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Statistical evaluation of low cycle durability for alloyed structural steels weld metals at room and elevated temperature

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1. Introduction

The low cycle loading in parts and structures appear near stress concentrators: in the zones of geometrical parameters change, near cracks, technological, weld and foundry defects [1]. Plastic strain in these areas appears in small material volumes. The conditions of loading in these zones are very similar to low cycle loading with limited strain, because plastic strains there are limited by adjacent elastic strained zones. In case of limitation of total strain, the cyclic hardened, softened or stabile materials accumulated only fatigue damage [2]. Therefore the conditions of loading with limited total strain are similar to the loading in real parts and constructions.

Weld metals of alloyed structural steels were specified according the main metal, such as 22K, 19MN5, 10ChN1M, 10GN2MFA, 12Ch2NMFA, 15Ch2MF, 15Ch2MFA, 15Ch2MFAA, 15Ch3NMFAA, etc. used in nuclear power equipments at room and elevated (250°C - 350°C) temperature. Different kinds of processing were used to get weld metals. Some of them are: welded by manual and automatic arc methods with electrodes such as UONI 13/45, UONI 13/55, 48N10, 48N3, 48N6, EA – 855/54, etc., automatic welding with wire, such as Sv – 10GSMT, Sv – 10G2, Sv – 08A, Sv – 10XMFT, etc., electroslag welding. In this work all the materials were divided into three groups according chemical composition.

In our previous research [3] the parameters of Coffin curves and the durability dependence on main mechanical characteristics and their combinations were investigated. In this work it was shown that fatigue curves parameters the best correlate with modified plasticity $(\sigma_u/\sigma_y)Z$ at room and elevated (250°C - 350°C) temperature, conformed according to normal distribution. Analyses of the dependence of Coffin's curves parameters on modified plasticity for Cr – Ni, Cr – Ni – Mo, Cr – Ni – Mo – V alloyed structured steels weld metals at room and elevated temperature is represented in this work. The results of the investigation of 67 weld metals at room and 37 weld metals at elevated (250°C - 350°C) temperatures were selected from laboratories of Kaunas University of Technology and other countries (Czech Republic, Russia, Hungary).

2. Parameters of low cycle fatigue curves

The parameters of fracture, under low cycle loading with limited strain, are understood as the durability or low cycle fatigue curves, which are composed in coordinates $lg\,\varepsilon - lg\,N$ and $lg\,\delta - lg\,N$ according the number of cycles till crack N_c or fracture N_f appears. The durability of the material under loading with limited strain is expressed by Coffin's equation

$$\delta N^m = C \tag{1}$$

where δ is the range of plastic strain or the width of plastic hysteresis loop; N is the number of cycles up to crack formation or fracture; m and C are characteristics of the material, which is proposed by Coffin: $m = 0.5$ and $C = 0.5 ln(1/(1-Z))$, where Z is the reduction of area at fracture.

The stresses and elastic-plastic strains vary during the low cycle loading with limited strain for hardened and softened materials, therefore it is proposed to calculate equivalent plastic strain by expression $\delta = \frac{1}{k_c}\sum_0^{k_c}\delta_k$, where k_c is the number of semicycles up to crack, or to the applied width of plastic hysteresis loop for durability $N/2$.

S.S. Manson has investigated 29 cyclic unstable materials and proposed a relation between total elastic plastic strain and the number of cycles till fracture [4]

$$\varepsilon = \delta_k + \varepsilon_{ek} = \left(ln\frac{1}{1-\psi}\right)^{0.6} N_f^{-0.6} + 3.5\frac{\sigma_u}{E}N_f^{-0.12} \tag{2}$$

B.F. Langer has proposed the similar equation to figure out the dependence of total stain on the number of cycles up to fracture

$$\varepsilon = \delta_k + \varepsilon_{ek} = \frac{1}{2}ln\frac{1}{1-\psi}N_f^{-0.5} + \frac{2\sigma_{-1}}{E} \tag{3}$$

where δ_k is the width of plastic hysteresis loop at k semicycle of loading, ε_{ek} is elastic strain, σ_{-1} is endurance limit; E is modulus of elasticity; σ_u is ultimate stress.

In work [5] it was proposed to change plastic deformation δ in equation (1) by ε, because the range of total strain ε remains constant at cyclic loading with limited strain therefore the durability is proposed to evaluate by the equation

$$\varepsilon N^m = C \tag{4}$$

This equation is correct for the majority of materials, when $\varepsilon > (3.0-3.5)e_{pr}$, and when $\varepsilon < (3.0-3.5)e_{pr}$ the durability greatly increases, therefore low cycle fatigue curves are defined in this work by the equation

$$\varepsilon = C_e N^{-m_e} + C_p N^{-m_p} \tag{5}$$

where ε is total elastic plastic strain; m_e, C_e, m_p, C_p are parameters of low cycle fatigue curves according to elastic and plastic strain accordingly.

