STRETCH FORMING OF ALIGNED DISCONTINUOUS FIBER COMPOSITES: EFFECTS OF ENVIRONMENTAL CONDITIONS ON FORMING OPTIMIZATION

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Introduction

• A thermoplastic matrix aligned discontinuous fiber (ADF) composite is a specialized material which becomes stretchable at high temperatures and solidifies upon cooling.
• Due to the discontinuous fibers, ADF composites can be formed into complex parts, while maintaining fiber alignment preserves aerospace-grade material properties.

Purpose

• Determine the effect of process conditions (temperature and strain rate) on material quality after stretch forming. Specifically, this analysis aims to determine the optimal temperature for stretch forming.
• Approach is to stretch samples in the fiber direction under controlled temperature and strain rate conditions.

Materials & Methods

• Fiber: 3mm IM7 Carbon Fiber
• Resin: Polyetherimide (PEI)
• 57% Fiber Volume Fraction
• Sample Dimensions: 8in x 1in
• Thickness: 1-ply (0.12mm)
• Sandblasted aluminum end tabs were attached to samples, which allowed the grips to secure each sample.
• Before testing, samples acclimated for 15 minutes inside the environmental chamber.
• 8 samples were tested at temperatures between 280°C and 350°C.

Analysis

• Raw Data Gathered:
  Force | Displacement | Time
• Graphs/Tables Constructed:
  Strain Softening Rate | Max Stress vs Temperature
  Normalized True Stress vs True Strain
• Image Analysis: DIC Replay Strain Map

Results

Samples After Testing:

Discussion

• Four samples (280°C, 300°C, 340°C, 350°C), at both high and low temperatures, failed before the test was complete.
• According to the DIC analysis, the 280°C, 290°C, and 340°C samples experienced localization at strains of $\epsilon_L \approx 9\%$, $\epsilon_L \approx 30\%$, and $\epsilon_L \approx 35\%$ respectively.
• Samples tested at 310-320°C achieved 100% elongation with no indication of localization.
• Strain softening slope was calculated by using the polyfit function on MATLAB for data points between $\sigma = 0.8$ and $\sigma = 1.0$.
• The strain softening slope is shown to be a good indicator of formability, where the smallest slope is desirable (-2 for 310 °C and 320 °C).
• Unexpected finding was that maximum stress increasing at temperatures above 320 °C, indicating the presence of another mechanism (e.g. polymer cross-linking).

Conclusions

• Material formability is highly sensitive to different temperature conditions.
• In the end, the 310°C sample showcased the best performance during stretch forming.

Path Forward

• Extend testing schedule to evaluate the effect of strain rate.
• Repeat all trials to prove data reliability.
• Determine the relationship between the forming process conditions and the mechanical properties of ADF composites.

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