Effect of thermomechanical treatments on microstructure and properties of Cu-base leadframe alloy

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The effect of thermomechanical treatments (TMT) on the microstructures and properties of Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy was investigated. The Cu-base leadframe alloy was received as hot rolled plates with 8 mm thickness. The hot rolled plates were solution treated at 700°C or 800°C for 1 hour, and cold rolled with 40–85% reduction, then followed by aging treatment at 450°C. The leadframe alloy solution treated at 800°C showed larger grain size of 15 μm comparing with the grain size of 10 μm in leadframe alloy solution treated at 700°C. The leadframe alloy with smaller grain size of 10 μm showed higher tensile strength and lower electrical resistivity than that with larger grain size of 15 μm. The dislocation density increased with increasing reduction ratio of cold rolling from 40% to 85% and resulted in finer Ni_2Si precipitates. Tensile strength increased and electrical resistivity decreased with increasing reduction ratio of cold rolling due to the formation of finer Ni_2Si precipitates. Two types of thermomechanical treatments were performed to enhance the properties of leadframe alloy. One type of thermomechanical treatment is to refine the grain size through the overaging, cold rolling followed by recrystallization. The recrystallization process improved the tensile strength to 540 MPa and elongation to 15% by reducing the grain size to 5 μm. The other type of thermomechanical treatment is to refine the precipitate size by two-step aging process. The two-step aging process increased the tensile strength to 640 MPa and reduced the electrical resistivity to 1.475×10^{-8} Ωm by reducing the size of Ni_2Si precipitates to 4 nm. © *2000 Kluwer Academic Publishers*

1. Introduction

The functions of leadframe in electronic packaging are providing channels for electronic signals between devices and circuits, and fixing devices on circuit boards. Leadframe alloys are required to have high strength and good formability as well as high electrical and thermal conductivity [1, 2]. Fe-base alloys and Cu-base alloys are the two most popular leadframe alloys. Fe-base alloy named Alloy-42 provides good tensile strength of 640 MPa and low coefficient of thermal expansion but has insufficient thermal and electrical conductivity of 3% IACS [3]. Cu-base leadframe alloys such as CDA19400 are used in plastic packaging applications due to higher thermal and electric conductivity of 65% IACS [4–6]. However, the Cu-base leadframe alloys have lower tensile strength of about 300–500 MPa which limits the applications for high performance electronic packaging. Cu-1.5Ni-0.3Si-0.03P-0.05Mg alloy was newly developed to obtain high tensile strength by the precipitation strengthening without losing electrical conductivity [7, 8]. Solute atoms in matrix can act as obstacles for the movement of conduction electrons [9]. Electrical resistivity decreases with reducing solute atom contents in matrix by aging treatment in precipitation hardenable alloys. The effect of precipitation hardening on strength and electrical conductivity is dependent on the initial microstructural parameters such as dislocation, defects and grain size [10–12]. Since the initial microstructure is determined by the previous thermomechanical treatment (TMT) history,

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the strength and electrical conductivity can be controlled by the modification of the thermomechanical treatment process.

In this study, the effect of thermomechanical treatment processes on microstructure and mechanical properties of Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy was investigated. The microstructural parameters such as dislocation density, grain size and precipitate size were observed with varying thermomechanical treatment of leadframe alloy. The relationship between mechanical and electrical properties and the microstructural parameters was characterized to optimize the thermomechanical process condition of the Cu-base leadframe alloy.

2. Experimental procedures

Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy was supplied from Poongsan Co. as hot rolled plates with a thickness of 8 mm after casting and homogenization treatment. The chemical composition of Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy was measured X-ray wavelength dispersive spectroscopy (WDS). Solution treatment was performed at 700 and 800°C for 1 hr, followed by 40–85% cold rolling and aging treatment in salt bath at 450°C. Two different types of thermomechanical treatments were performed in order to control the properties of leadframe alloy. One type of thermomechanical treatment was to refine the grain size through the overaging for 40 hrs at 500°C and cold rolling up to 70%, and followed by recrystallization treatment for 1 hr at 700°C. The other type of thermomechanical treatment was to refine the precipitate size by two-step aging process which consist of 40% cold rolling and first aging for 1 hr at 450°C, and followed by 80% cold rolling and second aging for 1 hr at 450°C.

