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IMPACT STRENGTH OF GX8CrNi12, GX5CrNi18-9 AND GX5CrNiMo19-11-2 CAST STEEL AT - 30 °C

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Preliminary Note – Prethodno priopćenje

The results of impact tests carried out at - 30 °C on cast alloyed GX8CrNi12, GX5CrNi18-9 and GX5CrNiMo19-11-2 steel grades are reported. It has been shown that at - 30 °C, the addition of 1 % Ni to cast GX8CrNi12 steel does not provide the required impact strength of 35 J/cm². In contrast, other tested materials containing 8 ÷ 9 % Ni can easily reach exceeding 50 J/cm². Numerous non-metallic inclusions present in the microstructure of cast GX5CrNiMo19-11-2 steel resulting from, among others, the miscalculated refining process were found to be one of the main causes of reduced impact strength as compared to the cast GX5CrNi18-9 steel.

Key words: alloying cast steel, Charpy energy, microstructure, fracture

INTRODUCTION

Studies of the toughness of structural materials at sub-zero temperatures are mostly carried out to determine the ductile-to-brittle transition temperature. Knowledge of this temperature is required by designers for proper selection of materials for cast components operating under dynamic loads when the operating temperature drops below 0 °C.

The ductile-to-brittle transition temperature is usually assumed to be the temperature to which corresponds a predetermined value of the impact strength. Typically for the cast steel this is the value of 35 J/cm² [1]. The factors strongly influencing the impact strength include chemical composition of the material (mainly the content of C, Al, N, P, Si, Ni, Cr and S), efficient deoxidation and desulphurization of the melt during melting, reducing the fraction of non-metallic inclusions by the application of ladle metallurgy, and well selected heat treatment process [2 - 4]. The choice of wrong deoxidizers or miscalculated time of cast steel holding before mould pouring are other reasons for the reduced impact strength. Non-metallic inclusions that remain in the melt have very adverse effect on both the reduction of area and impact strength [1].

In this study, the results of impact strength testing at - 30 °C obtained for the three grades of cast alloyed steel melted under industrial conditions and used for castings operating at ambient temperature and at temperatures down to - 30 °C are reported.

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MATERIALS AND METHODS

Tests were carried out on the three grades of alloyed steel commonly used for castings operating in industry. The chemical composition of the test material is shown in Table 1. The reported value of fracture energy for the cast GX8CrNi12 steel is 45 J at room temperature, while no data are available on the impact strength at sub-zero temperatures [5, 6].

In turn, the cast alloyed GX8CrNi18-9 and GX-5CrNiMo19-11-2 steels containing 9 to 12 % Ni, where nickel is generally considered the element highly beneficial for the impact strength at temperatures below 0 °C, are characterized by the fracture energy of 60 J at - 196 °C [1].

The impact test at - 30 °C was carried out using special metal container filled with a cooling medium (ethyl alcohol + liquid nitrogen). Fracture toughness was measured in the standard Charpy impact test on 10 x 10 x 55 mm specimens with 2 mm deep "V" notch [7].
Microstructure of the specimens was examined by light microscopy and scanning electron microscope (SEM). Fractography was made by SEM. The fraction of non-metallic inclusions in the examined materials was determined by the grid method. To determine the content of oxygen and nitrogen in test materials, a LECO apparatus was used (Table 2).

Table 1 **The chemical composition of investigated cast steel / mas. %**

Grade	C	Si	Mn	Cr	Ni	Mo
GX8CrNi12	0,07	0,09	0,54	12,5	1,0	-
GX5CrNi18-9	0,08	0,52	1,28	18,0	8,03	-
GX5CrNiMo19-11-2	0,07	0,68	1,18	18,2	9,2	2,0

* / P < 0,025 %, S < 0,007 %

Table 2 **The content of oxygen and nitrogen in investigated cast steel / ppm**

Grade	Oxygen	Nitrogen
GX8CrNi12	109	230
GX5CrNi18-9	112	972
GX5CrNiMo19-11-2	193	974

DISCUSSION AND RESULTS

The results of the impact test carried out on the examined materials at - 30 °C are compared in Figure 1. From the results it follows that the cast GX8CrNi12 steel is not capable of reaching the required impact strength at the test temperature showing, moreover, at this test temperature a large scatter of the results. Low Si content in the melt may indicate the incorrectly conducted process of deoxidation.

