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Some Research Topics of Ben's Laboratory at Nihon University in Japan

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ABSTRACT

This paper presents some research topics for advanced composites which have been conducted in Ben laboratory, College of Industrial Technology, Nihon University. The topics are applications of shape memory alloy(SMA) to composite structures, dynamic responses of CFRP and GFRP structures, fabrication of new type of GFRP, fatigue and weatherability strength of CFRP and new concept of joint for FRP structures, respectively.

1. Opening

Nihon University is a private university and has the biggest number of students in Japan. Our university has 14 colleges including 3 engineering colleges and our college is one of them. Our college has 7 departments namely, mechanical engineering, electrical/electronic engineering, civil engineering, architecture engineering applied molecule/chemistry, management engineering and mathematical/information engineering. Our university is apart 30 minutes from Tokyo station and one hour from Narita international airport by train. Our department has 26 Faculty members for 920 under graduate students and 60, 12 students for master and Ph. D courses. However the composite research laboratory is only my laboratory and I have 9 senior students of undergraduate, 8 and 2 students of master and Ph. D. courses at this year.

2. Research Subjects

2.1 Characteristics of Vibration suppression for SMA/CF and SMA/GF hybrid composites1)

When a temperature of shape memory alloys(SMA) is elevated, their shapes return to the memorized ones. Since their strength and modulus change according to the environmental temperature, SMA is now utilized as one of a candidate actuator of smart composites.

In this subject, we study how to fabricate two kinds of composites. One is a composites in which SMA fiber are perpendicularly embedded into CFRP laminates. Another is a composite in which the SMA fibers are perpendicularly embedded into glass cloth reinforced plastics. Then, we examine that the vibration of the SMA/CF and SMA/GF composite can be suppressed by heating/cooling the embedded SMA fibers. The embedded SMA fibers are heated by direct electric current, and cooled by a natural convection. The SMA fibers embedded in parallel should be connected in series to ensure a constant current through all the fibers.

Table 1 shows the electric resistance of the SMA/CF composites having the lamination of $[90^{\circ}CFRP_1/0^{\circ}SMAFiber/90^{\circ}CFRP_3]$ and SMA/GF composites. In the SMA/CF specimen, the direction of SMA fibers is in accord with the axis of the beam specimen. The electric resistance increases inversely in proportion to the diameter of SMA fiber. This resistance has an effect on the rapid suppression

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Table 1 Electic resistance for SMA/CF and SMA/GF composite specimens

Types of specimen	Electric resistance (W/m)	Volume fraction of SMA (%)	SMA fiber diameter (mm)
[90°$CFRP_1$/0°$SMAFiber$ /90°$CFRP_3$]	2.6	18.7	0.5
SMA/GF cloth	45.5	1.09	0.2
SMA/GF cloth	297.1	0.52	0.1

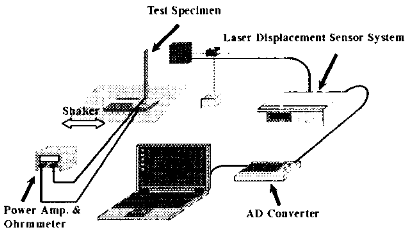


Fig. 1-1 Schematic apparatus for vibration suppression test.

time for resonance, and the SMAFRP embedded thinner fibers has a larger resistance. We are also able to find the phase transition process by measuring the electric resistance of the embedded SMA fiber.

Fig. 1-1 shows schematically apparatuses consisted of a shaker with a jig to fix the specimen, a power amplifier for an electric current generating heat, a laser displacement sensor system and an ohmmeter. The cantilevered specimen is fixed by the jig and it has same dimension as the tensile test specimen. The first resonance frequencies are 25.2 Hz(0.5mm diameter of SMA/CF composites), 23.5 Hz(0.2mm diameter of SMA/GF composites) and 22.5 Hz(0.1mm of SMA/GF composites), respectively.

Fig. 1-2 shows the first resonance unsuppressed vibration mode(thin curve lines) and the suppressed one(thick lines) for the 0.5 mm diameter of SMA/CF composites specimen. This specimen is suppressed about 6 sec. We also find the good suppressed oscillation for SMA/GF specimens. Although they take a little bit longer suppression time, a more rapid suppression can be obtained when a higher voltage current is supplied to the specimen. The vibration suppression test results demonstrate an effective possibility of SMA/CF and SMA/GF composites structural elements in the process of controlling the vibration. An active frequency control can be applied to avoid resonance in composite structures such as shafts, blades, aircraft wings etc..

