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Steel 51CrV4 under high temperatures, short-time creep and high cycle fatigue

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A R T I C L E I N F O

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A B S T R A C T

The use of a material for a particular purpose is based on its properties. In this sense, the article deals with the analysis of the results of experimental researches performed on steel 51CrV4. Experimental studies included responses of material at room and high temperatures as well as creep and fatigue behaviors of considered material. Responses of the material at room and high temperatures are displayed in the form of engineering stress-strain diagrams. Based on these responses were determined mechanical properties such as ultimate tensile strength (770 MPa/20 °C; 98 MPa/700 °C), 0.2 offset yield strength (642 MPa/20 °C; 60 MPa/700 °C) and modulus of elasticity (198 GPa/20 °C; 37 GPa/700 °C). Short time creep curves show the behavior of material at certain high temperatures and stress strevels. Each creep process is performed at constant temperature and the corresponding constant stress. Charpy impact energy (average values: 20 J/20 °C; 65 J/200 °C) was tested at different temperatures, and consequently, fracture toughness was calculated based on these results. Finally, uniaxial fatigue limit in amount of 251 MPa was calculated based on uniaxial high cycle fatigue tests at stress ratio of $R = -1$.

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1. Introduction

The idea of the design is to make the optimal product from materials whose properties best meet the requirements of exploitation. Design of the structure is a complex process that needs to take into account a variety of requirements, and hence is the result of a compromise between requirements and available features. Since the structure may have different shapes, and it can be subjected to different loads, the modeling of the structural geometry, boundary conditions and loads requires an appropriate design tool. It is evident that any solution of the differential equation in a closed form for this problem cannot be found. In this case, the finite element method is one of the most common numerical tools for obtaining the approximate solutions [1,2]. In design process as well as in manufacturing process of the considered structure, material is used under assumption that it does not contain any failure. However, many causes of failures can be mentioned that may arise during the design, manufacturing, assembling of structural elements, loading, maintenance, inspection, etc. In this sense as common causes of failures can be listed misuse, design errors, assembly errors, use of improper material, unforeseen operating conditions, inadequate control, corrosion, wear, etc. In accordance with the existence of the causes (origin) of the failure, commonly observed modes of mechanical failures are [3–5]: fatigue, fracture, yielding, force induced elastic deformation, creep, buckling, large strains, the presence of crack, etc. It is of importance to know how and why some structural element has failed. Namely, any of mechanical failure has its origin and mode of manifestation. Based on the analysis of the failure the answer on the question why and how a member has failed can be obtained. In this paper, in addition to considering the changes in material properties at elevated temperatures, two of mentioned failures were studied and analyzed and that creep and fatigue. Creep is usually defined as a continuous deformation of a material under constant stress [6]. When small strains are considered, experiments performed at constant stress and constant load are the same. Considering creep of metallic materials, creep curve representing creep process, can be divided into three areas and that: primary (transient) creep stage, secondary (steady-state) creep stage and tertiary (accelerating) creep stage. In engineering practice creep strain is commonly allowed in amount of 1–2%, and at the same time it can be said that creep is appreciable at temperature above 40% of melting temperature [7]. Regarding the fatigue of the material, it is known that strength of the material during the fatigue process may be significantly reduced, depending on the type of stress and stress ratio. However, both of mentioned failures are analyzed on the basis of experimental investigations of the considered material.

1.1. Some of the most recent published papers related to steel 51CrV4

For the purpose of gaining insight into the behavior of the considered material, its application and its properties, newer published papers dealing with the problem of the behavior of 51CrV4 steel are considered. In

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Table 1
Chemical composition: 51CrV4 steel.

Material: 51CrV4 steel (Chromium vanadium type spring steel)							
Designation							
Steel name (grade, quality)/i.e., letter mark of steel (EN and other norms)					Steel number (Mat. No; W. Nr; Mat. Code)/i.e., numerical designation of steel		
DIN EN 10083-3-2007-01: 51CrV4; (≈DIN: 50CrV4) USA: SAE/AISI 6150; BS: 735A50; 735A51					1.8159		
Chemical composition Mass (%)							
C	Si	Mn	P	S	Cr	Ni	Mo
0.455	0.319	0.919	0.0091	0.0042	1.09	0.0216	0.0053
Cu	Al	V	W	Rest			
0.0267	0.0227	0.127	0.0059	96.995			

Ref. [8] on the basis of microstructure analysis of 51CrV4 spring steel after cyclic quenching with both heating and cooling, some conclusions have been made. It was concluded that the strength increases, which is attributed to the ultra-refine grain formation. Further, the highest contribution to the strength and ductility comes from the micro-nano scale twins, etc. In Ref. [9], the specimens made of 51CrV4 after quenching and tempering in order to improve fatigue strength and mechanical properties were analyzed. The research showed that the used technological processes increased the fatigue strength limit as well as mechanical properties. Further, in Ref. [10], the research shows that that bainite can be spheroidised in similar way as pearlite. Namely, the article describes rapid carbide spheroidisation of bainitic structure of 51CrV4 spring steel. It is known that steel 51CrV4 has very good properties and heat treatment performance and is used as spring steel. In order to improve the properties of the existing saw blade steel, steel 51CrV4 was innovatively developed for manufacturing diamond welded saw blade matrix, as described in Ref. [11]. In Ref. [12] the effect of selected technological parameters of shot peening on process intensity of 51CrV4 steel was

