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Paper

Establishment of Aerospace Composite Materials Data Center for Qualification

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ABSTRACT: It is well known that the polymer matrix composite materials have good specific strength, making them appropriate for use in transport vehicle. Since the property of composite materials can be obtained only after manufacturing parts, the property depends on greatly on the fabrication process, which is different from metallic system. Therefore, in order to use composite materials for aircraft, the certifying agency requires a robust database with extensive tests and proof of the process unlike metals. Recently developed material qualification methodology by NCAMP (National Center for Advanced Materials Performance) has been accepted by FAA and EASA and can be applied to type certificate reducing time and cost of developing a composite materials database for aircraft application. This paper summarizes a study to establish the composite materials database to apply the NCAMP methodology to composite materials characterization for composite aircraft and to provide the effective materials database through Aerospace Composite Materials Data Center to be approved by Korea Civil Aviation Certification Agency.

Key Words: Composite materials, Aerospace, Certification, Database, Qualification, NCAMP, Data center

1. INTRODUCTION

Historically, composite materials have been introduced into military aerospace systems first because they offer the improved performance over conventional aluminum alloys. In civilian aircrafts, the amount of fiberglass in the Boeing 707 aircraft in the 1950s was about two percent of the structure, while the percentage of composite material usage in recent Boeing 787 in 2010s is 50% [1]. It is known that the Boeing 787 is 20% more fuel efficient than the Boeing 767 which it replaces due to the use of 35 tons of carbon fiber reinforced composite material in each aircraft. Since composites continue to penetrate the civil aviation structural materials with their superior strength-to-weight ratio, it is important to establish the composite materials characterization procedure based on the airworthiness requirement [2]. Since the properties of composites are a function of the properties of the constituent phases, their relative amounts, and processing methods, the overall processing must be carefully controlled.

Generally, each company desiring to use a composite material system in a product design of an aircraft must conduct a qualification process for the material in order to verify its properties and characteristics and the whole activity must be approved by the certifying agency [3,4]. Even for identical material systems, each company usually selects a different customized qualification process leading to a very detailed and expensive procedure for each program as shown in the Traditional Process of Fig. 1. This somewhat repeated process is time consuming and costly process. Most programs are limited to using materials previously qualified for other programs which leads to using older, out-dated material and not taking advantage of the latest technology and material advances in the industry [3]. This cost increases further as other procedures must be established for structural testing, manufacturing control and repair procedures [5]. A solution to this problem, as witnessed by the NCAMP program in Fig. 1 is to establish a national materials data center for composite material qualification, quality assurance, and sharing of database.

An extension of the AGATE Materials Working Group to take the AGATE Shared Database approach to the next level is

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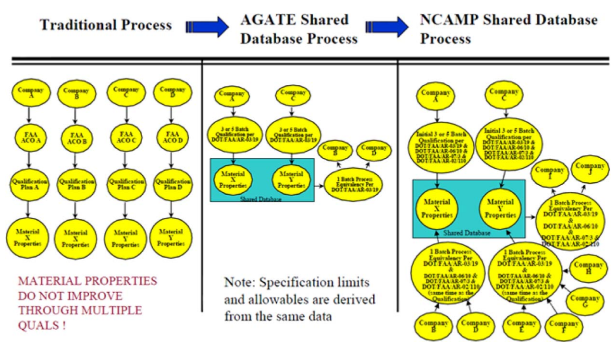

Fig. 1. Materials Qualification Process [5]

the basis of the National Center for Advanced Materials Performance (NCAMP) funded by NASA. NCAMP works with the FAA, NASA, Air Force and industry partners to qualify material systems and populate a shared materials database that can be viewed publicly [6]. Aircraft manufacturers can pull a system from the NCAMP database, prove equivalency and gain FAA certification in a quicker and cheaper manner than a typical qualification approach instead of qualifying an entire material system. Material suppliers can work with NCAMP to qualify material systems without having to be linked to an ongoing aircraft certification program. This allows the material supplier to get their material out into the market via a public forum with generated allowables and FAA certification. It is important to notice that both the Federal Aviation Administration [7] and the European Aviation Safety Agency [8] accept composite specification and design values developed using the NCAMP process.

