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Determination of the optimum deoxidant addition in steelmaking process and the investigation of an alternative deoxidant material

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Abstract

It is known that the oxygen in the liquid steel causes problems in the process and quality of steel. Nowadays, the addition of aluminum to molten metal is the most common application for deoxidation of liquid steel. In this study, the optimum aluminum addition levels have been determined and an alternative material that can be used as a deoxidant has been evaluated. The optimum addition amount and the optimum alternative deoxidant were determined by optical emission spectrometry, active oxygen measurement in liquid steel, microstructure investigations, and destructive/nondestructive testing methods.

1. Introduction

The active oxygen level in the liquid steel is an important factor for the quality of the steel casting. For this reason, the deoxidation process should be done in liquid steel after the melting process. Today, the usage of metallic aluminum alloys for this purpose is the most common practice in steelworks and steel foundries. However, metallic aluminum costs are quite high. In this study, optimum aluminum addition amount and more economical alternatives will be determined.

Obviously, a good deoxidant material should have a high oxygen affinity. For this purpose, Ellingham diagrams were used for deoxidant selection. An Ellingham diagram is a graph showing the temperature dependence of the stability of compounds. This analysis is usually used to evaluate the ease of reduction of metal oxides and sulfides (Figure 1).

As can be seen from this diagram, the best elements that can be used for this purpose are calcium, magnesium, aluminum, and titanium. But as an alternative to aluminum, Ca, Mg and Ti will not be a good choice due to their very high costs. As a result of the literature research carried out to determine the cheaper forms of these elements, aluminum dross, which is a waste of aluminum casting factories, has come to the fore as a good alternative [1-3].

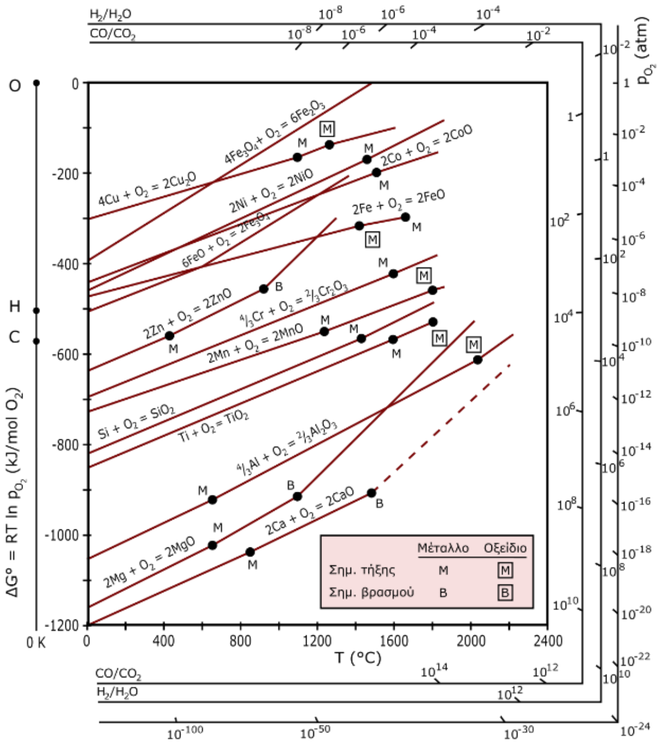

Figure 1. Ellingham diagram

2. Material and Method

Within the scope of this study, Al dross was obtained from an aluminum casting company (Döktaş Dökümcülük) and an active oxygen measuring device (Celox-Lab E) from an international technology supplier (Heraeus) (Figure 2).

(a) (b)

Figure 2a. Aluminum dross **2b.** Celox-Lab E

During the studies, firstly, the efficiency of our standard deoxidation process was examined and the success of the current process was determined by using an active oxygen level measuring device. After the optimization studies, the amount of aluminum and aluminum dross addition rate will be determined.

Theoretical studies were carried out on the data obtained as a result of the measurements. Studies were started based on the measurement results and the data obtained from the theoretical calculations, and the usability of aluminum dross as a deoxidant was evaluated by determining the optimum addition amount.

There is no chemical process that accelerates the melting process (oxygen blowing etc.) in our foundry, which melts with an induction furnace. In order to determine the oxygen level increase trend in the current melting process, active oxygen level and temperature controls were carried out at regular intervals without making any changes in the process (Figure 3).

