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Study of Mechanical Properties for the Aluminum Bronze Matrix Composites of Hot Pressing

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Abstract—The aluminum bronze matrix alumina composites using hot press and resin infiltration were investigated to study their porosities, hardness, bending strengths, and microstructures. The experiment results show that the hardness of the sintered composites with the decrease of porosity increases. The composites without and with resin infiltration have about HRF 42-61 of about 34-40% of porosity and about HRF 62-83 of about 30-36% of porosity, respectively. Besides, the alumina composites contain a more amount of iron and nickel powders would cause a lower bending strength due to forming some weaker bonding among the iron, nickel, copper, aluminum under this hot pressing of shorter time.

***Keywords*—**Aluminum bronze matrix composite, bending strength, hot pressing, porosity.

I. Introduction

THE copper alloys have high thermal conductivity, wear resistance, corrosion resistance, and good mechanical strength to be widely used in the applications of friction materials, grinding tools, structure parts, etc. For example, the sintered metal friction materials contain some typical copper matrix, friction modifiers, and lubricants to get a high and stable coefficient of friction, low wear loss, and good thermal conductivity under the operating conditions of high temperature, high load and high speed [1]-[4]. Besides, the metal-bonded diamond grinding tool usually use copper alloy matrix to get a good machining performance [5]-[7]. Hence, this study will try to fabricate aluminum bronze matrix and its alumina composite without and with resin infiltration under the hot press to study the mechanical properties.

II. Experiment Procedure

The aluminum bronze matrix alumina composites were hot pressed using several different of metal powders under 850^{o}C, 225Kgf/mm^2 and 30min. Group A as listed in Table I is aluminum bronze matrix and group B as listed in Table II is to add alumina into group A. Group C (samples CFN1-4) and group D (samples CWFN1-4) infiltrated resin into group A and group B, respectively. The obtained samples were tested to estimate their hardness, porosity, and three-point bending strength. Furthermore, the strain energy is calculated by 1/2 x bending strength x rupture strain. The polished surfaces of samples are observed and analyzed by SEM and EDAX to study their microstructures.

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III. Experiment Results

A. Porosity

Fig. 1 showed the average total porosity, open porosity and close porosity of aluminum bronze matrix alumina composites under a hot pressing of 850^{o}C and 225Kgf/mm^2. From the figure, it can be found that the sample WFN4 has a relatively highest average open porosity of 27.75% and a relatively lowest close porosity of 11.20%. All in all, the obtained total porosity for samples WFN with different amounts of copper, iron and nickel shows a similar condition with 36.64-39.16%, which displays a relatively good compressibility.

For the aluminum bronze matrix alumina composites containing resin infiltration under a hot pressing of 850^{o}C and 225Kgf/mm^2 the obtained average total porosity, open porosity and close porosity as shown in Fig. 2 presents that the samples CWFN have an average open porosity of 12.39-18.33% and a close porosity of 18.80-22.32%. All in all, the obtained total porosity for samples CWFN shows 32.26-37.14% that is lower than those of samples WFN. The samples CWFN display a lower open porosity than the samples WFN by 8-13%, which is due to resin infiltration after hot pressing.

TABLE I
Compositions of Aluminum Bronze Matrix for Group A

Type	Al_2O_3	Cu	Al	Fe	Ni	Mn	Total
FN1	0.00	89.00	10.00	0.00	0.00	1.00	100
FN2	0.00	86.00	10.00	2.00	1.00	1.00	100
FN3	0.00	82.00	10.00	4.00	3.00	1.00	100
FN4	0.00	77.99	10.00	6.00	5.01	1.00	100

TABLE II
Compositions of Alumina Composites for Group B

Type	Al_2O_3	Cu	Al	Fe	Ni	Mn	Total
WFN1	19.04	72.06	8.09	0.00	0.00	0.81	100
WFN2	19.07	69.60	8.09	1.62	0.81	0.81	100
WFN3	19.10	66.34	8.09	3.23	2.43	0.81	100
WFN4	19.13	63.07	8.09	4.85	4.05	0.81	100

