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Impact of cryogenic treatment on the microstructure and properties of a thermo-mechanically processed Cu-11Fe composite

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Abstract. The conductivity and strength of Cu-Fe composites are contradictory. Cryogenic treatment is a promising process to improve the conductivity and strength of materials at the same time. The impact of cryogenic treatment on a thermo-mechanically processed Cu-11Fe composite was studied using a digital micro-ohmmeter, a tensile testing machine and optical microscopy. The average size of the iron grain in the cryogenically treating Cu-11Fe alloy decreased and the distribution was more uniform after the cryogenic treatment. The grain refinement and the distribution uniformity increased with improving cryogenic treatment time. The elongation to fracture and tensile strength improved first with increasing cryogenic treatment time to a peak value at 18 h and 12 h respectively, and subsequently tended to be stable at longer cryogenic treatment time. The electrical resistivity decreased first with the increase of cryogenic treatment time, then reached an electrical resistivity valley value at 18 h, and subsequently tended to be stable at longer cryogenic treatment time.

1. Introduction

Copper matrix composites with good conductivity and high strength are important materials in many fields, such as metallurgy, energy, transportation, information, electronics, electromechanical and so on [1,2]. Cu-Fe composites have attracted extensive attention of researchers because of its low cost [3-5]. However, at high temperatures, the solid solubility of iron in copper matrix is high, at low temperatures, the diffusion rate is slow, which results in the content of solid solution iron in copper matrix is greater than the phase equilibrium concentration at room temperature. At the same time, the iron in the solid solution has a great effect on the electrical conductivity of copper matrix, which results in the poor conductivity of Cu-Fe composites [6].

Cryogenic treatment is a new treatment process with energy conservation, environmental protection and low cost. In recent years, it has attracted more and more attention in various fields and has shown certain advantages in the field of ferrous metals and non-ferrous metals [7]. Many previous investigations have indicated that cryogenic treatment can effectively reduce the deformation of metal materials, improve the uniformity, stabilize the size, increase the properties and service life [8,9]. In addition, it can also increase the electrical conductivity, thermal conductivity and other physical properties of metal materials [10].



Previous studies have shown that lead frames of large-scale integrated circuits, contact wires of high-speed electrified railways and high-strength magnetic field coils put forward higher requirements for the strength and conductivity of Cu-Fe composites [11]. Cryogenic treatment is promising process to increase these properties. Accordingly, this paper investigated the impact of cryogenic treatment on the microstructure and properties of a thermo-mechanically processed Cu-11Fe composite. The investigation is of great significance to broaden the application range of Cu-Fe composites in high-tech fields.

2. Experimental details

Cu-11Fe alloy was prepared by melting Fe and electrolytic Cu with a purity at least 99.9% in a magnesia crucible, then casting into a graphite mold. The Cu-11Fe ingot with a diameter of 42 mm was initially heat treated at 900 °C for 2 h using a box-type heat treatment furnace, and was hot rolled at 850 °C using a two high mill, then was processed into a cold-drawing sample with a diameter of 14.5 mm by removing surface oxides and defects using a conventional machine tool. The cold-drawing sample was cold drawn into a cryogenically treating sample with a diameter of 6.3 mm using a cold-drawing machine. The cryogenically treating sample was immersed in a liquid nitrogen tank holding different times of 2 - 24 h, and was taken out and warmed to room temperature to produce a final composite.

The test specimen was cut from the Cu-11Fe ingot, the cryogenically treating sample and the final composite. The microstructure was observed using optical microscopy. The resistance R was measured using a digital micro-ohmmeter. The corresponding resistivity was obtained by $\rho = RS/L$ (L and S are the length and cross-sectional area of the test specimen). The elongation and strength were evaluated using a tensile testing machine.

