

Solidification of Ledeburite Eutectic

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Abstract

The ledeburite eutectic is one from the most commercial eutectics of group the quasi-regular eutectics. The paper presents the knowledge of growth this eutectic. In the case high solidification, the foundation near which formulate the right growth eutectic they are fulfilled.

Keywords: Ledeburite eutectic, Solidification, Kinetics

1. Introduction

Eutectic alloys are the basis of most engineering. Eutectic alloys have relatively low melting points, excellent fluidity, and good mechanical properties. Consequently, a broad spectrum of eutectic alloys have been developed and are available for different applications.

In accordance with the old and universally accepted ideas the components of eutectic systems, which are almost insoluble (in many systems) in solid state, are infinitely miscible in the liquid state, i.e., at a temperature above the liquidus line on the phase diagram alloys are treated as liquid solutions of components. When cooled to the eutectic temperature T_e , a solution becomes supersaturated with both components; its crystallization occurs by diffusion decomposition into a mixture of crystals of almost pure components (solid solutions on their base, i.e., α and β). Eutectic equilibrium is described as $L = \alpha + \beta$ [1, 2].

The solidification of eutectic alloys generally gives rise to lamellar, fibrous, broken lamellar or complex regular spacings. The spacing of the lamellar or fibrous is typically very regular with a dispersion around an average value [3].

2. Solidification of a eutectic

A eutectic composition corresponds to such proportion of phases in the melt at which the entire dispersion medium is in a bound state, i.e., a state of solvation spheres of dispersed particles. Solvation, i.e., a change in the state of a dispersion medium under the action of the force field of the surface of dispersed particles (under the action of the interatomic interaction of the phases), is connected with the change in some properties of the medium, in particular, in the crystallization and melting temperatures. This explains crystallization of a eutectic at a lower (for the given system of components) and constant (in slow cooling) temperature T_e . Formation of a eutectic as a single (but two-phase) structural component of the melt occurs upon lowering of the temperature of the melt. When the temperature increases, the special state of the eutectic is not preserved (but this does not affect the general microheterogeneous structure of the melt); when the melt cools, the eutectic forms again. Since the eutectic has a two-phase structure in the liquid state, diffusion separation of the melt does not occur in crystallization; when T_e is overcome, the aggregative state changes only in the dispersion medium. The eutectic melts, as well as crystallizes, at the same critical (lower and constant) temperature T_e . Eutectic equilibrium can be described as $A_{liq} + B_{solid} = A_{solid} + B_{solid}$ [1].

Directional solidification of binary or pseudo-binary eutectics, may result in regular structures of fibrous or lamellar type. In fi-

brous growth, one of the phases grows in the form of fibres embedded into a continuous matrix of the other phase, while in the case of lamellar growth, two phases grow cooperatively side by side, in the form of lamellae. When two solid phases a and b growing from a liquid of eutectic composition C_E , the average undercooling ΔT at the interface results from three contributions.

$$\Delta T = T_E - T_L = \Delta T_c + \Delta T_r + \Delta T_k \quad (1)$$

where: ΔT is the average interface undercooling, T_E is the eutectic temperature and T_L is the local interface temperature, and ΔT_c , ΔT_r , ΔT_k are the chemical, capillary and kinetic undercoolings, respectively. For regular metallic eutectic systems, however, ΔT_k can usually be neglected compared to ΔT_c and ΔT_r . The α and β lamellae grow under steady-state conditions with a build up of B atoms in the liquid ahead of the α phase and the lateral transfer of solute to ensure steady-state growth [3].

Although the processes of solidification in cast irons have been studied now for several decades, the growth conditions governing formation of the various resulting morphologies are still neither fully defined nor properly understood.

A powerful tool for the study of the nature of the solid/liquid growth front is the directional solidification technique in which steady-state growth fronts are suddenly quenched. If the rate increase upon quenching is high enough, an abrupt change occurs in the microstructure at the growth front, which thereby reveals the growth front morphology [4].

The first rationalization of the gray-to-white structural transition (GWT) was based on the influence of cooling rate on the stable and metastable eutectic temperatures. As shown in Fig. 1, as the cooling rate increases, both temperatures decrease. However, since the slope of T_{st} is steeper than that of T_{met} , the two intersect at a cooling rate which is the critical cooling rate $(dT/dt)_{cr}$ for the GWT. At cooling rates smaller than $(dT/dt)_{cr}$ the iron solidifies gray, while at higher cooling rates it solidifies white. Magnin and Kurz further developed this concept by using solidification velocity rather than cooling rate as a variable, and considering the influence of nucleation undercooling for both the stable and metastable eutectics. Thus, a critical velocity for the white-to-gray transition and one for the gray-to-white transition were defined [5].

