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Development and Trend of Advanced Polymer Composites as Structural Materials in Korea

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Abstract. A brief review of recent research and development of advanced polymeric composite materials in Korea is discussed. This paper also introduces the government research institutes and universities doing active research on composite materials. Aerospace companies are developing many advanced composite materials for defense, aerospace, transportation, and industrial applications. The anticipated applications of polymer composite materials as a structural materials are also discussed.

Keywords: advanced composite materials, carbon fiber, glass fiber, composite processing

1. Introduction

Advanced composite materials in Korea started to emerge in the middle of the 1970s at some defense and aerospace industries, government institutes, and universities. At first, high performance ablative composite materials were studied and products were developed for solid rocket engines. Later, structural composite materials gained more attention due to the broad and important applications in the aircraft and aerospace industries. In the beginning of the 80s, the carbon fiber prepregs became available and also industries began to produce. The development and production of carbon fiber prepregs were important in the area of advanced composite materials in Korea, since the delivery and storage of prepregs are very important factors.

Government research institutes, universities, and industries carry out research and development both separately and jointly. Parts are developed for robots, aircrafts, land transportation, civil engineering applications, sports and leisure applications, bullet-proof helmets and other defense products, electric transformers, domestic applications, etc. Research in this area focuses on design and stress analysis, process development, various fiber and resin development, heat resisting composites for rocket propulsion unit, sheet molding compound (SMC) composites for high impact energy absorption, bulk molding compound (BMC) and carbon/carbon (C/C) composites, thermoplastic composites, etc. The aims of the research and development are the practical application of the composites and efficient production.

The fibers (glass, carbon, Kevlar), the resins (epoxy and polyester), and their prepregs are either manufactured by local industries or imported. However, those materials used for aerospace applications are still in the basic research and development stage and thus are imported.

In this article, a brief review of recent research and development and the anticipated applications of local advanced polymeric composite materials are discussed.

2. Major research organization and their research area

Research and development concerning advanced polymeric composite materials are carried out by government research institutes, universities and local industries. The research organizations, their areas, and products are discussed below.

2.1. Government research institutes

There are five government research institutes involved in working with composite materials. They are Korea Institute of Science and Technology (KIST), Korea Institute of Machinery and Materials (KIMM), Korea Research Institute of Chemical Technology (KRICT), Agency for Defense Development (ADD), and Korea Aerospace Research Institute (KARI). KIST concentrates on raw materials such as fibers and resins; KRICT concentrates on the fiber/matrix interface and intermediate materials such as prepregs, honeycomb cores, etc. KIMM is focusing on process technologies and product developments while ADD devotes more resources toward the development of defense products.

The Airframe Structural Laboratory of KARI is more interested in the design and stress analysis of composite structures, material characterizations, and performance evaluation of structures. The development of composites parts for an all-composite plane is one of its major on-going projects. Figure 1 is the all-composite aircraft, Twin Bee, ready for test flight. The institute also is planning to develop the composites parts for KOSAT (Korean Multipurpose Satellite), such as the antenna, solar panel, and ultralight structures.

In the Polymer Processing Laboratory of KRICT, raw materials for composites such as fibers, resin matrices, core materials for the sandwich, and adhesives have been studied for

Figure 1. All-composites aircraft (courtesy: Korea Aerospace Research Institute).

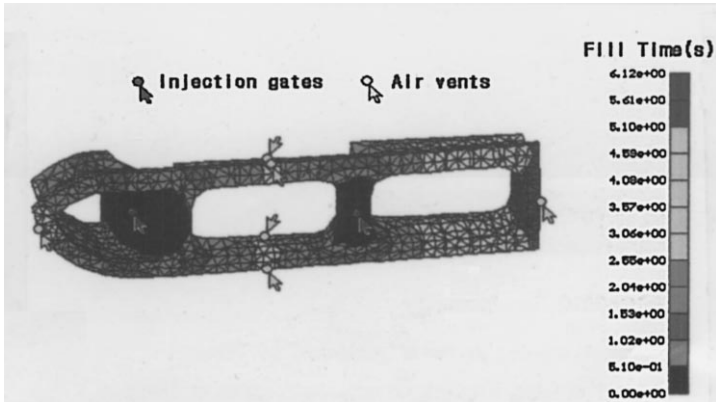

Figure 2. Resin flow prediction of automotive headlight casting using FEM (courtesy: Composite Materials Laboratory of KIMM).

last one decade. Currently, the high performance resins for advanced composites are under development in cooperation with companies.

