QUALITY SYSTEM DEVELOPMENT FOR THE MANUFACTURE OF PRIMARY COMPOSITE AIRCRAFT STRUCTURE

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ABSTRACT

In this contribution, a quality system for the manufacture of composite structure has been established to control composite parts manufacture and components acceptance. The quality system includes procedures that ensure the quality of incoming materials, the control of in-process manufacturing methods, and testing performed to evaluate the end product for conformity to design requirements. The quality system also includes standards to be used for nondestructive and destructive tests, visual inspection techniques during the manufacturing process, and product final acceptance. The proposed standards that determine the acceptance or rejection of manufacturing induced defects and damage consider the process and inspection capability. The standards take into account a lot of manufacturing defect types including visual and inner defects, e.g. surface scratches, surface depression, resin ridges, delaminations and inclusions, porosity, fiber waviness etc. These standards are based on approved data developed as a result of proof-of-structure evaluations conducted in accordance with AC 20-107B and applicable airworthiness standard. Future suggestions are given to complement and improve quality assurance system for the manufacture of primary composite structure.

1 INTRODUCTION

Steady growth in the use of composites has continued in transport aircraft and rotorcraft. Certification issues have emerged with respect to the philosophy of quality control and quality assurance methods needed to guarantee consistent structure performance. A quality system established for manufacturing of composite should be similar to any other quality system established to meet the requirements of CCAR 21.139. FAA issues AC 21-26A [1] to guide production approval holder to establish certification procedures for production, articles and parts for quality systems for the manufacture of composite structures.

During development process of composite structures for COMAC project, e.g. material specification and process specification development process, part process development and quality assessment (nondestructive and destructive) process, a quality system for the manufacture of composite structure has been established to control composite parts manufacture and components acceptance, as shown in Fig 1. The quality system includes procedures that ensure the quality of incoming materials, the control of in-process manufacturing methods, and testing performed to evaluate the end product for conformity to design requirements. The quality system also includes standards to be used for nondestructive and destructive tests, visual inspection techniques during the manufacturing process, and product final acceptance. The standards that determine the acceptance or rejection of manufacturing induced defects and damage consider the process and inspection capability. These standards are based on approved data developed as a result of proof-of-structure evaluations conducted in accordance with AC 20-107B [2] and applicable airworthiness standard.

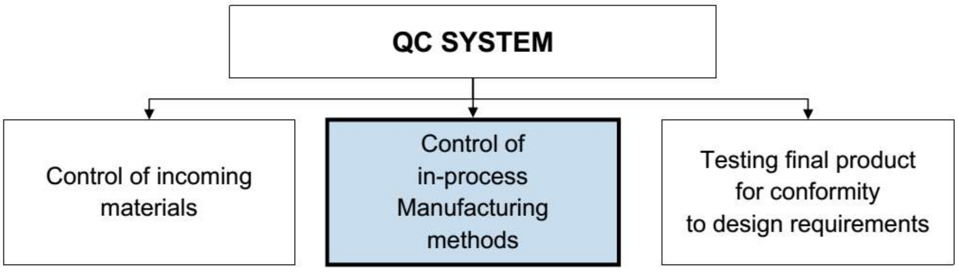

Figure 1: Quality system for manufacture of composite structure

2 CONTROL OF INCOMING MATERIAL AND IN-PROCESS MANUFACTURING

The material properties of a composite are manufactured into the structure as part of the fabrication process (process intensive material). Therefore, it is essential that material and process specifications used to produce composite materials contain sufficient information to ensure that critical parameters in the fabrication process are identified to facilitate production and adherence to standards in the final engineered part.

During development process of composite structures for COMAC project, material specifications which imposes control of key characteristics (physical, chemical, and mechanical properties) and process specifications that controls key characteristics (processing parameters) have established and approved by Authorities. References [3][4] give guidelines to develop material specification and process specification.