The first Korean small passenger plane built in compliance with international standards is a four-seat, low-wing, single-engine light aircraft with carbon fiber composite materials by Korea Aerospace, Industries, LTD [9]. A maiden flight was completed in July 2011 and concluded flight tests in March 2013. The Korean Government granted type certification to this composite aircraft in August 2013. On the 28th of October 2014, the Korean Ministry of Land, Infrastructure and Transport (MoLIT), the Korea Civil Aviation Certification Agency, announced [9] the revision of Bilateral Aviation Safety Agreement (BASA) between Korea and the U.S. to expand the scope of aeronautical items for export to the U.S. from aircraft components to small aircraft. The previous BASA was signed in Feb, 2008 and limited. Korea has been continuously promoting expansion of export items since it concluded the first BASA with the U.S. limitedly for components in 2008. MoLIT selected the 4-seater aircraft development as a pilot certification project and carried out an operation of aircraft safety certification for five years. US Federal Aviation Administration (FAA) dispatched a technical assessment team to Korea during the development period (Jun, 2008~Dec, 2013) of the Korean-made small aircraft, to ensure that the manufacturing phase and aircraft certification proceeded well without problems. It has been verified that Korea's certification system and competencies are equivalent to the FAA's own standard and finished the assessment process in January, 2014. Following a revision through working-level talk, Korea and the U.S. signed the implementation procedures on the 28th of October, 2014 [11].

BASA is an agreement signed between the two countries with an objective of sharing certification procedures in imports/exports of civil aviation products to save the duplicated efforts, including time and expenses needed to certify an aircraft in both nations [10]. With conclusion of the expanded BASA, Korean airplanes can be exported to the overseas market. Further, Korea's safety certification system for aircraft will be highly acknowledged by other countries boosting its competitiveness in aircraft exports with less time and expenses needed in aircraft certification. Once the agreement is expanded, Korea will be able to directly export independently manufactured small aircraft to the U.S., the largest aviation market. The US does not take aircraft certification applications from non-BASA partner countries. However, once BASA is signed following evaluation and recognition of a country's certification systems and capabilities, an aircraft that has been issued certification from a BASA signed country is easily issued US certification making exports to the US possible. Many countries also use US certification as import requirements and this means that Korean manufactured small aircraft can be exported to other countries more easily.

This paper summarizes a study to establish the composite materials qualification procedures to apply NCAMP methods to composite materials characterization for composite aircraft [11] and to provide the effective materials database to be approved by Korea Civil Aviation Certification Agency.

2. COMPOSITE MATERIALS DATA DEVELOPMENT

Korea Civil Aviation Certification (KCAC) Agency recognized the importance of composite materials compliance procedures and recently initiated the following project [11]:

Title of project: Composite Materials Database
Development for Small Aircraft
Duration of project: June 2012~May, 2015
Amount of Fund: $3.7 Million

The main purpose of the project is to establish the composite materials characterization procedures and effective certification methodology for small aircraft. This has been achieved by producing the materials database for three composite materials, which are carbon tape/epoxy composite, carbon fabric/epoxy composite, and glass fabric/epoxy composite. The materials are chosen based on the properties, handleability, availability and economy with consideration of popularity in general aviation. The materials database can be

