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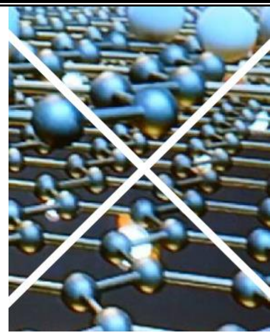

DISCONTINUOUS PRECIPITATION IN METALLIC ALLOYS

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Abstract

Discontinuous precipitation is a solid-state phase transformation. It is generally formed at grain boundaries. This paper presents a literature review on the previous investigations of discontinuous precipitation in metallic alloys. The mechanism of the occurrence and growth of this reaction is presented. In addition, the main parameters which affect its mechanism are listed. The future research questions will be formulated.

Keyword: Discontinuous precipitation, Phase, Metallic alloys, Grain Boundaries.

1. Introduction

Discontinuous precipitation (DP) (or cellular reaction) is a solid-state decomposition reaction that converts supersaturated solid solution α_0 into a two phasesα +β aggregate behind a migrating reaction front (RF) [1]:$\alpha_0 \rightarrow \alpha + \beta$

The cellular reaction originates at high angle grain boundaries by the formation of stable β-plate enriched in one of solute elements [2].The discontinuous precipitation (DP) is diffusive solid-state phase transformation during which a supersaturated solid solution decomposes into a usually lamellar structure of new phase β and solute depleted α phase having the same crystal structure as initial phase α_o (Figure1) [3]. The term "cellular precipitation" can be used instead of "discontinuous precipitation", because the shape of precipitates is as cells with lamellar structure.

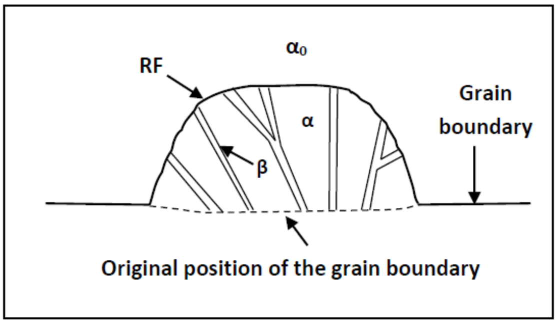

Figure 1. Schematic representation of a discontinuous precipitation at grain boundary.

The reaction front, which is usually an incoherent grain boundary (GB), migrates over the supersaturated matrix and is generally capable of supporting a composition gradient across it and a composition profile along it [4,5]. The reaction is the so-called discontinuous because it generates discontinuous changes in crystal orientation and solute concentration across the boundary-reaction front [2]. Figure 2 shows a typical of cellular precipitation in aged Mg-8 % Al. alloy at 150°C.

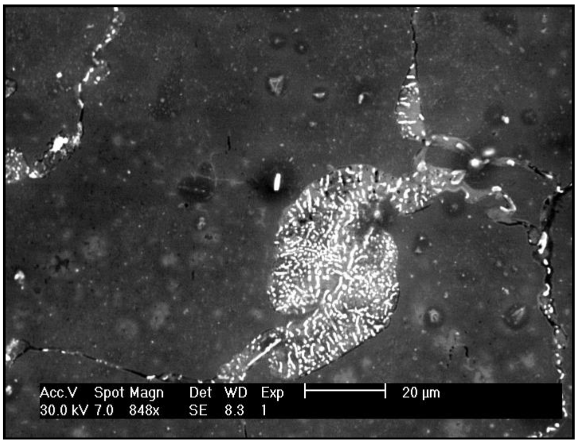

Figure 2. Cellular precipitation in Mg-8 % Al. alloy aged at 150°C for 50 h

In addition to the first reaction, a coarsening reaction is a second reaction which may also succeed the first finer structure formed after the discontinuous precipitation. The mechanism of this second reaction is achieved by a discontinuous process and the lamellae are larger.

1.2. Development of discontinuous precipitation in metallic materials

As mentioned by Manna et al. [6], a discontinuous precipitation has been observed in more than 131 binary alloys and 113 ternary alloys. However, in functional materials, a discontinuous reaction can generate dramatic effects on transport properties. It is therefore of practical importance to understand and control the kinetics of DP processes in alloy systems used in technology application, either to prevent it or to promote it [7]. Reviews on this subject [2, 5, 8] indicate that a wide variety of alloys undergo this kind of transformation. For the first 25 years following its discovery in 1930 [9], this precipitation reaction was considered as a curiosity. After this period, however, the number of annual publications on the event has not ceased to increase [7].