Vickers hardness was measured by Zwick 3212 hardness tester with a load of 0.5 Kg. Tensile tests were performed using static Instron with cross head speed of 1 mm/min using tensile specimen with gage length of 25 mm. Electrical resistivities were measured by four probe method at liquid nitrogen temperature. Specimens for optical microscopy were electrically polished at 4–6 V for 30–60 sec in H_3PO_4(70%) + H_2O(30%) solution and chemically etched using dilute HCl solution for 10 sec. Specimens for transmission electron microscopy were mechanically polished followed by jet polishing in 30% nital solution at −40°C. Microstructures were observed by transmission electronic microscopy using Philips CM20 with an accelerating voltage of 160 kV.

3. Results and discussion

Thermomechanical treatments (TMT) of Cu-base leadframe alloys consist of hot rolling, solution treatment, cold rolling and aging treatment as shown in Fig. 1. Table I shows the chemical composition of Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy measured by X-ray wavelength dispersive spectroscopy. Fig. 2 shows the effect of solution treatment temperature on grain size of Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy after solution treatment at 700 and 800°C. The average grain sizes of Cu-1.5Ni-0.3 Si-0.03P-0.05Mg leadframe alloy solution treated at 700 and 800°C were 10 μm and 15 μm, respectively.

TABLE I The chemical composition of Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy analyzed in weight percent

Element	Cu	Ni	Si	P	Mg	Fe	Pb	Zn
Nominal	Bal.	1.5	0.3	0.03	0.05	—	—	—
Analysis	Bal.	1.495	0.284	0.031	0.054	0.012	0.006	0.013

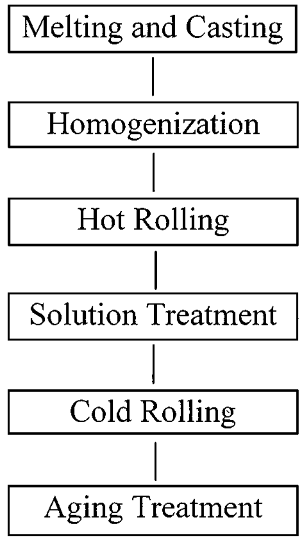

Figure 1 Schematic diagram of thermomechanical treatment for Cu-base leadframe alloy.

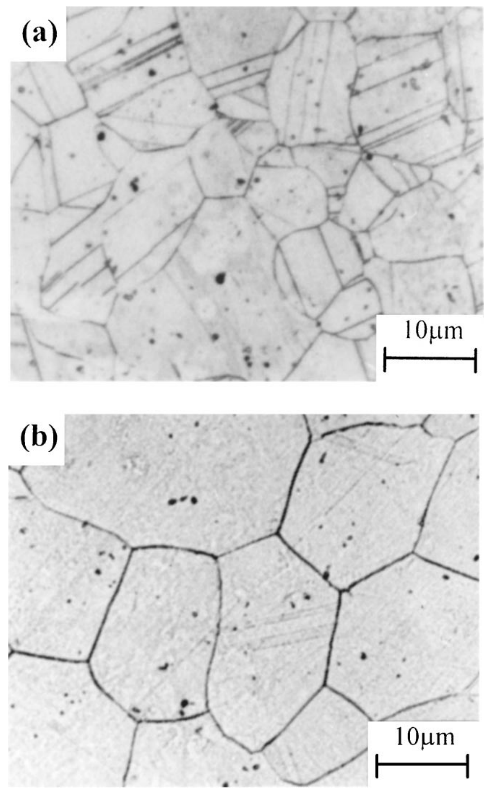

Figure 2 Optical micrographs of Cu-1.5Ni-0.3Si-0.03P-0.05Mg after solution treatment at different conditions; (a) Solution treated at 700°C for 1 hr, (b) solution treated at 800°C for 1 hr.

