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Analysis of the variation of metals mechanical properties depending on operation time

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1. Introduction

A safe and long term exploitation of various steel structures is a relevant engineering problem. In design calculations of structures and pipelines the materials features, which will be used for their production of structures, are assessed. Unfortunately in practice we face with ill-timed structures and their elements failure, which always are associated with economical losses and environmental damages. One of the main problems is to predict the changes of materials mechanical characteristics after particular. However, it is complicated to make aging test of materials tests in laboratory and this kind of tests requires plenty of time. One of the ways how to solve this kind of problem is to perform tests with exploited material. Often from the practical or scientific point of view only single cases are studied when it is necessary to identify the reason of failure, but there is no systematic data analysis yet. It is known, that characteristics of materials vary according to time, but relationships between materials mechanical characteristics and exploitation time are not defined. For new steel with high plasticity features various kinds of defects are not very unsafe, because in defected place plastic strains asserts and fracture processes are blocked. When materials plastic features decrease, even the same size defects can be the reason of material failure.

In common case materials aging process is understandable like complex of internal processes in material under the affect of different factors and the result of such influence is irreversible variation of materials features what worsens materials quality. The velocity of aging process depends not only on materials composition and structure but also on specific factor intensity and environmental conditions. Nevertheless various investigations are performed during the last decade in all over the world and lots of the received data are empirical.

During long time service the embrittlement leads to the decrease of critical flaw size of brittle fracture and to the reduction of the remaining life of a pressure vessel.

Problem of the pipes aging in the water supply system is analysed in the work [1]. Authors present the stochastic method of pipelines failure calculation.

The analysis of the influence of pipes properties on pipelines reliability and mathematical model is presented in the work [2]. The influence of external factors on degradation process is explored in research project [3]. Work [4] presents researches of gas pipeline, which were made of grade 19Г steel and were exploited for 30 years under internal pressure of 5 MPa. Mechanical characteristics of 30 years exploited pipelines were compared with the ones 30 years kept in storage. During exploitation yield stress increased 30%, limitary plasticity and impact bending and impact tension toughness decreased by 21% and 40% respectively [5]. Under the steady influence of stresses changes of exploited materials plasticity features displays [6], with growing of exploitation years the probability of pipelines collapse increases too. One of the factors, which influence this process, is stress state. As a result of internal pressure variation in pipelines vary during start-up and stop it is correct to assume that low cycle fatigue asserts and makes influence on cracks origin and development. The problem of this kind was explored in article [7]. Authors performed six different types of tests to determinate low cycle fatigue strength of pipelines steel and defined variation types of pipelines materials mechanical characteristics with pipelines assessment. The dependence of fracture behaviour on the strain rate of a commercial pipeline steel is investigated in work [8]. The issue of ductile tearing assessment for the cases with global plasticity, relevant to strain-based design of pipelines is analyzed in work [9]. The results of investigation of mechanical properties (such as tensile and impact strength) of pressure vessel and pipeline steel are presented and discussed in the work [10].

Making the analysis of failure reasons of exploited material gas and petroleum pipelines becomes clear, that during long-term exploitation real metal features are not assessed. Other way for the determination of relationships between mechanical characteristics and lifetime long term and unique experiments are necessary. After exploring of researches in this field it is possible to predicate, that for scientific researches single samples are used when it is important to clarify failure reasons however the level of systematic researches accomplishment is low.

In this article as a research object hot-water arterial pipelines was chosen. There are three external factors which influence the pipelines: water temperature, external environmental and pressure. Each of these factors has an influence on aging process. Parameters of hot water supplied by pipes: hardness of water up to 0.2 mg/eqv/l, there are no oxygen and carbon dioxide, salts. The temperature of water is 70-150^{o}C, operating pressure – 1.6 MPa (during hydraulic test reaches 2.0 MPa). Aim of this research is to identify relation between operating time and mechanical properties of material.

2. Experimental

The specimens from hot water pipeline material with different time of operating were chosen for the determination of materials mechanical characteristic variation.

