IMPROVED PRECISION OF IRON-COPPER-CARBON MATERIALS

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ABSTRACT

Copper is a common alloying element used in powder metallurgy (PM) materials to achieve improved mechanical strength and hardness. Different amounts of copper with course or fine particle sizes can be admixed with iron to achieve desired properties. However, the addition of copper has a great effect on the dimensional change of PM components. Variation in dimensions and large pores are often caused by copper segregation when the copper is admixed. One way to minimize this drawback is to diffusion-bond the copper to the iron particles with homogeneous distributions of copper. The diffusion-bonding method can help further improve the dimensional stability during sintering. This study introduced a newly developed copper diffusion bonded iron powder aiming for better dimensional control and stability. The mechanical properties and dimensional changes were examined compared to current copper diffusion-bonded iron powder and admixed powder containing elemental copper.

INTRODUCTION

Iron-copper-carbon is one of the most widely used material systems for manufacturing powder metallurgy (PM) components. The addition of alloying elements such as copper can improve the strength and hardness of an iron based material. Elemental copper has a low melting point of 1083 °C (1981 °F).[1,2] During sintering, the copper diffuses into the iron which improves particle bonding and strengthens the grain boundaries. This leads to added strength but results in growth in dimensions. After the sintering is complete, large pores may be left as the copper diffused into the iron depending on the particle size of the copper. The large pores left behind from the copper can also potentially lead to variation in dimensions. [3, 4, 5]

Admixing is the most common and simplest method to distribute alloying elements into base iron powder to form a mix before compaction and sintering. However, admixed materials are more prone to segregation from mixing in the alloying elements because the particles free to move. To eliminate the segregation factor, a diffusion-bonded method can be used. Rather than admix the copper, it is thermally bonded to the base iron.[6] With a well controlled manufacturing process, the diffusion-bonded copper alloyed powder also eliminates the large pores which copper leaves behind during sintering. Therefore, the diffusion-bonded powder is expected to provide improved dimensional change.[7,8]

Unlike prealloyed powder where the copper is completely alloyed to iron matrix, the diffusion-bonded powder with the copper has the copper partially alloyed to the surface of iron particles so that its compressibility remains unaffected. [6]

In this study, the dimensional change and the behavior of copper-diffusion after sintering were examined. Iron-copper-carbon material systems made with an improved copper diffusion-bonded iron powder were compared to the current copper diffusion-bonded iron powder and admixed materials containing elemental copper. Mechanical properties were also compared. A dimensional change study was conducted to evaluate the variation in dimensions and to show the differences between elemental copper and diffusion-alloyed copper materials.

EXPERIMENTAL PROCEDURE

Materials

The MPIF standard material systems used for this study were FC-0200 (0%), FC-0200 (0.2% C), FC-0205 (0.6% C) and FC-0208 (0.8% C). Within each material system, four different sources of copper were selected for evaluation. The copper sources were: elemental Cu-165 (ACupowder) which is a conventional PM grade, elemental Cu-200 (ACupowder) which is a conventional PM grade with finer particle size than the Cu-165 grade, diffusion-alloyed D.ACu (Höganäs Sweden), and diffusion-alloyed D.ACu Improved (Höganäs Sweden). The average particle size distribution for each copper source is shown in the table below.

Table 1: Average particle size distribution (PSD) of the copper sources

Cu Source	D_{50} (µm)
Cu-165	80
Cu-200	45
D.ACu	*150
D.ACu Improved	*150

*Note: Average PSD for base iron

Sintered Properties

Two types of test specimens were prepared for this study. Transverse rupture strength (TRS) bars and tensile strength (TS) bars were compacted to achieve a green density of 6.9 g/cm^3. The bars were sintered in a laboratory belt furnace at 1120 °C (2050 °F) for 20 minutes in a 90/10 N_2/H_2 atmosphere with a normal cooling rate of 0.5 °C/sec (1 °F/sec).

