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EXAMINATION OF CAST STEEL IN TERMS OF THERMO-MECHANICAL FATIGUE

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Abstract

The paper presents experimental verification of experimental tests methodology on the testing machine in the range of thermal and thermo-mechanical fatigue . Test samples were made of martensitic cast steel. Control parameter of the tests was temperature of the sample whereas there were recorded parameters as follows: loading force and temperature of the specimen. In this study it was stated that the temperature decreases the strength parameters of the cast steel and an increase its elongation. As the results of the changes of the temperature occured loading may exceed yield strength.

Keywords: *thermo-mechanical fatigue, fatigue life, cyclic properties, martensitic cast steel*

1. Introduction

The endless tendency to increase the performance of devices in the energy industry, aviation makes it necessary to determine the material characteristics in terms of thermo-mechanical fatigue. Complexity of tests in terms of thermo-mechanical fatigue and difficult interpretation of results caused that the basic guidelines for such testing were collected in the form of standards [1,2]. The thermal stress occurs when in operating conditions the deformation of component is inhibited due to an increase of temperature. Cyclic changes of the temperature may cause variable stress which may lead to the, so-called. thermal fatigue.

Thermal fatigue can be classified as thermal fatigue with external constraints (constraint reactions, the forces applied to the surface) or internal constraints (temperature gradient, anisotropy of the structure and the different thermal expansion values of coefficients adjacent grains, phases or composite components) [3,4,5,6].

Thermal load cycle can be divided into characteristic stages: heating up to the maximum temperature Tmax in a time of t1, withstand the maximum temperature during tTmax, cooling to minimum temperature Tmin in a time of t2, withstand a minimum temperature during the tTmin (Fig. 1). Stresses in machine parts undergoing mechanical loads during machine operation in conditions of temperature changes are interaction between stresses resulting from mechanical and thermal loads.

The aim of this study was an experimental verification of the methodology of experimental research in the field of thermal and thermo-mechanical fatigue on the testing machine. The scope of the work was to investigate the effect of temperature on the strength parameters which are determined in static tensile tests and stresses which generate in the metal under conditions of external constraints.

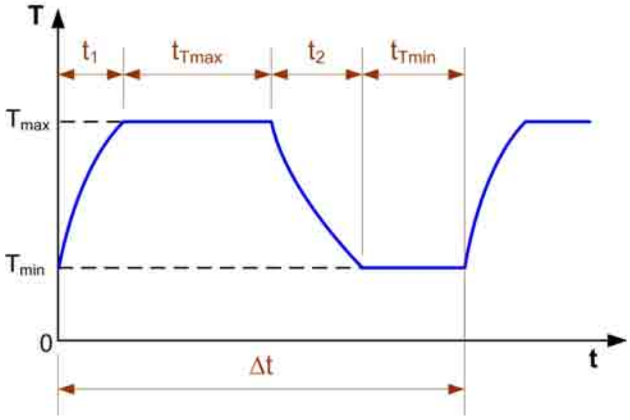


Fig. 1. Cycle stages of heat load

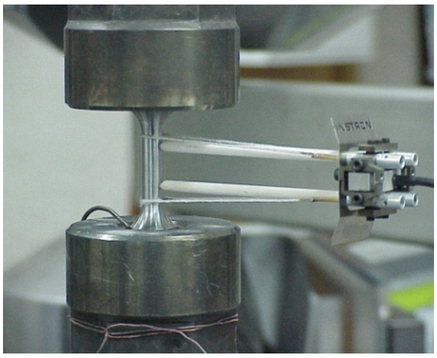
2. Description of tests

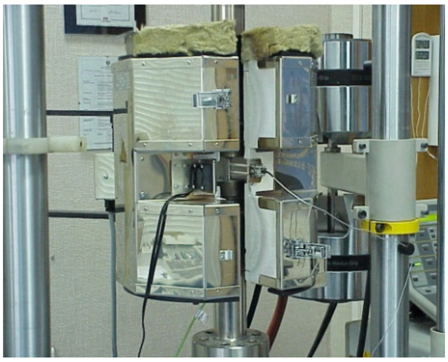
Martensitic cast steel GX12CrMoVNbN9-1 was used during verification tests. The chemical composition of the cast steel is given in table. 1.

Table 1. The chemical composition of cast steel GX12CrMoVNbN9-1 in%.

C	Mn	Si	P	S	Cr	Mo	V	Nb	N
0.12	0.47	0.31	0.014	0.004	8.22	0.90	0.12	0.07	0.04

Specimens were prepared according to the standard [7]. Static and cyclic tests were carried out under conditions of mechanical stress and under thermal load. Static tests were performed according to the standard [8] for the four levels of temperature. During the tests actual values of the loading force and deformation of the specimen were recorded. Fig. 2 presents the specimen fixed in the grips of the testing machine prepared for the static tensile tests.