3. Calculation results

The weld metals investigated in works [6, 7] were divided according temperature into 2 groups: 1) at room temperature; 2) at elevated (250°C - 350°C) temperature; according chemical composition into 3 groups: 1) Cr – Ni; 2) Cr – Ni – Mo – V; 3) Cr – Ni – Mo. Dependences of the parameters of low cycle fatigue curve m_e, C_e, m_p, C_p on modified plasticity $\left(\sigma_u/\sigma_y\right)Z$ for Cr – Ni – Mo alloyed structural steels weld metals at room temperature and 95% confidence interval ranges (dotted line) to theoretic line are given in Figs. 1-4. Figs. 5-8 represent the results for Cr – Ni – Mo – V alloyed structural steels weld metals at elevated (250°C - 350°C) temperature.

Figs. 1-8 show that 95% confidence interval

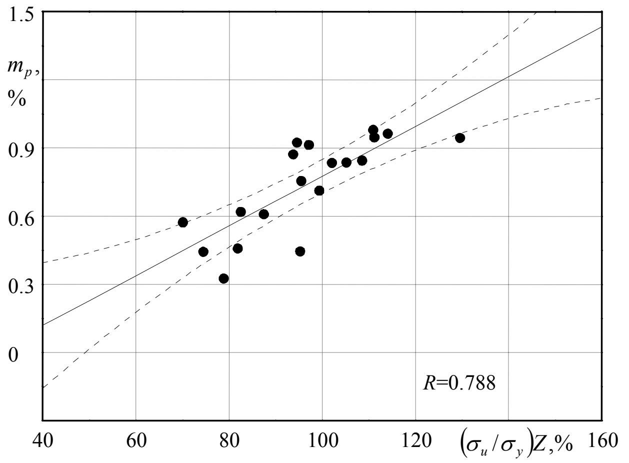

Fig. 1 Dependence of parameter m_p on modified plasticity $\left(\sigma_u/\sigma_y\right)Z$ for Cr – Ni – Mo alloyed structural steels weld metals at room temperature

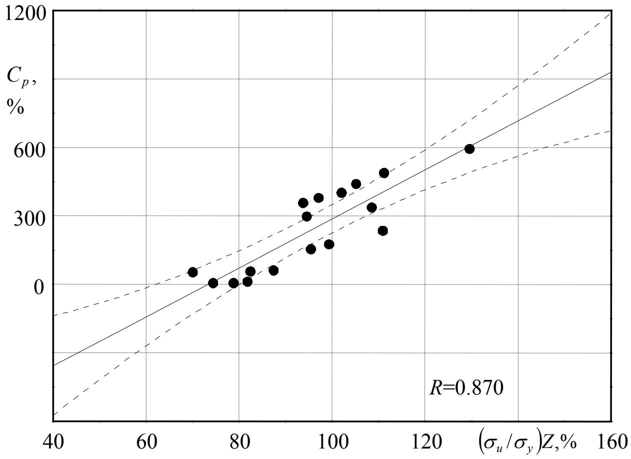

Fig. 2 Dependence of parameter C_p on modified plasticity $\left(\sigma_u/\sigma_y\right)Z$ for Cr – Ni – Mo alloyed structural steels weld metals at room temperature

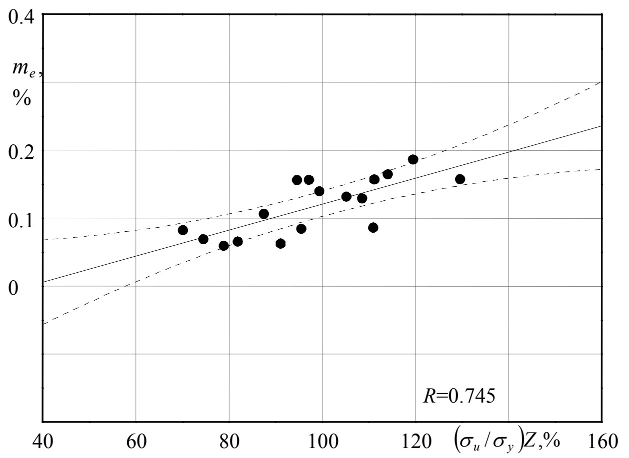

Fig. 3 Dependence of parameter m_e on modified plasticity $\left(\sigma_u/\sigma_y\right)Z$ for Cr – Ni – Mo alloyed structural steels weld metals at room temperature

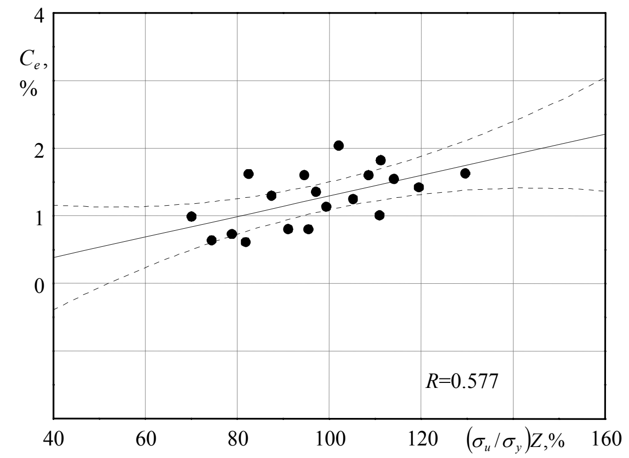

Fig. 4 Dependence of parameter C_e on modified plasticity $\left(\sigma_u/\sigma_y\right)Z$ for Cr – Ni – Mo alloyed structural steels weld metals at room temperature

ranges (dotted line) to theoretic line are narrower at room temperature comparing with the results at elevated temperature. Histograms of low fatigue curves parameters m_p according plastic strain for Cr – Ni – Mo – V alloyed structural steels weld metals at room and elevated temperature are given at Figs. 9, 10. Histogram of parameter m_p at room temperature has left skewness compared with normal distribution, while parameter m_p at elevated temperature has right skewness. Kurtosis coefficient shows that the results of parameters m_p for Cr – Ni – Mo – V weld metals of alloyed structural steels at room and elevated temperature are spread in wider interval comparing with normal distribution.

