Carbon Fiber

By Hirata Makoto

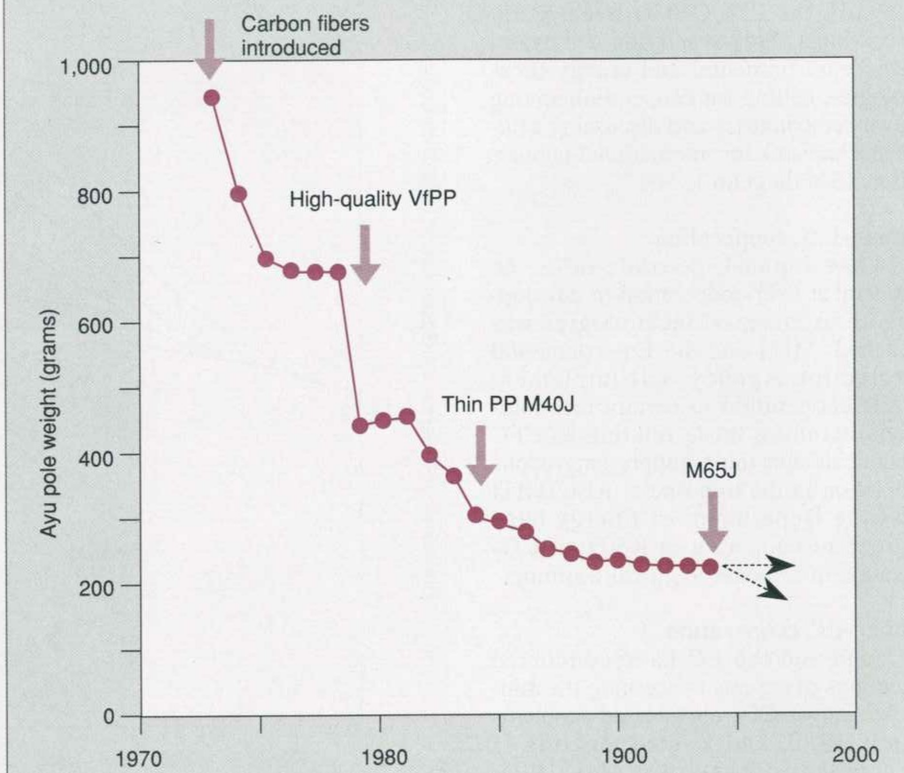
Developed in the 1960s, carbon fiber is a comparatively new type of material. Due to its high degree of comparative strength and elasticity, the material has attracted interest for use in the form of composites in combination with epoxy resins and other substances for aircraft bodies in place of aluminum alloys or other metals. Throughout the 1970s and 1980s applications for private sector aircraft as well as military planes were actively developed. Today these materials are indispensable to improved aircraft performance and weight reduction and have had a tremendous impact on aircraft body design.

In Japan, initial application developments focused on fishing rods, golf club shafts, tennis rackets and other sporting goods. Japan's superior fiber manufacturing technology was skillfully linked to demand, and with increasing and widening competition new varieties were developed yearly on a scale unimaginable in Western nations. These efforts resulted in expanded volume, which further led to improved performance, stable quality and a steady supply which played a role in the development of materials that could be used in aircraft and made a considerable contribution to Western aerospace industries.

From the beginning of the 1980s, carbon fiber compounds began to take the place of aluminum alloys in the control surfaces (ailerons, rudders, and such) of large-bodied passenger crafts and subsequently came to be used even for primary structures, such as tail fins, and the demand continued to expand. However, with the end of the Cold War, reductions in U.S. defense spending and the worldwide aircraft business slump that commenced with the Gulf War, demand slackened in the aircraft industry. Growth prospects then began to dim and the environment of the carbon fiber industry began to change.

Currently Japan holds about 90% of the world's supply of polyacrylonitrile (PAN) fiber, the basic material in carbon fibers, and a share of around 50% of carbon fibers, so it has a critical international responsibility. This article will discuss the current situation and prospects.

Fishing Rod Performance Improvements



Technical developments

In comparison with Western nations, where carbon fiber development proceeded with a focus on aircraft, development in Japan was mostly devoted to sports applications. During initial development, prices were high preventing demand from growing, and due to low growth, prices stayed high. As one would imagine, this vicious cycle resulted in a lack of expansion. However, with the boom in black golf club shafts and fishing rods, pricing became secondary to performance.