3. Results and discussion

3.1. Microstructure

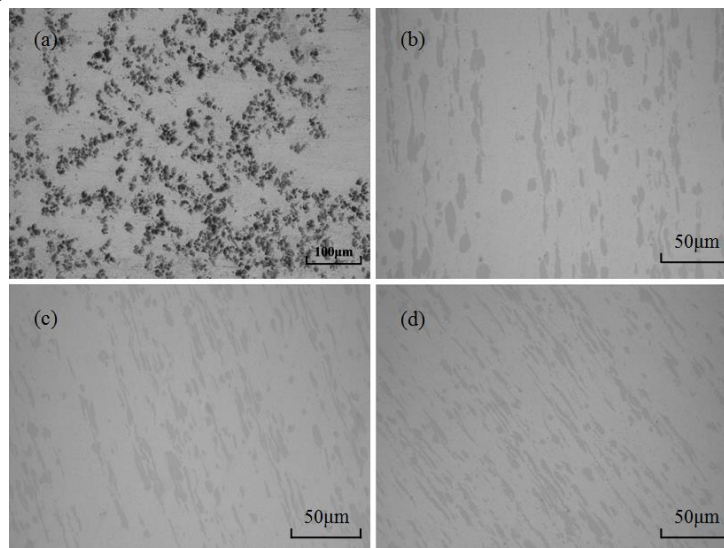


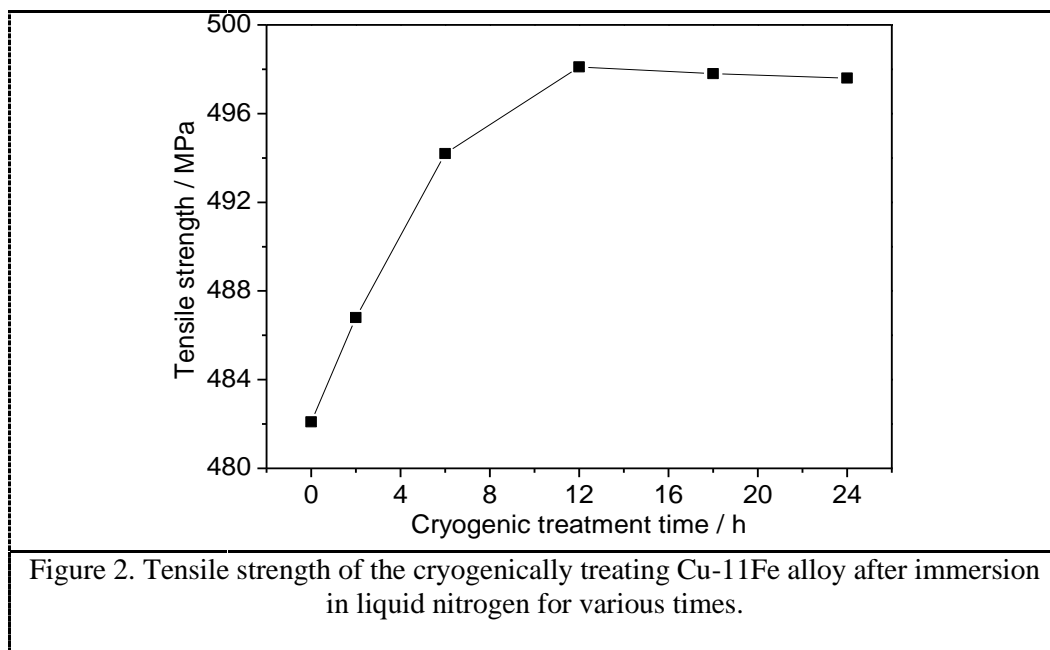
Figure 1. Microstructures of the Cu-11Fe alloy with different thermo-mechanical treatments: (a) as-cast, (b) cold deformation to a diameter of 6.3 mm, (c) cryogenic treatment for 6 h, (d) cryogenic treatment for 18 h.

Figure 1 presents the microstructures of Cu-11Fe alloy with different thermo-mechanical treatments. The as-cast microstructure was mainly composed of copper matrix and iron dendrite, as shown in Figure 1(a). Figure 1(b) showed that the iron dendrite was broken and transformed into tadpole iron grains in the cryogenically treating sample with a diameter of 6.3 mm. The average size and distribution of the iron grain in the cryogenically treating sample changed considerably after cryogenic treatment, as

shown in Figure 1(b)-(d). Figure 1(c) showed that the average size of the iron grain decreased and the distribution was more uniform after the cryogenic treatment in liquid nitrogen for 6 h. With the increase of cryogenic treatment time, the grain refinement became more obvious, and the distribution uniformity was further enhanced, as shown in Figure 1(d).