2. Research questions on discontinuous precipitation

It should be noted that the most important research questions on discontinuous precipitation can be divided into two categories:

The first category is related to the understanding of its mechanism, such as :

- Mechanism of the initiation of the discontinuous reaction
- Grain growth
- Coarsening
- Dissolution reaction

The second category concerns the effect of external parameters,such as:

- Effect of the temperature
- Effect of the third element in binary alloys.
- Effect of pressure.

In this following part, it is presented that some previous investigations related to the two main research questions: sites of initiation of DP and mechanisms of DP.

2.1. Sites of initiation

Seung Zeon Han et al [10] reported that numerous studies have suggested that in general the DP process starts at the grain boundary and the interface. In the previous investigations [11-16] it is confirmed the occurrence of discontinuous precipitation in grain boundaries and in other sites of the supersaturated phase α_0.

2. 2. Mechanisms of occurrence

Two main famous models are considered: precipitate-induced boundary migration and precipitation on migrating boundaries:

2.2.1. Precipitate-induced boundary migration

This model established by Tu and Turnbull [17] after investigation of Pb–Sn alloy on 1967. They observed that the first step for cell formation is the nucleation of a particle β at the grain boundary. Further growth of β may be determined by the habit plane with one of the two adjoining grains. Tu and Turnbull supposed that the orientation relationship is that of minimum interfacial energy. It is called also pucker mechanism. Figure 3 presents this ‘‘pucker’’ mechanism.

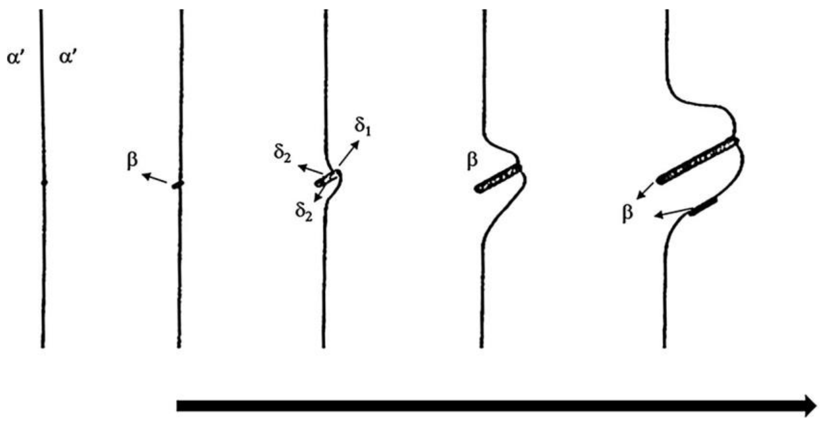

Figure 3. Pucker mechanism for initiation reaction according to Tu and Turnbull [17].

Figure 4 shows an example of discontinuous precipitation in Mg- 8 wt. % Al alloy. The new second phase nucleates at grain boundary which takes a shape of “S” and it is known as S-mechanism. This mechanism reflects the high mobility of grain boundary which accelerates the diffusion process of atoms during discontinuous decomposition. This initiation reaction is close to the Tu and Turnbull mechanism “Pucker mechanism”.

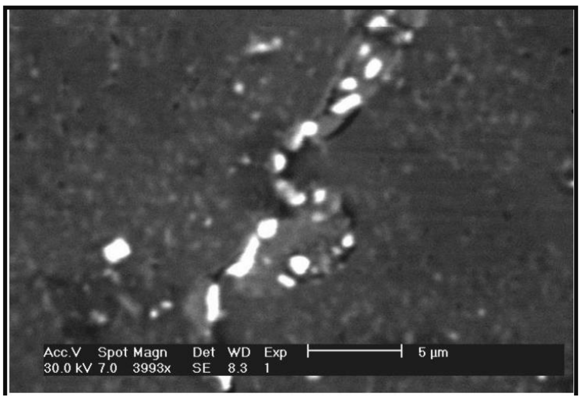

Figure 4. Microstructures of Mg- 8 wt. % Al after homogenization at 420 °C, quenched in water and followed by ageing treatment at 150 °C during 203 h.

2.2.2. Precipitation on migrating boundaries

This model proposed by Fournelle and Clark [18]. They considered the migration of a grain boundary due to its curvature. The migrating grain boundary depletes the area behind it of solute atoms by forming precipitates. This model is presented in Figure 5.

