Development of electric heating actuator of SiC\textsubscript{CVD}/Al composite

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Abstract: Two types of electric heating actuators used of SiC/Al composite were successfully developed, which could be used at elevated temperature. The experimental results reveal that the temperature of the actuators increases with the increase of the given electric power. The maximum temperature was found to be higher the 150\textdegree C and 200\textdegree C for 1-side electric heating actuator and 2-side electric heating actuator, respectively, when the electric power of about 10 W were given. It is found that the electric resistance of the actuators decreases obviously with the increase of temperature. A critical temperature was found to exist for the change of the displacement and curvature. The displacement and curvature almost remained unchanged when the temperature of the actuators was lower than the critical temperature. After that, the displacement and curvature increase with the rise of the actuator temperature. Because the 1-side and 2-side actuators have different response characteristics of the displacement and generated force, it is expected that the two types of actuators may be used in different areas.

Key Words: SiC\textsubscript{CVD}/Al composite, electric heating, 1-side heating actuator, 2-side heating actuator, actuator function

1. Introduction

The SiC/Al composites have been widely investigated as an excellent structural material due to their high specific strength and specific modulus [1-5]. In these investigations, some work was focused on the aluminum matrix composites reinforced by the SiC fibers. The authors have examined the strength reliability of composite relating to the fiber volume fraction [6], the interfacial shear strength [7], residual stress [8] and the size effect. The SiC\textsubscript{CVD} continuous fiber has used a carbon core with 30\textmu m diameter and a carbon coating layer of about 1\textmu m thickness on the outside surface. Because the SiC and carbon fibers do not only have good mechanical properties as the reinforcement, but also have many excellent functional properties as semiconductors and electric heaters [9], the investigation on the functional properties of the SiC and carbon fibers has attracted an increasing interest in the past five years. The authors have used SiC\textsubscript{CVD} fiber to investigate strength reliability of single fiber and fiber bundle of ceramics [10-11]. It is clarified that the SiC\textsubscript{CVD} fiber is used as excellent electric heater using the behavior of electric resistant at room and high temperatures [12]. Besides, developing actuation function of composite to reduce vibration and noise, and to control shape and self-repair of material is greatly noticed recently [13]. In 1999, CFRP/KFRP/metal actuator and active composite devices using electric heating of carbon fiber were developed [14-15]. However, application of the electric heating actuators with plastic matrix is limited to lower temperature. An all-organic composite actuator material with a high dielectric constant was developed in 2002 to expect applying human muscle [16]. Composites of metal and plastics matrix with heat-response, which use shape active alloy, were also developed [17-18]. Furthermore, the application of composite actuators to control robot [19] and roll maneuver of airplane wing [20] was tried in 2002.

In the present investigation, a new idea to develop actuator of metal matrix composite was suggested, and the SiC\textsubscript{CVD} fibers in SiC\textsubscript{CVD}/Al composite were used as the reinforcement as well as electric heater. Two types of electric heating actuators using SiC\textsubscript{CVD}/Al composite fabricated by hot press method were
developed, which could be used at elevated temperature. The response characteristics of temperature, curvature and generated force during electric heating were investigated and discussed.