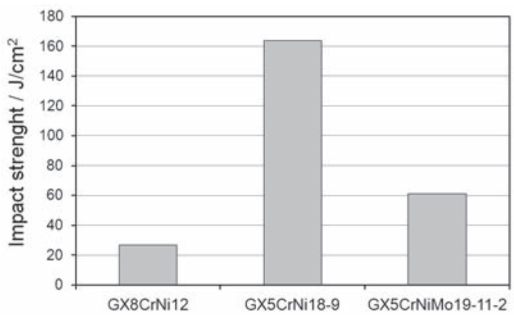

Figure 1 The impact strength of the investigated cast steel

In the group of materials with austenitic structure, the highest impact strength was obtained for the cast GX5CrNi18-9 steel, while, quite unexpectedly, the cast GX5CrNiMo19-11-2 steel had the impact strength nearly three times lower than the GX5CrNi18-9 grade. Both plastic properties and Charpy impact strength are adversely affected by the presence of non-metallic inclusions, predominantly oxides and sulphides (oxysulphides) [8, 9]. The adverse effect of non-metallic inclusions is mainly due to their physical properties quite different than the properties of the metal matrix. The intensity of the impact of inclusions on the properties of castings also depends on their shape, quantity, size and distribution in the structure. Studies of the microstructure have revealed an accumulation of non-metallic inclusions forming clusters and occurring in the vicinity of grain boundaries, mainly in the sample of the cast GX5CrNiMo19-11-2 steel.

The analysis of the chemical composition of inclusions present in the cast GX5CrNiMo19-11-2 steel indicates that these are mostly oxides and oxysulphides, in which the substrate for the nucleation of the sulphide phase is oxide usually occurring in the central part of the inclusion (Figures 2, 3).

The results of the analysis show that in the central part of the complex precipitates there are aluminium oxides containing about 36 ÷ 47 % Al and 45 ÷ 58 % O. Some oxides are additionally enriched in Ca (about 6 %). The presence of calcium and aluminium in the examined non-metallic inclusions is due to the widespread use of these two elements in the process of deoxidation and modification [8, 9]. The results of the chemical analysis of inclusions present in the investigated materials are in good correlation with the high oxygen content in this cast steel (by 80 ppm higher than in the cast GX-5CrNi18-9 steel – Table 2).

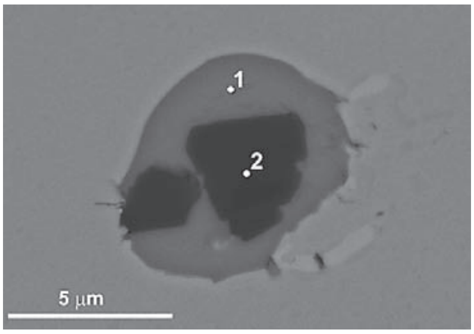

Figure 2 The non-metallic inclusion in the GX5CrNiMo19-11-2 cast steel, SEM

In the examined materials, the sulphur content was 0,007 %. Therefore, in the microstructure of the tested cast steel, a few sulphide inclusions were observed to occur forming, jointly with the inclusions of oxides (Figure 3), conglomerates particularly well visible in the fractures (Figure 4).

The cast GX5CrNiMo19-11-2 steel microstructure comprises, next to the oxide and oxysulphide inclusions, also manganese sulphides containing in addition to Mn (50 ÷ 56 %) and S (28 ÷ 34 %) also Ca (to 5 %). In the cast GX5CrNiMo19-11-2 steel, clusters of non-metallic inclusions are much more numerous than in the cast GX5CrNi18-9 steel.

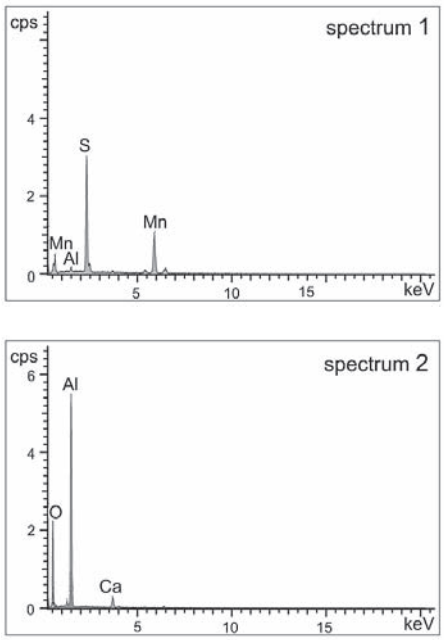

Figure 3 Energy Dispersive Spectroscopy (EDS) spectrum from the inclusion in Figure 2

