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The influence of vacuum degassing on improving the quality of ship's steels

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Abstract: In this paper, the authors chose to study the non-alloy steel grade S235JR, developed in the LD (Lintz-Donawitz) converter from Arcelor Mittal Galati plant, considering the quality and purity improving of the produced steel as a main objective. The correlation of mechanical properties with steel purity, as a result of the liquid steel processing to the continuous casting machine (CC) using three cases was followed. In the first case, the final chemical analysis of the liquid steel was taken at the end of the blowing operation without desulphurisation and degassing. In the 2nd case, the final chemical analysis of the liquid steel for CC was taken after the desulphurisation and chemical and thermal homogenization in the Ladle Furnace (LF) installation. In the 3rd case, the final chemical analysis of the liquid steel for CC was taken after the vacuum degassing, i.e after the treatment in the Ruhrstahl Heraeus (RH) installation.

1. Introduction

Steel is an important material in the dynamics of today's industrial development. The increased production is accompanied by a continued concerning regarding the production technologies improvement requirements regarding the metallurgical products quality. The naval board is a thick, hot rolled sheet with high corrosion and abrasion resistance, used in the shipbuilding industry for shipbuilding and various component parts. In recent years, safety and sustainability of ships and the marine environment protection have become of great importance. An increase in steel production for the shipbuilding sector by introducing and improving fast procedures regarding steel production and casting in Arcelor Mittal Galati Company was achieved. Thus, the Linz-Donawitz (LD) process by oxygen injection, leading to an increased productivity and cost reduction in manufacturing was introduced [1, 2]. This process has been improved and steel production in combustion insulated converters has been created, which generated metallurgical products with high quality. In order to meet the increasing requirements of steel quality, a series of technologies and techniques to treat the liquid steel are currently widely applied, aiming to transfer (or finish) the metalurgical processes outside of the aggregate [1- 5]. A particular feature of these steel treatment processes lies in the fact that, in most cases, an conjugate effects (deoxidation, desulphurisation, degassing) [6-11] are obtained. These effects lead to the following main technical and economical advantages: reducing fuel and electricity consumption as a result of reducing batch time in primary aggregates; improving the steel quality by reducing the content of non-metallic and gas inclusions, obtaining a high accuracy and homogeneous chemical composition; reducing the consumption of ferroalloys for alloying due to better assimilation of alloying elements; automatic management of technological processes [10-16].

2. Materials and methods

The chemical composition and mechanical properties for non-alloyed steel grade S235JR according to EN 10025-2 2004 / AC: 2005 are given in Table 1 and Table 2.

According to the classification system EN10025-2, it means: S - naval steels; 235 - minimum value of tensile strength for wall thickness ≤ 16 mm in N / mm^2; JR - quality class with minimum impact energy at 27J to +20° C; AR - the austenitic rolling path in which the recrystallization phase exists; S235JR, structural steel: $Rp_{0,2}$ = 235Mpa, 27J to 20°C (R) - steel standard 10025-2.

Table 1. Chemical composition for steel S235JR.

C max	Mn max	S max	P max	N max	Cu max
0,17 - 0,19	1,40 - 1,50	0,035 - 0,045	0,035 - 0,045	0,012 - 0,014	0,55 - 0,45

Table 2. Mechanical properties for steel S235JR according to EN 10025-2 2004 / AC:2005.

Tensile strength R_m [N/mm^2]	Minimum yield strength R_{eH} [N/mm^2]	Minimum elongation A% L	Minimum elongation A% T	Hardness HB	Minimum impact energy at 20^0 C KV[J]
360-510	235	26	24	104-154	27

The production of the S235JR naval steel was done in the LD converter. The mechanical properties correlation with steel purity, as a result of liquid steel processing to the continuous casting machine (CC) in three cases was followed.

In case 1, the final chemical analysis of the liquid steel for CC was taken at the end of the blowing operation, without desulphurisation and degassing.

Table 3. Final chemical composition of the liquid steel for CC without desulphurisation and degassing (charge A).

