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Improvement in Steel Smelting by Studying Melt Behavior

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Abstract—Analysis shows that the disequilibrium of melts may be used to characterize metal quality and to optimize smelting technology. For the production of pipe steel by means of a superpowerful DSP-135 arc furnace, a ladle–furnace unit, a vacuum-treatment system, and a continuous-casting machine, the sources of melt disequilibrium are studied in relation to the properties of the final steel. That provides the basis for the development of parameters characterizing different stages of the process. The proposed improvements in smelting technology are shown to be very efficient.

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Today, we may characterize metallic melts in terms of quasi-crystalline structure and microheterogeneity and also in terms of disequilibrium. In a solid–liquid phase transition, the disequilibrium of the melt is associated with its inheritance of heterogeneity and structural defects from the crystals and the activational character of change in melt structure. Solidification from nonequilibium melts results in unstable structure and properties of the final steel, according to many researchers. (For example, see [1].)

In modern steel smelting, consisting of the smelting of a low-carbon intermediate product and the subsequent adjustment of its composition in ladle refining, the disequilibrium of the melt is due to intense melting processes, the addition of large masses of material for carburization and alloying, and the extensive use of gas, liquid, and solid reagents.

From research on pipe-steel production by means of a superpowerful DSP-135 arc furnace, a ladle–furnace unit, a vacuum-treatment system, and a continuous-casting machine, we conclude that disequilibrium of the melt is primarily associated with decrease in plasticity of the final steel, as indicated by experimental data (Fig. 1). The disequilibrium of the melt is estimated from the damping time of fluctuations in the kinematic viscosity (the relaxation time) in isothermal laboratory experiments. The steel samples characterized by a long relaxation time—that is, by greater disequilibrium—are characterized by reduced relative elongation in fracture tests. In general, disequilibrium of the melt's structure is associated with defects of the cast billet.

We now consider in more detail the sources of melt disequilibrium and its relationship with the properties of the final steel [2]. That provides the basis for the development and optimization of parameters for different stages of the process.

1. SMELTING

The oxidation of the intermediate product has the determining influence on the disequilibrium of the melt and the plasticity of the steel (Fig. 2). For stabilization and enhancement of steel quality, the oxidation of the intermediate product should not exceed 800 ppm. Parameters characterizing the smelting of the intermediate product have been developed so as to ensure regulated oxidation by optimizing the oxygen injection and the slag conditions. To obtain oxidation in the range 500–800 ppm, the total oxygen consumption in the melt should be no more than 3000 m^3 (Fig. 3a). Correspondingly, the FeO content in the slag should be no higher than 20–30% (Fig. 3b).

2. ALLOYING IN THE LADLE–FURNACE UNIT

The alloying of the steel has a significant influence on the disequilibrium of the melt and the performance of the solid metal. Increase in the mass of ferroalloy

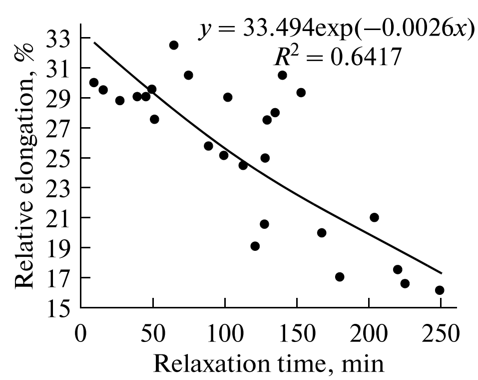

Fig. 1. Relation between disequilibrium of the melt and plasticity of carbon pipe steel.

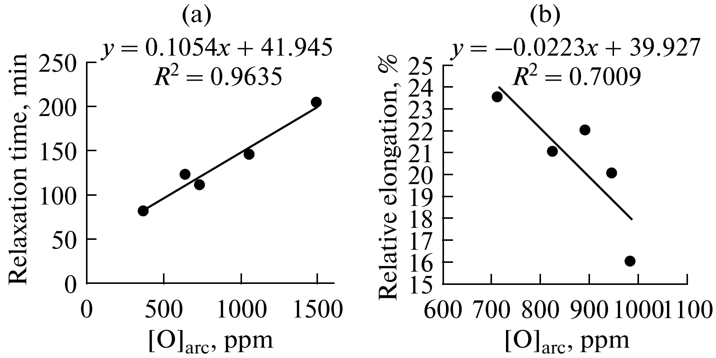

Fig. 2. Relation between the oxidation of the intermediate product and the disequilibrium of the melt (a) and the properties of Д steel pipe (b).

added during treatment of the steel in a ladle–furnace unit extends the relaxation time of the melt (Fig. 4a) and reduces the impact strength of the steel (Fig. 4b). The steel quality may be enhanced and stabilized by correcting the chemical composition at an earlier stage of treatment and by increasing the metal temperature when the additives are introduced.

