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# The Effects of Multiple Forming Operations on the Physical and Mechanical Properties of PEEK Laminates – Part 1

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**ABSTRACT:**

Thermoplastic materials have inherent attributes that are desirable for high speed/low cost part processing. Thermoplastic details can also be post-processed to add curvature, co-consolidate, and/or fusion weld to make complex advanced structures. In doing this, repetitive cycling may occur locally or on the entire assembly to accommodate secondary operations. Currently the accepted processing cycle for thermoplastic details have been limited by process specifications to only one forming cycle. This conservative approach does not allow part manufacturers to perform simplistic operations, such as porosity or thickness correction; let alone secondary operations. This paper will examine a series of cycles to determine what effect repetitive oven/press cycles have on the mechanical nature of the laminate and physical change of the polymer.

## 1. INTRODUCTION:

INITIAL PHASE:

- 12-ply laminate blanks with rejections for porosity, minor laminate thickness violations, and/or surface imperfections were run (re-processed) through the typical forming process cycle to determine if typical defects could be removed. After one (1) rework cycle, all defects were removed without any physical changes (DSC).

MATERIAL SELECTED / EXPERIMENTAL PHASE:

- TPCL PEEK-4-40-HTA E13 3K DT-5HS-285/10AB (consolidated blank, 10-plies thick)
- Full NDT inspection (void/porosity) assesements

TEST BLANK SETS:

- Set #1 Origin laminate – (no forming cycle)
- Set #2 Baseline laminate – One (1) forming cycle
- Set #3 Four (4) forming cycles
- Set #4 Eight (8) forming cycles

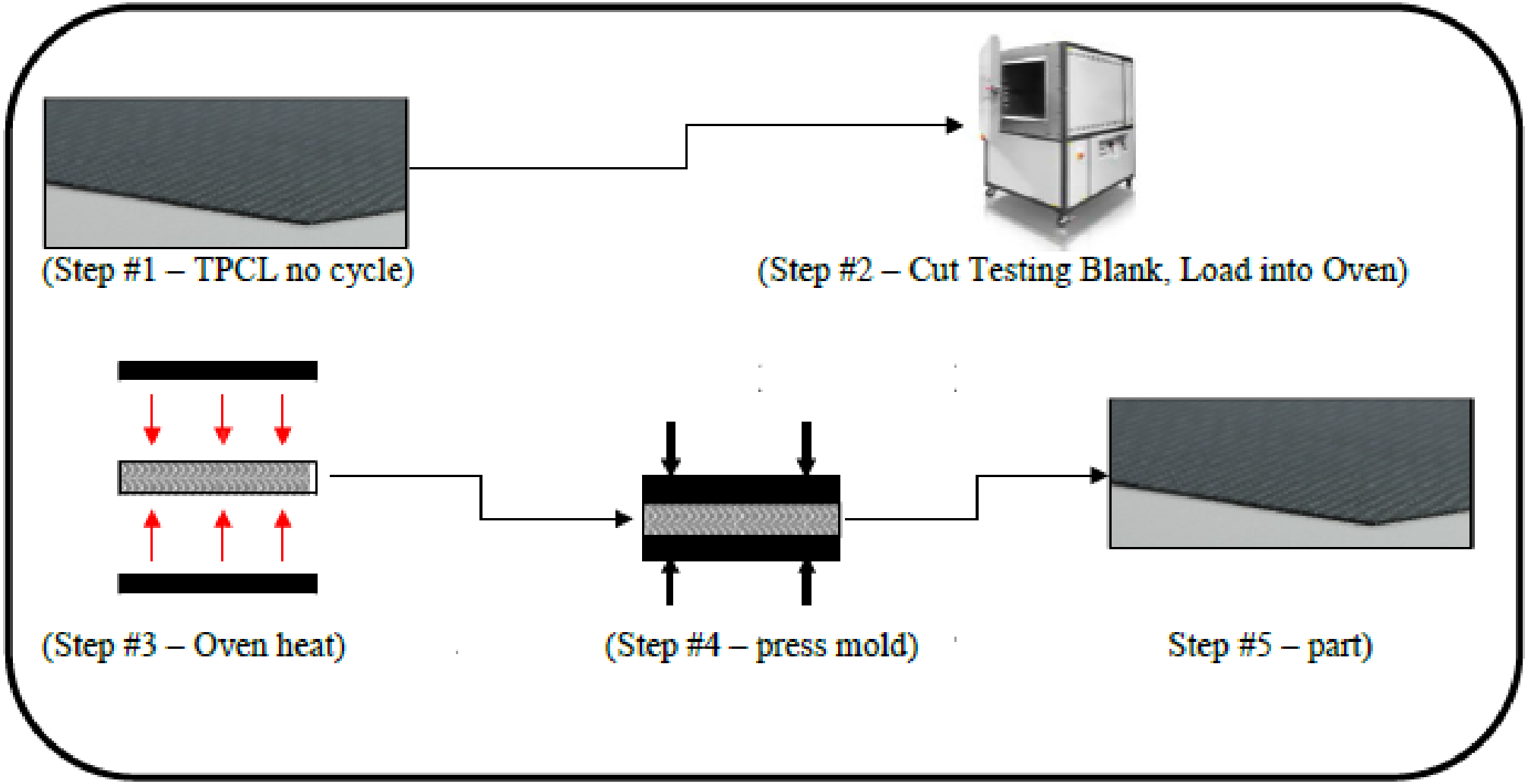
BLANK ATTRIBUTES:

