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MECHANICAL PROPERTIES OF THE AUSTENITIC STAINLESS STEEL X15CrNiSi20-12 AFTER RECYCLING

MEHANSKE LASTNOSTI AVSTENITNEGA NERJAVNEGA JEKLA X15CrNiSi20-12 PO RECIKLIRANJU

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X15CrNiSi20-12 is a steel that has excellent resistance to corrosion and heat as well as good strength at room and elevated temperatures. According to EN 10095, the forged steel is used for products resistant to hot gases and combustion products at temperatures above 550 °C. As annealed, the steel is nonmagnetic, but becomes slightly magnetic after cold working. Typical uses include furnace parts, heating elements, aircraft and jet-engine parts, heat exchangers, carburizing and annealing boxes, sulfite liquor-handling equipment, kiln liners, boiler baffles, refinery and chemical processing equipment, and auto-exhaust parts.
The influence of re-melted back (waste) materials on the quality of X15CrNiSi20-12 steel was determined for re-melted (MM) and re-alloyed (AM) material with tensile strength tests using two standard test specimens at room temperature and 740 °C. The tensile properties were used for the analysis and a comparison of the features in order to obtain suitable material for recycling.

Keywords: austenitic stainless steel, mechanical properties, re-alloying, recycling

Jeklo X15CrNiSi20-12 je toplotno obstojno, z odlično odpornostjo proti koroziji in visoki temperaturi ter z dobro trdnostjo pri sobni in pri povišanih temperaturah. Skladno s standardom EN 10095 se jeklo uporablja za odkovke, ki so odporni proti vročim plinom in produktom zgorevanja pri temperaturah nad 550 °C. Žarjeno jeklo je nemagnetno in pri hladni predelavi postane rahlo magnetno. Značilna uporaba je za dele peči, grelne elemente, letalstvo in dele reaktivnih motorjev, za toplotne izmenjevalce, škatle za naogljičenje in žarjenje, za opremo, ki pride v stik z raztopino sulfita, vodila v ogrevnih pečeh, za špirale kotlov, v rafinerijah, v opremi kemijske procesne industrije in za dele avtomobilskih izpušnih sistemov.
Vpliv pretaljevanja odpadkov materiala na kvaliteto jekla X15CrNiSi20-12 je bil določen na pretaljenem (MM) in na dodatno legiranem (AM) materialu z nateznim preizkusom materiala z navadnimi vzorci za natezne preizkuse pri sobni temperaturi in pri 740 °C. Natezne lastnosti so bile uporabljene za analizo in za določitev, kakšen material je primeren za recikliranje.

Ključne besede: avstenitno nerjavno jeklo, mehanske lastnosti, ponovno legiranje, recikliranje

1 INTRODUCTION

X15CrNiSi20-12 steel is resistant to corrosion and is generally considered to be a fire-proof alloy, with the temperature for the destructive loss of weight being about 1093 °C. The standard EN 10095 lists the requirements for the chemical composition of the austenitic stainless steel X15CrNiSi20-12. **Table 1** shows the chemical composition of the raw material (RM), the re-melted material without re-alloying (MM) and the material with re-alloying (AM).[1] The examinations were performed with a SPECTRO LAB LAVM10 metal analyzer.

1.1 Mechanical and working properties

The basic requirements for these steels involve their applications at elevated temperatures and at higher loads. The X15CrNiSi20-12 steel has a stable austenitic microstructure and it can be used up to 1000 °C. The occurrence of undesirable δ-ferrite is possible only in exceptional cases, when the contents of the elements that stabilize the ferrite are at the upper limit of the allowable content, with a low content of austenite-stabilizing elements that stabilize the austenite, especially in the case of low contents of carbon and nitrogen[2].

Table 1: Chemical composition of the X15CrNiSi20-12 steel according to EN 10095[1]
Tabela 1: Kemijska sestava jekla X15CrNiSi20-12 skladno z EN 100095[1]

Material condition	Chemical composition (mass fractions, w/%)							
	C	Mn	Si	Cr	Ni	N	P	S
EN 10095	<0.20	<2.00	1.5–2.5	19–21	11–13	<0.11	<0.04	<0.030
Raw – RM	0.149	1.89	1.53	19.33	11.39	0.061	0.028	0.002
Remelted – MM	0.130	1.59	1.34	19.30	11.44	0.065	0.029	0.013
Realloyed – AM	0.133	1.76	1.50	19.28	11.34	0.066	0.030	0.020

Austenitic steels show very good ductility and large elongations at low temperatures. Furthermore, the tensile strength is significantly increased at low temperatures. These properties make austenitic steels suitable for use at low temperatures. However, when increasing the temperature the strength properties are decreased. The influence of delta ferrite can also not be ignored, as it increases the tensile strength and also the dispersion-hardening mechanism that increases the yield strength[3].

