

Design Evaluation of Multi-Consolidation Effects on Crystallization and Mechanical Properties of Thermoplastic Composites



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Introduction

BACKGROUND: Thermoplastic carbon fiber composites are transforming aerospace through superior manufacturing, performance, and sustainability (see **Table 1** vs. thermosets). These composite layers are commonly consolidated into panels using a Hot Press. Multiple consolidations could allow for more complicated manufacturing, but it is unknown how it affects matrix properties.

OBJECTIVE: The objective of this capstone is to design a process to evaluate the effects of multiple consolidations on PEKK and AE250 thermoplastic composites during the manufacturing process.

Table 1. Advantages and disadvantages of thermosets vs thermoplastics.¹

	Thermosets (Traditional)	Thermoplastics
Advantages	<ul style="list-style-type: none"> • Low weight • High strength • High thermal and chemical resistance 	<ul style="list-style-type: none"> • Shelf-stable at room temp • High toughness and impact resistance • Repairable and recyclable
Disadvantages	<ul style="list-style-type: none"> • Energy-intensive freezer storage • Limited shelf life 	<ul style="list-style-type: none"> • Slower adoption in aerospace: required development of high-heat variants

Table 2. Proposed test matrix. Entries in red were not completed in this project.

Number of Consolidations	PEKK	AE 250 (PAEK)
1	KK1 w/ TC KK1 w/o TC	AE1
3	KK3	AE3
5	KK5	AE5
7	KK7	AE7
10	KK10	AE10

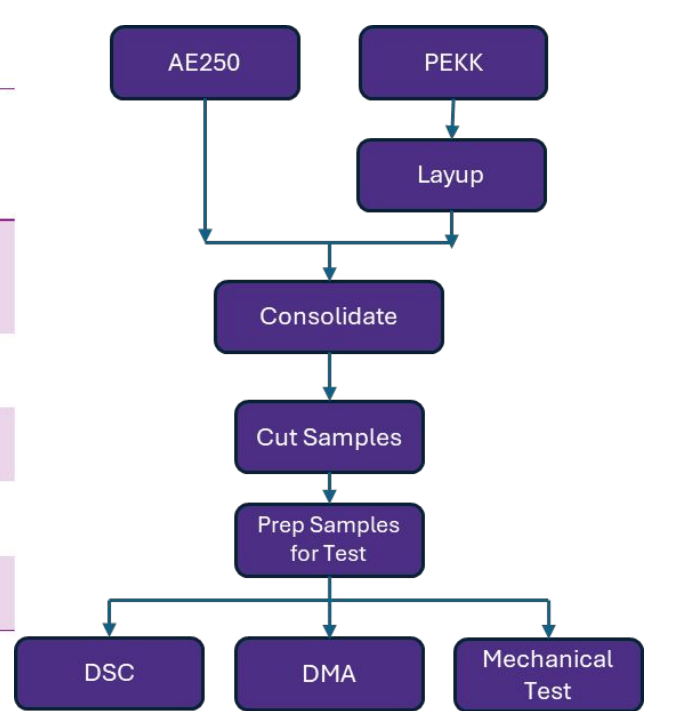


Fig. 1. Workflow for evaluation.



Fig. 2. The Hot Press used in this project

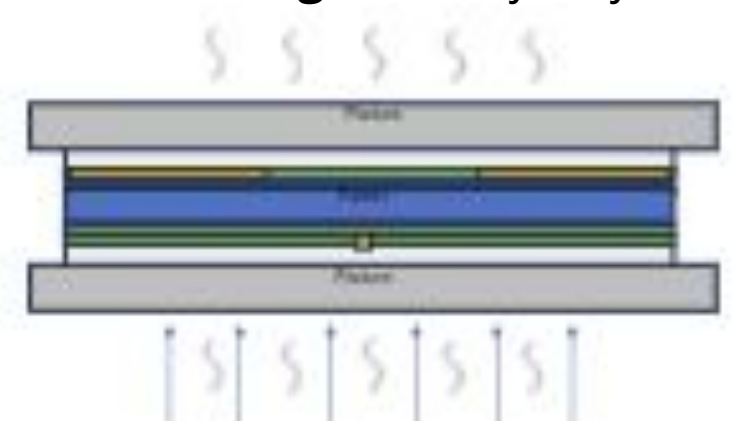


Fig. 3. Schematic of consolidation

Manufacturing

Materials: Custom-laid PEKK and pre-consolidated Daher AE250 panels.

