

The surface transfer kinetics of carbon in vacuum carburizing

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Vacuum carburizing is a developing carburization technology with many advantages, such as zero CO₂ emission, no internal oxidation, high utilization of fuels, and cleanness, which are both economically and ecologically beneficial. Although this technology has been utilized by industry, some fundamental properties, such as carbon potential (C_p) and the surface transfer coefficient (β) are not well understood, therefore hindering the development of process control. By analytic modeling and vacuum carburizing experiments for 17CrNiMo6, 20CrMnTi and 20CrMo steels with mixed C₂H₂ and N₂ fueling, we show that the C_p during the boost stage with pulsed fueling can be defined nominally and can be controlled continuously by tailoring the pulse frequency of fueling. Since the adsorption of C₂H₂ may not achieve thermodynamic equilibrium under low pressure condition, the C_p can be considered as a steady state variable instead of an equilibrium thermodynamic variable as used in atmospheric gas carburizing. The ratio of carbon diffusivity and β during the boost stage is determined to be lower than 10⁻⁸ cm at 930°C, much lower than that of the atmospheric gas carburizing, suggesting that the boundary condition of constant carbon content of C_p is more reasonable as compared to the usually used constant carbon flux boundary condition. In the diffusion stage under vacuum without fueling, there is no evidence of (de)carburization, that is, the value of β tends to be zero. These new findings show a feasibility of process control based on the steady-state C_p , and the infinitely large/small value of β during the boost/diffusion stage.

Keywords: Vacuum carburizing, Low pressure carburizing, Surface transfer, Carbon potential, Decarburization

1. Introduction

As early as 2400 BC, there were records in China of burning beans to make swords. This is actually a kind of solid Nitrocarburizing. The first industrial carburizing process using a carburizing powder was developed in the 19th century. But the control of the carbon flux or the carbon potential during the process is not possible. This is why the powder carburizing technique has no real importance anymore in today's industry.

The next step in carburizing was made at the beginning of the 20th century when the salt bath carburizing was developed. The carbon potential can be fixed by changing the composition of the salt bath. However, it is not possible to change the carbon potential during the process. Also, it is not environmentally friendly. So this technology is not in much use in today's industry.

In the second half of the 20th century, the first steps into the controlled gas carburizing were made, and it is the most successful carburizing technology. It is possible to change the carbon potential during a heat treatment process, by changing the composition of gas, such as CO, hydrogen, and so on. Nearly any type of carbon profile is attainable. But it has high CO₂ emission and the utilization of fuels is very low.

The latest development in carburizing is vacuum carburizing, also termed as low pressure carburizing. It represents a cutting-edge heat treatment technology and a research hotspot. The main difference compared to controlled gas carburizing is that the vacuum carburizing works with hydrocarbon gases as carbon donor in place of CO. As a consequence, there is no internal oxidation, and no CO₂ emission. In addition, the utilization of fuels is very high. Because the low pressure carburizing is combined mainly with a high pressure gas quenching, it is a very clean and environmentally friendly process.

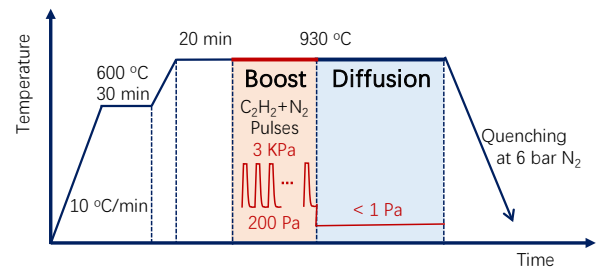
However, the surface transfer kinetics of carbon in

vacuum carburizing has not been well understood.

2. Experimental and Model

2.1 Experimental

We performed vacuum carburizing experiments for three types of alloy steels using the furnace by Beijing Research Institute of Mechanical & Electrical Technology. The Vacuum Carburizing Parameters are shown in Fig1. As shown, we studied the effects of three processing parameters. The Pulse Period of gasing, the boosting time and the diffusion time.



Batch	Pulse Period, min/pulse	Boost, min	Diffusion, min
1	6	42	140
2	3.5	42	140
3	3.5	49	140
4	3.5	35	100

Fig.1 Vacuum carburizing process parameters.