Rectangular diagram of parameters m_p for Cr – Ni – Mo – V alloyed structural steels weld metals on Figs. 11, 12 shows that scatter of results is not wide. Here we also can see the median value of parameter m_p. Statistical characteristics of low cycle fatigue curve parameters m_p, C_p, m_e, C_e according to elastic and plastic strain at room and elevated (250°C - 350°C) temperature are given in Table 1. Here we can see, that the mean values of parameters are similar to median, the implication is that here are no strongly outstanding materials. The mean values of results scatter of parameters m_e and m_p according elastic and plastic strain at room temperature is a little smaller than at elevated temperature.

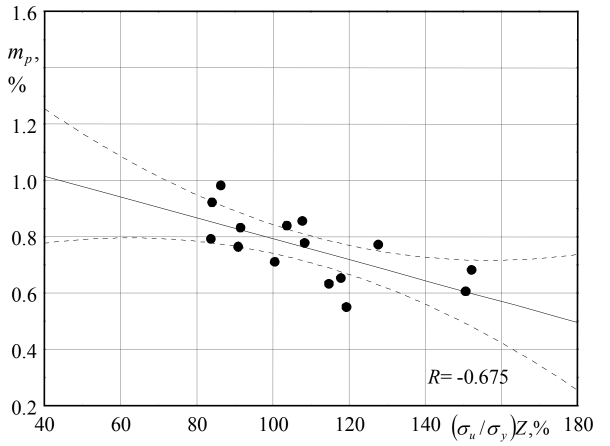

Fig. 5 Dependence of parameter m_p on modified plasticity $(\sigma_u/\sigma_y)Z$ for Cr – Ni – Mo – V alloyed structural steels weld metals at elevated temperature

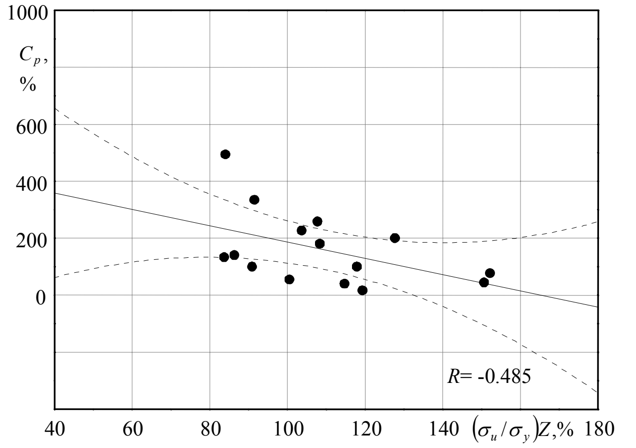

Fig. 6 Dependence of parameter C_p on modified plasticity $(\sigma_u/\sigma_y)Z$ for Cr – Ni – Mo – V alloyed structural steels weld metals at elevated temperature

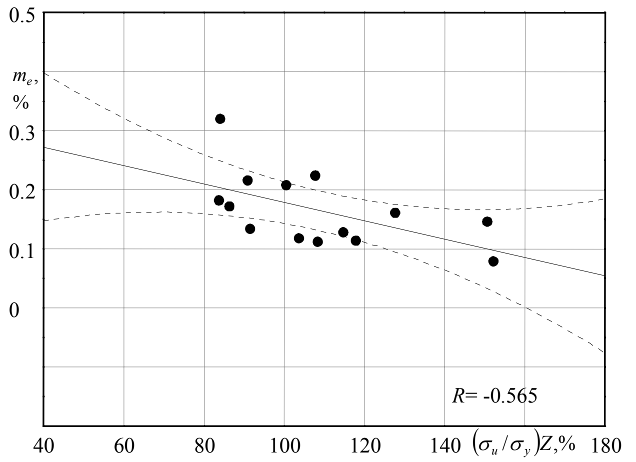

Fig. 7 Dependence of parameter m_e on modified plasticity $(\sigma_u/\sigma_y)Z$ for Cr – Ni – Mo – V alloyed structural steels weld metals at elevated temperature

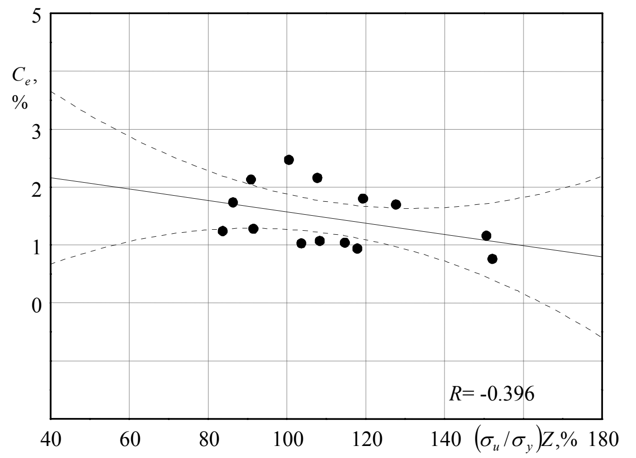

Fig. 8 Dependence of parameter m_p on modified plasticity $(\sigma_u/\sigma_y)Z$ for Cr – Ni – Mo – V alloyed structural steels weld metals at elevated temperature