After sintering, the TS bars were sent to Westmoreland Mechanical Testing & Research (Youngstown, Pennsylvania) to be tested for yield strength, tensile strength, and elongation. The testing was completed in accordance with MPIF standard 10. [9]

The TRS bars were used to evaluate compressibility, dimensional change (DC), apparent hardness (HRB) and microstructure. The testing was completed in accordance with MPIF standards. [9]

DC Study

A dimensional change (DC) study was completed to evaluate the variation in dimensional change between each of the materials over time. The DC study compared the variation when the graphite level was fixed and across all graphite additions. For each mix, five sets of samples (five TRS bars per set) were compacted to achieve a green density of 6.9 g/cm^3. Each set of samples were sintered at 1120 °C (2050 °F) for 20 minutes in a 90/10 N_2/H_2 atmosphere with a normal cooling rate of 0.5 °C/sec (1 °F/sec). The samples were sintered over a series of five days with one set sintered each day.

RESULTS

Green Properties

The compressibility curve for the FC-0208 mixes is shown in Figure 1. The FC-0208 was chosen since it is the most common material system for PM applications. Compared to the admixed materials with elemental copper, the diffusion-alloyed copper materials provided no significant difference in compressibility. With the diffusion-alloyed copper grades, the compressibility of the material containing the D.ACu Improved was comparable to the material with D.ACu.

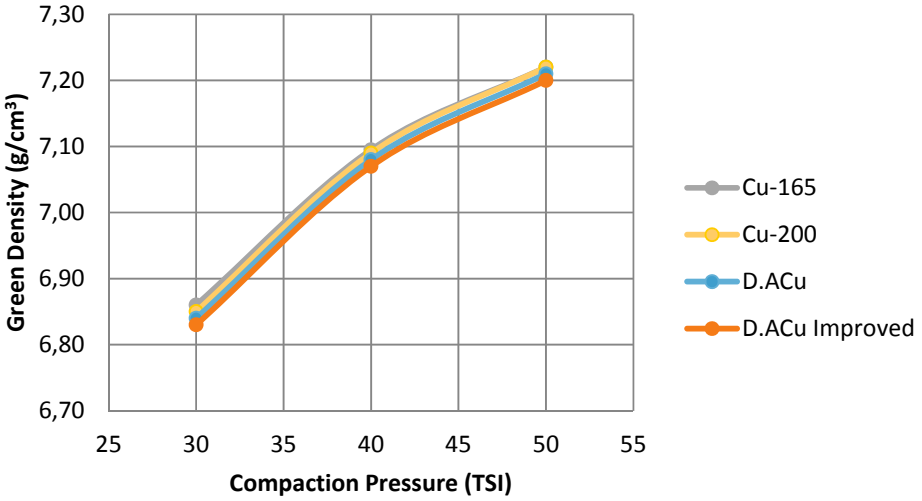


Figure 1: Compressibility Curve for FC-0208 mixes

Sintered Properties

The results of the apparent hardness, yield strength, tensile strength, and elongation for each material system after sintering are shown in Tables 2-5.

Table 2: Sintered properties for FC-0200 mixes (0 % Sintered C)

MPIF Code	Type of Cu	Sintered C (%)	HRB	TS (MPa)	YS (MPa)	Elongation (%)
FC-0200	Cu-165	0.008	21	228	169	6.5
FC-0200	Cu-200	0.007	22	228	171	6.5
FC-0200	D.ACu	0.007	25	228	174	3.2
FC-0200	D.ACu Improved	0.006	29	234	181	3.2

Table 3: Sintered Properties for FC-0200 mixes (0.2 % Sintered C)

MPIF Code	Type of Cu	Sintered C (%)	HRB	TS (Mpa)	YS (Mpa)	Elongation (%)
FC-0200	Cu-165	0.28	54	331	261	4.3
FC-0200	Cu-200	0.28	54	331	267	4.3
FC-0200	D.ACu	0.29	53	338	272	2.2
FC-0200	D.ACu Improved	0.28	56	352	274	2.2

Table 4: Sintered properties for FC-0205 mixes (0.6 % Sintered C)

MPIF Code	Type of Cu	Sintered C (%)	HRB	TS (MPa)	YS (MPa)	Elongation (%)
FC-0205	**Cu-165**	0.66	78	483	385	1.1
FC-0205	**Cu-200**	0.67	76	490	389	3.2
FC-0205	**D.ACu**	0.67	77	503	394	3.2
FC-0205	**D.ACu Improved**	0.66	78	510	396	3.2

