Effects Of Recrystallization Annealing On Hsi65-1.5 Silicon Brass Aided By Electric Pulse Treatment

S.A Tukur, QI Jin-Gang, WANG Jian-Zhong, ZHAO Zou-Fu, Aliyu Mohammed Aliyu

Abstract: An online production of Electric pulse induced recrystallization of a cold-rolled HSi65-1.5 alloy was studied under different annealing temperature and electric pulse parameters. The microstructure morphologies were observed by the optical microscopy and hardness test. Electric pulse treatment (EPT) substantially accelerated recrystallization of the cold-rolled HSi65-1.5alloy within a short time of several seconds at relatively low temperature, as well as suppressed precipitation of β- phase, the primary elongated strip β-phase broke up and almost all of the β phase was transformed into structure consisting of equiaxed, twinned grains of alpha solid solution. Based on quantitative analysis, we conclude that the decreased of the recrystallization temperature of the rolled HSi65-1.5 alloy under EPT is due to the short treating time, high heating rate, accelerated nucleation and lower final dislocation density. The optimum EP treatment parameters where found to be at annealing temperature of 300°C, pulse voltage 700V, pulse frequency 15Hz and pulse time 120s.

Key words: electric pulse modification, recrystallization annealing, silicon brass, microstructure, mechanical property, Pulse temperature, Pulse time

1. Introduction

IN many metallic material applications, a combination of strength and toughness is needed. Therefore, we need to design processes that involve shaping via cold working. Then there is need to control the annealing process to obtain a level of ductility and that is achieved by controlling the recrystallization temperature and the size of the recrystallized grains. Although the traditional recrystallization annealing the material can reduce the strength and hardness of the alloy, while improving its ductility to meet the subsequent processing needs, but still required a relatively higher temperature and longer time; low efficiency; high energy consumption and thick oxidation layer at the surface of the material difficult to clean. Industries usually uses mechanical or multiple strips pickling treatment, which cause an increased production costs, greatly reduces the efficiency of production, and the use of acid treatment method in the production process corrosive gases were emitted, causing environmental hazards [1-2]. A number of investigators [3-10] have now shown that application of electric current on recrystallization metals for deformation employed with a maximum current density from 10^2 to 10^3 A/mm^2. The frequency of electric current pulse was smaller than 10Hz and the pulse duration was varied from 50 to 200µs. Current pulse can enhance nucleation rate of recrystallization, lowered down the grain growth rate of recrystallized grain and promoted recrystallization. However the previous researches have been fragments, focus only on special material and theoretical or academic research. This paper is aimed to study the effect of recrystallization annealing aided by electric pulse in online production and its mechanism for brass factory production.

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2. Materials and Experimental Procedure

The composition of HSi65-1.5 silicon brass alloy, HSi65-1.5 alloy (65wt% of Cu, 1.5wt% of Si and remaining of Zn) will be prepared through conventional casting method from commercially pure Cu, Si and Zn ingots (purity of >99.9%). After rolling, HSi65-1.5 brass rods with a copper wire of 100mm long mounted at the brass end and to the EP device. The EP treatment together with the recrystallization annealing process was conducted concurrently under various annealing temperature and EP parameters as shown in the fig 1. After cooling, the samples were subjected to cutting, grinding, polishing and etching to get the metallographic specimens. The microstructure and Rockwell harness where analysed and observed. Comparison of grain structures and micro hardness obtained with and without electric pulse under different annealing temperature and holding time was made.

