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A Study on the Pilot Qualification and Qualification System Establishment of The Aerospace Composite Materials

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Abstract

The materials applied to the aircraft fuselage, parts, and components must be verified by relative authorities in accordance with the procedures set by the airworthiness authority to achieve the aircraft type certification. There are no examples of domestic composite materials which were verified in order to be applied to aircraft structure. In this study, the composite material certification system of NCAMP, an American composite material standard certification organization, was reviewed and used as the fundamentals of the first aerospace composite material certification system in ROK(Fig 2,8). Also updated material certification documents were developed and confirmed by material certification engineers and inspectors. This aerospace composite material qualification system is intended to modernize the material certification system for AAM(Advanced Air Mobility) as well as aircraft and to enhance the understanding of related technicians and inspectors.

Key Words : Material Qualification, Qualification Plan, Material Qualification Test Plan, Process Control Documents, NCAMP(National Center for Advanced Materials Performance), Advanced Air Mobility

1. Introduction

The airworthiness authorities must qualify the material design allowables of aerospace materials on the type qualification procedure. As for metals, its compliance may be relatively easily demonstrated using the existing database, which is accumulated for decades to design and develop various types of aircrafts and the material properties and allowables, which are already approved by the airworthiness authorities[1,2]. However, the composite material, which is characterized by its anisotropy, tends to present significant property variation. In particular, the following manufacturing parameters, such as the ratio between fiber and matrix, the directionality of the fabric weave, multiplex manufacturing process, manufacturing environment, and test methods, will have a direct impact on the composite material's properties. Moreover, these characteristics variations of composite material properties are hard to be identified after the fabrication of parts until multiplex tests are conducted[3]. This variability of composite material properties is prone to force us to waste a lot of time and budget as long as we rely on the conventional composite material qualification procedure.

The composite material qualification stands for the procedure composed of a series of tests and conformity inspections to confirm the composite material properties and the manufacturing process. The development and approval of Material and Process specification documents and buildup of the

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database with stable Material Manufacture Process also will be conducted on this phase.

The qualification authority's composite material qualification is conducted to verify the aerospace composite material's compliance and distinguish it from the aircraft certification[4].

As for the aircraft certifications, though they have designed and developed new aircraft parts using identical composite materials, they cannot share the manufacturing method, test procedure, and comparative data since the manufacturing procedure may cause a significant amount of material property variation. Therefore, the airworthiness authority encourages the manufacturers to develop the design allowables of their products through repeated tests until they achieve its approval[5,6]. Of course, this tedious approach causes a considerable workload and demands a lot of cost. In 1995, NASA (National Aeronautics and Space Administration) initiated the AGATE (Advanced General Aviation Transport Experiments) program in cooperation with FAA to develop a composite material property database to share within the aerospace industry. In 2005, NASA proposed the establishment of NCAMP (National Center for Advanced Materials Performance) within NIAR (National Institute for Aviation Research) to carry out composite material qualification activity and share the resultant database[7-9]. The material property database sharing systems, such as AGATE and NCAMP, are focusing on the material properties of laminar and laminated specimens, which is the lowest level of the BBA (Building Block Approach). This system stresses the importance of the approach in terms of design and engineering[10,11][Fig. 1].

It usually takes 2-3 years to opt for appropriate aerospace composite materials and build up a relevant database. Therefore, it is not surprising to find a few years of delay due to composite material after launching an aircraft development program. We may avoid this unnecessary program delay by developing a various composite material database in advance. Applying imported composite material to domestic aircraft tends to cause increased unit cost and unstable raw material supplies. This hurdle is caused by the lack of pre-certified domestic composite material and a ready-to-use material property database. The trial aerospace composite material qualification and qualification system establishment program is initiated by the civil aerospace industry and targeted to build up modernized indigenous composite material qualification system, ready-to-use carbon fiber composite material qualification, and relevant database [Fig. 2].

2. Qualification Documents for Aircraft Composite Materials

2.1. Qualification of Material and Database development

First of all, the authorized aircraft composite material agency should review the qualification test plan, material specification, process specification, and relative quality control documents. The qualification panels should be assembled to provide consultation, and the results of this activity should be applied afterward. An expert inspection agency should inspect the manufacturing procedures of prepreg and panel. This agency is expected to conduct the compliance

