Measurement of Mechanical Properties and Microstructure of Cu-Ni-Cr Spinodal alloy

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Abstract

The objective of the present examination is to learn the microstructure of copper-nickel-chromium spinodal alloy and its outcome on mechanical properties. A commercially important Cu-28.9%Ni-2.8%Cr alloy has been heat treated to create spinodal structures. Optical and transmission electron microscopic revision have been carried to learn the spinodally decomposed product and to compute the wavelengths in the sampling. The lattice imaging system of high-resolution electron microscopy is useful to investigate the compositional fluctuations in this alloy. Homogenized and solution treated samples were aged at various temperatures for unlike phase of time. The correlation of mechanical properties with microstructure then demonstrates a dependence of yield stress growth on lattice parameter change between the two phases.

Keywords

Cu-Ni-Cr alloy, heat treatment, Spinodal decomposition, microstructure, hardness.

I. INTRODUCTION

The objective of this research is to investigate the spinodal characteristics of Cu-Ni-Cr alloy and then correlate its mechanical properties with the changes in microstructure during spinodal decomposition. Cu-Ni-Cr was chosen particularly for its commercial importance as an alloy of excellent strength and corrosion resistance in naval environment. A set of study was committed to these alloys to advance their mechanical properties. By adding ternary alloying element like Cr will introduces miscibility gaps in Cu-Ni binary system which make this alloy subject to heat treatment and modify the properties of the binary alloys. Meijering et al. reported miscibility gap in the Cu-Ni-Cr structure, with the help of X-ray and metallographic diffraction process at 930°C (Fig. 1).

The changes in microstructure of the alloy have major result on its material goods. Spinodal decomposition produces modulated microstructure and period action develops the strong point of the spinodally decomposable alloys [1].

Hillert [2, 3] shows that the modulated structures are created when an alloy is inside the spinodal area of the time chart. Spinodal decomposition causes solute-rich and solute-lean

sections when it is matured at an appropriate heat [6]. The strain fields around the modulated configuration delay the interruption movement and thereby causing consolidate to take place [7]. However, very few systematic studies of other systems have been performed to examine the relationship of mechanical properties with the microstructural parameters of spinodal alloys [8]. Therefore, it is the intention of this research to investigate these parameters and to establish these relationships in a commercial Cu-Ni-Cr alloy.

Fig. 1. Cu-Ni-Cr ternary phase diagram metallographic diffraction process at 930°C. Shown here as (i) homogeneous b.c.c. [A segment] (ii) homogeneous f.c.c. [B segment], (iii) 2 f.c.c. phases[C segment](iv) b.c.c. and Cu-Rich f.c.c. [D segment](v) b.c.c. & Ni-rich f.c.c.[E segment] and (vi) b.c.c. and 2 f.c.c. phases[F segment] atomic concentrations [12].

II. EXPERIMENTAL PROCEDURES:

A. Sample

Pure forms of samples were procured from the commercial market. The sample is a commercial Cu-based alloy of following composition by weight %:

Cu - balance C - 0.014%,
 Ni - 28.9% Ti - 0.051%
 Cr - 2.84% Si - 0.091%
 Mn - 0.55% Fe - 0.32%
 Zr - 0.22%

B. Heat Treatment

The alloy was placed in an electric arc furnace with an inert atmosphere; Aragon generally used during the heat treatment. The temperature within the furnace hot zone was operating precisely to an

limiting accuracy $\pm 5\%$. The alloy becomes homogenized solution and heat treated at 1100°C . After that, the solution heat treated alloys were aged for 3 days. Alloys then quenched into brine solution. After cutting and machining, the various experimental specimens were annealed in quartz tubes filled with purified argon at 1100°C for two hours and quenched again in ice brine. The microscopic tests were carrying out using Carl-Zeiss metallurgical microscope.

C. Tensile Test

For tensile test specimens, the alloy was first cut into round bars and the heat-treatment subsequently performed. The round bars were then machined into standard tensile specimens is shown in Fig. 2[9].

Fig. 2. Tensile test specimen [9]

Specimens were tensile pulled in a Computerized Universal Testing machine (Fig.3).

Fig. 3. Computerized Universal testing machine

III. RESULTS AND DISCUSSIONS

The as-quenched specimen showed some details of segregation in matrix Fig.4. This suggests that the alloy starts decomposing at this condition.

