A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 59 2014 Issue 3

DOI: 10.2478/amm-2014-0190

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IMPACT STRENGTH OF AUSTENITIC AND FERRITIC-AUSTENITIC Cr-Ni STAINLESS CAST STEEL IN -40 AND +20°C TEMPERATURE

UDARNOŚĆ KWASOOSPORNEGO STALIWA Cr-Ni W TEMPERATURZE -40 I +20°C

Studies described in this paper relate to common grades of cast corrosion resistant Cr-Ni steel with different matrix. The test materials were subjected to heat treatment, which consisted in the solution annealing at 1060°C followed by cooling in water. The conducted investigations, besides the microstructural characteristics of selected cast steel grades, included the evaluation of hardness, toughness (at a temperature of -40 and +20°C) and type of fracture obtained after breaking the specimens on a Charpy impact testing machine. Based on the results of the measured volume fraction of ferrite, it has been found that the content of this phase in cast austenitic steel is 1.9%, while in the two-phase ferritic-austenitic grades it ranges from 50 to 58%. It has been demonstrated that within the scope of conducted studies, the cast steel of an austenitic structure is characterised by higher impact strength than the two-phase ferritic-austenitic (F-A) grade. The changing appearance of the fractures of the specimens reflected the impact strength values obtained in the tested materials. Fractures of the cast austenitic Cr-Ni steel obtained in these studies were of a ductile character, while fractures of the cast ferritic-austenitic grade were mostly of a mixed character with the predominance of brittle phase and well visible cleavage planes.

Keywords: Stainless cast steel, Microstructure, Impact strength, Fractographic examination

Zaprezentowane w artykule badania dotyczą popularnych gatunków kwasoodpornego staliwa Cr-Ni o różnej osnowie. Zastosowane do badań materiały poddano obróbce cieplnej (przesycanie w temperaturze 1060°C i chłodzenie w wodzie). Przeprowadzone badania oprócz charakterystyki mikrostruktury wybranych gatunków staliwa obejmowały ocenę twardości, udarności (w temperaturze -40 i +20°C) oraz charakteru przełomów uzyskanych w wyniku złamania próbek na młocie Charpie'go. Na podstawie uzyskanych wyników udziału objętościowego ferrytu stwierdzono, że w staliwie austenitycznym występuje 1.9% tej fazy, natomiast w dwóch staliwach ferrytyczno-austenitycznych (F-A) udział ferrytu mieścił się w przedziale 50÷58%. Wykazano, że staliwo o strukturze austenitycznej charakteryzuje się wyższą udarnością w porównaniu do dwufazowego staliwa ferrytyczno-austenitycznego (F-A). Zmiany jakie zaszły w charakterze przełomów próbek były odzwierciedleniem uzyskanych wyników udarności badanych materiałów. W zakresie przeprowadzonych badań przełomy austenitycznego staliwa Cr-Ni wykazują charakter ciągliwo-kruchy, a przełomy staliwa F-A są przeważnie przełomami o charakterze mieszanym z przewagą przełomu kruchego z widocznymi płaszczyznami łupliwości.

1. Introduction

Austenitic stainless steels are popular materials for castings widely used in corrosive environments. Their popularity is due to a beneficial combination of mechanical properties and corrosion resistance as well as high ductility and toughness in the range of temperatures from +20 up to −196°C [1]. On the other hand, cast two-phase ferritic-austenitic steels (duplex) containing 40 to 60% of the δ ferrite are characterised by the mechanical properties superior to cast austenitic steels and far better corrosion resistance, including resistance to pitting corrosion (PREN >30) in solutions of sodium chloride [2÷5]. For this reason, ferritic-austenitic steels and cast steels have found wide application in the petrochemical industry, in electric power industry and civil engineering. The microstructure of Cr-Ni steel and cast steel has a significant influence on the mechanical properties and corrosion behaviour [6÷8]. High-chromium ferrite present in the microstructure of ferritic-austenitic steels and cast steels reduces the work of fracture, especially at sub-zero temperatures.

Higher mechanical and corrosion properties of the stainless steel compared with cast steel of the same chemical composition have encouraged the authors of the present study to conduct impact testing at -40 and +20°C on the best known grades of the cast stainless Cr-Ni steel.