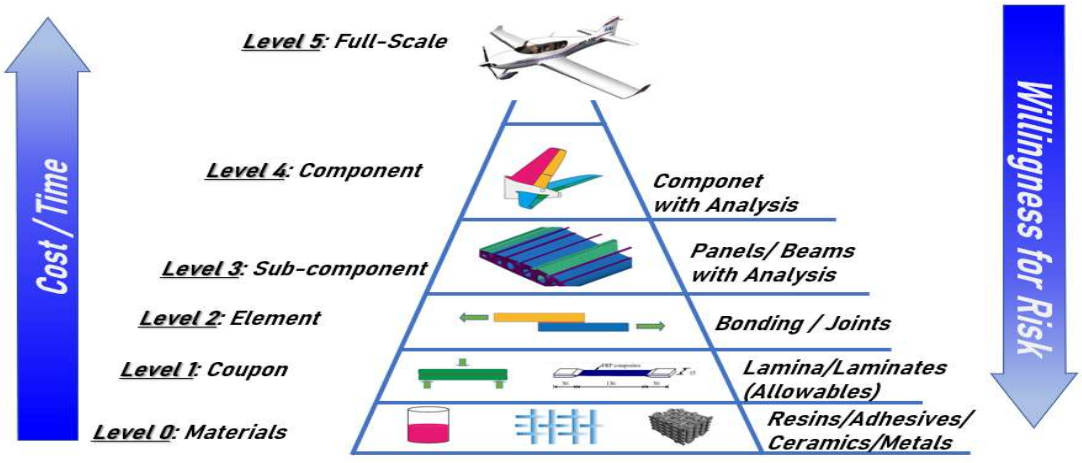

Fig. 1 Aerospace FAA approved building [12]

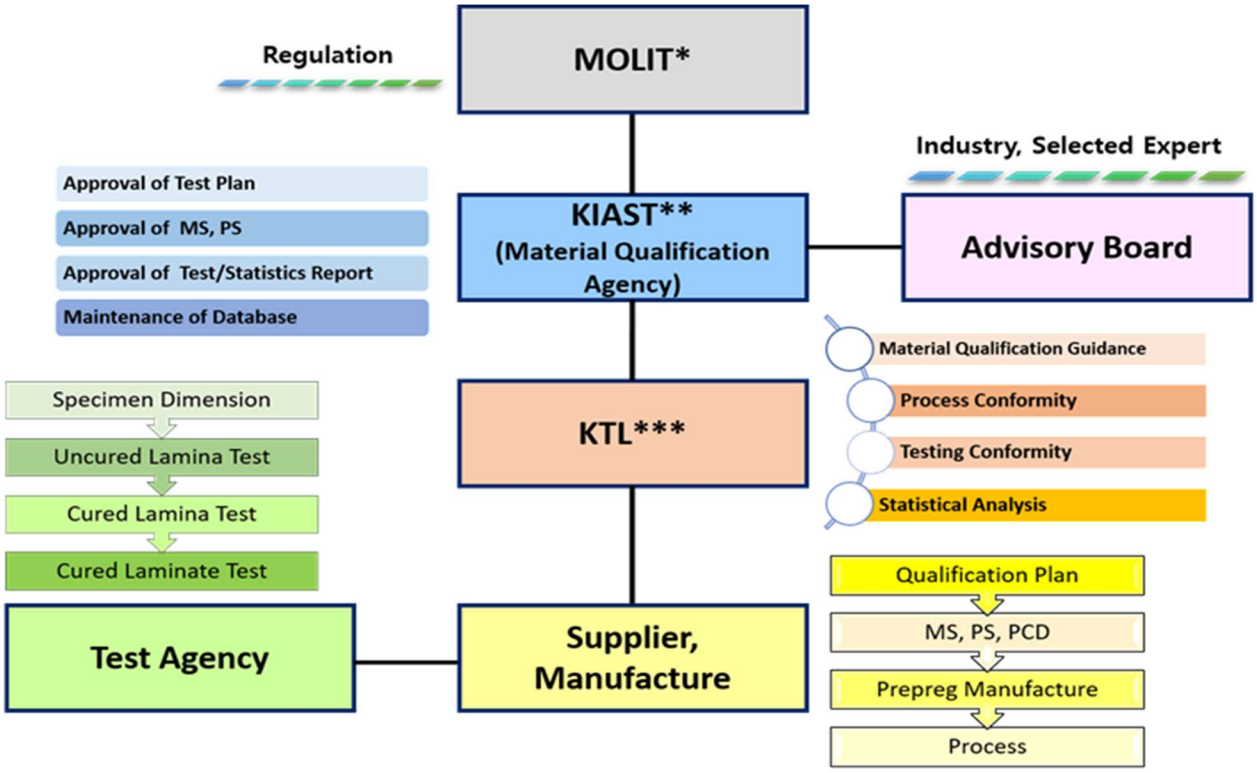

Fig. 2 Composite Material Qualification System by shared block
*MOLIT: Aviation Authority **KIAST: Certificate of Authorized Aircraft Certification Agency
***KTL: Material Qualification Commission Agency

inspection of the manufacturing process and PCD(Process Control Documents) Audit.

The applicants are expected to follow the following procedure:

1. Achieve the approval of the prepreg manufacturing (PCD Audit);
2. Achieve the approval of the composite panel manufacturing process;
3. Fabricate the prepreg with batch number and panel based on ASTM/SACMA test method;
4. Conduct the visual inspection, NDI (Non-Destructive Inspection), and manufacturing testing at each phase of the procedure;
5. Provide the specimina to the authorized testing laboratory.

The testing agency should conduct the glass transition temperature test, physical test, mechanical test, and fluid sensitivity test. The authorized aircraft composite material inspection agency conducts the specimen test, compliance verification of the test, and develops the statistical analysis report regarding the material properties.

