Three Point Bending of Top-Hat Stiffened Chopped Short Fibre Ramie/HDPE Thermoplastic Composite Beam

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Abstract. The use of natural fibre and thermoplastic matrices in composite materials increased significantly during the last decade especially in the automotive industries. Ramie is one of these potential natural fibres. In this paper, a three point bending of top-hat beam made of ramie/HDPE (High-Density-Polyethylene) composites was performed. Top-hat stiffened structures were common structures found in the aerospace industries. Nevertheless, these structures are beginning to be applied in automotive structures in the forms of chassis and bumpers. The ramie/HDPE composite was manufactured using hot-press technique. The temperature was set to be 135°C and the pressure was 6 bars. Chopped short ramie fibre was used, due to good drape ability characteristics. The experiments showed that the beams produced a large non-linearity. Linear Finite Element Analysis was carried out to be compared with the experimental data. The differences are reasonable.

1. Introduction
The use of natural fibre composites have increased drastically during the last decades, especially for automotive industries in European countries. European countries and Japan has released stringent guidelines for environmental effects for their automotive products. European Union legislation stated that by 2006, 80% of a vehicle must be reused or recycled and by 2015 the percentage is increased to 85%. Japan requires that 88% of a vehicle should be recovered in 2005, rising to 95% by 2015 [1]. The new legislation forces automotive industries to evaluate the environmental impact of a vehicle’s entire lifecycle. The cost and energy to produce of natural fibres are also considerably less than their glass or carbon fibres counterparts. Natural fibres cost US$200 – 1000/ton and use 4 GJ/ton to produce, compared to glass fibres (cost US$1200 – 1800/ton and energy to produce 30GJ/ton) or carbon fibres (cost US$12500/ton and energy to produce 130 GJ/ton) [2]. Kenaf, hemp, banana, sisal and also wood fibres are commonly used in natural fibre composites [3] as well as date palm fibres [4] and jute fibres [5].

Both thermosetting and thermoplastics have been used as matrices. However, thermoplastics matrices are gaining more attention due to the fact that these materials could be recycled more easily. Several thermoplastic matrices have been used, such as Polyethylene (PE) and Polypropylene (PP). The study of Ramie Fibre Reinforced Polypropylene (RF-PP) and their mechanical properties have been studied extensively [6, 7]. In this paper, Ramie Fibre Reinforced High Density Polyethylene (RF-HDPE) was used and studied. Chopped short fibre arrangement was used, due to better drape ability characteristics, compared to unidirectional or woven fabric layups. Therefore, it will be easier to be
manufactured into form such as top-hat beams. The tensile strength characteristic of chopped short ramie fibre and HDPE matrix has been studied previously [8].

The use of natural fibre composites in the automotive industries usually confined into secondary structures, such as door panels, instrument panel support or interior structures [3]. However, the use of glass fibres and carbon fibres in the main structures of aerospace, rail and automotive vehicles had been developed and studied. Glass fibre reinforced plastics (GFRP) composite has been used as a structural bogie component for urban subway trains [9] and a double hat shaped tube made of carbon fibre epoxy has been studied for car vehicle body frame [10].

In the aerospace industries, the use of top-hat structures was fully established in the design of a composite wing and fuselage. For thermoplastic matrix composite, top-hat structures have been implemented in fuselage floor structures, due to ease of manufacture. Therefore, the three-point-bending of top-hat structures are important in the development of fuselage floor beam structures.

In this paper, a top-hat structural beam made of chopped short RF-HDPE composite was manufactured, tested and analysed to study its characteristic. A three point bending test was carried out to study their stiffness and energy absorption capacity, and the finite element analysis was performed to be compared with the experimental data. The structure has a potential to be applied in light-weight automotive and rail components.

2. Specimen Manufacturing and Testing

The top-hat structures were manufactured using chopped RF-HDPE composites. The HDPE in the form of powder was mixed with chopped ramie fibres and placed into a hot-press machine. The temperature was set to be 135°C with the pressure of 6 bars for 1 hour. The fibre volume ratio was set to be 50% with the rest is HDPE powder. The resulted RF-HDPE composite plate was cooled down and cut into square plate with dimensions of 120 x 120 mm. The manufacturing detail can be found in [8].

