EXPERIMENTAL RESEARCH ON INFLUENCE ON SINGLE OVERLOAD ON FATIGUE LIFE OF CONSTRUCTIONAL STEELS UNDER COMPLEX LOAD

G.Cempel, G.Gasiak

Opole University of Technology, Opole, Poland

Abstract. The paper presents the results of fatigue life tests under complex load conditions (proportional bending with torsion) with single overload for the different overload ratios (k_j=1.5; k_j = 2). Specimens of square sections made of costructional steels: 10HNAP and 18G2A with unilateral sharp notches were tested. The tests were performed at the fatigue test stand MZGS-100; amplitude of resultant moment was M_a=16 N·m (proportion of bending and torsion moments was M_{ag}/M_{as} =1.73). Fatigue crack growth was measured with a microscope magnifying 25x. It was found that a single overload causes an essential change of fatigue life. It has been shown that the overload factor strongly influences those changes.

1. Introduction

Fatigue cracking and its influence on life have been tested for many years. There are many models describing fatigue life and fatigue crack growth for various materials [1]; they are usually based on analysis of crack propagation under simple loading states, i.e. tension-compression or bending [2]. However, there are not many papers about crack propagation under complex loading, for example combined bending and torsion. In practice, most real structures and machine elements are subjected to irregular types of loading including single or multiple instantaneous overloads**.**

In [3] it has been shown that cyclic loading can cause significant reduction of the element life time, and under some combinations of loading and overload the mean value does not influence the life. Negative influence of overload on fatigue life has been reported in [4] where the authors presented the test results for 1045 steel subjected to torsion with an occurring bending overload. From the test results presented in [5] it appears that one-cycle overload can cause the life increase, even 58 %. This fact is usually understood as a result of formation of a big plastic zone in the slot tip. This plastic zone comes from overload and is much greater than the plastic zone coming from the basic overload. The life increase can also be an effect of occurrence of local residual stresses [6-11]. Thus, including the loading interactions causing acceleration or delay of the fatigue crack seems to be an important problem during estimation of element life.

The aim of the paper is experimental analysis of life of specimens with fatigue cracks. The tested specimens were made of two steels: 10HNAP and 18G2A. The specimens were tested under the complex loading state, i.e. bending with torsion with one-cycle overload.

2. Experimental research

The fatigue test were carried out under proportional constant-amplitude loading for combined bending with torsion; a ratio of the bending moment amplitude to the torsional moment amplitude was M_{ag} / M_{as} was 1.73. The fatigue test stand MZGS-100 (Fig. 1) was applied

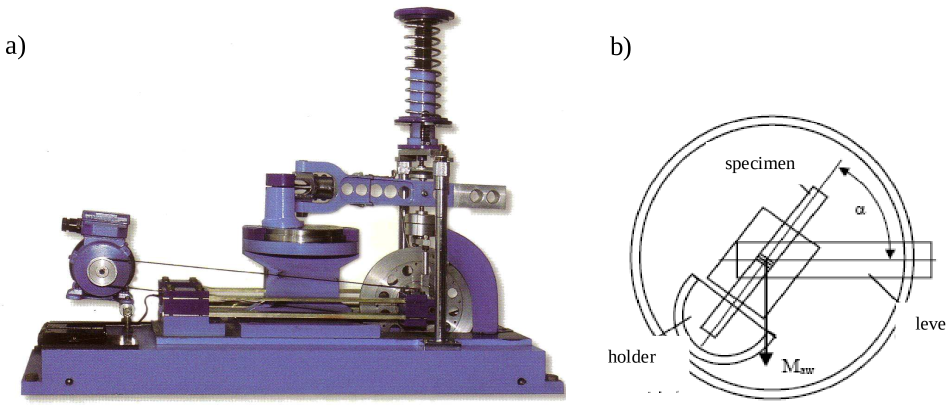


Fig. 1. a) fatigue test stand MZGS-100, b) load scheme

Chemical composition and mechanical properties of the investigated materials: 10HNAP and 18G2A steels, have been placed in Tables 1 and 2.