At the outset, manufacturers of sporting goods materials introduced products with new features, designs, and improved performance each season. In order to accomplish this, these manufacturers urged the development of carbon fibers with even better properties. Take for example the competition in fishing rod development and *ayu* rods, which are far longer than other types. Until around 1973, the longest rods were 7.8 meters in length and about 1 kilogram in weight. But with the appearance of carbon fibers, rods 10 meters in length became possible. With each subsequent improvement in carbon fiber properties (a high degree of elasticity), diameters have decreased and poles have become lighter. (See graph on page 20.) At 210 grams, rods are currently about one-fifth the former weight. As can clearly be seen from this example, the steadily increasing demand for carbon fibers in the sporting goods sector, primarily in Japan, led to quality improvements and stable supplies.

Creating results in the aerospace industry

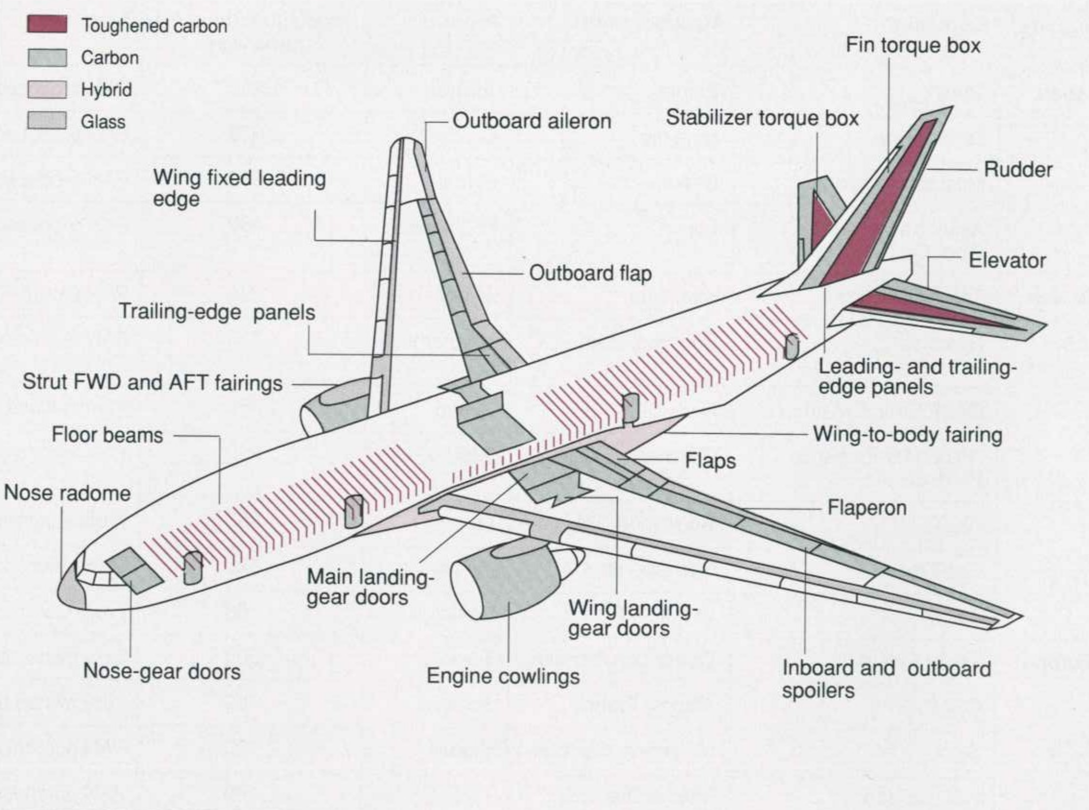
In aircraft and machine industry sectors, metals which had gained a reputation over the years were generally used. When carbon fibers appeared on the scene they were initially assessed as new, or "exotic." However, as results were achieved in the sports and leisure sectors, they came to be perceived as "engineering" materials. These results served as an element of support for actual utilization of carbon fibers in composites for aircraft, particularly passenger planes.

In the military aviation sector, performance was given top priority and carbon fibers have been actively employed. On the other hand, there was some initial caution in the field of civilian aircraft regarding the use of new materials, but aircraft fuel costs skyrocketed with the first and second oil shocks (1973 and 1978, respectively) and serious consideration had to be given to the operational crises into which many airlines had fallen. The National Aeronautics and Space Administration, in cooperation with three aircraft manufacturers, took the lead in Aircraft Energy Efficiency (ACEE) research and development projects to cut large-bodied passenger craft fuel costs through promoting engine efficiency and the development of new wing types and lighter aircraft bodies by using composites. This resulted in the production of carbon fiber composite spoilers, ailerons, and other control surfaces for Boeing 727s, 737s, DC-10s, and L-1011s which were then compared to metal components. It was ascertained that the use of carbon fiber compounds resulted in higher tensile strength, reductions in the number of components and fewer fasteners needed for connections. Weight reductions of about 20% to 25% and superior durability was also verified.