Fig 2 gives process for composite parts manufacturing development after fabricator's process qualification. The procedure contains several phases including NDI qualification, Part/Tool Thermal Profile, Pre-Part Manufacturing, Pre-Part Verification and First Part Qualification. Pre-Part Manufacturing phase is to develop part manufacture and inspection procedures/methods, improve tool design and part design drawings, and finally establish part manufacturing plan or route. Manufacturing plan includes critical control of in-process manufacturing methods and needs be approved by OEM. The purpose of the Pre-Part Verification activity is to verify that manufacturing procedures, inspection procedures, and inspection methods for the part are in compliance with engineering drawings and specifications. Pre-Part Verification evaluates internal part quality not inspectable using non-destructive techniques, i.e., Pre-Part Verification typically involves a destructive evaluation of the representative part. And defects found in Pre-Part Verification should meet acceptable limit developed in Pre-Part Manufacturing phase.

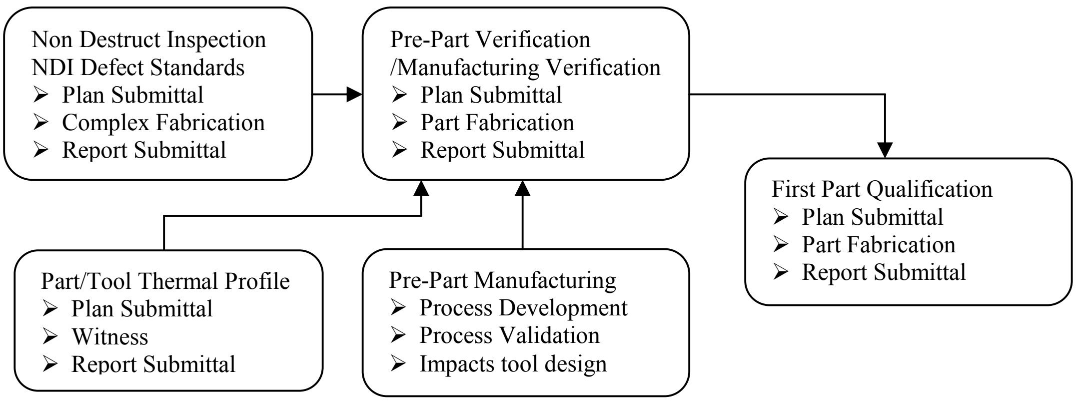

Figure 2: Process for manufacture development of composite Parts

3 NDI AND DESTRUCTIVE INSPECTIONS

Before production, manufacturing processes should be qualified by demonstrating that the combination of materials, tooling, equipment, procedures, and other controls making up the process will produce parts having consistent material properties that conform to design requirements. As part of the process qualification, appropriate destructive and non-destructive inspection/NDI of appropriate tool proofing parts should be conducted to determine conformity to specified design requirements. Destructive tests of parts verify conformity to the specified physical and mechanical properties. NDI of parts verifies that discrepancies caused by manufacturing procedures remain within allowable limits. Having assured in-process control, the detail composite parts must also be inspected for conformance to engineering drawings and specifications requirements and non-destructively inspected for processing induced defects and damage.

3.1 NDI

The extent of non-destructive inspection (NDI) on composite parts is dependent on whether the parts are primary structure, safety-of-flight or secondary structure, and non-safety-of-flight. The type or class of part is usually defined on the engineering drawing. The engineering drawing also references a process specification which defines the NDI tests and the accept/reject criteria. The NDI tests are used to find flaws and damage such as voids, delaminations, inclusions, and micro-cracks in the matrix. NDI techniques commonly used in production include visual, ultrasonic and X-ray inspection. Other methods, such as infrared, holographic, and acoustic inspection are being developed and may be used in production applications in the future.
In order for NDI techniques to be effective, repeatable and reliable, certain controls are necessary. These controls should be approved by the authorities.
A quality system approved NDI specification and procedure to be used. NDI system qualification should be completed prior to inspecting parts in accordance with NDI specification. The qualification must be in accordance with the NDI qualification requirements of the referencing specification. Procedure establishes the requirements for certification of employees performing nondestructive testing (NDT) for inspection and acceptance of production and in-service components [5] [6]. These requirements include periodic training, experience, and examinations. Calibration of equipment used in the inspection technique including any quality system standards with known defects that may be used. The calibration system should provide for periodic requalification of any such equipment at specific time intervals.

3.2 Destructive Inspections

Destructive evaluation allows inspection of internal features of interest not inspectable by NDI methods. Destructive tests include periodic dissection of the part to examine the interior of complex structures and mechanical testing of specimens cut from excess parts of the component.