Table 5: Sintered properties for FC-0208 mixes (0.8 % Sintered C)

MPIF Code	Type of Cu	Sintered C (%)	HRB	TS (MPa)	YS (MPa)	Elongation (%)
FC-0208	**Cu-165**	0.88	84	552	462	1.1
FC-0208	**Cu-200**	0.88	84	552	468	3.2
FC-0208	**D.ACu**	0.86	85	572	468	3.2
FC-0208	**D.ACu Improved**	0.87	85	579	481	3.2

As the sintered carbon level increased, the hardness and strength increased for the iron-copper-carbon materials regardless of the type of copper used. Although the hardness of materials was similar within the same sintered carbon level, the diffusion-alloyed materials consistently showed slightly higher strength results compared to the materials containing the elemental copper.

The elongation for the elemental coppers decreased as the sintered carbon level increased while the elongation for the diffusion-alloyed materials remained almost the same.

A graph showing the dimensional change vs. sintered carbon level is presented in Figure 2.

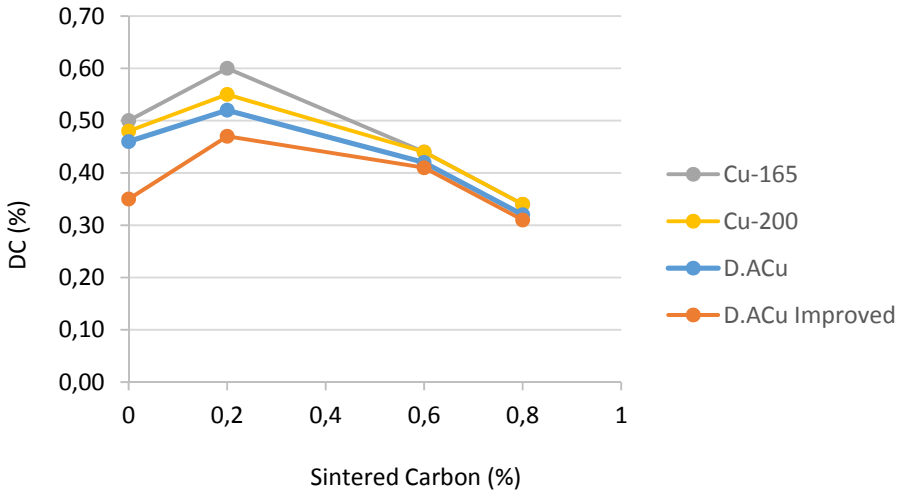


Figure 2: Dimensional change vs. Sintered Carbon

All materials showed a growth in dimensional change regardless the carbon level used. With the carbon level increased from 0.2% C, the growth was reduced. Compared to the other material groups, the D.ACu Improved had significant less growth when no carbon was added (0%) or at the low sintered carbon level (0.2 %). Overall, the D.ACu Improved material exhibited less effect in dimensional change from the carbon addition compared to the other material groups.

Dimensional Change Study

The dimensional change study was performed to evaluate the dimensional change between each of the materials and to develop an understanding of the consistency of the dimensional change over time. The variation in dimensions was evaluated across all graphite additions as shown in Figure 3.

