Development of Continuous Type High-speed Carburizing Furnace

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In our manufacturing plant, each production process has been improved from the point of environmental protection (energy-saving). Especially, much energy is consumed in the heat treatment process, and so, this reduction is an urgent and indispensable subject. In this paper, development of a continuous type high-speed carburizing furnace is reported as an example of energy-saving approach. This furnace has been developed with adoption of high carbon oxide carburizing technique in collaboration with Koyo Thermo Systems Co., Ltd.

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Key Words: high-speed carburizing furnace, bearing, energy saving

1. Introduction

For the purpose of providing environmentally-friendly (i.e., energy-saving) manufacture processes, every manufacturing plant in Koyo is taking various measures depending on each production process. One of the processes which require special attention from an environmental protection viewpoint is a heat treatment process because this process consumes a great amount of energy as compared to other bearing production processes (see Fig. 1). Thus, Koyo thinks that it is imperative to provide an energy saving measure to the heat treatment process. Among the steps composing the heat treatment process, a carburizing one operates at relatively high temperature for a long hours and thus is given a top priority as a step requiring environmental protection measures.

As an example of such energy-saving efforts by Koyo, in our manufacturing plant, each production process has been improved from the point of environmental protection (energy-saving). Especially, much energy is consumed in the heat treatment process, and so, this reduction is an urgent and indispensable subject. In this paper, development of a continuous type high-speed carburizing furnace is reported as an example of energy-saving approach. This furnace has been developed with adoption of high carbon oxide carburizing technique in collaboration with Koyo Thermo Systems Co., Ltd.

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2. Carburizing Technique with High Concentration Carbon Oxide

The migration of carbon from atmosphere gas to steel surface (i.e., carburizing) is mainly caused by the following carburizing reaction:

\[
\begin{align*}
\text{Boudoir reaction:} & \quad 2\text{CO} = \text{C} + \text{CO}_2 \\
\text{Water gas reaction:} & \quad \text{CO}_2 + \text{H}_2 = \text{CO} + \text{H}_2\text{O}
\end{align*}
\]

(1) + (2) yields:

\[
\begin{align*}
\text{Carburizing reaction:} & \quad \text{CO} + \text{H}_2 = \text{C} + \text{H}_2\text{O}
\end{align*}
\]

where the underlined parts show the incursion of carbon into the steel interior.

Equilibrium relations in the above formulas (1) and (3) are represented by the following formulas, respectively:

\[
\begin{align*}
\text{Ac} &= K_1 \left( \frac{\text{PCO}^2}{\text{PCO}_2} \right) \\
\text{Ac} &= K_2 \left( \frac{\text{PCO} \cdot \text{PH}_2}{\text{PH}_2\text{O}} \right)
\end{align*}
\]

where "Ac" represents carbon activity, magnitude of which determines carburizing capacity; the greater Ac is, the more active carburizing reaction happens. In other words, by the formulas (4) and (5), the greater the partial pressure of CO and the product of partial pressures of CO and H2, the larger Ac is, thereby improving the carburizing speed by atmosphere gas.

The above-described migration of carbon from atmosphere gas to steel surface has the following two stages:

The first stage is a carburizing stage in which the carburizing reaction between atmosphere gas and steel causes carbon to migrate. The second stage is a diffusing stage in which the atmosphere gas and the steel surface having equal carbon potentials cause the carbon existing on the steel surface to diffuse into the inside of steel, thereby reducing the carbon potential on the steel surface relative to the atmosphere gas. The reduced carbon potential is recovered by receiving carbon from the atmosphere gas, during which the diffusion rate of carbon from the steel surface into the inside of steel becomes rate-determining. Judging from the above, more efficient carburizing process with reduced process time can be obtained by increasing the carbon activity of the atmosphere gas as much as possible when the rate at which carbon migrates from the atmosphere gas to the steel surface is rate-determining. More specifically, it is preferable during the carburizing stage to increase the partial pressure of CO simultaneously with setting maximum value of the product of partial pressures of CO and H₂.

3. Evaluation of Carburizing with High Concentration CO

For using the high concentration CO-used carburizing technique using the above theory in mass production furnaces, an evaluation test was performed on this theory, results of which will be described below.

3.1 Details of Test

In this test, high concentration CO gas and commonly-used endothermic gas (RX gas) were used as atmosphere gases, compositions of which are shown in Table 1, respectively.