The authorized aircraft composite material agency must conduct the following tasks[**Fig. 3**]:

1. Supervise the applicant, testing and evaluation agency, and testing agency;
2. Approve the material property as the result of the test;
3. Develop the material property database and share it

2.2. Qualification Application

The applicant stands for whom applied for the composite material qualification and includes both the composite material manufacturer and the end-user.

The applicant should submit the necessary documents, including the application form, qualification plan, material specification, and process specification, to the Authorized Aircraft Certification agency. The application form must present the following information:

1. Applicant;
2. Material Specification and Process Specification;
3. Qualification plan and related information;
4. The manufacturer of the specimen panel;
5. The manufacturer of the specimen;
6. Testing agency information.

The designated testing agency should also provide the required document forms and assist how to fill the form.

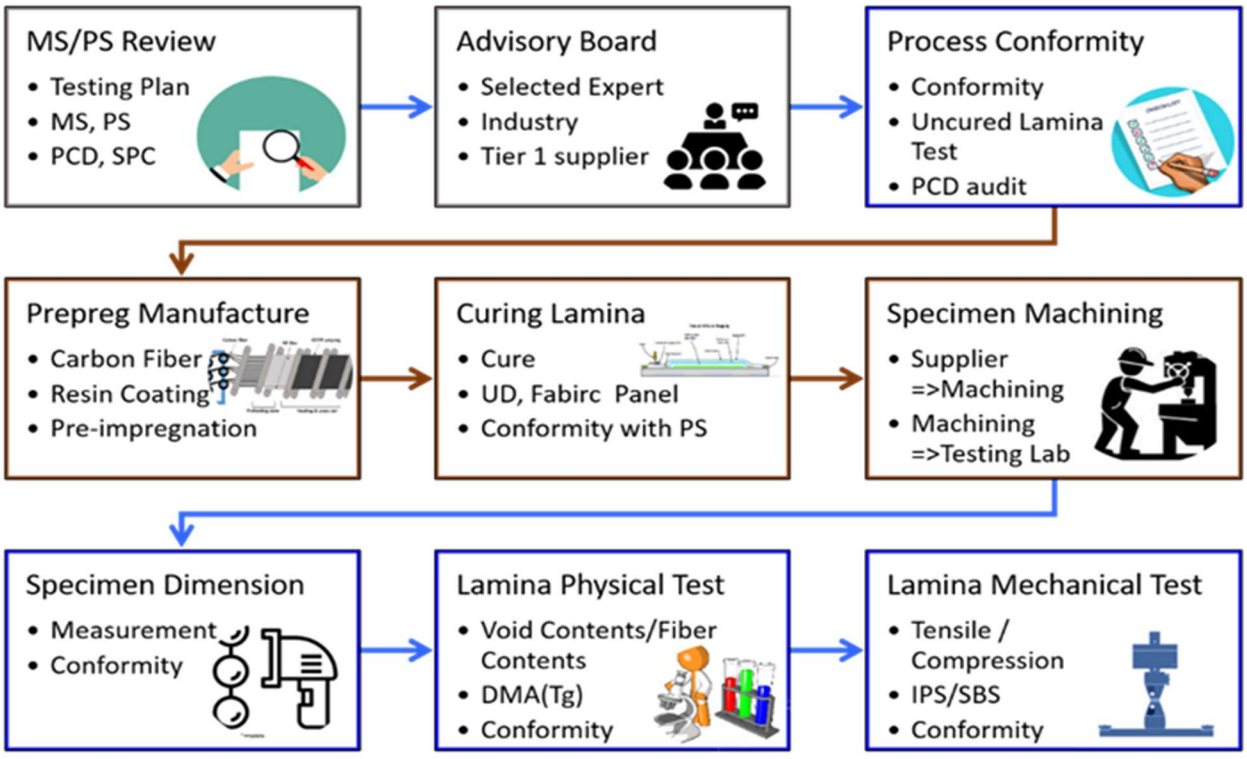

Fig. 3 Flow Chart of the Material Qualification

2.3 Qualification Plan

The qualification plan must include the composite material information about the raw material, composite material, manufacturing process, test temperature, and test specification. The detailed contents of the qualification plan are as follows:

1. General information;
2. The detail of composite material (Prepreg);
3. Methods of qualification;
4. Quality assurance plan;
5. Material qualification schedule;
6. Plans.

2.4 Material Specifications

The material specification should be developed to assure that the composite specimen used for the qualification test has identical quality and performance with the production material through statistical process control. Also, these material characteristics must be preserved through acquisition, maintenance, and management, regardless of the time spent[13].

The material specification limit defined in the material specification must be based on the qualification test using the specimen fabricated by the related process specification. The qualification data should include KC (Key Characteristics), which are essential for CPP (Controlled Process Parameter).

The qualification test data, including physical, chemical, and mechanical properties, is applied to prove the composition, stiffness, strength, durability, and reliability of the material[13].