Series A	**Chemical composition, [%]**			
Step 1 (at the end of the blowing operation)	C=0.0201;	Mn=0.1341;	P=0.0108;	S=0.012;
Step 2 (the final chemical analysis in CC)	C=0.1328; S=0.0067; Ca=0.0005; Mo=0.0034;	Si=0.1838; Al=0.0416; Cu=0.033; Nb=0.0013	Mn=0.6848; Ti=0.0012; Ni=0.0163;	P=0.0175; V=0.0021; Cr=0.0345;

In the 2nd case, the final chemical analysis of the liquid steel for CC was taken after the desulphurisation, chemical and thermal homogenization in the Ladle Furnace LF.

In the 3rd case, the final chemical analysis of the liquid steel for CC was taken after vacuum degassing, i.e after the treatment in the Ruhrstahl Heraeus (RH) installation. For the analysis, three differently charges of liquid steel processing of (A, B, C) were selected.

In tables 3, 4, 5 the final chemical composition for each charge was presented. In the first step of each series only four elements were determined: carbon, manganese, phosphorus and sulphur.

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Table 4. Final chemical composition of the liquid steel from CC after desulphurization, chemical and thermal homogenization in Ladle Furnace installations (charge B).

Series B	Chemical composition, [%]			
Step 1 (at the end of the blowing operation)	C=0.0244;	Mn=0.1974;	P=0.0217;	S=0.017;
Step 2 (the final chemical analysis for CC after desulphurisation, chemical and thermal homogenization)	C=0.1221; S=0.0081, Cu=0.012; Nb=0.002;	Si=0.2116; Al=0.0435; Ni=0.0079; B=0.0003	Mn=0.6606; Ti=0.0021; Cr=0.0199;	P=0.0161; V=0.002; Mo=0.0007;

Table 5. Final chemical composition of the liquid steel from CC after vacuum degassing and treatment in Ruhrstahl Heraeus (RH) (charge C).

Series C	Chemical composition, [%]			
Step 1 (at the end of the blowing operation)	C=0.0282;	Mn=0.068;	P=0.0046;	S=0.0103;
Step 2 (the final chemical analysis from CC after vacuum degassing)	C=0.119; S=0.003; Ni=0.008; Nb=0.002,	Mn=0.7158; Al=0.021; V=0.002; B=0.0001;	Si=0,203; Cu=0.011; Mo=0.001; N_2=0.0069;	P=0,010; Cr=0.022; Ti=0.002; H_2=0.0002

3. Results and discussions

3.1 Mechanical tests

Table 6 presents the mechanical properties values of S235JR non-alloy steel samples obtained for different liquid processing cases (A, B, C series). The mechanical tests were performed on samples corresponding to the different liquid processes for three charges. Tensile strength (R_m), yield strength (R_{eH}) and elongation (A) were determined. The results obtained and their histograms are shown in figures 1, 2, 3.

All the analyzed samples are in correlation with the S235JR non-alloy steel grade prescriptions, but the highest tensile strength values were obtained for the C-series with the lowest grade of non-metallic inclusions, corresponding to the finest grain, with the largest real grains.

Table 6. Mechanical properties values for series A (without desulphurisation and degassing), series B (with desulphurization, chemical and thermal homogenization in Ladle Furnace installation), series C (with vacuum degassing).

		R_m, [MPa]	R_{eH}, [MPa]	A, [%]
Series A	Sample 1	425	304	34
	Sample 2	430	318	34
Series B	Sample 1	414	275	30
	Sample 2	438	292	33
	Sample 3	438	292	33
Series C	Sample 1	438	308	30
	Sample 2	441	296	30
	Sample 3	469	366	31