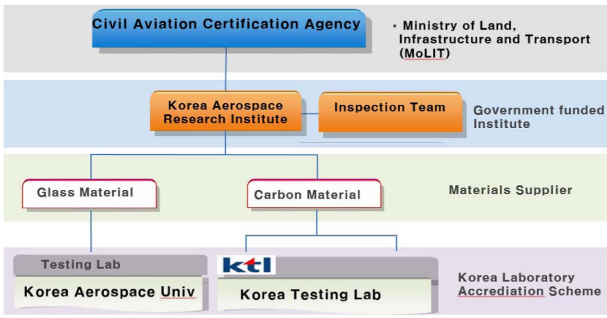

Fig. 2. Organization structure for composite materials certification in Korea [11]

alternatives to composite materials used to the four-seat aircraft approved under BASA. Korea Civil Aviation Certification (KCAC) agency is within the Ministry of Land, Infrastructure and Transport (MoLIT). Mechanical testing was performed by the testing laboratory accrediated by KOLAS(Korea Laboratory Accrediation Scheme) in accordance with the National Standards Act, ISO/IEC 17025 and ILAC (International Laboratory Accrediation Cooperation) guides [12]. The schematic organization structure for composite materials certification in Korea is shown in Fig. 2.

Since this is the first time for Korea to develop the composite materials certification program, the procedure was developed based on the AGATE (Advanced General Aviation Technology Experiments) method [13], the NCAMP process [14], and Composite Materials Hanbook-17 [15] under the recommendation of the NCAMP representatives [16,17]. The AGATE Method [18] describes a standardized coupon level material qualification test plan and statistical technique that yields lamina design allowables for a specific material system, such that allowables can be shared among multiple users without each user having to repeat the full qualification procedure.

In Fig. 3, a test matrix for mechanical property evaluation and allowables of lamina is shown. It is notable that for In-plane shear strength test, ASTM D3518 is used based on the recommendation of NCAMP [19]. It has been shown that the procedure of ASTM D7078 is not practical and needs to be revised. The problem is no tolerance requirement is given for notch radius in the specification [19].

	Test (Strain gages or extensometers)	Method Reference	No. of Specimens Per Test Condition (# of Batch x Spec)			
			CTD	RTD	ETW	ETD
1	0° Tensile Modulus, Strength and Poisson's Ratio	ASTM D 3039	5 x 6	5 x 6	5 x 6	5 x 6
2	90° Tensile Modulus and Strength	ASTM D 3039	5 x 6	5 x 6	5 x 6	5 x 6
3	0° Compressive Strength	ASTM D 6641	5 x 6	5 x 6	5 x 6	5 x 6
4	0° Compressive Modulus	ASTM D 6641	5 x 6	5 x 6	5 x 6	5 x 6
5	90° Compressive Strength	ASTM D 6641	5 x 6	5 x 6	5 x 6	5 x 6
6	90° Compressive Modulus	ASTM D 6641	5 x 6	5 x 6	5 x 6	5 x 6
7	In-Plane Shear Modulus and Strength	ASTM D 3518	5 x 6	5 x 6	5 x 6	5 x 6
8	Short-Beam Shear	ASTM D 2344	5 x 6	5 x 6	5 x 6	5 x 6

Fig. 3. Test matrix for mechanical property evaluation lamina [20]

The results of this project is in Reference [20] in detail. Since the manufacturing process of composite material is complicated the each step of the process must be controlled with the material and process specification and inspected by certified engineer [20,21]. This is because the control of the material and process specification must be carefully maintained and traceable at each stage of the process. Material property control may be lost if any of these linkages is severed. Until now, most general aviation manufacturers have had no choice but to use material and process specifications that are non-uniform with respect to the requirements established by the material supplier. This causes to change the specifications of the material if different companies try to use the same materials, and then characterization tests should be repeated at the aircraft manufactures to assure adherence to the specification and design application. In order to reduce this redundant effort and costs, uniform and standard specifications, which are acceptable to material producers, part fabricators, standards development organizations, testing facilities and appropriate aviation regulations, have been established. This is achieved by process control document (PCD). Even though this can be propriety, it is important to carefully audit the activity relating to PCD under the certifying agency [5,16,18,21]. The purpose of the process specification is to provide processing information for the fabrication of test panels for use in material qualification. This process specification may also be used for equivalency, and acceptance testing as well as a baseline by aircraft manufacturers to develop a process specification for the fabrication of aircraft composite parts. The format for engineering review and conformity inspection reports to be performed in each activity are shown in Fig. 4 [21]. The format is based on the NCAMP documentation. The materials data cannot be approved for aircraft usage without conformity inspection in each process step [22,23,24].

