MATERION

TECH BRIEFS

Spinodal Decomposition in ToughMet® and MoldMAX XL®

Most copper-base alloys develop high strength from either solid solution hardening, cold working, precipitation hardening, or by a combination of these strengthening mechanisms. In the ternary copper-nickel-tin alloys that include Cu-9Ni-6Sn (Brush Wellman ToughMet 2 and MoldMAX XL) and Cu-15Ni-8Sn (ToughMet 3), the high mechanical strength is produced by a controlled thermal treatment called spinodal decomposition.

WHAT IS SPINODAL DECOMPOSITION

Spinodal decomposition takes place "spontaneously" and needs no incubation period. A continuous diffusion process, in which there is no nucleation step, produces two chemically different phases with an identical crystal structure. The two phase structure in the spinodally hardened alloy is very fine, invisible to the eye, and continuous throughout the grains and up to the grain boundaries. The high strength of the copper-nickel-tin alloys resulting from spinodal decomposition has been attributed to the coherency strains produced by the uniform dispersions of tin-rich phases in the copper matrix. A three-fold increase in the yield strength over the base metal results from spinodal decomposition in the copper-nickel-tin alloys.

Certain conditions need to be fulfilled for hardening to occur by spinodal decomposition. The phase diagram of a spinodal system in the solid state must contain a miscibility gap, a region where the single phase alloy separates into two phases. The alloying elements must have sufficient mobility in the parent matrix at the heat treating temperature to allow interdiffusion.

SPINODAL HEAT TREATMENT

The heat treatment steps for spinodal decomposition include:

(a) Homogenization at a temperature above the miscibility gap to obtain a uniform solid solution of a single phase.

(b) Rapid quenching to room temperature.

(c) Reheating to a temperature within the spinodal region to initiate the reaction, and holding for sufficient time to complete the spinodal decomposition.

Brush Wellman copper-nickel-tin alloys are spinodally hardened at the mill, eliminating the need for any heat treatment by customers. In this prehardened condition, the alloys are fully machinable and offer unique combinations of high strength, corrosion resistance, and low friction and wear characteristics.

Unlike precipitation hardening, spinodal decomposition produces a continuing reduction in elongation during overaging. Therefore, care should be taken to avoid exposing these alloys to temperatures that can overage them. Spinodally decomposed materials have inherently good stress relaxation resistance. A consequence of this is that there is no procedure to stress relieve parts made from MoldMAX XL or ToughMet.

SPINODAL MICROSTUCTURE

Alloys strengthened by spinodal decomposition develop a characteristic modulated microstructure. Resolution of this fine scale structure is beyond the range of optical microscopy. It is only resolved by skillful electron microscopy. Alternatively, the satellite reflections around the fundamental Bragg reflections in the X-ray diffraction patterns have been observed to confirm spinodal decomposition occurring in copper-nickel-tin and other alloy systems.

The tin-rich particles formed by spinodal decomposition during the early heat treatment stages develop an ordered D022 structure in the peak aged condition. Overaging is a discontinuous grain boundary reaction consisting of an alternate $\alpha + \gamma$ phase mixture that consumes the spinodally hardened grains, leaving behind a soft structure.

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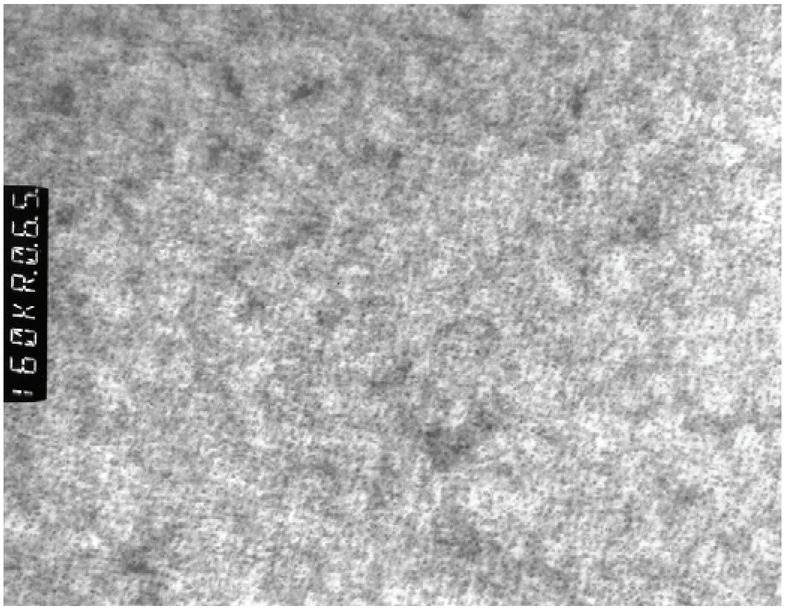

Transmission electron micrograph showing the spinodal structure in aged ToughMet 3, 160,000X (alternating waves of chemically different but structurally coherent atomic clusters of copper, nickel and tin present after spinodal decomposition.)

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