RESEARCH INTRODUCTION

Fabricating aircraft at lower cost

Selection of Hybrid fabrication technology

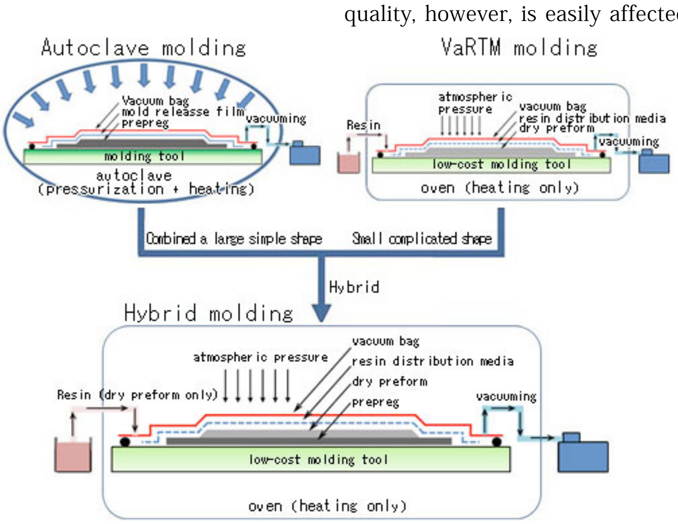
On December 17, 1903, an aircraft with a wooden airframe and cloth wings successfully completed the world's first powered flight. Not long after, the material for aircraft evolved to metals such as aluminum alloys. Now, more than 100 years later, Carbon Fiber Reinforced Plastic (CFRP) is in common use. As its name suggests, CFRP is made of plastic and carbon fiber. The material is lighter, stronger, and more resistant to corrosion than metal, and it can be molded in single pieces.

As a tradeoff against the very high performance of CFRP, structures made of this material cost considerably more to fabricate than comparable structures made of metal. Autoclave molding is the most popular method for fabricating aircraft structures with CFRP. In this method, carbon fiber sheets, called prepregs, are laminated into a desired shape, then cured at high temperature and pressure in a pressure vessel called an autoclave. To obtain prepregs, the interstices between adjacent carbon fibers aligned in one direction are impregnated with plastic (artificial resin). The main factor behind the high price of this manufacturing method is the special equipment, the autoclave, required.

A low-cost CFRP molding method known as Vacuum-assisted Resin Transfer Molding (VaRTM) is available in the vessel and automobile sectors. VaRTM uses only dry carbon fabrics to form the desired shape. The object thus formed is sealed in a vacuum bag to draw out trapped air. Resin is then poured into the object to permeate through the fibers, leaving no spaces between, and cured at atmospheric pressure by heating. Through their research on a new process for aircraft structure molding with VaRTM, engineers at JAXA expect to be able to mold structures at a cost about 25% less than that of the conventional method. Meanwhile, the molding of large structures requires extremely advanced skills. JAXA is advancing in its research on hybrid molding to further reduce cost while incorporating the advantages of the various molding methods applied in the hybrid process.(Figure 1)

Autoclave molding
High-performance CFRP structures for aircraft can be molded by curing at high temperature and pressure. Autoclaves large enough to mold large structures necessarily entail high costs.

VaRTM molding
This is a method for molding CFRP structures with a vacuum bag in atmospheric pressure at relatively low temperature. Carbon fiber (dry preform) alone has advantages over prepreg, as the fiber can be molded into complicated shapes more easily. The molding quality, however, is easily affected by the shape and size of the



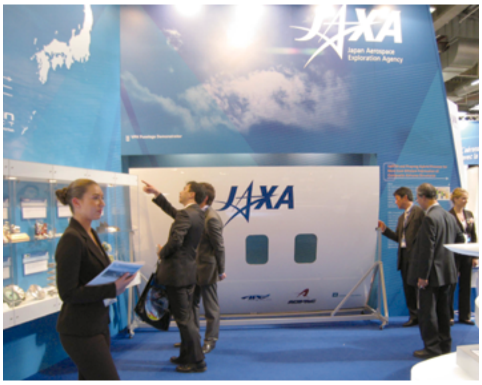
Hybrid molding
Structures with simple, large-area shapes are formed with prepreg, and structures with complicated, small-area shapes are formed with dry perform. Once formed, the two types of structures are integrated into a single piece. From this point on, the hybrid molding technique is identical to VaRTM molding. The entire surface of the structure is covered with a vacuum bag to remove air, then resin is selectively poured into the dry preform area. Finally, the whole structure is hardened in heat all at once.

Figure 1. Comparison of molding methods

Establish the process

Various technical challenges will have to be surmounted to develop an optimal hybrid molding technology. The first is the molding process. Here, two key points must to be solved: how to apply an optimal temperature to the resin, and how to pour the resin.

