Fibre Spreading and Bonding of Metal Matrix during Hot Pressing of SiC Fibre/Superplastic Zinc Alloy Composites

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In order to establish the application of a superplastic alloy as a matrix of fibre reinforced metals, bonding of fibre with metal matrix was investigated on the hot pressed composites. A superplastic zinc alloy was used as a metal matrix and a SiC multifilament fibre tow was embedded as a reinforcement in the composites. A bonding characteristic was investigated using an optical microscope.

Enough spreading of the fibre tow and favorable bonding of the matrix metal required a sufficient flow of metal matrix. The effect of bonding temperature on the bonding characteristic was negligibly small in the temperature range between 473 and 523 K. The bonding characteristic became critically worse as the number of fibre tows increased and the thickness of matrix metal plate decreased. The metal mold set in a hot press restricted the matrix metal flow, resulting in a poor bonding. The bonding characteristic in the composites was favorable without using the metal mold.

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I. Introduction

A fibre reinforced metal (FRM) was fabricated by various processes, such as a vacuum infiltration, a hot pressing, a squeeze casting and a plasma spray and roll diffusion bonding⁽¹⁾⁻⁽⁴⁾. These processes possess their merits and demerits. By using a superplastic alloy as a matrix metal of FRM, it is to be expected that the FRM can be fabricated under a low applied load and at a low temperature below the melting point of matrix metal. In this respect, the FRM was fabricated using a superplastic zinc alloy based on a Zn-22 mass% Al eutectoid alloy (SPZ) as a matrix metal⁽⁵⁾. When a SiC multifilament tow was used as a reinforcement, it was clarified that the FRM was formed simultaneously with the spread and alignment of fibre tow⁽⁵⁾. When a stainless steel wire was used as a reinforcement, it was also clarified that the bonding strength was 22.7 MPa which was nearly equal to the bonding strength of the W/Cu composite⁽⁶⁾. However, these results were obtained under the particular fabricating conditions. There is no information about effects of bonding temperature and a metal mold used during forming of FRM.

In the present paper, the effect of bonding temperature, the thickness of matrix metal, the number of SiC multifilament fibre tows and a metal mold restriction against metal flow on a bonding of matrix metal and a spread of fibre tow will be discussed for the SiC[†]/SPZ composite fabricated by hot pressing.

II. Experimental Procedure

The chemical composition of SPZ used as a matrix metal are shown in Table 1. The plates of 15 mm × 7 mm were cut from a heat treated SPZ rolled plate 5 mm in thickness. These plates were polished with successive grades of emery paper to a certain thickness, then polished on a buff with a diamond paste, and degreased with acetone before bonding. The thicknesses thus obtained are 5.0, 3.0, 1.0, 0.5 and 0.2 mm. The SiC reinforcement used was a Nicalon with an average diameter of 15 μm, and was immersed in acetone for 86.4 ks to dissolve a sizing material.

Figure 1 shows the setting of fibre tow and the pro-

Table 1 Chemical composition of SPZ (mass%).

Al	Cu	Si	Pb	Mg	Zn
21.29	0.51	0.07	0.01	0.006	bal.

Fig. 1 Setting of fibre tow (a). Hot pressing procedure with a metal mold (b) and without a metal mold (c).

1 SPZ plate, 2 SiC fibre, 3 mica, 4 metal mold, 5 steel plate

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† silicon-carbide fibre fabricated from an organosilicon polymer.

cedure of hot pressing. The SiC tow was used as one tow or a bundle of two or three tows. The SiC fibre tow was placed on the centre of the bonding plane of one SPZ plate, and then the other SPZ plate was placed on it. The longitudinal direction of the plate was parallel to that of the SiC fibre tow. Bonding was performed through a hot pressing at 473 or 523 K for 3.6 ks under a load of 39.2 kN with or without a metal mold.

The hot pressed samples were cut perpendicularly to the fibre direction, polished and observed under an optical microscope. The bonding of metal plates and the spread of fibre were examined.

