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Properties that Characterize the Material X46Cr13 Steel

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ABSTRACT

One of the most important issue in engineering design is the knowledge about the material to be used. In this sense, this study deals with the determination of material properties of investigated material X46Cr13. Ultimate tensile strength, yield strength, modulus of elasticity as well as creep behavior were determined using material testing machine. Results are presented in the form of engineering stress-strain curves and creep curves. On the basis of experimentally obtained results it is evident that this steel possess acceptable – high values of material properties but it cannot be tread as enough creep resistant. Although it is not presented in this study, this material is also tested to fatigue and Charpy impact energy was tested too.

Keywords: Mechanical properties, Short-time creep, X46Cr13 steel.

1. INTRODUCTION

In design procedure of engineering element or of any kind of engineering structure, it need to be said that the mentioned engineering element should be made of such a material that its properties could be suitable for operating conditions. In short, the selection of a proper material is thus one of the most important things. The modern design process is based on the highly capacitive computers and on the finite element analysis of the structure (Rao, 2011). Although the structure is designed under assumption that no failure is included in material or that no failure will arise during structure service life, in engineering practice many of mechanical failures may occur (Collins, 1993). Commonly observed modes of mechanical failures are: elastic deformation, yielding, brittle fracture, fatigue, corrosion, creep, thermal shock, buckling, etc. The most important question is why and how an engineering element has failed. The answer to this question gives the opportunity that any new design can be improved and that similar failure will not be repeated. The answer to the question why the considered structure has failed shows what is the reason or origin for failure occurring while the mode of the failure expression shows how the element has failed. Further, creep, as one of possible failure mode, in metals is usually represented by a curve consisting of three stages (transient, steady-state, accelerating). Creep phenomenon is usually defined as time-dependent behavior where strain continuously increases while the stress (load) is kept constant. Only a few percent of creep strains may be acceptable. Creep is considered to be appreciable at temperature above 0.4 T_m, where T_m is the melting temperature. Dislocation climb, vacancy diffusion and grain boundary sliding are numbered as mechanisms of creep (Raghavan, 2004). The reason that this investigations are performed is that they can be of benefit for design and nowhere similar results in this form can be found. However, some of known researched related to this material can be mentioned. In (Pfennig, Wiegand et al, 2013) the reduction of the lifetime of cyclically loaded X46Cr13 steel constantly exposed to highly corrosive CO2-saturated hot thermal water at 60°C is considered. The influence of microstructure and surface treatment on the corrosion resistance of martensitic steel was studied and results are presented in (Rosemann, Mueller & Babutzka, 2015). To have an insight in the mechanical behavior of other types of stainless steels, it is recommended to look at the papers (Brnic et al, 2016, Brnic et al, 2015, Brnic et al, 2011).

2. DATA RELATED TO RESEARCH

2.1 Tested material

Experimental results presented in this paper relating to the as – received material that was annealed and cold drawn 16 mm round bar, stainless steel X46Cr13, Fig 1. Chemical composition in mass %, was: C (0.442), Si (0.375), Mn (0.381), Cr (13.05), S (0.0192), P (0.0121), Mo (0.0493), Rest (85.6714). This steel is commonly recognized as high hardenability material in conjunction with good corrosion resistance. It is suited to be used in production of cutting tools due to its high hardness which is ensured due to its higher carbon content. It is used in production of valves, mould for plastic production, cutting tools industry, etc.

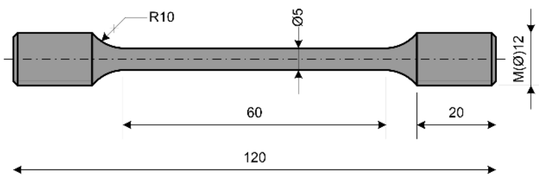

Figure 1 *Specimen used in tensile tests, geometry (mm).*

2.2 Equipment, specimens, testing procedures and standards

Uniaxial tests related to the determination of material properties and material creep behavior were performed using 400 kN capacity materials testing machine. Macro extensometer and high temperature extensometer were also used. Charpy impact energy determination, Charpy impact machine (150 J; 300 J) was used. Specimens were machined from 18 mm round bar and they as well as tensile tests related to the room temperature were done in accordance with ASTM: E 8M-15a. Tests related to high temperatures were performed in accordance with ASTM: E21-09 standard. Creep tests were carried out in accordance with ASTM: E 139-11 standard. Charpy tests were carried out and Charpy V-notch specimens, Fig. 2, were machined in accordance with ASTM: E23-12c standard. All of mentioned standard can be found in (Annual Book of ASTM Standards, 2015).

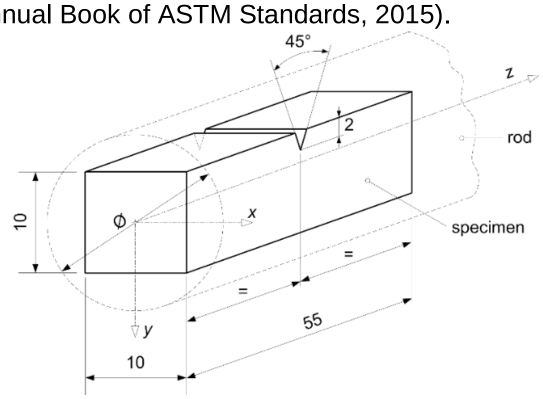

Figure 2 *Charpy V-notch specimen (mm).*

3. EXPERIMENTAL RESULTS AND DISCUSSION

Results of experimental researches related to the mechanical behavior of materials X46Cr13 are presented in the form of diagrams and / or tables. These experimental results include material mechanical properties, material creep behavior, impact energy and fatigue of considered material.