Of above five organizations, KIMM is considered the most active composite research group. They have been carrying out research for more than 17 years, working both alone and with local industries/universities. They have developed process technologies for the autoclave, RTM, filament winding, braided pultrusion, vacuum bag molding, etc. while developing parts for bicycle frames and other sports leisure products, pressure vessels for compressed natural gas vehicles, robot arms, transmission shafts, excavator arms for heavy machinery, etc. They also lead the RTM study group, publish the Composite Newsletter bimonthly and maintain the Korea Chapter of Society for the Advancement of Materials and Process Engineering (SAMPE). Figure 2 is an automotive RTM part depicting resin flow.

Research on advanced composite materials has been essential in the defense sector. Some research laboratories at the ADD are involved in developing heat resistant composite materials and lightweight airframe parts; their major roles are in system and part design. Intensive cooperation with industries has brought about the improvement of composite materials technologies. Because they require more strict specifications, this has led to the improvment of composite part quality. The filament wound structures, autoclave and tape-wrapping products, and sandwich panels are being developed for specific applications.

2.2. Universities and colleges

Various areas of basic researches on composites materials are performed by several local universities, including Seoul National University (SNU), Korea University, Hanyang University, Inha University, Pohang University of Science and Technology (POSTECH), Chungnam National University, Pusan National University, Korea Advanced Institute of Science and Technology (KAIST), Sung Kyun Kwan University, Kon Kuk University, etc.

Among the universities, SNU, POSTECH and KAIST are the most active. At SNU, the study of core process parameters is carried out for various process technologies, such as

the autoclave, RTM, filament winding, pultrusion and thermoplastics. At POSTECH and KAIST, research is carried out in the areas of materials characterization, fiber/matrix interface, some process technologies of thermoset and thermoplastic composites, stress analysis of composite structures, delamination and interlaminar fracture, buckling and post buckling problems, fatigue and fracture of composites and nondestructive evaluation, etc. In addition, they are offering specific courses on composite materials such as Introduction to Composite Materials, and Composite Materials Manufacturing, Design with Composite Materials, and Mechanics of Composite Materials at the department of mechanical engineering and aerospace engineering. The research areas for the rest of the universities are material characterization, carbon fiber of C-shape, carbon/carbon composites, thermoplastic composites, stress analysis of composite structures, fatigue and fracture of composites, and nondestructive evaluations.

One way to evaluate the activity of the composite society in Korea is to investigate the papers published in Journals of the Korea Society for Composite Materials (KSCM) and the Korea Society for Aeronautical and Space Sciences (KSAS). There were 109 papers published in KSCM from 1988 to 1994 and 26 papers related to composite materials appeared in KSAS, see [1]. Papers were classified into 7 different areas; structural design, stress analysis, processing, raw materials, materials characterization, performance evaluation of structures, combined categories (see Table 1). In KSCM, stress analysis, characterization, and raw materials composed 80% of total papers. Approximately 13% of the papers belong to the combined technology category, which deals with specimens, characterizations, and analysis. However, application papers, i.e., structural design and performance evaluations, composed only about 9% of the total.

The types of papers published in KSAS showed different trends compared to those of KSCM. In KSAS, about 70% of papers were the research of stress analysis and structural design and 20% were characterization and performance evaluations. It can be seen that the KSCM is focusing on materials and characterization while KSAS concentrates more on structural design and stress analysis. Further, in the research of composite materials, the more academic disciplines can become involved in materials, processing, testing, and design and analysis. Thus, KSCM appeared to hold various papers concentrating on composite materials.

Table 1. Classification of papers presented in Journal of KSCM and KSAS [2].

Classification	KSCM	KSAS	Detailed area
Structural design	6	9	Optimum design, vibrations, concept design, etc.
Stress analysis	14	10	FEM, failure analysis, etc.
Processing	19	0	Fabrication processing, optimum cure cycles, etc.
Raw materials	20	0	Reinforcements, matrices, prepregs, etc.
Materials characterization	30	4	Property test and evaluation, etc.
Structural performance evaluation	4	1	Performance analysis and evaluation
Combined category	15	2	Fabrication, analysis and characterization, etc.
Total	109	26	

Table 2. Local raw material production [3].

