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METAL DEGRADATION AS COLLECTION OF CHANGES IN STRUCTURE AND MECHANICAL CHARACTERISTICS

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1. Introduction

The estimation of a current state of equipment in chemical and oil-refining industry and forecast based on this remaining lifetime is a challenging and mani-sided task. Low equipment seriation, huge dimensions, medium and temperature turnover in the process of technical operations additionally complicate the task. Methodological problem resides in ambiguity of choice of values and criteria for remaining lifetime estimation. The loss of objective and approved methods demands fairly urgent actions for their creation. The absence thereof spells probable manmade disasters and essential financial losses.

2. Literature data analysis and problem statement

Structural adjustments and microdamage growth are the ultimate cause of mechanical and other metal performances changes [1]. Steels, used in chemical industry differ essentially in chemical and phase composition, structure. Thus, it is impossible to develop "general" laws, even changes tendencies of any performances in general for all steels. In certain cases one can trace a certain connection between structural adjustments during long-term usage and corresponding changes of mechanical data for steels similar in construction and operation conditions [2 – 5]. Analysis of such connection and regulatory documents composition based hereon is one of the ways to forecast more precisely the changes of various metal equipment performances: mechanical, electrochemical, physical etc.

3. Goal and objectives

Sparingly alloyed steels are one of the most common steels in chemical industry. They are used in the manufacture of heat-exchange equipment, column equipment etc. Much of such equipment operates subject to joint action of high temperatures and severe medium. The goal of the study is a comparative analysis and correlations definition between structural adjustments in metal and mechanical performances adjustments. Additionally, consideration has been given to the choice of mechanical values, which are sensitive to degradation during long-term usage.

4. Comparative analysis of changes in metal structure, microdamage growth and mechanical performances changes

The survey of basic material and welded joints state has been carried out by research team headed by F.A. Khromchenko [6] for sparingly alloyed chromium-molybdenum-vanadium steels, used for long time as a part of heating equipment.

They were offered special scales to estimate the remaining lifetime, which made it possible to estimate the degree of steel degradation according to structural factor via microdamage formalization and micro structural changes. The most intensive and destructive processes occur in heat-affected zone. Thus, a metal layer at the distance of 2-4 mm from alloy line is considered as an indicator. The analysis results show the correlation between microstructural changes and ability for microdamages and depletion of welded joints resources. It has been suggested to divide the microstructural changes into three stages, provided that depletion of the resource has been estimated not in absolute values but in relative ones: $\tau_н/\tau_{пр}$, where $\tau_н$ – operating time during study execution; $\tau_{пр}$ – time of maximum operation. Change in microstructure hasn't been detected at the first stage (up to 30% depletion of resource). Metal of heat affected zone preserves ferritic-pearlitic structure with dispersive carbides, which are mainly located at the grain boundaries. The second stage (30-60% depletion of resource) is marked by the enlargement of carbide parts up to 1-1,5 micron and simultaneous depletion with carbides of near-border parts with the width up to 2-3 micron in the grain body.

The de-bordering of grains and spheroidizing of decay products of pearlitic constituent take place. The third stage is defined by the further enlargement of carbide parts up to 1,5-2 micron (60-100% depletion of resource) and their accumulation as chains at the grain boundaries, strengthening of structure spheroidizing up to 4-5 grades, cementite layer-film creation.

The process of micro damages growth has been divided into five stages. The micro damageability (up to 50% depletion of resource) has not been found at the first stage. The authors suppose that micropores of creeping with the size of 0,05-0,5 micron appear at the end of the first stage. Singular pores (50-70% depletion of resource) with the size up to 2 micron have been found at the second stage in the amount from one to three on the field, which are covered by microscopic eyepiece at the increase ×100. The enlargement of pores up to 2,5-3 micron and the appearance of new ones (70-80% depletion of resource) with the size of 1,2 micron occurs at the third stage with the total expansion in the number from five to eight pores on the field of microscopic eyepiece. The pores of creeping as chains (80-90% depletion of resource) are torn on the grains borders or as accumulations up to 10-15 pores with the formation of micro cracks and their growth to the length of 50-200 micron at the fourth stage. The fifth stage (90-100% depletion of resource) is marked by the intergrain fragile macro damageability with the appearance of macro cracks with the length ~ 1,5 mm and their unification into main crack.

Complex correlation of changes stages of microstructure, damageability and depletion of resource are listed in the table 1.