III. Results and Discussion

1. Observation of cross section

Figure 2 shows the cross section of the sample fabricated at 473 K in a metal mold. The fibre spread in a direction perpendicular to a loading direction. This observation suggests that the matrix metal deformed and flowed in this direction by hot pressing in its superplastic temperature range and the SiC fibre tow spread in the same direction with this matrix metal flow. While the spread of fibre tow in this direction occurred under every bonding condition investigated, the width of the spread fibre and the bonding of the matrix metal (the bonding characteristic) differed from each other depending on the thickness of SPZ plate, the number of fibre tows and the bonding conditions.

Figure 3 and Figs. 4 and 5 show the microstructures of the cross section near the one-fourth distance from the edge of the spread fibre (X point in Fig. 2) as functions of the thickness of the SPZ plate and the number of fibre tows with and without a metal mold. The SiC fibre spread laterally in a row and the matrix metal flowed around each SiC fibre more effectively as the thickness of SPZ plate increased and the number of fibre tows decreased.

Fig. 2 Cross section of SiC/SPZ composite fabricated by hot pressing at 473 K under a load of 39.2 kN for 3.6 ks with a metal mold.

On the other hand, the block of the spread SiC fibre was observed as the thickness of SPZ plate decreased. In the case of 0.2 mm thick SPZ plate and three fibre tows, the two matrix plates were not in contact and divided into two parts by the SiC fibre.

The appearance of spread fibre was similar to that of the SiC/SPZ (powder) composite⁽⁷⁾.

It should be mentioned here that the suppression of matrix metal flow by the metal mold did not occur for the SPZ plates with thicknesses of 0.2 and 0.5 mm. Considerable suppression was observed for the composites of the SPZ with the thickness ranging from 1.0 mm to 5.0 mm.

2. Spread of fibre tow and bonding of matrix metal

The spread of fibre tow and the bonding of matrix

Fig. 3 Microstructures near the one-fourth distance from the edge of spread fibre depending on the thickness of SPZ plate and the number of fibre tows. Hot pressing was performed at 473 K under a load of 39.2 kN for 3.6 ks with a metal mold.

Fig. 4 Microstructures near the one-fourth distance from the edge of spread fibre depending on the thickness of SPZ plate and the number of fibre tows. Hot pressing was performed at 473 K under a load of 39.2 kN for 3.6 ks without using a metal mold.

Fig. 5 Microstructures near the one-fourth distance from the edge of spread fibre depending on the thickness of SPZ plate and the number of fibre tows. Hot pressing was performed at 523 K under a load of 39.2 kN for 3.6 ks without using a metal mold.

metal near the X point shown in Fig. 2 were assessed on the basis of the following criteria.

Bonding of matrix metal:

If a boundary line was discriminated under an optical microscope at the bonding place among the fibres, the bonding of matrix metal was faulty. If no boundary line was found, the bonding of matrix metal was sufficient.

Spread of fibre:

Consider a certain distance (L) in a direction normal to a loading direction (see Fig. 6). Pick up the fibres found in this distance and put them in a close line, as shown in Fig. 6. The F fibre shown in Fig. 6, which was isolated from a line of other fibres, was excluded from the consideration of the width (W) of these fibres. If W was

Fig. 6 Definition of L and W . Figure (a) shows fibres after hot pressing. A certain distance L is considered and fibres in L is closely put in a line as shown in Figure (b). Fibre F is excluded from the width W , because a spread of fibre normal to the loading direction is considered.

larger than L , the spread of fibre tow was insufficient. On the other hand, if W was smaller than L , then the spread of fibre tow was sufficient.

Tables 2–4 show the spread of fibre tow and the bonding of matrix metal assessed on the basis of the above-mentioned criteria, the L/W values. A good spread and a good bonding under a restraint of a metal mold were obtained when the thickness of SPZ plate was over 1.0 mm in the case of one fibre tow, and when the thickness of SPZ plate was over 3.0 mm in the case of two or three fibre tows. Without using the metal mold, on the other hand, a good spread and a good bonding were obtained for one fibre tow and two fibre tows when the thickness of SPZ plate was over 1.0 mm. Without metal mold, the spread of the fibre tow and the bonding characteristic were better, because the flow of matrix metal was not restricted by the metal mold. The more extensively the matrix metal flowed, the more fresh was the plane formed on the matrix metal, and the better bonding of

Table 2 Effect of the thickness of SPZ plate (10^{-3} m) and the number of fibre tows on the bonding characteristic of SiC/SPZ composite fabricated at 473 K with a metal mold. Values represent a L/W ratio. If $L/W > 1$, the spread of fibre is good.

