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IN SITU THERMOGRAPHIC PROCESS MONITORING DURING AUTOMATED FIBER PLACEMENT

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ABSTRACT

Process development cycles in Automated Fiber Placement (AFP) manufacturing are largely data starved and based on trial and error. NASA Langley Research Center has previously developed the In Situ Thermographic Inspection System (ISTIS) to perform online inspections of AFP for manufacturing defects. In this paper we have utilized ISTIS to perform process monitoring and correlated changes in machine operating parameters to overall part quality and defect occurrence.

Keywords: Automated Fiber Placement, thermography, in situ, process development

1. INTRODUCTION

Automated Fiber Placement (AFP) systems were developed to transition composite construction from a manual hand layup technique to a faster more repeatable automated technique. Several variants of AFP systems exist, but all operate on the same basic design principle (Figure 1).

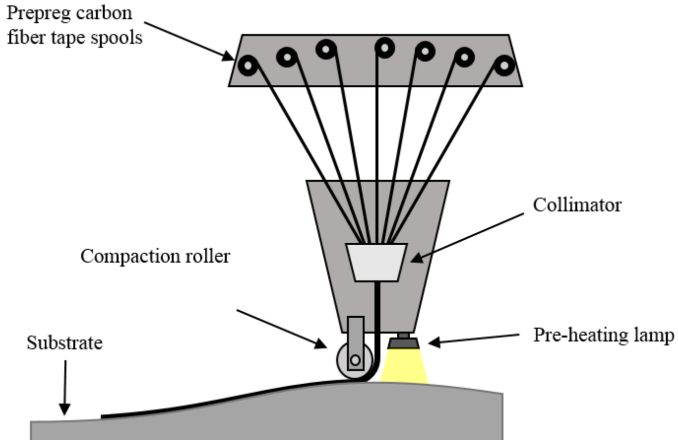

FIGURE 1: Simplified diagram of a typical AFP robotic platform.

A stationary or moving substrate is used as an inner mold for the composite part to guide the final shape. Preimpregnated carbon fiber epoxy tape strips (tow tape) are spool fed to a collimator that aligns them side by side. The row of fiber tows is then fed to the AFP 'head' which houses the compaction roller that travels along the surface of the substrate, depositing the tows onto the substrate. The substrate or the roller (or both) move and rotate so that the tows are deposited on a preset path. Traveling ahead of the roller is a heat source (usually a quartz lamp) that preheats the substrate to aid the adhesion of the ply onto the previous ply or substrate.

The data presented in this work was collected on the Integrated Structural Assembly of Advanced Composites (ISAAC) system [1]. The possible manufacturing flaws observed are tow overlaps, gaps between tows, and poor adhesion. Manufacturing flaws can lead to substantial decrease in part strength [2, 3] so preventing those flaws prior to cure can reduce the cost of post cure repairs or scrap.

2. EXPERIMENTAL SETUP

In AFP manufacturing, when constructing a new structural design or when using a new material system, it is common to perform lengthy process development cycles to find the operating parameters that produce the least amount of manufacturing flaws. The process development cycle is largely trial and error; with little data on how these parameters are actively affecting the build quality, operators rely on experience to optimize the manufacturing plan. These parameters, which include feed rate, layup direction, compaction pressure, and heat lamp output, all affect the adhesion and steadfastness of the deposited tows.

To aid in process development cycles, we have utilized our In Situ Thermographic Inspection System (ISTIS) [4]. ISTIS consists of a small thermographic camera and data processing computer installed to the end effector of an AFP robotic platform. The heat flowing from the preheated substrate through the newly deposited layer during layup is monitored by the thermographic camera. We have also made modifications to the AFP robot allow for the spatially incremented triggering of thermal images that can then be spatially registered to a model of the part.

Previously we have used ISTIS to perform online inspection for manufacturing defects in AFP manufacturing. These defects include tow overlaps, tow gaps, tow peel ups, wrinkling, and loss of adhesion [5]. The success of ISTIS relies on the changes in heat flow through the new layer caused by changes in material thickness (shown in Figure 2), changes in the thermal resistivity as a result in changes in adhesion quality, or changes in base ply heating.