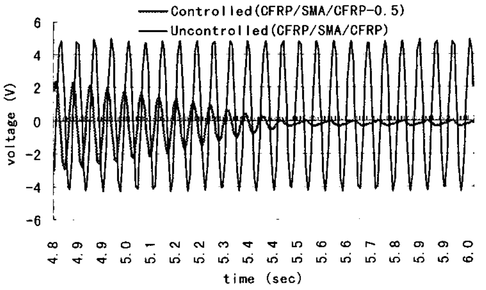


Fig. 1-2 Time domain response for SMA/CFRP composite (0.5-SMA).

2.2 Increase of Pressure Strength in Pressure Vessel by Shape Memory Alloy[2)]

When isotropic pressure vessels are received internal pressure, a circumferential stress in the pressure vessels becomes to be critical. So, the circumferential stress should be decreased in order to increase burst strength of the pressure vessels. This research devises a method how to reduce the circumferential stress. The shape memory alloy (SMA) wire memorized a compressive stress is wound around Aluminum and CFRP pipes which can be thought as a model of the cylindrical part of pressure vessel. When those pipes heated to the phase transition temperature of about 50℃ (Fig. 2-1), the memorized compressive stress of SMA wire is acting and is able to reduce the circumferential tensile stress of pipes owing to the internal pressure. Fig. 2-2 shows the circumferential break of aluminum pipe wounded around the SMA wire owing to the axial tensile stress, not to the

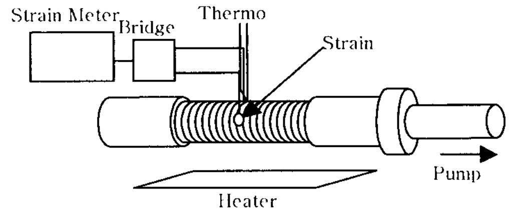


Fig. 2.1 Pipes wounded around SMA and experimental apparatus.

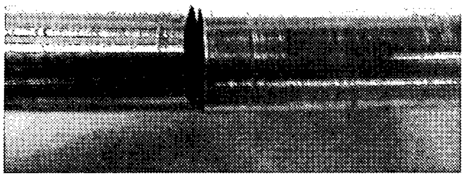


Fig. 2-2 Circumferential break of Al pipe wound around SMA.

circumferential stress. In the case of CFRP pipes, the winding angle of SMA wire and filament winding angle of CFRP can be considered to design variables in order to get the highest internal pressure in the CFRP pipe. We are now researching the optimum two angles by the FEM analysis and the experimental method.

2.3 Design Criterion of FRP Cylindrical Liquid Storage Tanks Based on Experiment and Fluid-Structure Coupled Vibration Analysis[3)]

In order to establish a safe structural design criterion of FRP cylindrical liquid storage tanks under earthquakes, this subject researches resonance frequencies of sloshing and bulging phenomena, responses of hydro dynamic pressure and dynamic strains to frequency and to excited time by using FEM and experimental methods. The FRP cylindrical liquid storage tank made of GFRP mat is shown in Fig. 3-1 and its diameter and height are 600mm and 2000mm, respectively. This tank filled up water is excited to the horizontal direction by a vibration apparatus. We propose a method of FEM modeling which can be applied to various FRP cylindrical liquid storage tank and employ multi-point constraint equations in the FEM(Fig. 3-2). The results of FEM simulation agree well with the experimental results and the relation of hydrodynamic pressure to the excited frequency is shown in Fig. 3-3, as one of examples. The present method is a useful and a convenient approach for analyzing a coupled fluid-structure behavior in cylindrical liquid storage tanks. We also show structural design criterion for safety of GFRP cylindrical liquid storage tanks under earthquakes and that their fixed condition gives many effects on their bulging frequencies and structural strength.

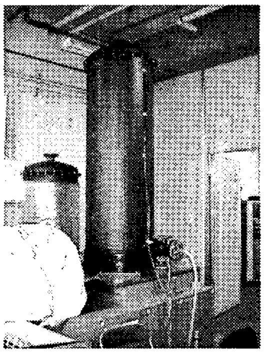


Fig. 3-1 GFRP cylindrical liquid storage tank and vibration apparatus.

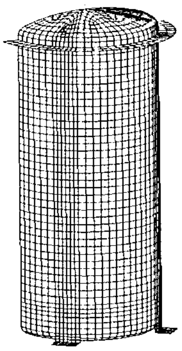


Fig. 3-2 Mesh division of tank in FEM.