Table 1. Chemical composition of the tested steels

Material	Chemical composition in %								
	C	Mn	Si	P	S	Cr	Ni	Cu	Fe
10HNAP	0.11	0.52	0.26	0.098	0.016	0.65	0.35	0.26	rest
18G2A	0.21	1.46	0.42	0.019	0.046	0.09	0.04	0.17	rest

Table 2. Mechanical properties of the tested steels

STEEL	Re [MPa]	Rm [MPa]	A_{10} [%]	Z [%]	E [GPa]	ν
10HNAP	418	566	30.7	36.5	215	0.29
18G2A	357	535	21	30	210	0.30

Specimens of square sections with unilateral notches described in the Polish Standards PN-84/H-04308 were tested. Shape and dimensions of specimens are shown in Fig. 2.

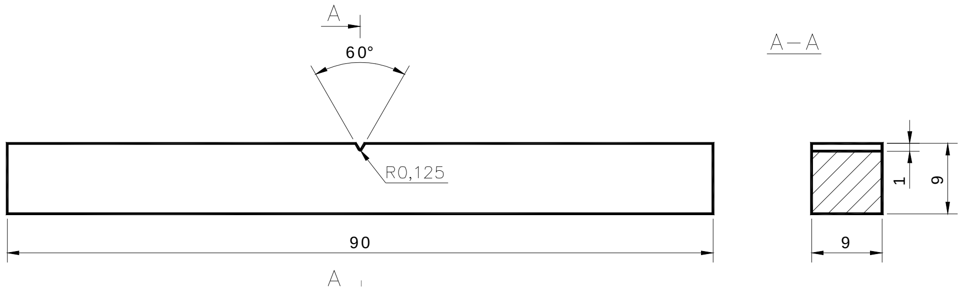
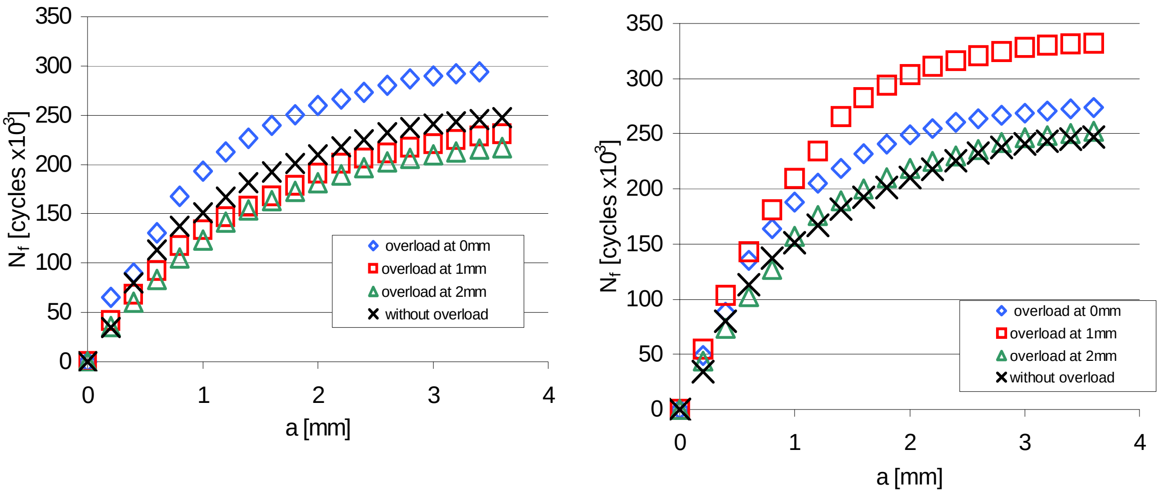


Fig. 2. Shape and dimensions of the tested specimens

Specimens were tested under the resultant moment amplitude M_a = 16Nm as basic load. Proportion of bending and torsion moment amplitudes was M_{ag}/M_{as} = 1.73 (torsion angle of test stand lever was $\alpha = 30^0$). Each specimen was subjected to single overload with amplitude of the resultant moment M_{ap} = 24Nm (18G2A and 10HNAP steels) and M_{ap} = 32Nm (18G2A steel). The overload factor was k_j = 1.5 and 2. Overload was given once for each specimen for a determined fatigue crack length a_p. Next, the fatigue load of the specimen was continued in the basic cycle up to the moment when the critical crack length (corresponding to the critical number of cycles N, i.e. the specimen life N_{pf}) was obtained.