The variations of hardness and electrical resistivity were measured with varying aging time at 450°C after solution treatment and cold rolling of 80% in order to

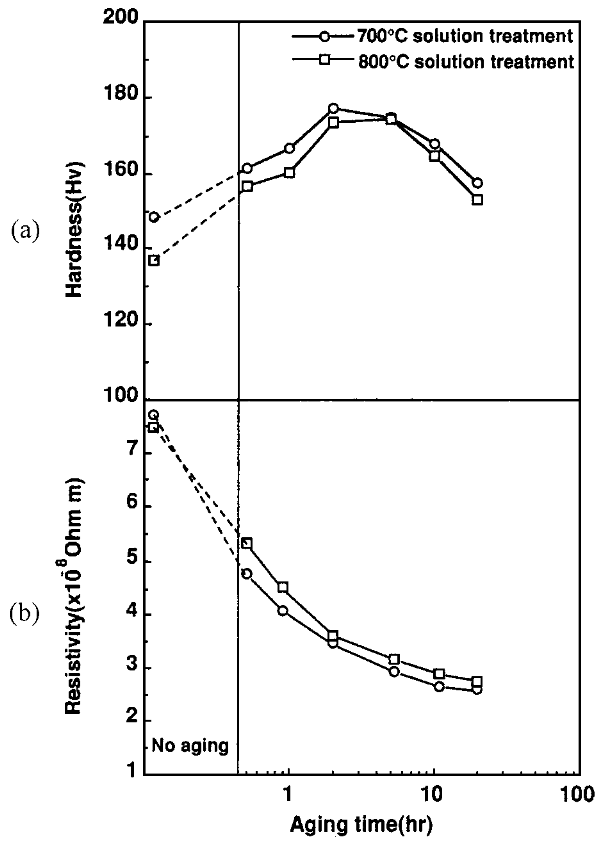

Figure 3 The variations of hardness and electrical resistivity of Cu-1.5 Ni-0.3Si-0.03P-0.05Mg leadframe alloy with varying aging time at 450°C. Cu-1.5Ni-0.3Si-0.03P-0.05Mg is cold rolled 80% and aged at 450°C after solution treatment; (a) Hardness, (b) electrical resistivity.

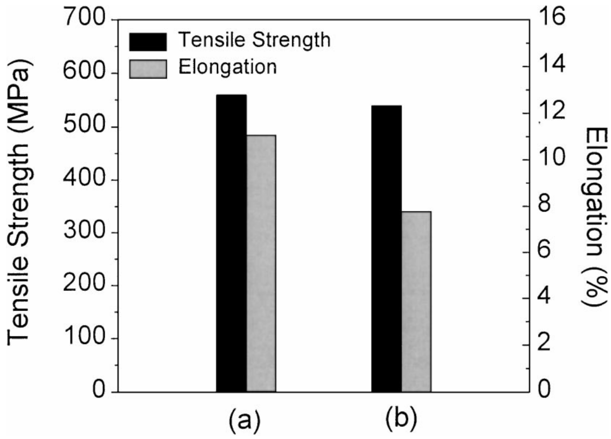

Figure 4 The comparison of tensile strength and elongation of Cu-1.5 Ni-0.3Si-0.03P-0.05Mg leadframe alloy with different initial grain size; (a) initial grain size of 10 μm after solution treatment at 700°C, (b) initial grains size of 15 μm after solution treatment at 800°C.

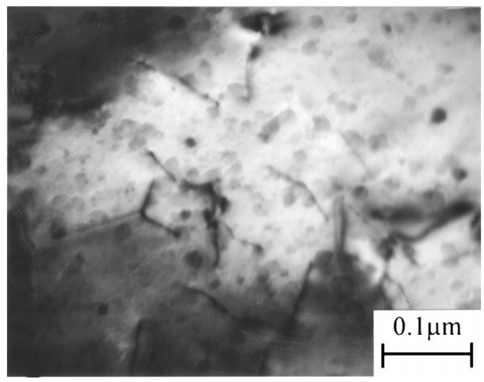

Figure 5 Transmission electron micrograph of Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy aging treated at 450°C after solution treatment at 700°C for 1 hr and cold rolling of 45%.

investigate the effect of initial grain size on the hardness and electrical resistivity. The hardness of Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy with smaller grain size of 10 μm was higher than that of specimens with larger grain size of 15 μm as shown in Fig. 3a. The electrical resistivity continuously decreased with increasing aging time, since the content of solute atoms in leadframe alloy decreased during the aging. Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy with smaller grain size of 10 μm showed lower electrical resistivity than that with larger grain size of 15 μm as shown in Fig. 3b.