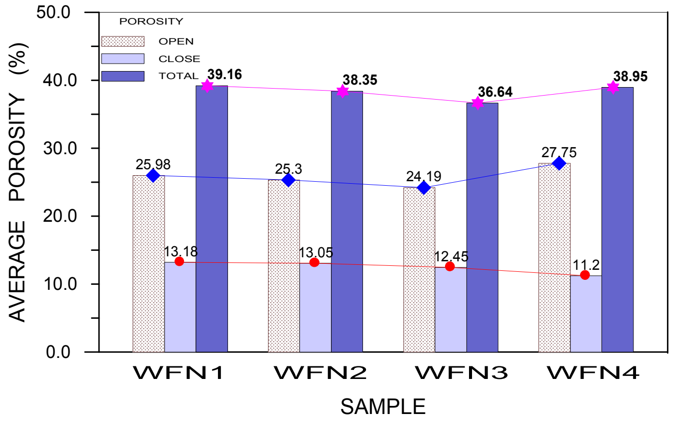


Fig. 1 The average porosity of aluminum bronze matrix alumina composites

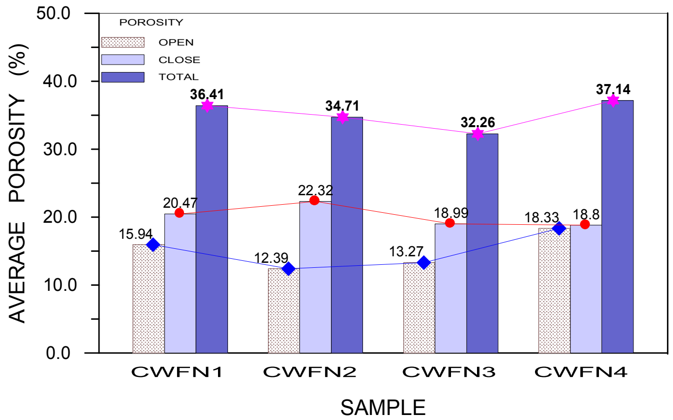


Fig. 2 The average porosity of aluminum bronze matrix alumina composites with resin infiltration

B. Hardness

Fig. 3 shows the average hardness obtained for aluminum bronze matrix alumina composites and their containing resin under a hot pressing of 850°C and 225Kgf/mm^2. From the figure, it can be found that the hardness of samples FN (matrix) and WFN (containing alumina) with the increase of nickel and iron amount ranges from about HRF 42.63 to HRF 61.81. When the samples CFN and CWFN containing resin infiltration were designed, the resulting average hardness obtained has a larger tendency from HRF 62.75 to HRF 83.75. This implies that the composites containing resin infiltration can improve their hardness by 24-68% (HRF 18-30), which depends on the samples containing the amount of resin and porosity.

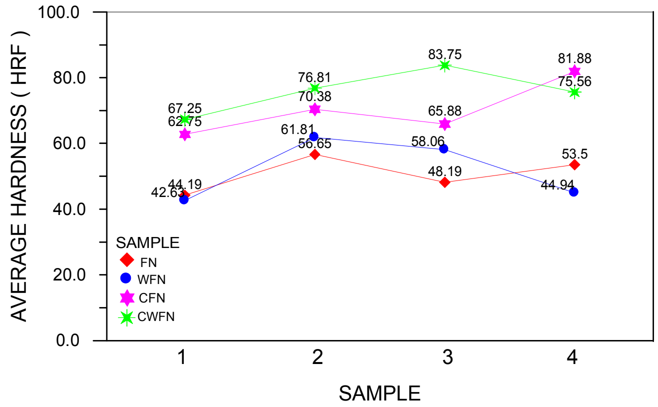


Fig. 3 The average hardness for aluminum bronze matrix alumina composites

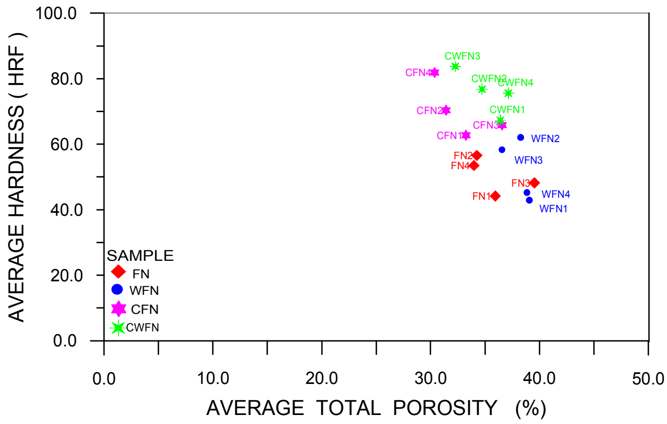


Fig. 4 The relation between the hardness and the total porosity

Fig. 4 showed the relation between the hardness and the total porosity for aluminum bronze matrix alumina composites. The hardness of the sintered composites with the decrease of porosity increases. All in all, the composites have 30-40% of porosity and the responding hardness is about HRF 42-83. The composites without resin infiltration have about HRF 42-61 with about 34-40% of porosity. However, the composites with resin infiltration have about HRF 62-83 with about 30-36% of porosity. Besides, the obtained hardness of composites is also improved by the larger amount of nickel, iron, alumina, and resin infiltration.