Table 2 lists the basic mechanical properties according to the EN 10095 standard.

Table 2: Mechanical properties of the austenitic stainless steel X15CrNiSi20-12[1]
Tabela 2: Mehanske lastnosti avstenitnega nerjavnega jekla X15CrNiSi20-12[1]

Yield strength $R_{p0.2}$ /MPa	> 230
Yield strength $R_{p1.0}$ /MPa	> 270
Tensile strength R_m/MPa	500–750
Elongation A/%)	> 28
Hardness, HB	< 223

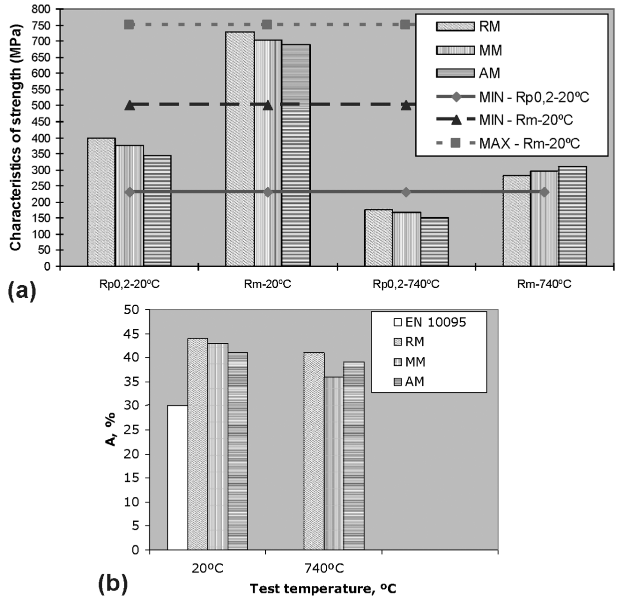

Figure 1: Tensile tests at temperatures of 20 °C and 740 °C: a) $R_{p0.2}$, R_m, b) A
Slika 1: Natezni preizkusi pri temperaturah 20 °C in 740 °C: a) $R_{p0.2}$, R_m, b) A

2 EXPERIMENTAL

2.1 Tensile properties at 20 °C and 740 °C

The tensile strength of the re-melted (MM) and re-alloyed (AM) steel after annealing was determined at room temperature and at 740 °C. The results showed that the tensile properties of both melts are uniform and within standard limits[4]. A metallographic analysis showed an austenitic microstructure with carbide precipitates at the grain boundaries. In the re-melted steel (MM) the grains are coarser due to the longer holding time at the quenching temperature[5]. The hardness testing was carried at room temperature and the results are given in **Table 3**.

Figure 1 provides a graphical representation of the tensile strength at room temperature and at 740 °C and the values prescribed in the standard EN 10095 for room temperature. The tensile properties at 740 °C are not prescribed by this standard.

The test results show that all the tensile strengths at 20 °C are within the limit values of the EN 10095 standard. The tensile strengths of the raw and re-melted steel are similar and close to the maximum prescribed in the standard[6]. The highest strength was obtained for the raw steel (RM) 730 MPa, followed by the re-melted steel (MM) 703 MPa, and the lowest value of 689 MPa for the re-alloyed steel (AM) (**Figure 2**).

The tensile strength at the test temperature of 740 °C shows a reverse trend, from 281 MPa for the raw steel, followed by the re-melted steel without re-alloying at 297 MPa, and finally for the re-alloyed steel a value of 311 MPa. The elongation shows the same behavior as the tensile strength for all three steels. The highest value of 44 % was for the raw steel, for the re-melted steel with-

Table 3: Results of the tensile tests at temperatures of 20 °C and 740 °C
Tabela 3: Rezultati nateznih preizkusov pri temperaturah 20 °C in 740 °C

