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Orientation of Carbon Fibers in Copper matrix Produced by Powder Injection Molding

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Abstract. Fiber orientation is a big challenge in short fiber reinforced composites. Powder injection molding (PIM) process has some intrinsic fiber alignment associated with it. During PIM process fibers in skin region of moldings are aligned as these regions experience higher shear flow caused by the mold walls. Fibers in the core region remain randomly aligned as these regions are far from mold walls and experience lesser shear flow. In this study short carbon fiber (CF) reinforced copper matrix composite was developed by PIM process. Two copper composite feedstock formulations were prepared having 5 vol% and 10 vol% CFs and a wax based binder system. Fiber orientation was controlled during injection molding by using a modified mold that has a diverging sprue. The sprue creates converging flow when feedstock enters into the mold cavity. Fiber orientation was analysed after molding using FESEM. The orientation of fibers can be controlled by controlling flow of feedstock into the mold.

1 Introduction

The alignment of fibers in short fiber reinforced composites is necessary because of the exceptional advantages that can be achieved with their alignment. The properties of fiber reinforced composites depend mainly on the orientation of the fibers [1]. PIM is a manufacturing process that allows production of small and complex shapes with good dimensional accuracy. These advantages give the PIM process an upper hand over its rival manufacturing processes [2]. A successful PIM process is dependent on many factors. These include the temperature of molding, amount of powder, type of binder, rheological properties of the mixture and its homogeneity [3]. Backbone polymer of a binder system affects the rheology and density of the feedstock, and the mechanical properties and dimensional stability, of the final sintered product [4]. Ahn et al. [5] noted the individual effects of powder and binder on the properties of the whole feedstock. The study showed that choice of binder had more influence than choice of powder on rheological properties and injection and mold pressures to be adopted. Moballegh et al. [6] molded a copper feedstock successfully using a mixture of paraffin wax, polyethylene and stearic acid as binder.

A common problem regarding PIM of composites is the skin-core effect [7]. PIM parts show good fiber orientation close to the mold walls while the core regions of the mold cavity show random

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orientation. The skin has high fiber orientation due to high shear imparted by the mold walls on the flowing feedstock. In the core regions there is lesser shear on the feedstock and hence fibers are randomly aligned. Pinwill et al. [7] and Ahmad [8] showed that an oscillating packing device placed between the injection machine and the mold imparts an additional pressure to increase shear flow in feedstock during injection resulting in more uniform alignment of the fibers. Fiber orientation in PIM is heavily dependent on fiber-fiber and fiber-wall interactions [9]. Zhang et al. [10] applied an open-ended mold during injection molding of alumina powder with carbon fibers and ferrous powder with alumina fibers. Waschitschek et al. [11] employed two injection molding machines, placed at opposite ends of the mold, to create a push pull effect on the glass fiber polypropylene composite feedstock to exert additional shear on the feedstock. The objective of this study is to minimize the skin core effect by controlling the flow of feedstock in the mold cavity.

2 Methods and materials

2.1 Materials

Copper powder used in this study was gas atomized. It was provided by Sandvik International, UK. Short carbon fibers were used as reinforcement in the composite supplied by China Beihai Fiberglass Ltd having dimensions 5mm x 5µm. A paraffin wax (PW) based binder system was used in this study. Polypropylene (PP) was used as a backbone polymer to provide the handling strength and stearic acid (SA) was added as a surfactant. Table 1 shows the composition of F-5 and F-10 feedstocks used in this study. The mold used had a diverging sprue so that feedstock undergoes converging flow when it enters the mold cavity.

Table.1 Composition of feedstocks used in this study

Compositions	Solid Loading (60 vol%)		Binder (40 vol%)		
	Cu Powder (vol%)	C Fibers (vol%)	PW (vol%)	PP (vol%)	SA (vol%)
F-5	57%	3%	28%	10%	2%
F-10	50%	10%	28%	10%	2%

2.2 Experimental Methods

2.2.1 Mixing of feedstock and Injection molding

Mixing was done in a z- blade mixer. All the contents of the feedstock were added into the mixer to create a homogenous mixture. Mixing speed was set at 60 rpm. A vertical injection molding machine was used in this study for molding. Barrel temperature during injection molding was set at 170°C and a 60 psi pressure was used to inject the feedstock. Molding was successfully completed without any physical defects.

2.2.2 Sample preparation for Field Emission Scanning Electron Microscopy (FESEM)

Fiber orientation was determined by observing the samples under FESEM. Two samples were cut at distances of 5mm and 60mm from the sprue. These areas are shown in Fig. 1. S1 is cut at 5mm from sprue and shows the fiber orientation right after diverging sprue. S2, at 60mm from sprue, shows fiber alignment further away from sprue. After cutting, these samples were ground and polished. These samples were cold mounted on the resin prior to grinding and polishing to get better handling. After polishing, FESEM was used to observe the fiber orientation in these samples. The observation was done at two places. Skin showed the orientation of fibers close to mold walls and core showed these away from the walls.