These ACEE successes were utilized in the development of new civilian aircraft and carbon fiber composites are now used in place of aluminum alloys for secondary structures such as control surfaces on Boeing 757s and 767s that came into service in 1983. At 1,530 kilograms, the composites used in 767s make up about 3% of the craft's structural weight, which is 560 kilograms lighter than if metals were used. According to operational data from All Nippon Airways (ANA), engine efficiency has improved and there have been benefits from the use of the new wing types. Fuel cost reductions of around 34% per seat and passenger kilometer compared to 727s in the same class have also been achieved. The use of carbon fibers was expanded to vertical stabilizers, horizontal tail planes, flaps and other primary structures on the newer Airbus A-320 and these components make up 15% of the craft's structural weight.

As illustrated in the diagram below, Boeing decided to use carbon fiber composites for the horizontal and vertical tail planes as a matter of course, as well as for the floor beams and even the GE-90

Boeing 777 Composite Structures



engine's fan blades in the 777, operational as of April 9. In recently developed small corporate jets and helicopters, about 80% of the structural weight consists of carbon fiber composites.

An issue for the future will be the attainment of the "Blackbird Plan" which both Boeing and the Airbus Industrie consortium competed to announce in the early 1980s. This was a plan to use carbon fiber composites for 65% of structural weight in order to make civil aircraft lighter and save energy. With the subsequent stabilization of fuel costs, it has been placed on the back burner, but applications for the main wings and fuselage on large-bodied crafts are steadily moving forward.

Production capacity and demand trends

The table below shows current carbon fiber production capacity. Supported by favorable growth in the aircraft sector in the late 1980s, plant capacity, mainly in the U.S., continued to expand. However, just when companies had completed plant expansions, the Cold War came to an end in late 1989 and the demand for carbon fiber shrank in conjunction with military reductions that began in each country. Especially in the U.S., plans for large-scale projects using great quantities of carbon fiber composites were either shelved or postponed and in 1991, Defense Department-related carbon fiber demand declined 40% compared to 1989.

Moreover, airline passenger numbers fell as a consequence of the Gulf War and with stagnating demand from the civil aviation sector, carbon fiber demand was sluggish. U.S. carbon fiber manufacturers and related industries were hit hard and market withdrawals and reorganizations continued. As a result, the Japanese firms that had taken the initiative in PAN development and supply from the initial development stage absorbed foreign companies that had withdrawn from the market. From the standpoint of production capacity, Japan came to control 51% of the world market. In terms of basic raw materials for PAN, they had a lock on about 90% of the supply.

Because Japanese carbon fiber manufacturers' sales have depended upon sporting goods, the effects of military reductions and the aircraft slump were not very serious. But because huge volumes of carbon fiber for U.S. military demand were transferred to sporting goods applications, the market collapsed, leading to reduced sales volumes and declining profits.

Demand and application development trends

It is estimated that PAN-based carbon fiber demand was 6,340 tons in 1993. Growth has averaged 15% per year for

World PAN-Based Carbon Fiber Production Capacity

Country	Company	Headquarters	Product	Production Capacity (tons/year)	Remarks
Japan	Toray	Ehime	Torayca	2,250	PAN produced in house
	Toho Rayon	Mishima	Besfight	2,020	PAN produced in house
	Mitsubishi Rayon	Otake	Pyrofil	500	PAN produced in house
	Asahi Kasei Carbon Fiber Co., Ltd.	Fuji	Hi-Carbolon	450	PAN produced in house
Taiwan	Taiwan Plastic	Kaosiung	Tairyfil	230	PAN produced in house
U.S.	Hercules	Bacchus, Utah	Magnamite	1,715	PAN technology licensed from Sumitomo Chemical
	BASF Structil Materials	Rockhill, SC	Celion	1,350	Plan to close plant
	Amoco Performance Products Inc.	Greenville, SC	Thornel	850	PAN technology from Toray
	AKZO	Rockwood, TN	Fortafil	360	From Courtaulds
	Grafil Inc.	Sacramento, CA	Grafil	320	100% owned by Mitsubishi Rayon
	Zoltek	Lowell, MA	Panex	60	From Courtaulds
Europe	Tenax Fibers	Oberbruch,Germany	Tenax	500	51% owned by Toho Rayon
	SOFICAR	Abidos, France	Torayca	700	70% owned by Toray
	Sigri	Meitingen, Germany	Sigrafil	100	PAN purchased from Courtaulds
	R.K. Carbon	Muir of Ord, UK		100	PAN purchased from Courtaulds

