Analysis of the Technology for Reducing the Amount of Gas Pores and Non-Metallic Inclusions in Liquid Steel Alloys

Nozimjon Kholmirzaev[1][a], Nosir Saidmakhamadov[2][b], Jamshidbek Khasanov[3][c], Shokhista Saidkhodjaeva[3][d], Abdujalol Bektemirov[1][e], Bekzod Yusupov[4][f], Ibrokhim Nosirkhujaev[4][g] and Nargiza Sadikova[1][h]

[1]Tashkent State Technical University, Foundry Technologies Department, 100095 Tashkent, Uzbekistan
[2]The Association of Building Materials Industry of Uzbekistan, R&D center, 100059 Tashkent, Uzbekistan
[3]Andijan Machine Building Institute, Technology of Machine Building, 170100 Andijan, Uzbekistan
[4]Almalyk Branch of Tashkent State Technical University, Technologic Machines and Equipment Department, 110100 Almalyk, Uzbekistan

Keywords: Gas Pores, Non-Metallic Inclusions, Liquid Steel.

Abstract: In this article, research was conducted on low-alloy steel alloy 35XGCL (analog is JIS G 5111). Research is aimed at reducing the amount of gas pores and non-metallic inclusions in the liquid alloy. This process was carried outside of furnace. SEM/EDS analyzes were conducted on each experimental sample obtained during the research. In the research, the analysis of the effect of Al and Zr elements on reducing the amount of oxygen and nitrogen in the liquid alloy is presented. For experiments, the alloys were melted in an electric arc furnace. Experiments were conducted with different amounts of Al and Zr. As a result, ZrO_2 and Al_2O_3 were formed. Processing in an argon flow after exposure to the elements increased the possibility of cleaning from large-sized (>7 µm) inclusions. At the end of the research, the cleaning of the alloy from gas pores and non-metallic inclusions led to a significant improvement in mechanical properties.

1 INTRODUCTION

The quality of iron and its alloys, particularly steel products, is generally determined by the minimal presence of harmful elements P and S. However, in accordance with modern materials science and construction requirements, the amount of non-metallic additives and gas cavities in the composition of alloys is becoming increasingly significant. Therefore, engineering teams are also focusing on these aspects when producing cast products. Usually, the components added during the alloy melting process are very important. Especially through modification, improving the hardness and wear resistance of steel alloys by post-processing, while also eliminating certain defects, gas cavities, and the presence of non-metals found in castings, is one of the main achievements of casting technologies. This primarily refers to modification and refining in the ladle.

Despite the limited amount of non-metallic additives in steels, they significantly affect the properties of the steel. It is impossible to completely remove certain types of non-metals from the alloy composition; we can only reduce their quantity and dispersion in such a way as to minimize the damage

[a] https://orcid.org/0009-0008-9662-4796
[b] https://orcid.org/0000-0002-7460-5972
[c] https://orcid.org/0009-0009-0741-1375
[d] https://orcid.org/0009-0008-8663-5061
[e] https://orcid.org/0009-0002-2583-0900
[f] https://orcid.org/0000-0002-2066-1872
[g] https://orcid.org/0009-0007-8527-1826
[h] https://orcid.org/0009-0006-7197-8059

Kholmirzaev, N., Saidmakhamadov, N., Khasanov, J., Saidkhodjaeva, S., Bektemirov, A., Yusupov, B., Nosirkhujaev, I. and Sadikova, N.
Analysis of the Technology for Reducing the Amount of Gas Pores and Non-Metallic Inclusions in Liquid Steel Alloys.
DOI: 10.5220/0014260800004738

In *Proceedings of the 4th International Conference on Research of Agricultural and Food Technologies (I-CRAFT 2024)*, pages 248-252
ISBN: 978-989-758-773-3; ISSN: 3051-7710

to the quality of the alloy. Non-metallic additives of this type mainly occur in the form of compounds as a result of chemical reactions during the melting of the alloy. Oxides (FeO, Al_2O_3, SiO_2), carbides (Fe_3C, WC), nitrides (TiN, AlN), and sulfides (FeS, MnS) are among them. Other types of non-metals arise from various separations. For example, the separations of furnace, ladle, and mold materials (Garcia-Casas et al., 2022; Beeley, 2001; Kendra, 2001; Tursunbaev et al., 2001; Tursunbaev et al., 2001). Gas voids are similar; they occur in the alloy due to the influence of oxygen during melting, and they can be completely eliminated in one stage. If partially lost under normal production conditions, they can be completely eliminated under special conditions, such as in vacuum production.

It is also very important to be able to eliminate such defects with metallurgical solutions under normal production conditions. This, in turn, opens the door for research in this area. In particular, scientists A.G. Svjazin, J. Siwka, Z. Skuza, and A. Hutnylar have provided useful recommendations on the formation and prevention of gas voids in their scientific research titled "The Gas Blow-Holes Forming in Nitrogen Iron Alloys and Steels during their Crystallization" (Svjażin et al., 2022). According to them, non-metals can also be partially purified during the reduction of gas voids from the alloy composition. In this case, the effectiveness of the deoxidizer's influence in the chemical reaction plays an important role.

