# EFFECT OF CONTINUOUS PRECIPITATION KINETICS ON DISCONTINUOUS PRECIPITATION IN Cu-Be AND Aℓ-Ag ALLOYS

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The extent of discontinuous precipitation in Cu-Be alloys, with and without Co and Ni additions, has been studied using optical, scanning and transmission electron microscopy. The effect of solutionizing temperature on the continuous precipitation and the segregation behavior and their subsequent effect on the discontinuous precipitation has been characterized. The effect of quenching the sample directly to the aging temperature as opposed to quenching to room temperature and subsequently aging the samples has been studied. As previously shown, the continuous precipitation is further advanced in the precipitation sequence in the water-quenched and aged samples. As a result of the differences in continuous precipitation, the directly-quenched alloys have <u>more</u> discontinuous precipitation. These results will be compared and contrasted to previous and recent work done on the Aℓ-Ag system. The results presented will be discussed in terms of the effective free energy available to drive the cellular reaction.

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The discontinuous precipitation reaction has been extensively studied and the major characteristics of the reaction have been reviewed recently by Gust (1) and Williams and Butler (2). The reaction proceeds by concomitant grain boundary precipitation and boundary migration, resulting in a lamellar, two-phase product. Only the case where the unconsumed matrix consists of a solid solution and a metastable phase will be considered in this paper. Previous work by Aaronson and Clark (3) showed that the discontinuous precipitation kinetics are affected by the presence of a continuous transformation product in the matrix. In this article, the effect of solutionizing temperature as well as the effect of quenching procedures on the continuous transformations and their subsequent effect on the discontinuous reaction will be examined. All samples used in this study were solution-treated in an argon atmosphere and either directly-quenched to the aging temperature (DQ) or water-quenched, held two minutes and then upquenched to the aging temperature (WQ).

## Results

### Cu-2 $^{w}/o$ Be Alloys

Optical micrographs of samples aged at 589 K for 31 hours are shown in Fig. 1. Note that an increase in the solutionizing temperature decreases the amount of discontinuous precipitation present. This is in agreement with work by Beck (4) on Cu-Be-Co (Cr) alloys. The WQ samples, however, show much less discontinuous precipitation than the DQ samples. This is in direct disagreement with the previous work of Aaronson and Clark (3) which compared DQ and WQ samples in an Aℓ-Ag alloy. To clarify these findings, transmission electron microscopy (TEM) was performed on the Cu-Be alloys and the results are shown in Fig. 2. The DQ samples have much smaller precipitates within the grains. The diffraction patterns also demonstrated this in that the WQ samples have more distinct $\gamma'$ reflections. This is in agreement with the previous work of Rioja and Laughlin (5). The samples which were solutionized at the higher temperatures are also much more advanced in the continuous precipitation sequence than those solutionized at lower temperatures. This is evidenced by the larger precipitates, and the more distinct $\gamma'$ reflections near the $\frac{2}{3}\{200\}$ position. This is confirmed by the hardness curves for these alloys shown in Fig. 3. Cu-Be alloys with Co or Ni additions exhibited the same properties as the Cu-Be binary work presented above.

### Aℓ-17.9 $^{w}/o$ Ag

Previous work by Aaronson and Clark (3) demonstrated that WQ samples had more discontinuous precipitation than DQ samples. To investigate this effect, TEM was performed and the results are shown in Fig. 4. Because of the large numbers of quenched-in vacancies, the general precipitation is much more homogeneous in the WQ samples. Examination near the grain boundary, however, reveals that there is a precipitate-free zone and an extensive GP-zone region, with no $\gamma'$ in the WQ samples (Fig. 5). The DQ samples are uniformly heterogeneous up to the boundary; that is, there are $\gamma'$ precipitates up to and near the boundary. The effect of varying solutionizing temperature is shown in Fig. 6. The higher the solutionizing temperature, the less discontinuous precipitation occurs. The higher solution-treated samples have a much smaller (if any) GP-zone region near the boundary, as shown in Fig. 5.

## Discussion

Aaronson and Clark (3) showed that the presence of a metastable precipitate in the matrix reduces the driving force for cellular precipitation up to 98%. We will examine the results presented here assuming that as continuous precipitation proceeds, the free energy of the matrix is continuously decreasing. In the Cu-Be samples, the matrices of the WQ and the higher solutionized samples should have lower free energies than the DQ and lower solutionized samples, respectively, since the continuous precipitation has progressed further in the former. This will reduce the driving force for cellular precipitation; thus less, if any, discontinuous precipitation should be observed. The experimental results presented above confirm these predictions.