Table 1

Chemical composition of the grade 10 steel

Date of pipelines operating beginning	Diameter of pipe, m	Chemical elements, percent							
		C	S	P	Si	Mn	Cr	Ni	Cu
1963	0.220	0.09	0.016	0.018	0.19	0.50	0.10	0.07	0.17
1966	0.220	0.14	0.016	0.016	0.24	0.52	0.07	0.06	0.20
1969	0.220	0.13	0.016	0.015	0.24	0.57	0.13	0.10	0.12
1980	0.635	0.12	0.016	0.017	0.10	0.46	0.05	0.03	0.07
1981	0.220	0.10	0.016	0.017	0.19	0.47	0.06	0.04	0.04

Table 2

Results of tensile test

Date of pipe-lines operating beginning	Strength force, kN	Yield force, kN	Ultimated stress, MPa	Yield stress, MPa	Relative elongation, %	Relative reduction of cross section area, %
1963	40.3	30.7	400.1	304.9	13.0	54.0
1966	46.6	34.7	444.0	330.7	8.5	47.3
1969	42.6	29.5	413.9	286.7	9.1	44.5
1980	42.7	28.6	404.9	271.9	8.3	44.5
1981	26.9	18.9	422.6	297.2	15.6	42.7

It is important for suitably accuracy of relationships between mechanical characteristic and maintenance time to analyze the same material, which was exploited in the same conditions during lifetime. Tests of chemical composition and material type determination were performed. Spectral analysis results showed that that majority of pipelines samplers of hot-water supply network are made from grade 10 steel. Tension test was performed with specimens from these samplers. During tension test mechanical characteristics of grade 10 steel was determined: yield stress σ_y, ultimate stress σ_u. According to geometrical parameters of specimens the main criterions, which characterize plasticity features of materials, were defined:

- the relative residual elongation of specimens

$$\delta = \frac{l_1 - l_0}{l_0} \cdot 100\%$$

- the relative reduction of cross-section area

$$\psi = \frac{A_0 - A_{fr}}{A_0} \cdot 100\%$$

here, l_1 is length of effective strip of a specimen after fracture; l_0 is original length of the specimen; A_0 is original cross section area of specimen; A_{fr} is cross section area of the specimens after fracture.

For tensile tests the specimens, which were made form materials of arterial hot-water pipelines, which operation started in 1963, 1966, 1969, 1980 and 1981 years were used. The specimens (10 samples) were made and tested from the material of each year pipelines samplers. Specimens were machined from exploited pipelines. For tensile test performing specimens were machined according to LST EN 10002-1:1998 standard (Fig. 1).

Hydraulic tension-compression machine P-50 was used for testing. It was defined that plasticity features of the materials are changed and also Charpy V-notch impact test was performed.

It was impossible to cut standard (ten millimeters width and ten millimeters thickness) specimens for impact test from the pipes, because maximum thickness of the pipe material was about eight millimeters.

For this reason nonstandard (ten millimeters width and five millimeters thickness) specimens were tested. Results from nonstandard test were equalized with standard using correction factor.

3. Results and discussion

After making tests, were calculated average values and variation coefficients of the data. Chemical composition of investigated grade 10 steel and tension tests results are presented in Tables 1 and 2.

According to experimental test results relationships between mechanical characteristic of grade 10 steel and maintenance time were deduced. Stochastic distribution calculations of test results were fulfilled as well. Variation coefficient of experimental results is between 3 and 10 percent.

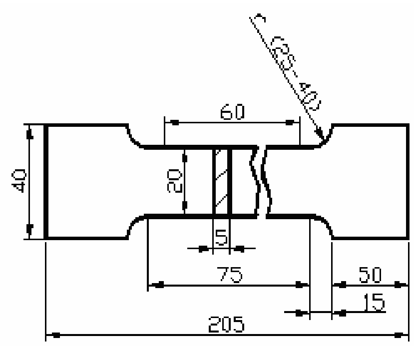

Fig. 1 Geometrical parameters of specimens used for tensile test

Exploratory results from the tests showed, that strength stress value grew up negligibly if compare with the strength stress value of the new material. In practical calculations concerned with design of new structures and elements materials yield stress is used as extreme boundary, because above it the irreversible plastic deformations start. Analysis of experimental results revealed that when operating time grows up materials yield feature appears later. Recording of yield stress in some case was unsuccessful. Relationship between materials mechanical characteristics and operating time is shown in Fig. 2