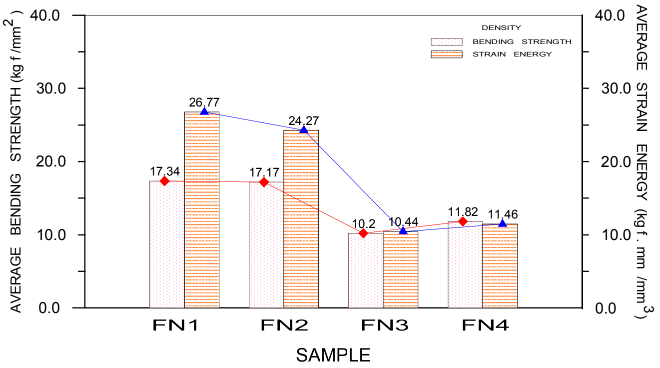


Fig. 5 The average bending strength and strain energy for aluminum bronze matrix

C. Bending Strength and Strain Energy

Fig. 5 shows the average bending strength and strain energy obtained for the samples FN of aluminum bronze matrix under a hot pressing of 850°C and 225Kgf/mm^2. From the figure, it can be found that the bending strength and strain energy of the samples FN1 and FN2 are the similar with a relatively larger value of about 17.34Kgf/mm^2 and 26.77Kgf· mm/mm^3, respectively. However, for the samples FN3 and FN4, their bending strength and strain energy are relative lower of about t 10.22Kgf/mm^2 and 10.44Kgf· mm/mm^3, respectively. The reason for this is that FN3 and FN4 contain a more amount of iron and nickel to cause a poorer bonding with copper and aluminum, which are due to short time of 30min during hot pressing to be more difficult of diffusion bonding to form a solid solution. Oppositely, containing a more amount of iron and nickel for an aluminum bronze displays a poor bending strength and strain energy under this hot pressing condition, not as expected to be better. Besides, even though FN4 has a larger hardness and a lower porosity, the resulting bending strength is still poor.

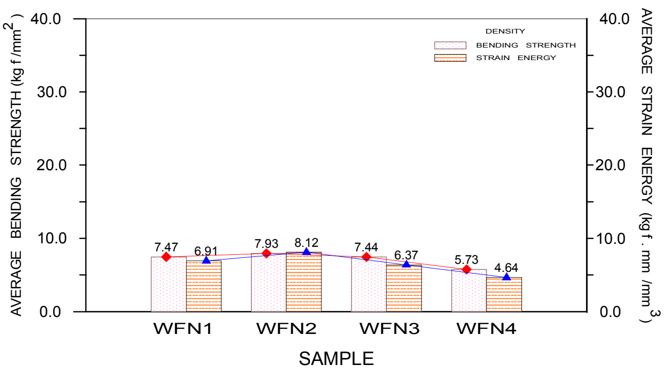


Fig. 6 The average bending strength and strain energy for aluminum bronze matrix alumina composites

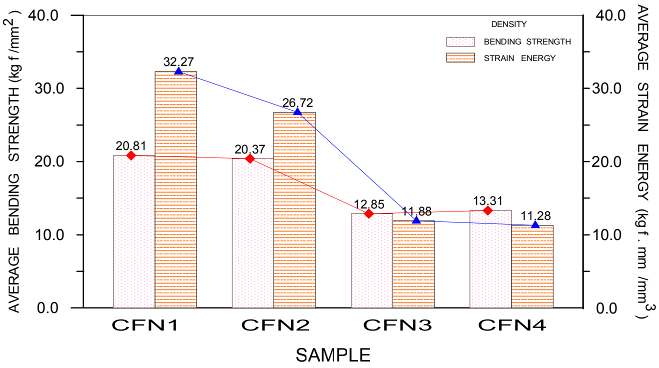


Fig.7 The average bending strength and strain energy for aluminum bronze matrix of resin infiltration

Fig. 6 showed the average bending strength and strain energy obtained for the samples WFN of aluminum bronze matrix alumina composites under a hot pressing of 850°C and 225 Kgf/mm^2. It can be seen that the bending strength and strain energy of the samples WFN1 and WFN2 are slightly larger than those of WFN3 and WFN4. Their bending strengths are about 7.47-7.93Kgf/mm^2 and their strain energies are about 6.91-8.12Kgf mm/mm^3. This implies that adding alumina into aluminum bronze matrix causes their bonding to be poor and adding a more amount of iron and nickel (WFN3 and WFN4) is poor bonding with a low strength and strain energy.