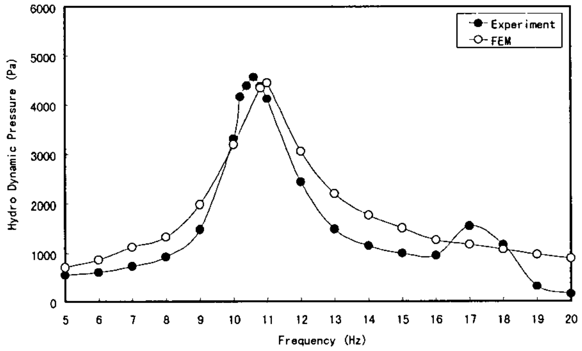


Fig. 3-3 Comparison of experimental hydro dynamic pressure with that of FEM.

2.4 Impact response experiment and analysis of thin CFRP belt[4)]

In order to efficiently absorb impact energy in a side collision of automobile accidents, steel impact beams are now

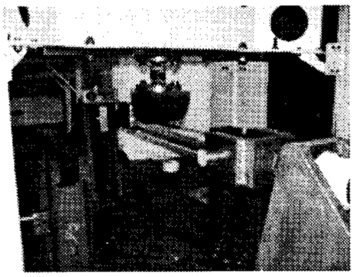


Fig. 4-1 Drop weight machine and CFRP belt.

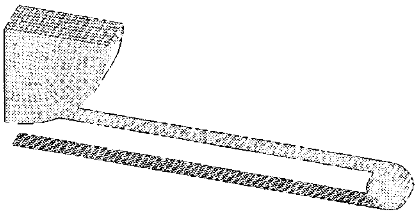


Fig. 4-2 Mesh division of belt and drop weight in FEM.

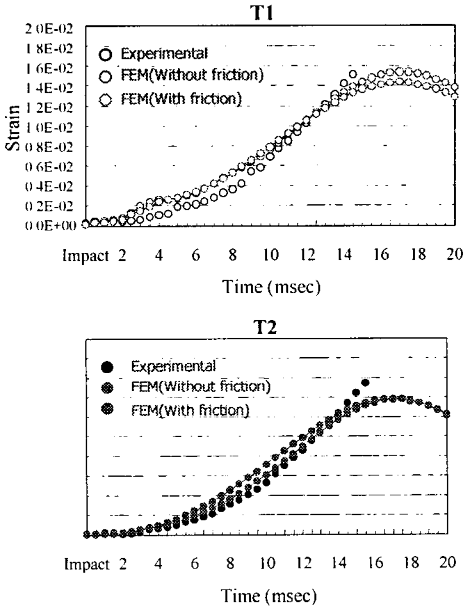


Fig. 4-3 Comparison of experimental dynamic strains with those of FEM.

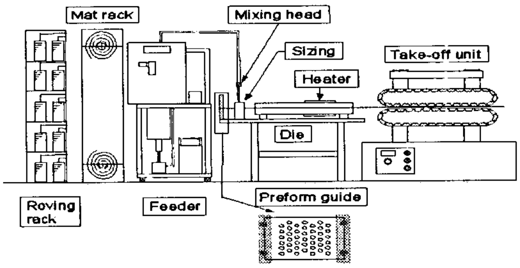


Fig. 5 Pultrusion facilities of phenol foam composite.

using to absorb impact energy by their bending deformation. For substituting these steel beams, CFRP belts having lighter weight are devised for absorbing impact energy by utilizing their higher tensile strength. Before a real test of the side collision of automobiles, a drop weight test machine as shown in Fig. 4-1 is used to give impact energy to CFRP belts. Fig. 4-2 shows FEM mesh elements and the elements between the surfaces of upper belt and the lower of weight, between the surfaces of the belt and the support pin, and between the surfaces of the upper and the lower belts after the upper belt deform are used the contact elements. The friction between the surfaces belt and pin is also considered in the FEM analysis. Fig. 4-3 shows that the experimental strains to the response time agree well with the FEM ones, especially taking account for the friction.

2.5 Development of Pultrusion Techniques of Phenol Foam Composite[5)]

Phenol foam composites use phenol resin foam as a matrix and roving glass fibers as a reinforcement and phenol resin is foamed among the glass fibers. These composites exhibit further weight saving, shock absorption, high insulation and *flame proof. The phenol resin has originally advantages of* heat proof, flame proof and less smoke during burning. These advantages are suitable for applying to materials in the field of construction. Furthermore, this composite may also apply to the fields of space structures because of the inflatable function.