In addition, the grade of the ferroalloy used for alloying also affects the time for the melt properties to stabilize after addition of the alloying additive. In particular, the replacement of FKh100 ferrochrome by FKh010 ferrochrome shortens the relaxation time for the melt, as we see in Fig. 5. That may be due to the influence of the formation of stable chromium carbides on the dynamics of melt formation when the carbon content of the alloy is high.

On that basis, we may develop recommendations for the alloying conditions and the types of alloys employed. When the ferroalloys are added, the metal temperature should exceed the specified steel temperature in the continuous-casting machine by at least 20°C. After delivery of the ferroalloys, the metal temperature must not fall below the specified steel temperature in the continuous-casting machine. At this time, the metal's chemical state may be corrected by means of ferroalloys whose total mass is no more than 100 kg. Low-carbon ferroalloys should be used for correction of the chemical composition in the ladle–furnace unit.

These recommendations have proven successful in stabilizing the quality of high-strength steel. In particular, a high proportion of the ductile component is observed in impact-strength tests of 13ХМФА steel.

3. ADJUSTING THE CARBON CONTENT

The carburization of the intermediate product in the casting ladle is of great practical significance, as confirmed by laboratory experiments. As we see in the table, periods when poor-quality material of VUM type (with up to 10% ash and volatiles and up to 1.5% nitrogen) is used for carburization of metal at discharge from the arc furnace and in the ladle–furnace unit are associated with a high and stable rejection rate of continuous-cast billet (diameter) on account of cold longitudinal cracking. The total consumption of carburization materials in the ladle–furnace unit is 200–300 kg/ladle (technology 1).

Metallographic data indicate that the metal structure at the cold crack and in its direction of propagation is characterized by increased ferrite content. The

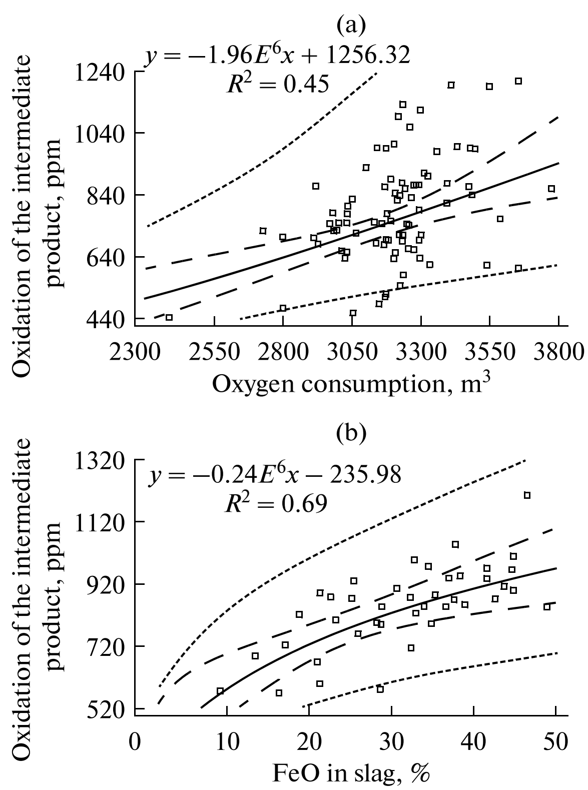

Fig. 3. Dependence of the oxidation of the intermediate product on the quantity of oxygen supplied through supersonic tuyeres (a) and on the oxidation of the slag (b).

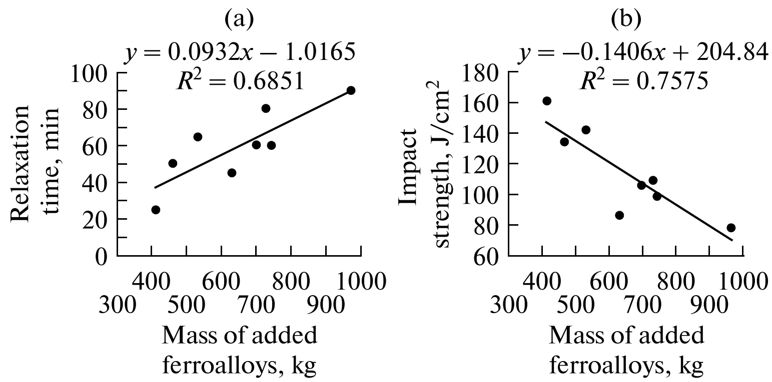

Fig. 4. Influence of added ferroalloys in the ladle–furnace unit on the disequilibrium of the melt (a) and on the impact strength of transverse samples of 20ХМФА steel.