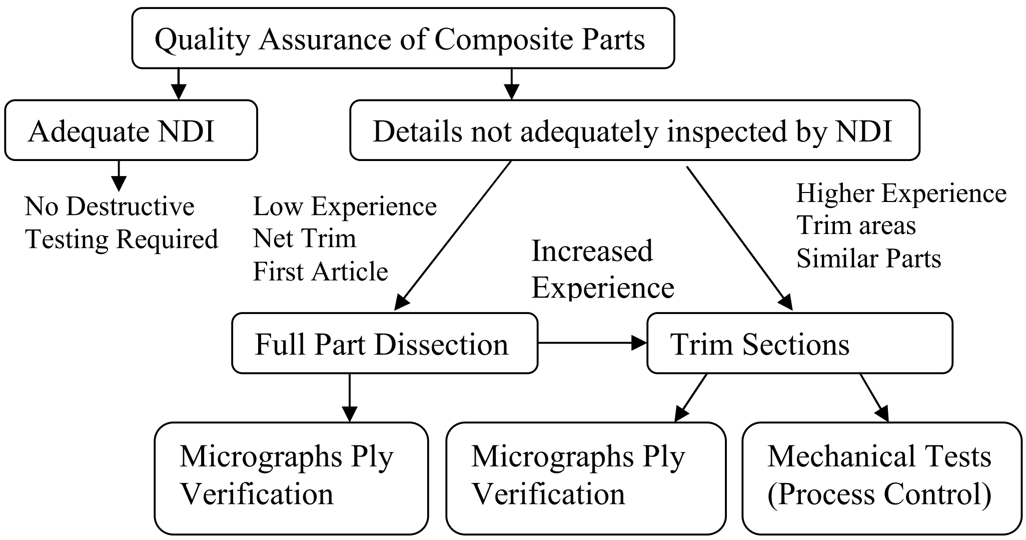

Figure 3: Destructive tests of composite Part

As shown in Fig 3, there are two primary categories of destructive tests: dissection of the full part or examination of trim sections of the part. Full dissection, generally done for the first part from a new tool, gives a complete examination of the part, but is expensive to perform. Examination of excess trim sections is the preferable approach whenever possible. The part is not destroyed, structural details can still be examined and mechanical test specimens can be obtained.

Since it prevents future use of the part, full part dissection should be reserved for parts that meet the following criteria:

- Areas cannot be adequately inspected by NDI
- Part is complex and there is a low experience level for working with the structural configuration or fabrication process
- Part is net trim; detail areas of interest cannot be examined using excess trim areas or part extensions.

Examination and testing of trim sections offers a balance of quality assurance and cost. Trim sections can be part extensions that are intentionally designed to go beyond the trim line or can be taken from cutout areas inside the part. Section cuts from detail areas can be examined for discrepancies. Test coupons can be machined from the sections and mechanically tested to ensure the structural capability of the part and verify the quality of the fabrication process. Using coupons in this way can satisfy destructive testing requirements and process control requirements

A typical sampling plan might include first article full part dissection followed by periodic inspections employing dissection of trim sections. The periodic inspection intervals can vary depending on success rate. After a few successful destructive tests, the interval can be increased. If nonconforming areas are found in destructive tests, the inspection interval can be tightened up.

Fig 4 gives sampling location for destructive evaluation plan of resin infusion super-stringer. Potential areas and items to examine include: primary load paths within the part, areas that showed indications from non-destructive inspection, Tool mark off near cocured details, Ply drop offs at a taper, Ply wrinkles, Resin starved and resin rich areas, Corner radii and cocured details.

Figure 4 sampling location for destructive evaluation plan of super-stringer

Both full part dissection and trim sections involve examination of detail areas. After machining the detail areas, photomicrographs can be obtained to examine the microstructure. Another type of destructive testing is ply verification. Only a small section is need to perform a deply to verify that the plies are laid up in the correct stacking sequence and orientation. When mechanical test specimens were machined from trim sections, the coupons should be tested for the critical failure mode for that part or that area of the part. Tests items include un-notched compression, open hole compression and interlaminar tension and shear.

