

Properties in Hardness of Al-Cu Couples Diffused at 813 K

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Abstract

Al-Cu couples were heated to 813 K during 200, 320 and 480 hours. The heat treatment conditions caused the welding of the metals. After the mentioned conditions, it was observed the formation of two contiguous plates like (~15 to 30 micrometres, width) in parallel direction to the contact section. These plates like were chemically identified and its compositions corresponded to the η_2 (CuAl) phase and to the θ (CuAl₂) phase of the aluminium-copper system. The measurements of micro hardness that were carried out on these plates like gave values of 620HV0.05 and 500HV0.05 (on the average) respectively. In the Cu-rich side no formation of intermetallic compounds was detected. The micro hardness average for this part was of 50HV0.05. On the other side of the welding line (opposite side to Cu), the micro hardness measurements varied in an alternate way, which indicates dispersion of intermetallic compounds of different chemical composition (mechanical mixture); the values of micro hardness present in this area go from 220HV0.05 (near to the welding line) to 180HV0.05 (far from the welding line) inside the space considered.

Keywords : quasicrystals; phases; icosahedral; decagonal; aluminum oxide

Introduction

For the electricity conduction, wires of aluminium.⁽¹⁾ or copper.⁽²⁾ are commonly used. When these two materials enter in contact, a deficient contact (hot points) in between both metals can occur occasionally. As a consequence, in electric lines, the deficient contact causes the heating of the joint arriving until the welding of the metals. The atomic diffusion in between the aluminium and the copper modifies the chemical composition of each metal. Additionally, the granular structure is changed as consequence of the heating. Therefore, the inter-diffusion between both metals modifies the mechanical properties of the joint and needs to be considered. The aim of this work is to determine the hardness profile and to correlate this profile with the observed structure in Al-Cu couples under heating up to 813 K.

Materials and Experimental Procedures

Materials

For experimentation, solid circular bars of 19 mm diameter of aluminium and copper (both commercially pure) were employed. These bars were cut in sections of ~10 mm length and Al-Cu couples were formed by making contact through their bases. Groups of Al-Cu couples were heated up to 813 K during periods of 200, 320 and 480 hours respectively, then cooled in air. Later on, welded couples were cut diametrically and the sections were mechanically polished.

Equipment for characterization

A conventional electric furnace was used to activate the diffusion through the interface between the sample cylinders.

A hardness meter "OPL-Made In France-No.034" with pyramidal indenter with a weight of 50 grams was used.

The observations of the grain shapes and sizes were carried out with a "JEOL 40 KV Scanning Electron Microscope" (SEM).

Results

Micro hardness profile

Perpendicular to the welding line, a set of aligned imprints of the diamond indenter was carried out. The two diagonals of the indentation left on the metallic surface after removal of the load were measured and their average calculated. A separation equivalent to ten diagonals was established among the imprints, for avoiding the interaction of the individual strain fields (except for imprints inside each intermetallic plate like along the welding line).

The micro hardness profile corresponding to Al-Cu couple diffused at 813 K during 320 hours is shown in Figure 1. The profile can be considered as representative of all the sample couples tested. On the graph, in the part corresponding to the copper zone, eliminating the maximum and minimum values, an average micro hardness of 50HV0.05 was determined (for recrystallized copper, a micro hardness of 50HV0.1 has been reported).⁽³⁾ In a previous work it was mentioned that in this part of the diffused couple, only copper crystals were detected.⁽⁴⁾ which is in agreement with the result of the micro hardness measures carried out there in. Therefore, the micro hardness measures carried out in the cross direction to the welding line, constitute an additional evidence of the single-phase character of the grains in this part of the diffused couple. On the other hand, from the tested samples, it is clear that the number and type of defects introduced in the cylinder manufacturing was substantially diminished at the given process temperature (813 K).