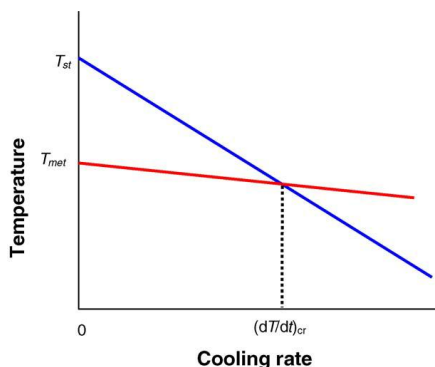


Fig. 1. Critical cooling rate for the GTW transition [5]

The next challenge of significant industrial interest was the prediction of the GWT. Fredriksson et al. and Stefanescu and

Kanetkar [6] approached it in 1986. By including both the stable and metastable phases in the calculation of the fraction solid, it was possible to output the solid fractions of gray and white eutectics. The basic equation was:

$$f_S = 1 - \exp[-4\pi/3(N_{Gr}r^3_{Gr} + N_{Fe_3C}r^3_{Fe_3C})] \quad (2)$$

where: N is the number of grains and r is their radius [5].

3. Solidification of ledeburite structure

Ledeburite is generally defined as the eutectic structure formed between Fe/Fe₃C. The term is used for both of the observed eutectic morphologies, i.e., rod ledeburite and plate ledeburite.

White iron structures generally form in a two stage process. First, plate-shaped dendrites of Fe₃C nucleate at a few locations in the supercooled casting and spread throughout the liquid in a fanlike growth pattern. This plate dendrite formation of Fe₃C occurred in both hypo- and hypereutectic alloys. In the hypoeutectic alloys, the first solid to form consisted of austenite dendrites, and the liquid between these dendrites was found to supercool significantly relative to the formation temperature of the white eutectic. Apparently, because of this supercooling, the first stage in the white iron formation was the growth of Fe₃C plate dendrites, just as in hypereutectic alloys; only in the hypoeutectic alloys, the Fe₃C dendrites grow around the preexisting austenite dendrites.

In the second stage for both hyper- and hypoeutectic alloys, a cooperative eutectic growth of austenite and Fe₃C occurs on the sides of the primary Fe₃C plates as the liquid between the plates solidifies, as Hillert and Subba Rao show schematically in Figure 2. The cooperative eutectic growth occurs at right angles to the primary Fe₃C plates, with the morphology being the very well-defined rod eutectic microstructure which is a dominant characteristic of white cast iron structures. In their model of the growth process, the initial edgewise growth (not shown on Figure 2) is a noncooperative growth of primary Fe₃C dendrites leading the growth front [4].

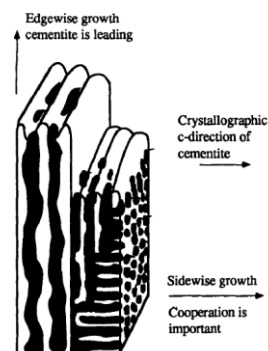


Fig. 2. Model of the structure of ledeburite growth by Hillert and Rao [4]

Figure 3 presents their conception of a section view of the growth front morphology of the ledeburite eutectic structure. The

growth front consists of platelike cells in which it is understood that the black parallel lines at right angles to the main growth axis are rod shaped. This structure occurs at a lower undercooling. Some cells, such as the left one, are drawn to indicate a cooperative growth mode of austenite and Fe_3C along both the main growth axis and the lateral direction, while other cells, such as the right one, show a leading Fe_3C front along the main growth axis, similar to the model of Hillert [4].



Fig. 3. Model of the structure of ledeburite growth by Rickard and Hughes [4]

During the side eutectic growth (x direction) the area of undercooling concentration of the liquid solution comes into being that leads to the destabilization of the front, which changes from the planar into cellular one. The growth of the cells leads to carbon enrichment in the intercellular niches, in which cementite can crystallize. Adjacent lamellar cementite shallows join together, the austenite shallow becomes distributed, plate eutectic changes into fibrous eutectic. During the further side growth of eutectic grains only fibrous eutectic still crystallizes. According to the observations, cementite eutectic changes into either continuous carbides phase with austenite inclusions interpolation of various degree of dispersal, or plate structure that consists of the austenite and cementite plates (Fig.4.) [7].

