ANALYSIS OF THE MECHANICAL PROPERTIES OF ADDITIVELY MANUFACTURED KEVLAR FIBRE COMPOSITES AND THEIR USE IN LAP-BONDED JOINTS

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MAE06
INTRODUCTION
Properties of Kevlar

HIGH TENSILE STRENGTH

LIGHTWEIGHT

HIGH RIGIDITY

HIGH TOUGHNESS
FUSED DEPOSITION MODELLING

3D-PRINTING

TRADITIONAL METHODS OF MANUFACTURING

EXPENSIVE

TIME-CONSUMING

CHEAPER

REDUCED TIME

FUSED DEPOSITION MODELLING (FDM) IN ADDITIVE MANUFACTURING
FUSED DEPOSITION MODELLING

3D-PRINTING

Process in which successive layers of materials are being deposited on the print bed

3D printed reinforcements have shown potential in real-world applications due to its increased shear strength at bond regions.

Allows for the printing of special computer designed parts with complex geometries

Highly advantageous for the manufacturing of lap joints as it allows for spatial tailoring of the adhesive bond geometries.
Adhesively bonded joints are used in joining of two or more components in complicated structures, especially in the aerospace industry.
RESEARCH OBJECTIVES

1. MECHANICAL PROPERTIES ANALYSIS
   To analyse mechanical properties of additively manufactured Kevlar reinforced thermoplastics manufactured by FDM method of 3D printing

2. BOND GEOMETRY ANALYSIS
   To investigate the effect of varying the bond geometry of fillets for single lap joint configuration

3. FAILURE ANALYSIS
   To analyse the failure of 3D-printed single lap bonded joints
TIMELINE OF RESEARCH INVESTIGATION
A brief overview

3D PRINTING
The printing of the test specimens are being conducted

SPECIMEN TESTING
Testing of the lap joint specimens

SPECIMEN TESTING
Testing of the Kevlar Tensile specimens

DATA ANALYSIS/WRITING OF JOURNAL PAPER

SPECIMEN TESTING
Testing of flexural and quasi-static indentation specimens
All specimens are modelled using CAD Software, SolidWorks®.

File is saved and transferred in the stereolithography file format.

The designed part is further processed using the software provided by Markforged, ‘Eiger’, which interfaces with the printer.

Mark One Composite 3D printer by Markforged Inc. is used for printing specimen.
METHODOLOGY
TENSILE TEST SPECIMENS

DIMENSIONS

Length: 250mm
Width: 15mm
Thickness: 1mm thick

8 layers of fibre printed unidirectionally (0°) and 2 layers of nylon

*in accordance with ASTM D3039/D3039M-17 (Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials)
METHODOLGY
FLEXURAL TEST SPECIMENS

DIMENSIONS

Length: 154mm
Width: 13mm
Thickness: 4mm thick

Support span of 128mm and printed unidirectionally (0°)

*in accordance with ASTM D7264/D7264M-15 (Standard Test Method for Flexural Properties of Polymer Matrix Composite Materials)
METHODOLGY
QUASI-STATIC INDENTATION TEST SPECIMENS

DIMENSIONS

Length: 100mm
Width: 100mm
Thickness: 1.6mm thick

Fibre direction [0/45/90/-45] for 14 layers.

*in accordance with ASTM D6264/D6264M-17 (Standard Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer-Matrix Composite to a Concentrated Quasi-Static Indentation Force)
METHODOLOGY

LAP JOINTS SPECIMENS

1. SIMPLE LAP JOINTS

2. LAP JOINTS WITH SPEW-FILLET

3. LAP JOINTS WITH CONVEX-FILLET
METHODOLOGY
QUASI-STATIC INDENTATION TEST SPECIMENS

DIMENSIONS

Length: 101.6mm
Width: 25.4mm
Thickness: 2.5mm thick
Area of bond: 25.4*25.4 mm²

Scaled down to 0.6 times of the ASTM specified dimensions. End-tabs are provided to avoid eccentricity in loading.

*with modification to ASTM D5868-01 (Standard Test Method for Lap Shear Adhesion for Fiber Reinforced Plastic (FRP) Bonding)
LAP JOINTS WITH SPEW-FILLET

Adherends

Bond area

$\theta = 45^\circ$

25.4mm

25.4mm

0.76mm

2.5mm

101.6mm
LAP JOINTS WITH CONVEX-FILLET

LAP JOINTS SPECIMENS

Adherends

Bond area

Radii = 8mm

25.4mm

101.6mm

0.76mm

2.5mm
METHODOLGY
QUASI-STATIC INDENTATION TEST SPECIMENS

TESTING

Equipment: A Shimadzu AG-X UTM with load cell of 10kN

Cross-head displacement: 1mm/min.