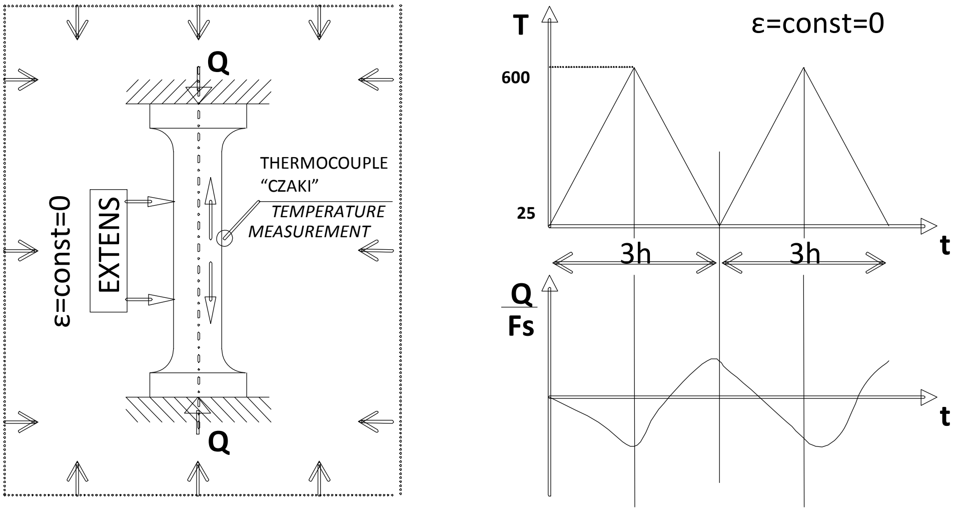


a) *b)*

Fig. 2. Tests at elevated temperatures: a) Fixing of the extensometer, b) The specimen in the heating chamber

Test was carried out under the heat load on the testing machine equipped with a heating chamber. Chamber heating elements are the resistive coils. Power of the installed heating elements allow to warm up the specimen with the speed of about 10° C / min. The temperature of the specimen was monitored using a thermocouple mounted to the measuring part of the specimen.

Specimen temperature was changed according to the program shown in Fig. 3. Recorded values during heating and cooling of the chamber was the force which loaded the specimen and specimen's temperature. The parameter which was maintained during the tests was the level of specimen deformation (ε=const). Deformation of the specimen was monitored using an extensometer with a measuring base of 12.5 mm.



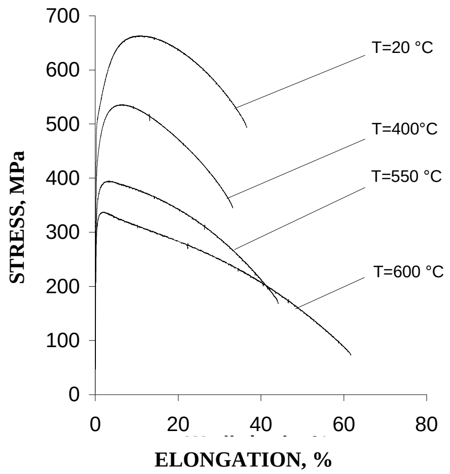
a) b)

Fig. 3. Thermal fatigue tests: a) measuring system b) program of changes of temperature and stresses

3. Test results

3.1. Mechanical stress

The results obtained under conditions of mechanical loading at different temperatures are presented in graphs, static stretching of the coordinate system of the stress-elongation (Fig. 4). Stresses in the specimen were calculated as the ratio of momentary value of loading force per cross-sectional area before the specimen loading.

