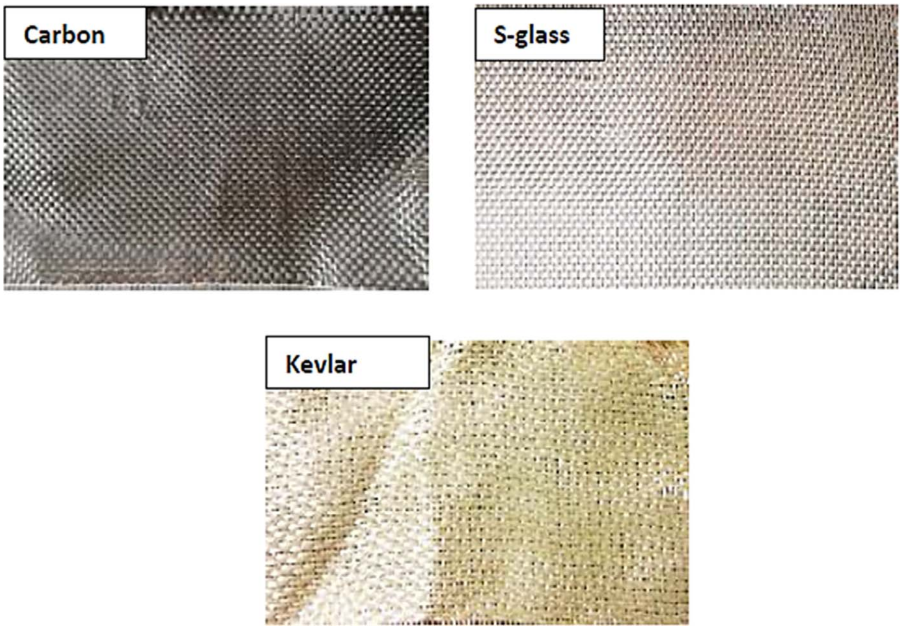

Fig. 1. Fibers used as major reinforcing materials.

2001). Kim et al. (2001) used the glass fiber reinforced composites with different silane coupling agents to study low-velocity impact and compression after impact tests. A strong correlation was found between interlaminate fracture toughness and impact resistance of hybrid composite laminates. Park and Jang (1998) studied impact behavior of Aramid/Glass fiber reinforced hybrid composites. The effects of stacking sequence and fiber volume fraction of the Aramid fiber were examined. It is found that composite laminates exhibit much more impact energy and delamination area when aramid layers are placed at back side of the laminate. However, impact energy of hybrid laminates is not significantly affected by the position of aramid layers. Tjong et al. (2003) investigated the impact properties of Polyimide 6 hybrid composites reinforced with short glass fibers with different ratios. It was indicated that hybrid composites exhibited much more impact strength and absorbed energy compared with Polyimide 6 hybrid laminates, particularly those with low- short glass fibers content. Salehi-Khojin et al. (2006) showed that impact behavior of glass/Kevlar composite laminates was highly sensitive to the role of the temperature at different energy levels (8, 15 and 25 J), influencing the failure mechanisms of the composites. Sreekala et al. (2002) investigated the influence of hybridization of oil palm fibers with glass fibers on mechanical properties of hybrid composite laminates. It was shown that hybridization of glass fibers contributed to increase in mechanical properties of overall hybrid structure showing a positive hybrid effect. Sayer et al. (2010) performed the experimental procedures to study impact behavior of carbon and glass fiber reinforced hybrid composite laminates. Hybrid combinations by carbon and glass fibers showed the highest impact resistance when carbon fibers were placed at tension side and glass fibers at impacted side. Gustin et al. (2005) showed the influence of hybrid Kevlar/carbon fiber reinforced face sheets on low velocity impact performance of sandwich composite plates, by indicating that addition of Kevlar fiber decreased the stiffness of the laminates while increasing energy absorption capacity of the laminates. Naik et al. (2001) performed low velocity impact tests on glass/carbon hybrid composites with different stacking sequences. Impact and post impact compressive behavior of hybrid composites showed the poor notch sensitivity when carbon and glass fibers were placed at outer and inner surfaces, respectively. As a result, the stacking sequence of the fibers played an important role for impact resistance and damage mechanism in performance of hybrid laminates. In this context, the analysis of the damage assessment involved in the impact event is thus needed considering hybrid effect concept.

The present study dealing with the damage characteristics and impact behavior of hybrid composites is organized to investigate study energy absorption and load carrying capacity of the hybrid composite laminates. Quasi-static indentation behaviors of the fiber reinforced hybrid composite laminates were identified to study the parameters of hybridization effect and stacking sequence configurations. Meanwhile, the failure modes and extension of damage mechanisms were characterized by observing the surfaces of composite samples incorporating two and three different fibers.

2. Materials and procedures

2.1. Production of composites

Fig. 1 shows the major reinforcing fibers during the production of hybrid samples. Twill 2 × 2 Aramid, plain carbon and plain S-glass woven fibers were used in the production of hybrid composites. The areal densities of the reinforcing fabrics are 173, 200 and 200 g/m^2 per ply, respectively. Table 1 represents the mechanical properties of the fibers.

Composite laminates were manufactured by using hand lay-up process at the room temperature of 25 °C. Chemical materials as like epoxy, hardener and all of fibers were supplied from Dostkimya Company in Istanbul. For impregnation of fibers, epoxy (Hexion MGS-L285) and hardener (Hexion MGS-H285) were mixed in the ratio of 100:40. Fibers were cut in the sizes of 350 × 250 mm, and were laid the layer by layer by the application of epoxy resin for each step.

Table 1
Mechanical properties of full composite laminates (Bulut and Erklig, 2017).

Fiber type	Areal density (g/m^2)	Tensile strength (MPa)	Elastic modulus (GPa)	Density (g/cm^3)
S-glass	200	3000–5000	72–82	2.48–2.61
Carbon	200	2500–3000	200–700	1.75–1.96
Kevlar	173	2750–3000	82–124	1.44