The result on tensile tests showed the effect of initial grain size on the tensile strength and elongation. The tensile strength and elongation of Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy with smaller grain size of 10 μm were higher than that with larger grain size of 15 μm as shown in Fig. 4.

The higher hardness and tensile strength of Cu-1.5 Ni-0.3Si-0.03P-0.05Mg leadframe alloy with smaller grain size can be explained by following reasons. First, the effect of grain size on strength generally follows the Hall-Petch type equation. Second, the leadframe alloy with smaller grain size generates more geometrically necessary dislocations during cold rolling as estimated by following equation [13].

$$\rho_G \propto \frac{\varepsilon}{bd} \tag{1}$$

where ρ_G is dislocation density, ε is strain, b is Burger's vector and d is grain size. Third, the precipitates in leadframe alloy with smaller grain size become more finer due to the higher dislocation density. The dislocations act as diffusion paths for solute atoms and provide nucleation site for precipitation during aging treatment. As a result, the aging time to peak hardness was reduced and the average size of precipitates was reduced as the grain size decreased. The growth of precipitates reduces the contents of solute atom in matrix and results in a continuous decrease in electrical resistivity during the aging [9].

Fig. 5 shows the transmission electron micrograph of Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy aging treated at 450°C after solution treatment at 700°C for 1 hr and cold rolling of 45%. Ni_2Si precipitates and dislocations are observed in the transmission electron micrograph of Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy.

The effect of the dislocation density on the hardness and electrical resistivity with increasing aging time was investigated by controlling the ratio of cold rolling from 40 to 85%. Fig. 6 shows the microstructures of Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy cold rolled up to 40, 70 and 85% after solution treatment at 700°C for 1 hr. The variation of hardness with increasing aging time at 450°C revealed that the peak hardness increased with increasing ratio of cold rolling and the time to peak hardness decreased with increasing

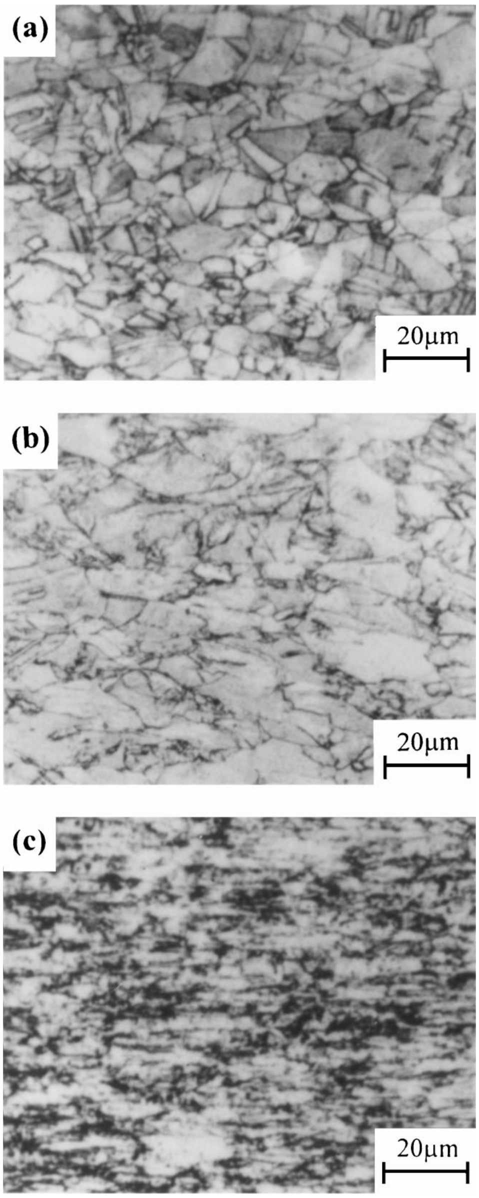

Figure 6 Optical micrographs of Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy with varying ratio of cold rolling after solution treatment at 700°C for 1 hr; (a) 40%, (b) 70%, (c) 85%.