In order to manufacture a top-hat beam structure, a RF-HDPE composite plate was heated in an oven until it was soft and quickly pressed to form a hat beam. The beam was then bolted with the lower plate to form a top-hat beam structure. The beam was then tested in a three-point bending test. Fig.1a shows the beam structures, while Fig.1b shows the three-point bending test.

![Figure 1. RF-HDPE beam structures (left) and Three-point bending test (right)](image)

3. Finite Element Analysis

A Linear Finite Element Analysis was performed. ANSYS software package was used extensively. Figure 2 shows the specimen dimension and the finite element model. A three dimensional brick element was used thoroughly. Three steel bolts were inserted to join the hat structure with the lower plate. The loading was given in the upper part of the hat. The mechanical characteristics of the RF-HDPE material are: Young Modulus was 489 MPa, shear modulus was 183 MPa and the Poisson’s ratio was 0.3. The mesh size was 3 mm with the skewness ratio of 0.4.
4. Results and Analysis
The experimental result in the form of load-displacement curves can be found in Figure 3 for the three specimens, while the data summary is given in Table 1. Figure 3 shows that RF-HDPE beam structures experienced high plasticity regions before failed. This is due to the behaviour of HDPE thermoplastics which has high plasticity region. This region is important in absorbing impact energy and thus increasing crashworthiness characteristics. The beam is able to absorb in the order of 37 Joule.
Figure 3. Experimental load-displacement curves for the three specimens

Table 1. Summary of Experimental Data

| Specimen No. | Maximum Load (N) | Maximum Displacement (mm) | Absorbed Energy (Joule) |
|--------------|------------------|---------------------------|-------------------------|
| 1            | 1690             | 19                        | 27                      |
| 2            | 2164             | 23                        | 39                      |
| 3            | 1991             | 29                        | 44                      |
| Mean         | 1948             | 24                        | 37                      |

In this work, a linear finite element analysis was performed and will be compared with the experimental data. Since linear finite element was used, the analysis was limited to the yield point. Figure 4 shows the finite element results. It shows the loading condition and the displacement results.

Figure 4. Loading conditions and displacement result

The maximum displacement was in the middle of the upper plate, as expected. The loading was modelled using actual plate with contact condition. The loading plate was made of steel. Since the loading was
modelled using a contact problem, the maximum displacement was in the centre of the upper plate. It should also be noted that the displacement on the lower plate was considerably lower than the maximum displacement.

Table 2 shows the comparison between the experimental data and the finite element analysis in the yield region. Table 2 shows that the finite element results are reasonable compared to the experimental data.

| Specimen No. | Experiment Data | Finite Element Results |
|--------------|-----------------|------------------------|
|              | Load (N)        | Deformation (mm)       | Load (N) | Deformation (mm) |
| 1            | 750             | 2.2                    | 750      | 1.84             |
| 2            | 700             | 2.1                    | 700      | 1.71             |
| 3            | 450             | 2                      | 450      | 1.12             |
| Mean         | 633             | 2.1                    | 633      | 1.56             |

The discrepancies between the finite element results and the experimental data are due to the fact that the beams are highly non-linear, due to the characteristics of the HDPE thermoplastic matrices. Figure 5 shows the failure characteristics of the beam due to three-point bending. It shows that high plasticity happened in the upper compressive plate of the beam. Therefore, it was obvious that the experimental data shows greater displacement compared with the finite element results even in the yield region.

![High non-linear behaviour of the beam](image)

5. Conclusion

The paper presents a three-point bending of chopped short ramie fibre and high-density polyethylene (RF-HDPE) thermoplastic composite beam structures. Experiments were performed and the resulted data were compared with a linear finite element analysis using ANSYS. The beam structures showed high non-linear behaviour due to the high plasticity characteristics of the HDPE thermoplastic matrices. Linear finite element analysis compared satisfactorily with the experimental data in the area before yield occur. The energy absorption capacity was calculated from the experimental data. From the analysis, it shows that the RF-HDPE beam structure has the potential to be applied in the energy absorbing structures, in the aerospace, rail and automotive vehicle structures.

6. References

[1] Holbery J, Houston D 2006 JOM J. Minerals, Metals and Material Society 58, issue 11, 80-86.
[2] Huda MS, Drzal LT, Ray D, Mohanty AK, Mishra M, 2008 Properties and Performance of Natural Fiber Composites, Woodhead Publishing, 221-268.
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