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Comparison of Mechanical Properties and Resistance to Creep of 20MnCr5 Steel and X10CrAlSi25 Steel

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Abstract

A comparison of both mechanical properties at different temperatures and resistance to creep related to steels 20MnCr5 and X10CrAlSi25 were investigated. In this sense, engineering stress-strain diagrams and creep curves are presented. Based on the mentioned diagrams, ultimate tensile strength, yield strength and modulus of elasticity as well as creep resistance may be compared. From the other hand, in accordance to measured Charpy impact energy, an assessment of fracture toughness was also made. In accordance with the experimental data, it is possible to say that structural steel 20MnCr5 (UTS: 20°C / 600°C = 562 MPa / 147 MPa; YS: 20°C / 600°C = 398 MPa / 141 MPa) and heat - resistant steel X10CrAlSi25 (UTS: 20°C / 600°C = 584 MPa / 487 MPa; YS: 20°C / 600°C = 132 MPa / 123 MPa) has have quite similar levels of the considered strengths at considered temperatures. Also, their resistance to creep is similar.

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Keywords: 20MnCr5 steel; X10CrAlSi25 steel; mechanical properties; creep resistance; Charpy impact energy

1. Introduction

Structure is designed and manufactured for a specific purpose, for example, to store a liquid or a gas, to carry a load, to transmit heat, to transport some media or whatever. The objective of the structural design is to create an engineering member that safely accomplishes its function [1]. Modern structural design is based on highly

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capacitive computers while necessary stress and strain analyses are made by finite element method [2]. Also, structural design requires optimization procedure in creation of the member. Optimization may be treated as the act of obtaining the best product under given circumstances [3]. A structural design is usually performed assuming that the designed element does not contain any failure as well as that failure will not occur in its service life. Despite the great progress in technology has been made failures continue to occur [4]. A large number of failures in engineering components occur due to preexisting defects, nonmetallic inclusions or other imperfections (casting, welding defects, etc.), [5]. However, it is of engineering interest to know how and why particular component has filed. This means that someone wants to know what is the cause of the failure and what is the mode of its expression. Except previously mentioned preexisting defects, as the causes of failures may be numbered also: misuse, design errors, assembly error, improper maintenance, etc. Despite all the possible errors, the number of successfully designed structures may be treated as satisfactory [6]. Creep as one of possible causes that can influence on the shape and dimension changes of the considered member, may also cause the fracture of the considered member. Creep arises in metals at enough high temperatures and appropriate stress levels. It is usually represented by a creep curve consisted of three stages, and that primary, secondary and tertiary. A few percent of creep strains as allowed in practice. Usually it is said that creep is appreciable only above 0.4 Tm, where Tm is a melting point [7]. However, some results related to investigations of the materials like 20MnCr5 and X10CrAlSi25 can be found in literature. In this sense, an investigation related to crack propagation using notch specimen made of 20MnCr5 was presented in Ref. [8.] Analysis the deformation behavior of a 20MnCr5 steel deformed in tension under hot-working conditions was presented in [9]. A comparison of the behaviour between this steel and similar steels was presented in [10]. Measurement of cyclic plastic response of X10CrAl24 ferritic stainless steel in a domain of plastic strain amplitude was performed and discussed [11]. Useful information related to material properties of this steel can be found in Ref. [12]. Also, some useful data related to classical structural steel can be found in Ref. [13].

2. Data relating to the research

Materials under consideration were steels: 20MnCr5 and X10CrAlSi25. Structural steel 20MnCr5 was delivered as hot-rolled 18 mm round bar, annealed. Ferritic steel X10CrAlSi25, was annealed 18 mm round bar. Their chemical compositions are given in Tab. 1.

Table 1. Material chemical composition

20MnCr5 (1.7147) - Chemical composition, Mass (%)														
C	Mn	Cr	Si	Ni	Cu	Nb	S	P	Ti	W	Mo	V	Al	Rest
0.22	1.23	1.1	0.3	0.08	0.06	0.03	0.025	0.02	0.02	0.02	0.01	0.01	0.01	96.865
X10CrAlSi25 (1.4762) - Chemical composition, Mass (%)														
C	Mn	Cr	Si	Ni	Cu	Nb	S	P	Ti	W	Mo	V	Al	Rest
0.102	0.52	23	1.2	0.685	0.096	-	0.01	0.022	0.013	-	0.016	0.2	1.23	72.906

Applications:

20MnCr5 steel is known as special structural steel (low-carbon, low-chromium steel), and may be recommended for the applications where wear resistance, medium strength and good toughness are requested. In this sense it is used mechanical engineering for highly stressed components, for example in automobile industry, for parts like gears, crankshafts. X10CrAlSi25 steel can be used in engineering where high temperature conditions and /or low tensile loads are required (furnace and steam boilers technology, oil and chemical industry, petroleum industry, etc.).

