Effect of Glass Fibers and Aramid Fiber on Mechanical Properties of Composite Based Unmanned Aerial Vehicle (UAV) Skin

Benni F. Ramadhoni[1](✉), Ara Gradiniar Rizkyta[1], Atik Bintoro[2], and Afid Nugroho[2]

[1] Balai Teknologi Polimer, Tangerang Selatan 15314, Indonesia
benni.ramadhoni@bppt.go.id
[2] Pusat Teknologi Penerbangan, Bogor 16350, Indonesia

Abstract. The use of carbon-based fiber that can disrupt radar signal transmission on the flights especially on UAV remains problem. To address the problem, composites based UAV skin using E-glass, S-glass and aramid fibres as well as epoxy resin has been successfully manufactured by vacuum infusion process. Full factorial design of experiment (DoE) and analysis of variance (ANOVA) was performed using Minitab 16 to analyse the effects of layer variations on specific tensile, compression and bonding shear. Fiber configuration was divided into two layers, namely layer 1–9 and 10–18. In general, mechanical properties i.e. tensile strength, bonding shears and compression strength increased compared with epoxy resin properties. Tensile strength and modulus increased by 484% and 204% respectively, while bonding shear and compressive strength increased by 24226% and 94% respectively. The overall result indicated that the best properties of composites-based UAV skin were obtained by the utilization of aramid fiber.

Keywords: Composite · Mechanical properties · UAV

1 Introduction

Property of composite depends on the behaviour of its constituents as well as of the interfaces between the fiber and resin [1]. Development of composite containing more than one type of reinforcement is motivated by the desire to combine advantageous features of reinforcement to improve performance as well as to reduce weight and cost [2].

In aerospace applications, especially Unmanned Aerial Vehicle (UAV), thermoset is more widely used than thermoplastic, due to its easier to fill in the fiber [3]. Among thermoset resins, epoxy is the most commonly used resin, due to its high chemical resistance, excellent dimensional stability, good fiber adhesion and performance under wet conditions.

To increase flight time of UAVs, lightweight materials are needed, namely S-glass, E-glass, aramid, carbon fiber and graphite. More specifically, carbon fiber is the most

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lathifarusita@gmail.com

suitable material for UAV due to its high specific strength-to-weight [4]. However, the use of carbon based fiber can disrupt radar signal transmission on the flights [5].

Processing methods that can be used for manufacturing composite for UAV include vacuum infusion, vacuum bag, hand lay up, resin transfer moulding (RTM), prepreg lay-up and filament winding with oven or autoclave curing [6, 7]. However, hand lay-up and pre-preg lay-up show low reproducibility while RTM and filament winding require sophisticated machine. In contrary, vaccum infusion and vaccum bag require only simple machine, facile set up but manage to produce good reproducibility, and improving fibres-to-resin ratio with minimized of voids so that improve mechanical properties compared with hand lay-up process [8].

In this research, we conducted a study to compare aramid, E glass and S glass fibers as well as hybrid arrangement thereof on the mechanical properties of UAV skin, manufactured using epoxy resin and vacuum infusion process. Main and interaction effect analyses on specific mechanical properties were carried out using ANOVA in Minitab 16.

2 Materials and Methods

2.1 Materials

Epoxy Renlam LY 5138-2and Ren Hy 5138(Huntsman, Indonesia) were used as the matrix and hardener respectively. E-glass EW 130 and S-glass SW220B-90A (JustusKimiaraya, Indonesia) as well as aramid (Coats Rejo, Indonesia) were used as the reinforcement.

2.2 Manufacturing Method

All composites were manufactured using vacuum infusion except for control sample. Control sample was made in advanced from unsaturated polyesther (UP) and a layer of E-glass using hand lay up method.

Table 1 list all layer combinations. In a typical experiment, eighteen layers of fibers were arranged and enclosed by bagging film that connected to inlet and outlet flow tube. Epoxy resin in a container was pumped through a tube to wet the entire laminate. The specimen was placed at room temperature (25 ± 2 °C) up to 3 h for curing.