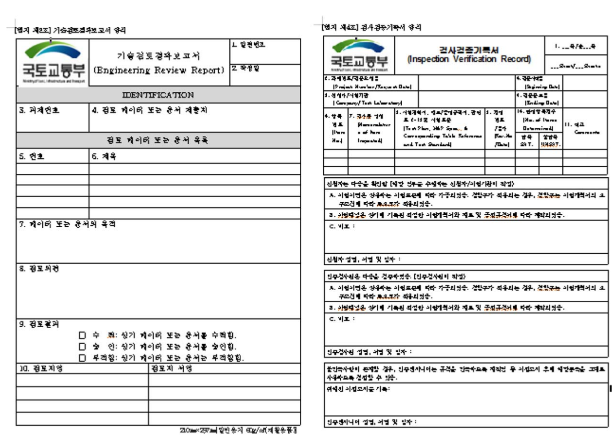

Fig. 4. Format for engineering review and conformity inspection reports to be performed in each activity [21]

3. AEROSPACE COMPOSITE MATERIALS DATA CENTER

In order to accelerate aerospace composite materials usage in aerospace industry by applying advanced materials processing technology into a shared database and equivalency testing, the Aerospace Composite Materials Data Center is established. The data center is qualified as the National Standard Reference Data Center in accordance with the Provisions of Article 16 of Frame-work Act on National Standards [25]. The role of the data center is to produce a shared, reliable database program for composite materials and to provide statistical materials management and control. The aerospace composite materials data are open to public in the home page of the data center as shown in Fig. 5.

It must be noted that the range of data which are concerned by the data center is generic database. In order to establish reliable strength of the composite structure, the building block approach (BBA) is practical as shown in Fig. 6 [26]. Test and analyses at the coupon, element, details, and subcomponent levels can be used to address the issues of variability, environment, structural discontinuity, damage, manufacturing defects, and design or process-specific details. Typically, testing progresses from simple specimens to more complex elements and details over time. This approach allows the data collected for sufficient analysis correlation and the necessary replicates to quantify variations occurring at the larger structural scales to be economically obtained [26].

Fig. 5. Home page of Aerospace Composite Materials Data Center (http://acdc.kari.re.kr)

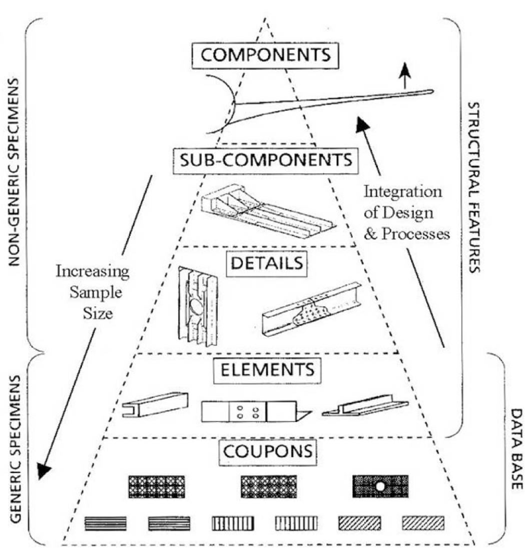

Fig. 6. Schematic diagram of building block tests for a fixed wing [26]

Since the database is generic, it can be used to civilian and military application both. It is understandable because the low level of the building block diagram does not provide any design-specific proprietorial information so that the certification methodology and test data can be shared with both civil and military aircrafts application. This is clear in NCAMP activities.