Manufacturing: Consolidated via hot press (Figs. 1 – 4; Table 3).

Temperature Monitoring: To enable repeat consolidations, thermocouples were placed in machined caul plate grooves and compared to the traditional embedded method (Table 2).

#	Procedure
1	Ramp to 377°C (711 F) at any rate with 1-2 bar pressure
2	Hold for 30 minutes at 5 bar pressure.
3	Ambient air cooling to room temperature.

Table 3. Procedure for consolidation cycles

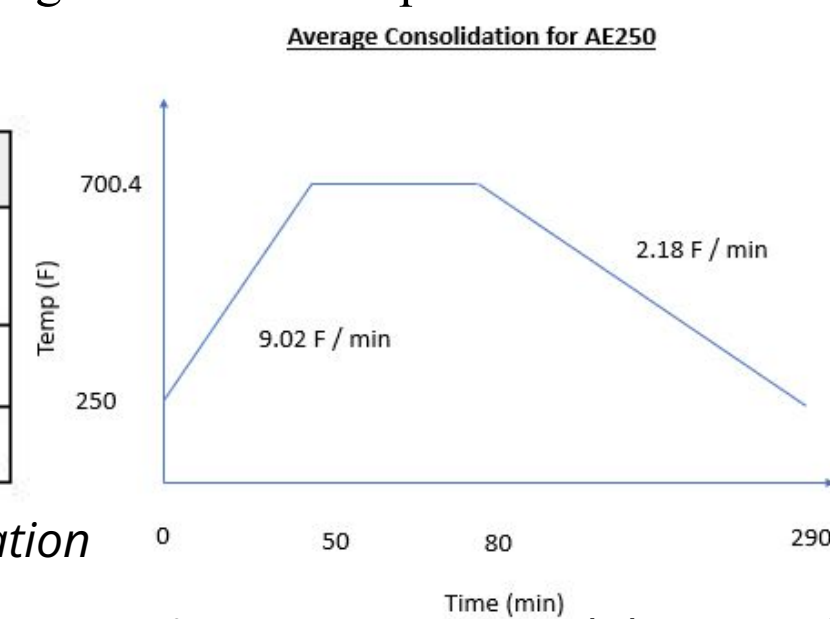


Fig. 4 Average consolidation cycle.

DSC

Percent crystallinity changes indicate impact of consolidations on properties.

$$X_c = \left(\frac{\Delta H_m}{\Delta H_m^0 - R_c} \right) \cdot 100\%$$

X_c : Percent crystallinity
 ΔH_m : Measured enthalpy of melting
 ΔH_m^0 : 130 J/g, R_c : 0.34