2.3 Measurement Testing

The cured specimen was conditioned at 23 ± 2 °C and 50 ± 5% humidity over 40 h prior to measurements. Density was obtained using analytical balance following the method in ASTM D792. A typical size specimen was weighed in air (m_{air}) and in a solution ($m_{dissolved}$) and both masses were recorded and the density was calculated. Tensile strength and modulus test were carried out according to ASTM D3039. The tests were carried out at rate of 2 mm/minute. Bonding shear test was carried out in

lathifarusita@gmail.com

Table 1. List of fiber combination

Formula	Layer 1–9	Layer 10–18
1	Aramid	Aramid
2	S-glass	S-glass
3	E-glass	E-glass
4	S-glass	Aramid
5	Aramid	S-glass
6	S-glass	E-glass
7	E-glass	S-glass
8	Aramid	E-glass
9	E-glass	Aramid

accordance with ASTM D5868 using epoxy resin as adhesive. Shear rate was 13 mm/minute. Compression test was carried out in accordance with ASTM 6641. Compression rate was 1.3 mm/minute. All properties were divided by density to obtain specific properties.

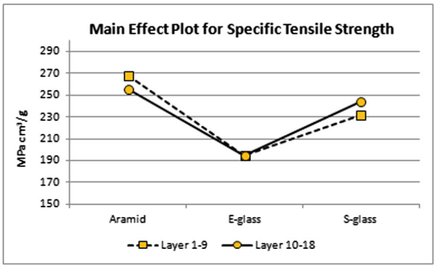
3 Results and Discussion

Main Effect Analysis of Mechanical Properties
Main effect analysis analyze the effect of isolated parameter on property of interest. Figure 1 (a) shows that specific tensile strength of layer 1-9 and 10-18 was mainly affected by aramid fiber, while E-glass fiber had the least effect. These results were consistent with specific tensile strength value of formula 1 (260.66 MPa cm^3/g) and formula 2 (184.16 MPa cm^3/g) in Table 2. E-glass fiber has the lowest strength compared to S-glass and aramid fiber.

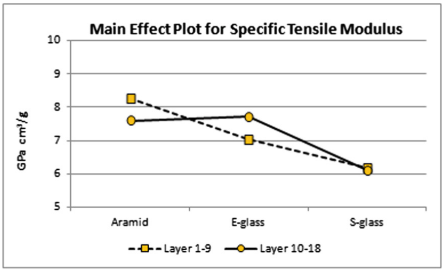
On the other hand, Fig. 1 (b) reveals that aramid and E-glass fiber positively effected specific tensile modulus of layer 1-9 and 10-18 respectively, while S-glass fiber gave the least influence. These followed the results of formula 1, 2 and 3 i.e. 6.81 GPa cm^3/g, 6.67GPa cm^3/g and 4.93 GPa cm^3/g respectively. Figure 1 (c) demonstrates that aramid fiber had the slightest effect on specific compressive strength, while E-glass withstood compressive stress superiorly. Figure 1 (d) shows that specific bonding shear was affected mostly by aramid fiber in layer 1-9 and S-glass fiber in layer 10-18, while E-glass and aramid fiber had minor effect on specific bonding shear in layer 1-9 and 10-18 respectively. Compared to S-glass and E-glass fibers, Aramid fiber not only has the highest specific strength, but also the highest tensile modulus. As well as aramid fiber has high stiffness caused by its symmetrical internal structure [9].

Interaction Effect Analysis of Mechanical Properties
Interaction effect analysis analyze the effect of combined parameter. Figure 2 (a) shows that regardless of aramid fiber has the most effect on specific tensile strength, utilization of whole aramid fiber at 18 layers (formula 1), did not resulted in the highest specific tensile strength. The highest specific tensile strength (321.9 MPa cm^3/g) was obtained

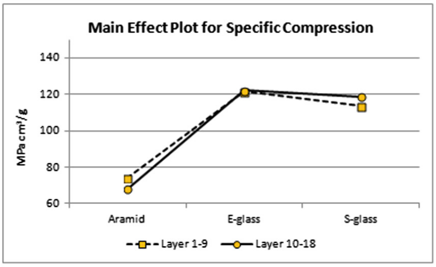
lathifarusita@gmail.com



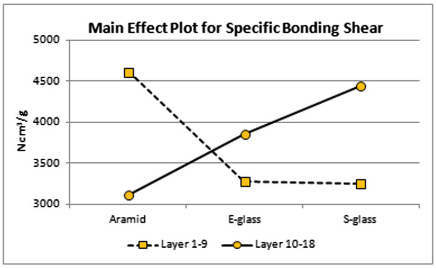
(a)



(b)



(c)



(d)

Fig. 1. Main effect analysis of specific (a) tensile strength (b) tensile modulus(c) compression (d) bonding shear

