Flexural Properties of Al/Floral Foam Sandwich Composite Prepared by Hand Lay Up Process

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Abstract. The flexural properties of aluminum sheet as the facings and floral foam as the core in layered sandwich composite were studied under three-point bending test. Adhesion of core onto aluminum sheets was done by manually spreading mixture of epoxy resin and hardener via hand lay-up procedure. There were four system studied, which are single foam-core sandwich system until four foam-core sandwich system. It was found that single foam-core sandwich has the highest flexural strength over the range of Al/floral foam-core sandwich system. The single foam-core sandwich has a well stress or total load distribution as compared to other three types of sandwiches. The smaller thickness to width ratio of single foam-core system is believed to enable the homogenous stress distribution of loading during testing. In addition, several modes of failure found such as delamination, crack and core failure. As the number of layers of sandwich increase, there were more modes of failure occur, which mostly due to the core failure of floral foam.

1 Introduction

A structural sandwich consists of face panels, a core material and adhesives to join them together. It is the structure composed of two thin, stiff face layers, separated by a thick, mid-layer of low-density materials. The faces protect the relatively vulnerable core material against damage or weathering [1]. The core layer is usually made of cellular polymeric foam materials, such as polyvinylchloride (PVC), polyurethane (PU), polystyrene (PS) while metallic and non-metallic honeycombs, balsa wood or trusses are the most common. In composite sandwiches, the faces are typically composite sandwiches or metals such as aluminum. Face panels are typically 0.3 to 13mm thick. They are chosen on the basis of weight, strength and in term of fabrication. A proper sandwich design based on dense face sheets can optimise compressional, tensional, torsional or flexural properties much more efficiently [2, 3]. Among many others, sandwich panels with metal and fibre reinforced plastics (FRP) skins have been investigated experimentally and analytically by several researchers over the years [4].

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1.1 Foam core sandwich panel

Under polymer matrix composites (PMCs), polymer is the medium which holds the reinforcing fibres in place. In order to giving the highest stiffness to weight ratio of common materials design, sandwich construction has been developed and improved to produce even tougher and lighter polymer composites in the future. This requires more reliable predictions about behaviours of polymer especially under extreme conditions.

A sandwich structure must have thin, dense, high strength facings, a low-density core, which is usually thick, relatively weak and a rigid attachment between them. If any one of those key requirements is missing, the structure is not a sandwich [5]. Stuart (1992) states there are no required relationship between the thickness of facings and the thickness of the core. However, in most practical cases, the core is at least three or four times the thickness of the facings and the more efficient sandwich structures are normally observed to have cores an order of magnitude thicker than the facings.

1.2 Adhesive technology

There are different types of adhesives for plastics including cyanoacrylates, urethanes, acrylics and epoxies. Cyanoacrylates are adhesives that cure at room temperature thus, mixing is not required. They produce bonds within a few minutes and some formulations can even achieve 89% of their bond strength after one hour. Cyanoacrylates have excellent shear and tensile strengths. However, they do have poor solvent resistance and poor peel strength. It can attack certain plastics such as polycarbonate (PC) that causes chemical stress cracks.

Solvent free products, for instance, acrylic adhesives, form a thermoset polymer bond with plastics. Upon exposure to light, cured acrylics will produce bonds. Its bond strength and curing times can be varied through intensity and exposure to the curing light. Acrylic adhesives produce polymer bonds that have good weather resistance but excessive oxygen exposure during bonding will produce weak bonds.

Urethane adhesive is available in one and two part systems. With the application of a catalyst or heat, curing time is able to be regulated and minimal surface is needed. Adhesive bonds of urethane adhesives are flexible and have good mechanical properties [6]. Epoxies are adhesives that have been used extensively in the automotive industry for body panels and components. Epoxies are usually a two part mixed system, one part epoxy and the other is catalyst or curing agent. By addition of heat, curing times can be accelerated. However, toughened formulations have been developed to improve impact resistance. Adhesive bonds are typically stronger than the substrates and epoxy adhesives offer excellent resistance to various chemicals such as dilute acids, bases, solvents and oils. Besides, these adhesives offer good weatherability.

1.3 Failure modes

The compressed face of a sandwich panel is typically a thin metal sheet which is restrained against its tendency to suffer local buckling by support from the core material. The beams of the sandwich panel are made of face and core materials that yield. Three modes of failure occur: face yielding, face wrinkling and core shear. Debonding is not a significant mode of failure in beams that do not have large flaws in the adhesive layer. Triantafillou and Gibson, 1987 noted that yielding strength of the core may fail because most resin adhesives used in sandwich panels are brittle; they fail by sudden propagation of cracks, causing debonding and delamination (Fig. 1) [7]. Debonding does not happen all the time. Most of the sandwich beams tested failed by face yielding, face wrinkling or core shear, only three failed by debonding and four by local crushing of the core.
2 Methodology

2.1 Materials

Floral foam is the core material for sandwich composite. It is dry and rigid floral foam which is mainly for artificial flower arrangement. For the skin, aluminum sheet is used for sandwich composite. The thickness for each face sheet is approximately 0.35mm. Epoxy resin 331 and hardener 8161 is the two-part adhesive for sandwich composites. The epoxy 331 is clear, with epoxide equivalent weight of 182-192, liquid diglycidyl ether of bisphenol-A (DGEBA). Hardener 8161 is a clear curing agent (isophorone diamine (IPD)).

Adhesive was the mixture of epoxy hardener and resin with ratio of 2:1. The adhesive acted as the binder for the floral foam to be bonded to aluminum sheets. Epoxy resin and hardener were weighed using analytical balance in the ratio of 1:2 and mixed well for 2 minutes.

