

Stabilization of the Chemical Composition of Slag and Minimization of the Effect of Magnesia Spinel on Steel Quality

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Abstract:

The article discusses the problem of the formation of magnesia spinel ($\text{MgO}\cdot\text{Al}_2\text{O}_3$) in steelmaking processes, affecting the quality of steel, especially in the production of electro-welded pipes. The mechanisms of spinel formation are described, including the interaction of refractories with melt and slag, as well as the main chemical reactions contributing to the formation of nonmetallic inclusions. The analysis of technological factors affecting the MgO content in bucket slag is carried out, and methods for its stabilization are proposed.

Technological measures have been developed and implemented to minimize the formation of inclusions: temperature control of the bucket lining, correction of the slag composition, digital monitoring of the bucket condition, optimization of argon purging and stricter requirements for slag-forming materials. Analysis of data for 2014-2017 showed a decrease in the MgO content in bucket slag and a decrease in defects in finished products.

The implementation of the proposed measures made it possible to stabilize the chemical composition of the slag, reduce the level of non-metallic inclusions and improve the quality of steel, which is confirmed by a reduction in the number of defects in pipe welds. The developed recommendations can be used to optimize steelmaking processes and increase the competitiveness of metallurgical products.

Keywords: steelmaking process, magnesia spinel, nonmetallic inclusions, bucket slag, composition stabilization, steel quality.

Introduction

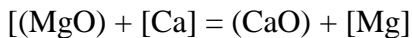
Modern steelmaking processes require minimizing non-metallic inclusions containing magnesium, since the bucket lining contains MgO, which promotes the formation of magnesia spinel (MgO·Al₂O₃). These inclusions degrade the quality of welds in electro-welded pipes, reduce the mechanical properties of steel and can lead to the formation of defects in finished products. This article discusses the processes of spinel formation, their impact on steel quality, and suggests methods for stabilizing the chemical composition of slag in order to minimize inclusions and improve the characteristics of the final product.

Materials and methods

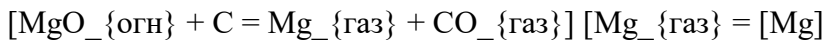
1. Mechanisms of formation of magnesia spinel

The formation of magnesia spinel is associated with the interaction of refractories with melt and slag.[1] The main reactions affecting this process are:

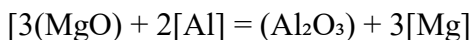
Recovery of magnesium from refractory aluminum:



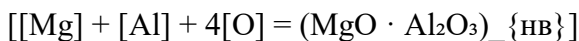
Reduction of magnesium by carbon from refractory:



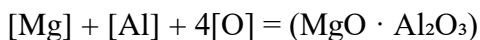
Condensation of gaseous magnesium in steel:



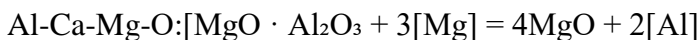
Recovery of MgO in bucket slag by aluminum:



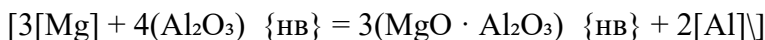
Reaction between aluminum, magnesium and oxygen:



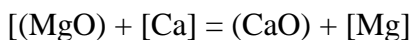
Restoration of MgO by calcium:



Reaction between non-metallic inclusions and magnesium:



Thermodynamic equilibrium of the Al-Ca-Mg-O system:



2. Methods of analysis and control of slag composition

Methods of spectral and chemical analysis, metallographic studies, and thermodynamic modeling are used to study the processes occurring in steelmaking.[2] The research was carried out at metallurgical enterprises in real production conditions with control of the main process parameters.[3]

Table 1. The effect of the initial aluminum content on oxygen supply from the outside and the degree of its oxidation under the same slag conditions

Initial content of [Al], mass. %	% loss of aluminum due to oxidation through slag	Oxygen supply of O ₂ to metal, kg/t
0,005	66,0	0,05
0,015	88,0	0,16

0,025	92,8	0,25
0,035	94,9	0,35
0,045	95,8	0,44
0,055 0,0006	96,5	0,60
The initial data for the calculation in TMS: T=1555 °C; metal weight (steel 20) - 15 t; slag weight (SiO ₂ - 40 wt. %) - 1 ton		

Results

1. The influence of technological factors on the formation of spinel

To minimize inclusions, it is necessary to take into account technological aspects:

