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Experimental determination and prediction of the mechanical properties of steel 1.7225

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ABSTRACT

This paper presents experimental results and the analysis of steel 1.7225 at different temperatures. First, experimental results related to the mechanical properties of the material and its resistance to creep are shown using stress–strain and creep curves. Then, the analysis of the sensitivity of the ultimate tensile strength and yield strength with respect to strain rate is given. Modeling of some creep curves using an analytic formula is also presented. An assessment of the fracture toughness based on Charpy impact energy is made. The obtained results show that both ultimate tensile strength and yield strength achieve their maximum at room temperature, but these values are reduced with an increase in temperature up to 650 K. At this temperature, they achieve approximately 20% of initial values. Notably, this steel may be treated as creep resistant only when it is subjected to a low level of stress at considered temperature.

1. Introduction

1.1. Desirable material properties and possible failures of engineering structures

Both design and manufacture of a product intended for a particular purpose are based on knowledge of the material properties. In this sense, it is necessary for the material of construction to choose such a material that best suits the conditions of structure service life. Recently, the structure design has been based on the finite element analysis supported by highly capacitive computers. The structure is usually designed and manufactured with the assumption that it does not contain any failure. However, in engineering practice, a lot of failures may occur. Commonly observed modes of mechanical failures are fatigue, creep, force and/or temperature induced deformation, corrosion, etc. Fracture may arise as a result of the existence of some failures. Fracture in technology is understood as the total or partial separation of an original structure [1]. Therefore, the fracture mechanics have become a discipline for analyzing fatigue and fracture failures in structures of all types [2]. This paper considers creep as one of possible failures of material. It is known that only a few percentages (1–2%) of creep strain are allowed in engineering practice. It is often said that creep should be considered at a temperature above $0.4T_m$ where T_m is the melting temperature [3]. A process of creep in metallic materials is often presented by the curve on which it is possible to distinguish three specific stages of creep (primary or transient creep, secondary or steady-state creep, and tertiary or accelerating creep). Below are mentioned some of the recent works relating to the testing of material that is discussed in this paper. When considering bending fatigue resistance of steel 42CrMo4 its microstructure, hardness as well as crack resistance were determined [4]. The influence of CO_2 and the pressure of the surrounding media on steels, including 42CrMo4 steel, demonstrated in laboratory experiments and providing a corrosive environment similar to a geological onshore CCS-site (Carbon Capture and Storage), were also studied and explained [5]. In some of the machining processes, heat has resulted in a phase transformation on the work piece surface layer. An approach to predict and analyze cutting induced phase transformations in surface layers related to 42CrMo4 steel was considered and explained [6]. In addition, during the drilling process high mechanical and thermal loadings of tool and workpiece have arisen [7]. In that way, distortion and modifications of the surface layer microstructure can be observed. Based on experimental results and 2D finite element machining simulations, a model representing the mechanical and thermal collective load of the drilling process has been developed in relation to the parameters of cutting speed and feed rate. A finite element model has been established to predict phase transformations of the steel 42CrMo4 (AISI 4140). As many machines can be loaded by different forces where fatigue may arise, a model has been created to simulate the damage process based on the growth of microcracks under the influence of cyclic loading [8]. According to the described procedure [9], material properties for two steels (DIN 41Cr4 and DIN 42CrMo4) have been determined. The hot tensile deformation of 42CrMo steel was studied [10] within the temperature range of 850–1100 °C. The effects of hot forming

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parameters on the elongation as well as fracture properties were also analyzed. Further, uniaxial ratcheting and fatigue failure of tempered 42CrMo4 steel (tempering at 560 °C after heating at 850 °C for 1 h and quenching in oil) were considered using uniaxial stress-controled cyclic loading [11,12]. A damage model has been proposed to simulate and predict the fatigue failure life. An experimental study of the rheology of some steels, including 42CrMo4 steel, over a temperature range from 20 °C to 1000 °C and with appropriate strain rates has been examined and presented in Ref. [13]. Research relating to the valve seat of the pump made from 42CrMo4 was corroded on its exterior surface and plowed on its seal face [14]. Because of this failure, the pump could not work in its operating pressure. The reason that causes the corrosion was clarified and corresponding measures were put forward. The effects of tempering temperature on the morphology, distribution of carbides and impact toughness were investigated for steel 42CrMo treated as heat resistant steel with hardening ability and good creep resistance [15]. To compare the mechanical properties of steel 1.7225 with mechanical properties of other materials, such as steel S275JR [16], steel for valves [17], steel AISI 420 [18], toll steels [19], steel AISI 316Ti [20], it is recommended to take a look at the aforementioned references.

1.2. Purpose of the research presented in this paper

The purpose of this research is to provide designers of structures an insight into the properties of the material and its creep resistance at different temperatures. In that way experimentally obtained stress–strain diagrams provide the determination of ultimate tensile strength and yield strength, while creep curves provide an insight into resistance to creep. Also, tensile tests at different strain rates provide insight into the influence of strain rate on the level of considered properties (ultimate tensile strength, yield strength). In addition, examination of impact energy allows an engineering calculation of fracture toughness.

2. Basic data related to research

Material under consideration was 1.7225 steel (DIN 42CrMo4, AISI 4140) delivered as soft annealed. It belongs to low alloy steels and is not corrosion resistant. For its use in corrosive or water environment, protective coating is to be used. Chemical composition of the considered material, in mass (%) is C (0.45), Cr (1.06), Mn (0.74), Si (0.32), Mo (0.17), S (0.018), P (0.014), and Fe (97.228).