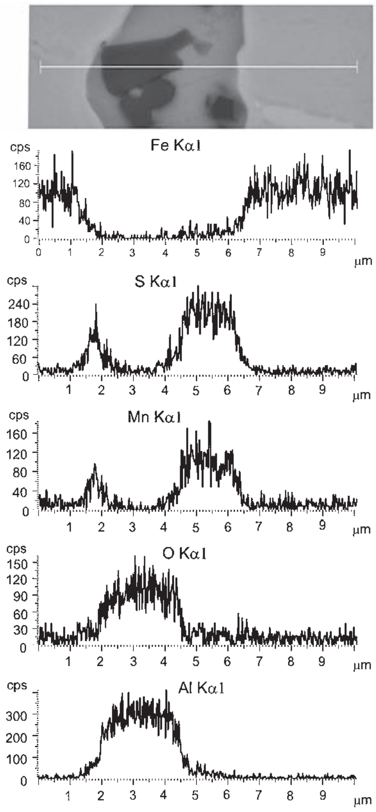

Figure 4 The non-metallic inclusion in the GX5CrNiMo19-11-2 cast steel and line scan analysis

Examinations of cast steel fractures after testing at - 30 °C

Fractures of the cast GX8CrNi12 steel samples characterized by the lowest impact strength are of a brittle nature. Additionally, they are observed to contain numerous non-metallic inclusions present in intergranular spaces in the form of continuous precipitates and cracks, which may significantly reduce the impact strength of the test material (Figure 4).

At - 30 °C, fractures of the cast GX5CrNi18-9 and GX5CrNiMo19-11-2 steel samples are of a ductile nature with many single inclusions or clusters of these inclusions (Figures 5, 6). Such accumulation of non-metallic inclusions, oxides in particular, can lead to crack propagation. Brittle oxide inclusions are in fact much more dangerous than sulphide inclusions with a high deformability index [4]. Discontinuities were also traced in fractures at the inclusion-matrix phase boundary after the specimen failure (Figure 7).

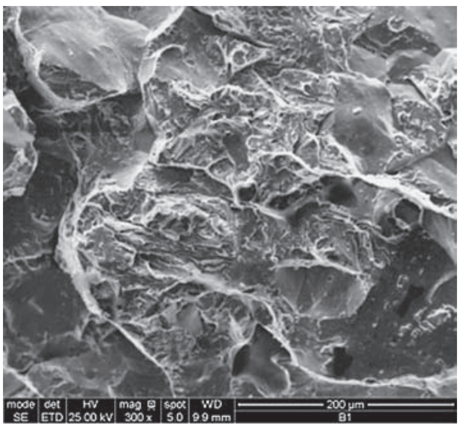

Figure 5 SEM fractograph of GX8CrNi12 cast steel specimen impacted at - 30°C

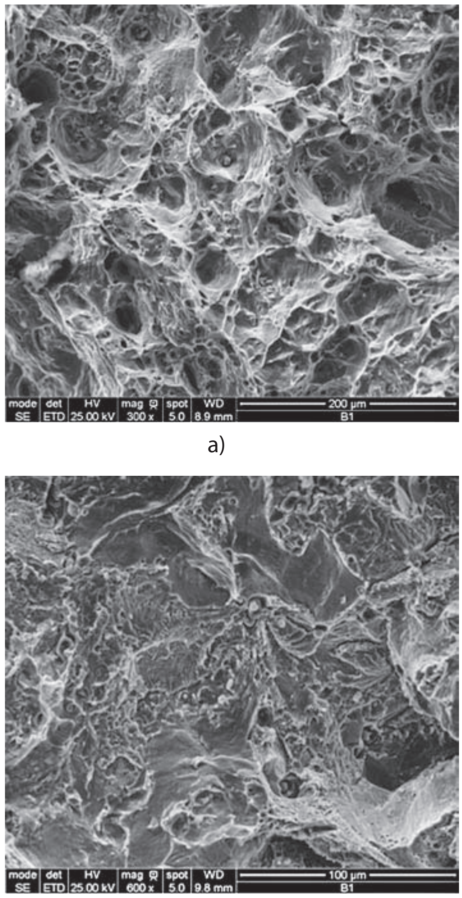

Figure 6 SEM fractographs of GX5CrNi18-9 (a) and GX5CrNiMo19-11-2 (b) cast steel specimens impacted at - 30 °C

Due to large discrepancies in the impact strength of cast GX5CrNi18-9 and GX5CrNiMo19-11-2 steels, an attempt was made to determine the amount of non-metallic inclusions in the test material. The volumetrical quantity of the non-metallic inclusion in the materials investigated, with regard to technological production (induction furnace) were high. The volume of non-metallic inclusion in GX5CrNiMo19-11-2 was approximately 42 % higher than GX5CrNi18-9 materials.