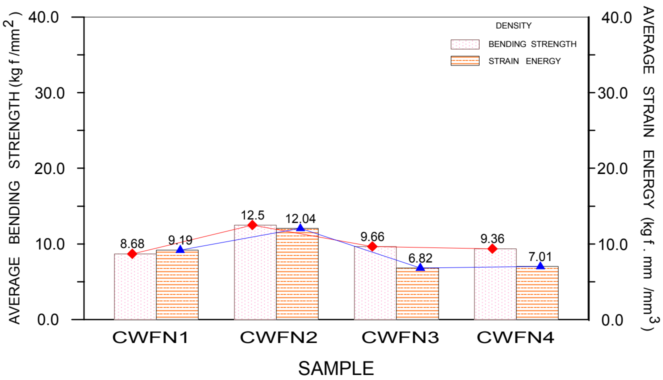


Fig. 8 The average bending strength and strain energy for aluminum bronze matrix alumina composites of resin infiltration

Fig. 7 showed the average bending strength and strain energy of the samples CFN obtained after resin infiltration of the samples FN. It can be seen that the bending strength and strain energy of the samples CFN1 andCFN2 are relative larger than those of CFN3 and CFN4. The bending strength and the strain energy of the sample CFN1 respectively are 20.18Kgf/mm^2 and 32.27Kgf · mm/mm^3, which show more than those of FN1 without resin. It implies that the resin infiltration of aluminum bronze matrix can improve the bonding ability among the powders to strengthen the mechanical properties.

Fig. 8 showed the average bending strength and strain energy of the samples CWFN obtained after resin infiltration of the alumina composites WFN. It can be found that the bending strength and strain energy of the samples CWFN2 are the relative largest among the samples CWFN and are larger than those of WFN2 without resin. The bending strength and the strain energy of the sample CWFN2 respectively are 12.50 Kgf/mm^2 and 12.04Kgf · mm/mm^3. It implies that the resin infiltration after hot pressing of aluminum bronze matrix composites can increase the bending strength and strain energy by about 16-57%, which its difference depends on the amount of open porosity and resin infiltrated into pores.

D. Relation of Bending Strength and Porosity

Fig. 9 shows the relation of the average bending strength and the total porosity. It can be found that the lower total porosity of the samples displays a relatively higher bending strength. Besides, the samples contain alumina and resin (CWFN) to show a relatively medium bending strength with about 8.68-12.5Kgf/mm^2 at the total porosity of 32-37%. The alumina composites without resin (WFN) of a relatively more amount of porosity display a relatively lower bending strength. The aluminum bronze matrix without alumina (FN1 and FN1) and with resin (CFN1 and CFN2) of a lower amount of iron and nickel displays a relatively larger bending strength up to about 20 Kgf/mm^2.