2.2 Hand lay up process

The floral foam core and aluminium sheets were cut into desired dimensions as tabulated in Table 1. Core and aluminium sheet had the same length and width.
Table 1. Core and aluminium sheet dimension.

| Element | Dimension (cm) |
|---------|----------------|
| Length  | 20             |
| Width   | 3              |

The adhesive mixture was spread using a flat blade onto aluminum sheets and slightly pressed the core to the surface of aluminium sheets. The sandwich composite was left for 2 days to ensure the sandwich composite to be cured completely. The sample dimension was prepared as in Table 2.

Table 2. Sample dimension.

| Sample                                      | Set Up                                      |
|---------------------------------------------|---------------------------------------------|
| Control (Double Aluminium sheets)           | ![Diagram](image1.png)                      |
| Length/cm: 20                               | ![Diagram](image2.png)                      |
| Width/cm: 3                                 | ![Diagram](image3.png)                      |
| Thickness/cm: 0.12-0.13                     | ![Diagram](image4.png)                      |
| Control (Floral foam)                       | ![Diagram](image5.png)                      |
| Length/cm: 20                               | ![Diagram](image6.png)                      |
| Width/cm: 3                                 | ![Diagram](image7.png)                      |
| Thickness/cm: 1.3-1.7                       | ![Diagram](image8.png)                      |
| Single layer core sandwich composite        | ![Diagram](image9.png)                      |
| Length/cm: 20                               | ![Diagram](image10.png)                     |
| Width/cm: 3                                 | ![Diagram](image11.png)                     |
| Thickness/cm: 1.75-1.80                     | ![Diagram](image12.png)                     |
| Double layer core sandwich composite        | ![Diagram](image13.png)                     |
| Length/cm: 20                               | ![Diagram](image14.png)                     |
| Width/cm: 3                                 | ![Diagram](image15.png)                     |
| Thickness/cm: 3.37-4.00                     | ![Diagram](image16.png)                     |
| Three layer core sandwich composite         | ![Diagram](image17.png)                     |
| Length/cm: 20                               | ![Diagram](image18.png)                     |
| Width/cm: 3                                 | ![Diagram](image19.png)                     |
| Thickness/cm: 5.05-5.30                     | ![Diagram](image20.png)                     |
2.3 Flexural analysis

Flexural test was performed to measure flexural strength and flexural modulus according to ASTM D790-10 standard using Universal Testing Machine (Instron 5569) with a 5kN load cell. Crosshead displacement rate of 50 mm/min was constant throughout the test with span of 16 cm. Five samples are prepared for each system.

3 Results and discussions

The floral foam cells were crushed and collapsed during bending and compression, thus its curve assembled many failures where a sharp drop in flexural stress were being observed (Fig. 2). The sudden sharp decrease in the floral foam graph shows the complete failure of the foam core, which represent the complete fracture of floral foam. Single foam core sandwich composite possesses a smoother curve where the flexure stress increased until the 5% strain and started to decline until a broad peak being observed. The broad peak indicated the bending of the foam core reaching an end with the crushed foam near the support. At this point, crushed and collapsed foam cells are no longer support the flexure loading.

Curve for double foam cores sandwich shows a sharp decrease after 10% of flexure strain. It might be due to core failure that tends to occur at the second layer of foam core. The facings of sandwich composite provided the strength for the sandwich until the second failure occurred. Besides, Al sheet which act as the skin was easily debonded from the second foam core. The debond failure mode makes the second foam core vulnerable to crack initiation because the foam core is rigid and brittle.

The curve presented by three foam cores shows significant drop in flexural stress but the flexure strain of the sandwich composite was improved as compared to single foam core and double foam cores sandwiches. Higher flexure loading is needed as the amount of Al sheets increases with every stacked of foam core. Al sheets provide the resistance to bending of the sandwich composite.

The flexural strength of four foam cores sandwich was quite similar to three foam cores. However, its flexural strain increased because of the amount of Al sheets that possesses high ductility. Continuous flexural loading affected the foam core as it failed along the increase in loading but Al sheets exhibit highest modulus of elasticity that helped to support the bending process [8]. The core or skins can fracture under such stress besides the interface between the skins and the core.
Fig. 2. Load displacement of double Al sheets, floral foam and four different types of sandwich composite.

As shown in Fig 3, single foam core sandwich has the highest flexural strength in comparison to double-foam-core sandwich, three-foam-core sandwich followed by four-foam-core sandwich. This is because of the single-foam-core sandwich has well stress or total load distribution as compared to other three types of sandwiches. Load is not distributed efficiently from the first foam-core layer until the final layer of foam-core as cracks or skin-foam delamination tends to fail the sandwich composite during flexural testing.
There is cracking in core of sandwich composite under three-point bending near support as shown in Fig 4. In the region between the loading point and the supporting point, small shear cracks were generated inside the core. The increasing thickness of sandwich composite shows more core failures as compared to double foam-core sandwich. Sandwich composite experienced less flexural modulus as the Al facings limit the bending of sandwich composite. The Al sheets were not stiff enough to prevent any skin indentation and local crushing of the core below the loading point or above the supporting points. The cracks region is where maximum shearing stresses generated under flexural loading [3].

There were small cracks coalesced and formed a single leading crack with further flexural loading on the left side of the sample. Weak adhesion between foam and Al sheets also contributed to this failure mode.

In Fig 5, the delamination happens at the first layer of the sandwich composite, where further loading contribute to failure and the second foam core was being forced into continuous delamination. Delamination of the cores and the facing is another important failure mechanism [3][9]. The epoxy adhesive joining the foam cores to polymer matrix composite skins is usually stronger than the foam. Thus, failure generally occurs at the adhesion area.
Fig. 5 Deformation of four layers foam core sandwich composite.

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