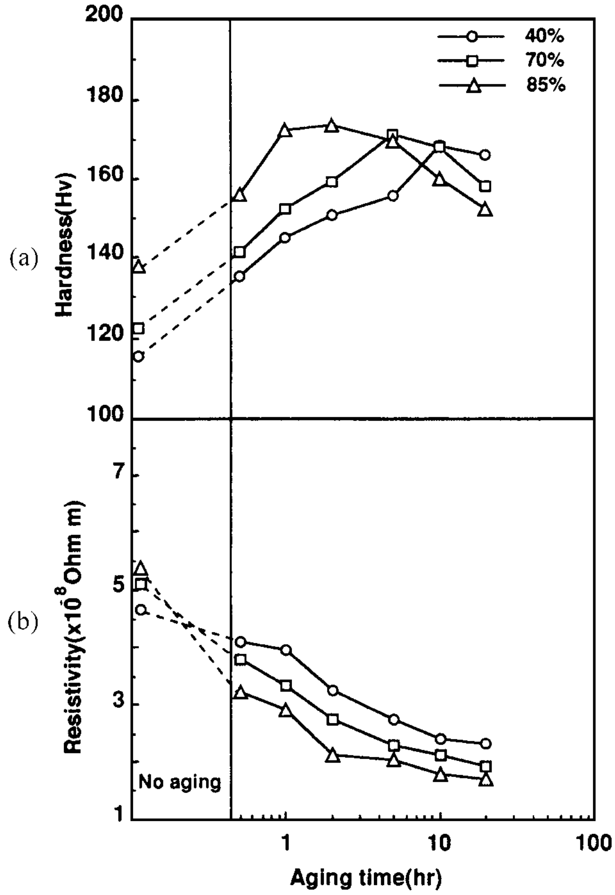

Figure 7 The variation of (a) hardness and (b) electrical resistivity of Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy cold rolled to 40, 70, 85% with increasing aging time at 450°C.

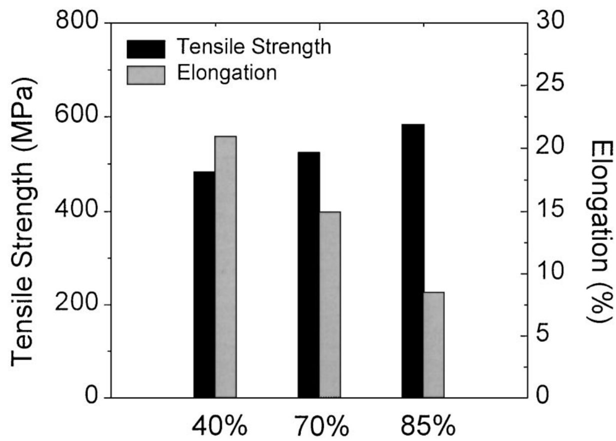

Figure 8 The variation of tensile properties of Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy with varying cold rolling ratio from 40 to 85% at peak aged condition at 450°C.

ratio of cold rolling as shown in Fig. 7a. The higher peak hardness and shorter time to peak hardness are associated with the finer Ni_2Si precipitates. The dislocation density increased with increasing reduction ratio of cold rolling and resulted in a finer size of Ni_2Si precipitates. Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy with higher ratio of cold rolling showed lower electrical resistivity than that with lower ratio of cold rolling as shown in Fig. 7b. Lower electrical resistivity in Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy with higher ratio of cold rolling is associated with the enhanced precipitation of Ni_2Si phase resulted from the higher dislocation density. The tensile strength increased with increasing reduction ratio of cold rolling due to the precipitation hardening effect from the finer precipitates as shown in Fig. 8. From these results, it is suggested that both the tensile strength and electrical conductivity can be increased thorough the control of grain size and precipitates size during the thermomechanical treatment of leadframe alloy.