Manufacturing Co.	Precursor	Glass (ton)	Carbon (ton)	Prepregs (million m^2)
Han Kuk Fiber Co.	Plant	9,360		300 (Carbon)
Hankuk Betrotex Co. Ltd.		25,000		1140 (Glass)
Sunkyoung Co. Ltd.				250 (Carbon)
Taekwang Co.	Plant		100	100 (Carbon)
LG Fiber Glass	Plant	25,000	100	100 (Carbon)
Total		59,360	100	650 (Carbon)
				1140 (Glass)

2.3. Industries

Local industries are involved in processing raw materials into product. Glass fibers are produced by Han Kuk Fiber Glass Co., Hankuk Betrotex Co. and Lucky Fiberglass Co. Taekwang Co. is the only carbon fiber manufacturer while Han Kuk Fiber Glass Co. and Sunkyung Industry Co. produce carbon fiber prepregs. The raw material suppliers are summarized in Table 2.

Local consumption on carbon fibers in 1991 was 567 tons, but gradually increased to about 675 tons by 1994. About 90,000 tons of polyester and 3,500 tons of epoxy were consumed annually in past 4 years, while 75,000 tons of polyester and 1,000 tons of epoxy were produced each year. Some resin manufacturing companies include National Chemical, Miwon, Aekyoung, Koreal Chemical, Kukdo Chemical, and Korea IPCO, etc.

About 80% of carbon fibers are used in for sporting goods. Annual consumption of carbon fibers is estimated to be about 900 tons. Most of the glass fibers are consumed for commercial applications. Some of the parts produced by major local industries are summarized in Table 2.

A consortium composed of aerospace companies is involved in developing a Korean version of the basic trainer aircraft for the Air Force. The trainer has some composites parts which are co-cured composite wings using carbon/epoxy and flight tests result in success. Samsung Aerospace and KARI are developing the eight-seat, all composite airplane sponsored by the Ministry of Science and Technology. This twin-engine composite aircraft is made of carbon/epoxy and glass fiber/epoxy prepregs; the fuselage size is 1.8 m (W) $\times$ 10.95 m (L), and the main wing size is 2.5 m (Cl) $\times$ 0.7 m (Ct) $\times$ 13.9 m (Span) [2]. The master model and lay-up mold, laminating, vacuum bagging, autoclave curing, and finishing is carried out by the Han Kuk Fiber Glass Co. under the subcontract by Samsung Aerospace Ind. The successful flight test has been conducted on March 1997. Korean Air has the experience to develop a solar panel for satellites. Prototypes of carbon/carbon composites have been partially produced at Daewoo Heavy Industries (DHI) through cooperative research with Russia (figure 3).

One of the commercial applications is seen in figure 4. This vertical axis type windmill system has composites blades fabricated by Han Kuk Fiber Glass Co. The blade is 2 m wide

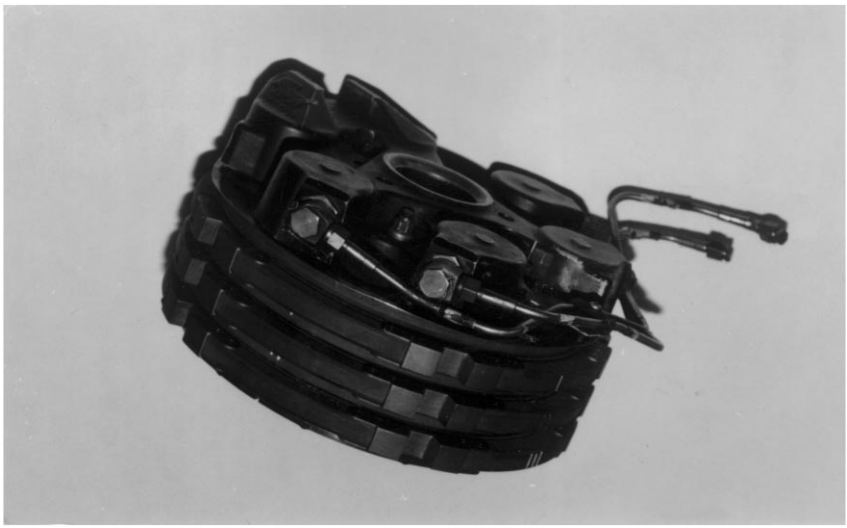

Figure 3. Carbon/carbon composites part (courtesy: Daewoo Heavy Industries Ltd.).

Figure 4. Vertical type windmill (courtesy: Han Kuk Fiber Glass Co.).

Table 3. Summary of typical products developed by industry.

