MECHANICAL PROPERTIES OF BIO-EPOXY AND RECYCLABLE BIO-EPOXY WITH MOISTURE ABSORPTION STUDY FOR AEROSPACE APPLICATIONS

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ABSTRACT

This study investigates the development of bio-epoxy materials as an environmentally friendly alternative to petroleum-based epoxy resins in the aeronautical industry. Three different bio-epoxy resins, including two non-recyclable (YDL 5551 and YDL 5561) and one recyclable (YDL 5544), were examined. Moisture absorption tests revealed varying absorption levels among the resins, with the non-recyclable resin (YDL 5561) exhibiting the highest absorption. Mechanical tests, including tensile, compression, and toughness tests, demonstrated the superior performance of the bio-epoxy resin with the highest bio-based carbon content (YDL 5561) in terms of tensile strength, yield strength, and elongation. The recyclable bio-epoxy resin (YDL 5544) also showed promising properties. These findings contribute to the development of sustainable composite structures and highlight the potential of bio-epoxy materials in the aeronautical industry.

1 INTRODUCTION

Composites structures based on epoxy matrix are extensively used in the aeronautical industry because of their high strength-to-weight ratio, chemical resistance, and higher corrosion resistance [20, 21]. However, epoxy resins present 2 mains disadvantages. It is synthetized from petroleum-based bisphenol A (BPA) [2000] and it cannot be recycle [13]. At present, more than 90 % of commercial epoxy resin is produced from petroleum-based bisphenol A (BPA) (Auvergne et al., 2013; Liu et al., 2021). In aeronautics, requirements and design are based on the visibility of the damage [1000]. So even damaged and without detectability, the design should ensure that the structure bears in-service loads: this is the principle of damage tolerance. The main properties driving the impact tolerance of composite laminate, i.e. the mode I and mode II fracture toughness, GIc and GIIc, are the most important [1, 2, 7–12]. The literature states that composites.

2 MATERIALS AND METHODS

2.1 MATERIAL FABRICATION

Three different bio-epoxy have been investigated provided by Aditya Birla Chemical. Two bio-epoxy are non-recyclable (YDL 5551 and YDL5561) while the last is recyclable (YDL5544). The bio-epoxy specimens were manufactured as follows: First, the resin and the hardener were mixed at the associated ratio and mixed thoroughly. Then, deglazing has been performed at 40°C and under a pressure of 1 bar for 240 min. Finally, the bio-epoxy was poured into metallic moulds. The curing conditions for each of these bio-epoxy are detailed in Table 1. Ten specimens have been produced per test and per type of bio-epoxy given a total of 120 specimens.

Reference	% of bio-based carbon content of resin	Tg (°C)	Curing condition
YDL5544 (recyclable)	22-23 %	105-115	80°C/25mins + 140°C/4h
YDL5551 (non-recyclable)	33 %	150-160	25°C/24h + 80°C/25mins + 140°C/4h
YDL5561 (non-recyclable)	48.9 %	120-130	80°C/25mins + 140°C/4h

Table 1. Bio-epoxy data

2.2 Moisture absorption tests

All specimens have been firstly heat at 100°C during 24h in order to remove the water and mass has been measured at the end of the process using a weight balance having a precision of 0.001 ± Xg. In order to study the effect of moisture absorption on the mechanical properties 5 specimens for each type of test have been placed in a container of water (70°C) for 14 days and mass has been recorded. The increase of mass is calculated using the following formula:

increase of mass=100×(M_1-M_0)/M_0 (1)

Where M0 and M1 are the mass after 24h at 100C and the mass after water processing respectively

2.3 Mechanical tests

All tests have been measured using a screw driven Instron machine with a 100 ± 10 kN load cell. Tests have been conducted under controlled environment in term of temperature (25°C) and humidity (40) following the NADCAP certification (REF). For each type of mechanical experiment, 5 specimens have been tested after processing the heat at 100°C during 24h and 5 after the moisture absorption process.

2.3.1 Tension tests,

Dog-bone specimens have been used and detailed geometry and dimensions are given in Figure 1a. An extensometer has been used to record the strain until a deformation of 3000µ Then, to avoid extensometer failure it has been removed and strain has been calculated using the UTM displacement. Tests have been conducted with a constant velocity of X mm/min following the ASTM D638

2.3.2 Compression tests

Following the ASTM D695, constant velocity of 1.7 mm/min, corresponding to an initial nominal strain rate of , has been used. To analyze the experimental results, the standard definitions for the engineering strain and stress have been used. Specimen geometry and dimensions are given in Figure 2a.

2.3.4 Toughness tests

Toughness tests have been carried out following the standard ASTM D5045. The geometry of the specimen is provided in the Figure 4a The distance between the two lower spans was 32 mm (Figure 4b) and the applied constant velocity was 2 mm/min. Round steel bars have been used as supports having a diameter of 1.7 mm.

The fracture toughness is given by:

K_Q=(P_Q/(BW^ (1/2)))f(x) (2)

Where KQ has a unit of MPa.m1/2, PQ is the critical load (kN), B and W are the specimen thickness (cm) and width (cm) respectively and finally a0 is the initial crack length (cm).
The validity of KQ is checked via the size criteria. KQ is equal to K1c if the following criteria are satisfied:

$$B, a, (W - a) > 2.5 \left(\frac{K_Q}{\sigma_y}\right)^2 \quad (3)$$

3 RESULTS

3.1 Moisture absorption

Increase of mass (%) is given for each bio-resin and for each test. It can be noted that compression specimen presents a lower moisture absorption compared to the others test specimen due to its higher volume. The bio-epoxy YDL5561 having the highest bio-based carbon content of resin (48.9%) shows the greatest moisture absorption while the bio-epoxy YDL5544 (27-28%) has the lowest measures.

