FIBER OPTIC STRAIN SENSOR FOR CREEP MONITORING

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1. Introduction

The destructive estimation of the service life could be examined during conventional creep tests (ASTM E139) during which creep deformation is measured under uniaxial tension, constant load and isothermal conditions as a function of time [1]. The strain changes are monitored by using extensometers with specific inertia. Their application affects the actual recordings from strain measurements, thus the material behaviour is not well represented. Therefore, some non-conventional systems for measurement of the strain under creep were proposed in the literature. These involve miniaturized creep tests, impression creep tests, small ring creep tests, digital image correlation-assisted creep tests, macro-pillar creep testing and potential drop technique. One should mention, that the application of fiber optic Bragg grating (FBG) sensors and linear sensors based on the Rayleigh scattering provides nowadays an attractive tool for the online determination of stress and strain changes in steel elements of the power line support structures [2-3]. Although, some preliminary reports confirmed the suitability of FBG sensors for strain measurement under creep conditions, none of them evaluated their applicability at high temperature. Therefore, the main aim of this research was to propose a non-destructive measurement system containing Rayleigh backscattering and single mod gold-coated fiber optic strain sensor for the experimental determination of strain changes in the elements subjected to creep at elevated temperature.

2. Method

A novel approach for creep monitoring by using a Rayleigh backscattering and single mod gold-coated fiber optic strain sensor is proposed.

Currently, the available software for linear sensors is based on the Rayleigh backscattering, however, it is not configured to measure temperature and strain shifts simultaneously. In the absence of a strain variation, a temperature change can be determined using the following relationship:

$$\Delta T = -\frac{\bar{\lambda}}{cK_T} \times \Delta\nu \qquad (1)$$

where $\bar{\boldsymbol{\lambda}}$ is the center wavelength of the scan and $\boldsymbol{c}$ is the rate of light. Similarly, in the absence of a temperature variation, a strain change can be calculated using the equation (3):

$$\varepsilon = -\frac{\bar{\boldsymbol{\lambda}}}{\boldsymbol{c}\boldsymbol{K}_\varepsilon} \times \Delta\boldsymbol{\nu} \qquad (2)$$

Assuming a scan center wavelength of 1550 nm, one can substitute the constants K_T and K_ε by the following conversion factors: $\Delta T=(-0.801°C/GHz)\Delta\nu$, and $\varepsilon=(-6.67\ \mu\varepsilon/GHz)\Delta\nu$, respectively. Thus, the distributed temperature and strain curves could be considered as merely rescaled copies of the spectral shift distribution.

3. Results and discussion

In this research, 13HMF power engineering steel of ferritic-perlitic structure was used as reference material (Fig.1). The geometry of the specimen was shown in Fig. 2.

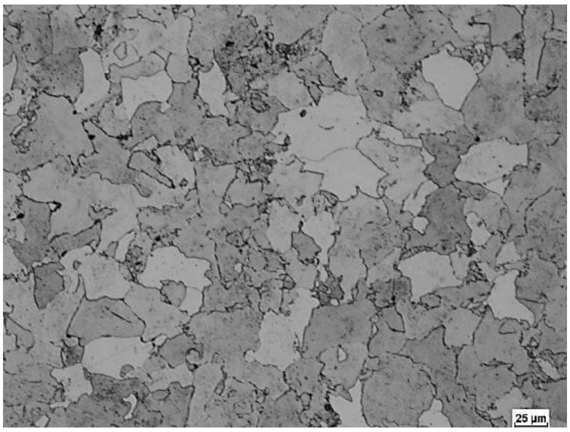

Fig. 1. The microstructure of 13HMF steel.

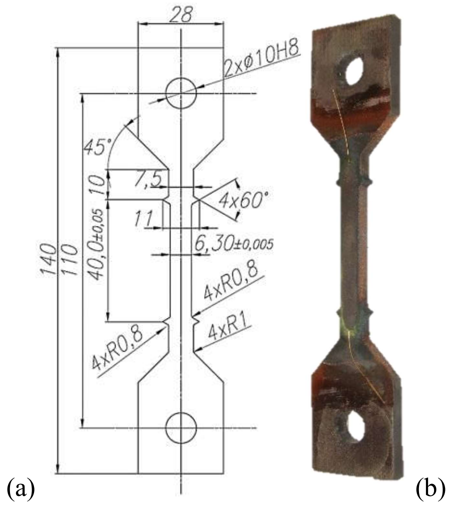

Fig. 2. Geometry of the creep specimen (a); the general view of the specimen with mounted sensor (b).

Once the specimen was machined to the geometry required, a long-term creep test for 678 days under stress of 130 MPa at a temperature equal to 540°C was executed on specimens of 40 mm gauge length and 5 mm × 7 mm cross-section dimensions.

Figure 3 presents a comparison between results obtained from conventional, mechanical extensometer and optical fiber sensor. It could be observed, that the agreement between those two methods is notable. The strain evolution recorded by optical fiber in every stage of creep damage development corresponds to results obtained from the extensometer. One should stress, that the process parameters used to attach the optical fiber to the specimen surface were successfully applied since the curves overlapped themselves during the whole testing time of over 2 years till specimen fracture.

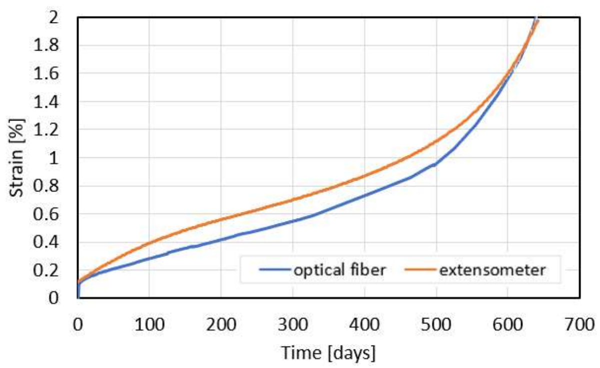

Fig. 3. The comparison of strain evolution of 13HMF subjected to creep at 540°C monitored by optical fiber (blue line) and extensometer (orange line).

The results of laboratory tests proved that the Rayleigh optic strain sensor and the method of sensor fixing enabled correct measurements of strains arising in the specimen due to creep. It was observed, that the constant increase of load led to the constant increase of strain. Within a set of advantages of measurements based on linear sensors and Rayleigh backscatter worth mentioning linear measurement with a resolution starting from 10µm, the possibility to measure up to 1000 points on one meter of optical fiber, and temperature measurement up to 900°C. On the contrary, the disadvantages include static measurement with a frequency of 1Hz, and the high price of the Rayleigh spectrum analyzer. In order to verify the laboratory tests data reported in this work, it is necessary to elaborate measurement installations and mount them on a real object. However, it could be concluded, that such methodology enables the precise measurement of deformation changes due to creep under long-term operating conditions up to 2% of the installed measurement system state at temperature up to 700°C. Furthermore, it could be considered as a powerful tool in stress and strain analysis of power plant structures since it enables the accurate prediction of elements' service life allowing a timely repair or replacement of damaged structural elements before their failure.

4. Conclusions

The suitability of a novel approach for creep monitoring by using a Rayleigh optic strain sensor was confirmed during over long-term creep test of 13HMF powder engineering steel at 540°C under a constant load of 130 MPa. The sensor attached to the specimen surface successfully monitored strain evolution during 678 days of high-temperature exposure under creep conditions. It was confirmed, that the methodology proposed could be successfully used to monitor strain changes due to creep as excellent agreement between Rayleigh optic strain sensor and extensometer was found.

References

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