2.2 Model

During the boost stage of vacuum carburizing, we consider the surface exchange as a diffusion process over a Pseudo distance of D/β above the surface. Also we assume constant parameters. The solution is the classic error function with the first-type of boundary condition. A

correction of Pseudo distance of D/β is introduced in the solution. So we can calculate the carbon profile for any values of D , β and C_p .

For the diffusion process. We assume that there is no carbon effusion, because it is not thermodynamically favored. By using green function method, the carbon profile can be predicted from the boost stage by the integral function. If the carbon profiles after boost stage and the diffusion stage are known from experiments, we can estimate the values of D , β and C_p by curve fitting.

Fig. 2 shows the models for the boost and diffusion stages of the vacuum carburizing process.

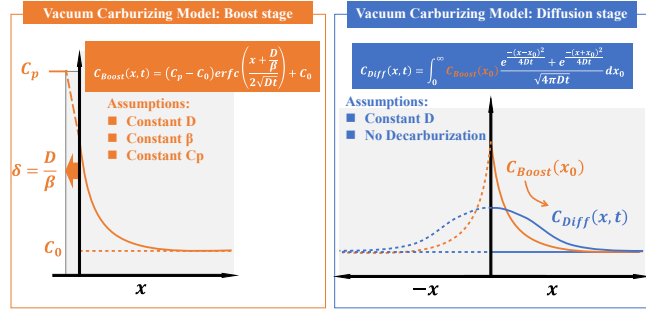


Fig. 2 The model for vacuum carburizing process.

3. Results and discussion

Fig.3 shows a carbon profiles after boost stage and diffusion stage. The scatters are experimental data, and the curve is the fitted one by the boost model.

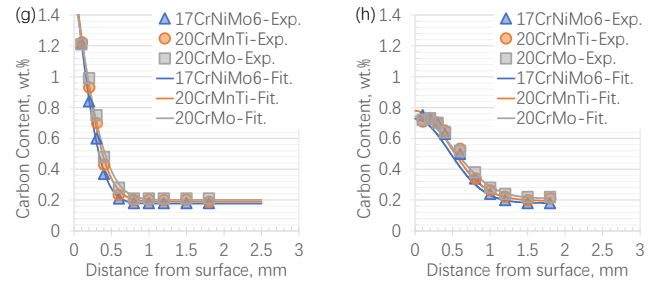
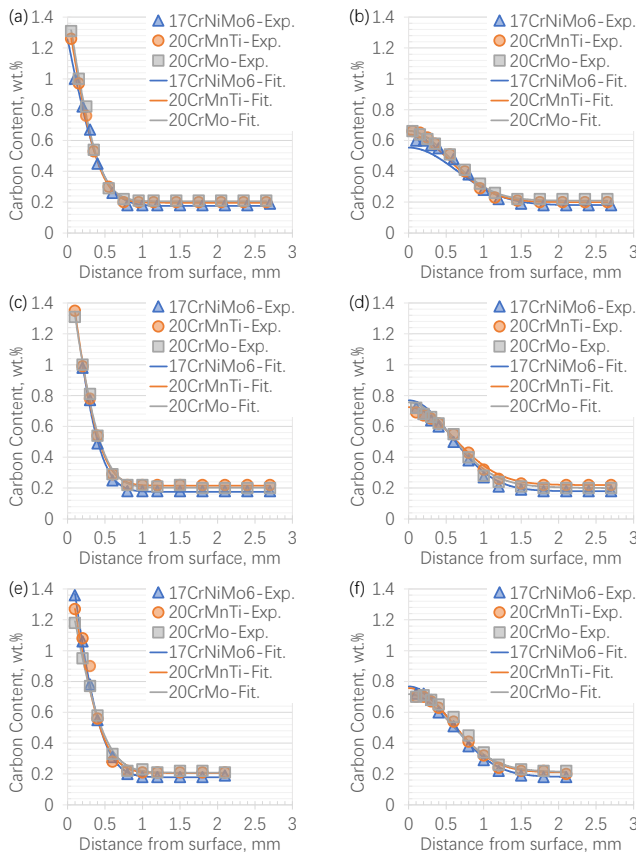


Fig. 3 The carbon distributions for steels 17CrNiMo6, 20CrMnTi and 20CrMo after boost (a, c, e, g) and boost-diffusion (b, d, f, h) by the vacuum carburizing batch 1 (a, b), 2 (c, d), 3 (e, f), and 4 (g, h) as noted in Figure 1. The scatters represent experimental data, and the curves represent fitting results by the analytical model.

