Concept of intelligent materials -- proposal of ken-materials

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Brevity is the soul of future in technology. We have to avoid spaghetti syndromes of modern technology. For this purpose intelligent materials must be developed. Yanagida proposes ken-materials to meet the requirement for the future technology. Authorities have to find novel concepts to make technology more easily understood to avoid unnecessary confusion. Integration is an important key word. Improvement of structural reliability and capability of self-damage monitoring may be achieved if we design so beforehand. This opens a new field of materials design in composite materials. Typical case is a concrete structure reinforced by CFGFRP (carbon fiber and glass fiber co-reinforced plastic) bars. This may be extended to diagnose damage of fragile materials such as ceramics used for heat engine component and concrete piles. R & D is conducted by Ken-materials Research Consortium led by Yanagida.

Keywords: brevity in technology, carbon fiber and glass fiber co-reinforced plastics, concrete piles, fragile ceramics, Ken-materials Research Consortium, spaghetti syndrome, wisdom index, self-damage monitoring, integration, soil ceramics, techno-democracy

I. INTRODUCTION

R & D of so-called intelligent materials is not only performed upon academic basis but also proceeded by industrial sector. In February 1994 some industrial companies gathered to form research consortium for R & D of so-called intelligent materials. H. Yanagida was appointed as the chairman of the consortium. Through discussion about the concept and naming of the consortium, the consortium has been called as "Ken-materials Research Consortium". This paper describes the outline of the consortium and typical examples of R & D. Objectives of R & D of ken-materials are intensively concerned with safety, environment and friendliness to people. Ken stems from the

pronunciation of some Chinese characters meaning wisdom (self-control); 賢, sensing (functional capability); 検, structure (reliability); 建, integration; 兼, simplicity; 儉, soundness (supported by people); 健 and ecology; 圈.

Typical examples are CFGFRP=carbon fiber and glass fiber co-reinforced plastics with improvement of mechanical performance and capability of self-monitoring of damage developed by Yanagida et al, and soil-ceramics or earth-ceramics by INAX where humidity and temperature adjusting capability like soil and mechanical strength like ceramics are achieved to save energy during fabrication and during actual duties.

II. KEN-MATERIALS RESEARCH CONSORTIUM

Researches co-operated between industries and academia are made accelerated if knowledge is spread easily among groups through agreements. Yanagida lab of University of Tokyo used to have several liaison contracts, among them Yanagida considered often it is necessary to transfer knowledge obtained by a contract A to another contract B to solve problem laid in the contract. Sometimes it is required to transfer knowledge from B to A. Thus a research consortium is established and expanded. The main concepts of the consortium are to pursue simplicity, to integrate structural reliability and useful functions, to make people willingly commit and conscious to environmental issues.

The logo-mark is shown in Fig. 1.

Fig.1. Logo-mark of Ken-materials Research Consortium.

III. DIRECTIONS OF TECHNOLOGY, MINIATURIZATION, ENLARGEMENT, INTEGRATION AND BREVITY

Yanagida proposes that directions of R & D in technology are miniaturization, enlargement of structures, integration and pursuing brevity. It may look that they conflict each other. However, they are based upon common concepts. Miniaturization of devices saves space, resources and energy. So-called advanced technology has been and still is being developed along this direction. Yanagida has been

directing a National Project 'Frontier Ceramics' sponsored by STA Japan as described in the other paper by Yanagida(Academic assembly upon Intelligent Materials, the Forum).

Large scale structures require much energy and resources. Development of technology related to large scale structure, therefore, is very important for saving energy and resources. Maintenance technology has also to be developed to save resources. Key-word to technologies related to large scale structures is simplification and plainness. Yanagida and his group have developed technology where strengthening and damage monitoring capability are fulfilled simultaneously by only one action. Simultaneous fulfillment of more than two requirements by one action leads to concept of integration. Integration makes technology simpler and plainer.

Ken-materials research consortium presided by Yanagida is trying to develop plain technology which is well accepted by general public. As the logo-mark shows in Fig. 1, key words are 7 Chinese characters pronounced as 'ken' in Japan.