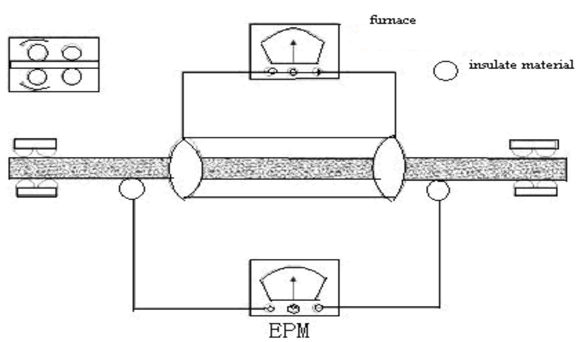
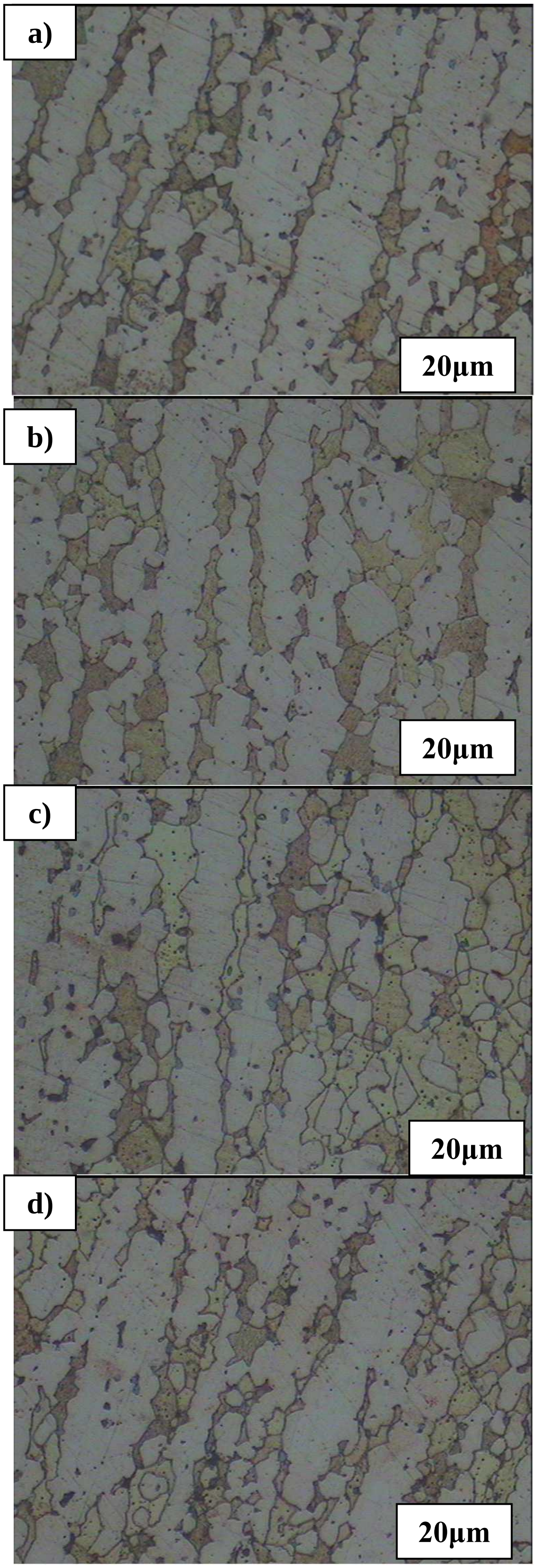


Fig 1 the sketch of annealing process aided by the electric pulse

3. Results and discussions

3.1 Microstructure and microhardness of annealed samples at different annealing temperature with no electric pulse treatment

Figure 2 shows different annealing temperatures without electric pulse treatment microstructure



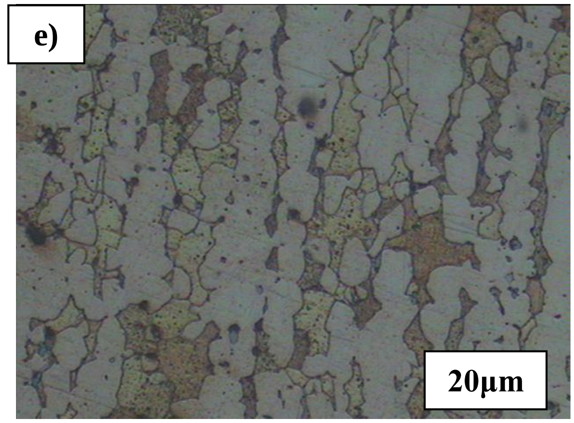


Fig 2.1 the microstructure of alloy at various annealed temperatures without pulsed and soaked for 30mins