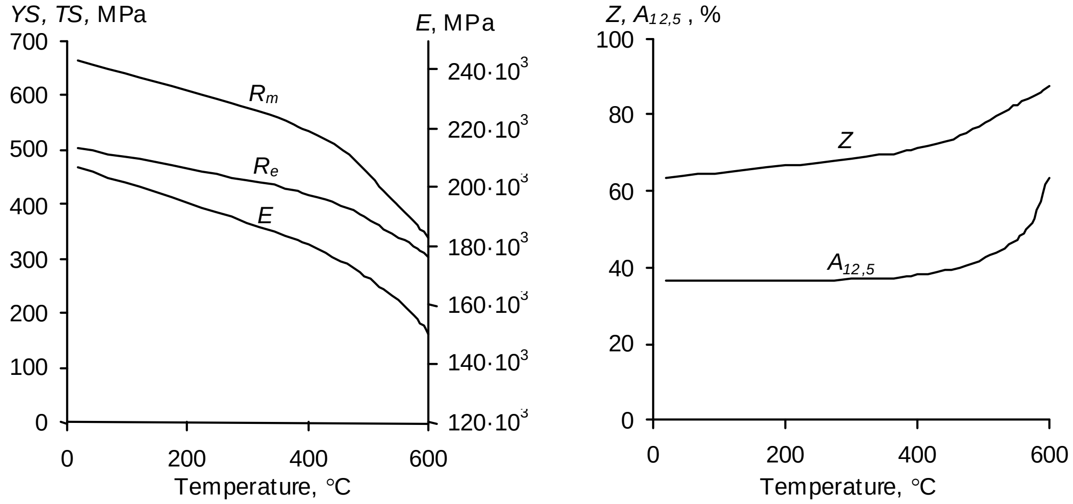


Parameter	Temperature°C			
	20	400	550	600
YS, MPa	503	418	339	303
TS, MPa	663	535	395	338
$El._{12.5}$, %	36.3	38	47.3	63.5
RA, %	63.4	71	82.7	87.3
E, MPa	206870	180234	161460	150120

a) b)

Fig. 4. The results of static tests: a) tensile graphs, b) influence of temperature on strength parameters

The results of static tensile tests were analyzed in the context of the effect of temperature on basic strength parameters. Fig. 5 summarizes the basic values of strength parameters in the function of temperature.



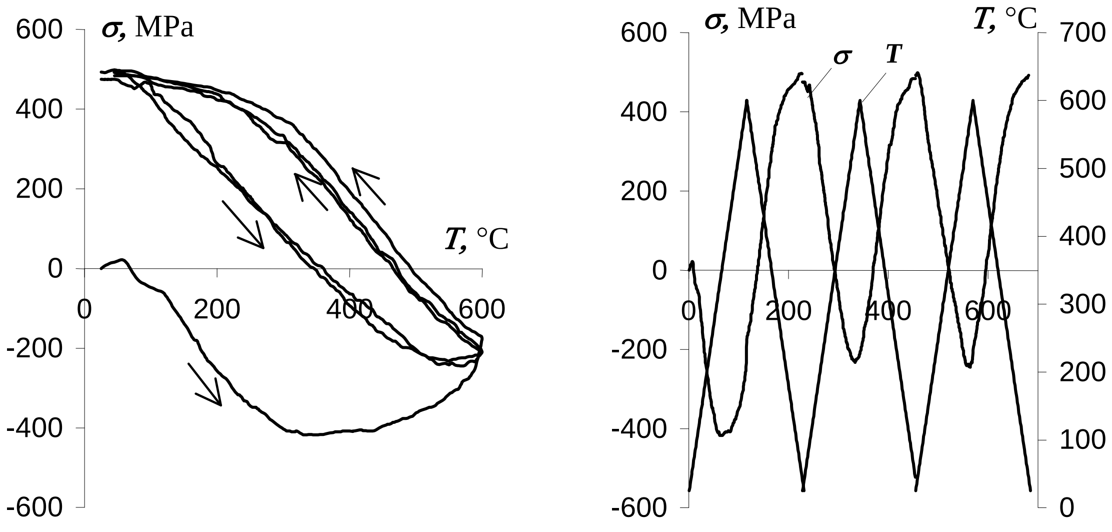
a) b)

Fig. 5. Influence of temperature on strength parameters: a) YS, TS, E, b) $A_{12,5}$, Z

As expected, the increase in temperature decreases the strength parameters Rm and Re, and slightly increases in elongation. Analysis of the graphs shows that the temperature exceeding about 450°C enhances the effect of temperature on the parameters.

3.2. Thermal loads

Recorded strength values and temperature during the tests allowed to the analysis of the courses of the stresses in the specimen. Selected results of thermal load conditions are shown in Fig. 6 in the form of graphs of changes in function of temperature stress (σ=f(T) - Figure 6a) and the stress time (σ=f(T)-Fig. 6b).



a) b)

Fig. 6. Changes in stress in the function of temperature and time

On the basis of the changes of waveform of stress in the function of time it can be stated that until the temperature of about 450°C changes of stress are linear. Above this temperature plasticity of the specimen occurs and the relationship between stresses and the temperature is no longer linear. Obtained results of verification tests show possibility to realize the tests in terms of thermo mechanical fatigue on standard testing machine.

Fig. 7. Picture of specimens after tests of thermal fatigue

In order to implement long-term fatigue tests it is necessary to elaborate and implement the system which would control the temperature of the specimen. Guidelines for the construction of such a system can be found in the work [2.9].

4. Summary

Elevated temperature causes decrease of the strength parameters of cast steel. In the temperature of 600°C ultimate tensile strength equals about 50%; yield strength equals 60% of ultimate tensile strength cast steel determined at room temperature.

From zero pulsating temperature changes may lead to the occurrence varying stresses in the material shuttles (tension-compression). The value of maximum stress variables depends on the level temperature. Tension in the material as a result changes in temperature may exceed the yield strength.

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