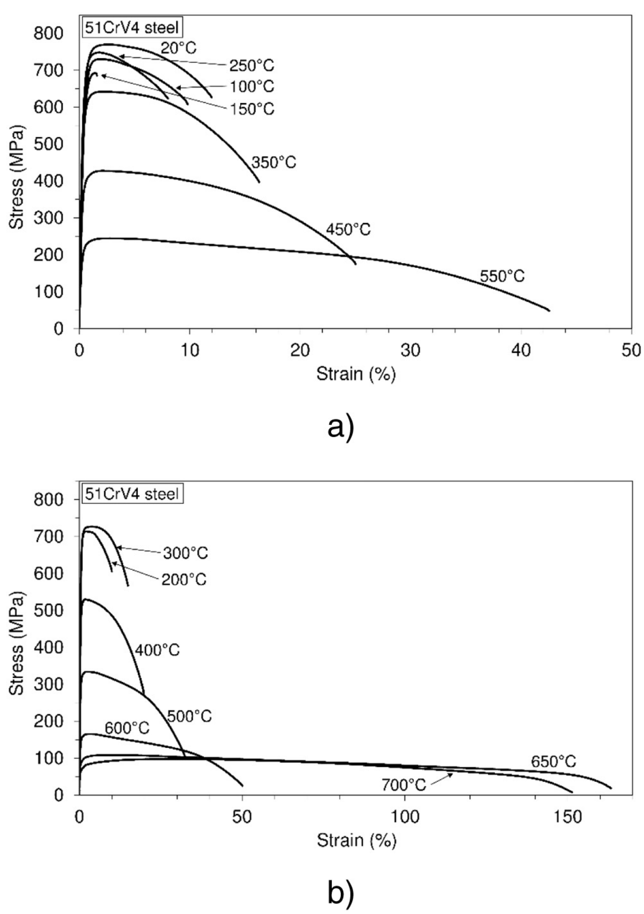

Fig. 1. Engineering stress-strain diagrams at different temperatures: 51CrV4 steel (first test for each of considered test temperatures). a) Temperature: 20 °C, 100 °C, 150 °C, 250 °C, 350 °C, 450 °C, 550 °C. b) Temperature: 200 °C, 300 °C, 400 °C, 500 °C, 600 °C, 650 °C, 700 °C.

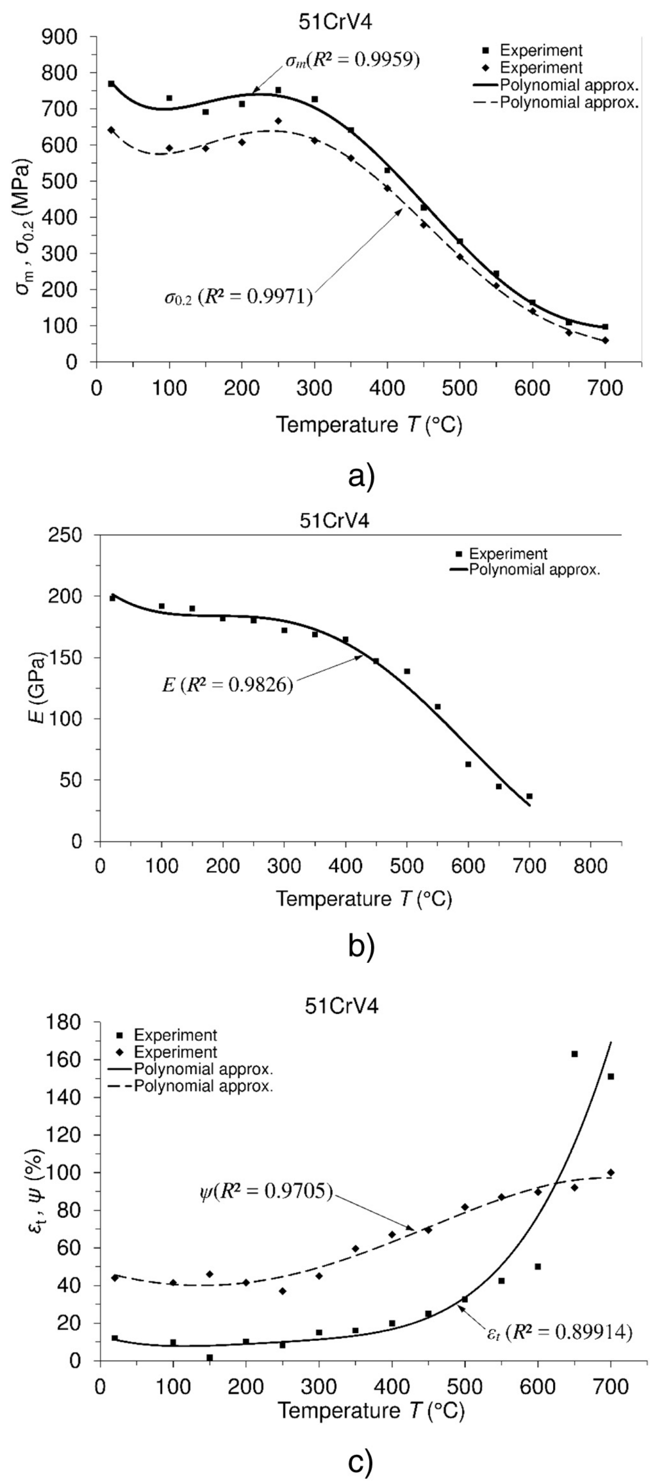

Fig. 2. Material properties versus temperature - graphical representation of experimentally obtained results and their polynomial approximations: 51CrV4 steel. a) Ultimate tensile strength (σ_m) and yield strength ($\sigma_{0.2}$). b) Modulus of elasticity (E). c) Total strain (ε_t) and reduction in area (ψ) of the specimen.

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