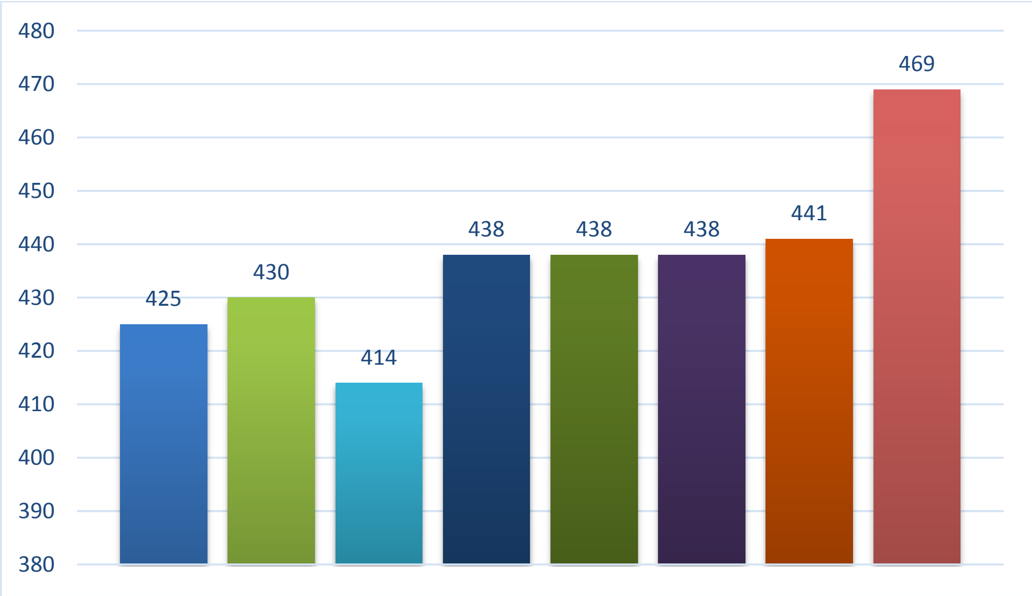

Figure1. Tensile strength variation Rm [MPa] for all samples from A series (without desulphurisation and degassing), B (with desulphurization, chemical and thermal homogenization in Ladle Furnace installations), C (with vacuum degassing).
Series A - (Rm=425, 430 [MPa])
Series B - (Rm=414, 458, 438[MPa])
Series C - (Rm=438, 441, 469 [MPa])

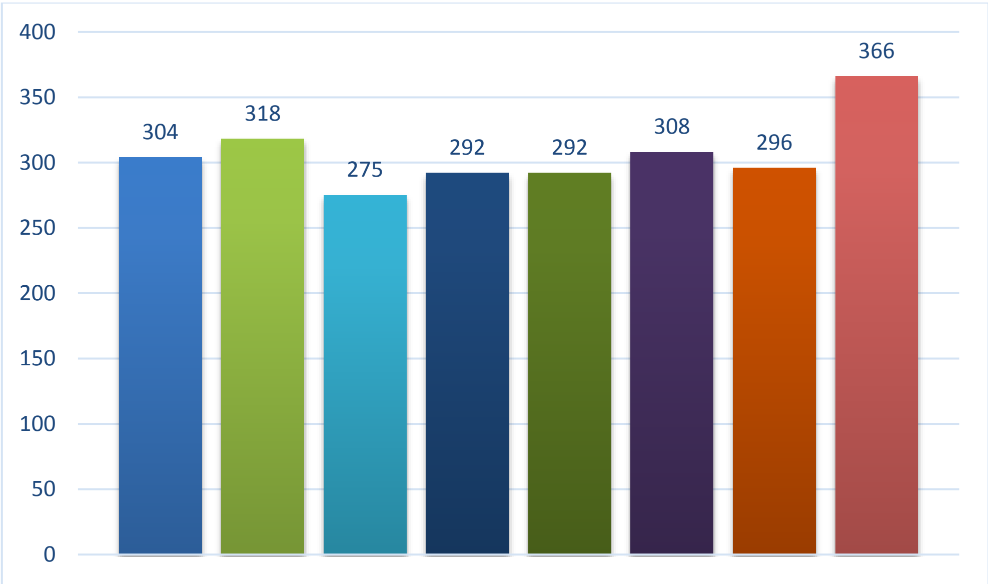

Figure 2. Yield strength variation ReH [MPa] for all samples from A series (without desulphurisation and degassing), B (with desulphurization, chemical and thermal homogenization in Ladle Furnace installations), C (with vacuum degassing).
Series A – (ReH=304, 318 [MPa])
Series B – (ReH =275, 292, 292 [MPa])
Series C – (ReH =308, 296, 366 [MPa])

