

Effect of Processing Parameters on the Elastic Deflection of P/M Ni-Fe36Ni Bimetal Strips during Heating

C.-C. Liu and W.-F. Wang

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Electrolytic nickel powder and water-atomized Fe36Ni alloy powder were consolidated into combined compacts with the "two-layer pressing" technique. The compacts, 1.6 mm thick, were sintered at 1200 and 1300 °C in hydrogen, and then rolled into strips 0.8 mm thick. The rolled and annealed strips were fixed at one end as a cantilever beam, and heated gradually from room temperature to 200 °C, in order to measure the thermal deflection of the free end. The measured displacement was always less than the theoretically calculated value, due to the existence of pores in the sintered products. The effect of the temperature and time of sintering on the thermal deflection of the bimetal strips was investigated. It was found that the proper degree of sintering is essential for the bimetal strip to exhibit the largest displacement upon heating. The microstructure and chemical composition across the nickel layer, the contact interface, and the Fe36Ni layer were examined with a SEM and EPMA.

Keywords P/M bimetal, processing parameter, thermal deflection

1. Introduction

Several kinds of bimetallic products have been developed for industrial use. Typical examples are: the powder metallurgy (P/M) copper-lead steel-backed bushing (Ref 1); the P/M copper-undercoated silver contact (to save the expensive metal) (Ref 2); a two-layer steel plate with a clad corrosion-resistant layer (Ref 3); bimetal steel plate made from shape rolling, sintering, and heat treatment of high-speed steel powder and low-alloy steel powder (Ref 4); and bimetal strips displaying an appreciable amount of bending deformation upon heating, widely used in family utensils and electrical apparatus. This elastic bending deflection can be utilized to control the operating temperature and time of the electrical apparatus and utensils. The conventional manufacturing method of bimetal strips is ingot metallurgy and rolling. Few works were found to develop the technology for fabricating bimetal strips by the P/M method (Ref 5). The present investigation used P/M to develop powder bimetal strips. Powder bimetal strips that combined a nickel layer with a Fe36Ni layer were consolidated using the two-layer compacting technique. The effects of the sintering temperature and time on the thermal elastic deformation of the P/M bimetal strips were studied. The interdiffusion occurring between the nickel layer and the Fe36Ni layer during sintering was examined using a scanning electron microscope (SEM) and electron probe microanalysis (EPMA).

2. Experimental Procedure

The powders used were: electrolytic nickel powder (with a purity greater than 99.6% and a particle size less than 100 μm), and water-atomized Fe36Ni alloyed powder (64% Fe and 36% Ni). The atomized Fe36Ni powder was reduced with bottled hydrogen, at 900 °C for 30 min, to decrease the oxygen content and improve compressibility. A portion screened through 200 mesh was used for compacting.

The specimens were two-layer compacted in a steel die. The die cavity was 13 mm wide and 37 mm long. Zinc stearate in acetone was applied to the die wall prior to the powder filling. Then, the nickel powder was poured into the steel die and compacted at a pressure of 200 MPa. After the upper punch was withdrawn, the Fe36Ni powder was poured and pressed at a pressure of 600 MPa. The resulting compacts had a double-layered structure and a thickness of 1.6 mm. The two-layer compacts were sintered at 1200 and 1300 °C in bottled hydrogen with a dew point of –25 °C. The sintered specimens were then cold-rolled to a final thickness of 0.8 mm and annealed.

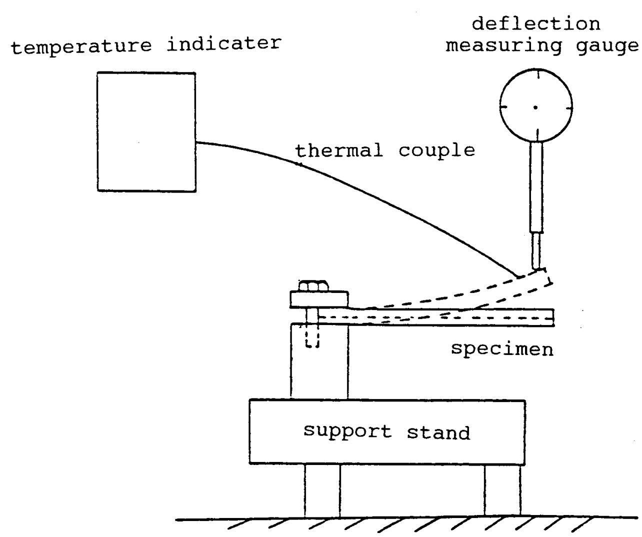

Fig. 1 Test apparatus of thermal deflection of P/M bimetal strips

C.-C. Liu, Kung-Shan Institute of Technology; and **W.-F. Wang,** Nan-Tai Institute of Technology, Tainan, Taiwan.