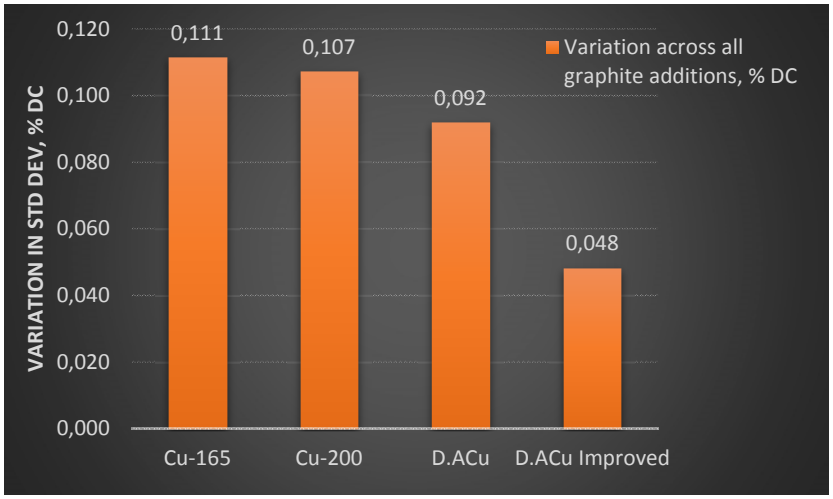


Figure 3: Variation across all graphite additions

The elemental copper (Cu-165 and Cu-200) containing materials presented similar variation in dimensional changes. The diffusion-alloyed materials had less variation compared to the materials with elemental