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INFLUENCE OF MICROSTRUCTURE ON THE MECHANICAL BEHAVIOUR OF STEEL IN EXTREME ENVIRONMENT

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ABSTRACT

In this study, the problem of brittle fracture of structures at low temperature conditions is connected to damage accumulation and ductile-brittle transition in metals. The data for energy equipment failure and locomotive tire contact impact fatigue are presented. The results of experimental testing show that the impact toughness drops at low temperature. The internal friction method was applied to revealing the mechanism of dislocation microstructure changes during the low-temperature ductile-brittle transition. It is possible to prevent the transition by severe deformation to change the steel microstructure which is quantitatively described by multifractal analysis. The proposed mechanism and revealing relationships would be used for theoretical and numerical modelling of damage accumulation and fracture in materials.

Keywords: extreme environment, low-temperature ductile-brittle transition, fracture, ultrafine-grained steel, damage nucleation.

INTRODUCTION

It is well-known that during the low temperature climate operation, catastrophic fracture of structure and machine elements often occurred. In that case, the plastic properties of the structure are decreased and the mode of failure changes from ductile to brittle. Significant loss of safety and economic efficiency result in the operation of railway equipment in extremely low climatic temperatures conditions. This leads to increased utilization of energy and resource intensity of transportation. The most important units of railway equipment are tire and rail. Their durability and reliability significantly affect operating costs, and their fracture is unacceptable because they pose a clear threat to traffic safety. The railroad located on territory of the Republic of Sakha (Yakutia) in Siberia (Russia) is distinguished by low climatic temperatures and acutely continental climate. The period of subzero lasts about 210 days; the minimum temperature reaches 60 ˚C below zero. The difference in the average temperature achieves 70 ˚C and more per season.

The diversity of the phenomenon of ductile-brittle transition is reflected by the factors affecting the type of fracture - both internal and external. Thus the chemical composition and the structure of the material reflect the physical nature of the phenomenon, and the loading rate, temperature, type of stress-strain state and the size of the structure define the mechanical nature, respectively. So the combination of severe deformation and thermal processing could change the mechanism of fracture and lead to a decrease in the ductile-brittle transition temperature range. Scanning electronic (SEM) and atomic-force (AFM) microscopy were used to estimate this quantitatively by multifractal analysis (Lepov *et al*., 2008, 2016).

RESULTS AND CONCLUSIONS

The mechanism of dislocation movement on microscale could be established by an internal friction measurement. Furthermore, the internal friction is a one of the main methods for the determination of energy dissipation localization in low-temperature ductile-brittle transition. The experiment by pendular oscillator for wire samples of structured low-alloyed steel was carried out. It has been used to establish the temperature dependence upon internal friction of both tempered and annealed samples of the test material in the temperature range 100÷300 K.

To reveal the changes of the mechanical properties of locomotive wheel, the impact toughness was measured at positive (20 °C) and below freezing (-20, -40, -60 °C) temperatures. Table 1 shows the results of impact test where the drop shown.

Table 1 - Results of test for impact toughness KCV

T (°C)	20	-20	-40	-60
KCV, J/cm2	2,29 1,75 1,69 1,72 1,64	1,33 1,37 1,38	0,71 0,54 0,96	0,70 0,58 0,74 0,51 0,67
Average	1,82	1,36	0,73	0,62

The modeling of damage accumulation processes should consider the complex effects of high-cycle fatigue and low-cycle impact loading and also friction damage. The impact toughness as shown in Table 1 greatly depends on the test temperature. So the overall damage could differentiate between high-cycle fatigue damage, low-cycle impact damage and contact wear damage also.

The investigation of the combined processed steel reveals that the mechanical properties and multifractal characteristics of microstructure are closely connected and could be used for multiscale modeling of damage accumulation and fracture.

The new criterion and approach of damage estimation for locomotive tire in extreme uncertainty conditions are also discussed. Our results reveal that the lifetime of tire is very sensitive to impact strength at low temperature during operation.

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