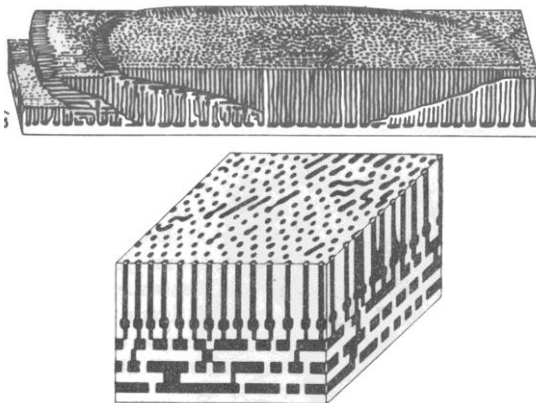


Fig. 4. Model of the structure of ledeburite growth [7]

3. Directional solidification of eutectic

Directional solidification technique is one of the most important methods to study crystal growth that is widely applied for the production of semiconductor material and casting such as Si single crystals and blades (Fig.5). However, all the directional solidification techniques at present are based on the positive temperature gradient on front solid/liquid interface, i.e. the constrained crystal growth. When the growth conditions are not controlled, the final eutectic morphology can be changed for dendrite or cellular microstructure or for anomalous eutectics structures. Comparison with the conventional directional solidification, the solidification of undercooled melts occur under a negative temperature gradient on front the solid/liquid and only dendrite structure can be obtained [8].

In the last years, the utilization of the directional solidification of eutectic alloys has been employed in a considerable number of experimental and theoretical investigation. The eutectic directional solidification provides us microstructures with the simultaneous formation of two solid phases from one determined liquid, i.e. the phases of interest are obtained directly from the melt [9].

The understanding of the phase relations around the eutectic region of binary systems is important because the binary eutectic liquid plays an important role in the overall magnetic performance of the magnets based on these rare earths metals. The experimental studies of alloys around the eutectic compositions of these binary systems showed that in alloys frozen quickly, metastable phases are observed and formed with an eutectic morphology, being easily identified through metallographic analysis [9].

Eutectic samples can be directionally solidified under an argon atmosphere in a Bridgman type furnace in order to determine the dependence of lamellar spacing λ_E , on the growth rate V , the temperature gradient G and the cooling rate GV [10].

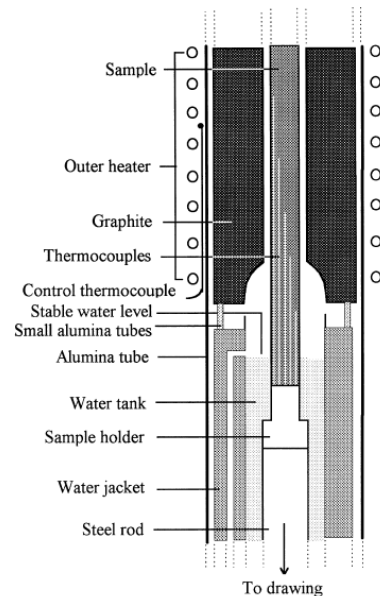


Fig. 5. Showing a schematic illustration of the Bridgman type directional solidification furnace [10]

4. Solidification process of faceted-nonfaceted eutectic alloys

The typical feature of quasi-regular eutectics, is much about equal volumetric contribution of both eutectic phases and the growth of one of the phases in the shape of the wall crystal. Typical examples of this kind of eutectic can be seen in the Fe-C alloys [11].

The characteristic of this group is that although they are in the anomalous (faceted/nonfaceted) class almost regular microstructures can be observed in these eutectics. In the quasi-regular eutectics the high degree of regularity may result from the fact that the faceted phase forms the matrix. Therefore, despite a high entropy of solution value, faceting may be prevented and the unpredicted appearance of almost regular microstructures can be explained [12].

It was demonstrated that the branching process proceeds in the direction of preferred orientation during nonfaceted-faceted eutectic growth. In nonfaceted-faceted eutectic alloys, the faceted phase acts as the leading nucleating phase, and the morphology of the nuclei depend on their preferred growth orientation. Branching of the faceted phase occurs in the preferred growth orientation during the growth process of eutectic grains [13].

Although the diffusions of solute and heat in the liquid ahead of the solid-liquid interface are all origins of the instability of the interface, they play different roles in the eutectic dendrite formation. With crystallization proceeding, the solute rejected by a eutectic phase is diffused to its adjacent phase and vice versa. Such a lateral interdiffusion supports their coupled growth, and is localized in a very narrow region. Its effect on the formation of the dendritic morphology can be ignored when the dendrite tip radius is much larger than the lamellar spacing [14].

5. Summary

The directional solidification of ledeburite eutectic can be observed in the Bridgman system. The influence of the growth direction on the establishment of ledeburite structure is interesting to investigate. In Bridgman growth, the difference between the thermal conductivities in solid and liquid phases induces a head loss to the crucible in the vicinity of the interface, which translates in a deformation of the front. The curvature of the solid-liquid interface is an obvious cause of radial segregation.

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