Fig 5. Percent crystallinity equation

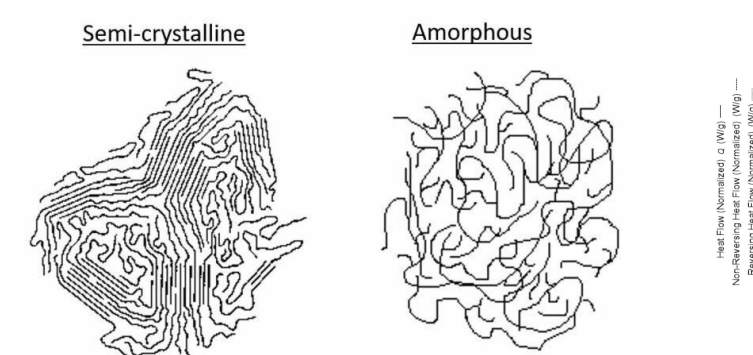


Fig. 7. Visual Example of crystallinity in a polymer.²



Fig. 6. TA Discovery DSC 2500

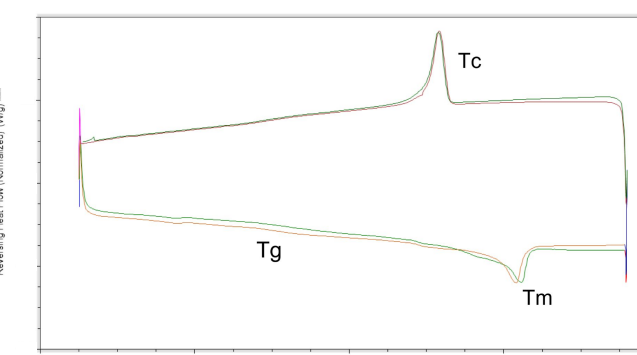


Fig. 8. DSC curve of samples with information of importance

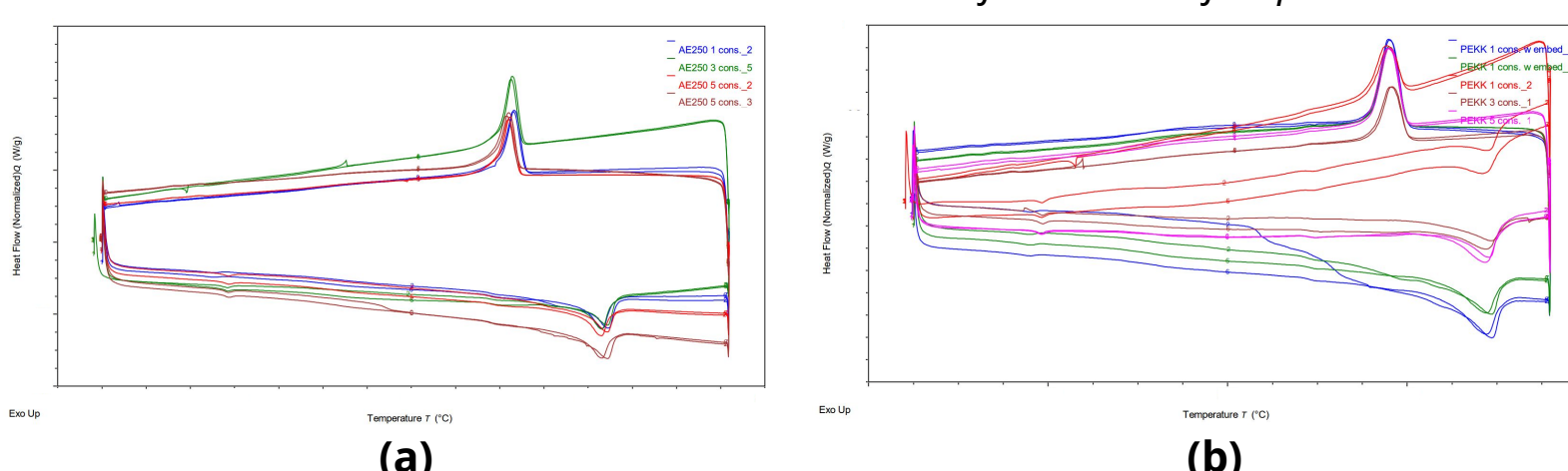