Table 2. Results of density measurement and mechanical test of composites

Formula	Density	Specific tensile strength (MPa cm3/g)	Specific tensile modulus (GPacm3/g)	Specific compressive strength (MPa cm3/g)	Specific bonding shear (N cm3/g)
1	1.103	260.66	6.81	61.13	3932.91
2	1.679	184.16	6.67	169.65	3817.15
3	1.696	233.01	4.93	129.92	4117.33
4	1.348	282.00	7.83	82.43	3206.23
5	1.404	321.90	7.35	92.08	5390.31
6	1.699	178.96	5.79	128.13	3238.38
7	1.723	176.82	6.07	134.54	3823.56
8	1.295	219.84	10.67	69.60	4519.69
9	1.276	222.88	8.35	61.40	2194.00
Control	1.747	150.51	3.03	55.84	921.00

by combining aramid and S-glass (formula 5). This is also true on applying merely whole E-glass for all 18 layers (formula 3). Whole E-glass fiber reinforced composite did not become the lowest specific tensile strength. The lowest specific tensile strength

lathifarusita@gmail.com

(176.8 MPa cm^3/g) was obtained by combining E-glass and S-glass fiber (formula 7). Similar with specific tensile strength, the highest specific tensile modulus was not resulted from applying whole aramid fiber in every layer. The highest specific tensile modulus (10.7 GPa cm^3/g) was obtained by combining aramid fiber in layer 1–9 with E-glass fiber in layer 10–18 (formula 8). On the other hand, applying S-glass fiber in layer 1–9 with E-glass in layer 10–18 (formula 6) gave the lowest specific tensile modulus (2.6 GPa cm^3/g). Figure 2(c) depict that whole E-glass fiber arrangement (formula 2) showed the best specific compressive strength (169.65 MPa cm^3/g), while whole aramid arrangement (formula 1) gave the smallest one (61.13 MPa cm^3/g). Figure 2(d) shows that combination between aramid and S-glass fiber (formula 1) gave the best bonding shear (5390.31 N cm^3/g), while combination between E-glass and aramid fiber (formula 9) gave the lowest one (2194.00 N cm^3/g).The interaction between two different fibers was responsible for all those results.

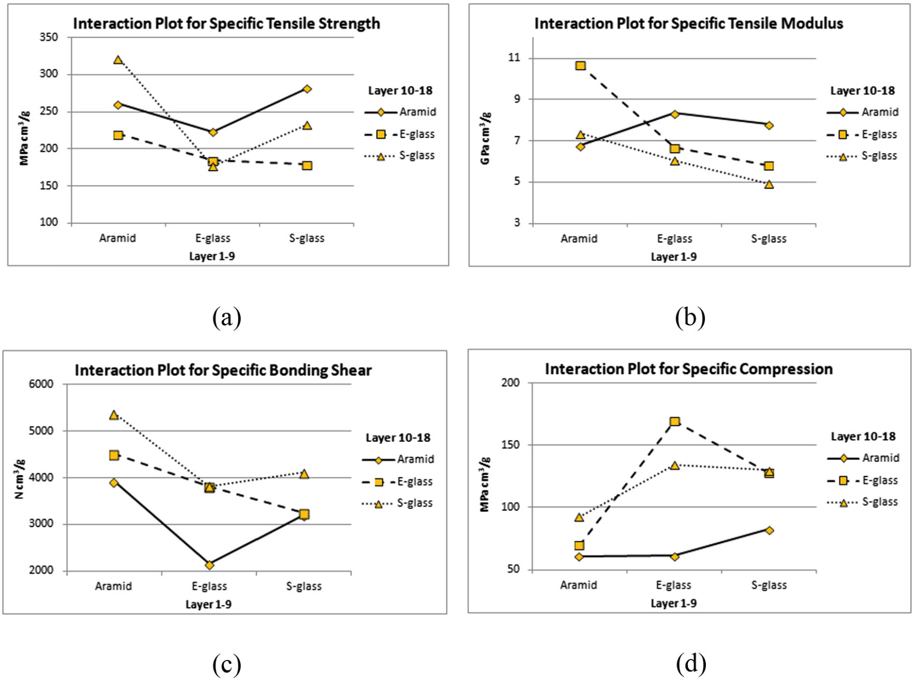


Fig. 2. Interaction effect analysisof specific (a) tensile strength (b) tensile modulus(c) bonding shear (d) compression

4 Conclusion

Composites based UAV skin has been successfully manufactured by vacuum infusion process using epoxy resin as matrix as well as E-glass, S-glass and aramid fibres as the reinforcements. The result show that specific tensile strength and specific modulus was

lathifarusita@gmail.com

mainly affected by aramid fiber. However aramid fiber had the slightest effect on specific compressive strength, while E-glass withstood compressive stress superiorly. The same results also occur at interaction effect analysis of compression that E-glass fiber arrangement showed the highest value.

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lathifarusita@gmail.com