2. Experimental
2.1 Fabrication of the composite

An Al1050 pure aluminum plate with thickness of 0.2mm and 0.4mm was used as the matrix material. The SiC\textsubscript{CVD} fiber (type: SCS-2, diameter: 140\textmu m) was used as both the reinforcement and the electric heater. Density, Young’s modulus, electric resistivity, CTE and heat capacity of the SiC\textsubscript{CVD} fiber and the pure aluminum used in present investigation are listed in Table 1. For reference, the parameters of carbon fiber and SiC fiber were also listed in Table 1. It can be seen that electric resistivity of the SiC\textsubscript{CVD} fiber is between carbon fiber and SiC fiber, and the CTE of SiC\textsubscript{CVD} fiber is as big as about 15 times of pure aluminum. SiC\textsubscript{CVD}/Al composite was fabricated using following procedure. Firstly, the aluminum plate was cut into pieces of 30\times70mm\textsuperscript{2}, which were then annealed at 573K for 30min in air. In order to arrange the fibers on the aluminum pieces orderly, U-shaped grooves with inter-space of 0.5mm were made on one side of the aluminum pieces with thickness of 0.2mm by pressing the stainless steel wires with diameter of 140\textmu m into the pieces. After that, the SiC\textsubscript{CVD} fibers were cut into a length of 70mm from the obtained continuous SiC\textsubscript{CVD} fiber, and then were put into the grooves on the surface of each aluminum piece. After putting the SiC\textsubscript{CVD} fibers into the grooves, the aluminum piece was then overlapped by another aluminum piece with a thickness of 0.4mm. Finally, this one-layer SiC\textsubscript{CVD}/Al preform was hot pressed into the composite under the pressure of 56MPa for 40min at 893K in the atmosphere. The SiC\textsubscript{CVD}/Al composite fabricated by this way has the thickness of about 0.5mm, fiber volume fraction of 9.2% and the fiber spacing of about 0.25mm.

2.2 Fabrication of the actuators

The SiC\textsubscript{CVD}/Al composite was cut into 10\times70mm\textsuperscript{2} pieces along the fiber direction, and each piece contains 30 SiC\textsubscript{CVD} fibers. Then the pieces of the composite were annealed at 573K for 10min. The aluminum matrix of the one side or the two sides was corroded and dissolved with 5%NaOH water solution, and the exposed SiC\textsubscript{CVD} fibers were used as the electrodes for electric heating. An outward view of the composite pieces for the two types of actuators is given in Fig.1. The schematic diagrams and dimensions of the actuators are given in Fig.2. In the case of exposing the one side, 4 SiC\textsubscript{CVD} fibers, which were located at the center of exposed 30 SiC\textsubscript{CVD} fibers, were cut off, and the each remaining 13-SiC\textsubscript{CVD} fibers were wrapped with copper foil of 4mm width as the two

<table>
<thead>
<tr>
<th>Materials</th>
<th>Density (g/cm\textsuperscript{3})</th>
<th>Young’s modulus (GPa)</th>
<th>Electric resistivity (f \textmu m)</th>
<th>CTE (\texttimes 10\textsuperscript{-6}/K)</th>
<th>Heat Capacity (J/g K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiC\textsubscript{CVD} fiber</td>
<td>3.05</td>
<td>421.7</td>
<td>1.9 \times 10\textsuperscript{13}</td>
<td>1.5</td>
<td>23.6</td>
</tr>
<tr>
<td>Pure Al</td>
<td>2.7</td>
<td>68.6</td>
<td>2.8 \times 10\textsuperscript{-12}</td>
<td>0.9</td>
<td>2.2</td>
</tr>
<tr>
<td>Carbon fiber</td>
<td>1.77</td>
<td>240</td>
<td>0.8 \times 10\textsuperscript{-13}</td>
<td>-0.7</td>
<td>0.71</td>
</tr>
<tr>
<td>SiC fiber</td>
<td>2.55</td>
<td>220</td>
<td>10\textsuperscript{3} \times 10\textsuperscript{-12}</td>
<td>2.2</td>
<td>1.14</td>
</tr>
</tbody>
</table>

Carbon fiber: TOHO RAYON CO., LTD.
SiC fiber: NIPPON Carbon CO., LTD.
SiC\textsubscript{CVD} fiber: SCS-2, Textron Specialty Materials CO., LTD.
Pure Al: 1050P

![Fig.1. Photocopy of SiC\textsubscript{CVD}/Al composite actuators.](image-url)
electrodes, respectively. In the case of exposing the two sides, the each 30-SiC<sub>CVD</sub> fibers on the two sides were wrapped with copper foil of 4 mm width as the two electrodes, respectively. The two types of actuators obtained from the above mentioned were named as 1-side and 2-side electric heating actuator, respectively. A SEM image of cross section microstructure of the actuator is shown in Fig.3. It can be seen that a good compound between the fiber and the matrix is obtained.