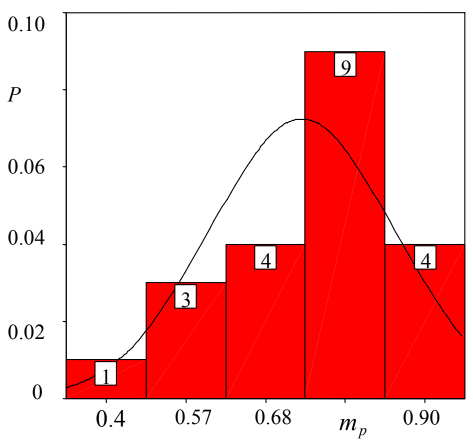

Fig. 9 Histogram of parameters m_p for Cr – Ni – Mo – V alloyed structural steels weld metals at room temperature

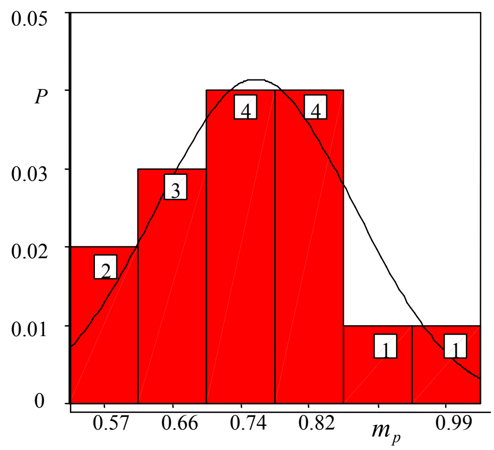

Fig. 10 Histogram of parameters m_p for Cr – Ni – Mo – V alloyed structural steels weld metals at elevated temperature

Analytical dependences of parameters of low cycle fatigue curve on modified plasticity $(\sigma_u/\sigma_y)Z$ for alloyed structural steels weld metals at room and elevated temperature are given in Table 2. These dependences of m_p, C_p, m_e, C_e are used for durability forecast of a material by Eq. (5).

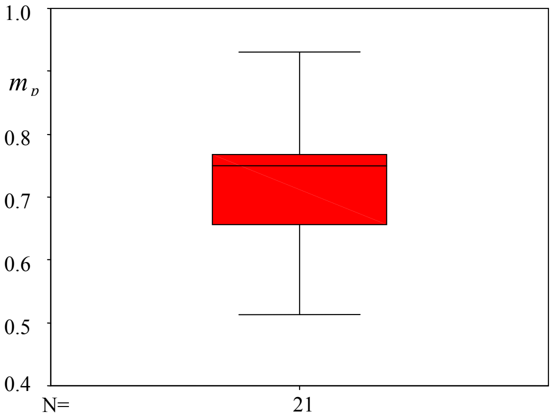

Fig. 11 Rectangular diagram of parameters m_p for Cr – Ni – Mo – V alloyed structural steels weld metals at room temperature

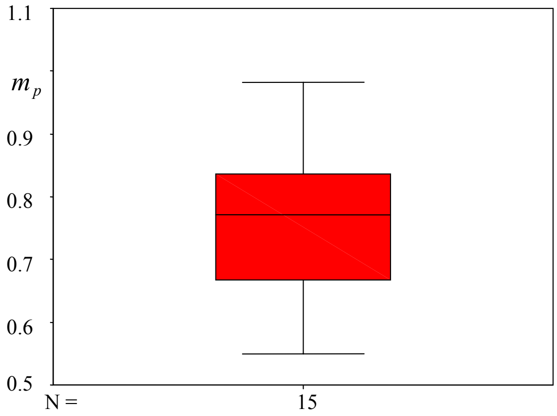

Fig. 12 Rectangular diagram of parameters m_p for Cr – Ni – Mo – V alloyed structural steels weld metals at elevated temperature

Table 1

Statistical characteristics of parameters m_e , C_e , m_p , C_p according to elastic and plastic strain at room and elevated (250°C - 350°C) temperature