(a) untreated （b）100°C（c）200°C（d）300°C（e）400°C

As shown in Fig. 2.1, the microstructure of the untreated sample and annealed samples without the EP treatment were obtained after heated at the respective temperature and hold for 30mins. By comparing the figures we can see that the microstructure of the cast material contains cored dendrites of alpha copper solid solution containing zinc and silicon. The coring occurs because the alloys solidify over a wide temperature range, which allows segregation of the alloying elements. The zinc and silicon composition varies from zero at the centre of the dendrite to a maximum at the outer edge. Following the subsequent annealing at (b), (c), and (d) the retained deformation of the primary strip form of β phase in the microstructure becomes distributed in the α-phase matrix.

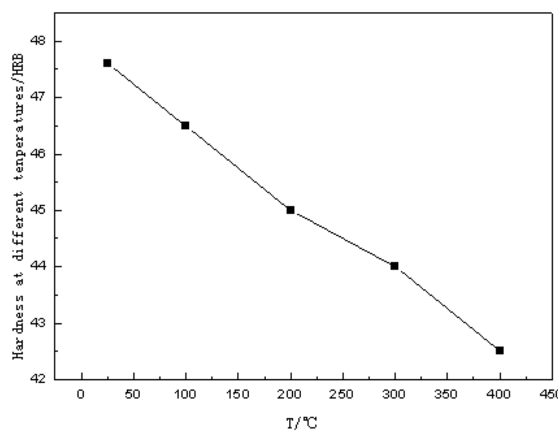


Fig. 2.2 micro hardness curve of alloy at various annealed temperatures without electric pulse

Fig. 2.2 shows the non-electric pulse treated HSi65-1.5 alloy hardness curve, it can be seen from the figure that, the hardness of the untreated sample was 47.5HRB as a result of much strain energy expended in the plastic deformation is stored in the metal in the form of dislocations defect, thus, the untreated sample has a higher internal energy when compared with other annealed sample; with increasing annealing temperature the hardness decreases, but the decrease is not obvious. Hardness reduced from 47.5HRB to 42.5HRB indicating 89.4% of the untreated value.