2 MATERIALS AND METHODS

The research work was carried out on high carbon steel 65Г and low-alloyed 35ХГСЛ alloys. Such alloys are typically used to manufacture parts of automobile bodies, sheets, strips, and various geometrically shaped components, particularly various wheels, springs, gears, sliding devices, friction discs in braking systems, and bearing housings, which require wear resistance and hardness (Sheraliev et al., 2001). To reduce gases in the usual composition of the alloy, aluminum was introduced in solid form at a concentration of 0.5% through out-of-furnace refining (Callister & Rethwisch, 2007; Turaxodjayev, 2016). Metallurgical and construction methods were used to reduce non-metals in the composition. In the metallurgical method, flux was added, while in the construction method, modifications were made to the casting mold feeders (Turaxodjayev, 2016; Tursunbayev et al., 2023; Kholmirzaev et al., 2023; Kholmirzaev et al., 2024a).

In these gas-voids, to purify the liquid metal, aluminum (Al) was added at a concentration of 0.5% based on the total weight of the alloy in an out-of-furnace condition. Aluminum (Al) was introduced into the liquid alloy composition using three different methods. In the first case, when the liquid metal in the furnace reached a ready state, that is, when it reached the pouring temperature into the ladle, 0.2% aluminum was added to the heated ladle, and the liquid alloy in the furnace was poured over it. In the second method, after pouring the liquid alloy into the ladle, 0.2% aluminum was added, and in the next stage, the liquid alloy in the ladle was introduced after being cleaned of slag. That is, 0.1% aluminum was added to the liquid alloy at the pouring temperature into the prepared mold, while the ladle was kept in the sand-clay mold during the pouring of the liquid alloy. In total, 0.5% aluminum was introduced. The process occurring in the ladle was as follows (Kholmirzaev et al., 2023; Ermatov et al., 2022; Mardonov et al., 2023a; Mardonov et al., 2023b; Mardonov et al., 2023).

Figure 1: Samples taken after refining.

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$$[3FeO] + [2Al] \rightarrow [3Fe] + (Al_2O_3) + Q$$

Here, aluminum serves to remove oxygen in the form of aluminum oxide. By applying this method, it was possible to eliminate non-metallic additives and gas porosity from the liquid alloy.

Samples taken from the refined alloy were checked for hardness and microstructures. The HBRV-187.5 Digital Hardness Tester device was effectively used to determine the hardness.

Figure 2: HBRV-187.5 Digital Hardness Tester.

3 RESULTS AND DISCUSSION

To test the state of gas porosity, pre- and post-research samples were processed using a mini analytical balance with very high accuracy. Additionally, the level of porosity was observed by monitoring the identical cross-sectional surfaces of the cast part obtained from the alloy (Fig. 3 a, b, c). The samples obtained in casting form were first polished for testing in the relevant trials. Then, modern equipment was used to compare its mechanical properties and structural changes.

Figure 3: Appearance of gas porosity in cast products.

The mechanical properties of the samples, particularly hardness, were determined using two methods: Brinell and Rockwell. The hardness test results are presented in Table 1.

After the hardness test, the samples were processed using a Grinding and polishing machine. Once the research samples were prepared, images of the alloy's microstructure were obtained using the "Zeiss Ultra Plus Field Emission SEM" scanning electron microscope (Fig. 4).

Table 1: The results of the test on hardness.

S/n	Hardness HBW				
1.	Cast samples	203	247	262	264
2.	Cast samples with heat treatment	245	307	323	328

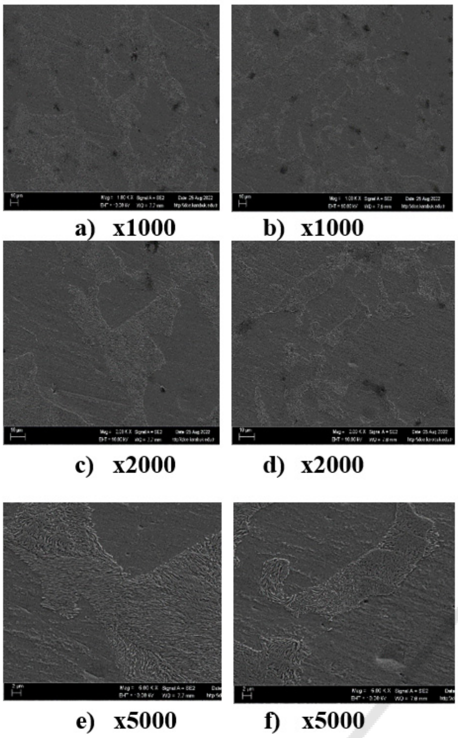

Figure 4: Microstructure images obtained from low-alloy steel alloy of 35ХГСЛ brand using Zeiss Ultra Plus Field Emission SEM scanning electron microscope at magnifications from x1000 to x5000.

4 CONCLUSIONS

By analyzing the results of the research, it can be concluded that the technology for optimal melting of low-alloyed 35 XGCL steel in an electric arc furnace has achieved energy and resource efficiency in obtaining cast products. An aluminum element was introduced into the liquid alloy outside the furnace, resulting in high-quality cast products free from gases. The implementation of the developed technology has reduced the amount of gas porosity in the cast products obtained from the steel alloy. By improving the binding clays in the sand-clay mold mixture, it was possible to produce sulfur-free cast products. As a result of the implementation, the gas permeability of the sand-clay molds increased by 13-15%. By improving the design of the placement of the valve components inside the mold, resource-efficient and economically viable cast products were achieved. Consequently, the raw material consumption for obtaining cast products decreased by 23-26%. To enhance the physical-mechanical and technological properties of the valve components cast in sand-clay molds, TiC nanocoatings were applied and subjected to thermal treatment, which resulted in improved wear resistance and hardness of the alloys.

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