GSCN NEWS LETTER No.49 2013.10

Green & Sustainable Chemistry Network

GSCN was established in 2000 to promote research and development for the Environment and Human Health and Safety, through the innovation of Chemistory.

GSCN Green & Sustainable Chemistry Network

JACI

Let Principles of Green Sustainable Chemistry be the Common Global Code of Conduct and Ethics

The Japan Petroleum Institute
Yutaka Yamada, President

"The 13th Symposium for Green Sustainable Chemistry (GSC)" was convened in Osaka, Japan in June 2013. This Symposium was the 2nd of its kind under the auspice of the Japan Association for Chemical Innovation (JACI). The theme of the Symposium had this: "Future Society Chemistry Creates: For Perpetual Development of Humankind". It is now essential for chemical researchers and engineers, fully aware of their social responsibility as those concerned with chemistry, to abide by the principles and pursue the ideals of Green Sustainable Chemistry (GSC).

Innovations in chemical technology prompted economic growth and greatly contributed to the realization and improvement of welfare and lifestyle of the peoples around the world. At the same time, however, the development of chemistry has come not without "adverse effects". With globalization permeating worldwide, it is becoming all the more important to set and observe common global rules so that we live as members of a community on this planet Earth. It is therefore necessary to translate the principles of GSC into practice on a global scale as the code of conduct and ethics for all engaged in chemistry.

Significant economic disparity exists today among countries and regions in the world, and the gaps between the principles and the ideals embodied in GSC and the reality of present human society. This difficulty of this situation may perhaps be similar to the dilemma between cost and environmental protection that arises when choosing the best mix of energy resources. "The Sun, The Earth, and Water" symbolized in GSCN's logo are for all who inhabit on this plant to share and the resources they live with. To carry out our duty to inherit this Earth to our future generations, we must now challenge and strive to achieve a common global framework in which the principles of GSC that preserve the blessings of the Earth are prioritized.

We at the Japan Petroleum Institute (JPI) re-appreciate the importance unique to petroleum in solving the global issue of optimization of energy resource mix and its versatility as basic raw material for multitude of derivative products, and endeavor to contribute to paving a path – "passing on to the future using petroleum". To achieve this, JPI will pursue principles and ideal of GSC as the code of conduct and ethics.

Environmental Impact-Reducing Carbon Fiber Composite Material

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"Light and strong" carbon fiber composite material, because of its ability to help reduce environmental impact, including energy conservation, has found increased use as a structural material for aircraft and automobiles. This paper describes the features of carbon fiber composite material that was born and nurtured in Japan.

1. What is carbon-fiber composite?

The carbon fiber used in aircraft and automobiles is a PAN-based carbon fiber made of polyacrylonitrile. The material was invented in Japan, which was also the first country to produce it on an industrial scale. As of 2011, Japan enjoys a 70% share in the global market for carbon fiber.

The carbon fiber composite material is a heterogeneous material in which carbon fiber (with a diameter of approximately 5μm) and resin (principally epoxy resin) are combined. As such, it is referred to as Carbon Fiber Reinforced Plastic (CFRP) (Fig. 1).

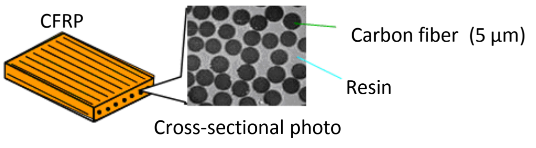

Fig. 1 Carbon-fiber composite material (CFRP)

CFRP, inheriting the features of carbon fiber and resin, has the following characteristics:

- High specific strength (strength/density) and specific elasticity (elasticity/density) (Fig. 2)
- Excellent fatigue resistance
- Small coefficient of thermal expansion (favorable dimensional stability)
- Non-rusting
- Electrical conductivity

The term "specific strength" refers to the value obtained by dividing the strength by the specific gravity (density). Physically, it means the maximum length at which the material can support its own weight. Because CFRP has a specific gravity of approximately 1.6, the material can deliver extremely significant weight-reduction effects.

The carbon-fiber composite material is characterized by its ability to outperform metals in durability (immunity to fatigue) and anti-rust properties (the ability to withstand humidity). In the case of aircraft, for example, the material permits the construction of larger cabin windows and the setting of in-flight pressure and humidity equal to what prevails on the ground. The result is a more comfortable flight experience.

2. Life-cycle assessment (LCA) of aircraft and automobiles built upon CFRP

Life-cycle assessment (LCA) is used as a quantitative measure of the environmental impact of aircraft and automobiles. Figure 3 shows the results of LCA calculations made by the Japan Carbon Fiber Manufacturers Association.