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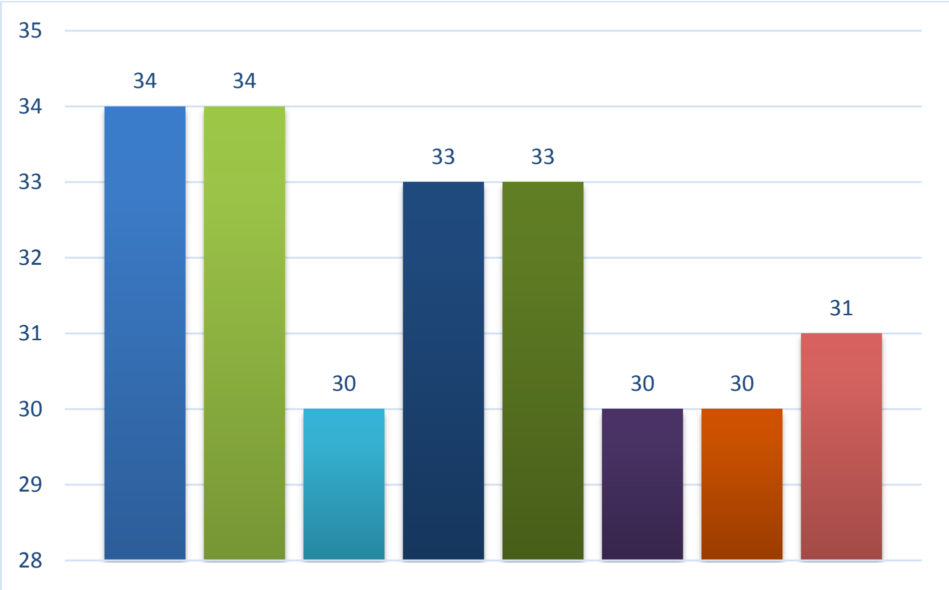
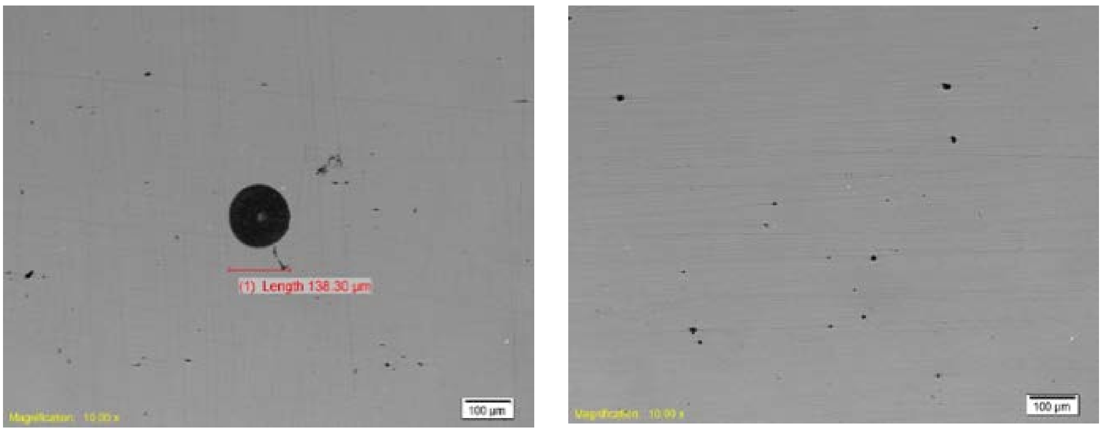