In order to mold phenol foam composites, a plutrusion technique, which can produce composites having the same cross section and optional length, is very useful because the volume and arrangement of fibers in the cross section of composite can be almost kept constant. We develop the original system of pultrusion facilities as shown in Fig. 5 with newly a devised feeder machine. This feeder machine can store and pump up phenol resin containing a foaming

Table 2 Comparisons of mechanical properties of phenol foam composite with those of cedar

		Phenol Foam Composite (Vf=6%)	cedar *(sugi)*
density(g/㎤)		0.42	0.33
compressive strength (MPa)	longitudinal	14.34	27.44
	transeverse	0.67	1.37
pull out strength of screw (N/mm)		4.89	5.86

agent, di-chloromethane, and a curing agent separately. This machine mixes them at a certain rate in the inside of mixing head just before feeding to glass fibers. On the other hand, in the case of molding phenol foam composites by pultrusion technique, it is important to control the foaming time together with the adjustment of temperature in the die.

As a result of practicing various experiments, plutrusion techniques to form phenol foam glass fiber composite materials can be executed by taking account of a proper control of the temperature distribution in the die. This temperature distribution implies to distinguish the area the immersion of glass fibers in phenol resin from the area of foaming of the immersed phenol resin in the die.

Furthermore, a bulky type of roving is employed because it is easiest to be immersed in the phenol resin among various types of roving glass fibers.

Table 2 shows the compressive strength and the pull out strength of screw compared with those of cedar. In this table, the phenol foam composite strength has almost the same pull out strength of screw as cedar but the compressive strength is smaller than that of cedar. In order to increase the compressive strength of phenol foam composite, the volume fraction of fibers, appropriate expansion volume ratio and/or better method of immersion should be investigated hereafter.

2.6 Observation of the Tensile Fatigue Failure Process in CFRP Laminates with a Hole[6)]

In order to design a mechanically jointed CFRP laminates with a hole structure subjected to repetitive loads, tensile fatigue properties of CFRP laminates are strongly demanded to be clear. The tested specimens are $[(0/90)_3]_S$, $[(0/45/90/-45)_2]_S$, $[0_8]$, $[90_8]$ laminates with and without a hole. A synthetic study of the specimens is performed by static tensile tests, fatigue tests, an in-situ monitoring of stress images(Fig. 6-1) and a 3-dimensional finite element analysis. The fatigue tests are executed in 5Hz, 10Hz under the stress ratio of 0.1(R=0.1). By using an infrared image system, the in-situ monitoring of a stress change on the specimen surface is able to obtain. As one of example, Fig. 6-2 shows the infrared images of the quasi-isotropic specimen with a hole to the repeated fatigue load and Table 3 lists the fatigue results of specimens. The inside failure of the specimen in the thickness direction is observed by an ultrasonic image system. Delamination positions are predicted by a 3-dimensional static finite element analysis and a failure criterion is matched well to experimental results of initial fatigue test.

Table 3 Fatigue test results of CFRP laminate specimens

Specimen	*f* (Hz)	A (MPa)	B (MPa)	A/*Ft*
$[(0/90)_3]_S$	5	1285	-18.6	1.06
	10	1361	-24.3	1.12
$[(0/90)_3]_S$ with a hole	5	1011	-12.3	1.12
	10	1014	-14.4	1.26

Specimen	*f* (Hz)	A (MPa)	B (MPa)	A/*Ft*
$[(0/45/90/-45)_2]_S$	5	770	-20.9	0.94
	10	883	-26.9	1.02
$[(0/45/90/-45)_2]_S$ with a hole	5	664	-15.4	1.07
	10	667	-21.5	1.08

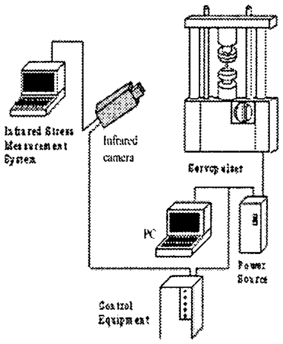


Fig. 6-1 Fatigue test machine combined with infrared image system.