As expected, it was observed that the dissolved oxygen in the liquid steel increased during the process (Figure 4).

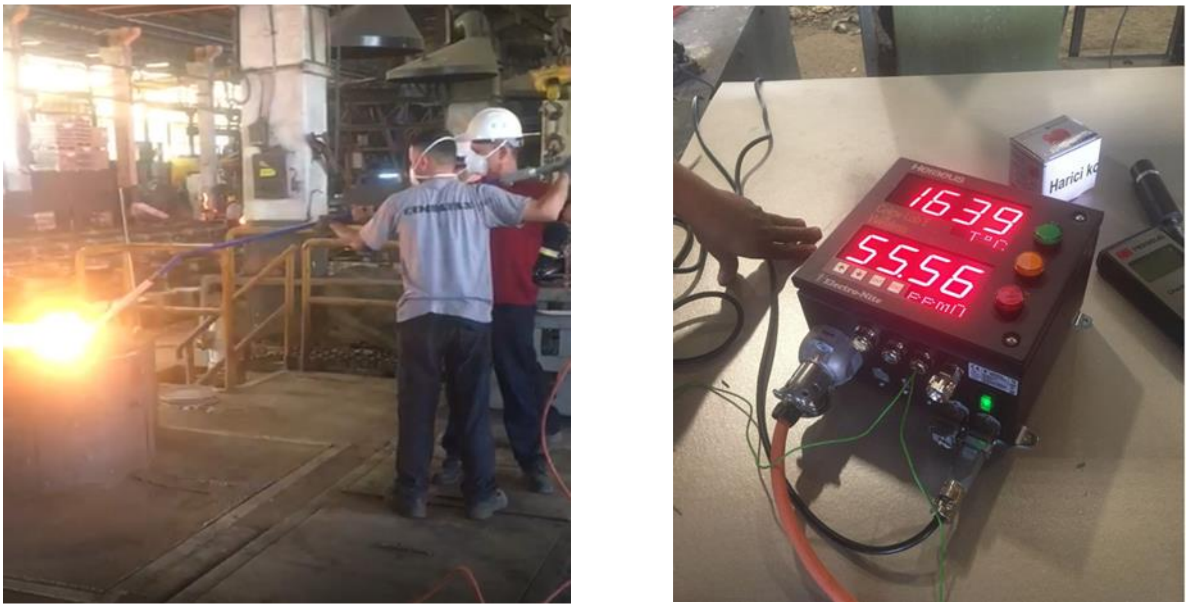

Figure 3. Temperature and oxygen levels measurements in induction furnaces

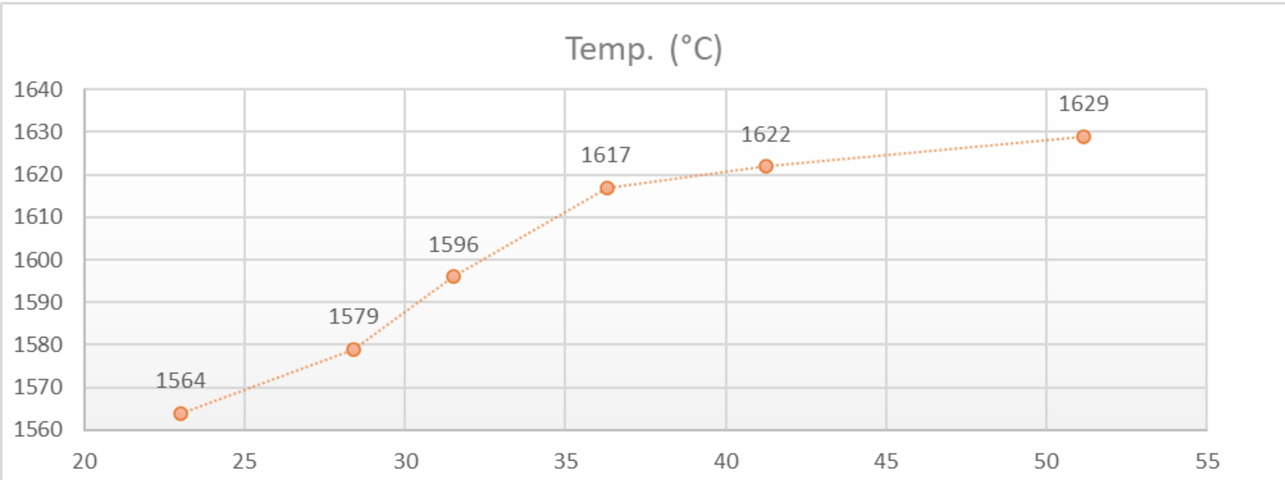

Figure 4. Active oxygen level measurement results during the melting process

After determining the active oxygen level change throughout the process, 3 different deoxidant applications were made in the same melting process in the same furnace. Since the deoxidant application is made while the liquid metal is being transferred to the laddle at the last stage of melting, all studies were performed in the same melting process, ensuring that all other steps are exactly the same except for deoxidation.

In the literature, it is stated that deoxidation occurs more slowly below the oxygen level of 20 ppm [4,5]. In these measurements made immediately after the addition of Al, if the oxygen level is measured below 20 ppm, the deoxidation will be considered successful.

Oxygen levels were determined before and after deoxidation in the current process (600 ppm Al) with an active oxygen measuring device and the results were recorded for theoretical calculations. The findings obtained from the experiments show that the currently applied deoxidation process is sufficient and even the amount of Al used may be more than necessary (Figure 5).

As a result of the theoretical calculations, it was decided to add 500 ppm Al to the second laddle and the oxygen level was measured again (Figure 6).

With the addition of lower Al in the second ladle, it was reduced below 20 ppm and residual Al was detected in the spectral analysis of the solidified steel (Figure 7). Residue Al rate is less than the previous laddle which was given 600 ppm aluminum. Seeing aluminum in the spectral analysis confirms the success of deoxidation, but is undesirable as residual aluminum can combine with nitrogen before solidifying and cause aluminum nitride embrittlement. For this reason, the addition of 500 ppm Al was found to be more reliable.

As a result of these studies, the necessary formula for the optimum amount of aluminum was found. In order to evaluate the deoxidation success of aluminum dross according to the equation found, studies were carried out by using aluminum dross instead of metallic aluminum (Figure 8).

The Al dross we used in the experiment has a grade of 50% and the addition rate has been calculated considering this grade.