Figure 3. Elongation A [%] variation for all samples from A series (without desulphurisation and degassing), B (with desulphurization, chemical and thermal homogenization in Ladle Furnace installations), C (with vacuum degassing).
Series A – (A =34 , 34 [%])
Series B - (A =30, 33, 33 [%])
Series C – (A =30, 30, 31 [%])

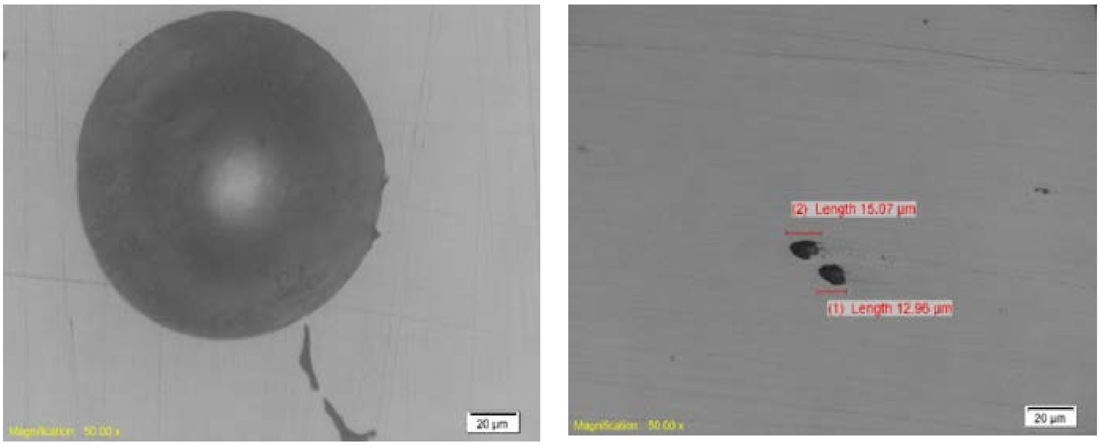
3.2. Microscopic analysis of non-metallic inclusions

Qualitative analysis of non-metallic inclusions according to STAS 5949-80, on polished and unetched samples was performed. The qualitative analysis of non-metallic inclusions in the light field, provides information on: contour, shape, distribution, fragility, influence of etchants. In the dark field, transparency (luminous inclusions), opacity (dark inclusions), and the color of the inclusions are highlighted.

The quantitative determination of non-metallic inclusions in steels is made using the comparison method with the standard charts and indicates the steel impurity degree. The polished and unetched samples are analyzed under a light microscope at a magnification of 100x.

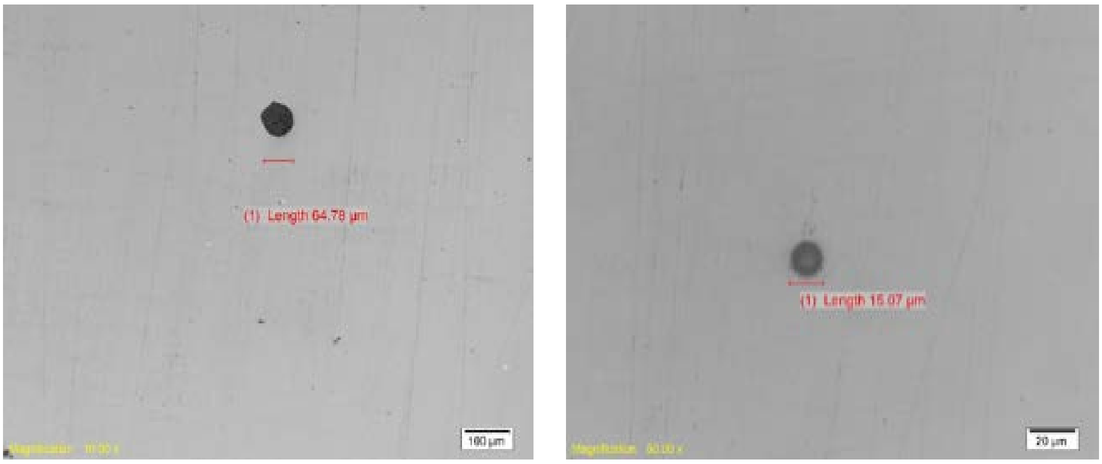


(a) (b)