The material specification defines the requirement of produced composite material derived from the qualification data. It also establishes the necessity of applied raw materials such as unidirectional tape and fabric prepreg, fiber tow and fabric yarn, and resin. The related contents are as the followings[**Fig. 4**]:

1. Amendment history;
2. Range;
3. Applicable documents;
4. Technical requirement;
5. Quality Assurance;
6. Delivery preparation;
7. Buyer quality management.

The development of material specifications is based on DOT/FAA/AR-06/10 (Guide-lines and Recommended Criteria for the Development of a Material Specification for Carbon Fiber/Epoxy Fabric Prepregs), and DOT/FAA/AR-07/3 (Guidelines and Recommended Criteria for the Development of a Material Specification for Carbon Fiber/Epoxy Unidirectional Prepregs Update)

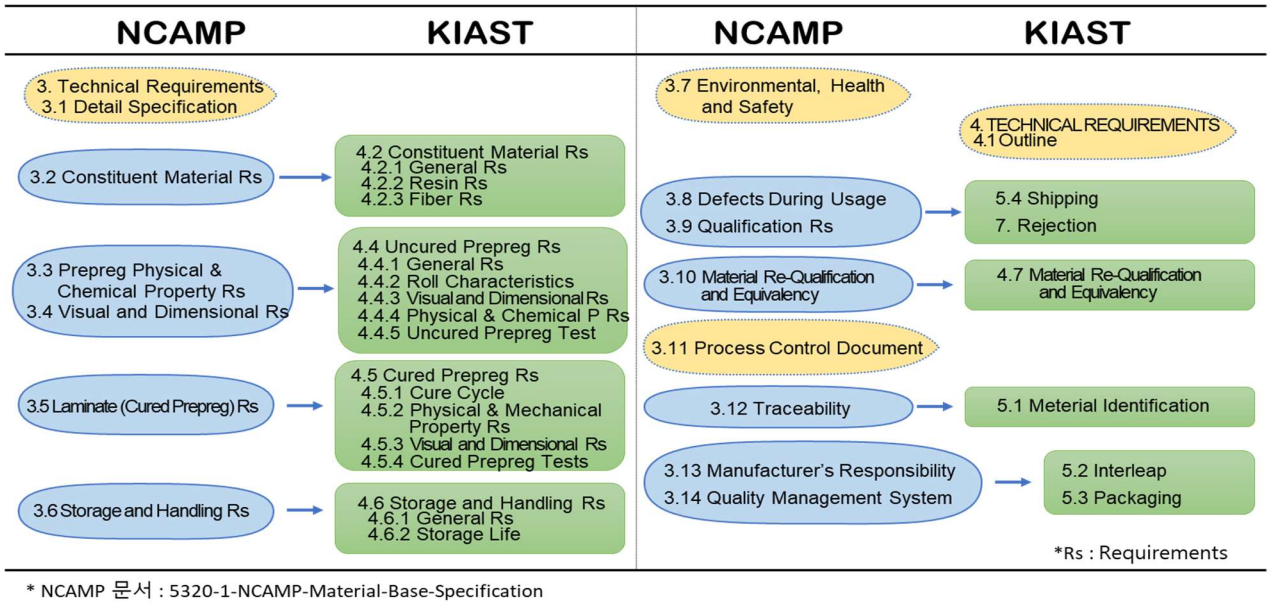

Fig. 4 Material Specifications Comparison (NCAMP vs. KIAST)

Each detailed specification must include the QPL (Qualified Products List) to identify the following information[14,15]. Since the material specification limit will be determined by the experimental data, it may be later be mark as "TBD (To Be Determined)"

2.5 Process Specifications

The Process specification states the composite panel's fabrication method for qualification, equivalency, and acceptance testing. This document must provide enough information about the fabrication method, such as the tooling system, bagging material, bagging procedure, and curing cycle. Process specification and Process Control Documents(PCD) are indispensable to ensure the material properties consistency and reliability. They must be developed for the aerospace structure with repeatability and reliability.

The means of PCD audit and acceptance tests on the material specification should represent the manufacturing procedure, which is expected to be applied to mass production. The CPP for specimen fabrication must in accord with the genuine process parameters. The authorized aircraft certification agency must verify the conformity with the manufacturing process and the process specifications[13].

(1) CPP (Controlled Process Parameter) tolerances;
(2) handing and storage limit of the material;
(3) Key characteristics of the finalized product.

Fig.5 shows of the related contents as follows, and the development is referred to as DOT/FAA/AR-02/110(Guidelines for the Development of Process Specifications, Instructions, and Controls for the Fabrication of Fiber-Reinforced Polymer Composites):

1. Amendment history;
2. Range;
3. Applicable documents;
4. Process requirement;
5. Fabrication of the panel;
6. Quality assurance;
7. Transport.

2.6 Material Qualification Test Plan

The material qualification engineer must verify the material qualification test plan, which the applicant submitted to the authorized aircraft certification agency. If the material qualification test plan is fit for material qualification requirements, the material qualification engineer should issue an 'Engineering Review Report' to approve the test plan[16,17].