Two different types of thermomechanical treatments were performed in order to control the grain size and precipitate size in Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy. The two types of thermomechanical treatments were shown schematically in Fig. 9. One type of thermomechanical treatment is to refine the grain size by the recrystallization of overaged and cold rolled leadframe alloy. The other type of thermomechanical treatment is to refine the Ni_2Si precipitates by repeated cold rolling and two-step aging of leadframe alloy.

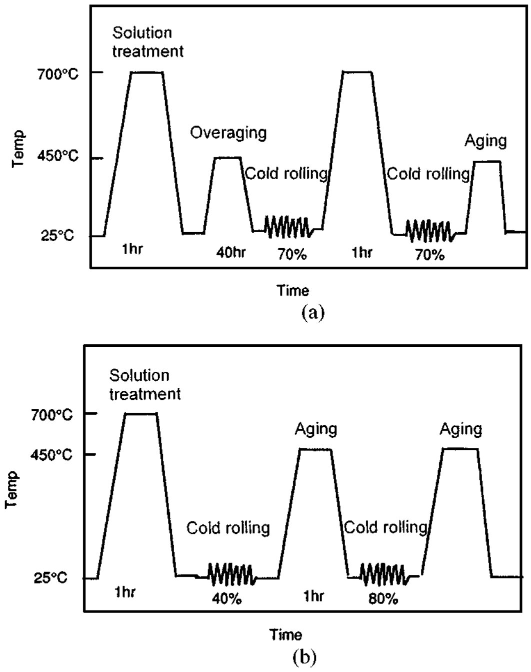

Figure 9 Schematic diagrams of two type of thermomechanical treatments for Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy; (a) Thermomechanical treatment with recrystallization process, (b) thermomechanical treatment with two-step aging process.

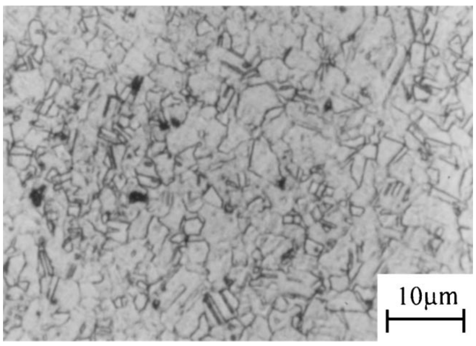

Figure 10 Optical micrograph of Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy after thermomechanical treatment with recrystallization process. The average grain size was measured as 5 μm.

The thermomechanical treatment with recrystallization process was intended to reduce grain size by the recrystallization of overaged and cold-worked alloy as shown in Fig. 9a. The thermomechanical process to refine the grain size consisted of the overaging at 500°C for 40 hrs of solution treated leadframe alloy and cold rolling up to 70%, then followed by recrystallization at 700°C. The size of Ni_2Si precipitates coarsened up to 19 nm after overaging. The large precipitates interacted effectively with dislocations during cold rolling process and resulted in densely populated dislocation structure.

The grain size decreased to 5 μm after recrystallization as shown in Fig. 10 mainly due to the increased nucleation sites for new grains in the cold worked leadframe alloy. The thermomechanically processed Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy with average grain size of 5 μm showed tensile strength of 540 MPa, elongation of 15% and electrical resistivity of 1.929×10^{-8} Ωm after aging treatment at 450°C for 1 hr. The tensile strength and elongation increased and the electrical resistivity decreased in the fine grained leadframe alloy compared to the conventionally processed leadframe alloy, which showed the tensile strength of 500 MPa, elongation of 6% and electrical resistivity of 2.0×10^{-8} Ωm.