Equipment, specimens and standards:

Tensile tests were carried out using a material testing machine, 400 kN, furnace (900°C) and a high temperature extensometer. Tests related to impact energy determination were performed by Charpy impact machine. Test specimens used in tensile testing were machined from 8 mm round bars. Specimens' geometry and shapes as well as tests procedures are prescribed in ASTM standards [14].

3. Test results

3.1. Material properties – Engineering stress-strain diagrams

Several uniaxial tests were carried out at different temperatures. Some of these tests for selected temperatures are presented in Fig. 1.

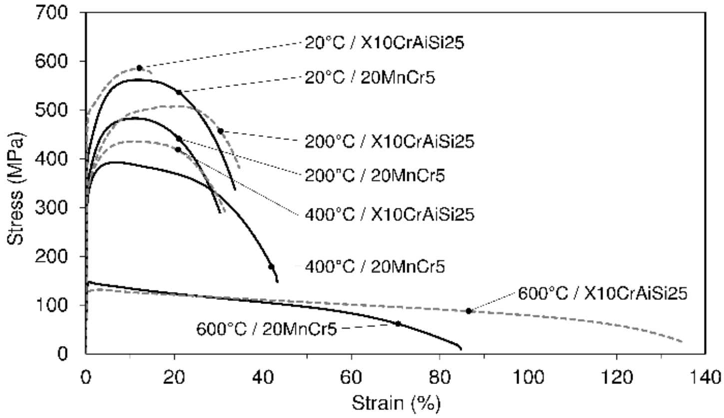


Fig. 1. Engineering stress – strain diagrams.

According to the stress-strain diagrams, numerical valus of mechanical properties are given in Tab. 2.

Table 2. Material properties: 20MnCr5 and X10CrAlSi25.

Material	Temperature °C	σ_m (MPa)	$\sigma_{0.2}$ (MPa)	E (GPa)
20MnCr5 (1.7147)	20	562	398	219
	200	483	349	192
	400	392	316	177
	600	147	141	76
X10CrAlSi25 (1.4762)	20	584	487	192
	200	507	330	173
	400	435	332	150
	600	132	123	90

In accordance with tests results it is visible that X10CrAlSi25 has higher strengths at all of considered temperatures except at temperature 600^{0}C. It is visible that tensile strength and yield strength in both of investigated steels are quite high and these properties decrease with temperature increase.

3.2. Creep tests

Creep tests were carried out for selected temperatures and selected stress levels, Fig. 2.