It is shown that the models fit well with the experimental. It is verified that the diffusion stage has no carbon effusion. Theoretically, we can estimate the values of D , β and C_p . But the fitted value of D/β is very small (order of 10^{-8} cm), that is the value of β is orders of higher than that of the gas carburizing. This indicates that we cannot obtain a rational value of β , but we can estimate the values of D and C_p .

Fig.4 shows the effects of pulse frequency of gassing and the boosting time on the C_p . We can see that the C_p is relatively higher than those of the gas carburizing. Although it is high, but it is finite. C_p can be tailored by pulse frequency of gassing, but is not sensitive to boosting time. It indicates that C_p can be considered as a steady-state variable. And the adsorption of C_2H_2 is not under local equilibrium, and is a rate limiting step. This means that the C_p as determined by the adsorbed C_2H_2 will decrease with the decreasing of C_2H_2 pressure.

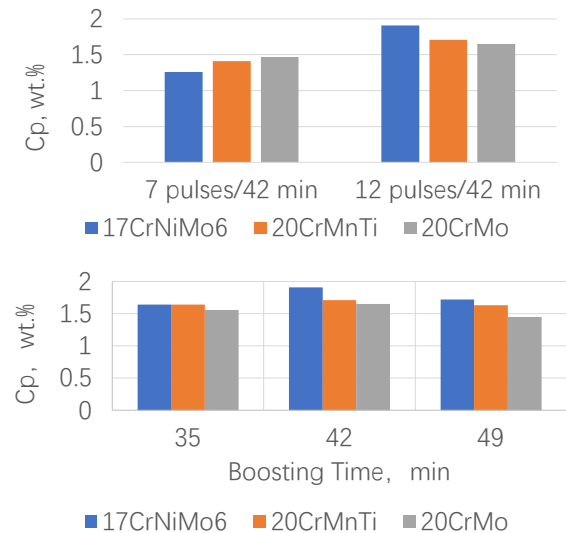


Fig. 4 The evolution of nominal carbon potential (C_p) with pulsed fueling. (a) Effect of pulse period on C_p at $930^\circ\text{C} \times 42$ min boost. (b) Effect of boosting time on C_p at $930^\circ\text{C} \times 3.5$ min/pulse fueling.

Fig. 5 shows the effects of boosting time and diffusion time on the diffusion coefficient. We can see that D is sensitive to process stage, time, and steels. That is D is sensitive to carbon content and alloy elements. But the

value is comparable to those of the controlled gas carburizing.

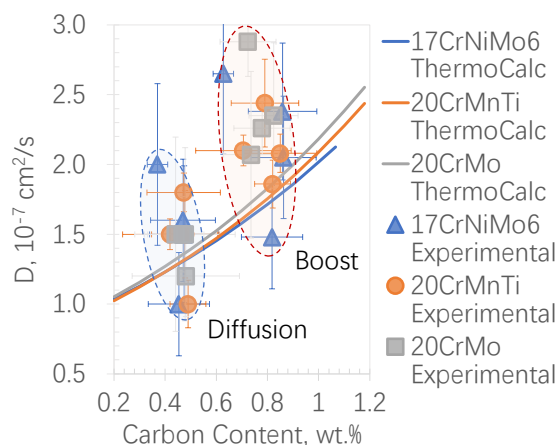


Fig. 5 The carbon diffusivities for the boost and diffusion stage where scatters are the fitted results with 95% confidence bonds, and curves represent the data from Thermo-Calc software.

4. Conclusion

First, β is much higher than that in controlled gas carburizing, that is fast exchange. Second, Adsorption of C_2H_2 is not under local equilibrium. This leads to Finite but high C_p . Third, The models fit well with experimental, suggesting that vacuum carburizing has no carbon effusion. Forth, the diffusivity of carbon during vacuum carburizing is comparable to those of controlled gas carburizing.

Acknowledgments

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