This material is actually used in the production of engineering components of larger cross-sections that are to be exposed to static and dynamic loads in any field of engineering.

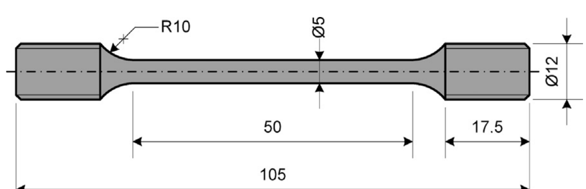


Fig. 1. Geometry of sub-size specimen for tensile testing (mm).

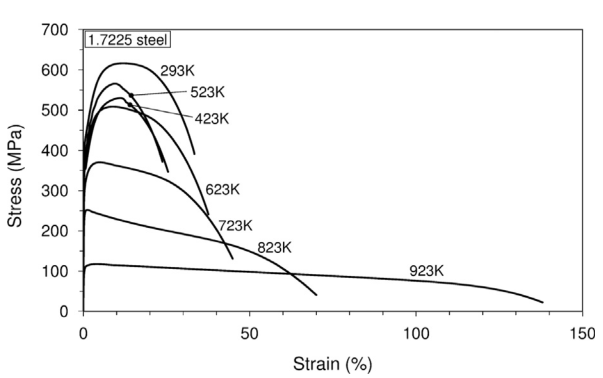
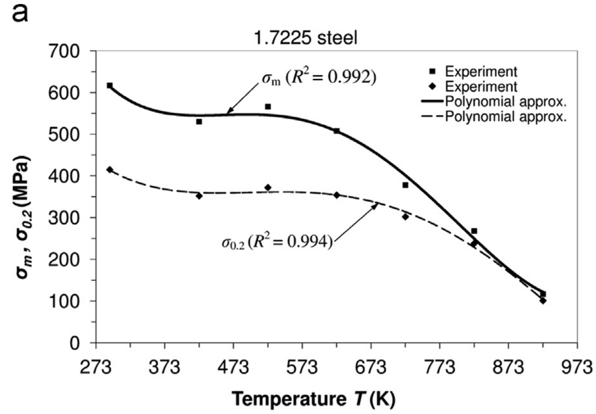


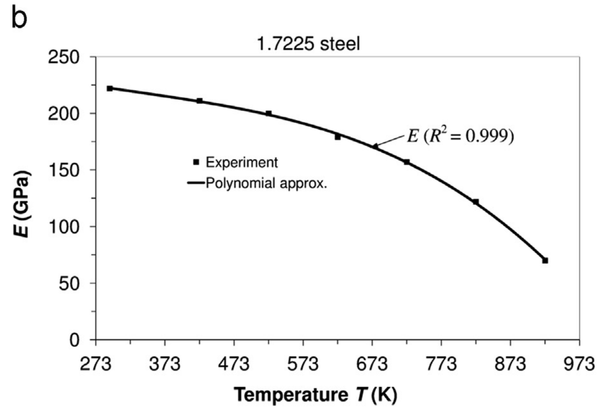
Fig. 2. Steel 17225 – engineering stress–strain diagrams at room and elevated temperatures.

a



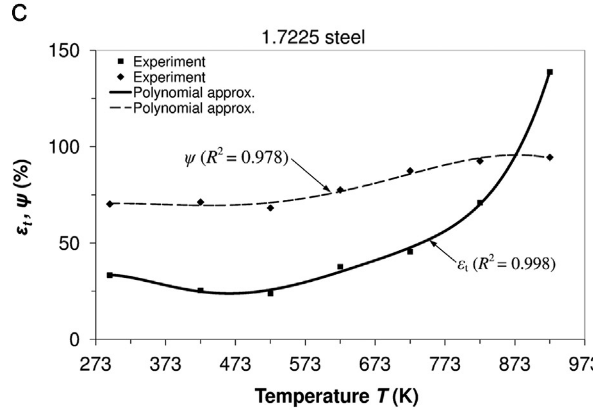
$$\sigma_m(T) = 2.01563\cdot10^{-8}T^4 - 5.07309\cdot10^{-5}T^3 + 4.43254\cdot10^{-2}T^2 - 16.3728T + 2733.81$$
$$\sigma_{0.2}(T) = 6.14438\cdot10^{-9}T^4 - 1.83216\cdot10^{-5}T^3 + 1.81895\cdot10^{-2}T^2 - 7.48101T + 1459.56$$

b



$$E(T) = -4.69731\cdot10^{-7}T^3 + 4.71796\cdot10^{-4}T^2 - 24.6882T + 265.99$$

c



$$\varepsilon_t(T) = 1.45971\cdot10^{-11}T^5 - 4.04467\cdot10^{-8}T^4 + 4.35306\cdot10^{-5}T^3 - 2.23554\cdot10^{-2}T^2 + 5.40854T + 460.424$$

$$\psi(T) = -1.29918\cdot10^{-9}T^4 + 2.79828\cdot10^{-6}T^3 - 2.02609\cdot10^{-3}T^2 + 60.1589T + 7.45445$$

Fig. 3. Steel 1.7225: changes in material properties as a function of temperature. (a) Mechanical properties (σ_m=ultimate tensile strength, $\sigma_{0.2}$=0.2 offset yield strength) versus temperature. (b) Modulus of elasticity (E) versus temperature. (c) Total elongation (ε_t) and reduction in area (ψ) versus temperature.