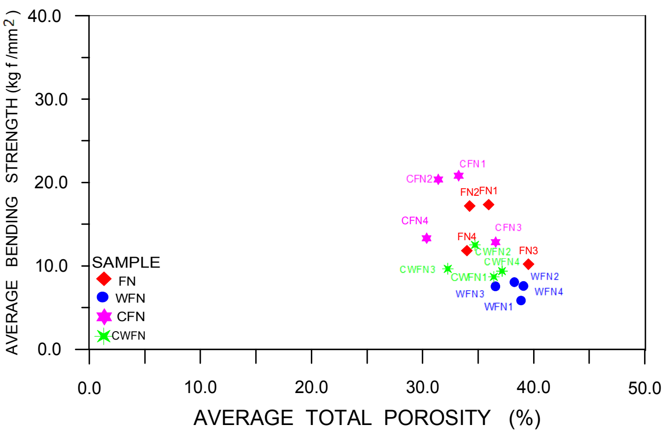


Fig. 9 The relation of the average bending strength and the total porosity

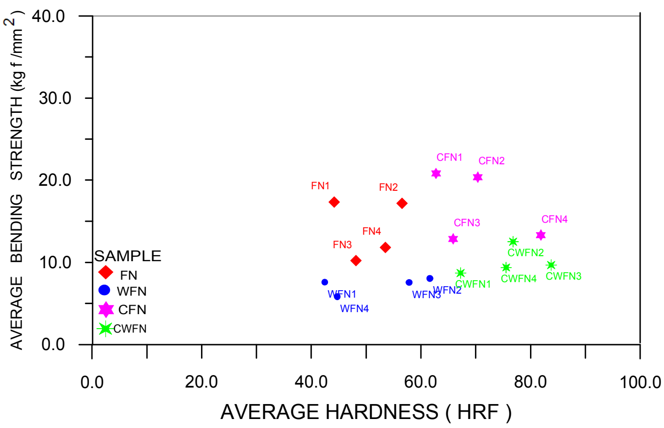


Fig. 10 The relation of the average bending strength and the hardness

E. Relation of Bending Strength and Hardness

Fig. 10 shows the relation of the average bending strength and the hardness. It can be found that the larger hardness of the samples does not significantly affect their bending strength, but it is subjected to the effect of their structures. The samples CWFN1-4 present a relatively medium strength of 8.68-12.5 Kgf/mm^2 at HRF 67-83. The samples WFN with low hardness have low strength. For CFN1, CFN2 and FN1, FN2 the bending strength shows a relative high of about 20Kgf/mm^2 and 17Kgf/mm^2 at HRF 62-70 and HRF 44-56, respectively.

F. Relation of Strain Energy and Porosity

Fig. 11 shows the relation of the average strain energy strength and the total porosity. It can be found that the alumina composites (WFN) have a relatively lower strain energy (4.64-8.12 Kgf · mm/mm^3) with a relatively larger total porosity (36-39%). When the resin are added into the samples CWFN1-4, the resulting strain energy increases to 6.82-12.04 Kgf mm/mm^3 and the total porosity reduces to 32-37%. Besides, CFN1-2 and FN1-2 displays a relatively higher strain energy (24.27-32.27 Kgf · mm/mm^3) at the total porosity of 32-36 %.

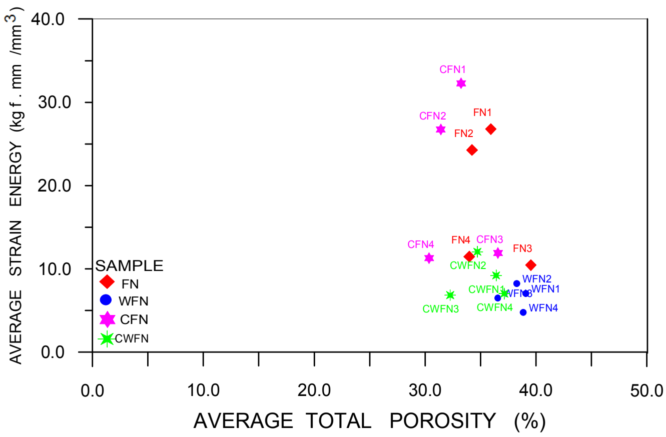


Fig. 11 The relation of the average strain energy strength and the total porosity

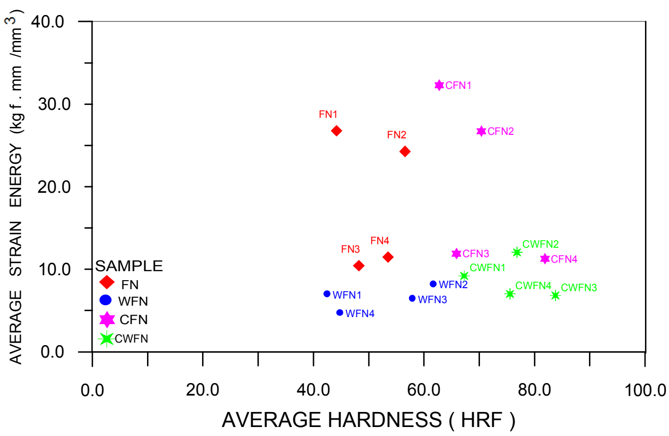
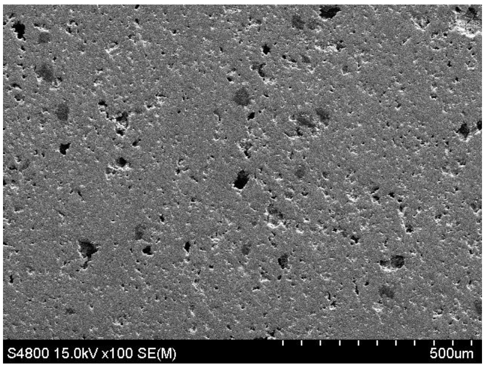