Parameters	Alloyed structural steels weld metals at room temperature				Alloyed structural steels weld metals at elevated temperature			
	m_p	C_p	m_e	C_e	m_p	C_p	m_e	C_e
Cr – Ni alloyed structural steels weld metals								
Number of materials	15	15	15	16	5	5	6	6
Mean value	0.620	81.712	0.121	1.091	0.940	286.059	0.153	1.441
Median value	0.612	70.730	0.111	0.939	0.995	321.233	0.165	1.520
Minimum value	0.477	10.778	0.068	0.522	0.555	52.420	0.063	0.600
Maximum value	0.878	296.192	0.170	1.640	1.106	417.080	0.223	2.057
Kurtosis coefficient	1.686	6.541	-1.593	-1.282	3.232	2.997	-1.954	-1.600
Skewness coefficient	0.942	2.241	0.051	0.335	-1.749	-1.573	-0.383	-0.404
Cr – Ni – Mo – V alloyed structural steels weld metals								
Number of materials	21	21	20	20	15	15	14	14
Mean value	0.725	174.110	0.095	1.040	0.758	160.404	0.165	1.466
Median value	0.749	141.846	0.089	1.072	0.772	133.430	0.154	1.260
Minimum value	0.449	5.755	0.048	0.738	0.550	16.770	0.079	0.760
Maximum value	0.930	513.833	0.162	1.511	0.982	494.530	0.320	2.470
Kurtosis coefficient	-0.115	0.742	-0.396	-0.723	-0.472	1.990	1.726	-0.902
Skewness coefficient	-0.419	1.019	0.320	0.265	0.064	1.363	1.126	0.571
Cr – Ni – Mo alloyed structural steels weld metals								
Number of materials	19	17	17	19	11	11	11	11
Mean value	0.737	238.244	0.117	1.257	0.792	135.390	0.150	1.678
Median value	0.835	234.797	0.129	1.298	0.736	131.220	0.132	1.360
Minimum value	0.325	5.630	0.059	0.611	0.592	38.740	0.080	1.040
Maximum value	0.980	593.132	0.186	2.037	1.148	300.060	0.288	2.890
Kurtosis coefficient	-1.020	-1.190	-1.583	-1.018	1.405	-0.786	2.191	-1.205
Skewness coefficient	-0.593	0.240	-0.027	-0.013	1.140	0.805	1.306	0.643

Correlation analysis is statistical relation strength between analyzed variables, which is expressed by correlation coefficient. Pearson correlation coefficient measures the linear relation strength. It was confirmed that the parameters of low cycle fatigue curves m_e, C_e, m_p, C_p for alloyed structural steels weld metals (Table 3) and modified plasticity $(\sigma_u/\sigma_y)Z$ at room and elevated temperature are correlated. Pearson correlation coefficient has the minimum value $|-0.395|$ for Cr – Ni – Mo – V alloyed structural steels for coefficient C_e at elevated temperature and the maximum value $|-0.875|$ for Cr – Ni – Mo alloyed structural steels for coefficient m_p at elevated temperature.

Table 2

Analytical dependences of parameters m_e, C_e, m_p, C_p on modified plasticity $(\sigma_u/\sigma_y)Z$ at room and elevated (250°C - 350°C) temperature

Alloyed structural steels weld metals at room temperature	Alloyed structural steels weld metals at elevated temperature
Cr – Ni alloyed structural steels weld metals	
$m_p = 0.1844 + 0.0044(\sigma_u/\sigma_y)Z$ $C_p = -159.3128 + 2.3638(\sigma_u/\sigma_y)Z$ $m_e = -0.0162 + 0.0013(\sigma_u/\sigma_y)Z$ $C_e = -0.2951 + 0.0135(\sigma_u/\sigma_y)Z$	$m_p = 2.6487 - 0.0130(\sigma_u/\sigma_y)Z$ $C_p = 1128.4934 - 6.3870(\sigma_u/\sigma_y)Z$ $m_e = 0.5402 - 0.0028(\sigma_u/\sigma_y)Z$ $C_e = 4.6316 - 0.0231(\sigma_u/\sigma_y)Z$
Cr – Ni – Mo – V alloyed structural steels weld metals	
$m_p = 0.0199 + 0.0070(\sigma_u/\sigma_y)Z$ $C_p = -500.1568 + 6.6423(\sigma_u/\sigma_y)Z$ $m_e = 0.2279 - 0.0014(\sigma_u/\sigma_y)Z$ $C_e = 2.0927 - 0.0107(\sigma_u/\sigma_y)Z$	$m_p = 1.1632 - 0.0037(\sigma_u/\sigma_y)Z$ $C_p = 473.5682 - 2.8660(\sigma_u/\sigma_y)Z$ $m_e = 0.3344 - 0.0016(\sigma_u/\sigma_y)Z$ $C_e = 2.5500 - 0.0098(\sigma_u/\sigma_y)Z$
Cr – Ni – Mo alloyed structural steels weld metals	
$m_p = -0.3200 + 0.0110(\sigma_u/\sigma_y)Z$ $C_p = -786.5090 + 10.7347(\sigma_u/\sigma_y)Z$ $m_e = -0.0708 + 0.0019(\sigma_u/\sigma_y)Z$ $C_e = -0.2253 + 0.0151(\sigma_u/\sigma_y)Z$	$m_p = 1.4751 - 0.0072(\sigma_u/\sigma_y)Z$ $C_p = 378.3107 - 2.5507(\sigma_u/\sigma_y)Z$ $m_e = 0.3746 - 0.0024(\sigma_u/\sigma_y)Z$ $C_e = 4.3379 - 0.0279(\sigma_u/\sigma_y)Z$

Table 3

Correlation analysis of parameters m_e, C_e, m_p, C_p and modified plasticity $(\sigma_u/\sigma_y)Z$ at room and elevated temperature