4 STANDARDS DEVELOPMENT FOR DESTRUCTIVE TESTS

Typical section cut of skin-stringer is shown in Fig 5. The section is used to assess skin fiber wrinkles near and below the stringer flange. Element test specimens can then be machined from the article such that the test section contains the known defects. The impact of the defect on structural performance can then be determined. Knockdown factor of the defect is very valuable to the material review board disposition process and acceptance limits of inner quality during process qualification. Typical defects to include within the destruct article include: delaminations, wrinkles or ply waviness, thickness variation, tool mark off (resin ridge or surface wrinkle), porosity or voids, foreign inclusions. Lots of papers give the effects of fiber waviness on stiffness and strength of composite structure [7] [8].

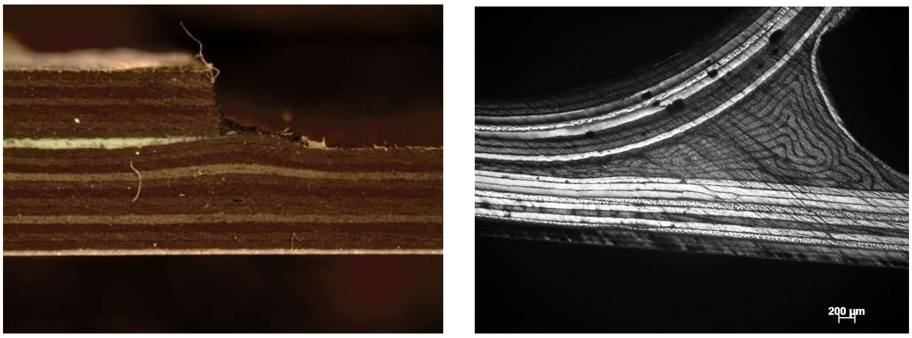

Figure 5 photomicrograph of skin-stringer interface

Reference [9] gives a manufacture method of this kind of test specimens with fiber waviness defect. Typical fiber waviness defect effect curve is shown in Fig 6. Higher knockdown factor of CAI property than OHC and FHC can be seen in Fig 6. Many kinds of manufacturing defects should be considered to determine the acceptance standards, e.g. surface scratches, surface depression, resin ridges, delaminations and inclusions, porosity etc. Some kinds of manufacturing defects may need detail and subcomponent tests with static and fatigue loading to gain the effects on structural performance. These standards are based on approved data developed as a result of proof-of-structure evaluations conducted in accordance with AC 20-107B and applicable airworthiness standard. An effects database of manufacture defects established to assess and improve manufacture quality of composite parts is necessary, so thousands of element tests and higher structural tests should be completed in future.

Allowable manufacture defects, like ADLs, are determined by the OEM, since accurate values require knowledge of the internal loads, structure definition, and design requirements. These allowable manufacture defects should be recorded in composite engineering requirement documents for process qualification to assess the surface and inner quality of composite parts.

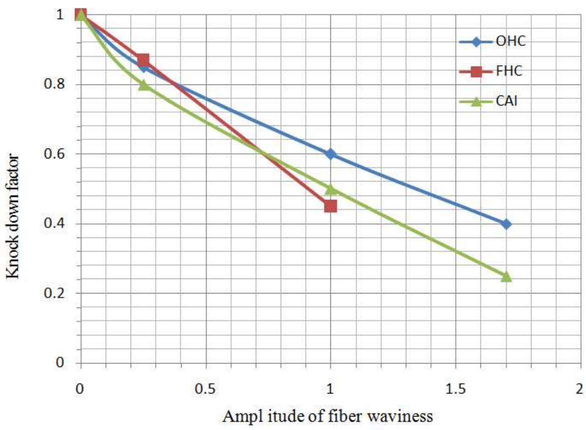

Figure 6 Fiber Waviness Defect effects on Compression strength

5 CONCLUSIONS

A quality system for the manufacture of composite structure has been established to control composite parts manufacture and components acceptance.

The proposed standards that determine the acceptance or rejection of manufacturing induced defects and damage consider the process and inspection capability. An effects database of manufacture defects established to assess and improve manufacture quality of composite parts is necessary.

ACKNOWLEDGEMENTS

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