The increase of mass divided by the bio-based carbon content of resin ratio has been calculated for each bio-epoxy reference and for each test type (Figure 6). As observed, constant ratio is determined for the 2 non-recyclable bio-epoxy and therefore the mass absorption is proportional to the quantity of bio-based carbon content. Proportionally to its bio-based carbon content, recyclable bio-epoxy absorbs more water as it shows a higher ratio than the 2 non-recyclable bio-epoxy.

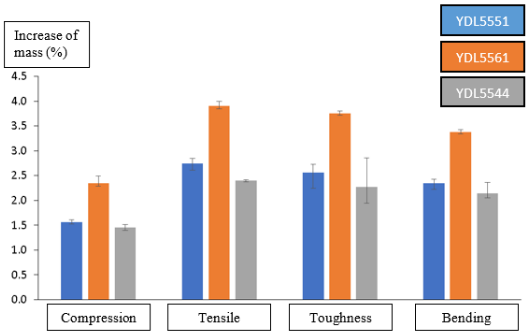

Figure 1: Moisture absorption.

3.2 Tensile results

Stress-strain curves are given for the recyclable bio-epoxy YDL 5544 (Figure), the bio-epoxy YDL 5551 (Figure) and finally the bio-epoxy YDL 5561 (Figure). Stress-strain response consists firstly in the elastic behavior (1), followed by the plastic behavior (2) and finally the failure (3). It can be noted the good reproducibility of the results for the elastic part while a large dispersion for elongation is observed.

Comparison between the different bio-resin of the young modulus, yield strength and elongation is given in the Figure 2. For these 3 properties, the resin YDL5561, having bio-source content of 48.9%, has the highest values while the resin YDL5551 (bio-source).

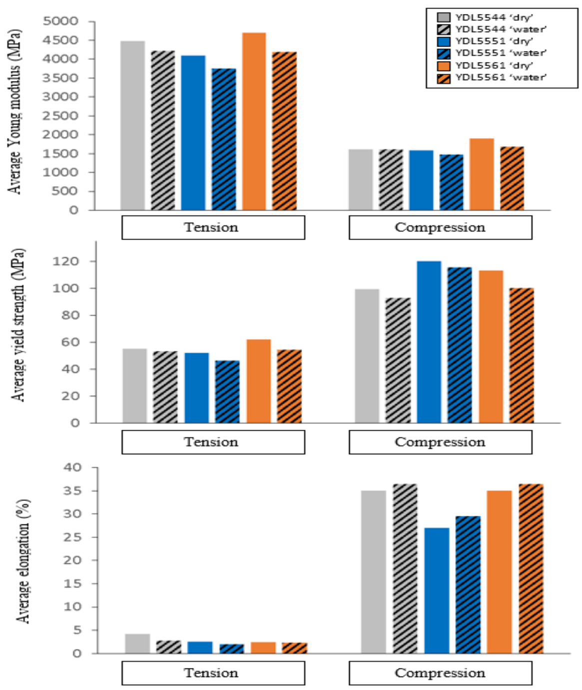

Figure 2: Comparison between the different bio-resin of the young modulus, yield strength.

3.3 Compressive results

Stress-strain curve in compression are provided for the recyclable bio-epoxy YDL 5544 (Figure), the bio-epoxy YDL 5551 (Figure) and finally the bio-epoxy YDL 5561 (Figure). Stress-strain response consists firstly in the elastic behavior (1), followed by a slight decrease of stress (2), then the plastic behavior (3) and finally the crush of the specimen (3). As in tension, it can be observed the good reproducibility of the results for the elastic part while failure presents a dispersion. Decrease of stress observed after the yield strength is not present for the bio-epoxy YDL5551.

The bio-epoxy (YDL 5561) having the highest bio-source content (43.9%) presents the highest Young modulus in compression as observed in tension. Contrary to the tension results, this bio-epoxy shows a lower yield strength than the bio-resin having the lower carbon content (33%). As in tension, the recyclable bio-epoxy exhibits the greatest elongation. Finally, the same effect of the water is. observed on the mechanical properties excepted for the elongation.

9 CONCLUSIONS

The study focused on the development of bio-epoxy materials as environmentally friendly alternatives to petroleum-based epoxy resins in the aeronautical industry.

Three different bio-epoxy resins were examined, including two non-recyclable (YDL 5551 and YDL 5561) and one recyclable (YDL 5544) resin.

Moisture absorption tests showed varying levels of absorption among the resins, with the non-recyclable resin (YDL 5561) exhibiting the highest absorption.

Mechanical tests, including tensile, compression, and toughness tests, demonstrated the superior performance of the bio-epoxy resin with the highest bio-based carbon content (YDL 5561) in terms of tensile strength, yield strength, and elongation.

The recyclable bio-epoxy resin (YDL 5544) also showed promising mechanical properties.

These findings highlight the potential of bio-epoxy materials in the aeronautical industry and contribute to the development of sustainable composite structures.

Further research and development of bio-epoxy materials can lead to more environmentally friendly and recyclable options for aerospace applications.

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