copper. Compared to the D.ACu material, however, the D.ACu Improved material showed significant improvement in reducing the variation of dimensional changes.

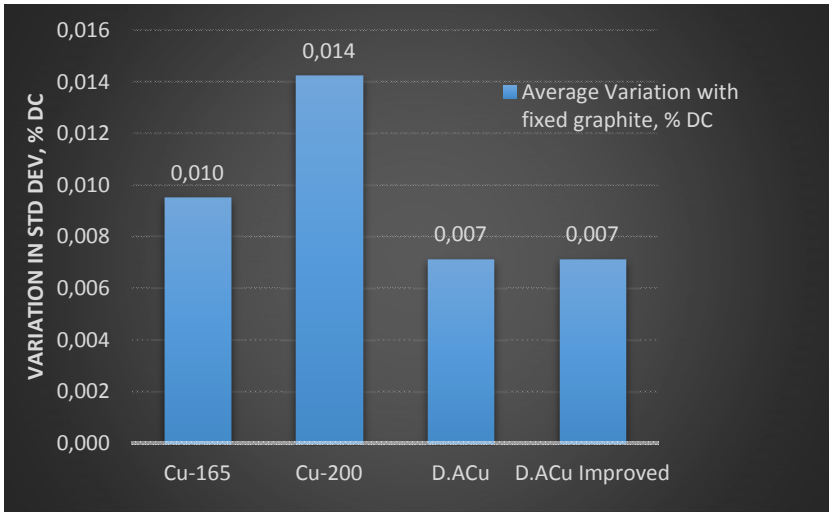


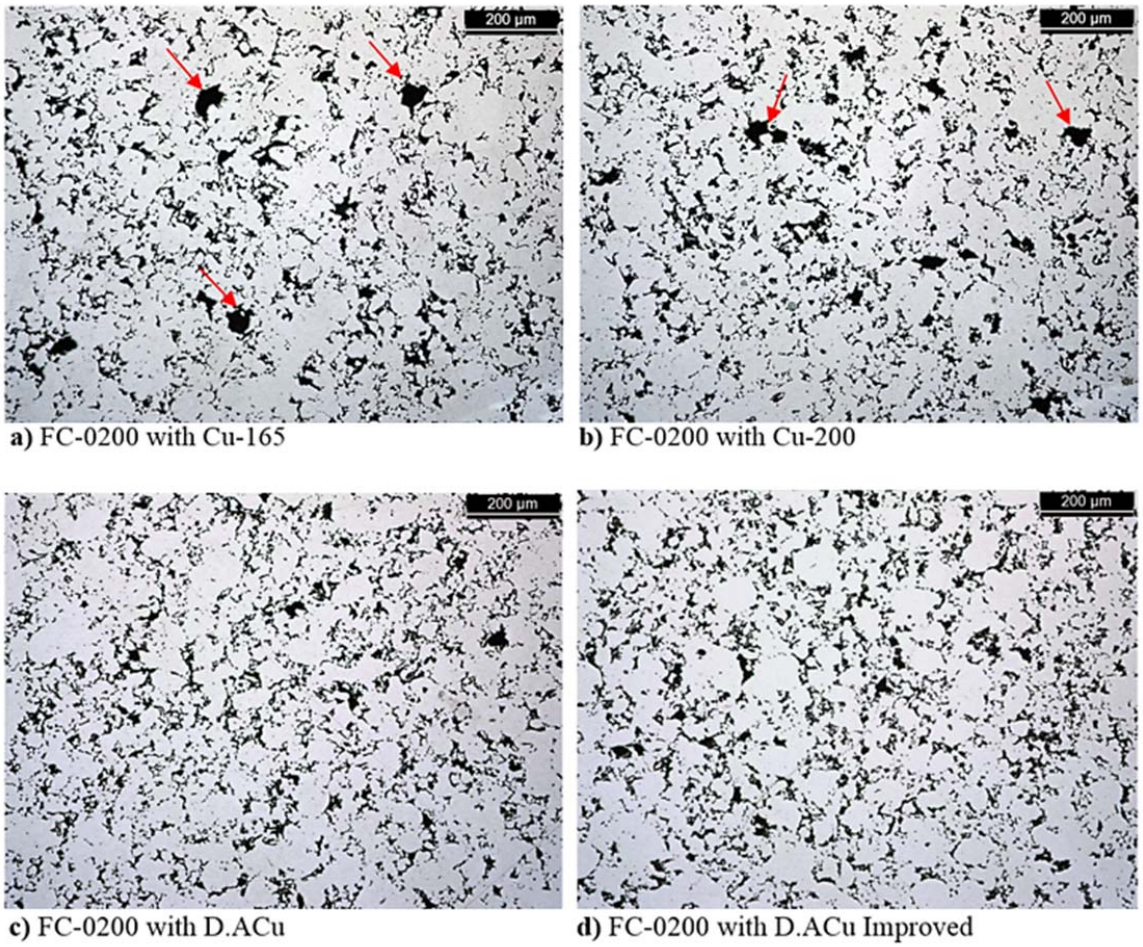
Figure 4: Variation with fixed graphite levels