the past 10 years. The table to the right shows demand by region and use. In 1993 demand totaled 1,430 tons in Japan, 2,330 tons in the U.S., 1,130 tons in Europe and 1,450 tons in Southeast Asia. In Europe and the U.S., the effect of the aerospace industry slump has been heavy and compared to the 50% share held in 1991 it dropped to about 30% in 1993. Compared to the 60% devoted to sporting goods uses in Japan, no more than 3% is used in the aircraft sector; in Taiwan and South Korea 100% is used for sporting goods.

Surveying future demand, carbon fiber use for fishing rods and tennis rackets in the sporting goods sector has temporarily slowed and there is little expectation for huge growth. But, growth is still seen in golf clubs and, along with bicycle applications, golf iron shafts and faces are items for which there is optimism.

In the industrial sector, there are hopes for volume in car applications and development efforts have continued over a lengthy period. The use of carbon fibers has come to be common in racing vehicles, including Formula One racers and road rally cars. It is widely recognized that crash fatalities have declined drastically since carbon fibers began to be employed in F-1 car bodies. However, costs are a problem when it comes to ordinary cars and carbon fibers are still impractical. The keys to rapid progress lie in economical molding and volume production technologies. Volume demand can be expected in sectors such as compressed natural gas tanks for natural gas cars, whose development is mainly proceeding in the U.S., and propeller blades for wind-powered generators scheduled to be made of carbon fiber.

In the case of aircraft applications, there are no large scale aircraft development programs for the time being, but we can look forward to the use of carbon fibers for super jumbo jets, hypersonic transport craft, and in the fuselages and main wings of large-bodied passenger craft. In the civil engineering construction sector, examples of carbon fiber used as reinforcing filament in concrete for its properties of lightness, strength, lack of corrosion and durability in bridge and other kinds of construction have begun to accumulate. Efforts are steadily continuing and their results are awaited.

PAN-Based Carbon Fiber Demand by Region and Use

(Unit: tons)

	Use	1991	1993	1995	1997
U.S.	Aerospace	1,080	730	730	950
	Sporting goods	530	760	800	860
	Industrial	700	840	1,130	1,500
	Total	2,310	2,330	2,760	3,160
Europe	Aerospace	600	385	410	520
	Sporting goods	350	330	360	400
	Industrial	300	415	460	600
	Total	1,250	1,130	1,230	1,520
Taiwan/South Korea	Aerospace	0	0	10	20
	Sporting goods	1,350	1,450	1,580	1,700
	Industrial	0	0	0	30
	Total	1,350	1,450	1,590	1,750
Japan	Aerospace	60	50	85	150
	Sporting goods	940	980	1,030	1,150
	Industrial	350	400	515	760
	Total	1,350	1,430	1,630	2,060
Total	Aerospace	1,740	1,165	1,235	1,640
	Sporting goods	3,170	3,520	3,770	4,110
	Industrial	1,350	1,655	2,105	2,890
	Total	6,260	6,340	7,110	8,640

Cooperative overseas relationships

Carbon fiber is a sector in which there has been very close collaboration with overseas firms since the initial development stage. Japan and the U.K. took the lead in the development of carbon fiber production technologies, but because the U.S. was central to the promotion of aircraft development and large projects related to military demand carbon fiber manufacturers have always had a primary interest in the U.S.

Reviewing Japanese manufacturers overseas relationships, Toray licensed technology to Union Carbide (now APPI) in 1982 and in 1985 established a joint venture in France with ELF AQUITAINE, SOFICAR, which produces carbon fibers locally. Japan Exlan was supplying PAN fibers, the raw material for carbon fibers, to Hercules, number one in the U.S., and in 1989 formed a joint venture to build a PAN manufacturing facility in the U.S. Toho Rayon has been licensing technology to AKZO in Holland since 1986 and supplied PAN to AKZO's carbon fiber plant in Germany. Taking the initiative to establish a carbon fiber manufacturing facility in 1991, Toho Rayon established Tenax Fibers with AKZO (with ownership at 51% and 49% respectively) and the plant is currently in operation. Mitsubishi Rayon is now operating the U.S. carbon fiber manufacturing plant it purchased from the U.K. firm Courtaulds in 1991. JJTI

Hirata Makoto, long engaged in the development of carbon fiber, works in the ACM Technology Department of Toray Industries, Inc.