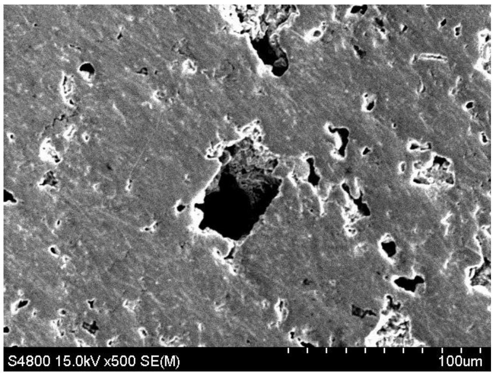
Fig. 12 The relation of the average strain energy strength and the hardness

G. Relation of Strain Energy and Hardness

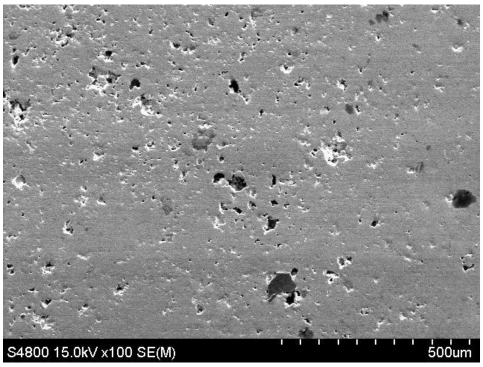
Fig. 12 showed the relation of the average strain energy and the hardness. It can be found that the samples CWFN1-4 with resin present relatively low strain energy of 6.82-12.04 Kgf· mm/mm^3 at HRF 67-83. The samples WFN1-4 with low hardness have low strain energy. For CFN1, CFN2 and FN1, FN2 the strain energy shows a relative high of about 26.72-32.27Kgf· mm/mm^3 and 24.27-26.77Kgf· mm/mm^3 at HRF 62-70 and HRF 44-56, respectively.



