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

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Introduction

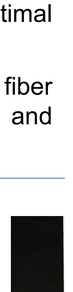
- A thermoplastic matrix aligned discontinuous fiber (ADF) composite is a specialized material which becomes stretchable at high temperatures and solidifies upon cooling.
- Due to the discontinuous fibers, ADF composites can be formed into complex parts, while maintaining fiber alignment preserves aerospace-grade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

Purpose

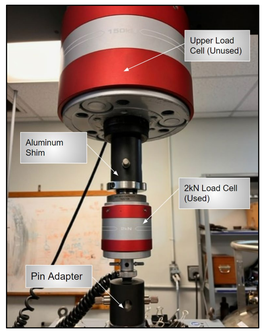
- Determine the effect of process conditions (temperature and strain rate) on material quality after stretch forming. Specifically, this analysis aims to determine the optimal temperature for stretch forming.
- Approach is to stretch samples in the fiber direction under controlled temperature and strain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

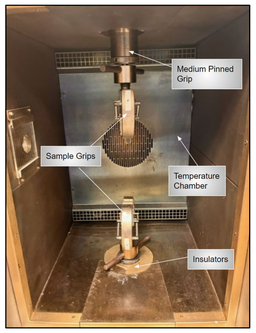
Materials & Methods

- 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.



- Tension was applied to each sample at an engineering strain rate of $\dot{\varepsilon}_L$ = 0.001 s^{-1} until an engineering strain of 100 percent was achieved.
- Tests were conducted using an Instron Tensile Testing Machine & Environmental Chamber.
- A Video Extensometer with a 9mm lens was used to capture images during testing for digital image correlation (DIC) analysis.
- All tested samples had a gauge length of 94.3mm ± 2.8mm.





Analysis

- **Raw Data Gathered:**

  Force | Displacement | Time

- **Graphs/Tables Constructed:**

  Strain Softening Rate | Max Stress vs Temperature

  Normalized True Stress vs True Strain

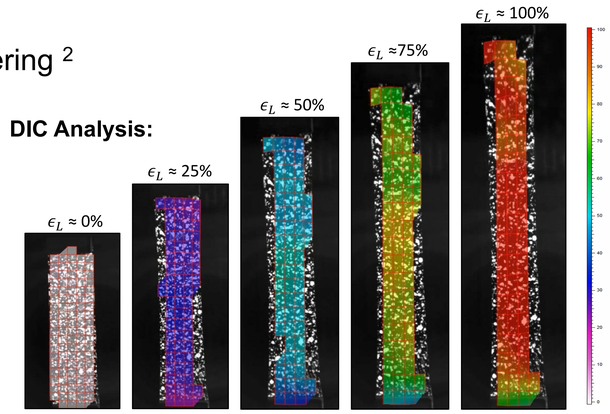
- **Image Analysis:** DIC Replay Strain Map

Results

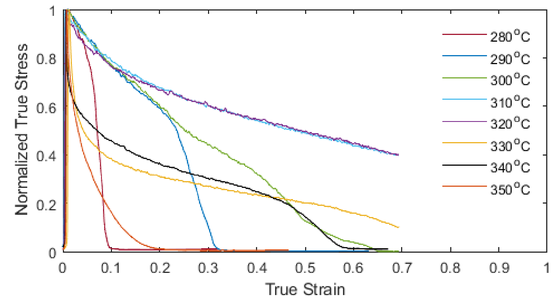
Samples After Testing:

280°C 290°C 300°C 310°C 320°C 330°C 340°C 350°C

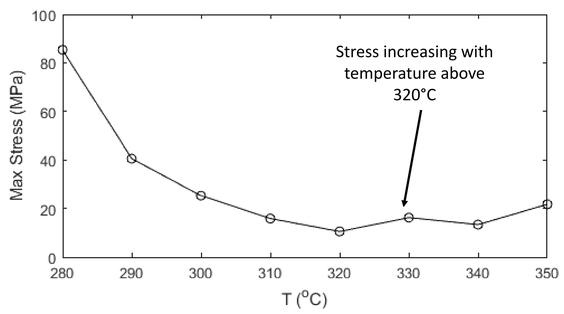
DIC Analysis:



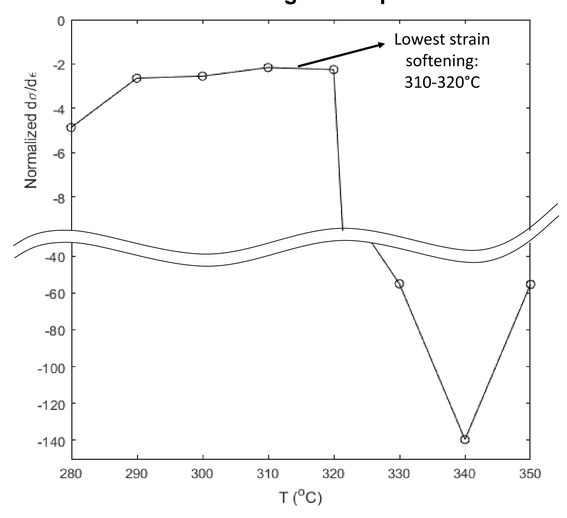
Normalized True Stress vs True Strain:



Maximum Stress vs Temperature:



Strain Softening vs Temperature:



Discussion

- Four samples (280ºC, 300ºC, 340ºC, 350ºC), at both high and low temperatures, failed before the test was complete.
- According to the DIC analysis, the 280ºC, 290ºC, and 340ºC samples experienced localization at strains of ϵ_L ≈ 9%, ϵ_L ≈ 30%, and ϵ_L ≈ 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 σ = 0.8 and σ = 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 310ºC 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.

Acknowledgements

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