For the Aℓ-Ag samples, what appears to be more important for cellular precipitation is the microstructure in the immediate vicinity of the boundary. The WQ samples, although possessing more $\gamma'$, have only GP zones near the boundary as a result of the more severe quench. The boundary, therefore, has a larger driving force for the initiation of the cellular reaction,

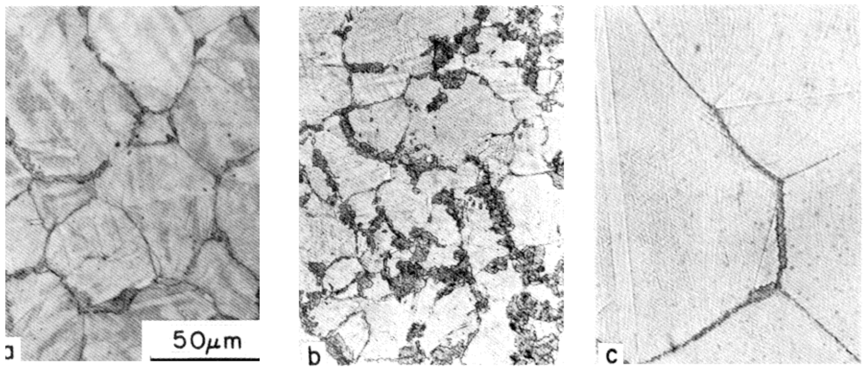


Fig. 1. Optical micrographs of Cu-2Be aged 31 h at 589 K
(a) Solutionized at 1033 K - WQ (b) Solutionized at 1033 K - DQ
(c) Solutionized at 1083 K - DQ

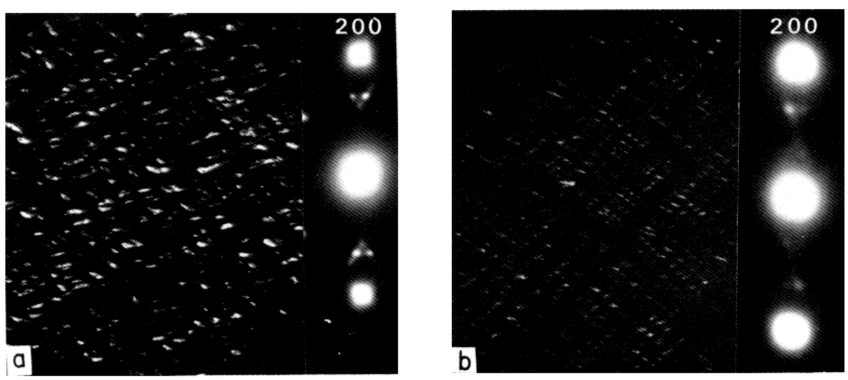


Fig. 2. TEM dark-fields from 2/3 (200) position of Cu-2Be aged 31 h at 589 K. (a) Solutionized at 1033 K - WQ (b) 1033 K - DQ.

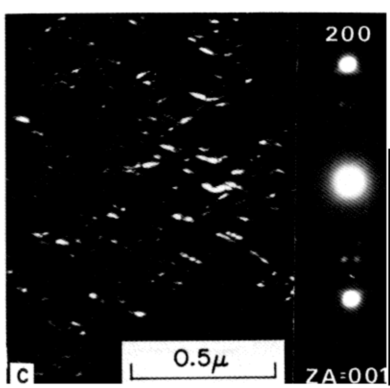


Fig. 2(c) Solutionized at 1083 K DQ

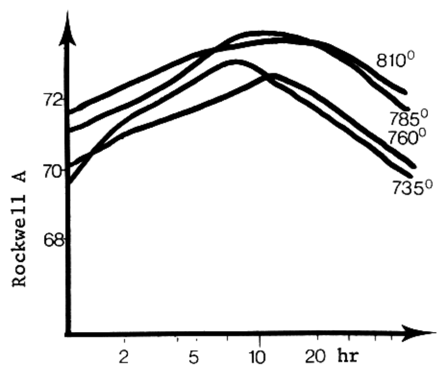


Fig. 3. Hardness curves (Rockwell A) of Cu-Be samples DQ from temperature given.