*in accordance with ASTM D5868-01 (Standard Test Method for Lap Shear Adhesion for Fiber Reinforced Plastic (FRP) Bonding)
RESULTS AND DISCUSSION

TENSILE TEST SPECIMEN

Table 1. Tensile properties of Kevlar fibre reinforced nylon matrix composite, a comparison.

<table>
<thead>
<tr>
<th></th>
<th>Manufacturer’s data</th>
<th>Experimental value (avg.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate strength (MPa)</td>
<td>610</td>
<td>513.9 ± 52.9</td>
</tr>
<tr>
<td>Young’s modulus (GPa)</td>
<td>27</td>
<td>14.2 ± 1.3</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

TENSILE TEST SPECIMEN

TENSILE STRENGTH: UNI-DIRECTIONAL (0°) KEVLAR FIBRES
RESULTS AND DISCUSSION

FLEXURAL TEST SPECIMEN

FLEXURAL STRENGTH: UNI-DIRECTIONAL (0°)

KEVLAR FIBRES
The maximum Flexural Stress on any point of the load–deflection curve is found by,

\[ \sigma = \frac{3PL}{2bh^2} \]

The maximum strain on any point of the load–deflection curve is found by,

\[ \varepsilon = \frac{6\delta h}{L^2} \]

Table 2. Flexural properties of Kevlar fibre reinforced nylon matrix composite, a comparison.

<table>
<thead>
<tr>
<th></th>
<th>Manufacturer’s data (ASTM D790)</th>
<th>Experimental value (approx.), (ASTM D7264)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexural strength</td>
<td>190</td>
<td>150</td>
</tr>
<tr>
<td>(MPa)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexural Stiffness</td>
<td>26</td>
<td>21</td>
</tr>
<tr>
<td>(GPa)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

QUASI-STATIC INDENTATION TEST SPECIMEN

Table 3. Quasi-static indentation properties of Kevlar fibre reinforced nylon matrix composite, a comparison.

<table>
<thead>
<tr>
<th></th>
<th>Additive manufactured Kevlar fibre reinforced nylon matrix composite</th>
<th>Additive manufactured carbon fibre reinforced thermoplastic</th>
<th>Additive manufactured glass fibre reinforced thermoplastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Force (N)</td>
<td>1803 ± 102</td>
<td>1410 ± 108</td>
<td>1080 ± 123</td>
</tr>
<tr>
<td>Displacement at Maximum Force (mm)</td>
<td>6.84 ± 0.32</td>
<td>7.68 ± 0.43</td>
<td>3.54 ± 0.20</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

LAP JOINTS TEST SPECIMEN

Simple Lap Joints

Lap Joints with spew-fillet

Lap Joints with convex-fillet
RESULTS AND DISCUSSION

LAP JOINTS TEST SPECIMEN

Maximum Load (kN)
- Simple Lap joints: 1.059
- Lap joints with spew-fillet: 1.233
- Lap joints with convex-fillet: 1.89

Stiffness (MPa)
- Simple Lap joints: 1.128
- Lap joints with spew-fillet: 1.478
- Lap joints with convex-fillet: 1.816

Maximum Stress (MPa)
- Simple Lap joints: 4.56
- Lap joints with spew-fillet: 5.307
- Lap joints with convex-fillet: 8.139
FAILURE ANALYSIS
LAP JOINTS TEST SPECIMEN

PEEL STRESSES

COHESIVE FAILURE
<table>
<thead>
<tr>
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<th>CONCLUSIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The ultimate tensile strength and Young's modulus of the Kevlar fibre composites are found to be lower than the values claimed by the manufacturer.</td>
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<tr>
<td>2</td>
<td>The results from quasi-static indentation test demonstrated that the maximum force incurred during the test for Kevlar composite was considerably higher than that of carbon or glass fibre composites.</td>
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<tr>
<td>3</td>
<td>The lap joints results reveal that the failure was mainly due to nylon being a weak adhesive.</td>
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<td>4</td>
<td>Additive manufacturing is a favourable way of producing Kevlar composites and is ideal for prototyping geometrically complicated parts.</td>
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<tr>
<td>5</td>
<td>The nylon matrix does not serve as an ideal bonding adhesive.</td>
</tr>
<tr>
<td>6</td>
<td>3D printed Kevlar composites have its own limitations in terms of material compatibility at this stage of development.</td>
</tr>
</tbody>
</table>
FUTURE WORK

1. MICROSCOPIC ANALYSIS
   Micro-scale analysis of mechanical failure of Kevlar fibres and Kevlar lap joints

2. OTHER POLYMER MATRICES
   Use of progressively improved polymer matrices (such as Onyx) as more effective adhesives

3. OTHER TYPES OF JOINTS
   Testing of butt joints and scarf joints with a compatible composites printer.
THANK YOU
FOR YOUR KIND ATTENTION