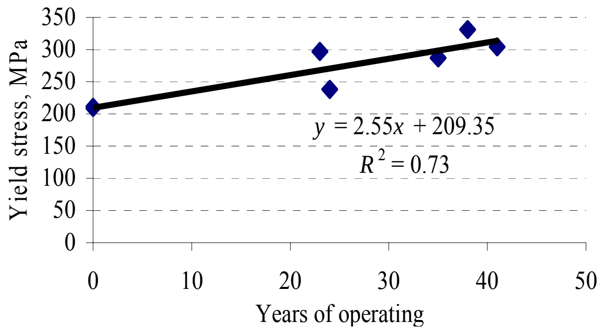

Fig. 2 Relationship between yield stress of materials and operating time

Materials plasticity features in the best way shows relative extension parameter of a specimen. The relationship between relative residual length variation of specimen and materials is represented in Fig. 3. The relationship between relative residual cross section area variation and materials is presented in Fig. 4.

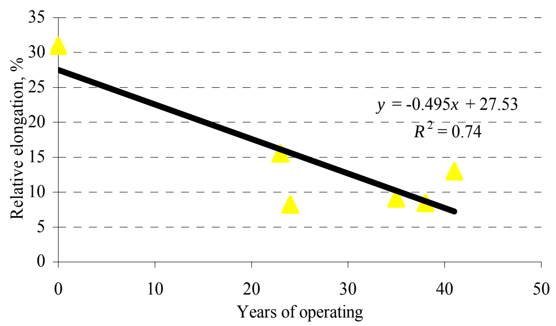

Fig. 3 Relationship between relative elongation and operating time

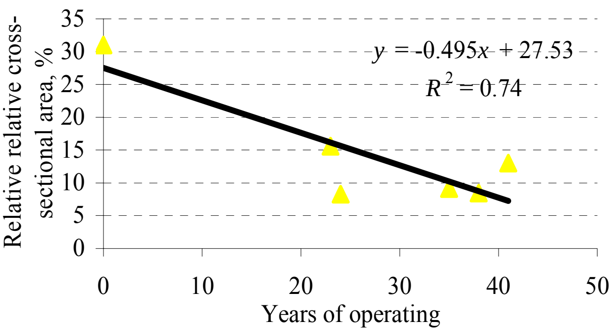

Fig. 4 Relationships between relative reduction of cross-section area and operating time

After impact test of the investigated material it was observed that impact toughness decreased. Table 3 presents results of the test. During impact test differences in fracture way were noted. It should be mentioned that chemical composition of the materials is very similar. (Fig. 5, 6) contains pictures of plastic and brittle fracture.

With the intention to identify different fracture reason identifying, optical analysis of materials microstructure was performed with metallographic microscope KRUSS.

An enlarged view of the materials microstructure in the case of plastic fracture and brittle fracture is presented additional in Fig. 7 and Fig. 8.

Table 3

Impact test results

Date of pipelines operating beginning	Absorbed impact energy of standard specimen, J
1963	48.42
1966	47.71
1969	51.44
1980	19.11

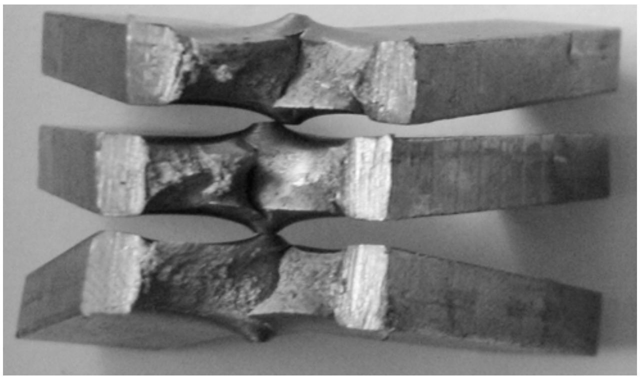

Fig. 5 Specimens after impact test (plastic fracture)