The test plan is developed to collect the material allowables, material property data and must include detailed requirements, as you may find below:

1. Test temperature;
2. Test method;
3. Specimen shape.

The material database is developed to be shared by many aerospace manufacturers to maximize its application. The test matrix is usually built up to share the laminar and laminated data, and therefore the material property data may not satisfy all requirements for the specific application[18,19].

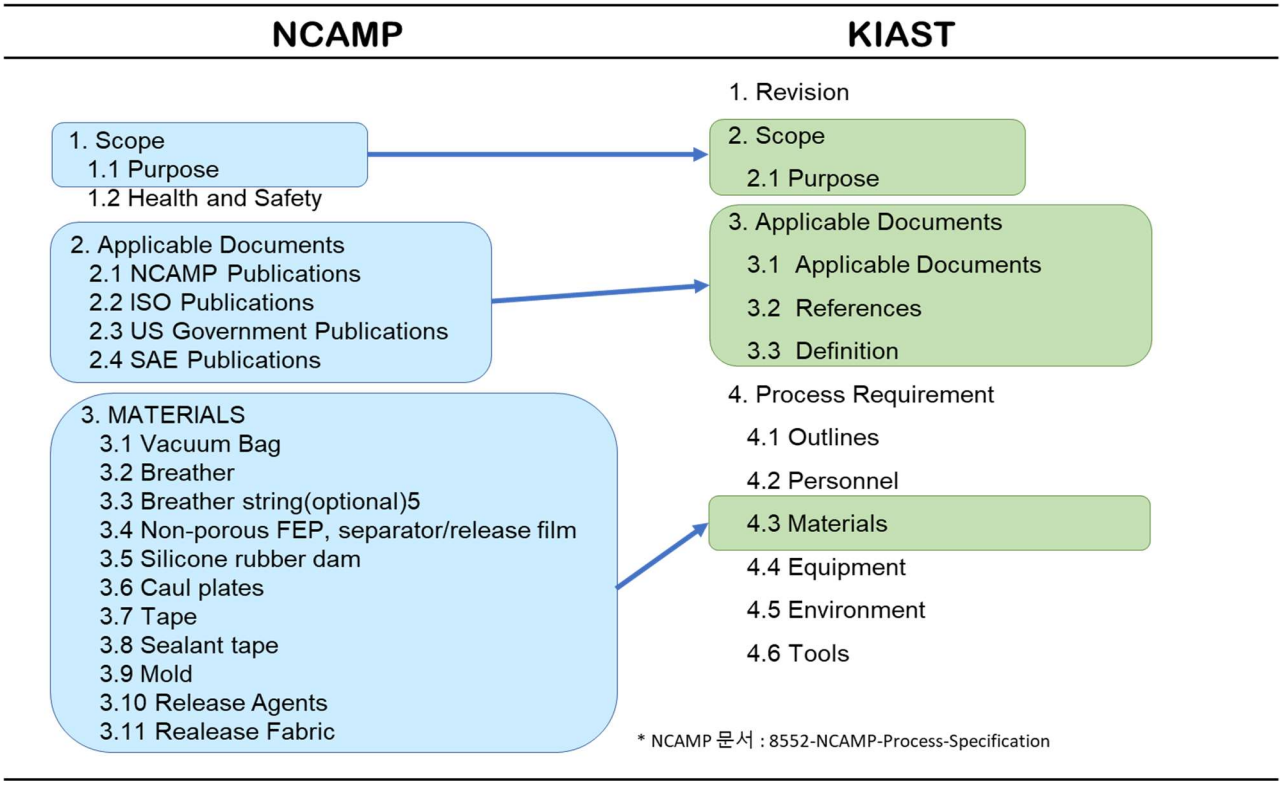

Fig. 5 Process Specifications Comparison (NCAMP vs. KIAST)

The general contents of the test plan are summarized as the followings:

1. Introduction;
2. Scope (Test, panel, Specimen, equipment);
3. Test equipment and tool;
4. Qualification test condition and procedure;
5. Quality assurance method;
6. Test result.

2.7 Process Control Documents (PCD)

The PCD should record the detailed specification of Raw ingredients (ex. name, lot number, manufacturer, storage, major production equipment), and the aircraft manufacturer must control the changes of PCD since the material supplier may amend it[13].

The changes of PCD, commonly happening in complicated aerospace part fabrication, are classified by the "Levels" as you may find the detail below.

Level 0 is applied to a change, which does not affect the material and is allowed by the manufacturer. Level 1 is used to a minor modification, which is confirmed not affecting the material by the internal acceptance test. The ACN(Advanced Change Notice) must be issued for Level 2~4 and verified by the authorized aircraft certification agency.

Suppose the change may affect the composite material property or the composite part manufacturing process. It corresponds to Level 4, and the resulting product must be regarded as a new composite material, and individual qualification is required.

If required, the ACN may be forwarded to the authorized aircraft certification agency to maintain the material's qualification.

The PCD is an entire document of the manufacturer, and therefore, classified contents such as sensitive information and manufacturing process information may be protected by using a security code. To review such manufacturing processes with confidential contents, the manufacturer can submit their PCD without sensitive information.