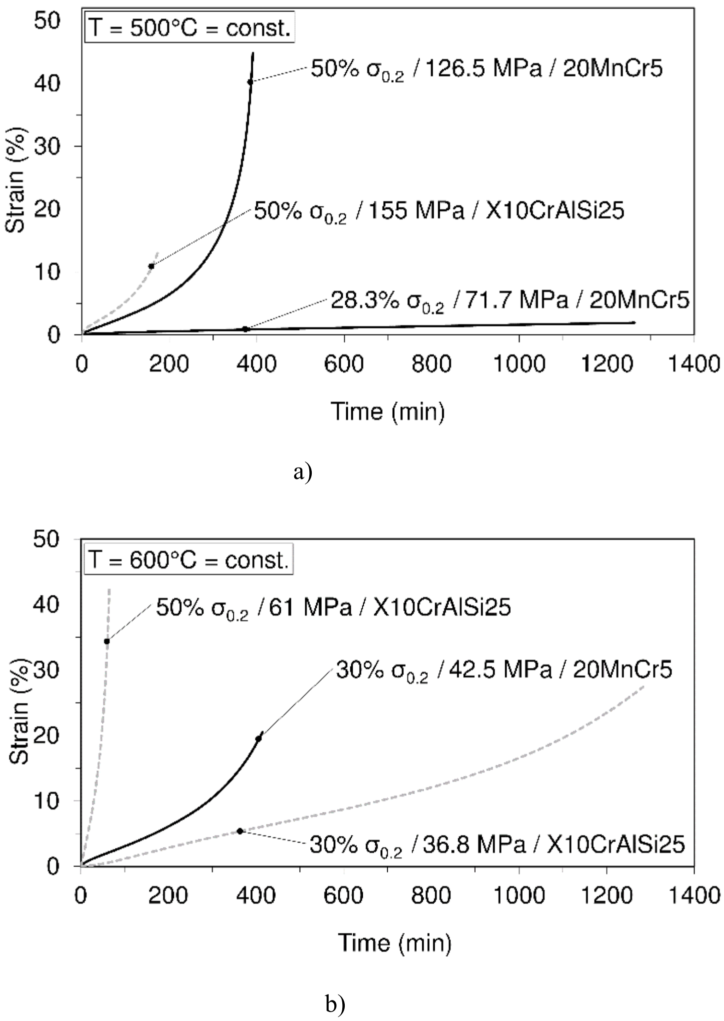


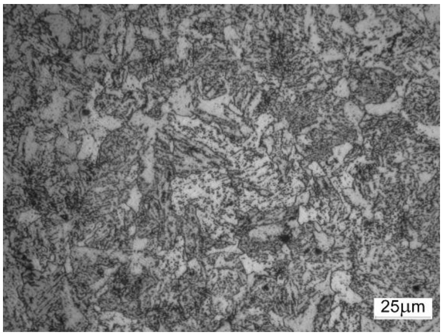
Fig. 2. Creep behaviour of steel 20MnCr5 and X10CrAlSi25 at different temperatures.

a) Temperature of 500^{0}C. b) Temperature of 600^{0}C.

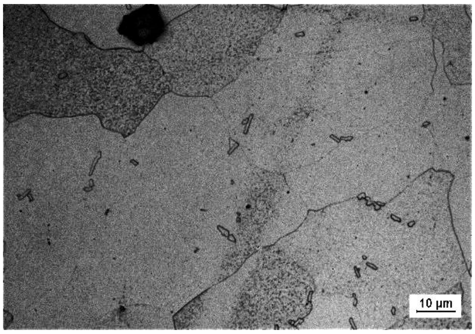
Regarding the creep behaviour it may be said that both materials have some resistance to creep but only at low stress levels.

3.3. Microstructure analysis

Two specimens were selected for the microstructure analysis. One specimen was made of steel 20MnCr5 while the other was made of steel X10CrAlSi25. In this sense, an optical micrograph of as-received material for each of considered steels is presented in Fig. 3. Fig. 3a shows a mixture of ferrite and cementite without significant segregation. In Fig. 3b, in accordance with the crystalline structure of the considered steel, it is visible that ferritic structure is under consideration.



a)



b)

Fig. 3. Optical micrograph of as received material (cross-section of the specimen), 4% nital.
a) 20MnCr5: Cross – section. b) X10CrAlSi25 – cross-section

3.4. Charpy impact energy

Usually it is said that yield strength is a measure against plastic deformation while fracture toughness is a property that defines material resistance to crack propagation [15]. However, fracture toughness is a property that can be obtained in laboratory conditions and manufacture of the specimen, its sizes and inability to manufacture it from the real part of the structure, may be certainly great disadvantages. There are other methods to evaluate material toughness. Well known method is Charpy impact energy method. Roberts-Newton formula, which is recommended for the assessment of fracture toughness independently of temperature level, can be used [16]:

$$KIc = 8.47\ (CVN)^{0.63}. \tag{1}$$

Table 3. Charpy impact energy.

Material	Temperature °C	CVN (J) (2V-Notch)	K_{Ic} ($MPa\sqrt{m}$)
20MnCr5	- 20	160	207
(1.7147)	20	178	221.6
X10CrAlSi25	- 20	4	20.3
(1.4762)	20	4	20.3

Conclusion

In the structural design it is of importance to be familiar with the knowledge of material properties and structural behavior in their service life conditions. In this sense, experimental research related to the considered materials was carried out. Although investigated materials are quite different, namely, one is structural steel and second one is stainless steel with high level of chromium, both steels have high ultimate tensile strength at considered temperatures. The same goes for the yield strength. In terms of impact toughness it is visible that steel 20MnCr5 has significantly higher impact toughness. Both considered steels may be treated as not enough creep resistant.

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