Width Deformation of Thermoplastic Prepreg Tapes during Automated Fiber Placement

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1. INTRODUCTION

Automated Fiber Placement (AFP) is a commonly used technology to manufacture typical aerospace structures with a possibility for in-situ processing (no autoclave/oven/press required) for thermoplastic prepreg tapes. However, in-situ AFP technology is still in its development phase.

One of the primary causes for the gaps and overlaps is the tape width deformation during placement.

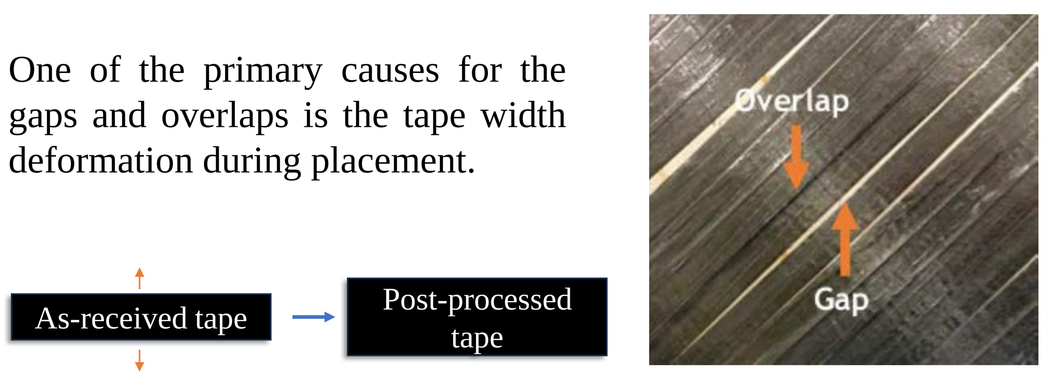


Figure 2. Gaps and Overlaps is a major manufacturing defect for AFP.

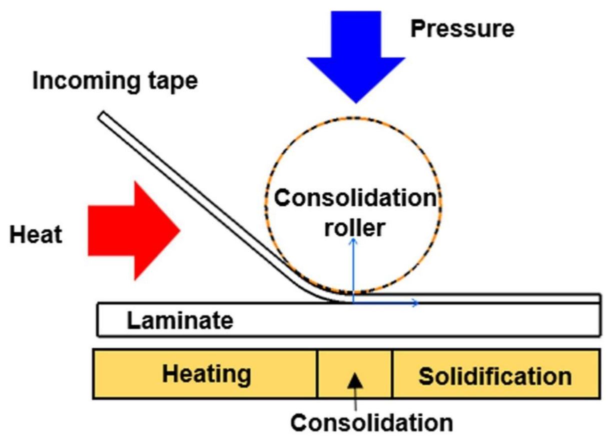


Figure 1. AFP processing phases [1].

Current literature on tape width deformation shows that the resulting tape width is influenced by processing parameters such as temperature, pressure and placement speed [2][3][4]. However, results from different studies do not agree with each other.

Additionally, the conventionally considered tape width deformation mechanism, namely, transverse squeeze flow has been suggested to be incorrect for the AFP process as the experimental deformations do not agree with the results of the transverse squeeze flow model [2].

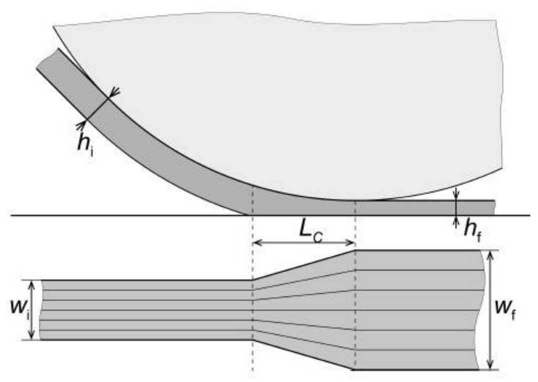


Figure 3. Tape width deformation based on transverse squeeze flow [2].

2. EXPERIMENTATION

This study experimentally investigates the tape width deformation mechanism and the influence of processing parameters for thermoplastic prepreg tapes using in-situ AFP manufacturing.

Table 1. Fiber placement set-up.

Material	Heating Device	Compaction Roller
0.25" UD Toray Cetex® TC1225	Xenon flashlamp: humm3®	silicone roller (60 shore)

Table 2. Process parameters used. Full factorial DoE with 3 samples of length 580 mm for each combination.

Heated length	Compaction force	Temperature (℃)
Short (35-40 mm)	300	370
Long (45-50 mm)	900	420

- Tape width measurement pre and post processing → To investigate the influence of the processing parameters.
- Post-processing analyses: Width measurement in the heating phase of the process, surface roughness analysis and tape cross-section profile and edge inspection → To understand the tape width deformation mechanism.