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TABLE 1

Chemical composition of the stainless cast steel

Materials	C	Mn	Si	Cr	Ni	Mo	P	S	other
	wt. %								
A	0.1	0.75	1.01	18.97	10.56	2.05	0.005	0.015	0.072%Al 0.13%Nb
B	0.037	1.03	0.41	22.9	4.46	2.93	0.035	0.017	2.9%Cu 0.013%Al 0.048%N
C	0.045	4.93	0.77	21.4	1.93	–	0.019	0.014	0.017%Al 0.250%N

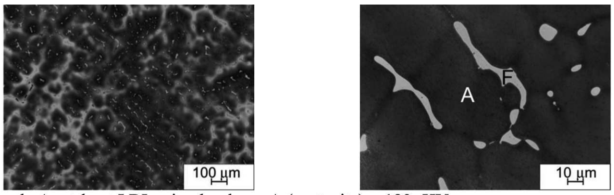
2. Materials and methods

The test material was melted in an electric induction furnace. Chemical composition of the tested cast steel is given in Table 1. The heat treatment involving solutioning at 1060°C was conducted in a laboratory. After the heat treatment, samples with 10×10×55 mm dimensions and a V notch were prepared for impact testing. The impact tests were performer according to PN-EN 10045-1: 1994 using the 150 and 300 J Charpy tester [9,10]. The tests were performed at -40 and +20°C. Using an MPD100A ferritoscope, the volume fraction of ferrite was determined in the tested grades of cast steel. To study the microstructure and give characteristics of the obtained fractures, a Neophot 32 light microscope and an Inspect S50 FEI scanning electron microscope were used. Hardness of cast steel was measured with a Brinell hardness tester.

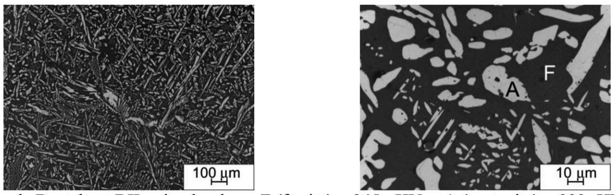
3. Results and discussion

The microstructure of the examined cast steel is composed of austenite and some percentage of ferrite (specimen of the chemical composition A, Fig. 1a) and of ferrite and austenite (specimens of the chemical composition B and C, Fig. 1b,c). The cast austenitic steel is a representative of the typical cast acid-resistant steels used by domestic producers for castings operating in harsh corrosive environments. The other two grades belong to the cast two-phase ferritic-austenitic steel (F-A) family characterised by good resistance to intergranular and pitting corrosion in the environment of Cl ions. The average volume fraction of ferrite in the microstructure of the examined cast steels in the base condition and after heat treatment is shown in Table 2.

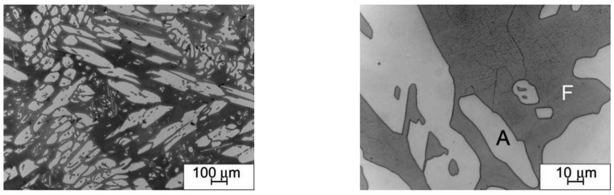
The obtained results have indicated that the cast austenitic steel had a small content of ferrite reaching the value of 1.9%. On the other hand, in a typical cast two-phase ferritic-austenitic steel, the ferrite fraction was at a level of 54.2÷58.1% (cast steel B). In the cast steel designated as C, the content of manganese and nitrogen was increased at the expense of the reduced Ni content to obtain a ferrite fraction in the range from 50 to 60% (50.5%÷56.5%). The obtained results of the ferrite content measurements show some variations between the ferrite content in the base condition and after the solution annealing heat treatment, mainly due to a heterogeneity of the cast steel microstructure in untreated condition.



a) sample A, etchant LBI, microhardness A (austenite) = 189μHV_{20}



b) sample B, etchant BII, microhardness F (ferrite) = 245 μHV_{20}, A (austenite) = 223μHV_{20}



c) sample C, etchant BII, microhardness F (ferrite) = 242 μHV_{20}, A (austenite) = 270μHV_{20}

Fig. 1. Microstructure of the investigated stainless cast steels after the solution annealing heat treatment, LM

TABLE 2

The average content of ferrite in investigated stainless cast steel

Materials	ferrite, %	
	As cast condition	After heat treatment
A	1.3	1.9
B	54.2	58.1
C	50.5	55.3

The increased content of austenite-forming nitrogen in cast steel (cast steel C) has increased the microhardness of austenite by about 50 μHV_{20} compared to austenite present in the microstructure of cast steel B.

Average hardness of the cast ferritic-austenitic steel amounted to 265 HB (cast steel B) and 240 HB (cast steel C), respectively. In contrast, the average hardness of cast austenitic steel was lower and amounted to 196 HB (cast steel A). It is expected that the high values of hardness will be accompanied by low values of the impact strength obtained in the tested materials.

Impact strength of the stainless cast steel at -40 and +20°C

At ambient temperature, the cast austenitic steel was characterised by high impact strength, exceeding the measuring range of the Charpy 150 J pendulum. Therefore, to measure the impact strength of this cast steel, Charpy pendulum with 300 J energy was used.

