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ORIGINAL ARTICLE

Microstructural consideration on quantitative analysis of thermal treatment: Application to decarburization of steel

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Abstract Microstructural consideration is implemented in the calculation using commercial finite element analysis to study the effect of thermal treatment for engineering applications. As a typical example, decarburization problem has been studied in the paper. The modeling analysis is then to be compared with the experimental results. The simulation of phases such as single γ-Fe, mixture of γ-Fe and α-Fe, and the mixture of α-Fe and Fe_3C is performed by altering the heat treatment temperature. The simulated models have good agreement with the experimental results. The decarburization rate is the lowest at the temperature range between the two phases of γ-Fe and α-Fe coexist.

1. Introduction

The growing competition in manufacturing industries has made the thermal processing particularly become very important, since the properties and characteristics of the product are largely determined in this stage. The dependence of properties to the final product must be clearly understood, so that any analysis or experimentation can be used to design processes to achieve optimum quality at desired production rates (Chaengkham and Srichandr, 2011; Karbasian and Tekkaya, 2010). Engineers often have difficulties to analyze materials that involve more than one phase. Typically, this leads to homogenizing the materials that are microscopically far from being homogeneous. As a result, quantitative analysis is done poorly. In this paper, the basic idea of accommodating the phase difference into a model is outlined. Microstructural consideration is implemented in the calculation in a simple manner using commercial finite element analysis. The results are then compared with the experimental data. This technique is very useful for almost any type of materials that require quantitative analysis involving microstructure consisting of more than one phase.

As an example, typical decarburization process has been chosen in this study. The decarburization effect is defined as the loss of carbon atoms from the surface of ferrous materials, and produced a carbon concentration gradient across short distance below the surface. It is either as the result from preexisting condition in the material itself after being heat treated or the carbon is induced during heat treatment, which the atmosphere condition allows the depletion of carbon from the surface (Zhang et al., 2009; Prawoto et al., 2004).

1.1. Physical metallurgy of decarburization

Three types of decarburization mechanism are reported for different temperature ranges in the iron–carbon equilibrium dia-

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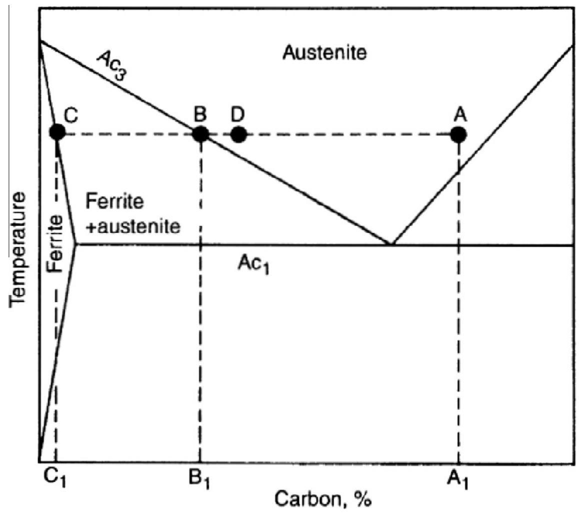

Figure 1 Iron–carbon equilibrium diagram for decarburization under different furnace atmospheres.

gram (Fig. 1) (Prawoto et al., 2004; Geoffery, 1999): above AC_3, between AC_1 and AC_3, and slightly below AC_1, referring to carbon–iron phase diagram. Above the upper critical temperature AC_3, the steel is in γ-Fe phase and if the furnace atmosphere is decarburizing, the steel may undergo decarburization process. The carbon tends to leave the surface to restore the equilibrium with the surrounding furnace atmosphere. A negative carbon gradient is produced with the carbon feeding down the gradient across the depth of the surface of the steel where the carbon content of the surface is determined by the carbon potential of the furnace atmosphere. The decarburizing reaction is different for temperatures between the upper critical temperature, AC_3, and the lower critical temperature, AC_1. For steel with high carbon content at A, the amount of carbon will drop rapidly to B when the furnace atmosphere is decarburizing in nature. For further lowering the carbon content will form equilibrium state at C, from carbon content at B. Finally, any further lowering of the average surface carbon content must be resulting from the development of single α-Fe phase with maximum carbon content C. The formation of α-Fe layer will reduce the rate of decarburizing. The α-Fe can only have a shallow carbon gradient, and then the rate of flow of carbon through the layer is reduced. As the thickness of α-Fe increases, it will cause further reduction in the rate of decarburizing due to the decrease in the effectiveness of the driving force for the movement of the carbon atoms across the layer. In a controlled furnace atmosphere, for instance with a carbon potential D which lies between A and B, a gradient is produced between A and D, and as time increases the gradient is slowly reduced until eventually no gradient across the surface. With the carbon content D it will not produce an α-Fe layer as the carbon content of the surface equilibrium with the furnace atmosphere, see Fig. 2 (Geoffery, 1999).

In this research, three different temperatures were chosen, 900, 800, and 700 °C, which are, respectively, to represent above AC_3, between AC_1 and AC_3, and slightly below AC_1. The chosen object was a hypoeutectoid steel due to its wide use in industries, from manufacturing to architecture (Ochshorn, 2004).

2. Computational approach

Computational analysis was done using *Abaqus*™ to simulate mass diffusions leading to the decarburizing effect. Three different ranges were chosen: above the AC_3, where there is only single phase of γ-Fe, between AC_1 and AC_3, where the mixture phases of γ-Fe and α-Fe coexist, and slightly below AC_1, where the phases are pro-eutectoid α-Fe and pearlite (mixture of α-Fe and Fe_3C). To accommodate the different phases present, sub-modeling technique was used. The sub-modeling technique allows the users to use the result of the global model as a boundary condition rather than giving the applied condition on each phase (Prawoto, 2011). The global model basically assumes that the material is homogeneous; to take into account the phase difference among the phases, local model is created. This technique allows the users neither to embed microstructure inside the model without the need to program in the form of multi-scale, which is cumbersome nor to model the whole structure with microstructure, which is practically almost impossible.

2.1. Global modeling

The global model is used to simulate the decarburization effect of steel to show the carbon concentration gradient from the surface to the bulk by mass diffusion of carbon. The global

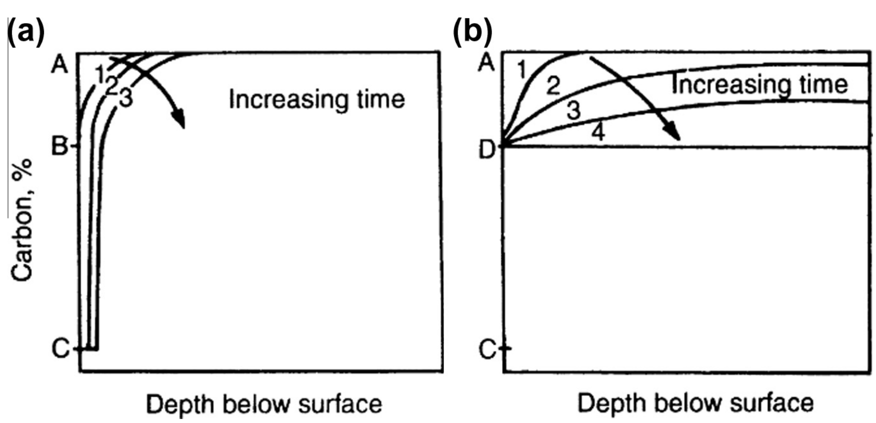

Figure 2 Effect of carbon potential at the surface to the decarburized surface. (a) Decarburizing atmosphere with carbon potential less than B. (b) Decarburizing atmosphere with carbon potential equals to D.