Industry	Product
Korean Air	Aircraft products, Boeing 747 flap., MD-11 fillet and spoiler
Daewoo Heavy Ind.	Aircraft fuselage, wing parts, F-16 fuselage and airframe
Samsung Aerospace	Aircraft products, B747/B757 skeleton, stringer, PW 4000 nose cone
Hankuk Fiber Glass	Defense products, sporting goods, windmill blades, aircraft parts for CASA and Boeing, automotive parts
Oriental Industry	Defense products, armored wall, bulletproof helmet etc.

and 30 m long. The spar material is carbon/epoxy and the skin has a glass/epoxy honeycomb structure cured by autoclave. This project was supported by the Ministry of Commerce and Industry.

"FRP Association" was organized for the local industries, in early 1980. The association now has members from more than 200 companies. These small to mid sized companies produce large tanks, containers, pipes as well as sporting goods (tennis rackets, fishing rods, golf shafts, etc.) "The Korean Society for Composite Materials" which publishes bi-monthly journals, was also founded with industrial support in 1986. Table 3 summarizes typical products developed by local industries.

2.4. Source of research funds

The research funds by the government are supported largely in two areas; basic and applied research. The government supports much more applied research since this R&D can lead to product development. Basic research funds are supported by the Ministry of Science and Technology (MOST), Korea Science and Engineering Foundation (KOSEF), and the Ministry of Education and Agency for Defense Development (ADD). However, applied research funds are supported by the Ministry of Commerce and Industry (Korea Academy of Industrial Technology) and the Agency for Defense Development (ADD).

3. Production and demand

Demand for carbon fiber in 1987 is about 250 tons and its market size was about five million dollars. In 1991, all composites market including carbon and glassfiber composites grew to 0.4 billion dollars. Details of production and market share is shown in Table 4. Data of GFRP is taken from [3] and those of CFRP and KFRP are from 1994 data.

4. Conclusions

Advanced composite materials technologies has been developed by institutes and industries. In addition, academia has played important roles in theoretical background and manpower. The status of major technologies, including autoclave processing, filament winding,

Table 4. Production and sales in Korea [4].

	Production (tons)	Sales (tons)	Applications
GFRP	—	50	Aerospace prepreg
	2,200	2,200	Sports and leisure
	1,000	1,200	Industrial prepreg and products
	610	610	Defense, electrical products
	2,000	2,000	Architect products
	300	300	Building constructions
	2,000	2,000	Shipbuilding
	1,000	2,400	Closed cable loops
	150	150	Booths and panels for automotive
	360	350	General plastic products
	3,000	5,000	Car parts, domestic products
	172	155	Aircraft parts
Subtotal	12,729	15,458	
CFRP	100	100	Fishing rod
	100	200	Sports items
	50	100	Aerospace prepreg
	200	400	Leisure prepreg
Subtotal	450	700	
KFRP*		30	Aerospace prepreg
Total	13,179	16,158	

*Kevlar Fiber Reinforced Plastics: 1994 data.

honeycomb sandwich process, and cutting and bonding process, is close to that of the developed countries. Automated processing, process, specifications, and quality controls, however need to be improved.

Technology of designing structures with composite materials appear to be in the mid-level. The design of shapes, stress analysis, failure analysis, joint analysis, fracture, and vibrations are studied in many universities and institutes. Some companies appear to have the capability to design and fabricate the secondary composites structures for aircraft.

The research and industrial history of advanced composite materials is not as extensive compared to developed countries. However, the production and applications are growing rapidly. The nation's momentum is moving towards the aerospace industry and high value-added products. Thus, the future of advanced composite materials in Korea is toward improving both quantity and quality. Many experts anticipate that the composite industries will catch up technologically with the developed countries in several years.

Further, expected applications and R&D areas extend to aerospace, land transportation, offshore and civil engineering, and industrial applications. The defense industry is not as large, but will grow consistently.

References

1. K.J. Yoon, I.H. Hwang, T.W. Kim, and E.J. Jun, State-of-the-art of technologies related to composite material structures of aerospace vehicles, Korea Society of Aerospace and Astronautics **22**(4), 130–149 (1994).
2. D.H. Choi, et al., Development of a twin-engine composite aircraft (I), UCN93630, Korea Aerospace Research Institute, 1994.
3. B.S. Kim, R&D activities on composite materials in Korea, *Proceedings of KIMM-BIAM Joint Symposium on Advanced Aeronautical Materials* (Korea Institute of Machinery and Materials, Changwon, Korea, 1994), pp. 1–26.
4. K.S. Han, W.B. Hwang, and J.I. Song, Survey on current status of composite materials in Korea, Korea Society of Composite Materials **4**(2), 79–95 (1991).