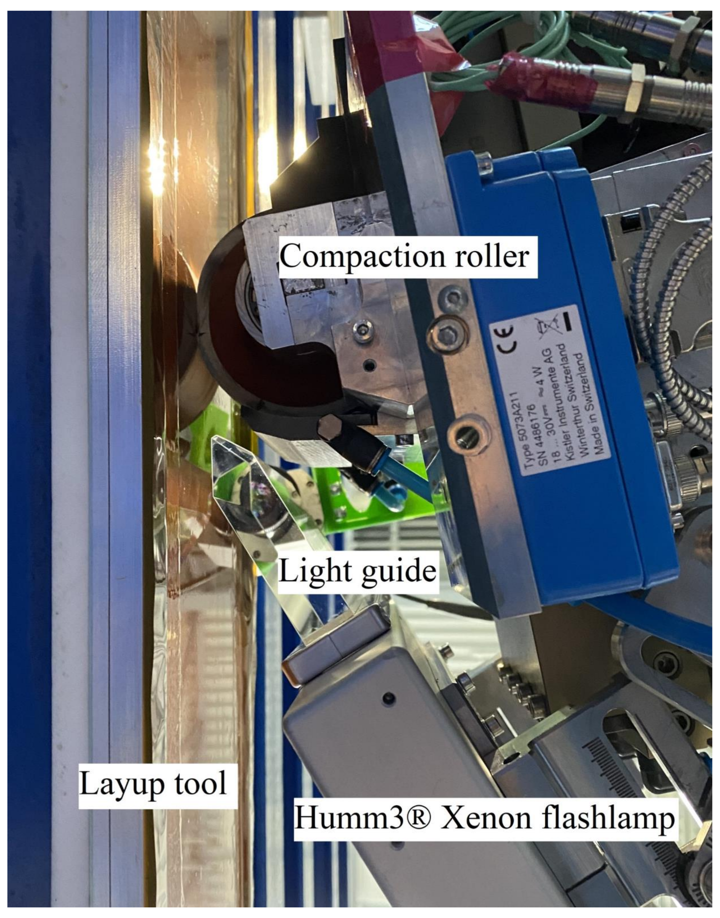


Figure 4. Specimen manufacturing set-up.

3. RESULTS AND DISCUSSION

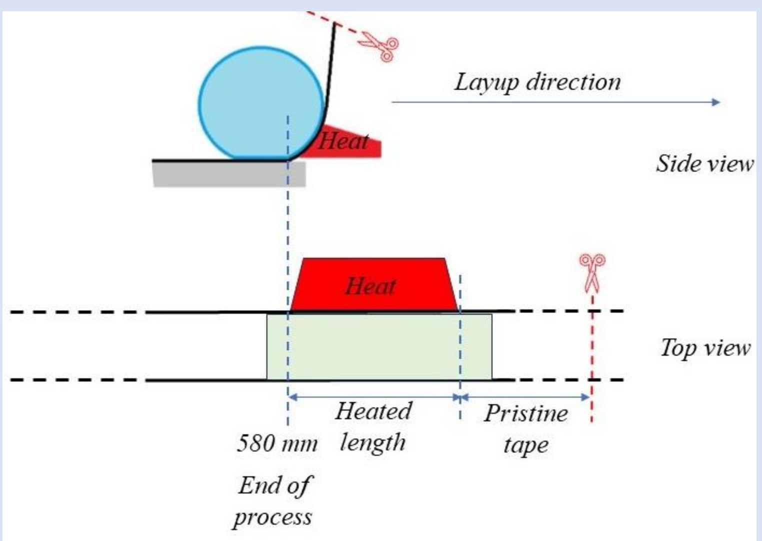


Figure 5. Tape after end of process and scanned area (in green) for width data in heating phase.

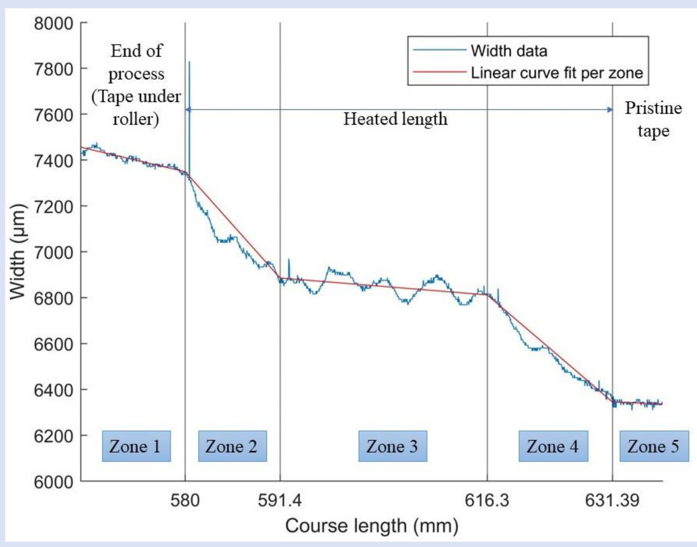


Figure 6. Tape profile inspection in heating phase: Width data with zone divisions