The apparatus used to measure the elastic deflection of the P/M bimetal strips during heating is shown in Fig. 1. The specimen, 13 mm wide and 50 mm long, was fixed at one end. The nickel layer, with a high thermal expansion coefficient, was placed at the lower half so that during heating the free end of the bimetal strip would move upward and continually keep contact with the stylus of a measuring gage. The free end was welded with a thermal couple. The bimetal strip was heated gradually from room temperature to 200 °C, and the displacement of the free end, as measured by the gage, was recorded. The metallography of the sintered specimens and the chemical composition of points along the scanning line across the nickel layer, the contact zone, and the Fe36Ni layer, were examined with a SEM and EPMA.

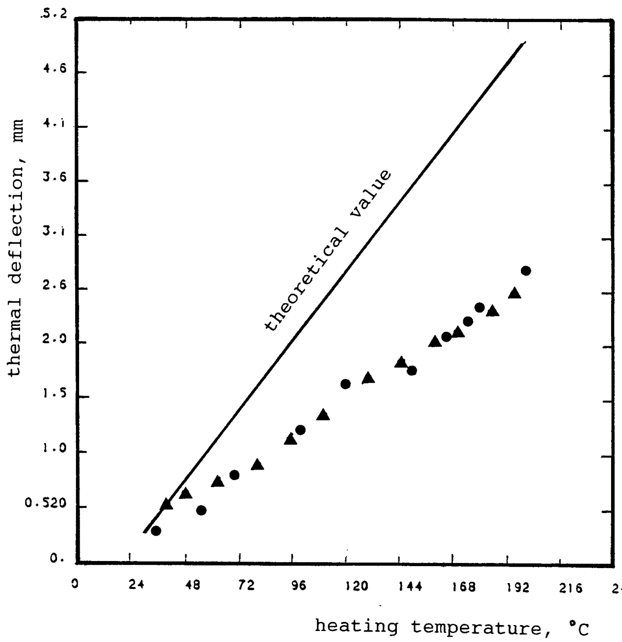

Fig. 2 Variation of thermal deflection of bimetal strips sintered at 1200 °C for 1 h, with the heating temperature

3. Results and Discussion

The displacement of the free end of a bimetal strip, which is fixed at one end as a cantilever beam and subjected to a temperature change, can be calculated with the following equation (Ref 4):

$$D = K\Delta TL^2/t \quad \text{(Eq 1)}$$

where D is thermal displacement, ΔT is the temperature difference, L is the length of the bimetal strip, t is the total thickness of the bimetal strip, and

$$K = 3(\alpha_2 - \alpha_1)(1 + m) /[3(1 + m)^2 + (1 + mn)(m^2 + 1/mn)] \quad \text{(Eq 2)}$$

where $\alpha_2 - \alpha_1$ is the difference of the coefficient of thermal expansion of the two layers of the Ni-Fe36Ni bimetal strip, m is the t_1/t_2 ratio of the thickness of the Fe36Ni layer to that of the nickel layer, n is the E_1/E_2 ratio of the elastic modulus of the Fe36Ni layer to that of the nickel layer.