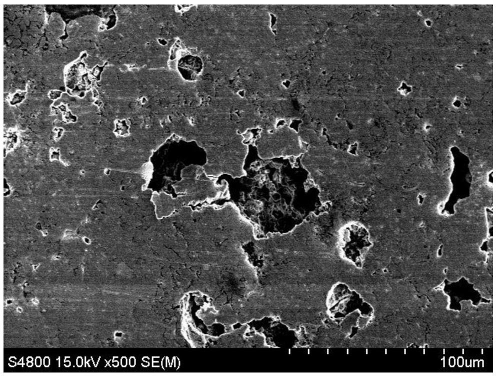
(a1) FN1



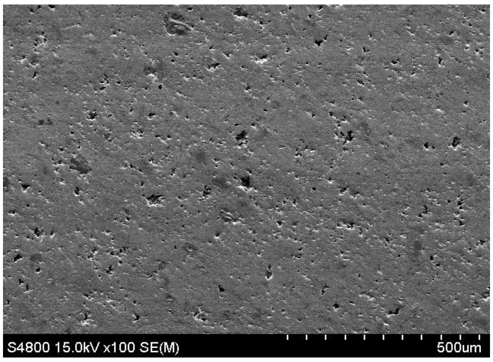
(a2) FN1



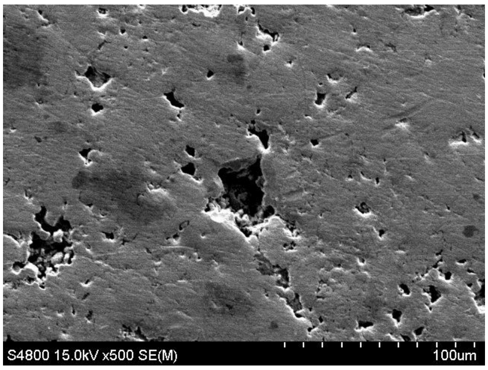
(b1) FN2



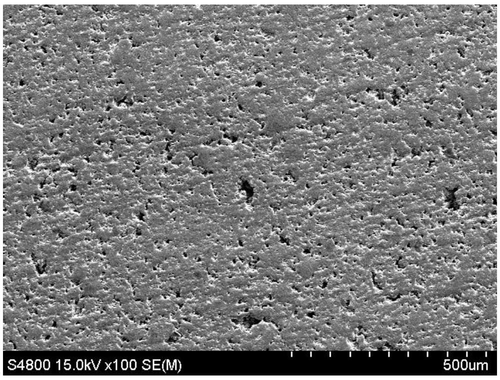
(b2) FN2



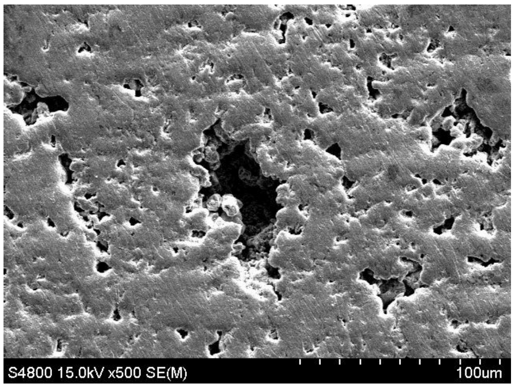
(c1) FN3



(c2) FN3



(d1) FN4

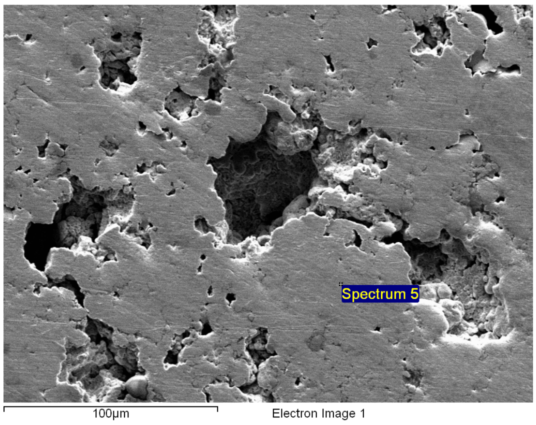


(d2) FN4

Fig. 13 The polished microstructure

Spectrum processing :
Peak possibly omitted : 9.640 keV

Processing option : All elements analyzed (Normalised)
Number of iterations = 2



Element	Weight%	Atomic%
O K	1.03	3.58
Al K	8.18	16.88
Cu L	90.79	79.54
Totals	100.00	

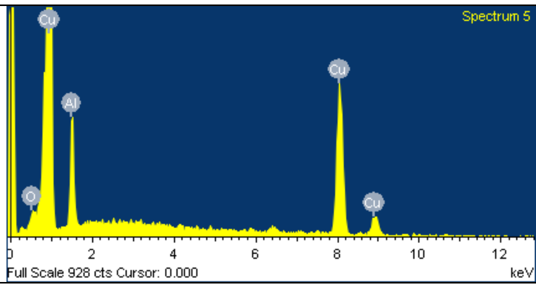
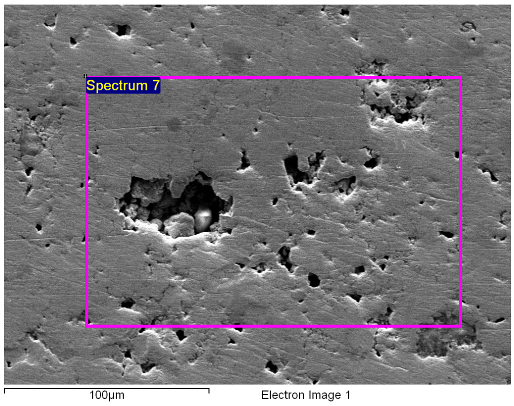


Fig. 14 EDAX at spectrum 5 of sample FN2

Spectrum processing :
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 4



Element	Weight%	Atomic%
C K	3.58	13.97
O K	2.47	7.23
Al K	8.49	14.76
Mn K	0.93	0.79
Fe K	5.51	4.62
Ni K	5.01	4.00
Cu L	74.02	54.63
Totals	100.00	