3.2 Microstructure of alloy at various pulsed times for 100°C

Fig 3.1 shows the microstructure of alloy at various pulsed times for 100°C

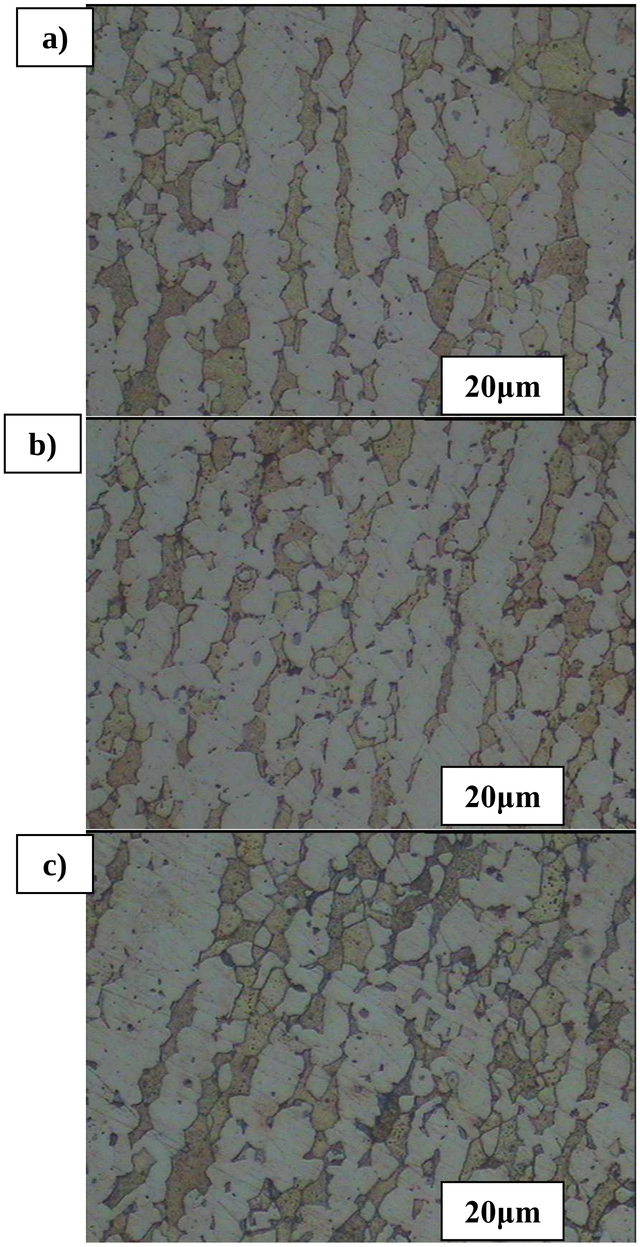


Fig. 3.1 the microstructure of alloy at various pulsed times for 100°C （a）0s（b）30s（c）60s

From fig. 3.1 the very coarse structure can be observed at (a) indicating that the alloy contains cored dendrites of alpha copper solid solution containing zinc and silicon. Fig (b), (c) can be seen that the apparent coarse dendrite broken off phenomenon particularly at (c) which grains appeared more equiaxed. The elongated deformed β phase portion transformed into equiaxed α-phase matrix, although with relatively coarse shape showing that the β phase does not turn equiaxed completely.

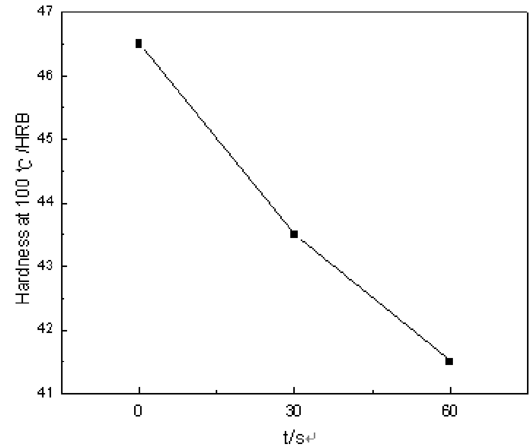
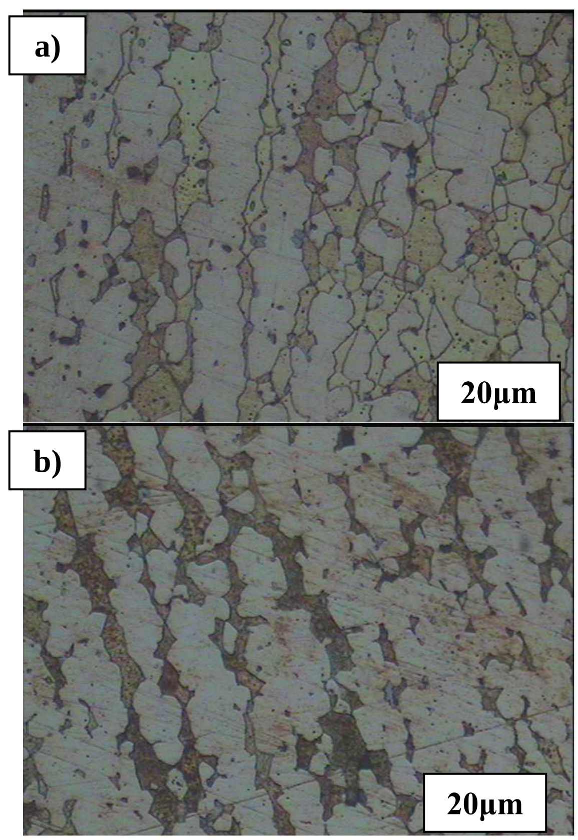


Fig.3.2 micro hardness curve of alloy at various pulsed time for 100°C

Fig. 3.2 shows the micro hardness curve of the alloy at various pulse times for 100°C it can be seen from the figure that the highest hardness value of 46.7HRB was obtained at (a), with electric pulse treatment the hardness of the alloy has been significantly reduced and with the electric pulse treatment time increases hardness decreases. When the electric pulse voltage was 700V, frequency of 15Hz, time of 60s, the hardness value was found to be 42HRB.

