Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, Volume 21, No. 1, ISSN 1726-9679
ISBN 978-3-901509-73-5, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria, EU, 2010
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DAAAM Symposium

PROPERTIES COMPARISON OF TWO CONSTRUCTURAL STEELS: ASTM A709 AND ASTM A505

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Abstract: *In this paper some of experimentally determined properties related to constructural steels are presented. That way mechanical properties, creep response and fracture toughness of two known constructural steels were determined. Engineering stress-strain diagrams as well as creep curves were determined by uniaxial tests using modern materials testing machine. On the basis of engineering stress-strain diagrams mechanical properties were determined and an effect of temperature on mentioned properties are shown. Fracture toughness was calculated on the basis of Charpy impact energy. Comparing all of mentioned properties some conclusions about use of these steels may be given.*
Key words: *ASTM A709 and ASTM A505, Material properties, Different environmental conditions, Creep response, Fracture toughness*

1. INTRODUCTION

Modern structural optimal design, has become a very powerful toll in engineering practice. The designed structure has to be of enough safety, functionality and cost-effective. The structure operating regime at some special environmental conditions may causes certain failure modes like: mechanical overload, creep, fatigue, and many others (Collins, 1993). Creep may be defined as a phenomenon of plastic deformation of the metal at high temperature under constant load (stress) and it is thermally activated process (Solecki & Conant, 2003; Raghavan, 2004). Creep is appreciable at temperature above 0.4 T_m, where T_m is the melting temperature.

Structure which operates at low temperature requires steels exhibiting good fracture toughness behavior combined with high strength. However, both knowledge of mechanical properties as well as creep behavior are of importance for designer of structure. In this paper some actualities about mentioned materials are presented. For more details according mentioned properties of these materials can be found in (Brnic et al. 2010a, Brnic et al. 2010b).

2. EXPERIMENTAL INVESTIGATION

2.1 Materials, equipment, standards

Materials under consideration were steels: ASTM A505 and ASTM A709. First of mentioned steels is widely used in statically and dynamically stressed larger cross-sections constructural components. Its applications are in automotive and industry aircraft, engines and machines, axles, rings etc. Second one is high strength low alloy steel (HSLA), which is usually used in highly stressed structures like bridges and cranes. Due to its superior toughness, strength and weldability it is also common in mechanical engineering.

Materials testing machine, 400kN, was basis of all experimental investigations. Mechanical properties as well as creep behavior were determined by tensile tests. Mechanical properties at ambient temperature were carried out according to the ASTM E8 standard, at lowered temperatures according to ISO 15579:2000(E) standard, while mechanical properties at elevated temperature were determined according to the ASTM E21 standard. Testing procedures with reference to material creep behavior according to ASTM E139 standard were carried out. Notch impact energy test was carried out according to ASTM E23-05 standard.

In this research some limitations can arise. For example, maximal temperature that can be used in this testing system is 900^0C. Also, maximal testing force which can be applied is 400kN. Creep test conditions were selected according to these constraints. In future research in the field of fracture toughness would be interesting to make at different temperatures, e.g at elevated as well as at lowered temperatures.

3. EXPERIMENTAL RESULTS

3.1 Mechanical properties at different temperatures

For both steels engineering stress-strain diagrams at lowered and elevated temperatures were determined. According to these diagrams ultimate tensile strengths (σ_m) and 0.2 percent offset yield strengths ($\sigma_{0.2}$) were determined. The test specimens were taken from considered steel rods. They were prepared according to appropriate standards.

An effect of lowered and elevated temperature on ultimate tensile strength and 0.2 percent offset yield strength for both steels using marked points is presented in Fig. 1. On this figure polynomial approximations are presented by continuous lines.

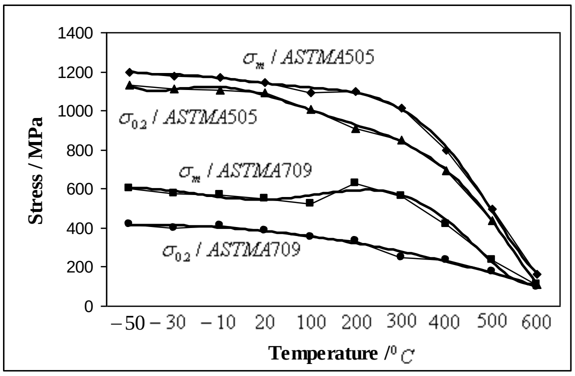
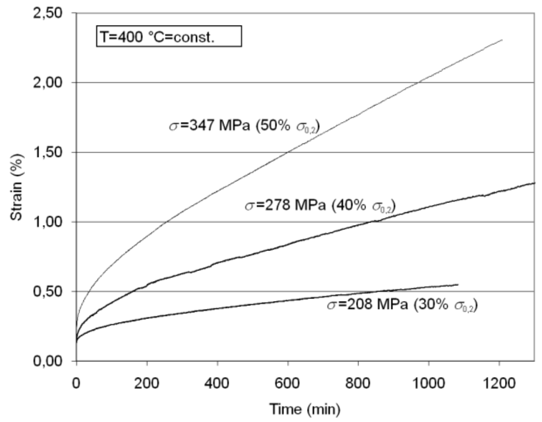