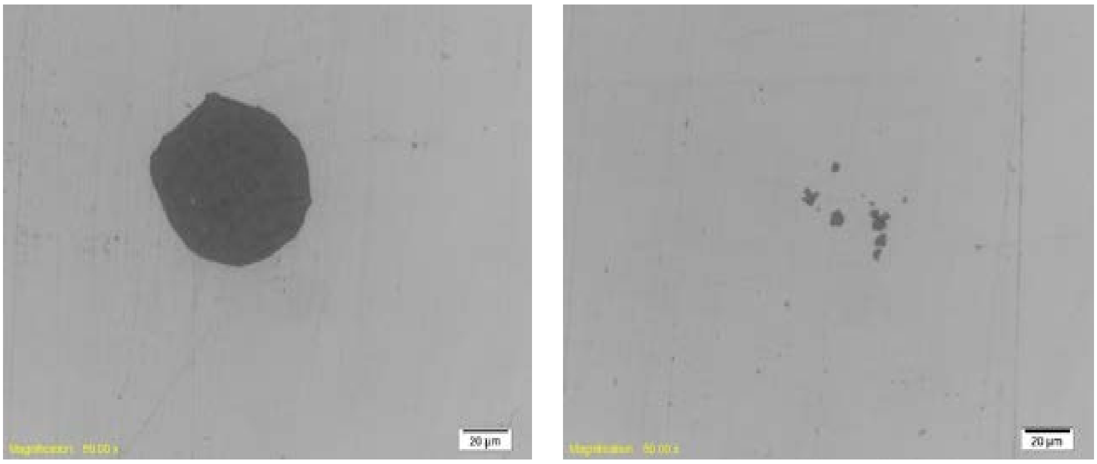


(c) (d)

Figure 4. The appearance of non-metallic inclusions on the unetched surface of the A series (without desulphurisation and degassing): (a) and (b) 100X; (c) and (d) 500X.



(a) (b)



(c) (d)

Figure 5. The appearance of non-metallic inclusions on the unetched surface of the B series (with advanced desulphurization, chemical and thermal homogenization): (a) and (b) 100X; (c) and (d) 500X.

The inclusions types that are determined by different standards charts are: OL + OP - linear and point oxides; S-sulphides; SF + SP - fragile and plastic silicates and SN - non-deformable silicates; NT + NA - titanium and aluminum nitrides. The analysis consists in examining the sample at a microscope on the whole surface prepared and comparing the most impure visual fields with the standard charts with levels from 1 to 5.

In figures 4, 5, 6 are presented the microstructures of unetched samples for non-metallic inclusions rate for the charges corresponding to the series A, B, C. The inclusion level for the A series (without desulphurisation and degassing) was P_A = 3.5. For the B-series (with advanced desulphurization, chemical and thermal homogenization), the inclusion level was P_B = 2.5. For C series (with vacuum degassing), the inclusion level achieved was P_C = 1.0.