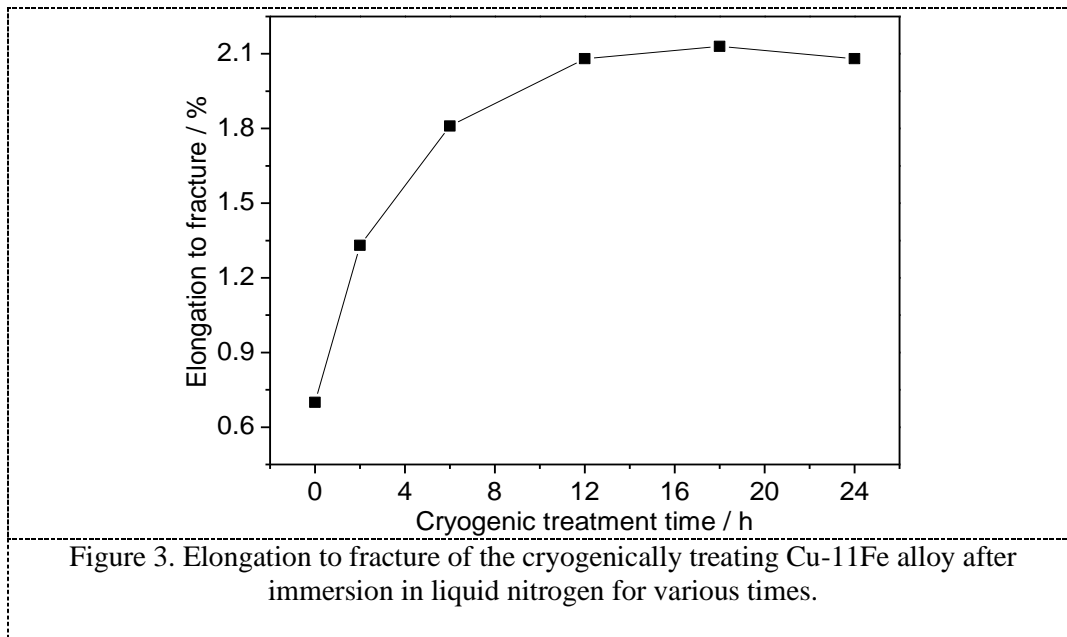
3.2. Tensile strength

Figure 2 shows the tensile strength of the cryogenically treating Cu-11Fe alloy after immersion in liquid nitrogen for 0 - 24 h. After immersion in liquid nitrogen, the strength of the cryogenically treating Cu-11Fe alloy changed considerably. The tensile strength increased first with improving cryogenic treatment time in liquid nitrogen, then reached a tensile strength peak value at 12 h, and subsequently tended to be stable at longer cryogenic treatment time, as shown in Figure 2. This is due to the fact that the average size of the iron grain decreased and the distribution was more uniform after the cryogenic treatment in liquid nitrogen, and the grain refinement and the distribution uniformity increased with improving cryogenic treatment time, and subsequently the change tended to be stable after reaching a certain time.