3.2 The microstructure and microhardness of alloy at various pulsed times for 200°C

Fig. 4.1 shows the microstructure of alloy at various pulsed times for 200°C



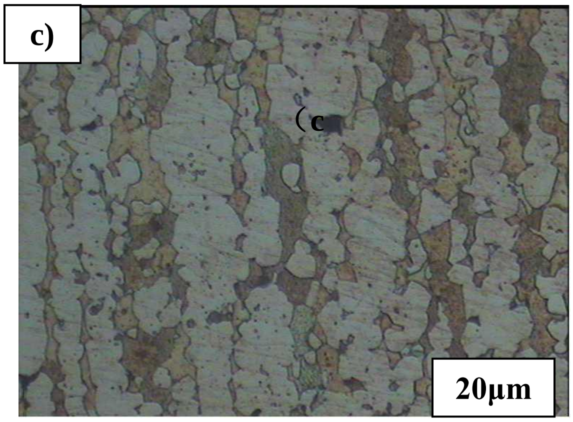


Fig. 4.1 the microstructure of alloy at various pulsed times for 200°C

（a）0s （b）30s （c）60s

Fig. 4.1 shows the microstructure of the alloy at 200°C with different pulse times, it can be seen that the structure followed the same trend with that of 100°C, with electric pulse time increases, the elongated deformed primary strip of β phase portion transformed into equiaxed α-phase in the matrix and also at the same temperature, the shape was still relatively coarse, β phase does not completely become equiaxed and hence the recrystallization process was not completed.

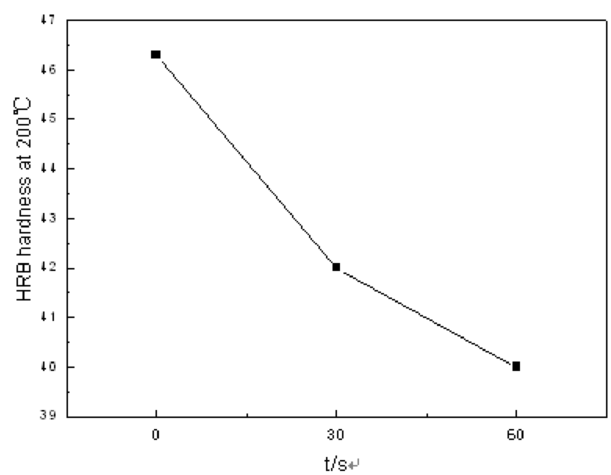
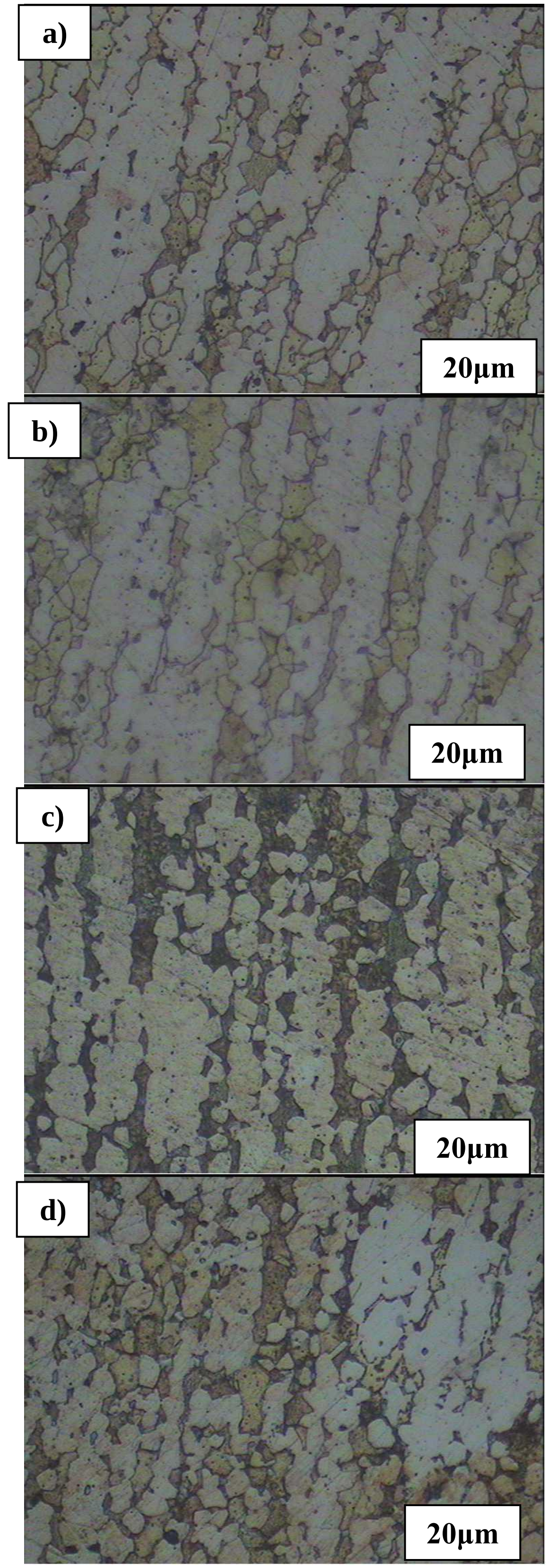