Fig. 4. Periodic structure in as-quenched Cu-28.9%Ni-2.8%Cr alloy

(a)

(b)

Fig. 5. Surface structure of the sample aged at (a) 700°C for 10 min (b) 700°C for 1 hour.

In Fig. 5, a very fine and wavy microstructure is observed for specimens aged about 700°C for (a) 10 min., (b) 1 hour respectively. If we look at the microstructures of small time aged samples at $300\text{--}400^{\circ}\text{C}$, we can only see mottling; however, clear periodic structures are observed above 500°C (Fig 6).

Fig. 6. Clear periodic structure

Furthermore, no heterogeneous nucleation and grain boundary particles have been observed in short time aged samples. After long time ageing, the microstructures were clearly periodic showing Cu-rich and Cu-poor regions. In images, light regions match up to the Cu-rich phase and darker region match up to the Cu-poor phase.

The outcomes of the tensile tests are reviewed in the following Table 1.

Table 1 A. Tensile Stress Results at 600°C

Aging Time	As-Quenched	10 min.	1 hr.	50 hr.	150 hr.	600 hr.
Yield stress (MPa)	153	202	260	332	318	330
Ultimate Tensile stress (MPa)	352	395	400	418	410	430
% Elongation	30	26	18	8	8	6

Table 1 B. Tensile Stress Results at 700°C

Aging Time	As-Quenched	10 min.	1 hr.	50 hr.	150 hr.	600 hr.
Yield stress (MPa)	153	282	290	288	243	235
Ultimate Tensile stress (MPa)	352	390	443	420	360	386
% Elongation	30	21	19	13	18	16

For alloys aged at 700°C, the yield stress remains almost constant between aging times as short as 10 min. and as long as 50 hours. It then decreases for longer aging times. For alloys aged at 600°C, the yield stress increases with aging time and then remains constant (Fig. 7).

(a)

(b)

Fig. 7. Graph of yield stress versus aging time for alloys aged at (a)600°C and (b)700°C

From the tensile test results of this research the yield stress of the spinodally decomposed alloys increased with longer aging time until the equilibrium were reached. Rao P.P. et al[14] has

calculated the defer strain of alloys with coherent lamellar microstructure and his theory is based on the elastic strains required to maintain coherency between the two phases. The conclusions reached by Rao P.P. et al [14] in his calculations are that the defer pressure of spinodally decayed Cu-Ni-Cr alloys depends on the differences in cubic lattice property of the two phase, and is independent of the wavelength and of the amount portion of the impulsive stages between certain critical values.

The physical properties are summarized in the following Table 2.

Table 2. Physical properties of specimen

Property	Specimen of present work
Density (lb/in ³)	0.32
Specific heat (Btu/lb-°F)	0.09
Modulus of elasticity (10 ⁶ psi)	18.35
Thermal conductivity (Btu/ft-hr-°F)	24.2
Thermal diffusivity (in ² /s)	0.02
Coefficient of Thermal expansion (10 ⁻⁶ /°F)	9.2

IV. CONCLUSION

Due to Spinodal decomposition a solution consists of more than one components can divide into separate phases with clearly dissimilar physical properties and chemical compositions. This system varies from the traditional or conventional nucleation. From the current study the following conclusion can be drawn:

1. Cu-Ni-Cr alloys including 25-30 wt % Nickel and up to 3 wt% Chromium have highest strengthening was obtained.
2. The yield stress increased rapidly during the initial stages of ageing.
3. In the early stages of ageing, hardness values amplify quickly due to spinodal decomposition, they remain constant for a while at maximum hardness values and then decrease slowly due to particle coarsening.
4. The decrease in yield stress of Cu-Ni-Cr alloy occurred when the particles began to drop coherency.
5. The yield stress increases as aging time increases for the alloys aged at 600°C and decreases for alloys aged at 700°C.
6. Any definite relationship between the mechanical properties and microstructure can be seen to depend on the compositional fluctuations.
7. The alloy demonstrates morphological character.
8. The highest strength was obtained at 600°C for the present alloy, therefore this temperature is the ideal temperature for the heat treatment of Cu-30Ni-2.5Cr; it has three times more mechanical strength than Cu-30Ni classical alloy is obtained.

9. The spinodal decomposition is an unstructured un-mixing dissimilar from typical nucleation and expansion in metastable clarifications.
10. Dispersion strengthening, Precipitation hardening, and spinodal decomposition methods provide more or less the same strength values.
11. In the present alloy, only Face Centered Cubic structured particles are detected.

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