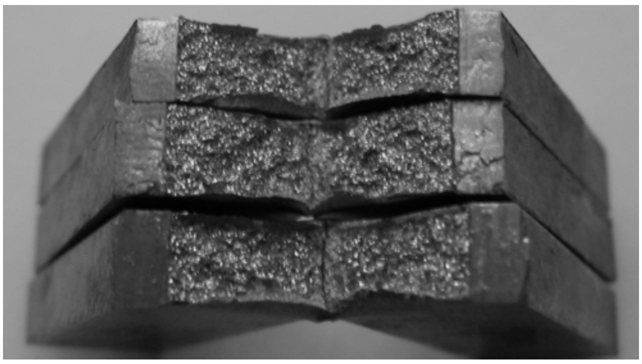

Fig. 6 Specimens after impact test (brittle fracture)

Microstructure researches confirmed that bigger grains are one of the factors which make an influence on brittle fracture. The size of the grains was measured. Value of correlation coefficient ρ between size of the grains and values of impact test was calculated ($\rho = -0.9$). Correlation coefficient shows inverse dependence.

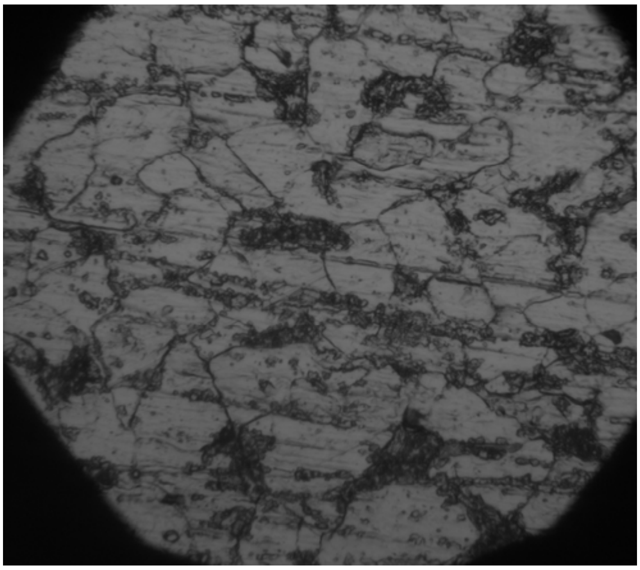

Fig. 7 An enlarged view (400 times) of materials microstructure

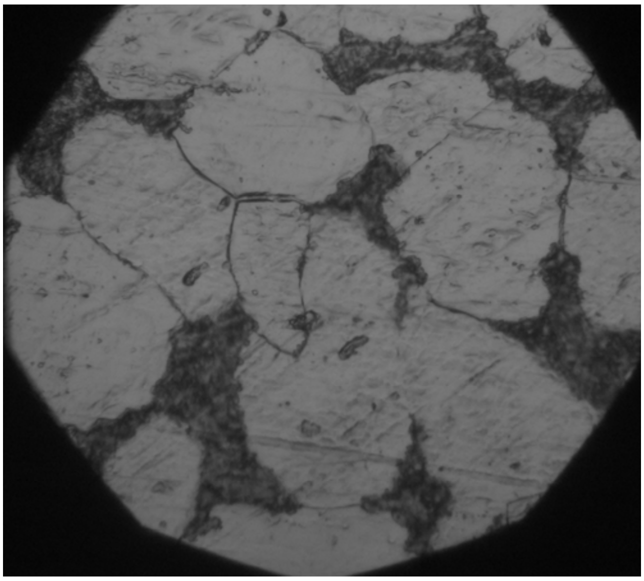

Fig. 8 An enlarged view (400 times) of materials microstructure (in the case of brittle fracture)

4. Conclusions

1. Steady effect of stresses changes plasticity features of exploitable materials. Experimental research of material showed, that plasticity features of the material grow down according to lifetime of the pipelines. With the increment of maintenance time of pipelines the probability of failure increases as well.

2. Plasticity features of materials in the best way outline relative residual length variation of the specimen. Depending on tests results the variation of specimen relative residual length value grows down when lifetime of pipeline increases. This relationship for grade 10 steel was expressed by the equation: $\delta = -0.495x + 27.53$, where δ is relative elongation, x is years of operating.

3. The variation of value of relative residual cross section area variation changes according to pipelines. This relationship approximately can be described using the equation: $\psi = -0.24x + 52.46$, where ψ is relative cross-sectional area, x is years of operating.