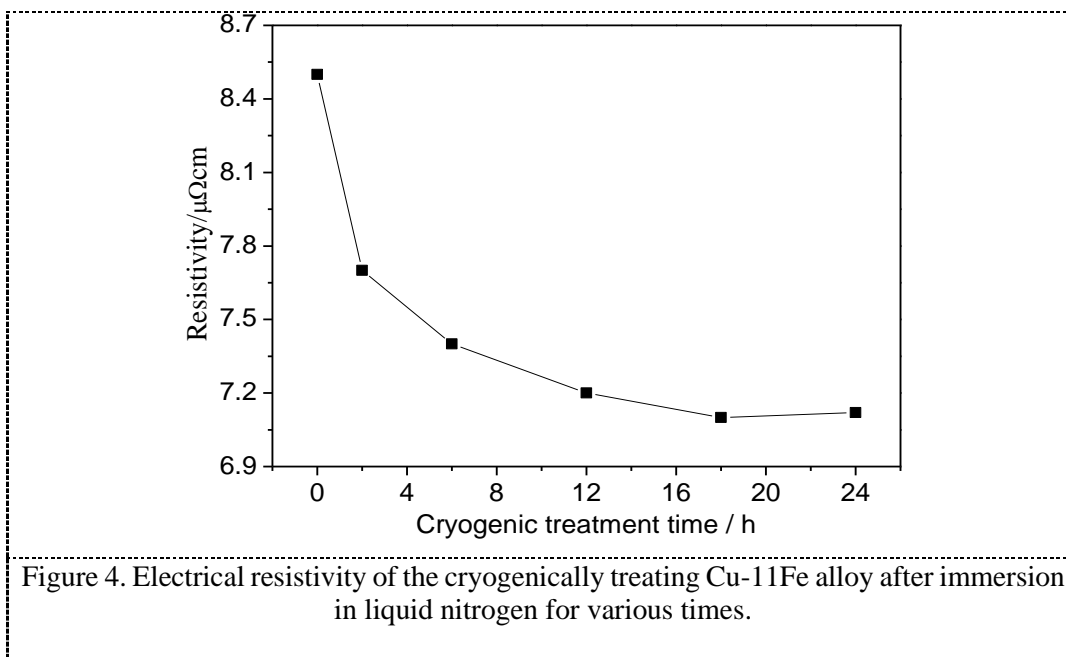
3.3. Elongation to fracture

Figure 3 presents the elongation to fracture of cryogenically treating Cu-11Fe alloy after immersion in liquid nitrogen for 0 - 24 h. Similar to the effect of cryogenic treatment on the tensile strength of the cryogenically treating Cu-11Fe alloy, the elongation to fracture increased first with improving cryogenic treatment time in liquid nitrogen, then reached a elongation to fracture peak value at 18 h, and subsequently tended to be stable at longer cryogenic treatment time, as shown in Figure 3. Cryogenic treatment significantly decreased the temperature of the alloy, promoted the reduction of internal grain gap and the volume shrinkage to decrease the internal defects of the alloy, which increased the elongation to fracture. With improving cryogenic treatment time, the effect of temperature was reduced, the internal defects of the alloy tended to balance, which made the elongation to fracture tend to be stable after a certain time.



3.4. Electrical resistivity

Figure 4 shows the electrical resistivity of the cryogenically treating Cu-11Fe alloy after immersion in liquid nitrogen for 0 - 24 h. Different from the impact of cryogenic treatment on the elongation to fracture, the electrical resistivity decreased first with improving cryogenic treatment time in liquid nitrogen, then reached an electrical resistivity valley value at 18 h, and subsequently tended to be stable at longer cryogenic treatment time, as shown in Figure 4. Cryogenic treatment promoted the precipitation of fine dispersed second phase in the grains and grain boundaries of the cryogenically treating Cu-11Fe alloy. With improving cryogenic treatment time, the number of precipitated second phase particles increased, which decreased the electrical resistivity. After a certain time, the precipitation of second phase particles was basically completed, which made the electrical resistivity tend to be stable.



4. Conclusions

(1) The average size of the iron grain in the cryogenically treating Cu-11Fe alloy decreased and the distribution was more uniform after the cryogenic treatment. The grain refinement and the distribution uniformity increased with improving cryogenic treatment time.

(2) The tensile strength increased first with improving cryogenic treatment time, then reached a tensile strength peak value at 12 h, and subsequently tended to be stable at longer cryogenic treatment time.

(3) The elongation increased first with improving cryogenic treatment time, then reached a elongation to fracture peak value at 18 h, and subsequently tended to be stable at longer cryogenic treatment time.

(4) The electrical resistivity decreased first with the increase of cryogenic treatment time, then reached an electrical resistivity valley value at 18 h, and subsequently tended to be stable at longer cryogenic treatment time.

(5) The cryogenic treatment increased the comprehensive properties, which was of great significance to broaden the Cu-Fe composites application range in high-tech fields. In the future, the influence mechanism and application of cryogenic treatment still need to be further investigated.

Acknowledgments

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