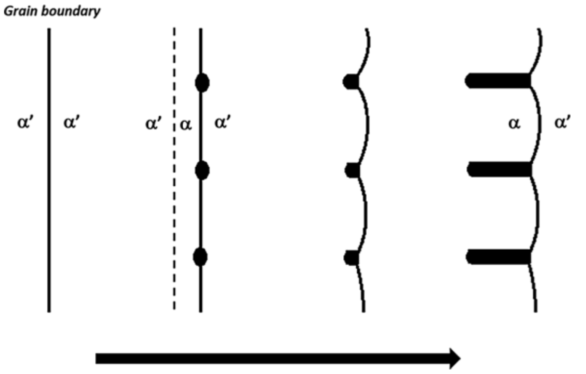

Figure 5. Development of a precipitation cell according to Fournelle and Clark [18].

2.3. Parameters affecting DP.

In this part, two parameters will be considered: the degree of deformation, and the addition of the third element in binary alloys. Concerning the effect of the degree of deformation on the DP reaction, Abdou et al [19] found that the discontinuous precipitation rate depends strongly on the degree of deformation in Ni-In Alloy. In the previous investigation, it is studied the effect of plastic deformation by compression on the occurrence of discontinuous precipitation in Al-30% Zn alloy after ageing at two different temperatures (348 and 423 K). As shown in Figure 6, this reaction is observed only for low degree of deformation. For higher deformation, the alloy is occupied only by deformation bands (Figure7) which represent favorite sites of finer continuous precipitates [14].

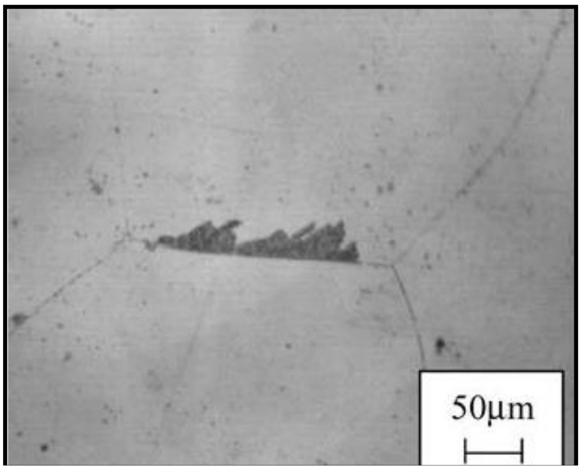

Figure 6. Microstructural of Al-30 wt% Zn alloy during aging at 348 K for 5 h [14].

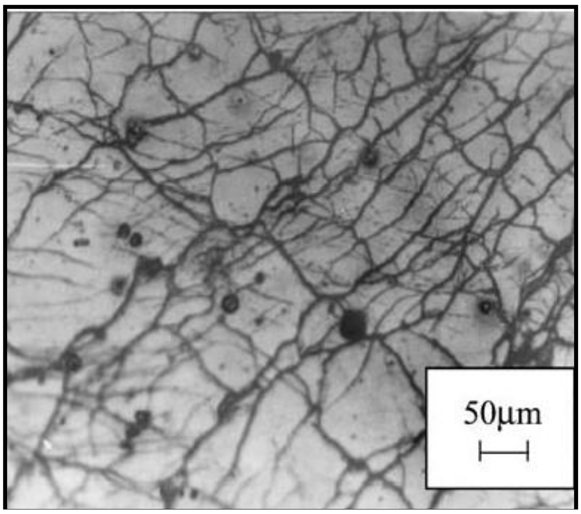

Figure 7. Microstructures of Al-30 wt% Zn alloy after 45% compressive strain and aged at 348 K for 5 h [14].

Concerning the effect of the third element addition in binary alloys, there are some published works. For example, Semboshi et al. [20] investigated the effect of boron doping on cellular discontinuous precipitation for age-hardenable Cu–Ti alloys. They found that the volume fraction of the discontinuous precipitates is lower in the Cu–4Ti–0.03B alloy than the Cu–4Ti alloy.

3. Future scope of DP

As mentioned by Zieba [3], the understanding the mechanism and kinetics of the discontinuous precipitation requires the use of very sophisticated analytical tools [3]. The objective of the future workwill be to measure the solute redistribution across the reaction front and within solute depleted lamella, especially for new types of discontinuous reactions. The future second challenge is to understand the mechanism of discontinuous precipitation. The third challenge is to investigate the effect of third element on controlling of the discontinuous precipitation in binary alloys. In addition, the observation of the discontinuous precipitation in meteorite [21], had given a large research field to this phase transformation.

4. Conclusions:

A discontinuous precipitation is among of phase transformation at solid state. Discontinuous precipitation is a diffusion reaction, and it has been observed in more than 131 binary alloys and 113 ternary alloys. However, in many metallic materials, discontinuous reaction can generate dramatic effects on their properties. Consequently, understanding the mechanism, and the effect of external parameters on its development remain a future scientific challenge.

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