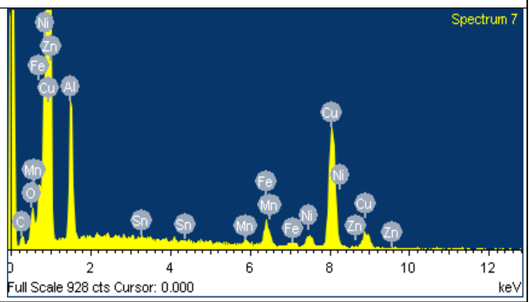
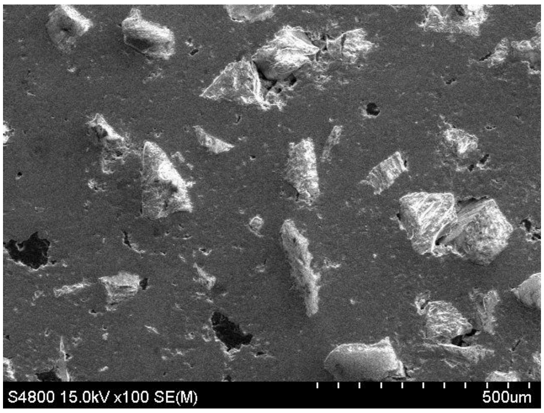
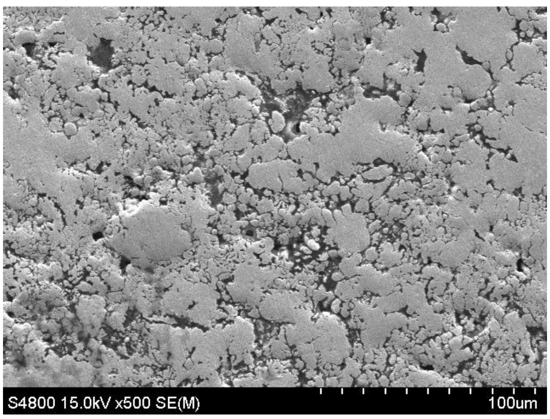


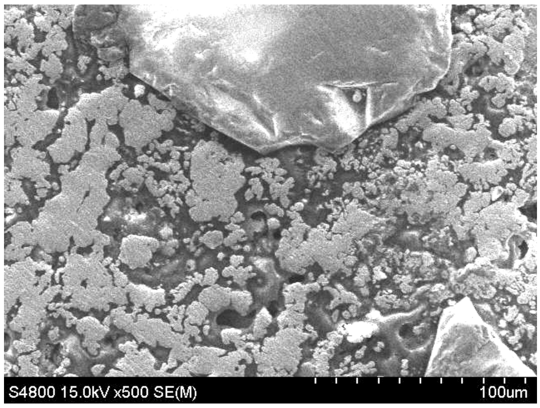
Fig. 15 EDAX at spectrum 7 of sample FN3



(a) WFN



(b) CFN



(c) CWFN

Fig. 16 The typical polished structures

H. Microstructure

Fig. 13 (a)-(d) showed the polished microstructure of FN1-4, respectively. From these figures, it can be found that the polished surfaces exist some pores, which are examined by EDAX as shown in Fig. 14 to display the most of copper and aluminum compositions of FN2. It implies that aluminum element melts into copper matrix during the hot pressing of 850 ^{o}C. Fig. 15 showed the element spectrum of EDAX on the FN3 to display the existence of Cu, Al, Fe, Ni, Mn, etc. Some pores on the polished surface are covered by the deformation of matrix. These pores and their surroundings were examined by EDAX to show a larger amount of iron and nickel elements.

This implies that these iron and nickel powders may be more difficult to diffuse bonding with copper and aluminum powders due to higher melting point and shorter time during the hot pressing, thereby forming a larger number of pores with a weaker bonding state. Hence, causing the FN3 and FN4 containing a larger amount of iron and nickel produces a weaker bending strength and strain energy (refer to Fig.5), not as expected to have a higher strength.

Besides, the typical polished structures for the samples WFN, CFN and CWFN were showed in Fig. 16 (a)-(c), respectively. It can be seen that alumina particles on matrix display a uniform distribution in Fig. 16 (a). The appearances of CFN (Fig. 16 (b)) and CWFN (Fig. 16 (c)) show some dark areas of the resin infiltrated into the matrix, thereby can improve the bonding strength.

IV. Conclusion

(1) The alumina composites after hot pressing have a relatively larger porosity than the aluminum bronze matrix. Besides, the resin infiltration after hot pressing is employed to can reduce the open porosity by about 10-13%.
(2) The aluminum bronze matrix composites infiltrated resin after hot pressing can improve their hardness by 24-68% (HRF 18-30), which depends on the composites containing the amount of resin and porosity.
(3) The bending strength of alumina composites displays a relatively low value. Besides, when the composites containing a relatively smaller amount of iron and nickel are employed, the resulting bending strength and strain energy are relative higher. This is because the powders among the matrix display a better diffusion bonding under hot pressing.
(4) The alumina composites with the more amount of porosity show a relatively lower bending strength and strain energy.

Acknowledgment

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