3. Results & Discussion

The flow direction in these samples was from top to bottom. An arrow on the top left corner of all FESEM images is shown to signify this direction.

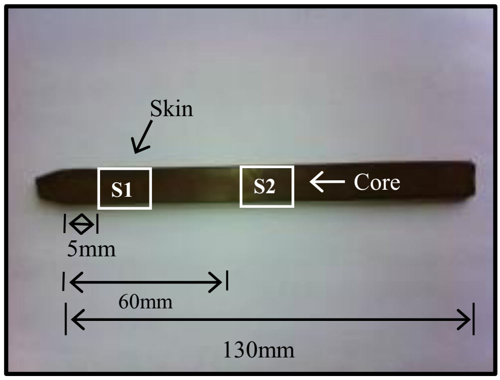

Figure. 1 Positions of samples for fiber orientation analysis shown on a green molding

3.1 Fiber orientation in F-5 moldings

3.1.1 Fiber orientation at S1

FESEM images of S1 samples taken from F-5 moldings are shown in Figs. 2 & 3. Fig. 2 shows the skin region. Fibers in skin achieve fiber orientation parallel to flow direction. Fibers in core region are shown in Fig. 3 and are randomly aligned. These fibers show a higher degree of randomness as compared to skin. Fibers in core are very close to diverging sprue and do not show any significant influence on skin core effect.

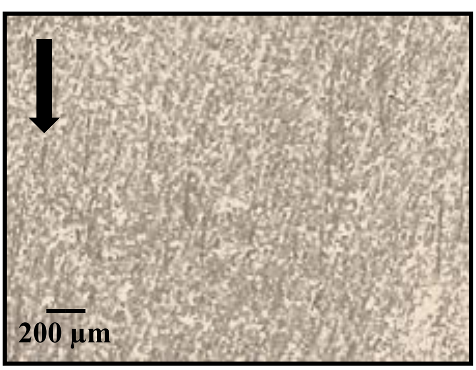

Figure 2: Aligned fibers at S1 skin obtained for F-5 moldings

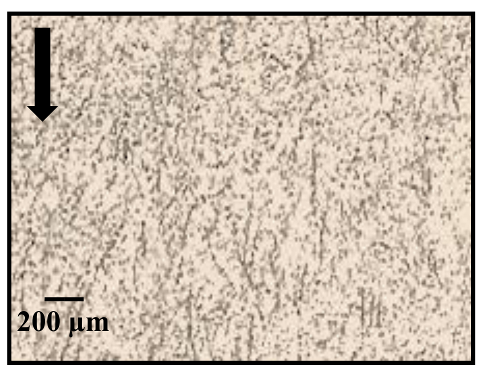

Figure 3: Randomly aligned fibers at S1 core in F-5 moldings

3.1.2 Fiber orientation at S2

FESEM analysis of S2 sample at skin from F-5 moldings is shown in Fig. 4. This figure shows excellent fiber alignment in flow direction. The fiber orientation in S2 core is shown in Fig. 5. It can be easily noted that fibers in the core are also better aligned in flow direction as compared to S1. The better fiber alignment in S2 is probably because fibers have shear flowed enough with the feedstock to allow them to rotate completely parallel to flow direction. The fiber alignment as seen in Figs. 4 and 5 show that skin core effect can be effectively minimized by controlling the flow during molding.

