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Investigation of the Structural Characteristics of Amorphous and Nanocrystalline Copper - Loaded Solders

I. Theoretical Part

Kseniya Shmakova

Ural Federal University, 620002 Mira 19, Yekaterinburg, Russia

Gennady Tyagunov

Ural Federal University, 620002 Mira 19, Yekaterinburg, Russia

Evgeniy Baryshev

Ural Federal University, 620002 Mira 19, Yekaterinburg, Russia

Vladimir Tsepelev

Ural Federal University, 620002 Mira 19, Yekaterinburg, Russia

Andrey Tyagunov

Ural Federal University, 620002 Mira 19, Yekaterinburg, Russia

Abstract

Samples of crystalline, amorphous and nanocrystalline copper-loaded solder with additions of nickel, tin and phosphorus produced under factory and experimental technologies structural changes has been studied. Analysis of structural changes of melt taking place during melting and amorphization has been performed.

Keywords: copper-loaded solder, amorphous ribbons, nanocrystalline material, liquid metal structure

Introduction

The study group of alloys is used for the manufacture of thin-walled structures for various purposes: honeycomb panels, heat exchangers, compact components with internal cooling, etc.

The main alloying elements of copper in these alloys are nickel, chrome and manganese, which improve strength properties and castability. Its crystal structure is isomorphic to the copper one and impact on stability of solid solutions, and near equal values of the electrode potential does not reduce the chemical and electrochemical resistance of copper. As amorphizating elements phosphorus and tin were used in different quantitative combinations.

In the development, production and study of technological suitability of solders great attention was paid to finding a correlation between composition, structure and properties. In addition, the inherent instability of molten metal structure and properties caused by the uneven distribution of dissolved elements in the matrix was taken into account.

Main Part

The main mechanism of the micro-structure change is known to be a triggered migration of atoms, proceeding at the interface of structural components of different levels. However, structural-phase condition of the material is determined not only by the interaction of chemical elements, but also by alloy production conditions. In particular, when melting of solder in the original charge the same elements are combined in different ways with others, i.e. the atomic structure of materials used is distinguished by the short-range order. In the process of melting the formed melt is characterized by non-equilibrium and inhomogeneous state. The non-equilibrium shall be understood to mean the uneven volume distribution of the sample with clusters of different composition.

After melting the unstable state of the melt persists for a long time in a wide temperature range, up to a certain temperature t_C. When heated to such a temperature the melt structure is changing rapidly, accompanied by a sudden and significant abnormal deviations of kinematic viscosity polytherms, conductivity, magnetic susceptibility, density and other physical properties of famous classical patterns. Reliability of structural change is confirmed by the data of X-ray diffraction study of metal liquids [1-3].

The essence of structural changes, in particular, is the collapse of non-equilibrium clusters and the equilibrium distribution of the atoms of all components and reducing the volume of newly formed clusters. Resulting from the increase in atoms oscillation of the outer layer their interaction with the atoms inside the cluster is weakened. As a result the electronic structure is deformed which leads to a change of their valence and electron density [4].

Cluster size reduction is accompanied by rise of intercluster volume. According to the research data [1-3, 5] the diameter of nuclear associations in metal alloys is in the range of 1-4 nm. Consequently, when reducing the cluster size up to 1 nm, the proportion of the intercluster space increases from 4-5% to 15-18% of the total volume of the substance. Also changing the structure increases supercooling in the solidification process, accelerating the diffusion processes, which creates favorable conditions for forming amorphous state.

The technical use of the copper-loaded solders in the form of amorphous ribbons in this study is attractive because of its simplicity of installation and assembly operations, high durability and reliability of brazed seam, economic efficiency and other technological and operational advantages [6].

From a physical point of view, amorphous state is an analogue of liquid metal. At high speeds of cooling the melt passes to a solid state, while still being supercooled liquid, that is metallic glass with a certain short-range order, while not having long-range order which is typical for a crystal structure. In amorphous metal, as well as in liquid, the information about the localization of nanoscale atomic associations (microassociations, clusters, etc.), low-energy spectra of vibrational excitations of disordered solids, thermal conductivity and heat capacity studies, and X-ray diffraction studies [7] show that in the chaos, which usually involved an amorphous structure there is a universal specific spatial scale, that is a kind of order parameter in amorphous materials of different nature. For the theory of amorphous and liquid state it can play as important a role as the elementary cell played for the theory of crystals [8]. The absence of crystals reduces the rate of defect formation.

The propensity to alloy amorphization depends on the liquidus temperature (t_L) and the glass transition temperature (t_a). When the critical thickness of amorphous ribbon is 100-200 nm and cooling rate is ~ 10^6-10^7 $^oC/s$., then the value of t_a/t_L is close to 0.45.

The amorphous ribbon copper-based alloys, which were studied in the work and containing nickel, tin and phosphorus, were obtained by single-roll spinning. Tin and phosphorus included as compounds of alloys dramatically lower the melting temperature. Nickel is isomorphic to copper and has one valence electron at the 4-s level.

Conclusion

Amorphous state is an analogue of liquid metal. At high cooling rates during solidification, while still being supercooled liquid, that is metallic glass with a certain short-range order, while not having long-range order which is typical for a crystal structure. Equilibrium and homogeneous state of the liquid before spinning process contributes to forming a structure of amorphous material.

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