Steel condition X15CrNiSi20-12	20 °C				740 °C		
	$R_{p0.2}$/MPa	R_m/MPa	A/%	HB	$R_{p0.2}$/MPa	R_m/MPa	A/%
EN 10095	> 230	500–750	> 28	< 223	–	–	–
Raw – RM	400	730	44	194	177	281	41
Remelted – MM	376	703	43	190	168	297	36
Realloyed – AM	345	689	41	180	150	311	39

Table 4: Tensile properties at 20 °C for the melted and re-alloyed steel, cast and annealed
Tabela 4: Lastnosti pri nateznem preizkusu pri 20 °C za staljeno in ponovno legirano jeklo, ulito in žarjeno

Steel condition X15CrNiSi20-12	Remelted steel - MM			Realloyed steel - AM		
	$R_{p0.2}$/MPa	R_m/MPa	A/%	$R_{p0.2}$/MPa	R_m/MPa	A/%
Casted	628	813	28	367	696	42
Annealed	403	717	41	346	691	38

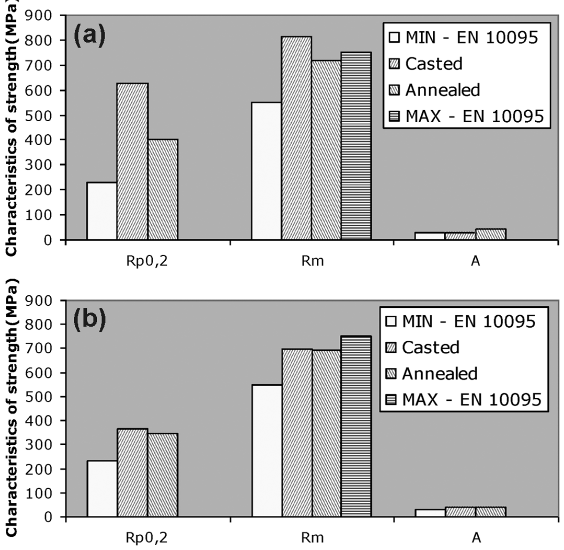

Figure 2: Results of tensile tests at 20 °C in the as-cast and annealed conditions for: a) re-melted and b) re-alloyed steel

Slika 2: Rezultati nateznih preizkusov pri temperaturi 20 °C v litem in žarjenem stanju za: a) pretaljeno in b) ponovno legirano jeklo

out re-alloying the value was 43 % and for the re-melted and re-alloyed steel it is 41 %. The elongation at 740 °C is above the prescribed value for room temperature and it is not prescribed in the standard.

Figure 2 shows the results of tensile tests for the re-melted and re-alloyed steel, cast and annealed, and in **Table 4** are the results of the tensile tests for the cast and annealed, re-melted and re-alloyed steel.

A comparison of the results in **Table 4** indicates that the properties of the re-melted (MM) and the re-alloyed (AM) steel are reduced after annealing and are much closer and more balanced than the re-alloyed steel. The thermal annealing treatment was performed to obtain the same conditions as were present for the raw steel.

The hardness values are the values prescribed by the standard for all steels and the maximum hardness is 223 HB. The hardness of the steel is the highest for raw steel, HB 194, for the re-melted steel it is 190 HB, and it is the lowest value, 180 HB, for the re-melted and re-alloyed steel.

2.2 Metallographic analysis

The microstructure was examined with a light microscope, OLYMPUS, BX60M, according to ASTM E 407[7]. **Figure 3** shows the microstructure of the raw steel (RM), the re-melted (MM) and the re-alloyed steel (AM) after quenching with a magnification of 100-times and 500-times is shown after etching with the Kalling reagent[8].

For all three steels the microstructure consists of an austenitic base and carbide precipitates in the interior and boundaries of the austenite grains. **Figure 3** reveals the difference in the amount of carbides. In the re-alloyed material a certain amount of carbides are inside