The examined grades of the cast two-phase steel F-A were characterised by the impact strength inferior to that of the cast austenitic steel (Fig. 2). The differences in the impact strength of cast steels B and C observed at a temperature of +20°C were probably due to a high nitrogen and manganese content in cast steel C compared to cast steel B. At -40°C, the impact strength of specimens made from the cast ferritic-austenitic steel was similar.

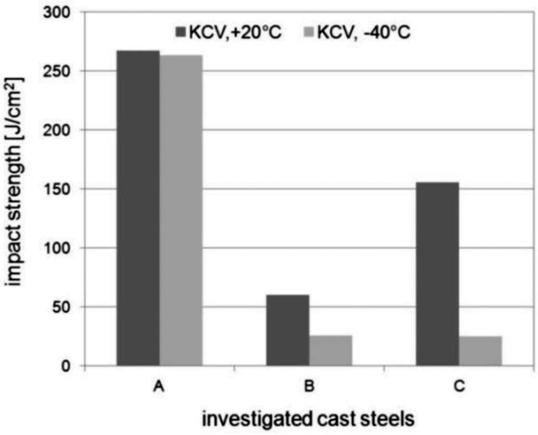
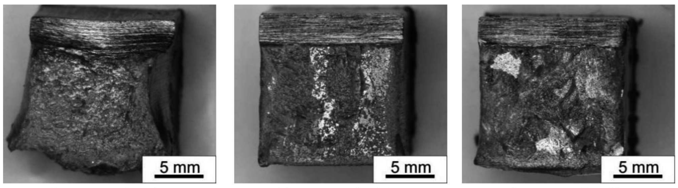


Fig. 2. Impact strength of the cast steel tested at -40 and +20°C, for A – Charpy pendulum of 300 J energy, B, C – Charpy pendulum of 150 J energy

Fractures of specimens after impact tests carried out at -40 and +20°C

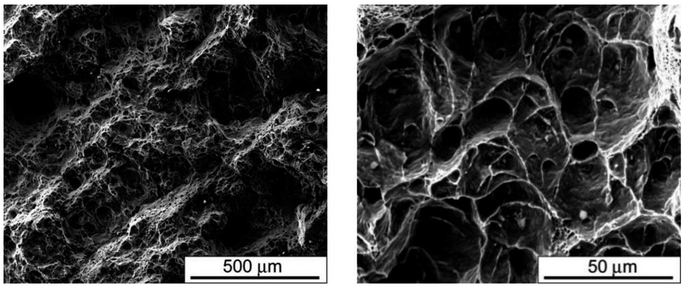
The visual inspection of fractures obtained after failure of the specimens tested on a Charpy pendulum impact machine showed that, compared with the cast ferritic-austenitic steel, the specimens of the cast austenitic steel were characterised by higher plastic deformation in the outer areas surrounding fractures (Fig. 3).



a) sample A b) sample B c) sample C

Fig. 3. Appearance of specimens of the cast steels after failure in -40°C

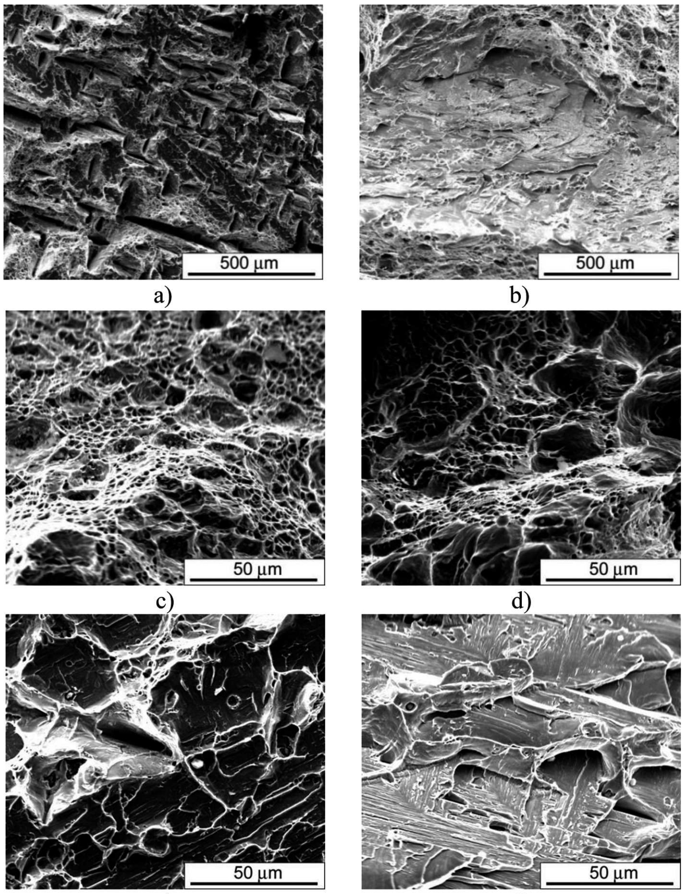
Fractures of the specimens of cast austenitic steel (cast steel A) which failed at +20 and -40°C, examined by SEM technique, were of a ductile nature with well visible dimples, typical of this type of fracture (Fig. 4), like in [10÷12].