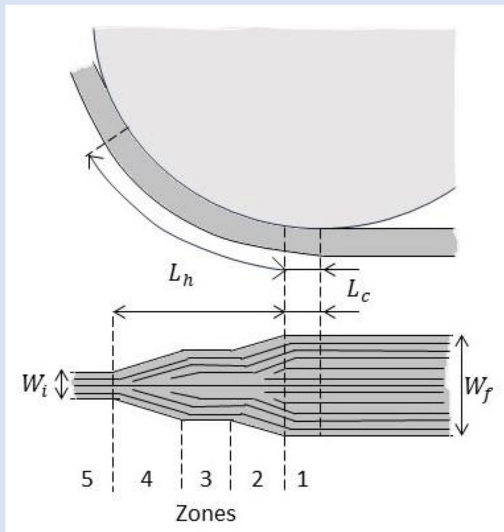


Figure 7. Tape width deformation as observed from results.

- Tape width deforms in the entire heated length i.e., the heating phase of the process.
- Moreover, the deformation follows a unique pattern which can be divided into 3 zones i.e., zones 2, 3 and 4 in Figure 6. Zones 2 and 4 have a clear slope whereas, zone 3 is mostly flat.
- Zone 2 slope indicates that there is width deformation due to the roller compaction in zone 1 and therefore the tape further widens before the nip-point i.e., in zone 2.
- Since not the entire heated length was heated above the T_m ,the slope in zone 4 is an indication of the tape below the T_m as the tape is not in the melt state completely and is therefore restricted in the width deformation due to the restricted polymer chain movement. And, the plateau in zone 3 is an indication of the tape that is completely in the melt state and therefore, it can deform freely.

- The tape cross-section shape shows a thickness slope at the edges of the tape, compared to the rectangular edges for the as-received tape. The tape under the roller takes the shape of the transitioning shape of the conformable roller at the edges as the tape is in the melt phase and can easily deform.
- The edge micrographs shows the presence of both fibers and resin.
- A linear decrease in roughness with increase in processing temperature for short heated length and 900 N compaction force specimens, including the extra temperature data point specimen at 300 ℃, is clearly observed.
- The surface roughness results show that the roughness remains almost the same as the as-received tape for the long heated length and higher temperature configuration specimens. This indicates that the temperature distribution might have an influence on the roughness value as the material would be able to flow more easily and consolidate more uniformly when the tape is more uniformly heated with larger part of the tape (both in length and thickness direction) in the melt state.