Fig .1. The effect of temperature (lowered and elevated) on mechanical properties

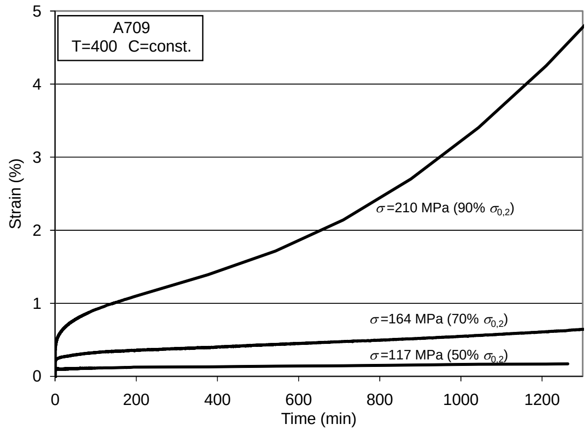
On the basis of Fig. 1 it is visible that both ultimate tensile strength as well as 0.2 percent offset yield strength of ASTM A505 steel are quite higher than at ASTM A709 steel.

3.2 Creep behavior

Several creep procedures for both steels at selected stress levels and selected temperatures were performed. In this paper, for possible creep resistance comparison, creep curves at temperature of 400^0C are presented (Brnic et al. 2010a, Brnic et al. 2010b).



a)



b)

Fig. 2. Creep behavior of ASTM A505 steel and ASTM A709 steel at temperature of 400^0C. a) Steel ASTM A505. b) Steel ASTM A709

3.3 Fracture toughness assessment

Usually selected properties, like 0.2 percent offset yield strength, modulus of elasticity, fracture toughness, etc., can be of special importance in design procedure. Fracture toughness (K_{Ic}) is used to design structure against fracture while yield strength ($\sigma_{0.2}$) is used to design structure against plastic deformation. Fracture mechanics may be treated as a subject concerned with predicting the failure of a structure containing crack-like defect (Zhang, 2010). A fracture toughness test can be used to measure the resistance of a material to crack extension (Anderson, 1995) but there are also other tests that provide fracture resistance measurement. Measurements of K_{Ic} involve the use of large specimens which are difficult to excise from operating structural component. An impact test, is one of such tests performed by Charpy pendulum impact machine which may be used as a very useful test for assessing the quality of a product. From the other hand this test may be misleading to directly apply the results to real industrial applications. However, some of relationships between fracture toughness (K_{Ic}) and Charpy V-notch impact toughness CVN were proposed. One of them was presented and explained in (Brnic et al. 2010b):

$$K^2_{Ic}=\frac{1}{f}E\ \overline{K}\ (1+\nu) \qquad (1)$$

In present case, 2 V notch was used, cross-sectional area of each specimen was A=80 mm^2. Also an average value of f = 15 was adopted. In eq. (1) there are:

K_{Ic} (MPa $\sqrt{m}$) - fracture toughness, E (MPa) - modulus of elasticity, $\overline{K}$ (J/mm^2) - impact toughness, and ν – Poisson's ratio. In this case $\nu = 0.3$ was adopted. The toughness $\overline{K}$ can be calculated as:

$$\overline{K} = CVN/A. \qquad (2)$$

Usually fracture toughness is calculated at room temperature. At the temperature of 20^0C the following values were measured / calculated (using eq. (1, 2)):

ASTM A505: E = 203900 MPa, CVN = 69 J, $\overline{K}$ = 0.8625 J/mm^2, K_{Ic} = 123.46 (MPa $\sqrt{m}$)

ASTM A709: E = 209000 MPa, CVN = 94 J, $\overline{K}$ = 1.125 J/mm^2, K_{Ic} = 145.89 (MPa $\sqrt{m}$).

According to equation (Roberts & Newton, 1981):

$$K_{Ic} = 8.47\ (CVN)^{0.63}, \qquad (3)$$

which is assumed to be applicable to test data at all temperatures, the following values for fracture toughness were calculated:

ASTM A505: K_{Ic} = 122 (MPa $\sqrt{m}$)

ASTM A709: K_{Ic} = 148.24 (MPa $\sqrt{m}$)

Good accordance between the obtained values using formulas (1) and (3) is visible.

4. CONCLUSIONS

In this paper a very useful data related to material mechanical properties as well as creep behavior and fracture toughness are presented. These data can be of importance in any structure design where environmental conditions of structure service life are similar like mentioned. According to these experimental investigations it can be said that ultimate tensile strength and 0.2 percent offset yield strength of ASTM A505 steel at any temperature are higher than similar at ASTM A709 steel. For creep behavior it can be said that both steels can be treated as quite resistant at temperature of 400^0C when stress level is quite low according to 0.2 percent offset yield strength.

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