The PCD is expected to have the following contents:

1. Composite material information;
2. Document management, maintenance, and amendment procedure;
3. Raw material information, procurement, management, inspection method;
4. Composite material fabrication using prepreg (**Fig. 6**);
5. The test method, applicable instruments, CPP (Controlled Process Parameter) and Spec Limit;
6. Packing, delivery, storage, and record management.

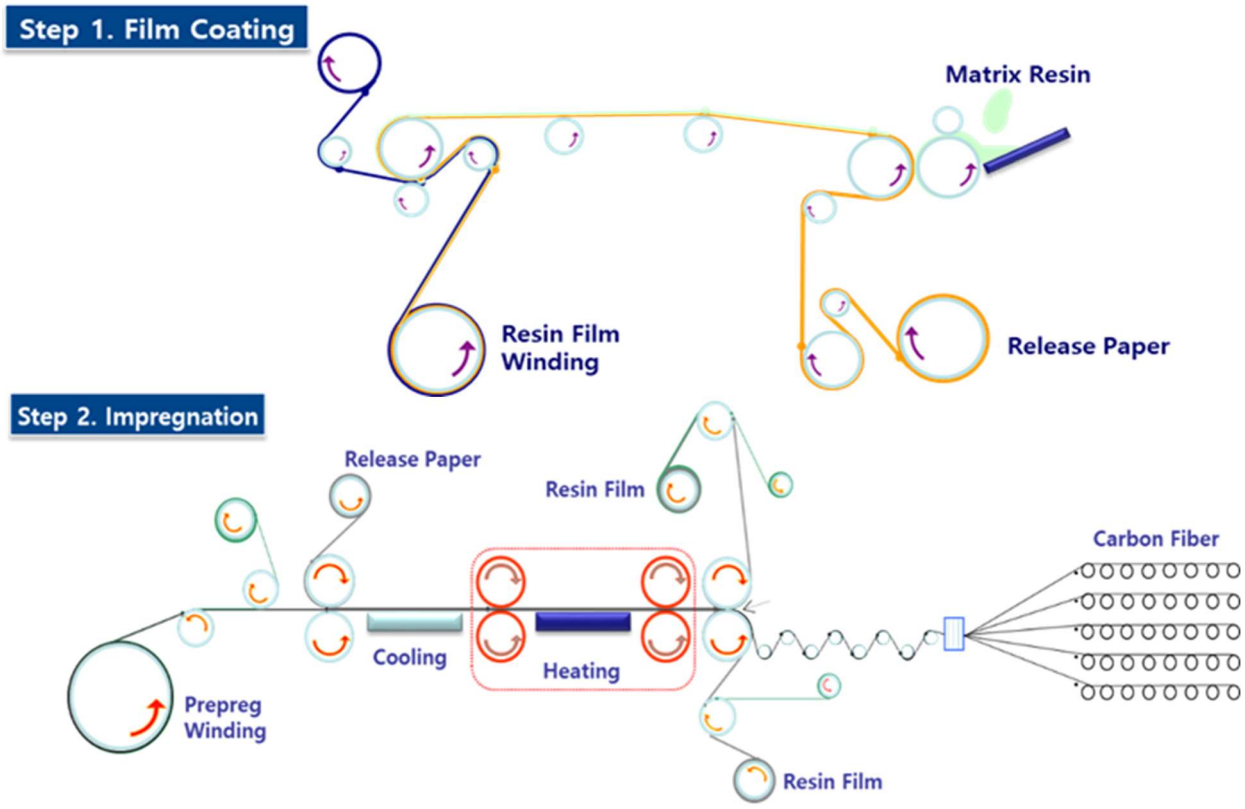

Fig. 6 Prepreg manufacturing process (Film coating and Impregnation)

The raw material manufacturer and authorized aircraft certification agency reviews the manufacturing document review aircraft certification agency approves procedures. The related facility, raw materials, expandable materials, and entire manufacturing process will be audited.

2.8 Material Property Data Report (MSDR)

Generally speaking, the MSDR presents each material's material property data only. The MSDR must be admitted by an authorized aircraft composite material inspection agency, which has the responsibility. The test data obtained by the testing agency should be forwarded to the material manufacturer. The manufacturer must submit the material property data and the agency's test report. After verifying the test report, the Authorized Aircraft Composite Material Inspection Agency should start the statistical analysis as stated in DOT/FAA/AR-03-19 and CMH-17-1G.