Thickness \ Number of tows	1		2		3	
	M	F	M	F	M	F
5.0	○	○ 2.38	○	○ 1.85	○	○ 1.39
3.0	○	○ 1.85	○	○ 1.67	×	○ 1.39
1.0	○	○ 1.67	○	○ 1.52	×	×
0.5	×	×	×	×	×	×
0.2	×	×	×	×	×	×

M: bonding of matrix, F: spread of fibre tows,
○: good, ×: bad, —: $L/W < 0.5$

Table 3 Effect of the thickness of SPZ plate (10^{-3} m) and the number of fibre tows on the bonding characteristic of SiC/SPZ composite fabricated at 473 K without using a metal mold. Values represent a L/W ratio. If $L/W > 1$, the spread of fibre is good.

Thickness \ Number of tows	1		2		3	
	M	F	M	F	M	F
5.0	○	○ 3.33	○	○ 2.08	○	○ 1.85
3.0	○	○ 1.85	○	○ 1.39	×	○ 1.39
1.0	○	○ 1.28	○	○ 1.52	×	×

M: bonding of matrix, F: spread of fibre tows, ○: good, ×: bad,
*: Spread in the loading direction was considered.

Table 4 Effect of the thickness of SPZ plate (10^{-3} m) and the number of fibre tows on the bonding characteristic of SiC/SPZ composite fabricated at 523 K without using a metal mold. Values represent a L/W ratio. If $L/W > 1$, the spread of fibre is good.

Thickness \ Number of tows	1		2		3	
	M	F	M	F	M	F
5.0	○	○ 2.08	○	○ 1.85	○	○ 2.08
3.0	○	○ 2.38	○	○ 1.52	×	○ 1.52
1.0	○	○ 1.39	○	○ 1.67	×	×
0.5	×	×	×	×	×	×
		0.79		—		—
0.2	×	×	×	×	×	×
		—		—		—

M: bonding of matrix, F: spread of fibre tows, ○: good, ×: bad, —: $L/W < 0.5$, *: Spread in the loading direction was considered.

matrix metal was achieved.

No effect of the bonding temperature on the spread of fibre tow and the bonding of matrix metal is found in Tables 3 and 4. The spread of fibre tow and the bonding of the matrix metal at 473 K were similar to those at 523 K. This type of FRM can be fabricated, therefore, at the temperatures between 473 and 523 K which is the typical temperature range of the superplasticity of SPZ.

The results mentioned above suggest that a good bonding characteristic requires a certain amount of matrix metal flow in good agreement with the result obtained by Lloyd⁽⁸⁾.

The width of fibre spreading became small with the decrease in bonding temperature and with the increase in the number of fibre tows. However, the increase in the width of fibre spreading was not proportional to the increase in the number of fibre tows. Generally, the spread of fibre tow and the bonding of matrix metal became poor with increase in the volume fraction of

fibres, that is, favorable spreading of fibre tow and good bonding of metal matrix were obtained with a smaller thickness of SPZ plate and a larger number of fibre tows.

IV. Conclusions

A FRM was fabricated through a hot pressing of a SPZ as a matrix metal and a SiC fibre tow as a reinforcement. The effects of the thickness of the matrix metal plate, the number of fibre tows and bonding temperature on the spread of fibre tow and the bonding of matrix metal were investigated with an optical microscope.

A good spread of fibre tow and a good bonding of matrix metal required a sufficient flow of the matrix metal, a certain thickness of the matrix metal and a small number of fibre tows. Bonding characteristic in the spread of fibre tow and the bonding of matrix metal were favorable at temperatures between 473 and 523 K. The application of the metal mold suppressed the spreading of fibre tow.

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