The quality of CFRP changes at different molding temperatures and when applying different heating methods. In the process under development, we focus on a molding temperature of 120 ℃ . Our data indicate that a gradual increase in temperature results in better material quality than a sharp increase. The resin inlet and outlet positions are important factors to consider when pouring the resin into the carbon fiber, as is the timing from when air is removed from the carbon fibers to when the resin is poured in. By determining an optimal method for each stage, step-by-step, we have established a hybrid molding process for the molding of aircraft structures with ideal strength.(Figure 2).



The prototype exhibited at the 48th Paris Air Show held in June 2009 was well received by experts from various nations.

Figure 2. Quadrant fuselage structure prototype fabricated by hybrid molding

Findings from test results

The application of hybrid molding in the aviation sector will require solutions to other challenges besides the molding process itself. The exacting specifications and stable quality required for CFRP in the field of aircraft manufacturing can only be achieved by firmly curing the work pieces at high pressure. As of this writing, none of the prepregs for the main aircraft structures can be molded at atmospheric pressure. In the process under development, we are therefore applying a substitute, an industrial-use prepreg capable of hardening at atmospheric pressure. Henceforth we will need to develop a prepreg which performs well enough to apply to the primary aircraft structures and which can be molded at atmospheric pressure.

Another challenge is the interface strength. At this stage of development, the in-plane (in a two-dimensional plane) strengths of the tension and compression in our process have reached the design requirement of target structure. But the interface, the contact face between the prepreg and the dry preform impregnated with resin, still lacks the necessary strength. To increase the interface strength, we have been improving a bonding method and developing a resin with characteristics suitable for hybrid molding.

With this new method of hybrid molding for the fabrication of main aircraft structures, JAXA seeks a 50% cost reduction compared to autoclave molding. We are determined to continue our development research on new technologies useful for the development of next-generation passenger airplanes.

[Advanced Composite Group]

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RESEARCH INTRODUCTION

Developing a new material resistant to heat

New possibilities through the development of high heat-resistance CFRP

Carbon Fiber Reinforced Plastic (CFRP), a composite material formed by combining carbon fiber with plastic, is used frequently in the aerospace sector. Various types of plastics (synthetic resins) are used as CFRP components. Epoxy resin, a material with outstanding strength and moldability, is popular as the plastic component of aerospace CFRP The allowable temperature limit of epoxy-based CFRP is about 120 ° C. If its resistance to heat can be further increased, this CFRP can be used to form engine components which are exposed to high temperatures. By replacing the metal materials normally used in engines with CFRP, the airframe weights can be substantially reduced (Figure 1).

Polyimide, a plastic resin composing the circuit boards in cell phones and personal computers, is widely known for its high strength and outstanding heat resistance. The use of polyimide further enhances the heat resistance of CFRP while maintaining the specific strength. The National Aeronautics and Space Administration (NASA) and JAXA are both researching polyimide.

To easily fabricate high heat-resistance CFRP

To mold the airframe structure of an aircraft or spacecraft with CFRP, prepregs, or carbon fibers impregnated with resin, are laminated to form desired shapes and cured at high temperature and pressure (refer to page 1). The prepreg condition is attained by dissolving resin in an organic solvent to facilitate the impregnation of carbon fibers with resin. Conventional polyimides hardly dissolve in organic solvents.

Polyimides can be formed by heating amic acid, a resin easily soluble in organic solvents, to induce a chemical reaction. In conventional methods, a polyimide-based CFRP structure is molded by laminating amic acid prepregs and curing them at high temperature and high pressure to induce a chemical reaction. The finished structure from this process may have voids, however, as the transformation of amic acid inpolyimide (imidization) generates water. In conventional methods, a complicated process is required to remove the generated water.

JAXA has developed a new polyimide with dramatically improved solubility based on a polyimide source material called TriA-PI. This new material can be used at the prepreg stage. Through this development, JAXA has been the first in the world to develop a molding method which produces no water.