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METALŲ MECHANINIŲ SAVYBIŲ KITIMO PRIKLAUSOMAI NUO EKSPLOATACIJOS TRUKMĖS TYRIMAS

R e z i u m ė

Šiame darbe nagrinėjama, kaip keičiasi medžiagų mechaninės savybės priklausomai nuo eksploatacijos trukmės. Karšto vandens vamzdynus eksploatacijos metu veikia išorinė aplinka, skatinanti įvairios rūšies medžiagų koroziją. Kartu, ilgalaikis įtempių būvis keičia medžiagų mechanines savybes.

Medžiagos mechaninėms savybėms nustatyti pagal LST EN 10002-1:1998 atliktas bandinių, pagamintų iš karšto vandens magistralinio vamzdyno vamzdžių tempimo bandymas. Bandinių gamybai pasirinkti 20 - 40 metų eksploatuoti karšto vandentiekio vamzdžiai, pagaminti iš

plieno 10. Vamzdžių medžiagos cheminė sudėtis nustatyta atlikus spektrinę analizę.

Metalų plastiškumo savybes geriausiai nusako bandinio santykinio liekamojo ilgio pokyčio charakteristika bei santykinė bandinio skerspjūvio ploto pokyčio charakteristika. Eksperimento rezultatai parodė, kad medžiagų stiprumo riba pakito nedaug. Pakitusias medžiagos plastiškumo charakteristikas labiausiai atspindėjo bandinio ilgio santykinio pokyčio bei santykinio bandinio skerspjūvio ploto pokyčio reikšmės. Pagal gautus eksperimentinius duomenis gautos medžiagos santykinio bandinio ilgio pokyčio, santykinio bandinio skerspjūvio ploto pokyčio bei medžiagos takumo įtempio reikšmių kitimo priklausomai nuo eksploatacijos trukmės tiesinės priklausomybės.

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ANALYSIS OF METALS MECHANICAL PROPERTIES VARIATION DEPENDING ON THE OPERATION TIME

S u m m a r y

A long-term operating influence on mechanical properties variation of constructional materials is analysed in this article. During the exploitation of structures and pipelines the consistent surrounding influence causes corrosion of the structures materials. Beside the surrounding influence of the constant stress state affects structures too. For constant stresses mechanical properties of structural elements are variable and the metal is ageing. The article presents experimental researches of hot-water pipelines material. From 20 - 40 years exploited pipelines specimens were cut and tension test was fulfilled. The test results disclosed that material strength stress increased minutely. The value of materials yield stress in exploited specimens showed up later if compared with new material. In the best way the changed materials plasticity properties were exposed by specimens relative elongation, which characterizes materials fragility. Linear materials mechanical properties dependenty on lifetime is presented in the article. According to this linear law it is possible to calculate materials mechanical properties of a structure, which is exploited, and assess safety of this structure.

Й. Янутенене, Р. Диджёкас, М. Гинталас

АНАЛИЗ ЗАВИСИМОСТЕЙ ИЗМЕНЕНИЯ МЕХАНИЧЕСКИХ ХАРАКТЕРИСТИК МЕТАЛЛОВ ОТ СРОКА ИХ ЭКСПЛУАТАЦИИ

Р е з ю м е

В работе исследовано изменение механические характеристик материалов в зависимости от времени их эксплуатации. На трубопроводы горячей воды во время их эксплуатации действует окружающая среда, которая вызывает коррозию различной природы. В тоже время воздействие длительного состояния напряжений изменяет механические свойства материалов. Для исследования механических свойств материалов проведены эксперименты на растяжение по стандарту LST EN 10002-1:1998 с использованием образцов, изготовленных из стали 10 трубопроводов горячей воды после их эксплуатации в течении 20 - 40 лет.

Установлено, что предел прочности стали мало изменяется вследствие её эксплуатации, однако предел текучести заметно повышается, а характеристики пластичности существенно понижаются, свидетельствуя об эксплуатационной деградации металла. При этом получены линейные зависимости изменения относительного удлинения и относительного сужения, а также предела текучести от времени эксплуатации трубопровода.

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