- The impact of bucket operation: buckets contain more oxide inclusions after repairing the lining or prolonged exposure to the burner (>5 hours).[4]
- Minimizing the residence time of metal in the bucket, which reduces the risk of accumulation of non-metallic inclusions.[5]
- Control of the chemical composition of the slag: prevention of excessive liquefaction ($\text{CaO}/(\text{SiO}_2 + \text{Al}_2\text{O}_3) < 1.3$) or excessive thickening (> 1.9), which worsens desulfuration and assimilation of inclusions.[6]
- Maintenance of refractories in proper condition: removal of the slag crust, temperature control of the lining before release, timely repair.[7]
- Efficient argon purging of metal to remove non-metallic inclusions.[8]

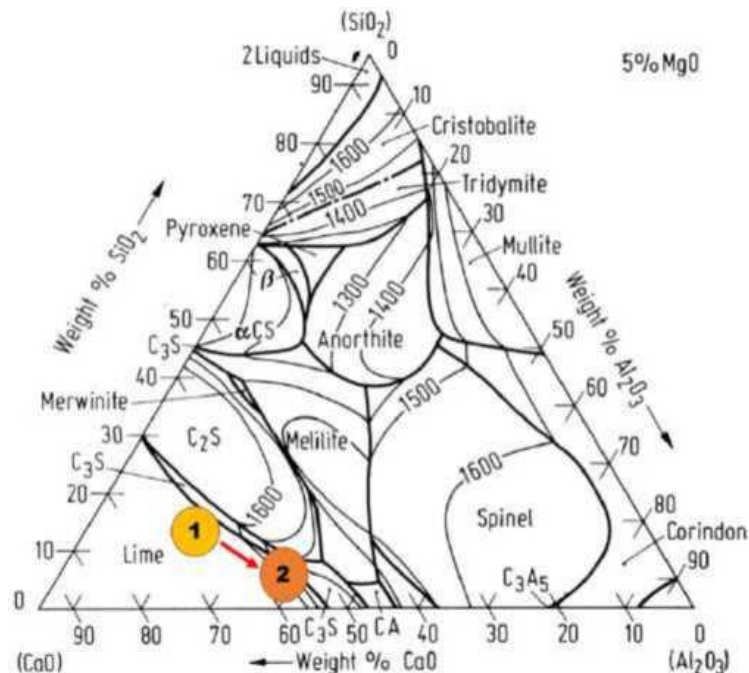


Figure 1. Phase diagram of CaO-SiO₂-Al₂O₃ for the content of MgO - 5 wt. %; 1) - technology "before" and 2) - technology "after"

2. Development of measures to reduce the content of MgO

The implementation of the following measures in the LPC made it possible to stabilize the MgO content in the bucket slag:

- Monitoring of buckets and their heating (>5 hours under the burner) using an electronic system.[9]

- Correction of the slag composition for new buckets by increasing the consumption of lime and flux.[10]
- Continuous analysis of the chemical composition of slag-forming materials and slag.[11]
- Introduction of digital monitoring of the condition of buckets, their repair and maintenance.[12]
- Enhanced control over the operation of purge lances and argon supply systems.[13]

Discussion

The measures taken have led to a reduction in the number of defects and defects in the pipes. [14]The maximum effect is observed on buckets with the first three revolutions, which confirms the effect of stabilization of the chemical composition of the slag on the purity of the steel.

Additionally, a set of requirements for materials (ferroalloys, deoxidizers, slag-forming components) has been developed, including minimizing the content of harmful elements (S, P, SiO₂, MgO, Ti, TiO₂, B) [10]. The introduction of these requirements has significantly reduced the level of defects associated with non-metallic inclusions, increased the strength of welded joints and reduced the likelihood of microporation and cracks.[15]

Conclusion

For the production of high-quality steel, it is important to reduce the content of non-metallic inclusions of MgO and Al₂O₃, since their presence worsens the properties of the final product. The main ways to solve the problem:

- ✓ Stabilization of the chemical composition of the slag, prevention of deviations in its composition.
- ✓ Full control of the slag parameters and the materials used.
- ✓ Digital monitoring of the steel ladle condition and monitoring of its technical condition.
- ✓ Improvement of technology of preparation and operation of refractories, introduction of new materials with improved heat resistance.
- ✓ Reducing the time spent by metal in the bucket to minimize contact with refractories.

The implementation of these measures ensured the stabilization of steel quality, reduction of defects in pipes and increased competitiveness of products. The developed recommendations can be used to optimize processes in the metallurgical industry and improve the quality of welded products.

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