The examinations have revealed a higher fraction of non-metallic inclusions in the cast GX5CrNiMo19-11-2 steel.

CONCLUSIONS

- The cast GX8CrNi12 steel at - 30 °C has the impact strength of 28 J/cm^2, i.e. lower by approximately 7 J/cm^2 than the required value of 35 J/cm^2.
- The highest impact strength of 153 ÷ 175 J/cm^2 at a temperature of - 30 °C was obtained for the cast austenitic GX5CrNi18-9 steel.

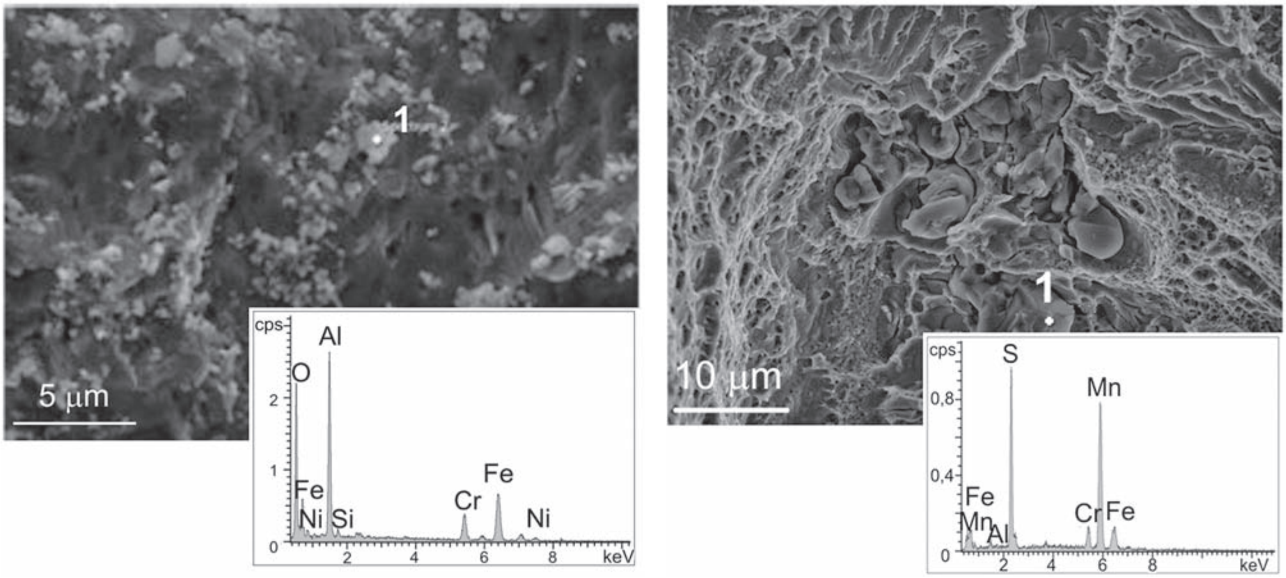

Figure 7 SEM fractographs of GX5CrNiMo19-11-2 cast steel and EDS analysis of precipitates

- The impact strength of the cast GX5CrNiMo19-11-2 steel at - 30 °C was comprised in the range of 48 ÷ 58 J/cm^2. The impact strength so low is due to high content of oxygen and the presence of numerous inclusions. Local accumulations of inclusions lead to reduced toughness of material, particularly at sub-zero temperatures.
- The chemical composition of the examined inclusions is closely linked with the cast steel melting technology, and next with the type of materials used for the deoxidation and modification of these inclusions, and with the oxygen and sulphur content in metal bath.

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Note: Translation of the text of the Polish to English made by D.Sc. John Komusiński, sworn English included on the list of sworn translators Minister of Justice under no. TP/2877/05, Kraków, Poland