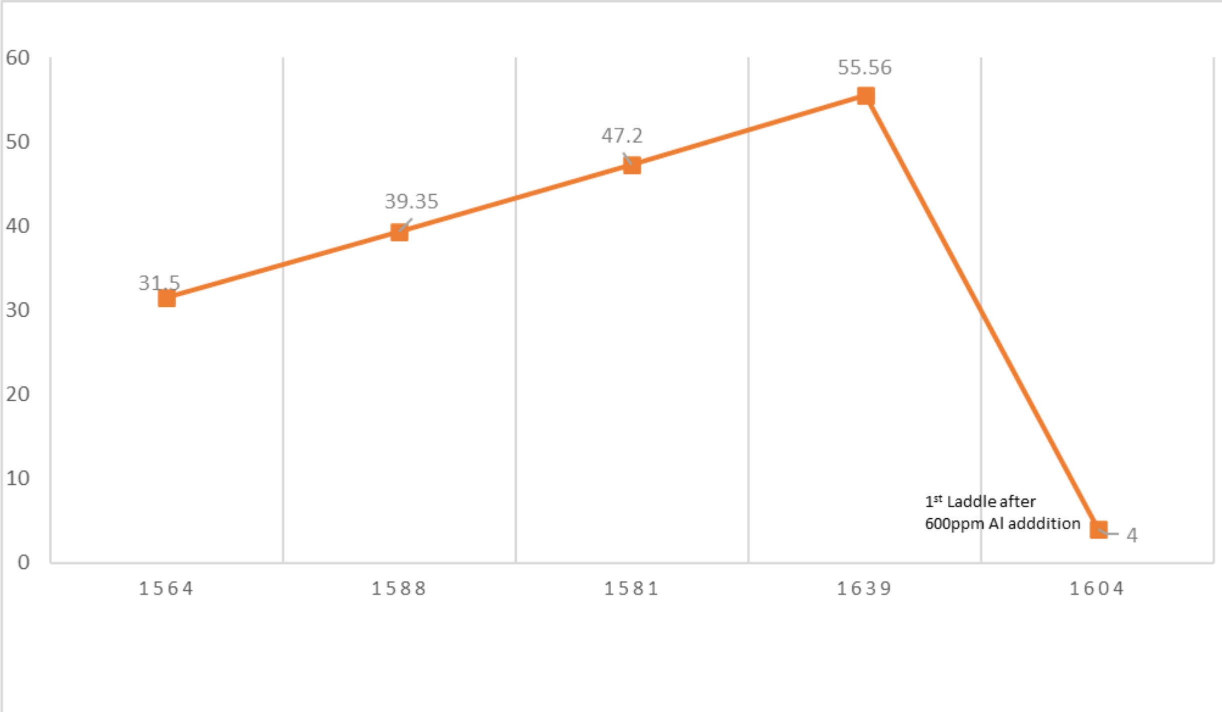

Figure 5. Oxygen level decrease in the 1st ladle after the addition of aluminum deoxidant

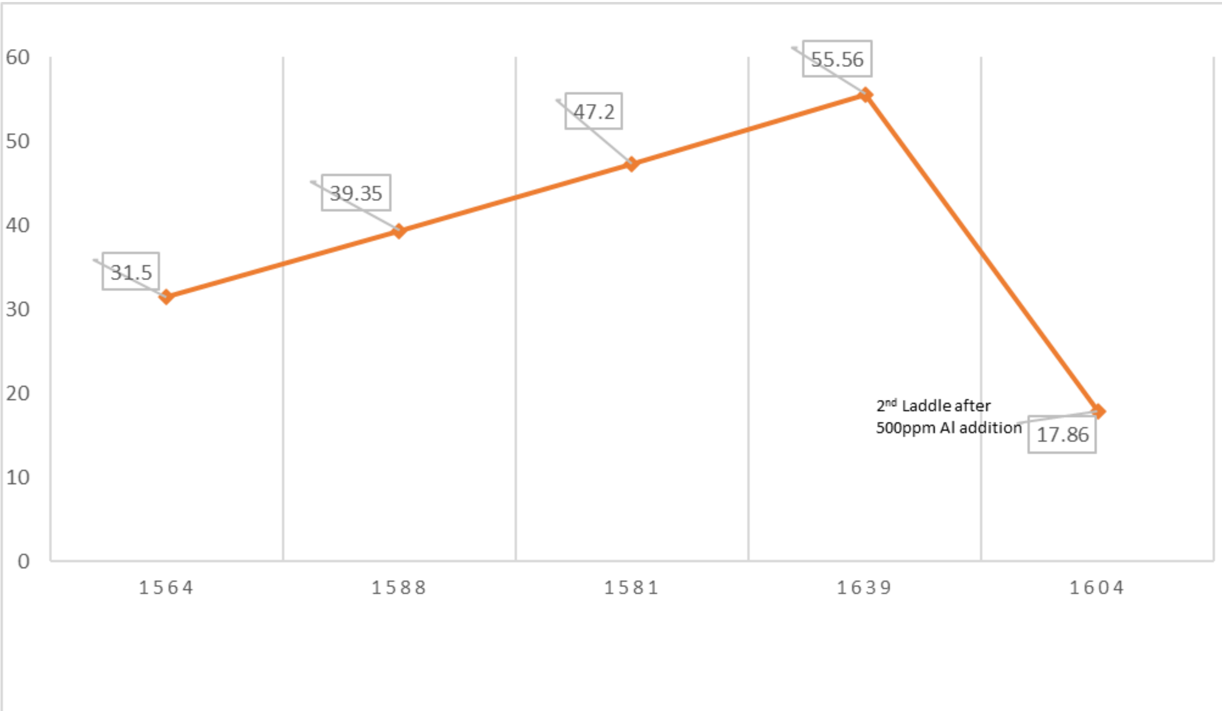

Figure 6. Oxygen level decrease in the 2nd ladle after the addition of aluminum deoxidant

	C [%]	Mn [%]	Si [%]	P [%]	S [%]	Cr [%]	Ni [%]	Mo [%]
AVG	0.26718	0.67611	0.42187	0.01302	0.00893	1.06655	0.04890	0.2675
	V [%]	Cu [%]	B [%]	Ti [%]	Sn [%]	Al [%]	Zr [%]	Nb [%]
AVG	0.00807	0.11425	0.00027	0.00213	0.00373	0.03190	0.00066	0.0087
	Pb [%]	Sb [%]	Fe% [%]	CEQ [%]	Zn [%]	Ce [%]	Bi [%]	W [%]
AVG	0.00113	0.00017	97.034	0.65918	0.00261	0.00111	0.00064	0.0000
	As [%]	Co [%]	Ca [%]	N [%]				
AVG	0.00414	0.00757	0.00000	0.01077				