The results of fatigue life tests for of 18G2A and 10HNAP steels versus fatigue crack length a_p are shown in Fig. 3 and 4.



a) b)

Fig. 3. Course of fatigue life N_f of specimens made of 18G2A steel subjected to overload: a) overload factor $k_j = 2$, b) overload factor $k_j = 1.5$

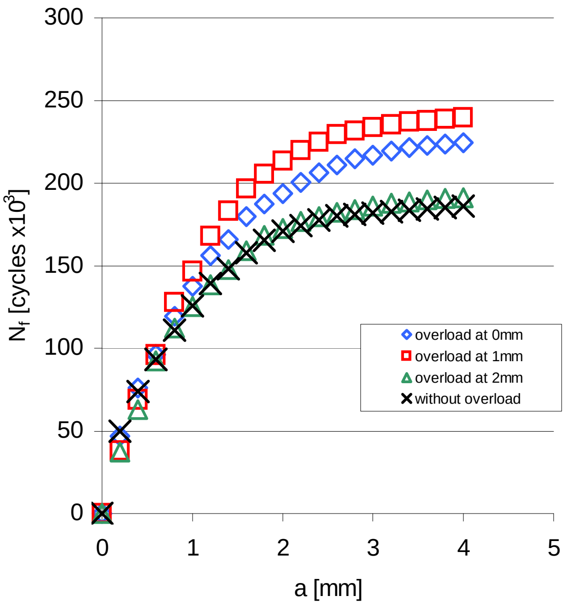


Fig. 4. Course of fatigue life N_f of specimens made of 10HNAP steel subjected to overload with overload factor $k_j = 1.5$

3. The result analysis

The analysis was based on the graphs of life courses N_{pf} depending on the crack length a_p, corresponding to the overload moment M_{ap}. The experimental data from Table 3 was also used. The fatigue life under bending with torsion of specimens without an overload is $N_f = 249 \cdot 10^3$ cycles (steel 18G2A) and $N_f = 188 \cdot 10^3$ cycles (steel 10HNAP).

Table 3. Results of tests for 18G2A and 10HNAP

	18G2A			10HNAP		
Overload factor $k_j = 1,5$						
Crack length under overload a_p [mm]	0	1	2	0	1	2
Fatigue life N_{pf} [cycles x10^3]	276	335	253	225	240	192
Overload factor $k_j = 2$						
Crack length under overload a_p [mm]	0	1	2	0	1	2
Fatigue life N_{pf} [cycles x10^3]	295	238	221	-	-	-

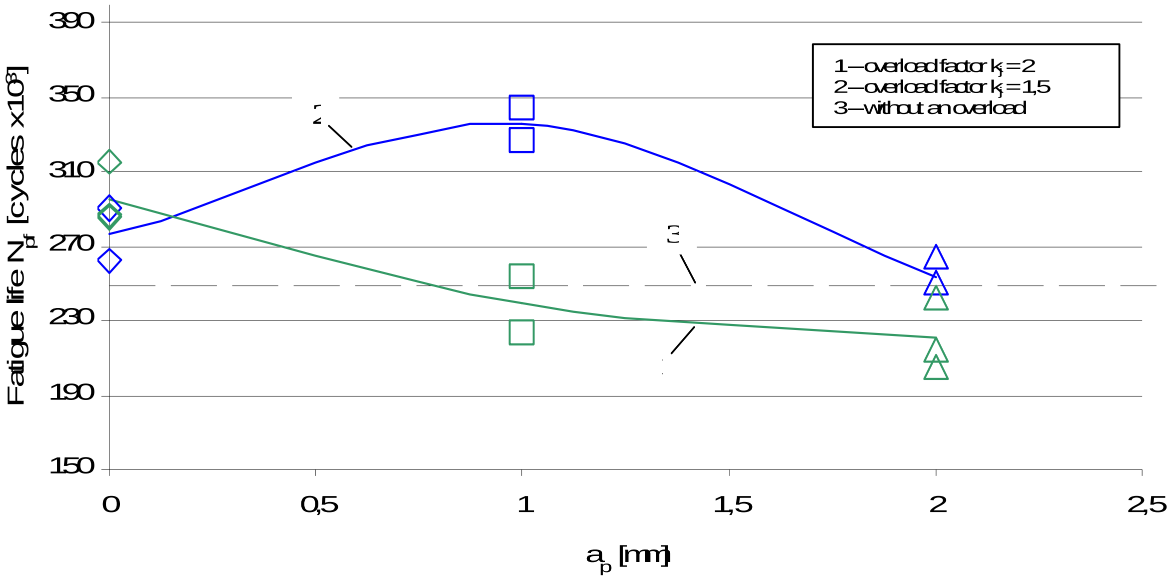


Fig. 5. Course of fatigue life N_{pf} versus fatigue crack length a_p during bending with torsion with bending and torsion moment amplitude ratio M_{ag}/M_{as} = 1.73 for specimens made of 18G2A steel