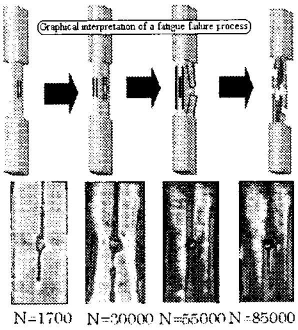
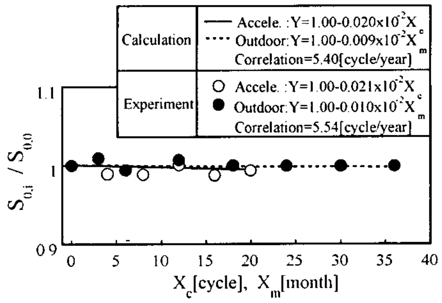


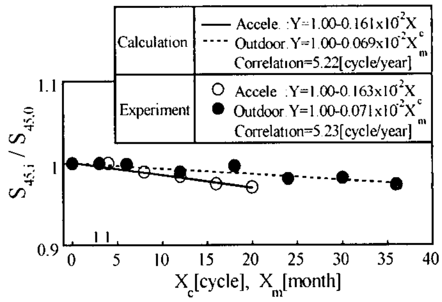
Fig. 6-2 Infrared image of quasi isotropic laminate with a hole along fatigue process.

2.7 Weatherability Flexural Properties of CFRP Subjected to Accelerated and Outdoor Exposures[7]

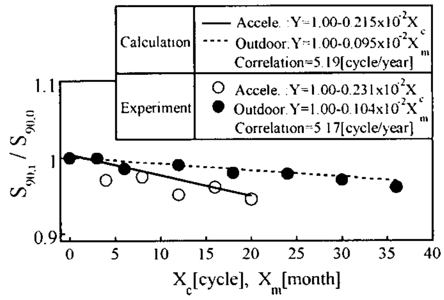
This subject discusses the weatherability flexural properties of CFRP subjected to accelerated and outdoor exposures. We use two classes of specimens. The first class of specimens is three unidirectional CFRP laminates having different fiber orientation angles; 0, 45, or 90 degree, respectively. The second class of specimens is made solely of epoxy resin identical in chemical composition to the matrix of the above CFRP laminates. In order to clarify the effects of exposure period on the variation of flexural strength and modulus, matrix volume fraction, thickness and absorption rate of infrared rays, a complex accelerated exposure test is conducted to continue for up 20 cycles and a direct outdoor exposure has been also conducted to continue for 4 years. Fig. 7 shows that both the weatherability flexural strengths can be calculated by the results of epoxy resin and thickness change of CFRP during the exposures. After confirming the agreement of the experimental flexural strength with the calculated one of the CFRP, it is also shown that a weatherability outdoor flexural strength at four years can be predicted from one at three years and the correlation of the acceleration exposure test to the outdoor one is demonstrated.



(a) CF0



(b) CF45

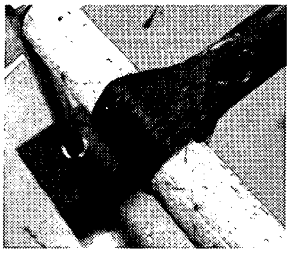


(c) CF90

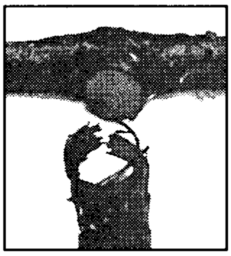
Fig. 7 Comparison of experimental weatherability flexural strength with calculated ones.

2.8 Development of New Joint Method for CFRP Pipes[8]

This subject proposes a new adhesive method fir CFRP pipes. The new method removes the resin from adhesive areas of CFRP pipes by burning and in consequence only carbon fibers remain in the adhesive areas. After these remained fibers are wounded around another pipe not burned, epoxy resin is again impregnated in order to connect two pipes. The two pipes connected by a T style is shown in Fig. 8 in which the black color pipe is the burned pipe and the white is the not burned one. The experimental result of the tensile share strength for the new adhesive pipes is compared with one of the conventional jointed pipes. The comparison shows new type joint method is useful and convenient.



(a) Before Test.



(b) After Test.

Fig. 8 New joint method for CFRP pipes.

3. Closing

Besides the research topics stated above, our laboratory executes cooperative researches with Prof. M. Natoti at the Institute of Space and Astronautical Science(ISAS) and with Dr. T. Ishikawa at National Aeronautical Laboratory(NAL).

After, I got Ph. D. from the University of Tokyo, I joined to Nihon University on 1975. I am now a project leader of high technology research center sponsored by our college and Japanese government from two years ago. During the past 28 years, I could get appropriate and necessary apparatuses for composite research. Especially I got the required ones for performing the project and then our laboratory is now one of laboratories having the best experimental facilities in Japan. I would like to execute cooperative researches with some Korean professors and doctors. If someone has interest with our research topics, please contact me, not to hesitate.

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