Fig. 9. Overlay of DSC curves (a) AE250 and (b) PEKK

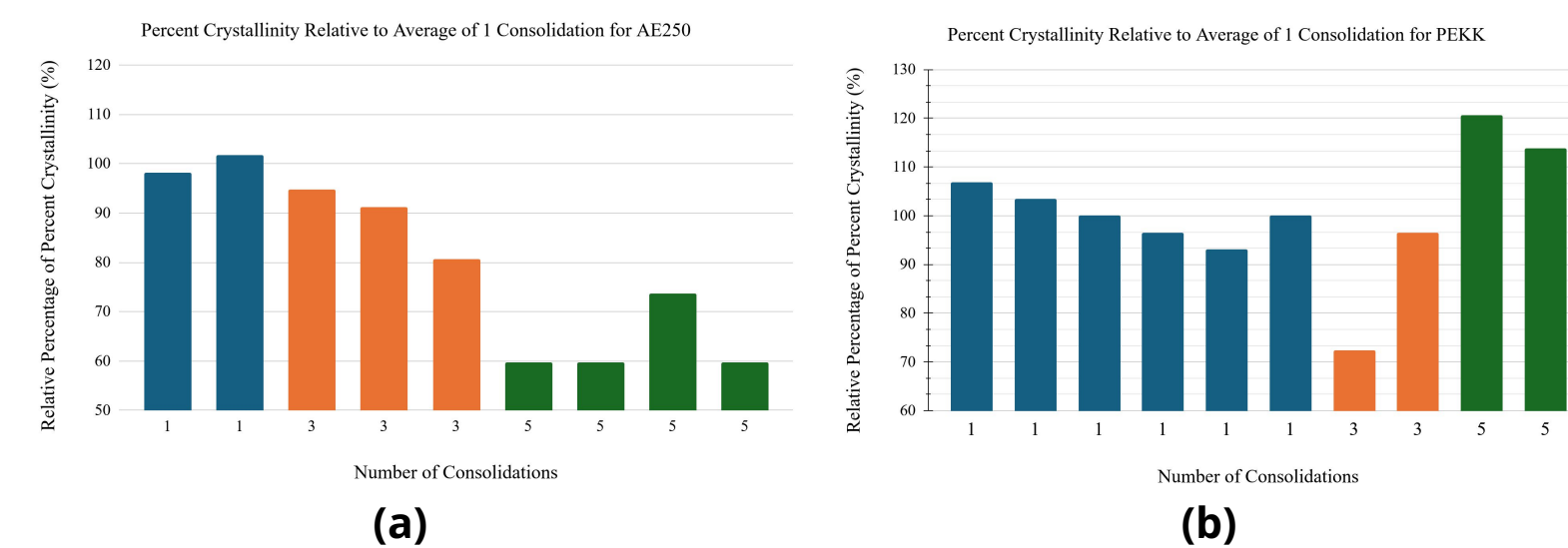


Fig. 10. Relative percent crystallinity to avg of 1 consolidation (a) AE250 and (b) PEKK

DMA

Analysis of onset temperature on storage modulus used to identify Tg region of samples.