Chemical composition (groups)	Pearson correlation coefficient			
	m_p	C_p	m_e	C_e
Alloyed structural steels weld metals at room temperature				
Cr – Ni	0.723	0.675	0.745	0.727
Cr – Ni – Mo – V	0.573	0.523	-0.438	-0.480
Cr – Ni – Mo	0.788	0.870	0.745	0.578
Alloyed structural steels weld metals at elevated temperature				
Cr – Ni	-0.700	-0.560	-0.800	-0.749
Cr – Ni – Mo – V	-0.675	-0.485	-0.565	-0.395
Cr – Ni – Mo	-0.875	-0.506	-0.772	-0.789

The scatter between experimental and calculated by Eq. (5) results of durability for alloyed structural steels weld metals (according analytical dependences given in Table 2) at room and elevated temperature is given in Table 4. The scatter of results between experimental $N_f^{\exp}$ durability and calculated N_f^{cal} durability for Cr – Ni, Cr – Ni – Mo – V, Cr – Ni – Mo alloyed steels weld metals at room and elevated (250°C - 350°C) temperature are similar. The scatter of results between experimental N_f^{exp} durability and calculated N_f^{cal} durability for integrated group at elevated temperature is greater than at room temperature.

The comparison between those durabilities for Cr – Ni and Cr – Ni – Mo – V alloyed structural steels weld metals at room and elevated temperature is shown in Fig. 13-16. In Table 4 we can also see, that the scatter of results (when calculated lifetime for integrated group) between experimental N_f^{exp} durability and calculated N_f^{cal} durability are 2.35%, 4.6% smaller than the scatter of results for Cr–Ni, Cr – Ni – Mo – V at room temperature, and 8.05% at elevated (250°C - 350°C) temperature. The scatter of results, when the durability is calculated for integrated group, between experimental N_f^{exp} durability and calculated N_f^{cal} durability for alloyed structural steels weld metals at room and elevated temperature is shown in Fig. 17-18.

Table 4

Comparison of experimental $N_f^{\exp}$ and calculated N_f^{cal} durability for alloyed structural steels weld metals at room and elevated temperature

Chemical composition (groups)	Total number of specimens	Number of specimens, when scatter of results between experimental and calculated lifetime is					
		four fold		nine fold		sixteen fold	
		number	%	number	%	number	%
Alloyed structural steels weld metals at room temperature							
Cr – Ni	184	113	61	141	77	157	85
Cr – Ni – Mo - V	275	180	65	217	79	239	87
Cr – Ni – Mo	247	101	41	141	57	173	70
Integrated group	706	416	59	539	76	588	83
Alloyed structural steels weld metals at elevated temperature							
Cr – Ni	85	55	65	67	79	74	87
Cr – Ni – Mo - V	177	115	65	143	81	154	87
Cr – Ni – Mo	121	75	62	105	87	110	91
Integrated group	383	207	54	276	72	305	80

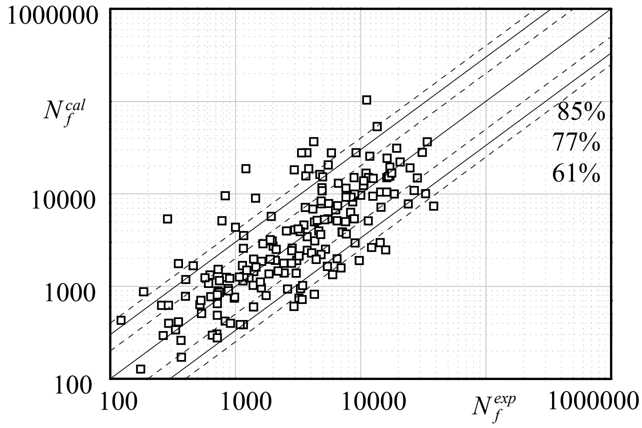

Fig. 13 Comparison of experimental N_f^{exp} and calculated N_f^{cal} durability for Cr – Ni alloyed structural steels weld metals at room temperature

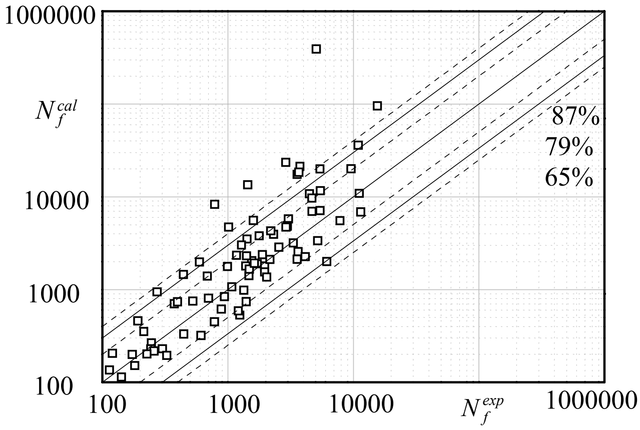

Fig. 14 Comparison of experimental N_f^{exp} and calculated N_f^{cal} durability for Cr – Ni alloyed structural steels weld metals at elevated (250°C-350°C) temperature