For the same graphite addition, the variation for the material added with finer elemental copper (Cu-200) was higher compared to the material with coarse elemental copper (Cu-165). Both the D.ACu and D.ACu Improved showed less variation in dimensions, i.e. more consistent in dimensional changes than the admixed material with the elemental copper grades.

DISCUSSION

The diffusion-bonding technology aims to minimize the segregation of alloying elements without detrimental effect on compressibility. The results obtained in this study showed that the diffusion-alloyed copper materials had similar green and sintered properties to the admixed elemental copper materials. They also achieved improved dimensional change, i.e. more stable in dimension changes due to the reduction in segregation of copper. In addition, the diffusion-alloyed materials showed a significant improvement in elongation compared to the admixed elemental copper materials at higher carbon contents.

The porosity of sintered FC-0200 materials made with admixed and diffusion-bonded copper grades is presented in Figure 5. For the material admixed with Cu-165, large pores were observed where the space was left after coarse copper particles melted and diffused into iron during sintering. Large pores were also presented in the material with Cu-200, although the amount was considerably reduced. However, no large pores were found in the diffusion-bonded materials. The size and distribution of pores in the diffusion-alloyed copper materials was more uniform compared to the elemental coppers admixed materials

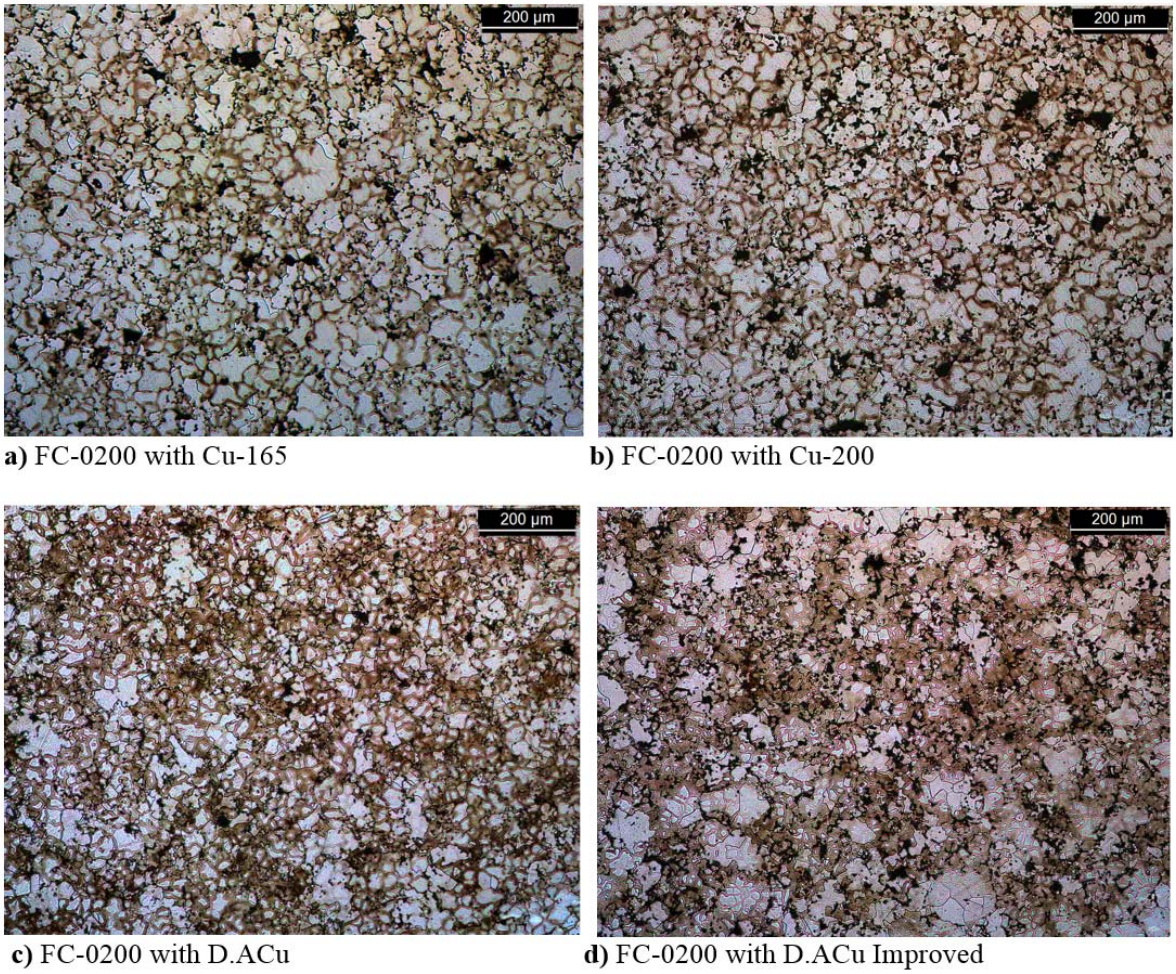


a) FC-0200 with Cu-165 **b)** FC-0200 with Cu-200

c) FC-0200 with D.ACu **d)** FC-0200 with D.ACu Improved

Figure 5: Comparison of porosity between the sintered FC-0200 materials made with admixed and diffusion-bonded copper grades

Figure 6 shows the status of copper diffusion in the sintered FC-0200 materials made with admixed elemental copper and diffusion-bonded copper grades without carbon addition. In the elemental copper admixed materials, the diffusion was concentrated around the grain boundaries of iron particles while the copper in the diffusion-alloyed materials was diffused more into the iron particles. Compared to the D. ACu material, more copper was diffused into the iron matrix in the D.ACu Improved material. Figure 7 illustrates the status of copper diffusion in the microstructures of the FC-0200 materials at a higher magnification.