Fig. 4.2 micro hardness curve of alloy at various pulsed time for 200°C

Fig. 4.2 shows the micro hardness of the alloy at 200°C under different pulse times, it can be seen that the trend is the same as that of 100°C, it can be seen from the figure that the highest hardness value of 46.3HRB was obtained at (a), with electric pulse treatment the hardness of the alloy has been significantly reduced and with the electric pulse treatment time increases hardness decreases. When the electric pulse voltage was 700V, frequency of 15Hz, time of 60s, the hardness value was found to be 40HRB.

3.4 The microstructure and microhardness of alloy at various pulsed times for 300°C

Fig. 5.1shows the microstructure of alloy at various pulsed times for 300°C



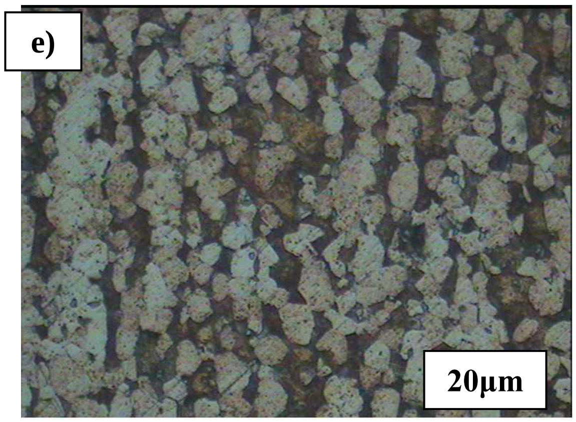


Fig. 5.1 the microstructure of alloy at various pulsed times for 300°C（a）0s （b）30s （c）60s （d）90s（e）120s

Fig. 5.1 shows the microstructure at 300°C for different pulse times, from (a) β phase is like long rods, with coarse grains; the structure refinement is more obvious than before, β phase morphology was changed into being short rod like from long-rod-like and the sharp corners becomes blunt; with pulse time increased, β phase becomes shorter and more uniform. In Figure (d), (e), there has been no deformation of the primary elongated strip β-phase, almost all of the β phase was transformed into structure consisting of equiaxed, twinned grains of alpha solid solution.