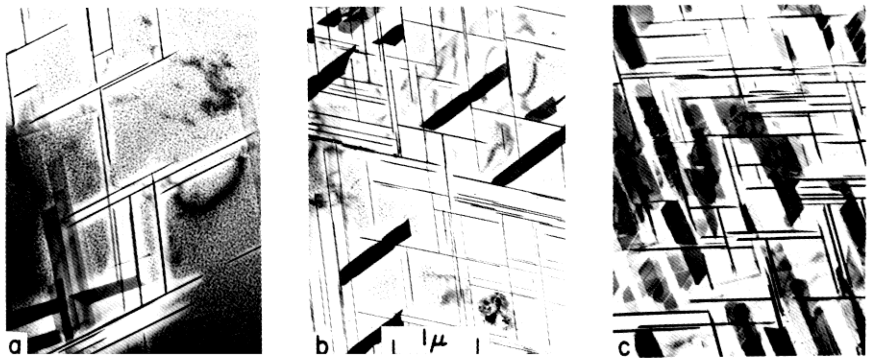


Fig. 4. General matrix precipitation in A$\ell$-17.9 Ag aged for 10 min at 578 K. (a) Solutionized at 813 K - DQ (b) Solutionized at 813 K - WQ (c) Solutionized at 843 K - WQ.

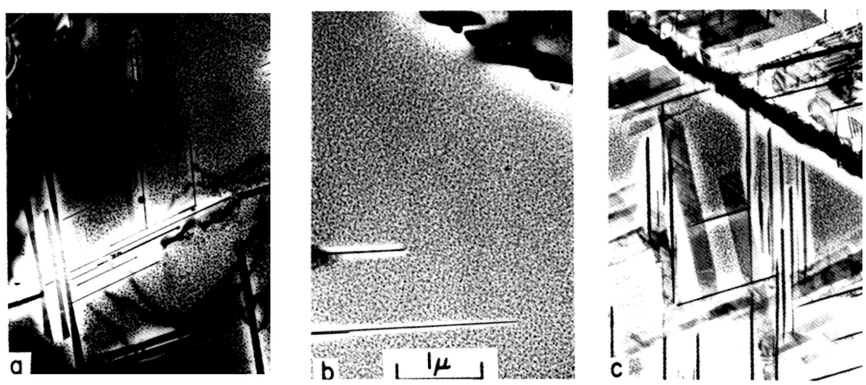


Fig. 5. Matrix precipitation near the grain boundary in A$\ell$-17.9 Ag aged 10 min at 578 K (a) Solutionized at 813 K - DQ (b) Solutionized at 813 K - WQ (c) Solutionized at 843 K - WQ

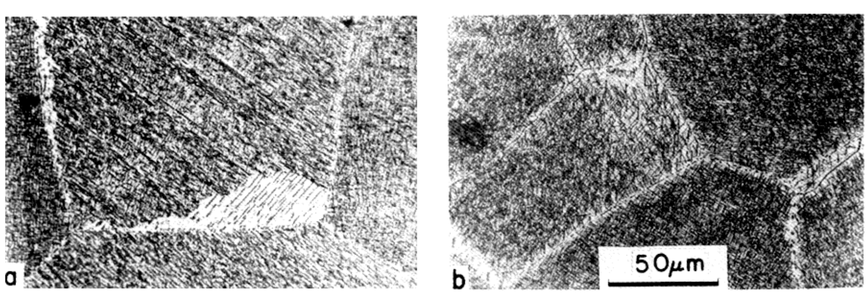


Fig. 6. Optical micrographs of A$\ell$-17.9 Ag aged 24 h at 578 K. (a) Solutionized at 758 K - WQ (b) Solutionized at 788 K - WQ.

since a greater free energy decrease can be realized locally.

As predicted the WQ samples have more cellular precipitation (3). The samples which were solutionized at higher temperatures have much more heterogeneous GP + $\gamma'$ matrix precipitation near the grain boundary, and thus show less discontinuous precipitation. (See Fig. 6.)

Several important conclusions can be drawn from the results presented here:

1. Since the solutionizing temperature and quenching procedure affect the presence and kinetics of the cellular reaction (3), it is imperative that both be clearly stated when attempts are made to illustrate regions in the phase diagram where the cellular reaction occurs.

2. The matrix precipitation has a large influence on the presence and kinetics of the discontinuous precipitation. As shown in Cu-Be, these precipitates sometimes must be characterized via TEM, since they are often unresolvable by optical methods.

3. As shown in Aℓ-Ag, it can be the microstructural features of the matrix near the boundary ($\sim$ 1 μm) which control the initial kinetics of the discontinuous reaction, not the general matrix precipitation.

4. It is often proposed that ternary alloying additions suppress the cellular reaction by segregating to, and thus reducing the mobility of the grain boundary. Our observation on the Cu-Be-X alloys show that this is not the operative mechanism in this system. If it were, the higher solutionizing temperatures should reduce the solute segregation, resulting in more discontinuous precipitation, not less as observed in these experiments.

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