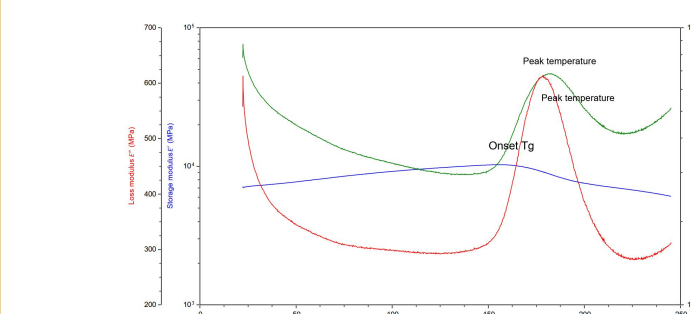


Fig. 11. DMA curves of samples



Fig. 12. TA Discovery DMA 850

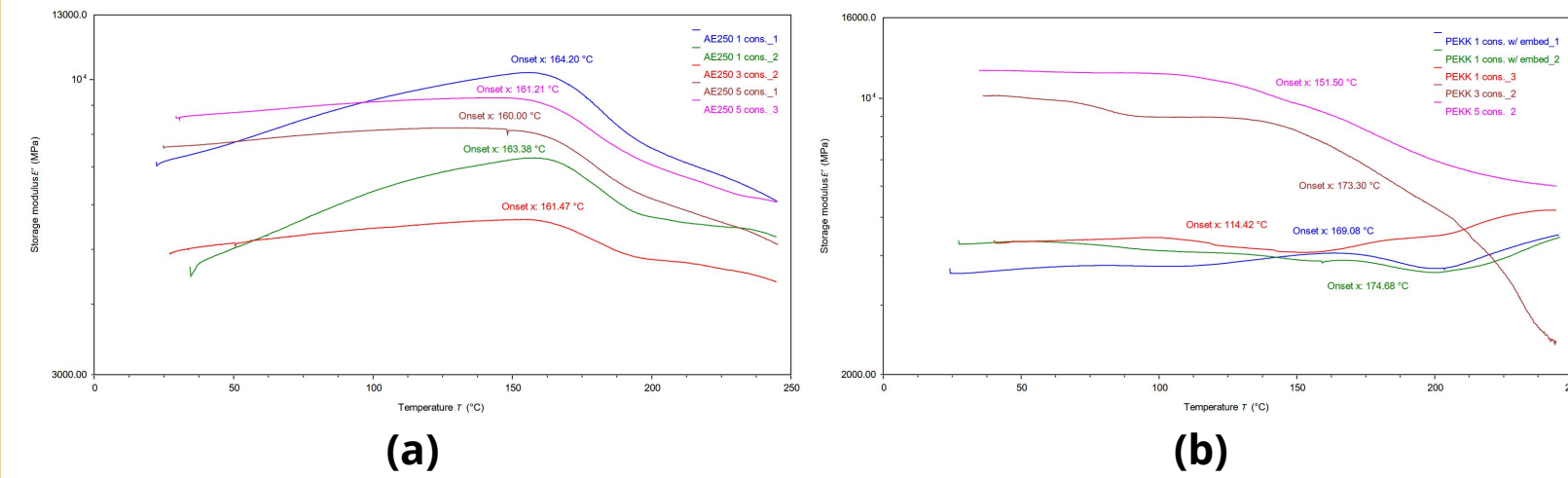


Fig. 13. Overlay of storage moduli (a) AE250 and (b) PEKK

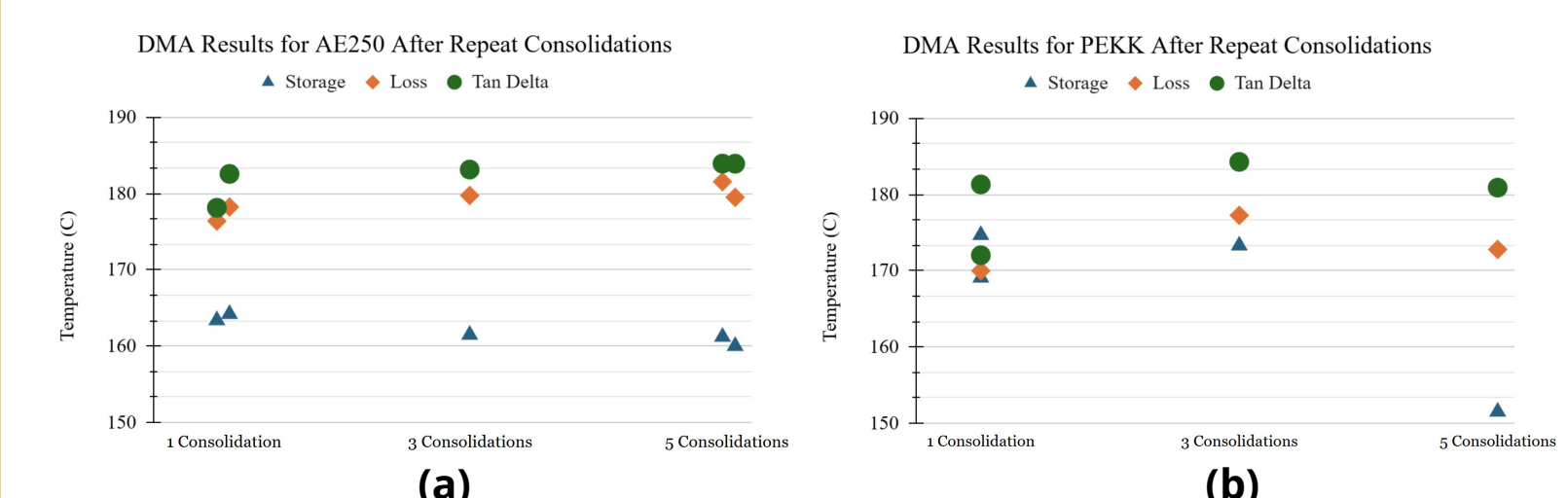


Fig. 14. The onset results of DMA of (a) AE250 and (b) PEKK

3-Point Bend Test

Analysis of percentage change of flexural modulus and ultimate flexural strength indicate no changes from consolidations.