Integration of structural reliability and capability of self-damage monitoring is said to have opened new dimension in R & D of composite materials.

IV. EXAMPLES OF KEN-MATERIALS

Yanagida has proposed a typical case for self-damage monitoring capability and improvement of mechanical performance in CFGFRP, carbon fibers and glass fibers co-reinforced plastics.¹⁻³ Shimidzu Co. Ltd. and SOK Co. Ltd collaborated him. If we start with FRP, glass fiber reinforced plastics, an action of mixing with carbon fibers improves elastic modulus and gives rise to capability of damage monitoring by checking change in electric conductance. If we start, on the other hand, with CFRP, carbon fiber reinforced plastics, the action of mixing glass fibers improves stiffness to avoid sudden fracture. Figure 2 shows relation between load and deformation. CFGFRP has been developed

as an alternative of steel bars to reinforce concrete structure to avoid troubles arising from erosion of steel. Yanagida has reached the material from a completely different view point to design strengthening and capability of self-damage monitoring simultaneously. In CFRP we can measure electric conductance. However, the loss of electrical conductance there means fatal fracture of the material. The change in electric conductance before the carbon fibers undergo fracture is very small to detect. Mixture with glass fibers makes possible the material stand further behind the point the carbon fibers suffer fracture. A remarkable change is observed while the material remains still unfractured. The decrease in conductance corresponds the portion of fractured carbon fibers. Life detection is possible by measuring the change. Latent damage after an earthquake of large scale structures such as bridges, highways, buildings can be monitored by measuring the change in conductance including carbon fibers. Damage by invaders through the shell walls of safety chamber can be delayed and monitored by applying the CFGFRP to reinforce the walls. Mixture of carbon fibers with FRP enables not only improvement of mechanical performance of the material but also monitoring of damage. No additional sensors to monitor damage is added here. This is the typical case of integration and integrated material.

Breakdown of carbon fiber usually takes place when the fiber is elongated around 1.0%. In order to check damage due to strain less than 1.0%, change in percolation of carbon powders around the fibers to reinforce ceramic matrix is developed by Ken-materials group of Japan Fine Ceramics Center.^{4,5} Micro cracks of the order of 0.01 % in concrete structure is easily detected. This method can be applied to the cases to monitor damage of the structures under high temperature, in deep water or ground, or exposure to strong irradiation.

V. ENVIRONMENT RELATED MATERIALS

Figure 2. Load/Strain Relation (Steel, Carbon Fiber, Glass Fiber, CFGF Composite).

Soil-ceramics was first developed to use industrial waste from tile manufacturing factories. If the waste is heated up to high temperature, energy consumption becomes too much. Ishida of INAX treated the waste with natural fibers hydrothermally around 150 °C to achieve enough strength as wall or floor materials. Mixture of natural fibers used to be popular in earthen wares of Jomon-era. The materials hydrothermally treated still have enough porosity to adsorb and desorb water. The materials can adjust humidity and temperature mildly. Air conditioners usually require help of humidifier when used for warming or dehumidifier when used for cooling. The soil-ceramics make technology simple and comfortable. Technology used for the material is very old and very new.

VI. AVOIDING SPAGHETTI SYNDROME OF TECHNOLOGY

Modern technology is sometimes too much complicated to understand. Yanagida defines such a complicated technology as suffering spaghetti syndrome. There are five symptoms in the syndrome. The first is a complicated appearance difficult to understand. The second is a method to apply more

components to solve problems. The third is one's values to consider the more complicated the more advanced. The fourth is paying more attention to trivial things overlooking essential matters. Finally technology becomes degraded by making more complicated. This is not only true for technology itself but also leads to distrust from people.

To estimate degree of intelligence Yanagida proposes an equation. He defines 'Wisdom index' as:

$$W_I = (\text{Necessary Merits}) / (\text{The number of Components})^n$$

where n is greater than 1.

In the case of CFGFRP, merits in numerator are strength as steel, chemical stability better than steel, two-step wise fracture as steel, lighter weight than steel, damage monitoring capability. Only carbon fibers and glass fibers embedded in plastics are used in dominator. Sometimes one suffering from spaghetti syndrome boasts of large value of dominator instead.

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