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Figure 7. Optical emission spectrometer results for 2nd ladle

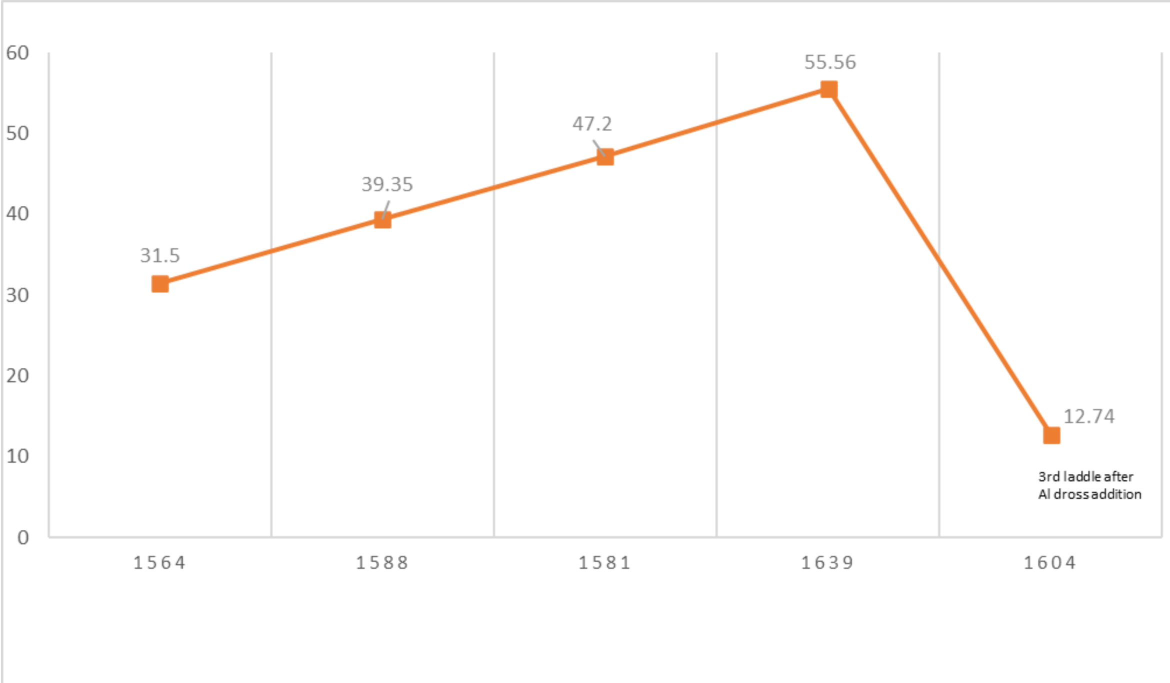
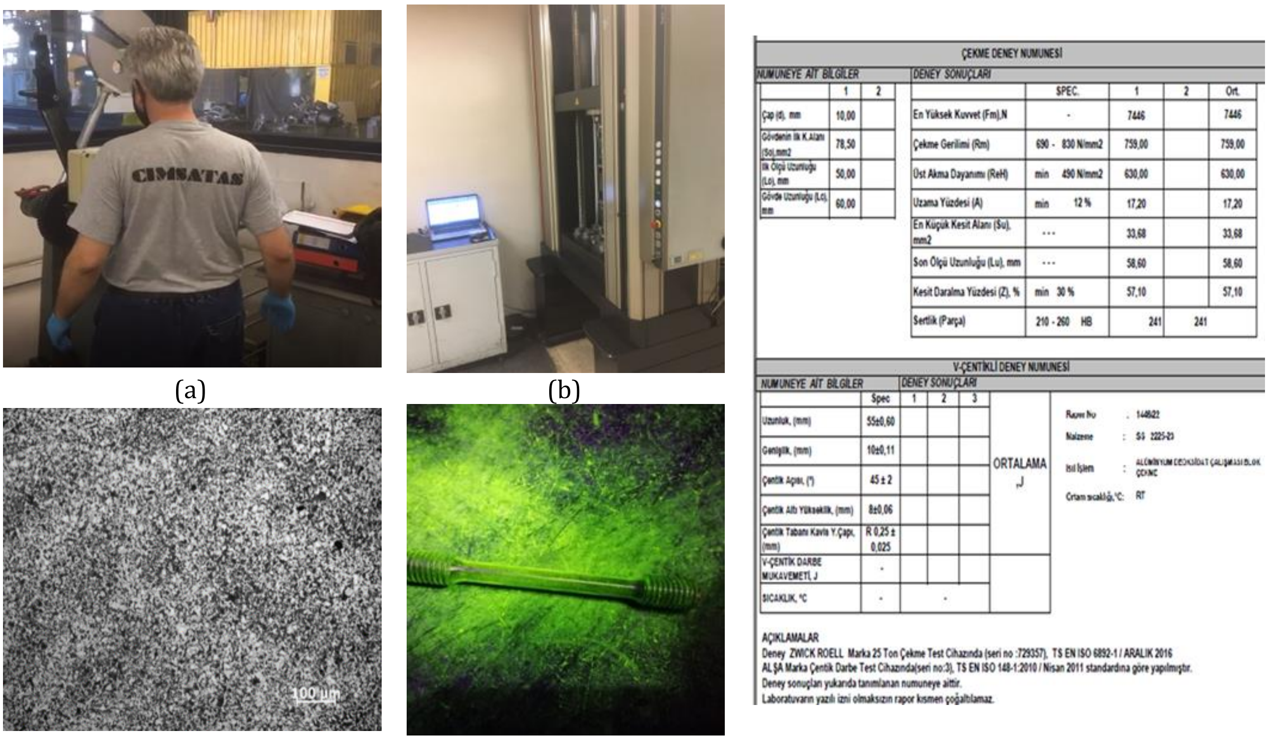