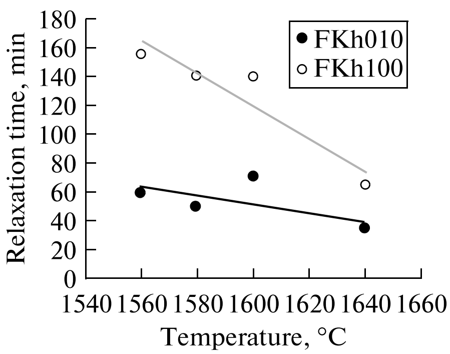

Fig. 5. Influence of the temperature and type of alloy on the relaxation time in alloying with chromium.

melt produced on carburization by VUM reagent exhibits sharp disequilibrium (Fig. 6a). The disequilibrium of the melt ensures considerable nonuniformity of the austenite after crystallization, which, in turns implies considerable fluctuation in its stability over the ingot volume, nonuniformity of the melt on cooling, and the appearance of low-strength zones as a result of enrichment with ferrite.

To reduce the rejection rate, a different carburizing agent is employed: high-quality graphite (≤3% ash and volatiles and ≤0.5% nitrogen). We find that carburization with graphite results in significantly less disequilibrium of the melt (Fig. 6b). By switching to graphite, eliminating the VUM additions in the ladle–furnace unit, and reducing the consumption of carbon wire to 100 kg/ladle, the rejection rate due to cold longitudinal cracking may be radically reduced (technology 2 in the table).

In terms of metal quality, we must pay careful attention not only to the type and quantity of carburizing agent but also to its time of introduction. Correction of the carbon content in the final stages within the ladle–furnace unit is found to increase the billet's defect content and reduce pipe quality.

On the basis of the results, we propose early carburization of the intermediate product by high-quality

Influence of carburization on the cold longitudinal cracking (CLC) in pipe steel

Period (2009)	Billet (diameter 400 mm) with CLC, %	Consumption of carbon-bearing materials, kg/ladle			
		at melt discharge from furnace		in ladle–furnace unit	
		VUM	graphite	VUM	C-wire, no more than
Technology 1					
February	2.18	400	–	100–200	100
March	2.80	400	–	100–200	100
April	3.17	500	–	100–150	150
Technology 2					
May	0.00	–	450	–	100
June	0.49	–	450	–	100

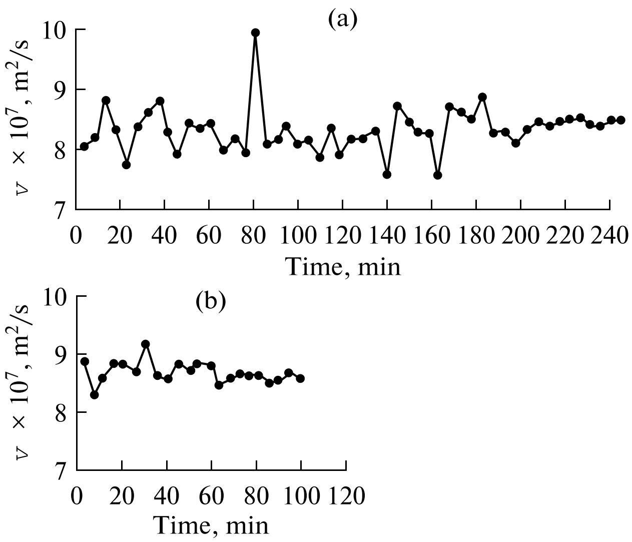

Fig. 6. Influence of the carburizing agent on the equilibrium of Д steel melt: (a) VUM; (b) graphite.

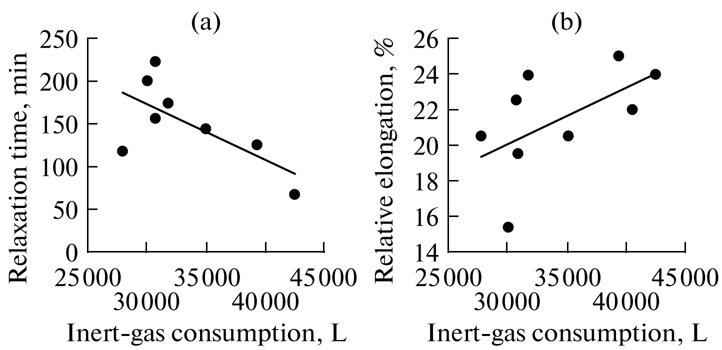

Fig. 7. Influence of the inert-gas consumption in the ladle–furnace unit on the equilibrium of Д steel melt (a) and the steel's plasticity (b).

graphite at discharge from the furnace. The carburizing agents used for correction of the melt in the ladle–furnace unit should not exceed 100 kg/ladle. These proposals prove highly effective in eliminating cold longitudinal cracking from high-strength carbon steel (Д, 32Г2, and so on).

Thus, research on melt formation in modern smelting technology provides an effective means of improving the process and boosting steel quality. The formation of equilibrium melts may also be fostered by improving inert-gas injection (Fig. 7) and vacuum treatment and by modifying the melts with rare-earth alloys [2].

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