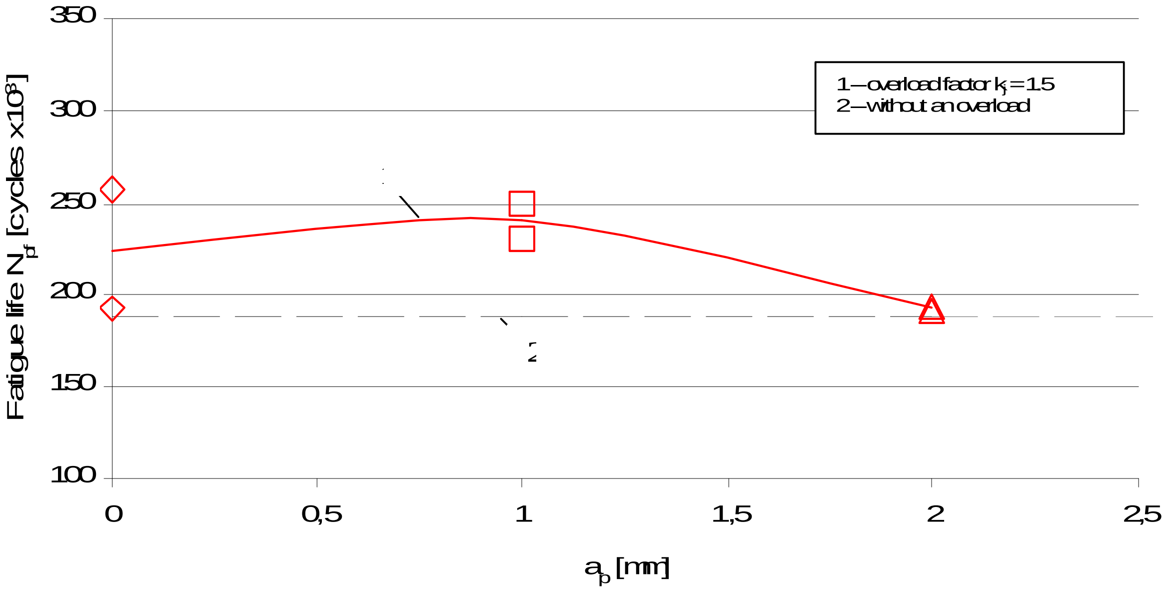


Fig. 6. Course of fatigue life N_{pf} versus fatigue crack length a_p during bending with torsion with bending and torsion moment amplitude ratio M_{ag}/M_{as} = 1.73 for specimens made of 10HNAP steel