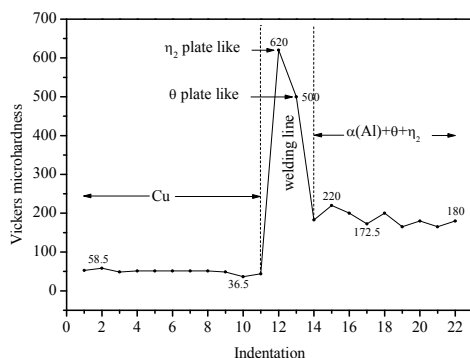


Figure 1. Micro hardness profile performed in the perpendicular direction to the welding line. Note the high values of hardness in the diffusion weld bead.

Referring to the welding line, which has been schematized in Figure 1, the hardness measures showed abrupt changes in comparison to those carried out on the copper-rich side. As it was reported in a previous work,⁽⁴⁾ the welding line is constituted by two contiguous plate likes with different compositions, to know, the η_2 (CuAl) phase and the θ (CuAl₂) phase.⁽⁵⁾ These platelets extend along the welding line with a variable width in a range between 15 to 30 μm each one. A number of imprints were carried out with the Vickers micro hardness indenter throughout each plate like; the average of the hardness values obtained is 620HV0.05 and 500HV0.05 for the plates like of the intermetallic η_2 and θ phases, respectively. The imprints left by the indenter on the plate like of the intermetallic η_2 (small imprint) and on the Cu part can be seen in Figure 2.

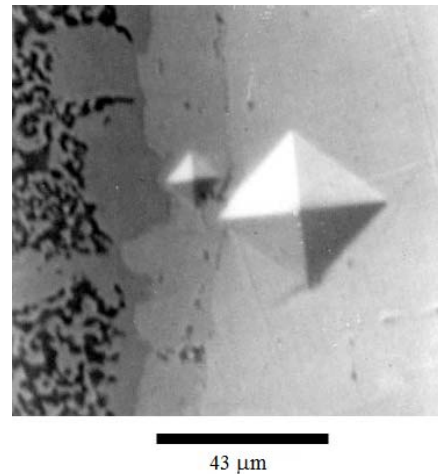


Figure 2. Image of the hardness meter imprint on the Cu side (big imprint) and on the η_2 (CuAl) plate like.

In the zone comprised among the welding line and the aluminium, the hardness measurements show changes in an alternate way. The values alternation has broad variations near the welding line and has small variations far of that such a line. This fact indicates that the measurements performed correspond to grains with different chemical composition (mechanical mixture) and size (Figures 3, 4). For the Al-Cu couple in this study, the reported micro hardness values are: 220HV0.05, close to the welding line; and 180HV0.05, far from the welding line.

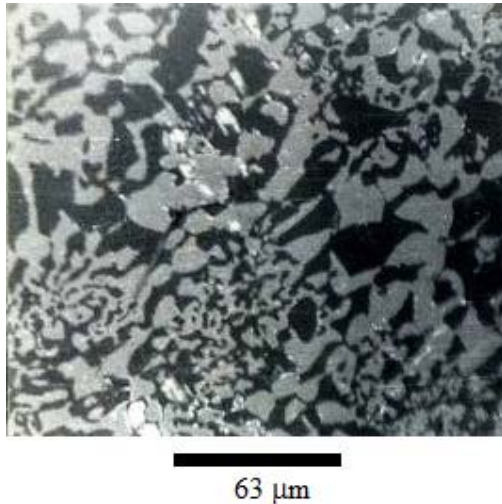


Figure 3. Granular structure observed close to the welding line in the opposite side to the copper. In the image, θ (CuAl₂) grains are surrounded by a network of α Al solid solution. Note the wide range of grain size.

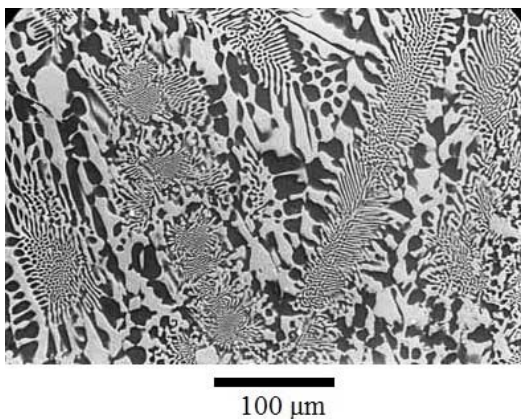


Figure 4. Granular structure observed far to the welding line in the opposite side to the copper. In detail, fine structure is constituted by lamellar pearlite and granular pearlite.

