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PROCESS FOR PRODUCING A LOW-TEMPERATURE TOUGH STEEL

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This invention relates to processes for producing a steel having a good weldability and a high toughness at a low temperature.

In order that a steel may be tough at a low temperature, its transition temperature must be low enough for the using condition. Such transition temperature is a criterion for judging the low-temperature brittleness of a steel but it is remarkably affected by the chemical composition, producing process, and thermal hysteresis of the steel.

Carbon has the greatest effect among the chemical components. With the increase of the carbon content, the transition temperature will increase. Phosphorus and nitrogen together will increase the transition temperature. Manganese is an effective component. The ratio of Mn/C of not less than ¾ is considered acceptable. Such gases contained in a steel as oxygen, nitrogen and hydrogen will make the steel brittle. In case the steel is not well deoxidized, the transition temperature will increase.

In spite of such harm, on the other hand, nitrogen in the steel results in favourable toughness at low temperature when aluminum nitride is separated at the temperature of A_3 transition point. Therefore, a certain amount of nitrogen rather favours aluminum contained steel. By taking the above mentioned points into consideration it is possible, especially with the recent top blowing converter steel making process and vacuum-degassing process, to produce a low temperature tough steel in which the transition temperature is low enough. According to such treating process, the chemical components in the steel which act in the direction of increasing the transition temperature can be remarkably reduced but the oxygen in the steel can not be so easily removed.

We have confirmed that, when the nitrogen content in a molten steel of a carbon content of not more than about 0.15% as refined in an open-hearth furnace, electric furnace or converter is adjusted to be about 0.008 to 0.04% by adding additional nitrogen in accordance with this invention and said molten steel is degassed in a vacuum, the oxygen content will be remarkably reduced. As a result, a low-temperature tough steel superior to any conventional one will be obtained.

In an ordinary open-hearth steel, electric furnace steel or converter steel, nitrogen is removed only slightly. This is because the nitrogen content in the molten steel is of a value (of not more than about 0.008%) near the balanced solubility under a pressure of 1 to 40 mm. Hg in degassing. If the nitrogen content is made higher than about 0.008% and the molten steel denitrified under a

pressure of not more than 40 mm. Hg, this results in promoting an ardent foaming phenomenon within the vacuum vessel and serves to increase the surface area of the molten steel in the vacuum. In this manner the CO reaction and therefore deoxidation will be accelerated. On the other hand, the nitrogen content after the refinement in vacuum will be reduced to near the amount as of before the addition. But the necessary amount of nitrogen will remain to obtain a steel having excellent toughness at low temperature.

The present invention has succeeded in obtaining a steel of a very low oxygen content by accelerating deoxidization by utilizing the above-described phenomenon, and separating residual nitrogen as aluminum nitride.

In the process of the present invention, it is for such reason as is mentioned above that the nitrogen content in the molten steel is adjusted to be higher than about 0.008% in the first step. However, if the nitrogen content is too high, it will not be economical. It is, therefore, preferable that the maximum be about 0.040%.

In order to adjust the nitrogen content, nitrogen may be added in the state of gaseous nitrogen or as a nitrogen alloy. The thus adjusted molten steel is to be degassed in a vacuum. According to the present invention, there is used a method wherein a part of molten steel in a ladle is successively sucked into a vacuum vessel, remains therein for a short time and is returned to the ladle. By carrying out such vacuum degassing, not only the dissolved hydrogen can be removed and any internal defect in the steel material can be prevented but also the reaction $C+O=CO$ is promoted and oxygen can be removed in the form of CO gas. As a result, a steel of a remarkably low oxygen content can be obtained.

Depending on the circumstance, any desired alloying elements may be added to the molten steel vacuum-degassed according to the present invention so that the composition may preferably be not more than 0.15% C., 0.01 to 0.10% Al, 0.5 to 2.0% Mn, 0.01 to 1.0% Si and, as required, a total of 0.01 to 0.02% of one or more of Nb, Ta and V. By thus limiting the composition, a steel which is tough at a lower temperature can be obtained.

Further, according to the present invention, if the nitrogen content in the molten steel as refined in an open-hearth furnace or the like is adjusted to be between about 0.008 to 0.04%, at the same time the ratio of C/O in the molten steel is adjusted to be about 3/4 by adding such adjusting agent as a deoxidizing agent or a carburizing agent. Said molten steel is then degassed in a vacuum whereby carbon and oxygen contents will be reduced to an extreme low.