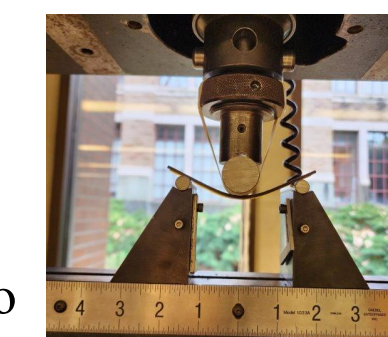


Fig. 15. 3-point bend test set-up

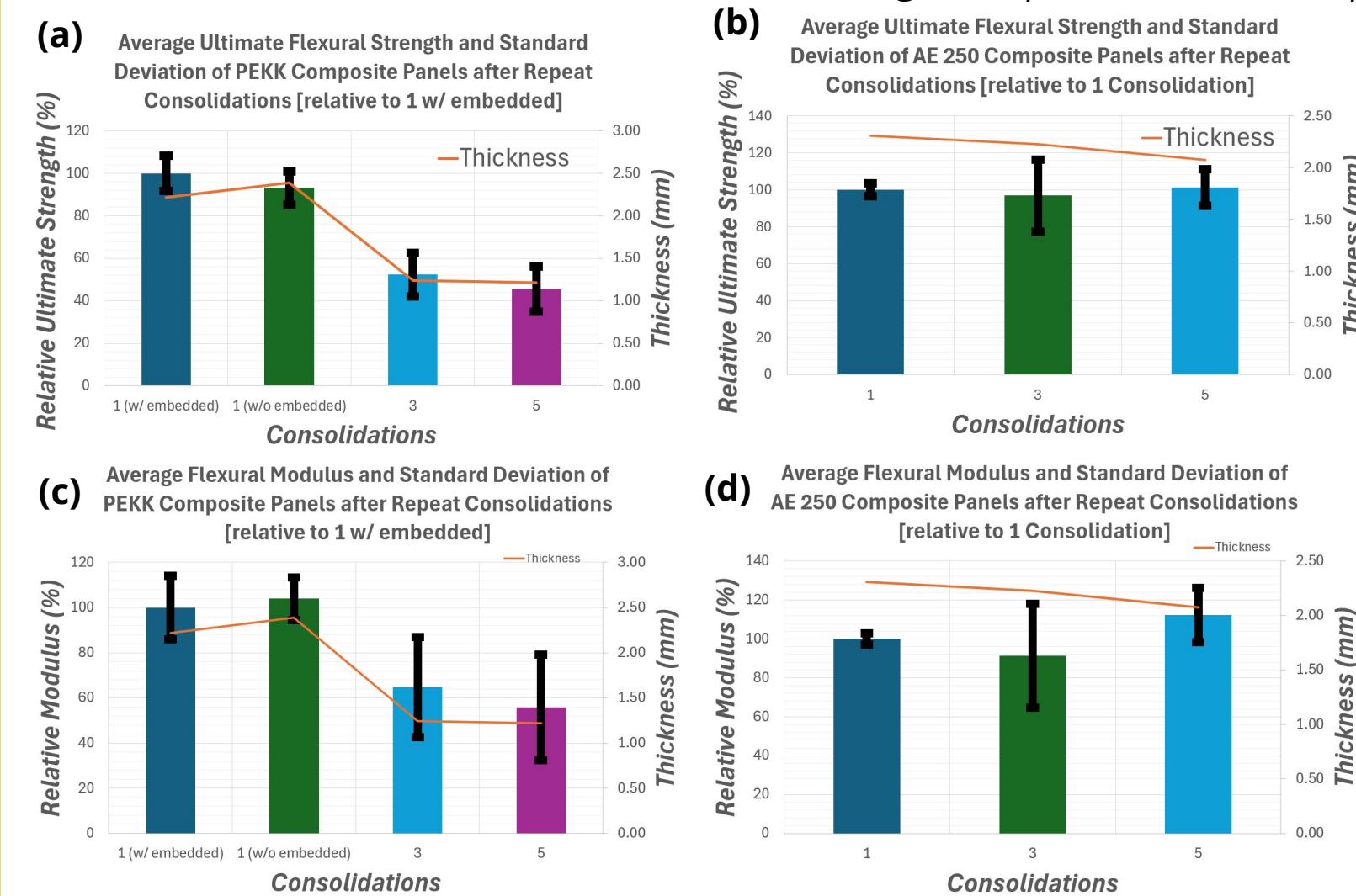


Figure 16. Error bar graphs of consolidation results. Ultimate strength of (a) PEKK and (b) AE250. Modulus of (c) PEKK and (d) AE 250.

Conclusions

MANUFACTURING

- The grooved caul plate accurately monitored temperatures without degrading PEKK mechanical properties.

DSC (Crystallinity)

- **AE250:** Showed a general reduction in crystallinity.
- **PEKK:** Exhibited no observable trend.
- *Note:* PEKK's significant thickness reduction implies resin loss, which skews calculations.

DMA (Thermal Properties)

- **High Stability:** The Glass Transition Temperature (Tg) and overall thermal profiles for both materials remained highly stable across all 5 consolidations.

MECHANICAL PROPERTIES

- **AE250:** Highly stable, with negligible changes in strength or thickness across all cycles.
- **PEKK:** Performance and thickness dropped between 1 and 3 Consolidations. 3 and 5 Consolidation samples did not fracture; flexibility exceeded machine limits, indicating critical resin loss.

Future Work

- Test beyond 5 consolidations to determine if further consolidations causes degradation.
- Improve the caul plate design to eliminate panel thinning.
- Use TGA and optical microscopy to find the true resin weight percent and distribution for accurate crystallinity data.

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[1] Mallick, P. K., "Fiber-reinforced composites: Materials, manufacturing, and design", 3rd ed., CRC Press, 2007 [2] J. Jansen, "The Importance of Crystallinity in Plastics Performance", The Madison Group