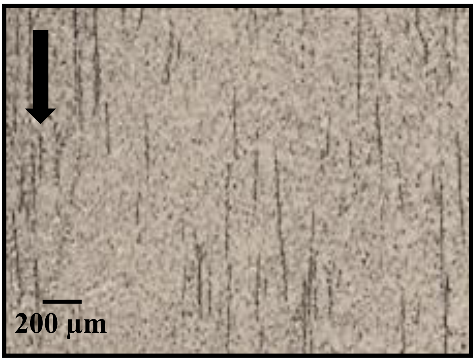

Figure 4: Aligned fibers at S2 skin obtained for F-5 moldings

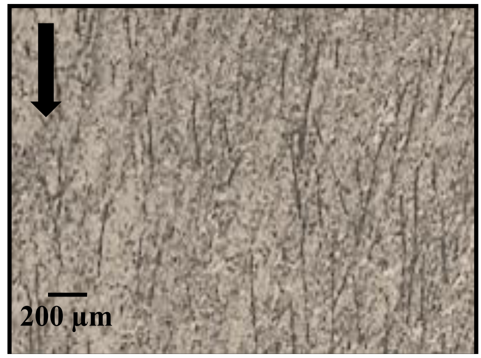

Figure 5: Aligned fibers at S2 core attained for F-5 moldings

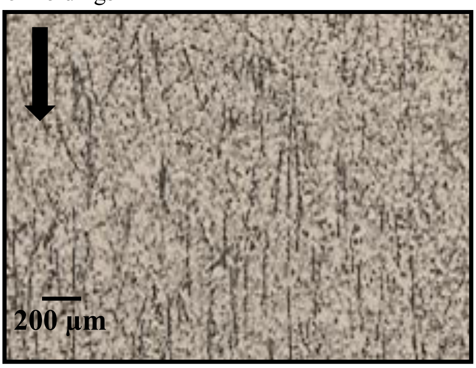

Figure 6: Aligned fibers at S1 skin obtained for F-10 moldings

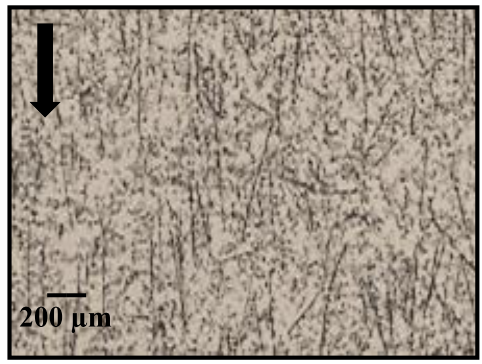

Figure 7: Partially aligned fibers at S1 core obtained for F-10 moldings

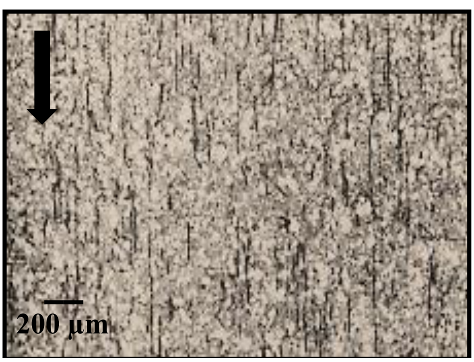

Figure 8: Aligned fibers at S2 skin attained for F-10 moldings

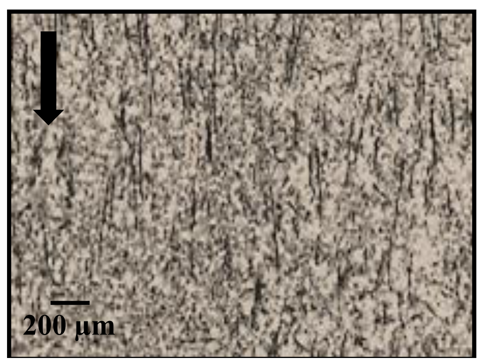

Figure 9: Alinged fibers attained at S2 core for F-10 moldings

3.2 Fiber orientation in F-10 moldings

3.2.1 Fiber orientation at S1

Orientation of fibers in S1 samples from F-10 moldings are shown in Figs. 6 and 7. In Fig. 6 skin shows orientation of fibers along the direction of flow as expected. The core in Fig. 7 shows fibers partially aligned towards flow direction. This is better than the random orientation as was seen in F-5 moldings. This partial fiber orientation is probably again because this section is very close to sprue and fibers do not undergo enough shear flow to obtain complete fiber alignment. The F-10 formulation shows slightly better alignment of fibers at S1 possibly because of the higher fiber volume fraction. The higher volume fraction causes higher shear as shear from fiber-fiber interactions is also increased with the increase in fiber volume percentage.

3.2.2 Fiber orientation at S2

S2 samples from F-10 moldings show good fiber orientation throughout the whole cross section at S2. Fibers in skin are shown in Fig. 8. These fibers are aligned with flow direction. Core region shown in Fig. 9 also shows fibers aligned with flow direction. Fibers are not aligned completely in flow direction but it can be safely stated that skin core effect is seen to be minimized. This is also consistent with results obtained from F-5 feedstock. Fibers at S2 have more time to rotate and align in flow direction and generally have better alignment than S1 samples.

4. Conclusions

1. F-5 & F-10 feedstocks were molded successfully by PIM and the moldings showed no major molding defects.
2. Fiber orientation in PIM can be controlled by controlling the flow of feedstock during injection molding.
3. The diverging sprue was successful in rotating fibers in flow direction and minimizing the skin-core effect.
4. F-10 formulation generally showed better fiber alignment in flow direction as compared to F-5 formulation perhaps because of the higher fiber fiber interactions in F-10 formulation.

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