In the case of vacuum-degassing the molten steel, carbon and oxygen will be removed at an equivalent mol ratio, that is, at a weight ratio of $C/O=3/4$. Therefore, in order to reduce both carbon and oxygen, it is advantageous to degas the molten steel with the C/O ratio kept at about 3/4. In the present invention, from such viewpoint, the nitrogen content in the molten steel is adjusted according to the present invention, and at the same time the C/O ratio is maintained at about 3/4 so that the carbon and oxygen contents may be reduced to extreme low and a steel having excellent low-temperature characteristics obtained.

In order to adjust the C/O ratio of the starting molten steel, any known deoxidizing agent or carburizing agent may be used. The deoxidizing agent to be added may be Al, Si or C. In case carbon is used, there will be a feature that no deoxidization product will remain in the steel. Further, such compound as Si–C–Fe can be also used.

The above mentioned addition of carbon will act for carburization under the normal pressure and will perform a deoxidizing action under a reduced pressure. Therefore, in the present invention, there is no distinction between "the deoxiding agent" and "the carburizing agent."

The present invention shall be explained more particularly with reference to the following example. Table 1 shows the chemical composition of sample A which is a steel refined by an ordinary process in a basic open-hearth furnace; sample B which is a steel made by reducing oxygen by vacuum-sucking up and degassing a molten steel in a ladle after tapping and then adding such elements as Mn, Si and Al within and vacuum vessel; and sample C which is a low-temperature tough steel of the present invention is made by refining a molten steel ordinarily in a basic open-hearth furnace, then adding manganese nitride to the molten steel in a ladle at the time of tapping so that the nitrogen content might be 0.013% and further vacuum-degassing the molten steel to remarkably reduce oxygen, and then adding such elements as Si and Al within vacuum vessel. Each of these steels was rolled into a steet sheet 25 mm. thick and was normalized for 1 hour. In the steel of the present invention, the nitrogen content become 0.005% due to degassing, being removed by 0.008% to be the amount as of before the addition. The deoxidization was accelerated by the increase of foaming due to denitrification. Though the sample C was degassed for the same time as in the sample B, the oxygen content of C decreased to 0.002%.

Table 2 shows the V-notch charpy 15 ft.-lb. transition temperature (abbreviated as Vtr. 15) and the pressed notch charpy coated surface transition temperature (abbreviated as PTC) of each of said steels.

According to the results of the charpy tests, the sample C of the present invention was superior to the samples A and B due to the deoxidizing effect. On the other hand, in the double-tension test crack stopping temperature (abbreviated as Tra.), the effect of removing oxygen appeared more clearly. The sample by the process of the present invention showed an especially high Tra. value. Though open-hearth furnace steels are shown in the example, the same effects will be obtained with electric furnace steels and converter steels.

TABLE 1

Example of chemical composition

Sample	Carbon	Silicon	Manganese	Phosphorus	Sulphur	Nitrogen	Oxygen	Remarks
A	0.14	0.26	1.03	0.016	0.023	0.004	0.006	
B	0.14	0.23	0.99	0.015	0.022	0.003	0.004	Degassed by vacuum-sucking up.
C [1]	0.15	0.25	1.01	0.018	0.025	0.005	0.002	Degassed by vacuum-sucking up after adding nitrogen.

[1] Steel of the present invention.

TABLE 2

Various transition temperatures

Samples	Vtr. 15 (°C.)	PTC (°C.)	Tra.[1] (°C.)
A	−32	−11	−13
B	−33	−19	−25
C[2]	−36	−40	−52

[1] The stress used was ½ the yielding point stress.
[2] Steel of the present invention.

What is claimed is:

1. A process for producing low-temperature tough steel which comprises adding a nitride to a molten steel prepared in an open-hearth furnace and containing 0.15% by weight carbon to raise the nitrogen content of said molten steel to between about 0.008 to about 0.04% by weight for effecting ardent foaming phenomenon during the subsequent degassing treatment, sucking up successively a part of the thus obtained molten steel into a vacuum degassifying vessel, degassifying the thus sucked up molten steel in said vacuum degassifying vessel while maintaining a pressure in said vessel of from 1 to 40 mm. Hg, said degassifying reducing the oxygen content of said molten steel to not more than 0.002% by weight and the nitrogen content to about that which it was before adding nitrogen thereto, and recovering the product.

2. A method for producing a low-temperature tough steel claimed in claim 1, in which manganese nitride is added to a molten steel in a ladle so as to make the nitrogen content of said molten steel about 0.013% by weight.

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