Figure 8. Oxygen level decrease in the 3rd ladle after the addition of aluminum dross as a deoxidant

In the last experiment, 500 ppm aluminum equivalent dross was added and it was observed that the oxygen level decreased to 12.74.

After the studies, destructive non-destructive inspections and metallographic examinations were made on all samples, and no adverse events were encountered in the tested samples (Figure 9).



ÇEKME DENEY NUMUNESİ

NUMUNEYE AİT BİLGİLER

	1	2
Çap (d), mm	10,00	
Gövdenin İlk K.Alanı (So),mm2	78,50	
İlk Ölçü Uzunluğu (Lo), mm	50,00	
Gövde Uzunluğu (Lc), mm	60,00	

DENEY SONUÇLARI

	SPEC.	1	2	Ort.
En Yüksek Kuvvet (Fm),N	-	7446		7446
Çekme Gerilimi (Rm)	690 - 830 N/mm2	759,00		759,00
Üst Akma Dayanımı (ReH)	min 490 N/mm2	630,00		630,00
Uzama Yüzdesi (A)	min 12 %	17,20		17,20
En Küçük Kesit Alanı (Su), mm2	...	33,68		33,68
Son Ölçü Uzunluğu (Lu), mm	...	58,60		58,60
Kesit Daralma Yüzdesi (Z), %	min 30 %	57,10		57,10
Sertlik (Parça)	210 - 260 HB	241	241	

V-ÇENTİKLİ DENEY NUMUNESİ

NUMUNEYE AİT BİLGİLER / DENEY SONUÇLARI

	Spec	1	2	3	ORTALAMA J
Uzunluk, (mm)	55±0,60				
Genişlik, (mm)	10±0,11				
Çentik Açısı, (°)	45 ± 2				
Çentik Altı Yüksekliği, (mm)	8±0,06				
Çentik Tabanı Kavis Y.Çapı, (mm)	R 0,25 ± 0,025				
V-ÇENTİK DARBE MUKAVEMETİ, J	-				
SICAKLIK, °C	-	-			

Rapor No : 146622
Malzeme : SS 2225-23
Isıl İşlem : ALÜMİNYUM DEOKSİDAT ÇALIŞMASI BLOK ÇEKME
Ortam sıcaklığı,°C: RT

AÇIKLAMALAR
Deney ZWICK ROELL Marka 25 Ton Çekme Test Cihazında (seri no :729357), TS EN ISO 6892-1 / ARALIK 2016
ALŞA Marka Çentik Darbe Test Cihazında(seri no:3), TS EN ISO 148-1:2010 / Nisan 2011 standardına göre yapılmıştır.
Deney sonuçları yukarıda tanımlanan numuneye aittir.
Laboratuvarın yazılı izni olmaksızın rapor kısmen çoğaltılamaz.