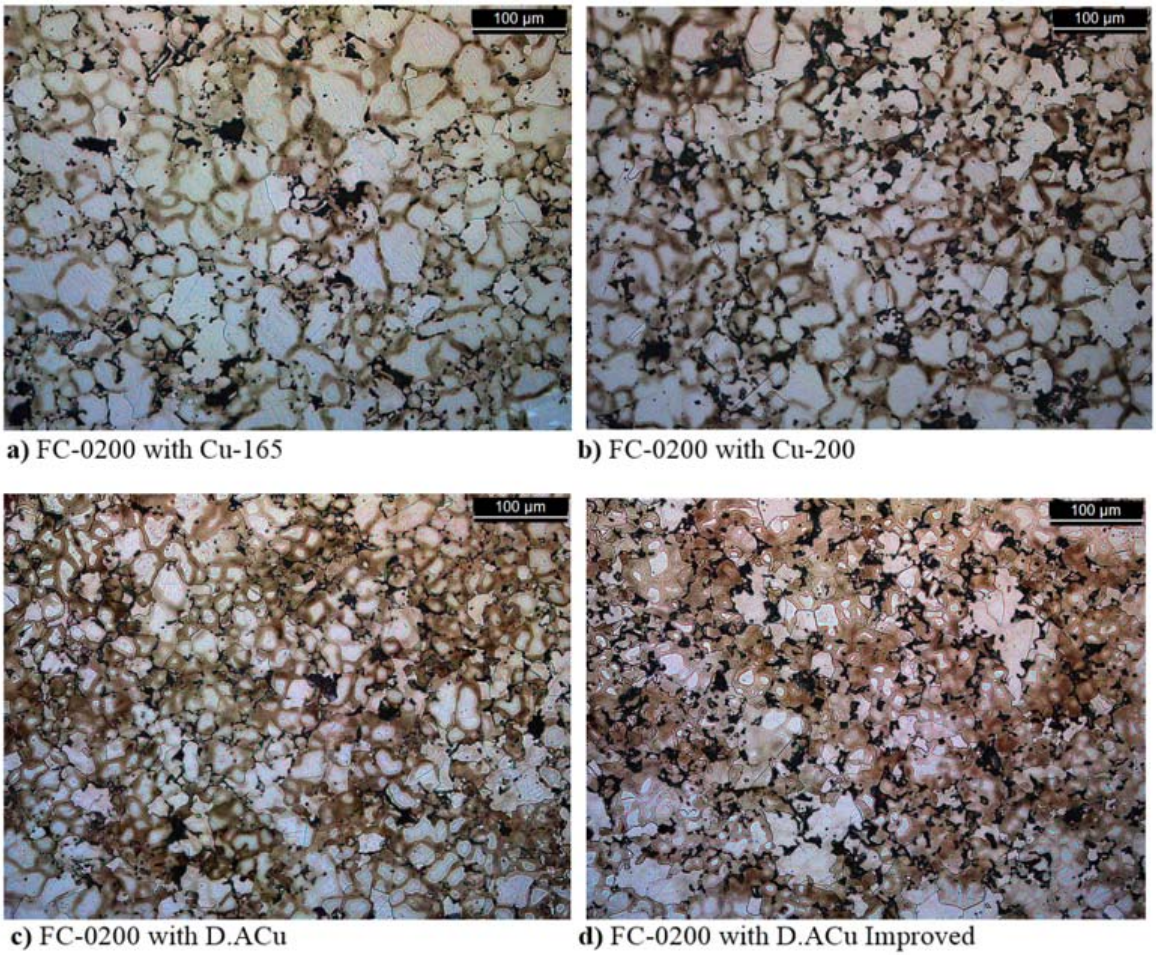
a) FC-0200 with Cu-165 **b)** FC-0200 with Cu-200

c) FC-0200 with D.ACu **d)** FC-0200 with D.ACu Improved

Figure 6: Comparison of copper diffusion between the sintered FC-0200 materials made with admixed and diffusion-bonded copper grades

If copper segregation occurs in admixed materials, the large copper particles or agglomerates can cause variation in dimensions or a shift in the properties. When using copper diffusion-bonded material, copper segregation can be eliminated and the diffusion of copper into the iron matrix is more consistent which leads to reduced variation in dimensional changes.

The analysis on the status of copper diffusion in iron matrix explains why the copper diffusion-bonded materials have less variation in dimensional changes and higher elongation than the elemental copper admixed materials. With more copper diffused into iron particles rather than concentrated on the grain boundaries, the distribution of copper in the iron matrix becomes more homogeneous and makes the matrix more homogenous, resulting in more stable dimensional changes and stronger in toughness.



a) FC-0200 with Cu-165 **b)** FC-0200 with Cu-200

c) FC-0200 with D.ACu **d)** FC-0200 with D.ACu Improved

Figure 7: Comparison of copper diffusion between the sintered FC-0200 materials made with admixed and diffusion-bonded copper grades

CONCLUSION

The following conclusions can be drawn from this study:

- D.ACu Improved demonstrated better dimensional control than the current diffusion-bonded material.
- The amount of variation in dimensions for the D.ACu Improved material was reduced by 50% in comparison to the admixed materials.
- Improved strength and elongation was observed for the diffusion alloyed materials compared to the elemental copper.

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