Discussion

The results of the hardness measurements carried out on the Cu-rich side, show a mean value of $\bar{x} = 50\text{HV}$ (without considering the extreme values) with a standard deviation value of $s = 2.6$. Now, it is clear that at the test temperature (813 K) and the established periods (200, 320 and 480 hours) the mobility of the atoms in the solid is vigorous; then, it is a fact that the recrystallization of the Cu-rich side took place in a full way. Reports of hardness for copper, under the same conditions, are in the literature and are in agreement with our experimental results. Benchabane G.⁽³⁾ and co-workers reported the same value that is presented

here; therefore, it can be assumed that this part of the Al-Cu couple is only constituted with Cu pure recrystallized.

The high values of micro hardness obtained on the plates like η_2 and θ (constituents of the welding line) are indicative of crystalline complex structures. For the intermetallic η_2 , it is known that this phase has a body centred orthorhombic structure having 10 Cu atoms and 10 Al atoms by cell⁽⁶⁾. Consequently, due to this structure, the high density of the packaging and the difference of the atomic sizes (metallic radii: Al, 1.43 angstrom; Cu, 1.28 angstrom)⁽⁷⁾, it makes scarce the number of slip systems. In the case of the intermetallic θ phase (having a tetragonal structure with 4 atoms of Cu and 8 atoms of Al by cell)⁽⁶⁾, similar assumptions can be thought; then, the opposition to the displacement of atomic planes is still significant although less difficult than in the previous case.

The measurements of micro hardness in the opposite part to the Cu show that there is heterogeneity as for the distribution of phases that conforms this part; that is to say, the variations in the measurements indicate the presence of grains of different chemical composition as mentioned before. Near the welding line, the structure is a mechanical mixture of θ grains surrounded by a network of α Al solid solution. In some zones, the mentioned mixture has the appearance of fine pearlite; meanwhile in other zones, the θ grains are irregular with a wide range of sizes. From the before mentioned facts, the big grains are causing the high variations in the micro hardness (220HV_{0.05}). It is important to mention that in this mechanical mixture the phases are saturated (metastable state), then they are susceptible of decomposition.

Finally, far from the welding line, the primary θ grains decompose into alternating lamellae of α Al and α Cu, which give place to the lamellar pearlite that can be viewed in the Figure 4. This lamellar pearlite show small variations in the micro hardness values as can be observed in the last four points on the right of the graph, Figure 1. Then, although the number of interfaces here is major (α Al+ α Cu+ θ) that near the welding line (α Al+ θ), the small thickness of the lamellae (fine microstructure) and small grain caused the decrease of the average of the micro hardness values.

Conclusions

1. The average micro hardness value corresponding to the Cu side before the welding line of the Al-Cu couple that it was diffused at 813 K, is the same than the micro hardness value found in the literature for the Cu pure recrystallized (50HV0.1). Then, chemical homogeneity is assumed to exist in the Cu grains in the entire zone under consideration.

2. The welding line is formed by two plates like possessing a complex crystalline structure, where each plate like shows values of micro hardness that they are superior (one order in magnitude) to those values measured to both sides of this line. For the plate like of the η_2 intermetallic an average micro hardness value of 620HV0.05 was obtained, meanwhile for the plate like of intermetallic θ the mean hardness value was 500HV0.05.

3. The micro hardness values obtained in the rich part in aluminium show discreet variations in an alternate way from 220HV0.05 up to 180HV0.05. A clear correspondence exists between these values and the granular structure; that is, the first value corresponds to a structure of irregular metastable grains of θ phase with a wide range of sizes surrounded by a network of α Al solid solution, while the last value corresponds to a structure which is the most part pearlitic.

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