**2.3 Measurement of the response characteristics**

A schematic drawing for measuring the response characteristics of the 1-side electric heating actuator is given in Fig.4. The one side of the actuator was fixed, and electric power was impressed into the two electrodes by the same side. The displacement and generated force were measured by a ruler and a spring balancer at the other side, respectively. The temperature in the actuator was measured at three points (I, II and III) (Fig.4), and the average value of three points was used in some cases. A schematic drawing for measuring the response characteristics of the 2-side electric heating actuator is given in Fig.5. The two sides of the actuator were fixed, and electric power was impressed into the two electrodes through the two sides. Actuator temperature was also measured at three points (I, II and III), but the displacement and generated force were measured at the center. A direct-current power source was used for heating the actuators. The displacement and the distance between the fixing end and displacement measurement point were expressed by \( x \) and \( y \), respectively, and the actuator curvature can be calculated by equation (1)

\[
\frac{1}{r} = 2\frac{x}{(x^2+y^2)} \quad \ldots \ldots \quad (1)
\]

**Fig.2.** Schematic diagrams and dimensions of SiC<sub>CVD</sub>/Al composite actuators.

**Fig.3.** SEM micrograph of cross section of SiC<sub>CVD</sub>/Al composite actuator.

**Fig.4.** Schematic diagram of the measuring system of temperature, displacement and generated force for the 1-side heating actuator.

**Fig.5.** Schematic diagram of the measuring system of temperature, displacement and generated force for the 2-side heating actuator.
3. Results and Discussion

3.1 Electric resistant and heating temperature of the actuators

Though the electric resistance of the actuator is related to length of the exposed fibers and width of the wrapped copper foil, the electric resistance of the actuators is very small, 25 Ohm and 15 Ohm at room temperature for the 1-side and 2-side electric heating actuators, respectively. Relationship between the electric resistance and the temperature of the actuators during electric heating is shown in Fig.6. It can be seen that the electric resistance of the actuators decreases with the increase of temperature for the two types of actuators, which can be explained by author’s previous results [12] that the electric resistant of the actuators are mainly influenced by the SiC\textsubscript{CVD} fibers.

Relationship between the given electric power and the temperatures of the 1-side and 2-side electric heating actuators is given in Fig.7 and Fig.8. The effects of the electric power on the temperature of the actuators were found to show almost same patterns for two types of actuators. That is, the temperature of the actuators increases with the increase of the given electric power. The maximum temperature was found to be higher the 150°C and 200°C for 1-side actuator and 2-side actuator, respectively, when the electric power of about 10 W were given.

3.2 Temperature and curvature of the actuators

The temperature, displacement and the curvature of the two types of actuators are given in Fig.9 and Fig.10. A critical temperature was found to exist for the change of the displacement and curvature. The critical temperature was about 40°C and 70°C for the 1-side and 2-side electric heating actuator, respectively. The displacement and
curvature almost remained unchanged when the temperature of the actuators was lower than the critical temperature. After that, the displacement and curvature increase quickly with the increase of temperature. Comparing the displacement of the two types of actuators, the maximum displacement of the 1-side electric heating actuator was bigger than 12.5mm, which was 3.5 times of that in the 2-side electric heating actuator.

3.2 Temperature and generated force of the actuators

Relationship between the generated force and the temperature or the curvature for two types of actuators is given in Fig.11 and Fig.12. The generated force also rises with the increase of temperature or the curvature for the two types of actuators. The generated force in the 2-side actuator was found to reach about 20gf, which was bigger than that in the 1-side electric heating actuator. This may be because that 2-side electric heating actuator is supported by the two sides.

4. Conclusion

Two types of the electric heating actuators using one-layer unidirectional SiC<sub>CVD</sub>/Al composite were
suggested and successfully developed. The developed actuators can be heated well by electric power. The big response characteristics such as the displacement, curvature and generated force can be obtained with the change of the temperature in the actuator. Because the 1-side and 2-side electric heating actuators have different response characteristics of the displacement and generated force, it is expected that the two types of actuators may be used in different indifferent fields.

References
(20) D. SAHOO and C. E. CESNIK: Collect tech Pap AIAA, 43-1.6(2002), 3867-3877.