(a) (b) (c) (d) (e)

Figure 9a. Charpy Impact Test, **9b.** Tensile test **9c.** Microstructure, **9d.** Fluorescent Magnetic Particle Inspection, **9e.** Mechanical Tests Results

3. Conclusion

As a result of the measurements, it is seen that the oxygen in the liquid metal increases as the process progresses. This confirms the information in the literature that oxygen solubility increases with increasing temperature and that dissolved oxygen will increase over time [6,7]. There are many sources for the deoxidation of liquid steel in the literature, but the recommended additional amounts and/or relations in these sources depend on the type of deoxidant used, grade, furnace type, how the deoxidation is done, climate, etc. It depends on many variables within the foundry/meltshop. Therefore, there may be changes according to the operating conditions. In this study, which we aim to start with a theoretical approach and find the optimum amount of addition experimentally, the best results were obtained with the addition of 500 ppm aluminum for 1 ton of 25CrMo4 material melted with an induction furnace.

As a result of the studies, successful deoxidation was achieved with aluminum dross. While the oxygen level decreased to 17.86 in the experiment with 500 ppm metallic aluminum, the oxygen level decreased to 12,74 in the experiment with the equivalent amount of aluminum dross. From this point of view, it can be said that aluminum dross is more successful in terms of deoxidation than metallic aluminum used in equivalent amounts. This observation is the result of the large surface area of metallic aluminum in the aluminum dross [8]. As a result of the metallographic, destructive and non-destructive investigations, it was observed that the trace amounts of inclusions (strontium, titanium, silicon, magnesium, and their oxides) in the aluminum dross did not have any negative effect on the casting part properties.

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Author contributions

Ferhat Tülüce: Conceptualization, Methodology, Software **Buğra Erbakan:** Data curation, Writing-Original draft preparation, Software, Validation. **Alper Yoloğlu:** Visualization, Investigation, Writing-Reviewing and Editing. **Mustafa Murat Zor:** Visualization, Validaation **Serdar Kesim:** Writing-Reviewing and Editing **Vedat Uz:** Writing-Reviewing and Editing

Conflicts of interest

The authors declare no conflicts of interest.

References

1. Hasirci, H. (2020). Çelik dökümde alternatif gaz giderme malzemesi olarak alüminyum cürufu kullanımının incelenmesi. *Politeknik Dergisi*, *23*(3), 641-647.
2. Huh, W. W., & Jung, W. G. (1996). Effect of slag composition on reoxidation of aluminum killed steel. *ISIJ international*, *36*(9), 136-139.
3. Aydemir, O. (2007). *Use of aluminium dross for slag treatment in secondary steelmaking to decrease amount of reducible oxides in ladle furnace* (Master's thesis, Middle East Technical University).
4. Silva, A. C. E. (2018). Non-metallic inclusions in steels–origin and control. *J. Mater. Res. Technol*, *7*(3), 283-299.
5. Turkdogan, E. T. (1999). Rationale on composition of slags in oxygen steelmaking processes. *Ironmaking & steelmaking*, *26*(5), 358-362.
6. Turkdogan, E. T. (1996). Fundamentals of steelmaking, the institute of materials. *London*, *656*, 96.
7. Conejo, A. N., & Hernandez, D. E. (2005). Analysis of Aluminum Deoxidation Practice in the Ladle Furnace. In *AISTech 2005 Volumes I & II and ICS 2005 Conference Proceedings; Volume I* (pp. 947-957).
8. Aydemir, O. (2007). *Use of aluminium dross for slag treatment in secondary steelmaking to decrease amount of reducible oxides in ladle furnace* (Master's thesis, Middle East Technical University).
9. Tuluce, F., Erbakan, B., Yoloğlu, A., Zor, M. M., Kesim, S., & Uz, V. (2022). Determination of the optimum deoxidant addition in steelmaking process and the investigation of an alternative deoxidant material. *Advanced Engineering Days (AED)*, *5*, 29-32.