If we consider a civilian jet that is operated in Japan in a standard manner, of the total CO_2 emissions from the manufacture of the materials for the body of the aircraft to the final disposal of the body, the amount of CO_2 emitted during operations represents an astounding 99%. According to calculations made by the Japan Carbon Fiber Manufacturers Association, based on a model in which CFRP is used in 50% of an aircraft body having the structural weight of a Boeing 787 with a 20% reduction in body weight compared to the conventional aircraft, and assuming that the aircraft is operated on domestic routes (Fig. 3, left panel), a CO_2 reduction effect of 2700 tons per year per aircraft can be expected. If the body weight of all passenger jets in Japan is reduced to the same extent, with bodies that are lighter to an equivalent degree, an annual CO_2 reduction effect of 1,200,000 tons can be achieved.

The results of LCA calculations on automobiles indicate substantial energy-savings effect similar to that of aircraft (Fig. 3, right panel). Furthermore, in the case of an electrical vehicle the reduction of the car's body weight can cut the weight of the batteries that are installed contributes to energy saving. Moreover, because the motor capacity can also be minimized, the economic impact of weight reduction in an electric vehicle is said to be greater than that of a car with a gasoline-power engine.

3. Looking ahead

We must therefore tackle the challenge of improving the productivity of CFRP manufacturing and enhancing its performance in order to ensure the widespread use of CFRP, which is an environmentally benign material, and further increase its energy-savings effect. Given Japan's leadership with respect to carbon fiber, if industry, government and academia work together to challenge these issues, I believe it will be possible to build a solid system of technology that is a trailblazer for the world, including the task of international standardization.

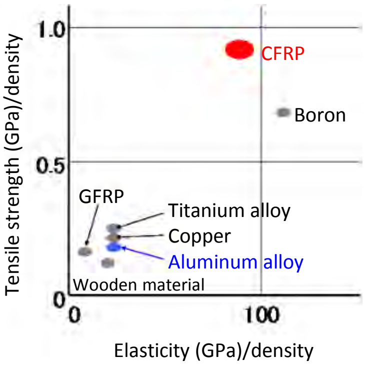

Fig. 2 Specific strength and specific elasticity of various materials

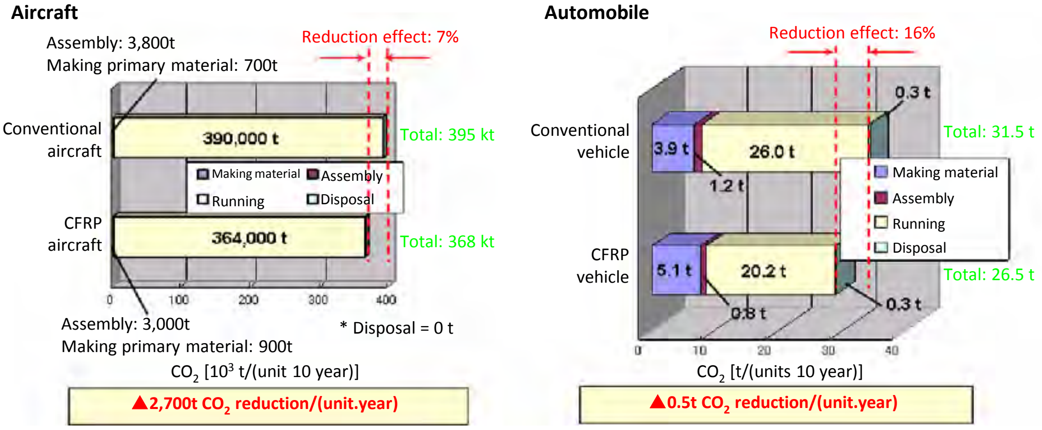

Fig. 3 LCAs of aircraft and automobiles (Japan Carbon Fiber Manufacturers Association's model)

Advanced green innovation discovered by self-healing materials

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Fiber reinforced self-healing ceramic composite consists of oxide fiber bundle, oxide matrix and non-oxide interlayer, exhibiting the ultrahigh self-healing ability. The superior self-healing ability gives the composite time-dependent type life time, although the ordinary ceramics have to take into consideration the probability of occurrence of excessive load. Therefore, the composite can actualize the ceramic turbine blade substituting from the ordinary metal turbine blade, lead to develop an advanced jet engine having 15% higher fuel efficiency than the latest jet engine.

Self-healing is the capability (or function) for material to restore autonomically the damage, similarly as the living thing, thereby adapting the function to the materials for structural and mechanical use gives rise to the huge enhancement in its lifetime and reliability. The self-healing materials for structural and mechanical use usually include the healing agent which acts as adhesives to re-bond the crack surfaces, because the self-healing target should be the cracks. The healing agent is flowed into the space between the cracks at the crack initiation and propagation, thereby reacts at the crack surface to re-bond the crack surfaces.