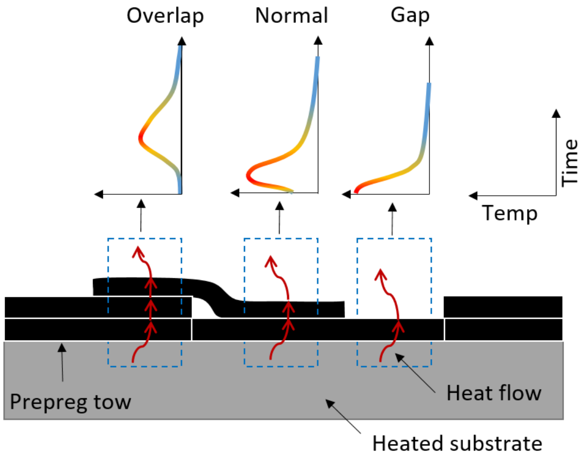

FIGURE 2: Visualization of how heat flow through newly deposited layer can be used to identify defects.

3. RESULTS AND DISCUSSION

Using ISTIS we were able to observe inconsistencies in heating during a build on the Complex Contour Tool (CCT) shown in Figure 3a. These inconsistencies resulted from several factors, and ultimately correlated with the presence of manufacturing defects. In Figure 3c there is higher than average temperatures in a particular section of the CCT part. An examination of the course paths in Figure 3b shows that the narrowing of the course width meant that the heat lamp passed over this area repeatedly. In Figure 4, the darker (colder) regions of the part are the result of inadequate exposure to the heat lamp due to the complex geometries. These areas are correlated with peel up defects as a result of inadequate adhesion.

Additionally, the spatially incremented data capture allows us to reconstruct the data to extract the temporal element of the heat flow. The reconstructed data set can then be analyzed as a traditional thermographic inspection, using techniques such as Principle Component Analysis (PCA).

4. CONCLUSIONS

By making apparent the affect build parameters have on part quality, ISTIS will reduce process development times by eliminating the guess work involved in trial and error. The presentation for this work will include how the data is captured, what metadata is required for reconstruction, and additional examples of how the thermal data reconstruction revealed process anomalies and aided in the development cycle.

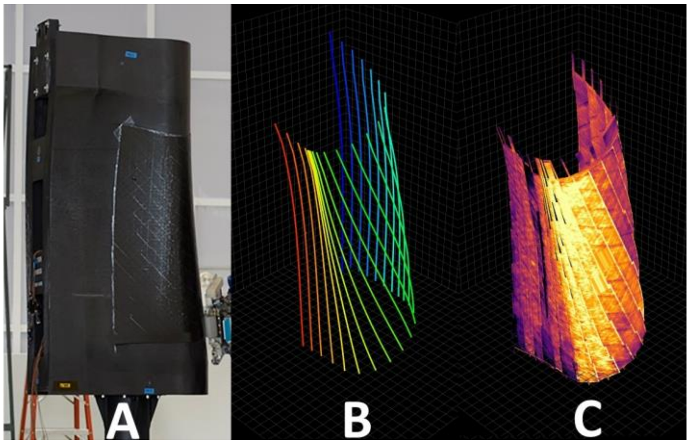

FIGURE 3: A) photo of the Complex Contour Tool B) image depicting the tool path for each course C) the 3D reconstruction of the ply layup thermal data

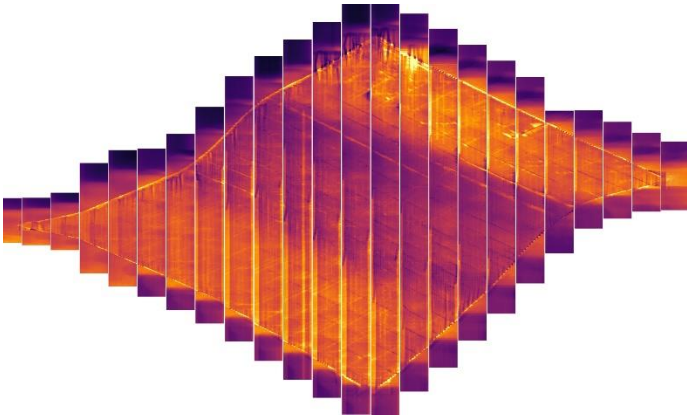

FIGURE 4: Flat image of thermal data taken from a 45 degree ply layup on the CCT. Each vertical path corresponds to a course. Colder region on the center is the result of inadequate heat lamp exposure.

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