NCAMP-qualified materials systems are currently following (as December 2015):

① Cytec MTM45-1 PW, acS2, and 7781 (AFRL/Navair)
② Hexcel 8552 AS4 & IM7 tapes and AS4 PW (Gulfstream)
③ Newport NCT4708

Some of the on-going materials systems for evaluation are [27]:

① Tencate TC250, 12 k HTS40 F13 (265°F oven cure)
② Cytec 5320-1, T650 3K PW (US Air Force)
③ Cytec EP2202
④ Renegade MVK-14, T650 3K 8HS (US Air Force)
⑤ Cytec 5215, T40-800 12K (NASA)

In order to use the composite materials in aircraft, not only the prepreg is important, but also additional materials must be qualified, including adhesives, core materials, core splice materials, and potting compounds [28]. Some of these can be qualified in the element level of the BBA, but it must be considered so that the processing condition is to be harmonized. An example of the activities of the data center involved is shown in Table 1. The responsibility of these activities is with the applicant for the composite materials. Data center reviews and performs audit for each activity with following engineering reports. It is recommended that the mechanical testing is performed by the testing laboratory accredited by KOLAS (Korea Laboratory Accrediation Scheme) for the specific test. KOLAS evaluates the technical competence of testing and calibration laboratories based on the general requirements of ISO/IEC 17025 for the competence of testing and calibration laboratories and specific technical requirements of each field [29]. Test laboratories that demonstrate competence and meet the requirements of KOLAS are granted accreditation for testing of composite materials for the purposes of aircraft certification.

Table 1. An example of the activities of the Data Center

Test Plan / Test Reports		Mechanical Properties	
	Quality audit		Environmental conditioning for mechanical test
	Uncured Properties		"dry" / "wet" coupon conditioning
	flow 및 gel time/volatile content/resin content/FAW		Strain gaging
	shop handling properties (out time and storage life)		"wet" coupons handling procedure
	Thermophysical and chemical test (DSC, RDS, HPLC, FTIR)		Environmental conditioning during test
	Cured Properties		0°(warp) tensile properties
	Density, Ply thickness/fiber volume fraction/Tg		0° (warp) compression strength/modulus
	Maximum operation condition (dry and wet)		in-plane shear properties
	Flammability		90° (fill) tensile properties
	moisture diffusivity, equilibrium moisture content		90° (fill) compression properties
	Coupon accept/reject standard		longitudinal flexure properties
Fabrication of test specimens and Test			interlaminar shear strength
	Manufacturing Panels for test specimen		edgewise shear strength
	panel processing to production parts processing		quasi-isotropic open hole tension properties
	lay-up procedure		quasi-isotropic open hole compression properties
	control of voids and resin content (bagging)		bearing strength
	Cure cycle determination		compression after impact
	Laminate/coupon traceability		
	Laminate secondary operations		
	Selection of adhesives		
	tab (doubler) construction and bonding		
	NDI		
	Fabrication of test specimens		

Since composite materials exhibit a high degree of material property variability compared to metallic materials, statistical analysis is important. This variability is due to many factors, including raw material and prepreg manufacture, material handling, part fabrication techniques, ply stacking sequence, environmental conditions, and test methods, and thus increases testing costs and tends to render smaller data sets than are used for metallic materials [30]. The use of statistical techniques to determine reasonable composite material allowables becomes necessary and in most cases, the CMH17STATS software supplied by CMH-17 can be used without difficulty [31]. In this data reduction method, the data from all environments, batches and panels are utilized together to generate statistical information about the corresponding test. This approach utilizes essentially small data sets to generate test condition statistics such as population variability and corresponding basis values to pool results for a specific failure mode across all environments [30,32].

In Korea, it is necessary to share composite materials database and certification methodology with both civil and military application in order to obtain the global competitiveness by reducing the time required for certification of new composite materials and the cost of certification as NCAMP does. This will significantly save the cost and the time for otherwise redundant process.

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