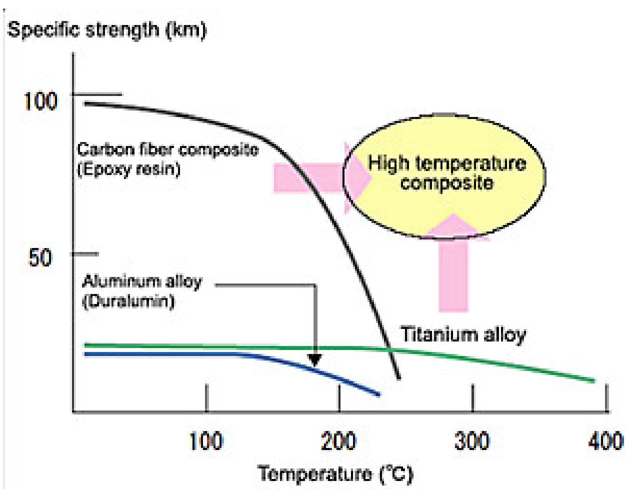


Fig.1 Positioning of high heat-resistance CFRP

Application in the aircrafts and spacecrafts of the future

As explained earlier, this molding method generates water. Even so, the strength of the molded material may be compromised by voids formed as a consequence of other factors. These factors can be eliminated by establishing a verification technology to enable the stable fabrication of structures at a certain quality level. At the beginning of our development effort we conducted verification tests with a 2 mm-thick 10 cm × 10 cm test piece. Now, after several years of progress, we can mold 4 mm-thick 30 cm × 30 cm test pieces free of voids and cracks (Figure 2). In coming months we will be further increasing the thickness of the test pieces for ongoing evaluations of moldability and heat resistance.

CFRP with improved heat resistance will open up possibilities in application to aircraft and spacecraft. JAXA is researching and developing a silent supersonic transport technology and would like to conduct a flight demonstration with a test model now being designed. This test model is assumed to travel at 1.6 times the speed of sound (Mach 1.6), and the surface temperature of its main wing and fuselage is assumed to be about 43 ℃. If the test model attempts to fly at Mach 2, the surface temperature will rise to about 100 ℃. The tip of the nose and the leading edge of the wing heat to still higher temperatures. CFRP with improved heat resistance will be essential to achieve the necessary weight reductions for supersonic transports.

There are still no domestically produced space planes in Japan, but research and development on various themes and flight demonstrations have been conducted. When a space plane reenters the earth's atmosphere, the friction with the atmosphere generates extreme heat on the outer surface. The plane needs to be firmly covered with heat-insulating materials to protect the airframe from the high temperatures. If heat-resistant CFRP can be applied as a structural material of the airframe, the thickness of the heat-insulating materials and the weight of the structural material itself can both be reduced, leading to a significant weight reduction of the airframe overall.

In 2008, JAXA developed TriA-SI-2, a polyimide with higher heat resistance (370 ℃) and the same levels of strength and moldability as earlier CFRPs (Table 1).(*) We will continue to evaluate the moldability and heat resistance of this material.

(*) TriA-SI-2 was developed in cooperation with Kaneka Corporation.

Table 1. Creation of the new polyimide resin

	NASA PMT15	NASA PETI-5	JAXA TriA series		
			TriA-PI (1999)	TriA-SI (2005)	TriA-SI-2 (2008)
Mechanical characteristic	×	◎	◎	◎	◎
Strength at elevated temperature (250℃ or more)	△ (Tg 330℃)	× (Tg 260℃)	◎ (Tg 340℃)	○ (Tg 320℃)	◎ (Tg 370℃)
Solubility	Monomers are soluble	insoluble	~ 20 %	~ 33 %	~ 33 %
Moldability	×	△	△	◎	◎

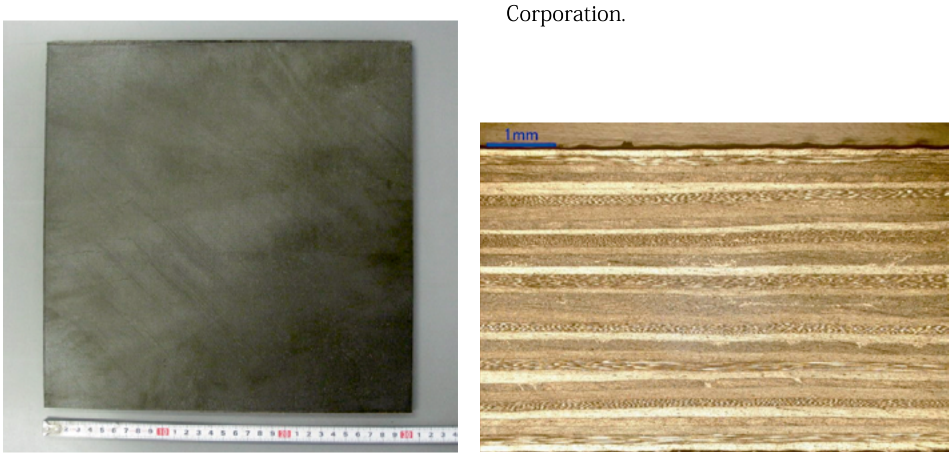


Fig.2 Polyimide-based CFRP (on the left) and microphotograph of its cross section (on the right)

[Advanced Composite Group]