3.1 Uniaxial tensile tests

3.1.1 Engineering stress-strain diagrams and mechanical properties versus temperature

As the results of uniaxial testing of considered material at different temperatures, engineering stress-strain diagrams were obtained, Fig. 4. A few tests made at each temperature, but as the resulting diagrams differ too little, the Fig. 1 shows the results of the first test. Also, in the same manner, in Tab. 2, numerical values of mechanical properties related to the first test at each testing temperature are shown.

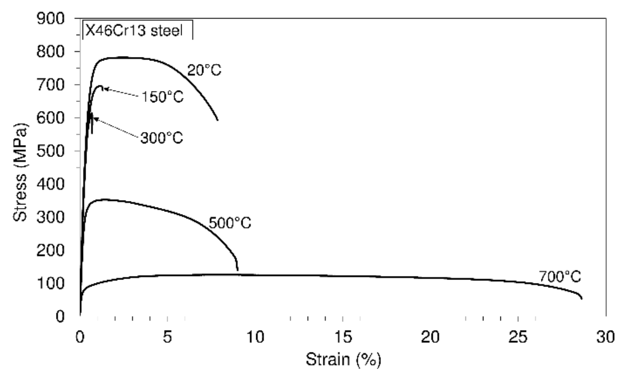

Figure 3 *Engineering stress-strain diagrams at different temperatures: X46Cr13 steel.*

Based on the experimental results it is visible that considered steel is a material of high ultimate strength and high yield strength at room testing temperature. Also, this steel exhibits high level of modulus of elasticity. Further, with temperature increase all of mentioned properties decrease.

3.2 Uniaxial short – time creep tests

Testing of materials to creep can be classified into two groups: short-term and long-term testing. In any case, long-term testing is very expensive. In accordance with the possibilities of available equipment in this study short-term creep will be considered. It is useful to simulate / model of material creep behavior for those materials for which the behavior of creep in certain conditions is already known. Modeling / simulation can be performed for each creep curve separately, for several creep curves that belong / related to the defined creep temperature or for selected creep curves within selected temperature range. Modeling can be performed using rheological models or by certain formula such as (Brnic et al, 2013):

$$\varepsilon(t) = D^{-T}\sigma^{p}t^{r} \quad (1)$$

In Eq. (1) there are: T – temperature, σ - stress, t – time and D, p and r are parameters which need to be determined. Several creep tests for different temperature levels are presented in Figs. 4-5.

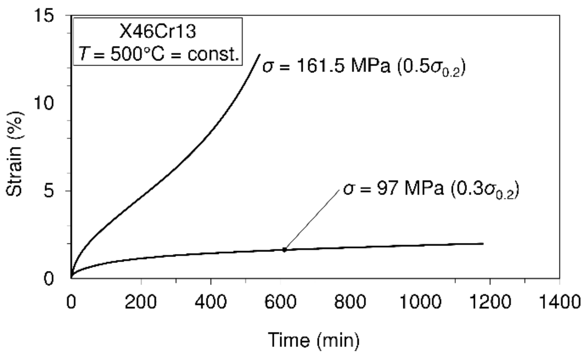

Figure 4 *Short-time creep behavior of steel X46Cr13 at the temperature of 500°C.*

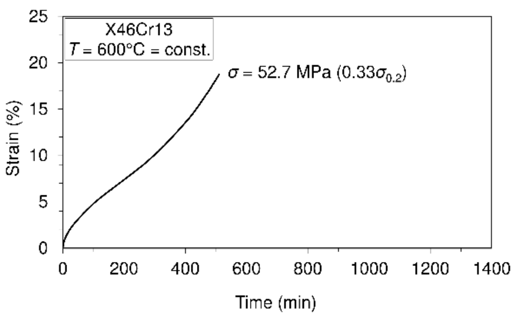

Figure 5 *Short-time creep behavior of steel X46Cr13 at the temperature of 600°C.*

It is visible that this material may be treated as creep resistant at temperature of 500°C when applied stress does not exceed 30% of yield stress, and finally, at temperature of 600°C when applied stress does not exceed 20 % of yield stress

3.3 Charpy V-notch impact energy and fracture toughness calculation

In accordance with the design strategy, two of material properties are usually mentioned and that yield strength ($\sigma_{0.2}$) and fracture toughness (K_{Ic}). Yield strength serves as a criterion for design structure against plastic deformation while fracture toughness serves as a criterion for design structure against fracture. Since experimental investigations related to fracture toughness can be expensive and requires some efforts in manufacture of specimens, also another method exists that is quite simple and may serve in fracture toughness assessment of considered material. This method is Charpy impact method that enables Charpy impact energy determination using which fracture toughness can be calculated. The obtained results related to impact energy are as follows:

Table 1 Charpy V-notch energy, steel X46Cr13.

	Temperature T (°C)			
	0	20	50	100
CVN (J)	7	8	17	30
KIc ($\mathbf{MPa\sqrt{m}}$ 8.47(CVN)0.63….[11]	28.9	31.4	50.5	72.2

Fracture toughness was calculated by well known the Roberts - Newton equation (Chao, ward & Sands, 2007):

$$K_{Ic} = 8.47\ (CVN)^{0.63}\ . \quad (2)$$

4. CONCLUSION

The investigations carried out provide good information that can be used in structural design. Obtained results related to mechanical properties show that this material has enough high strength which is in accordance with his possible applications. It is visible that these properties continuously decrease with temperature increase. Regarding the impact energy and fracture calculated fracture toughness it is quite low and a slightly increases with temperature increase.

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