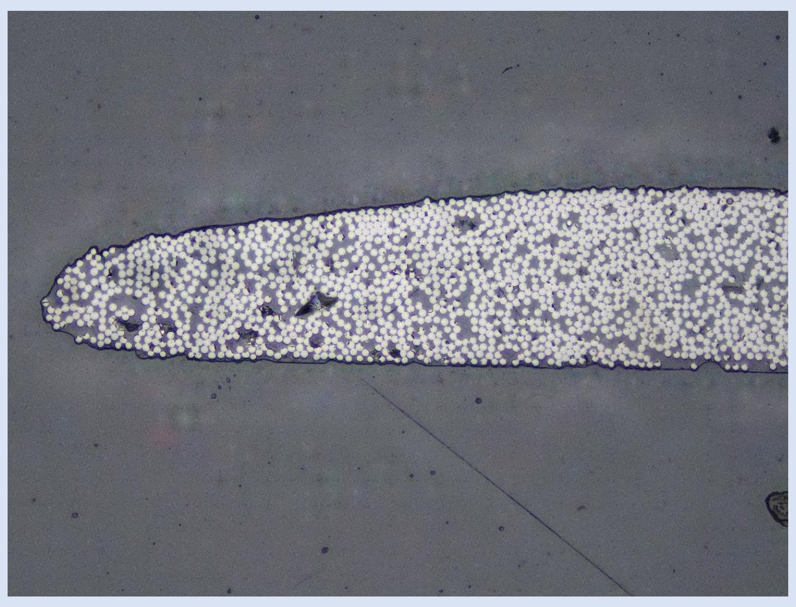


Figure 8. Typical tape edge cross-section view after processing

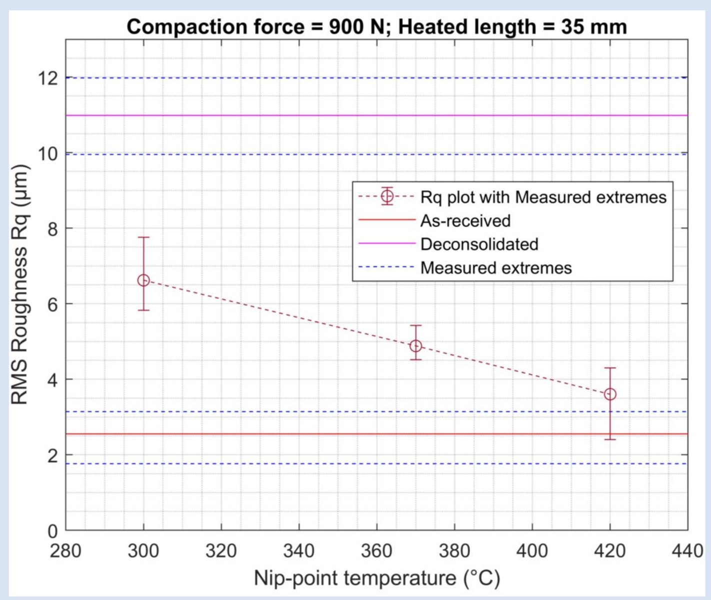
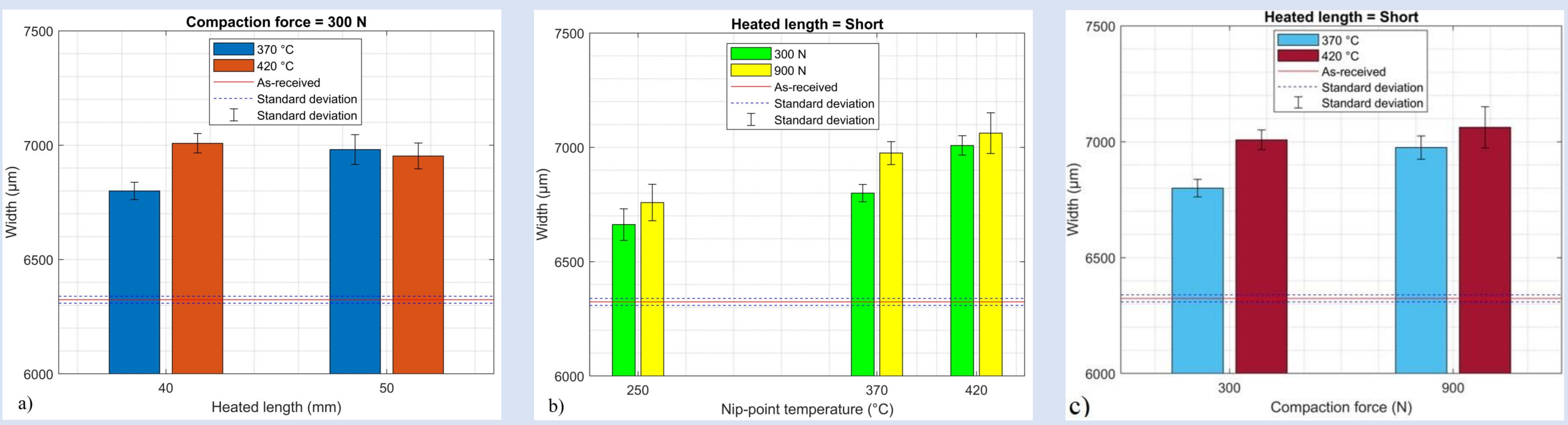


Figure 9. RMS Roughness R_q values over nip-point temperature.



Tape width values over: a) heated length b) nip-point temperature and c) compaction force.

- The width increases with the heated length, nip-point temperature and compaction force, but only for the specimens at lower temperature, shorter heated length and lower compaction force.
- For the specimens at higher temperature, longer heated length and higher compaction force, the width deformation does not show any clear trends.
- This exception with higher process parameter settings point towards the role of temperature distribution in the length and thickness direction of the tape.
- A better heat distribution thereby promote the spreading of the fiber-resin mixture due to less restricted polymer chain movement that leads to the overshadowing of the effect of other parameters.

4. CONCLUSION AND FUTURE WORK

- Width deformation involves the spreading of the fiber-resin mixture in the consolidation as well as the heating phase of the process.
- The tape deformation profile shows a gradually decreasing thickness on the edges which indicate an influence of the conformable roller.
- The process parameter settings promoting a uniform temperature distribution in both the length and thickness direction of the tape i.e., longer heated length and higher temperature, in general stabilizes the surface roughness and width deformation.
- For future work, the influence of other processing parameters and boundary conditions such as placement speed and roller hardness should be inspected.
- Finally, these results should be incorporated into the current AFP processing models to accurately predict the tape width deformation and therefore, mitigate the problem of gaps and overlaps.

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