(from left) Hisaya Katoh, Yuichi Ishida, Toshio Ogasawara

CFRP — Plastic and carbon's children

■ Aiming to pick the best of everything

Wood, glass, plastic, aluminum, and so on. The world is full of materials. Roughly speaking, they can be divided into two types: organic materials (materials composed of organic compounds) and inorganic materials (those composed of inorganic compounds) (Figure 1).(*1)

A material consists of atoms. There are various types of atoms, and their properties differ according to how they are combined or bonded. When you combine materials with different properties together, you can produce a "composite material," a new material which shares the properties of its different components. Steel-reinforced concrete, a combination of reinforcing bars and concrete, is a well-known example of a composite material (Figure 2). Engineers in the aerospace sector use carbon fiber reinforced plastic (CFRP), a composite of carbon fiber and plastic, as a structural material for aircraft and spacecraft.

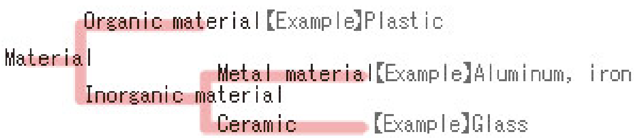
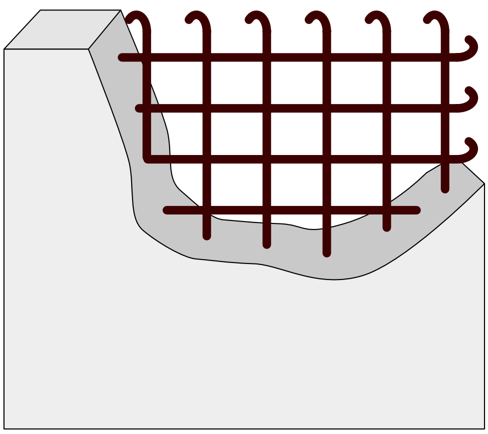


Fig.1 Organic material and inorganic material



Concrete is resistant to compressive force (a force in the direction of crushing) but not tensile force. A material resistant to both compression and tension can be produced by embedding bars in concrete for reinforcement.

Fig.2 Steel-reinforced concrete

■ What kind of material is plastic?

We live every day of our lives surrounded by plastic products such as plastic bottles, stationery, and dishware (Figure 3). But what kind of material is plastic?

Plastic is a synthetic resin made from petroleum. You can produce various kinds of plastics by decomposing or polymerizing(*2) naphtha yielded from the process for refining crude oil. Plastic is generally light and strong, but not very resistant to heat.

Plastic can be grouped into two types, depending on the susceptibility to heat: thermoplastic plastic and thermosetting plastic. A thermoplastic plastic is often compared to chocolate. It gradually softens when heated and begins to show liquid properties when it reaches or surpasses a given temperature (glass-transition temperature). Contrarily, a cooling thermoplastic plastic will become less liquid and ultimately harden when it reaches temperature lower than the glass-transition temperature. A thermosetting plastic behaves differently.

This plastic hardens when heated. And once hardened it will never soften, even if heated or cooled. This is because the molecular structure of thermosetting plastic changes before and after heating. Heat induces chemical reactions which change it into a material that shows no liquidity even when exposed to high temperatures. For this reason, thermosetting plastics are more resistant to heat than thermoplastic plastics.

■What kind of material is carbon fiber?

Carbon fiber is a fiber made up of almost entirely of carbon (Figure 4). Acrylic resin, pitch, and other substances are converted into fiber, then heated into graphite at high temperature to form carbon fiber. Acrylic resin is a kind of plastic, and pitch is a material obtained by distilling petroleum. Carbon fiber has many excellent material characteristics, including light weight, high strength, high resistance to corrosion, outstanding low-thermal expansibility, and electric conductivity. In manufacturing, it is seldom used alone, uncombined with other materials. Combinations with base materials such as plastic, metal, and ceramic add to the functions of carbon fiber and reinforce the base material.

CFRP, a plastic reinforced with carbon fiber, combines the lightness of plastic with the strength of carbon fiber. The aerospace sector relies on CFRP heavily for the engineering of spacecraft and aircrafts, vehicles which require lightweight designs. CFRP is also used for a wide range of sports equipment such as tennis rackets and golf clubs, as well as for the chasses of cars and trains.

(*1) An organic compound is a substance structured with a carbon atom at the core. Other substances are generally inorganic compounds. There are, however, exceptions. Graphite, diamond, carbon monoxide, and carbon dioxide, for example, are inorganic compounds which have the carbon atom at the cores of their structures.

(*2) Polymerization: the combination of molecules of similar types to form compounds with larger molecular weights

Fig.3 Various types of plastic products

Fig.4 Carbon fiber