The Fe36Ni alloy is the so-called "Invar," with a very low coefficient of thermal expansion, while the nickel strip expands markedly upon heating. When heated from room temperature to 200 °C, the linear dilation ratio ($\Delta l/l$) of the Fe36Ni alloy is 6

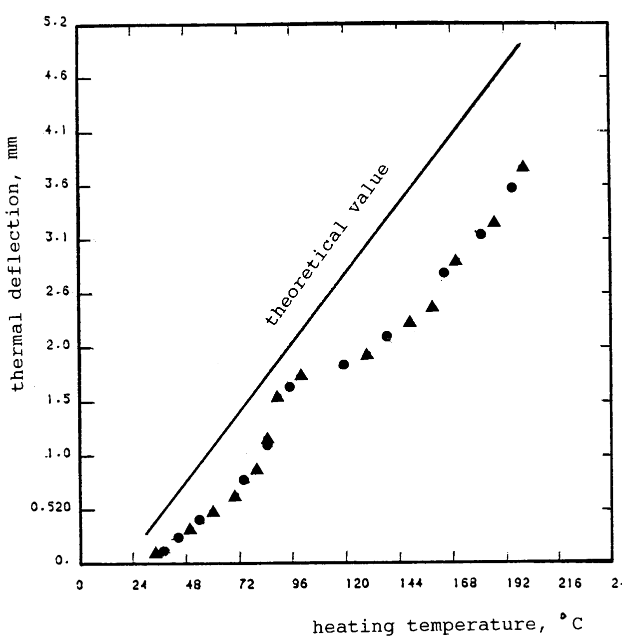

Fig. 3 Variation of thermal deflection of bimetal strips sintered at 1200 °C for 2 h, with the heating temperature

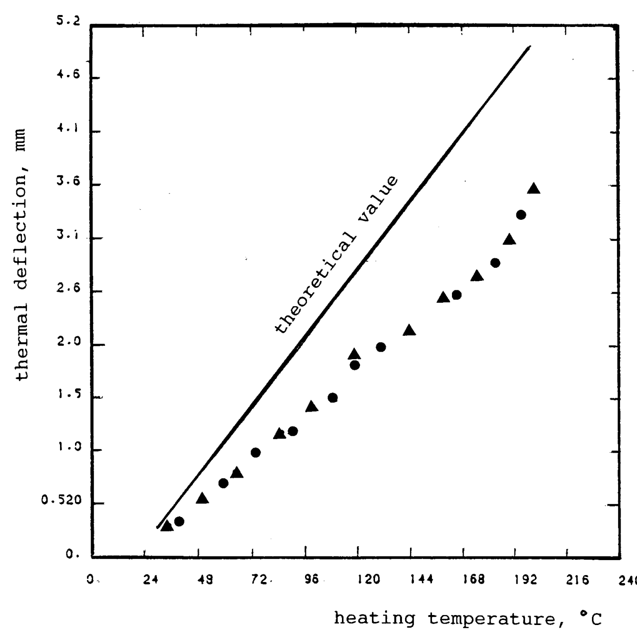

Fig. 4 Variation of thermal deflection of bimetal strips sintered at 1300 °C for 1 h, with the heating temperature

× 10^{-4}, and that of nickel is 25 × 10^{-4} (Ref 5). Therefore, the bimetal combining the nickel layer with the Fe36Ni layer displays an appreciable amount of deflection during heating. In this study, the bending displacement of the free ends of the specimens was between 2.8 and 3.8 mm when heated to 200 °C. After cooling to room temperature, the thermal distortion vanished and the original shape and dimension restored completely. No residual distortion could be measured from the tested specimen.

The bending deflection of the specimens sintered at 1200 and 1300 °C was measured gradually during heating, and compared with the value calculated from the theoretically derived equation, as shown in Fig. 2 to 5. The calculated values from Eq 1 are shown as a solid line. For specimens sintered at 1200 °C for one hour, there is a large disparity between the experimental data and the solid line, as shown in Fig. 2. The thermal deflection at 200 °C was 2.8 mm. The extent of sintering at 1200 °C for 60 minutes might not be enough to reduce significantly the porosity of specimens. Although the sintered specimen had been rolled to increase the density, and the total volume of pores was reduced and some pores were closed, the amount of deformed pores and the discontinuity in the material were still high, resulting in the deterioration of the performance of the P/M bimetal strips.