Table 1

Correlation of change stages of micro-structure and micro-damageability with depletion of resource of welded joints of 12X1MF steel under creeping

Stage of micro-structure change	Stage of micro-damageability	Depletion of resource	
		%	$\tau_н / \tau_{пр}$
I_M	$I_п$	0	0
		20	0.
II_M		40	0.
	$II_п$	60	0.
III_M	$III_п$	80	0.
	$IV_п$	100	1
	$V_п$		

In the majority of technological documents the estimation of current equipment state and establishment of the further lifetime is carried out based on the comparison of current values of mechanical performances with the minimum allowed values. The estimation of changes of mechanical performances is executed according to the plan during complete overhauls and on the ground of emergency stops. The metal analysis is performed by use of different mechanical performances for various technical objects: pipelines, column equipment, pipes, compressors etc [7, 8]. Generally, the most universal and common are such mechanical performance as $\sigma_{0,2}$, σ_b, $\sigma_{0,2}/\sigma_b$ and δ, ψ.

Let us use the dislocation theory for the informativity of these characteristics. According to the Petch and Hall theory the greater the resistance to the dislocation displacement is, then smaller is grain size. In accordance with the Petch and Hall equation the liquid limit is determined:

$$\sigma_T = \sigma_0 + Kd^{-1/2} \qquad (1)$$

where σ_0 – stress to support sliding in active dimensions of sliding within the grains, between which there is a token passing of sliding;

$Kd^{-1/2}$ – stress for token passing of sliding between grains with the size d.

The parameter K after Kotrel characterizes the "difficulty" of excitation to sliding in the neighboring grain and Petch has added that it is also determined by the disordering coefficient of active sliding surfaces in the grains, between which there is a token passing of sliding. Frequently (but not always) the process of stress ageing is accompanied by grain refinement (decreasing d and difficulty of movement of dislocations due to barriers as newly formed carbides at the grain boundaries), which directly affects $\sigma_{0,2}$.

Beyond the liquid limit the stress-strain curve is approximated by a famous expression:

$$\sigma = K\varepsilon^{n} \qquad (2)$$

where σ and ε –true stress and strain subsequently;

n – strengthening factor;

K – constant for a given state.

To that end the speed of strain strengthening beyond the liquid limit in stress ageing is determined by the expression: $d\sigma/d\varepsilon = Kn\varepsilon^{n-1}$.

Based on the results of studies [1], time-varying performances after static tension during stress aging may be presented as a scheme (Fig. 1):

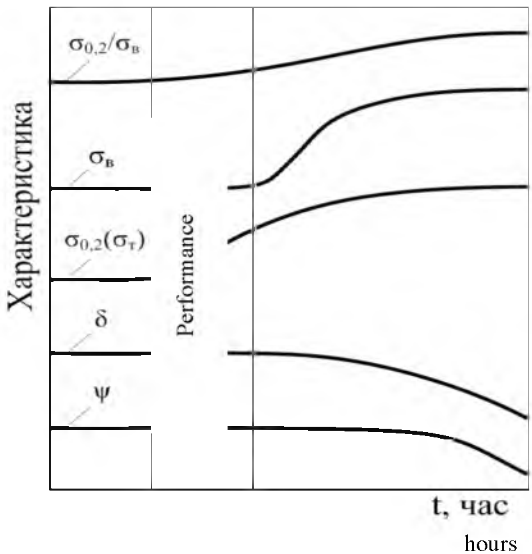

Fig. 1. Sensitivity shift dynamics of mechanical characteristics

The analysis of curves in Fig. 1 suggests that the sensitivity to stress aging in σ_b and δ in comparison with $\sigma_{0,2}$ starts at the later stages of operation. Thus, in terms of continuity of tracking of the metal ageing processes the use of $\sigma_{0,2}$ appears the most rational, among the characteristics of plasticity this is δ. But the values of the relative elongation and relative narrowing in the operation are more complicated in nature in interaction with the deformation than stress. Their values depend both on the distribution of dislocations and the steel structure. Thus, because of changes it is more difficult to estimate the steel stress stage, which is confirmed in practice. In case of absence of the study of metal from the same batch, not being in operation, it is more reasonable to use the indicator $\sigma_{0,2}/\sigma_b$.

5. Conclusions

The problem of definition of the remaining lifetime is complex and many-sided. For exact forecasting it is necessary to conduct analysis on the ground of the range of current hypotheses and theories, which consider changes in structure, micro damages appearance and their growth dynamics, relevant choice of mechanical values and account of the changes character. The choice of such characteristics and account of changes in structure should be carried out with regard to operating conditions, primarily temperature. The most sensitive among the mechanical characteristics are $\sigma_{0,2}$ and δ, or $\sigma_{0,2}/\sigma_b$.

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