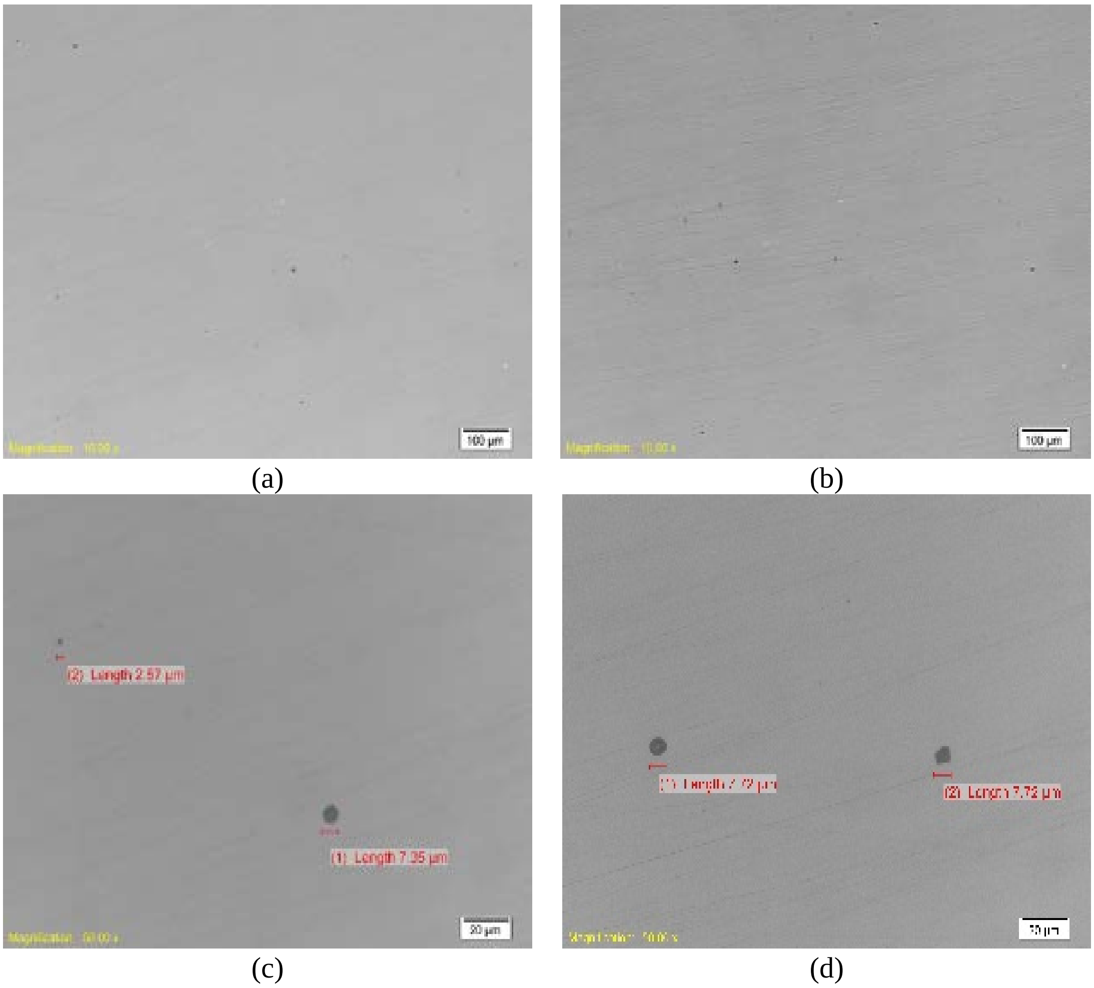


Figure 6. The appearance of non-metallic inclusions on the unetched surface of the C-series (with vacuum degassing): (a) and (b) 100X, (c) and (d) 500X.

The objective of this research was to demonstrate that improving the steel quality sheets by production of charges with increasingly low inclusions (i.e with increasing purity) had as effect the finishing and homogenize the grains, tensile strength improvement, elongation remaining at the values required by the current standard.

The research has shown that the target requirements can be achieved through a rigorous technology and process-controlled processing. Increased quality means fewer scrapes and relatively lower production costs.

4. Conclusions

In order to improve the steel quality and purity, an important place is occupied by the functional and technological adjustment of RH-type vacuum steel treatment plants equiped.

Research has shown that treatment in RH has led to: an increased in purity due to degassing; reducing the H_2 content; reducing of O_2 content by vacuum de-oxidation; decreasing content of non-metallic inclusions; the possibility to produce steels with narrow limits of the chemical composition; vacuum steel carburizing, reducing the liquid metal viscosity; reducing the N_2 content.

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