Study on mechanical properties and wear resistance of aluminum alloy composites reinforced by basalt fiber

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Abstract. Basalt fiber is a new type of environmentally friendly materials with excellent performance in the 21st century. Basalt fiber (BF) reinforced aluminum alloy composites with different length-diameter ratios (200:1, 400:1), different volume fraction (1%, 4%, 8%) was fabricated by room-temperature pressing and vacuum sintering method. It was found that the BF treated with electroless copper plating on the surface enhanced the mechanical properties and wear resistance of the composites, while the BF without copper plating on the surface weakened the hardness. With increasing the volume fraction of BF with copper plating, the hardness and the wear resistance of the composites increased. The length-diameter ratio ~400:1 is superior enhancement aspect ratio of 200:1 of the reinforcing effect.

1. Introduction
Basalt fiber is an environmental-friendly inorganic fiber discovered by modern scientists. There is the characteristics of high temperature, acid and alkali corrosion resistance, good chemical resistance and excellent thermal stability. Compared with carbon fiber, it has the advantage of cost performance. It is a new material and high-tech fiber that can meet the development needs of basic industries of national economy [1-8].

There are the advantages of higher strength, low thermal expansion coefficient for the aluminum alloy composite in metal matrix composites, especially in dispersion particles as enhancing body of aluminum alloy composite material, isotropic characteristics, easy processing and low cost. The preparation of BF reinforced aluminum composite material and study the change of its mechanical properties caused more people’s attention.

Xie[9] successfully prepared BF reinforced aluminum alloy composites by the pressure infiltration, and analyzed the detailed process and material transfer of the composites at the Al-SiO$_2$ interface by means of thermodynamic data analysis[10-15]. More excellent performance of multifunctional composite material obtained through the preparation and performance of aluminum alloy composite material research is significant for the increasingly influence of aluminum alloy composite material.

In this work, the mechanical properties and wear resistance of BF reinforced aluminum alloy composites is investigated. The copper plating effect on the BF surface of the hardness and wear of the composites is studied.

2. Experimental
The matrix used in this paper was aluminum-silicon alloy powder. BF with diameters of 7 μm was selected and the surface was pretreated for electroless copper plating, then the BF of copper plating was
processed according to its aspect ratio of 200:1 and 400:1, respectively. BF of copper plating was mixed with aluminum alloy powder, and after mixing evenly. The blank was pressed by cold pressing process, and then the pressed sample was put into a tubular resistance furnace for vacuum sintering to obtain aluminum alloy composite material. BF reinforced aluminum alloy composites were prepared by powder metallurgy. The volume fraction of BF in the aluminum alloy matrix was 1%, 4% and 8%, respectively. The original microstructure of aluminum-silicon alloy was characterized by XRD (Shimadzu XRD-6100) and the cross-sectional morphology were observed by SEM (Shimadzu SSX-500).

3. Results and discussions

Figure 1 showed XRD patterns of the composite (BF 200:1, 4%). It can be seen that the chemical components are Al and Si. SiO$_2$ and Al$_2$O$_3$ as the main components of BF were not detected because BF is amorphous.

![X-ray diffraction pattern of BF reinforced composite with length-diameter ratio ~200:1 and BF content ~1%](image)

Without copper plating the BF surface appearance color is golden with a smooth luster (see figure 2(b)). After electroless copper plating the BF surface appears a metallic luster, with the color of pure copper (see figure 2(a)). Figure (c) and (d) showed the micromorphology of BF surface of after and before electroless copper plating treatment, respectively. By surface pretreatment of BF and electroless copper plating process, the surface of BF is covered with a uniform and dense copper layer to improve the permeability of the interface with the Al alloy matrix. The surface of the unplated BF is transparent, while the smoother surface of the plated BF is a uniform, dense copper layer (seen from figure 2).
Figure 2. Comparison between the BF surface morphology before and after electroless copper plating

Figure 3 showed the Cu plated BF distribution in aluminum alloy composites with the volume fraction of 1%, 4% and 8%, respectively in the cross-sectional direction. The Cu plated BF was marked by the arrows in figure 3. With the increase of the volume fraction from 1% to 8%, the number of copper-plated BF in the aluminum alloy matrix increased, and the distribution became more and more uniform. The distribution mode was copper plated BF embedded in the matrix, parallel to the normal direction of the matrix.

Figure 3. Cu plated BF distribution in aluminum alloy composites with different volume fraction. (a) Al alloy matrix; (b) 1%; (c) 4%; (d) 8%.

Table 1 for different materials the hardness of statistics. It can be seen that the hardness of aluminum silicon alloy matrix is greater than that of 1%-BF without copper plating. It showed that the hardness of the composite material decreases when basalt fiber is added without copper plating on the surface. This may be because the main content of BF is non-metallic SiO$_2$ and Al$_2$O$_3$, and Al is metallic, causing weaker interfacial adhesion between BF and Al. Surface copper plating played an important role in the mechanical properties of composites. At the same time, with the addition of BF surface copper-plating, the higher the length-diameter ratio, the higher the hardness of the composite material, which is obviously higher than that of the Al-Si matrix.
Table 1. Comparison of hardness of different materials.

| Materials                              | Hardness (HBS) |
|----------------------------------------|----------------|
| Al-Si alloy matrix                      | 24.8           |
| 1%, No copper plating, 200:1           | 23.8           |
| 1%, Copper plating, 200:1              | 31.8           |
| 1%, Copper plating, 400:1              | 32.2           |

Figure 4 showed the relationship between the hardness and the wear resistance and the BF volume fraction. When the aspect ratio is constant, the hardness of the material increased with the increase of BF volume fraction of copper plating. When the volume fraction is fixed, the hardness of 400:1 aspect ratio is higher than that of 200:1. With the addition of surface copper plating BF, the hardness of the sample is significantly higher than that of the sample without BF, which also indicated that the addition of surface copper plating BF has significantly enhanced the mechanical properties of the composite material (see figure 4(a)). When the aspect ratio is constant, the wear quality of the composite material decreases with the BF volume fraction increasing, as shown in figure 4(b). It indicated that with the increase of surface copper plating BF content, the wear resistance of the composite material gradually improves, which is consistent with the change of the relationship between the hardness of the composite material and BF content.

![Figure 4](image)

Figure 4. The relationship between hardness, wear resistance and volume fraction. (a) Variation of hardness with different volume fraction of BF. (b) Variation of wear quality with different volume fraction of BF.

4. Conclusion
1. The basalt fibers surface plated Cu played an important role for enhancing the mechanical properties and wear resistance of the Al alloy composites.
2. When the composite material with Cu plated BF was added, the hardness and wear resistance increased with the increase of the volume fraction of copper plated BF at a certain aspect ratio.

5. References
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