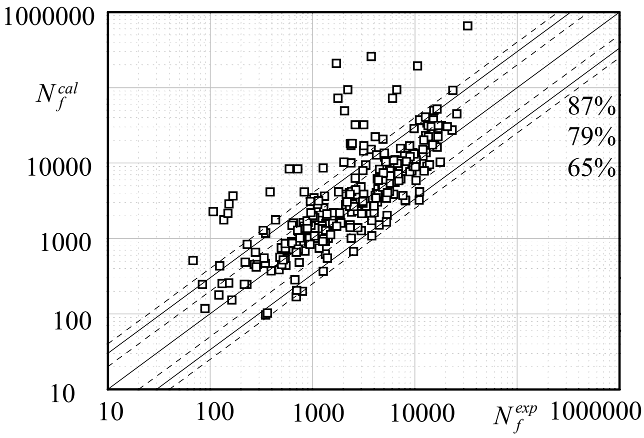

Fig. 15 Comparison of experimental N_f^{exp} and calculated N_f^{cal} durability for Cr – Ni – Mo – V alloyed structural steels weld metals at room temperature

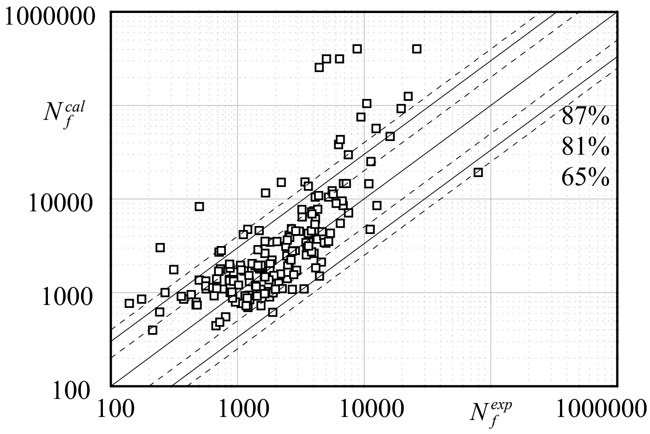

Fig. 16 Comparison of experimental N_f^{exp} and calculated N_f^{cal} durability for Cr – Ni– Mo – V alloyed structural steels weld metals at elevated (250°C-350°C) temperature

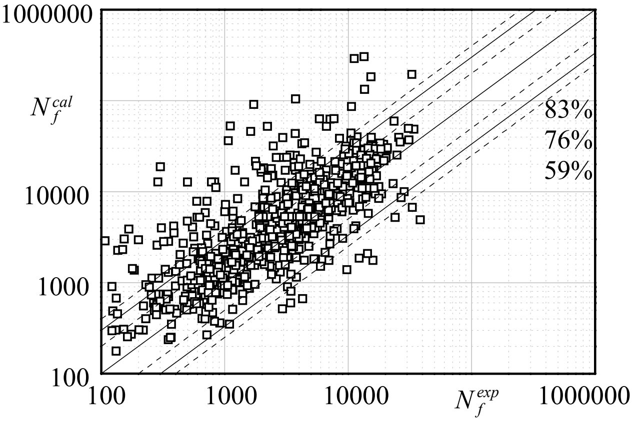

Fig. 17 Comparison of experimental N_f^{exp} and calculated N_f^{cal} durability for integrated alloyed structural steels weld metals at room temperature

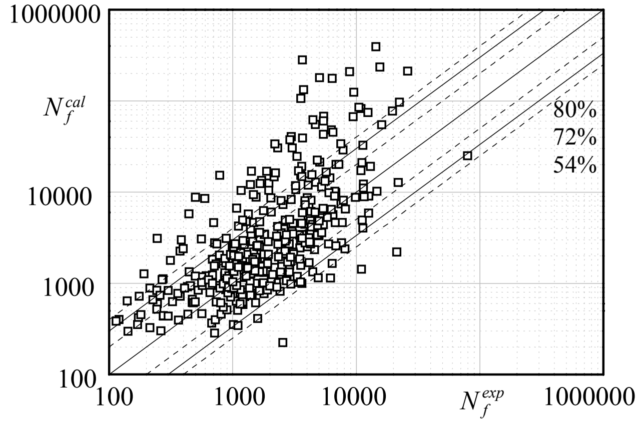

Fig. 18 Comparison of experimental N_f^{exp} and calculated N_f^{cal} durability for integrated alloyed structural steels weld metals at elevated (250°C-350°C) temperature

4. Conclusion

1. The parameters of low cycle fatigue curves $m_e, C_e, m_p,\ C_p$ for alloyed structural steels weld metals on modified plasticity $(\sigma_u/\sigma_y)Z$ at room and elevated temperature are correlated by linear regression.

2. The mean value of parameter m_p for alloyed structural steels weld metals at room and elevated temperature is greater than Coffin's constant $m = 0.5$. The obtained mean values at room temperature: $m_p = 0.620$ for Cr – Ni, $m_p = 0.725$ for Cr – Ni – Mo – V, $m_p = 0.737$ for Cr – Ni – Mo. At elevated temperature: $m_p = 0.940$ for Cr – Ni, $m_p = 0.758$ for Cr – Ni – Mo – V, $m_p = 0.792$ for Cr – Ni – Mo.

3. The mean values of scatter results of parameter m_p according plastic strain for Cr – Ni, Cr – Ni – Mo – V, Cr – Ni – Mo alloyed structural steels weld metals at room temperature are 34.04%, 4.35%, 6.94% accordingly smaller than at elevated temperature.