Oxide based fiber reinforced self-healing ceramic composite (shFRC) developed by the present authors has human bone-like structure (Figure 1), which consists of oxide fiber bundles, oxide matrix and non-oxide interlayer. Especially non-oxide interlayer is most important and characteristic consistent. Crack initiation and propagation allows the non-oxide interlayer react with the oxygen in the surrounding atmosphere, and then the formed oxide and the reaction heat bond the branched crack. Furthermore, the interlayer possesses the function to branch the crack propagation. The crack branching leads to the huge resistance to crack propagation and the conducts the crack to the healing agent. Due to these functions, shFRC can exhibit the high self-healing ability.

The life time of shFRC can be considered to be the same time-dependent type (Figure 2) as metal material, although the life time of the ordinary ceramics must be considered to take into consideration the probability of occurrence of excessive load. Ceramic materials, which are well-known as brittle materials, are easily fractured by the excessive loads due to crush of foreign objects and thermal shock. The fracture resistance of ceramic materials is quite low so that the cracks introduced by the excessive load propagate to the opposite side in an instant. Therefore, the life time of ceramic components is exhausted abruptly by generating of excessive load. Similarly silicon carbide based fiber reinforced ceramics reach the final fracture by repeating the excessive loads although the composites have the high fracture resistance. On the other hand, shFRC can autonomically recover the strength degraded by the excessive load, so that one can use the shFRC components with high mechanical reliability until the self-healing capability is exhausted.

Large green innovation which is to develop an advanced jet engine with ultrahigh fuel efficiency can be achieved by using shFRC. The enhancement in fuel efficiency of jet engine has been attained by the increment in the combustion gas temperature (turbine inlet temperature) with the aids of the heat-resistant improvement in a base material as well as the development of cooling technology, such as adapting air cooling blade and thermal barrier coating. Alternatively the increment of the combustion gas temperature gives rise to the increase in NOx concentration in combustion gas. Thus, it is hard to further increase the combustion gas temperature, based on the view of environmental protection. If one substitutes the shFRC turbine blade for the ordinary blade, the advanced jet engine with non-cooling of turbine blade and ~22% weight reduction can be actualized. The advanced engine can exhibit ~15% higher fuel efficiency than the latest jet engine, and the fuel efficiency enhancement corresponds to the reduction of the CO_2 exhaust by half of the total CO_2 emission equivalency of our country.

shFRC possesses large potential to adapt many application except turbine blade. The present author wishes that the readers will be interested in the self-healing materials.

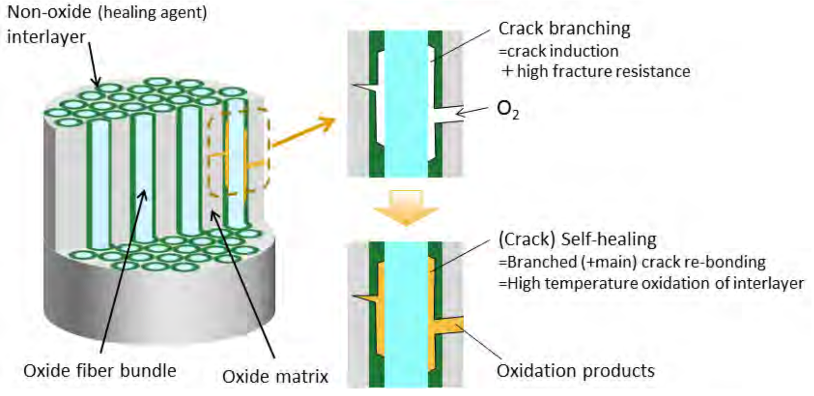

Figure 1 Schematic of fiber-reinforced self-healing ceramics

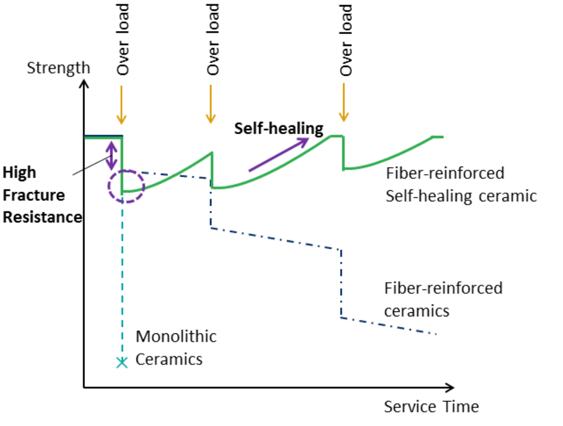

Figure 2 Time dependent deterioration in strength of fiber-reinforced self-healing ceramic