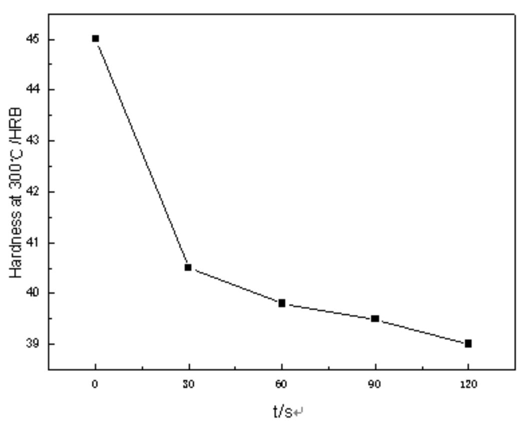


Fig 5.2 micro hardness curve of alloy at various pulsed time for 300°C

Fig. 5.2 microstructure hardness curves of HSi65-1.5 silicon brass alloy when treated under different pulse time at an annealing temperature of 300°C can be seen from the figure that with increasing electric pulse time to 30s hardness has been significantly reduced from 45HRB to 40.5HRB. But as the electric pulse times continue to increases the hardness of the alloy has increases slowly, at 90s and 120s the hardness stabilized, no obvious reduction in hardness. When the electric pulse voltage was 700V, frequency of 15Hz, time of 120s, the lowest hardness value was found to be 38.5HRB, 81.8% of the untreated sample.

3.5 Mechanism of Electric Pulse Modification

The HSi65-1.5 alloy is a single phase alloy. The zinc and silicon contents of the HSi65-1.5 alloy are low enough that the alloying elements remain in solid solution. The microstructure of the cast material contains cored dendrites of alpha copper solid solution containing zinc and silicon. The coring occurs because the alloys solidify over a wide temperature range, which allows segregation of the alloying elements. The zinc and silicon composition varies from zero at the center of the dendrite to a maximum at the outer edge. The subsequent working and annealing breaks up the dendrites and results in a structure consisting of equiaxed, twinned grains of alpha solid solution, although the traditional annealing did not completely break up the long-like-rods with coarse grain structure., that was why the changes in mechanical property is not obvious as showed in Fig 2 and Fig. 3. The microstructure of the wrought materials consists of equiaxed, twinned grains of alpha copper solid solution. As shown from the microstructure and mechanical property tested, application of electric pulse on HSi65-1.5 alloy resulted in refined microstructure. This is thought due to the short treating time, high heating rate and accelerated nucleation and lower final dislocation density under electropulsing condition. The lower dislocation density in recrystallization means the lower driving force for crystal growth. Dislocation structure in electropulsed sample is found vast different from that of the thermal treated one. The movement of dislocation is enhanced by electropulsing through the mechanisms of: a) Electron wind effect; b) localized (atomic scale) heating; c) Increment of the dislocation vibration frequency, and d) improvement of sub-grain coalescence. The heating temperature and time is significantly less when induced by external electric field the atomic concentration of flux migration β phase in the matrix depends on the diffusion coefficient. From Arrhenious equation,

$$D = D_0 \cdot e^{\frac{-\Delta G}{kT}}$$

Where ΔG-diffusion activation energy for diffusion species under consideration (Zn in Cu), k is gas constant, T is the absolute temperature. With the electric pulse, it can be expressed as

$$D = D_0 \cdot e^{\frac{-(\Delta G + \Delta E)}{kT}} = D_1 \cdot e^{\frac{-\Delta E}{kT}}$$

Where ΔE is the activation energy with the EP. According to electron migration view, electric pulse treatment improves the recrystallization by enhancing the Zn diffusion activation energy, so that the diffusion coefficient D increases, thus accelerating the Cu, and the Zn atoms uneven distribution becomes uniform, thereby improved the annealing process.

Conclusion

Electric pulse treatment significantly accelerated the recrystalliazation annealing of HSi65-1.5 alloy due to the short treating time, high heating rate and accelerated nucleation and lower final dislocation density and the optimum parameters where found to be annealing at 300°C, pulse voltage of 700V, pulse frequency of 15Hz and pulse time of 120s.

Acknowledgements
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