<table>
<thead>
<tr>
<th>Atmosphere Gas</th>
<th>CO</th>
<th>H₂</th>
<th>N₂</th>
<th>PCO × PH₂ × 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>RX gas</td>
<td>24</td>
<td>29</td>
<td>47</td>
<td>7</td>
</tr>
<tr>
<td>High concentration CO gas</td>
<td>30</td>
<td>70</td>
<td>-</td>
<td>21</td>
</tr>
</tbody>
</table>

In this test, a commonly-used batch-type carburizing furnace was used and carbon potential was controlled by an O₂ sensor. Since each of the atmosphere gases has different CO concentration, gas in the furnace was sampled and measured to feedback the result to the O₂ sensor controller so that the carbon potential in each of the atmosphere gases could be subjected to the carburizing process with the same setting.

This test used a heating pattern as shown in Fig. 2 and set three levels of test temperatures as shown in the Figure in order to clarify whether the difference in processing temperatures has an influence on a carburizing process. High concentration CO gas can use its feature only in the first stage of carburizing process. Thus, in this test, high concentration CO gas was used only in the first stage of carburizing process in Fig. 2 and RX gas was used in the other stages (e.g., diffusing stage).

3.2 Result of Evaluation Test

Figure 3 shows the result of investigating the effective case depth of carburized samples by each atmosphere gas.

As shown in Fig. 3, high concentration CO gas shows superior carburizing performance than that of RX gas at every process temperature. As the slopes of high concentration CO gas and the RX gas show, the high concentration CO gas at high process temperature has higher rate at which the effective case depth increases than that of the RX gas. This is presumably caused by the fact that the increase in processing temperature accelerates the rate at which carbon diffuses from the steel surface into the inside of steel, thereby allowing high concentration CO gas to fully provide its feature by which the carbon migration from atmosphere gas to steel surface is more activated. As can be seen from the above result, use of high concentration CO gas can provide a synergistic effect as described above. Therefore, it would be desirable to set higher processing temperature.

4. Feature of Development Furnace

As described above, use of high concentration CO gas provides reduced carburizing time, thereby providing an advantage of energy saving. The high concentration CO gas can provide maximum effect on reducing carburizing time in a continuous type heat-treatment furnace. Thus, a continuous high-speed carburizing furnace as shown below was developed, the outline of the structure and the appearance are shown in Fig. 4 and Fig. 5 respectively.

Fig. 2 Heating pattern in evaluation test

Fig. 3 Effective case depth by each atmosphere gas

Fig. 4 Continuous high-speed carburizing furnace
4. 1 High Concentration CO Atmosphere

The greatest feature of this heat-treatment furnace is the provision of stabilized high concentration CO atmosphere in carburizing zones. A basket-conveying-type continuous furnace generally receives and transmits workpieces and quenches therein with a regular cycle. This causes the internal pressure of the furnace to fluctuate whenever the furnace performs each of the above operations with a regular interval, thereby causing the furnace to receive disturbance such as external air. To avoid such a disturbance, this furnace has a vacuum purge system at front and rear doors thereof and also has a carburizing zone sandwiched by isolation doors, which are the weakest part to such disturbance. The furnace also ensures the control of the position and volume of the atmosphere gas introduction as well as the emission volume of exhaust furnace gas, thereby optimizing the gas flow therein and ensuring high CO concentration in the carburizing zones as well as the accurate control of the atmosphere therein.

4. 2 High-temperature Carburizing

Since high-speed carburizing requires high temperature, this carburizing furnace is designed to be used at high temperature. This furnace is also designed to have a lengthened heating zone so that workpieces therein can be uniformly heated to the predetermined temperature before reaching the carburizing zones. This is because that the reduced carburizing time requires heating within a shortened cycle. Therefore, the heating zone in the furnace is provided with a regenerative burner having high combustion efficiency, thereby providing an advantage of energy saving.

5. Energy Saving Effects

The result of the above test showed that this high-speed carburizing furnace with high concentration CO had 54% reduction in carburizing time and 50% reduction in energy cost as compared with the same type of heat-treatment furnace provided with a conventional electric heater, providing substantial energy-saving effect (Fig. 6).

This heat-treatment furnace used a roller hearth system for the transportation to accommodate a plurality of isolation doors. As the result, this roller hearth system is combined with the above high-speed carburizing process to allow this furnace to have 75% reduction in the length of a setup replacement time as compared with a tray pusher system, thereby providing a substantial advantage for reducing a lead time.

6. Conclusion

As described above, a continuous-type high-speed carburizing furnace developed through the collaboration with Koyo Thermo Systems Co., Ltd., was introduced as an example of Koyo's energy-saving efforts. This furnace has remarkable effects as described above and will be one of Koyo's core products which provide both of environmental friendliness and lower cost.

Koyo is and will be a contributor to an environmental protection and a recycle-oriented society by providing innovative production apparatuses including the above furnace as well as new production methods.

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