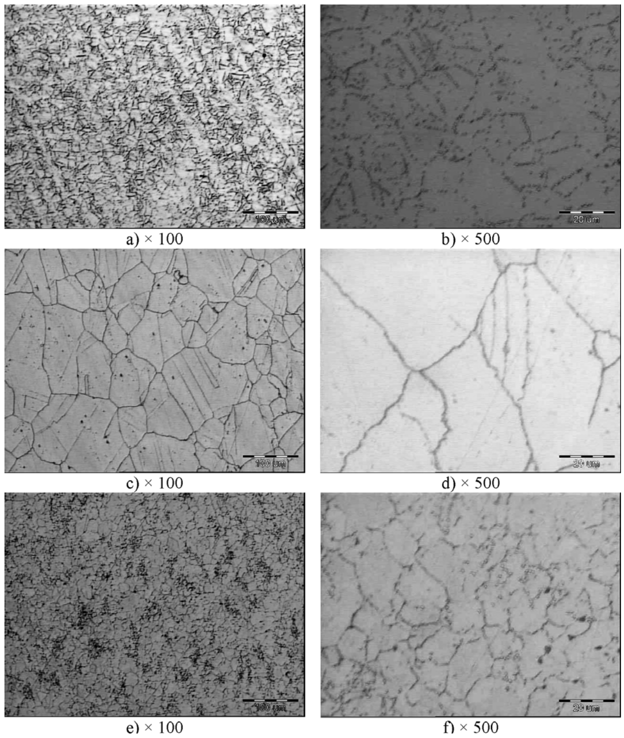

Figure 3: Microstructure of: a), b) the raw steel (RM), c), d) re-melted steel (MM) and e), f) re-alloyed steel (AM)

Slika 3: Mikrostruktura: a), b) jeklo (RM), c), d) pretaljeno jeklo (MM), e), f) dolegirano jeklo (AM)

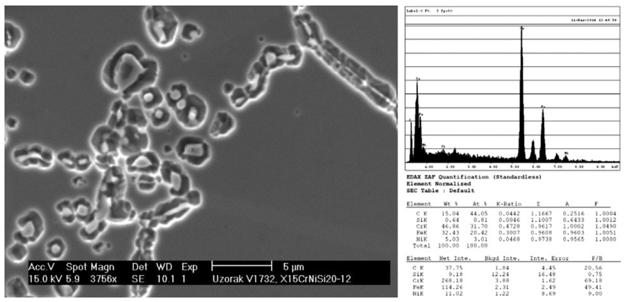

Figure 4: EDS analysis of carbides in re-alloyed steel (AM)

Slika 4: EDS-analiza karbidov v dolegiranem jeklu (AM)

the grains. This may be regarded as a consequence of the cooling rate. Considering the location and the size of the carbide it is assumed that these are complex chromium carbides[9]. The composition of complex chromium carbides can be found in a number of references.

The examinations were performed with a Philips XL-30 Scanning Electron Microscope. **Figure 4** shows the analysis of the carbides in the re-alloyed steel. **Figure 4** shows the results of the EDS analysis of the carbides in the re-alloyed steel that confirms the presence of chromium carbides.

3 CONCLUSIONS

Based on an analysis of the literature data and the conducted experimental studies, as well as the results of laboratory tests, the possibility of recycling the revert scrap of the austenitic stainless steel X15CrNiSi20–12 was investigated.

Re-melted (MM) steel and re-melted steel with re-alloying (AM) were processed into square rods of 36 mm, and quenched to obtain the same condition and dimensions as the raw steel (RM). The tensile properties and microstructure of both melts X15CrNiSi20-12 were examined with forging and rolling deformation and subsequent heat treatment of the experimental melts, approximately equal raw steels were obtained and then used for comparative laboratory tests. All the technical parameters of the heating, deformation and heat treatment were fixed.

The mechanical properties were tested at room and elevated temperatures. The mechanical properties at room temperature show that the tensile strength of raw steel (RM), of re-melted steel (MM) and of (AM) are fairly uniform and are close to the upper prescribed limit of 750 MPa in the standard EN 10095. The highest strength is obtained for the raw steel (RM), then the re-melted steel (MM) and the lowest value of 689 MPa for the re-melted and re-alloyed steel (AM). The same trend of results is present for the yield stress $R_{p0.2}$ and the elongation. At elevated temperatures the strength shows the opposite trend, with the maximum value of 311 MPa for re-melted and re-alloyed steel (AM) and for the raw steel (RM) a value of 281 MPa. For the yield stress $R_{p0.2}$ the trend is reversed with the largest value of 177 MPa for the (RM) to a minimum of 150 MPa for the AM. The high tensile properties are due to the austenitic structure and the carbide precipitates at the austenite grain boundaries.

The experimental results show that with the recycling process for X15CrNiSi20-12 steel it is possible to obtain the steel properties required by the standard EN 10095. The obtained results can be used with recycling technology in industrial conditions. The proper recycling process can ensure competitive products by the use of an accurate regime of re-melting, processing and heat treatment.

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