4. The scatter of results (when calculated durability for integrated group) between experimental N_f^{exp} durability and calculated N_f^{cal} durability is 2.35%, 4.6% smaller than the scatter of results for Cr – Ni, Cr – Ni – Mo – V at room temperature, and 8.05% at elevated temperature. While the scatter of results (when calculated durability for integrated group) between experimental N_f^{exp} durability and calculated N_f^{cal} durability is 18.57% greater than the scatter of results for Cr – Ni – Mo at room temperature, and 13.75% smaller at elevated temperature.

5. Analytical dependences of low cycle fatigue curve parameters on modified plasticity for Cr –Ni, Cr – Ni – Mo – V, Cr – Ni – Mo alloyed structural steels weld metals are enough correct to figure out the durability at room and elevated temperature. The scatter of results is 2 - 3 times greater than for one material experimental durability at low cycle loading with limited strains.

6. Dependencies proposed in this work may be used for preliminary evaluation durability of alloyed structural steels weld metals at low cycle loading.

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LEGIRUOTŲ KONSTRUKCINIŲ PLIENŲ SUVIRINTŲJŲ SUJUNGIMŲ SIŪLŲ MEDŽIAGŲ MAŽACIKLIO ILGAAMŽIŠKUMO STATISTINIS ĮVERTINIMAS KAMBARIO IR AUKŠTESNĖJE TEMPERATŪROJE

R e z i u m ė

Straipsnyje nagrinėjama atominėje energetikoje naudojamų legiruotų plienų suvirintųjų sujungimų siūlių medžiagų mažaciklio ilgaamžiškumo priklausomybė nuo šių medžiagų mechaninių charakteristikų. Tyrimui panaudota 67 medžiagų kambario ir 37 medžiagų aukštesnėje temperatūroje išbandytų Kauno technologijos universitete, o taip pat Čekijoje, Rusijoje ir Vengrijoje rezultatai. Atliekant tyrimą buvo sudarytos mažaciklio nuovargio kreivės naudojant tampriąją ir plastinę bendros deformacijos dedamąsias ir nustatytos Kofino lygčių konstantos pagal tampriąją deformaciją C_e, m_e ir pagal plastinę deformaciją C_p, m_p. Nustatyta, kad mažaciklis ilgaamžiškumas tiesiškai koreliuoja su medžiagų modifikuotu plastiškumu $\left(\sigma_u / \sigma_y\right)Z$. Pasiūlytos analitinės priklausomybės konstantų C_e, m_e, C_p, m_p apskaičiavimui naudojant modifikuotą plastiškumą. Skaičiuoto ir eksperimentinio ilgaamžiškumo rezultatų palyginimas parodė, kad pasiūlytas metodas gali būti pritaikytas preliminariam medžiagų atsparumo mažacikliam apkrovimui įvertinimui.

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STATISTICAL EVALUATION OF LOW CYCLE LIFETIME FOR WELD METALS OF ALLOYED STRUCTURAL STEELS AT ROOM AND ELEVATED TEMPERATURE

S u m m a r y

The dependence of low cycle durability on mechanical characteristics for alloyed steels of welded joints weld metals used in nuclear power energetic is investigated in this work. The results of 67 materials tested at room temperature and 37 at elevated temperature in Kaunas university of technology and Czech, Russia, Hungary are used. At this investigation were made up the low cycle fatigue curves were obtained using elastic and plastics strains and constants of Coffins equations for elastic C_e, m_e and plastic C_p, m_p strains were calculated. It is determined, that low cycle durability has linear correlation with the modified plasticity of materials $\left(\sigma_u / \sigma_y\right)Z$. Analytical dependences for constants C_e, m_e, C_p, m_p calculation according to the modified plasticity are proposed. The comparison results of analytical and experimental durability showed, that proposed in this work method may be used for preliminary estimation of low cycle durability of materials.

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СТАТИСТИЧЕСКИЙ АНАЛИЗ МАЛОЦИКЛОВОЙ ДОЛГОВЕЧНОСТИ ДЛЯ МАТЕРИАЛОВ СВАРНЫХ ШВОВ ЛЕГИРОВАННЫХ КОНСТРУКЦИОННЫХ СТАЛЕЙ В УСЛОВИЯХ КОМНАТНОЙ И ПОВЫШЕННОЙ ТЕМПЕРАТУРЫ

Р е з ю м е

В статье рассмотрена зависимость малоцикловой долговечности швов сварных соединений легированных сталей используемых в атомной энергетике от механических характеристик этих материалов. Исследовано 67 материалов испытанных при комнатной температуре и 37 материалов испытанных при повышенной температуре в Каунасском технологическом университете, а также в Чехии, России и Венгрии. При проведении данного исследования были построены кривые малоцикловой усталости с использованием упругой и пластической составляющих общей деформации и вычислены константы уравнении типа Коффина для упругой деформации C_e, m_e и для пластической деформации C_p, m_p. Определено, что малоцикловая долговечность имеет линейную корреляцию с модифицированной пластичностью материала $\left(\sigma_u / \sigma_y\right)Z$. Предложены аналитические зависимости для расчета констант C_e, m_e, C_p, m_p с использованием модифицированной пластичности. Сопоставление результатов расчета и эксперимента показало, что полученные зависимости могут быть использованы для предварительной оценки сопротивления материалов малоцикловому нагружению.

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