Table 1 Nickel and iron concentration in the bimetal strip sintered at 1300 °C for 2 hours

Distance from the interface, μm	Position	Ni, wt%	Fe, wt%
200	Ni side	98.8	1.2
170	Ni side	96.5	3.5
120	Ni side	94.7	5.3
60	Ni side	80.6	19.4
30	Ni side	67.5	32.5
10	Ni side	51.1	48.9
0	interface	38.8	61.2
10	Fe36Ni side	37.9	62.1
40	Fe36Ni side	37.3	62.7
80	Fe36Ni side	36.6	63.4

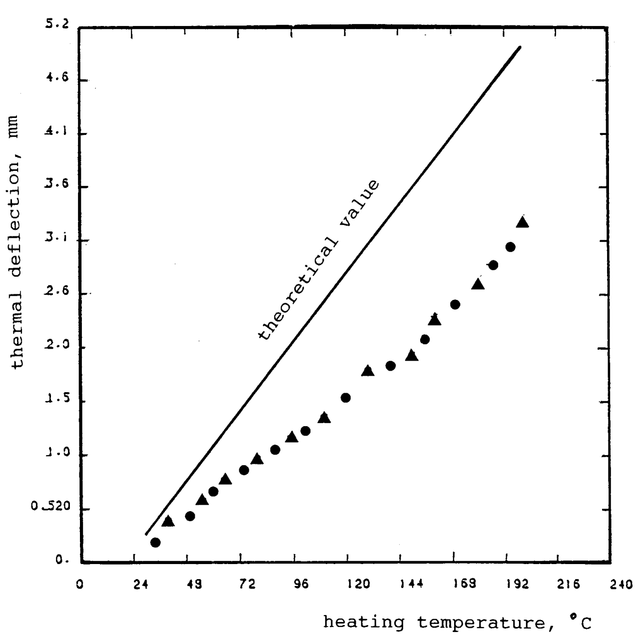

Fig. 5 Variation of thermal deflection of bimetal strips sintered at 1300 °C for 2 h, with the heating temperature

For specimens sintered at 1200 °C for two hours, the variation of bending displacement with heating temperature is depicted in Fig. 3. Due to the more intense sintering, the volume and amount of pores decreased markedly, and the consistency between the measured data and the theoretical value was improved. The thermal deflection at 200 °C reached a value of 3.8 mm. As for the specimens sintered at 1300 °C for one hour, shown in Fig. 4, the curve of variation of the thermal deflection with the heating temperature resembles that of specimens sintered at 1200 °C for two hours. The thermal deflection at 200 °C was 3.6 mm, which was a little lower than that in Fig. 3. The degree of sintering and the microstructure developed in both specimens might be similar based on the observation of microstructure of these two groups of specimens under an optical microscope.

For specimens sintered at 1300 °C for two hours, as shown in Fig. 5, the difference between the tested data and the theoretical value has not been further reduced with this highly intense sintering. The thermal deflection at 200 °C decreased to a value of 3.3 mm. The degraded performance may have resulted from over-sintering. During the extended high-temperature sintering, the interdiffusion between the nickel layer and the Fe36Ni layer prevailed. Massive iron atoms diffused into the nickel layer, which lowered the purity and the coefficient of thermal expansion of the nickel layer. At the same time, the composition of the Fe36Ni layer also changed, and the thermal dilation of this layer may increase during heating. The difference between the coefficient of thermal expansion of these two layers decreased, as did the thermal bending of the bimetal strip.

From this group of samples sintered at 1300 °C for two hours, the nickel and iron concentrations were measured along the scanning line across the nickel and Fe36Ni layers, by point-counting the intensity of NiK_α and FeK_α with a SEM. The measured data of 10 points are shown in Table 1. It can be seen that iron atoms have diffused into the nickel layer for a distance of about 200 μm (the thickness of nickel layer is 400 μm), while nickel enrichment in the Fe36Ni layer only proceeded to a depth of about 80 μm. The decrease in the thermal bending of specimens can be attributed to this intense interdiffusion and the resulting variation in compositions and coefficients of thermal expansion of both the nickel layer and the Fe36Ni layer.

4. Conclusions

- The bimetal combining of a nickel layer with a Fe36Ni layer can be successfully fabricated by the P/M method, consisting of two-layer compacting, sintering, rolling, and subsequent annealing.
- The bending displacement of P/M bimetal strips displayed during heating is invariably less than the theoretically predicted values, due to the existence of pores.
- The proper degree of sintering is essential for the P/M bimetal strip to display significant bending displacement during heating. It is important to avoid intense interdiffusion of the nickel layer and the Fe36Ni layer.

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