a) b)

Fig. 4. Photographs of the investigated cast steels – sample fractures, sample A, temp. -40°C, SEM

Fractures of the specimens of cast ferritic-austenitic steel (cast steel B, C) obtained at -40°C (Fig. 5) were of a ductile – brittle nature with the predominance of brittle phase. Compared to fractures obtained in the specimens of cast steel B, fractures of cast steel C were observed to have numerous smooth fragments forming cleavage planes (Fig. 3, 5). In both grades of cast steel, some cracks were noted on the fractures.



a) b) c) d) e) f)

Fig. 5. Photographs of the investigated cast steels – sample fractures, temperature -40°C, samples B (a,c,e) and C (b,d,f), SEM

In contrast, fractures of this cast steel obtained at +20°C showed the prevalence of ductile areas (Fig. 6). The globular non-metallic inclusions visible on fractures were manganese sulphides originating from the melt refining process (Fig. 7).

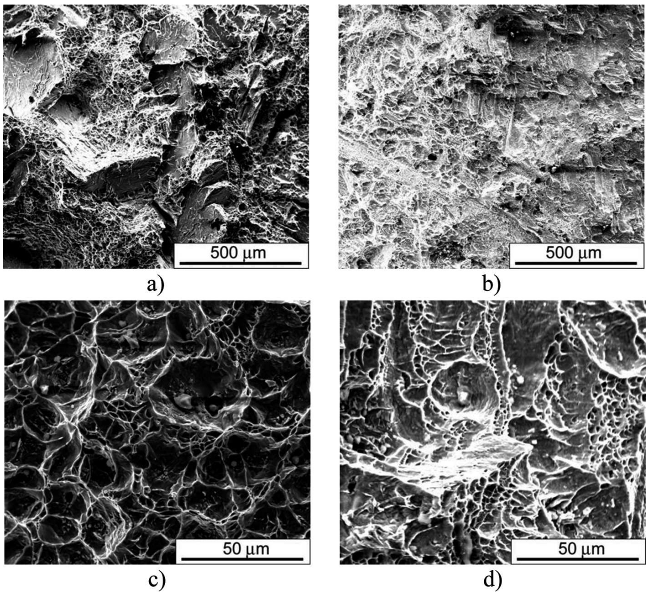


Fig. 6. Photographs of the investigated cast steels – sample fractures, temperature +20°C samples B (a,c) and C (b,d), SEM

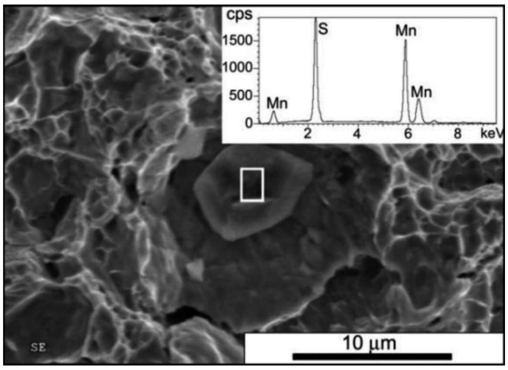


Fig. 7. Non-metallic inclusion in investigated cast steel

4. Conclusions

- The highest impact strength values at -40 and +20°C were obtained in the cast Cr-Ni steel of austenitic structure.
- At a temperature of -40°C, the impact strength of the cast ferritic-austenitic steels (22.9%Cr-4.46%Ni-2.9% Mo and 21.4%Cr-4.9% Mn-1.9%Ni-0.25%N) showed only some minor differences, while determined at a temperature of +20°C it was by over 90 units higher for the 21.4%Cr-4.9% Mn-1.9%Ni-0.25%N grade.
- It was proved that in specimens of the cast austenitic Cr-Ni steel, fractures obtained at -40 and +20°C were of a similar ductile character.
- Fractures obtained at -40 and +20°C in specimens of the cast ferritic-austenitic steel were characterised by a ductile-brittle nature.

Acknowledgements

The research part of the study has been partially executed under a Statutory Work no 11.11.170.318 Task no.5 (2014).

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Received: 20 March 2014.