- 10-plies - .125” nominal thickness
- 4” X 5” overall size (12” X 12” laminate)

## 2. EXPERIMENTAL (Process Parameters):

- → Blanks loaded into oven
- → Dwelled @795±25˚F (till pliable) for10-15 minutes.
- → Transfer blanks into forming tool, within 30-60 seconds.
- → Forming Tool/Press platen(s) were maintained @ 465±15˚F.
- → Cycle the press – Heat set @ 465±15˚F with a pressure setting of 435 psi minimum.
- → Dwell at pressure/temperature for a minimum of 10 minutes minimum.
- → Upon completion of the dwell, blanks were cooled; under pressure, at a rate not to exceed 50˚F per minute to below 200˚F.
- → Blank(s) removed from the form tooling.

## PROCESS MAP:


(Step #1 – TPCL no cycle)
(Step #2 – Cut Testing Blank, Load into Oven)
(Step #3 – Oven heat)
(Step #4 – press mold)
Step #5 – part)

## 3. RESULTS:

DSC values for cycled TPCL - (Table 3):

| Physical Property | TempValue / % Crystalinity |
|---|---|
| DSC testing per ASTM E1269 with No Cycle | 344°C (651°F) / 26.2 |
| DSC testing per ASTM E1269 with 1 Cycle | 352°C (665°F) / 26.4 |
| DSC testing per ASTM E1269 with 4 Cycles | 353°C (667°F) / 26.5 |
| DSC testing per ASTM E1269 with 8 Cycles | 347°C (657°F) / 26.4 |

**Table 3 – Physical Values Cycled Laminate**

Note:
1). Crystallinity range 32±10%.
2) Temperature Value range 343±15° (649±27°F)

TYPICAL DSC (Tg) averaged 152-158˚C (305-316˚F) on all test cycles

## 3. RESULTS (continued):

| Property (test direction) | | Stacking sequence | Units | Condition/Test temperature | Typical value (Avg.) |
|---|---|---|---|---|---|
| Flexure (0°)-No cycle | modulus | [[(0,90)/(±45)]2/(0,90)]s | GPa | RTD | 63 |
| | strength | | MPa | | 1014 |
| Flexure (90°)-No cycle | modulus | [[(0,90)/(±45)]2/(0,90)]s | GPa | RTD | 59 |
| | strength | | MPa | | 972 |
| Flexure (0°)-Baseline (1 cycle) | modulus | [[(0,90)/(±45)]2/(0,90)]s | GPa | RTD | 61 |
| | strength | | MPa | | 1000 |
| Flexure (90°)-Baseline (1 cycle) | modulus | [[(0,90)/(±45)]2/(0,90)]s | GPa | RTD | 57 |
| | strength | | MPa | | 980 |
| Flexure (0°)-4cycle | modulus | [[(0,90)/(±45)]2/(0,90)]s | GPa | RTD | 64 |
| | strength | | MPa | | 998 |
| Flexure (90°)-4 cycle | modulus | [[(0,90)/(±45)]2/(0,90)]s | GPa | RTD | 60 |
| | strength | | MPa | | 977 |
| Flexure (0°)-8 cycle | modulus | [[(0,90)/(±45)]2/(0,90)]s | GPa | RTD | 60 |
| | strength | | MPa | | 1011 |
| Flexure (90°)-8 cycle | modulus | [[(0,90)/(±45)]2/(0,90)]s | GPa | RTD | 56 |
| | strength | | MPa | | 957 |

## 4. CONCLUSIONS:

The proceeding Physical and Mechanical data revealed no significant change in properties from the origin state of the TPCL (consolidated laminate) through 8 repetitive cycles of 795-degree F, along with repetitive pressure cycling at 435 psi, hence in this testing revealed no change in strength or crystallinity of the PEEK fabric-reinforced material.

With this outcome, this specific PEEK TPCL can be processed through multiple rework and forming operations to fabricate complex structures or to leverage the advantage of thermoplastic materials. This would include co-consolidation (fusion welding), secondary forming operations (compound curvature structures, and repair.

## FUTURE WORK:

Additional testing will be done to determine where the actual polymer degradation begins. It is ascertained that this will occur in excess of 10 cycles, so Part 2 of this experiment will look at 12 cycles in the laminate and beyond, as necessary.

Additionally a second source of PEEK will be used for comparison. During this cyclic testing, Evonik Vestakeep was used in the laminates. This testing will be repeated compared to the performance of Victrex 450 or similar (PEEK) and Arkema 7002 or 7003, or similar (PEKK).


***Questions ?????***