2.9 Material Qualification Statistical Analysis Report (MQSAR)

The statistical analysis of the data, including the calculations of the b-basis, is given in the MQSAR. An individual statistical analysis report is required for each type of composite material. The material allowables may be calculated using spreadsheet macros, such as ASAP, STAT-17-1G, and CMH-17 STATS, approved by CMH-17. The authorized aircraft certification agency and advisory group may review the documents for verification

2.10 Statistical Equivalency Test Plan

The material equivalency stands for a procedure to validate the material property to share the composite material quality assurance database and prove that the minor change in the manufacturing process is unlikely to affect the material property of the finalized product. The equivalency test stands for the test to assure that the follow-on material in the shared database or follow-on procedure will result in identical material properties with the original product. The equivalency test plan targets the assurance that the material properties in the database agree with the product from the production line. As a general rule, less data than that of the initial qualification may be applied to verify

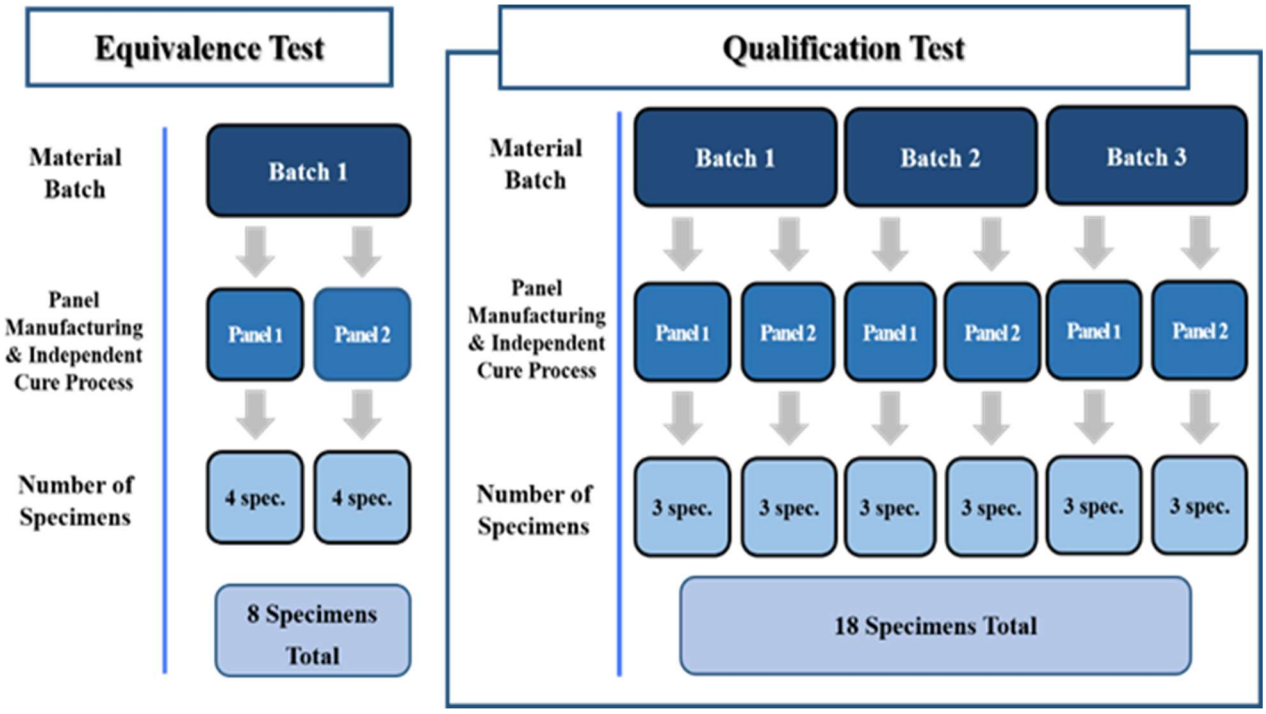

Fig. 7 Material Qualification Test vs. Equivalency Test Matrix

the equivalency. Generally speaking, the test method of equivalency test should be identical to that of initial qualification, and the equivalency test plan must state the target of the test[20-22].

Refer to Section 6 (Material Equivalency and Acceptance Testing) of DOT/FAA/AR-03/19 and Section 8.4.1(Tests for determining equivalency between an existing database and a new dataset for the same material) of CMH-17-1G to find the detail of equivalency test[23].

2.11 Equivalency Statistical Analysis Report

In general, the equivalency statistical analysis report includes the equivalency data set and the statistical comparison result of the first material qualification data set (**Fig. 7**). To carry out this comparison, a spreadsheet, such as HYTEQ (Hypothesis Testing of Equivalence), which is applying the statistical method of DOT/FAA/AR-03/19 and CMH-17-1G, may be used. To determine the material equivalency, the probability of rejecting a good property (α) should be less than 5%, as recommended as DOT/FAA/AR-03/19 and CMH-17-1G. Otherwise, the foundation must state the foundation of making an exception in the report. Since one re-test is allowed for an equivalency test, the actual probability of rejecting a good property is reduced to 0.25%[4].

3. Conclusions

Developing the indigenous composite material qualification system and supporting database may be integrated into the type certification procedure's structural certification. The domestic material developers in ROK have insufficient opportunities to participate in the aircraft development program.

Therefore, it is challenging for them to develop the material property database and achieve the manufacturing system's technical reliability.

The ROK material certification system was developed based on NCMAP and AGATE. The contents of material specification and process specification are based on NCAMP specification and DOT/FAA/AR-07/3 and DOT/FAA/AR-02/110 guidelines. Even though there are slight differences between that of ROK and NCAMP, the requirements for the composite material qualifications are identical. As shown in Fig. 4 and 5, there are differences in the contents and order of preparation of related certification documents by applying them according to the local situation. However, the requirements for qualification of composite materials have remained identical.