The thermomechanical treatment with two-step aging process was designed to increase the dislocation density before aging treatment in order to refine the size of precipitates as shown in Fig. 9b. Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy solution treated at 700°C was 40% cold rolled and firstly aged at 450°C for 1 hr to form underaged precipitates. The underaged precipitates interact with dislocations and resulted in an increase of dislocation density during the second cold rolling of 80%. The cold rolled leadframe alloy was secondly aged at 450°C for 1 hr. The average size of Ni_2Si precipitates after two-step aging treatment refined to 4 nm compared to that of 7 nm in conventionally processed Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy. The two-step aged Cu-1.5Ni-0.3Si- 0.03P-0.05Mg leadframe alloy showed tensile strength of 640 MPa, elongation of 9% and lower electrical resistivity of 1.475×10^{-8} Ωm after aging treatment. Both the tensile strength and elongation increased, and the electrical resistivity decreased in two-step aged leadframe alloy compared to the conventionally processed leadframe alloy.

The mechanical property and electrical resistivity of two processes are compared with conventionally processed alloy in Fig. 11. The thermomechanical

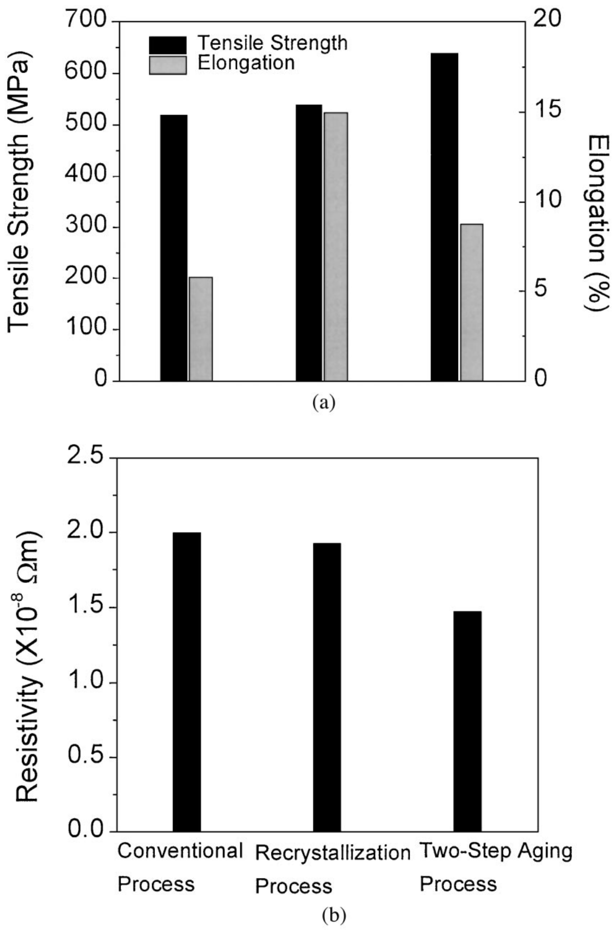

Figure 11 The variation of (a) tensile properties and (b) electrical resistivity of Cu-1.5Ni-0.3Si-0.03P-0.05Mg thermo-mechanically treated with conventional, grain size refinement and two-step aging processes.

treatment with recrystallization process was effective to increase both tensile strength and elongation by reducing the grain size of leadframe alloy. While, the thermomechanical process with two-step aging process was effective to increase the tensile strength by reducing the inter-precipitate spacing and to decrease the electrical resistivity by reducing the solute content in matrix of Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy.

4. Conclusions

The effect of thermomechanical treatments on the mechanical and electrical properties of Cu-1.5Ni-0.3Si-0.03P-0.05Mg leadframe alloy was investigated and the major conclusions are summarized as following:

1. The thermomechanical treatment with recrystallization process, which consisted of overaging and cold rolling followed by recrystallization, improved the tensile strength to 540 MPa and elongation to 15% by effectively reducing the grain size to 5 μm.

2. The thermomechanical treatment with two-step aging process, which consisted of two-step cold rolling and aging treatment, increased the tensile strength to 640 MPa and reduced the electrical resistivity to 1.475×10^{-8} Ωm by reducing the average size of Ni_2Si precipitates to 4 nm.

3. The refinements of grain size and precipitate size were effective to enhance the tensile strength and elongation by reducing the inter-precipitate spacing, and to reduce the electrical resistivity by decreasing the solute content in matrix of leadframe alloy.

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