Fig. 8 shows the results of the composite material qualification system that will be established, as the outcome of this study may contribute to the material

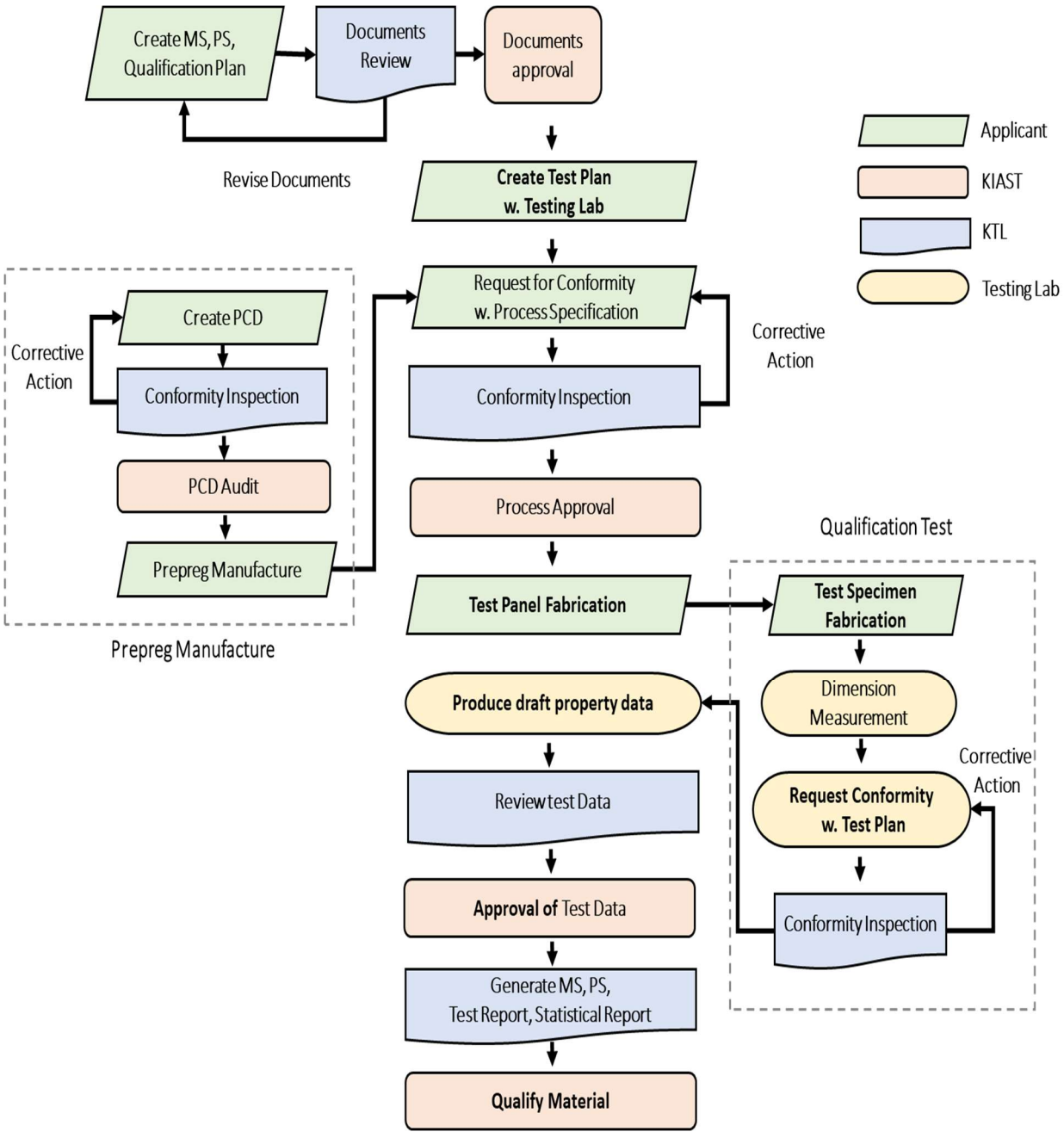

Fig. 8 Flow chart of composite material qualification process establish through pilot certification

property database and production system management.

Developing the database of indigenous composite material properties and material allowables in ROK will indeed contribute to developing the rotorcrafts, light crafts, and any other type of similar aircraft (same as AAM) in terms of composite airframe structural analysis.

Moreover, we may avoid repeated material property tests and lessen the aircraft development costs using identical composite material. This approach will also identical composite material. This approach will also activate the material qualification system, which we may apply for new indigenous composite materials.

Therefore, the related certification documents produced through this study will refer to the NCMAP and AGATE Systems, optimize them for domestic conditions, demonstrate them through the approval process, and modify and supplement them to complete the confirmed composite material certification system process.

Finally, this study represents a part of "A Study of Aerospace Composite Materials on the Pilot qualification and qualification System Establishment" and the detailed qualification screening process is subject to change depending on the research result.

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