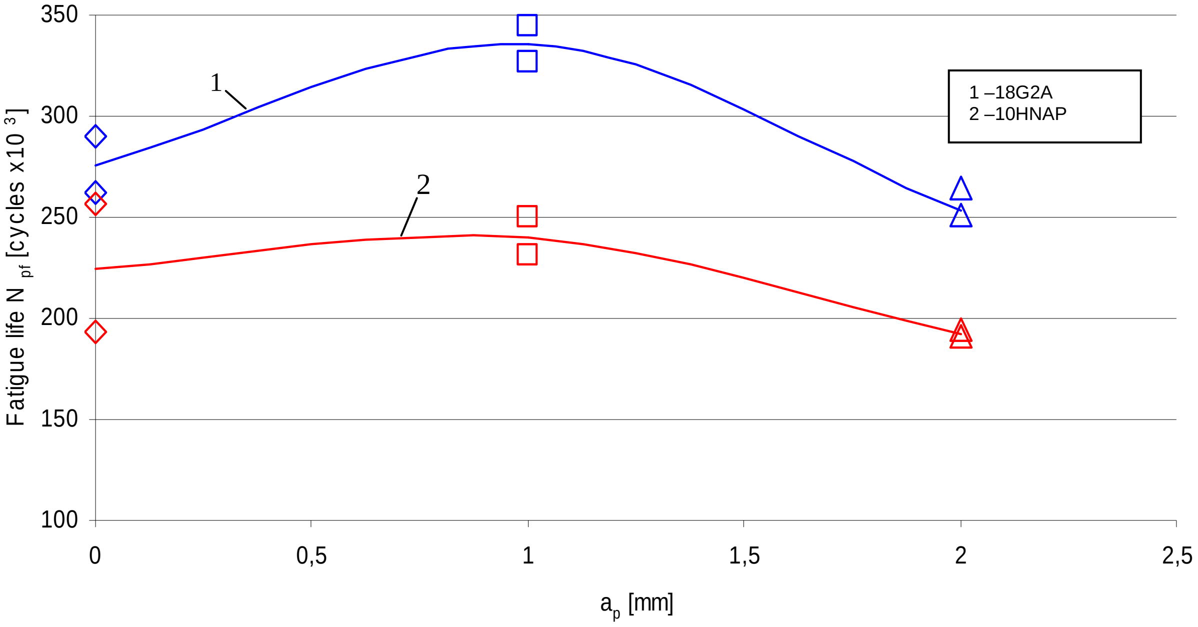


Fig. 7. Course of fatigue life N_{pf} for 18G2A and 10HNAP steels versus fatigue crack length a_p during bending with torsion for overload factor $k_j = 1.5$

The analysis of fatigue life courses allowed to define single overload influence on tested elements made of constructional steels 10HNAP and 18G2A. Table 4 shows the values of fatigue life changes (in %) of specimens subjected to overload. The presented data were calculated with reference to fatigue life of specimens without overload for the corresponding steels.

Table 4. Changes of fatigue life of specimens subjected to overload

Material	Crack length under overload a_p [mm]	Fatigue life changes ΔN_f [%])
Overload factor $k_j = 1.5$		
18G2A	0	increase 10.84%
	1	increase 34.73%
	2	increase 1.8%
10HNAP	0	increase 19.68%
	1	increase 27.65%
	2	increase 2.39%
Overload factor $k_j = 2$		
18G2A	0	increase 18.6%
	1	drop 4.41%
	2	drop 11.24%

From Figs. 5-7 and Table 4 it appears that overload with the factor k_j strongly influences the fatigue life N_{pf} in both tested steels. A value of the overload factor k_j is very important, too. Under $k_j = 1.5$ the overload caused the life increase for all crack lengths a_p in both steels. The greatest increase was reached when the specimen was overloaded in the moment when the crack length $a_p = 1$ mm.

For $k_j = 2$, the life increase was observed for the slot length $a_p = 0$ mm. When overload occurred at the length a_p greater than about 0.7 mm, it caused a drop of N_{pf}.

Fig. 7 shows lives of the considered materials for the overload factor $k_j = 1.5$. The courses of N_{pf} for both materials are similar, and a difference is caused by different strength properties.

4. Conclusions

From analysis of fatigue life courses N_{pf} of specimens subjected to bending with torsion with occurence of single overloads for different factors k_j we can draw the following conclusions:

1. Single overload of specimens with sharp unilateral notch made of constructional steels: 10HNAP i 18G2A subjected to bending with torsion causes an essential change of fatigue life. It has been shown that the overload factor strongly influences those changes.
2. The fatigue crack length a_p for which the overload occurs is very important. The greatest sensitivity to overload with the factor k_j = 1.5 is observed for the fatigue crack a_p = 1 mm (life increase by 34.73 % for 18G2A steel and 27.65 % for 10HNAP steel)
3. Fatigue life N_{pf} course versus the fatigue crack a_p for the overload factor k_j = 1.5 is similar for both investigated materials (Fig.7).

Literature

1. Gasiak G., Trwałość materiałów konstrukcyjnych przy obciążeniach cyklicznych z udziałem wartości średniej obciążenia, Oficyna Wyd. PO, Opole 2002.
2. Achtelik. H, Gasiak G., Grzelak J., Doświadczalna weryfikacja modeli trwałości na przykładzie próbki płaskiej z centralnym karbem poddanej zmiennemu rozciąganiu, XXI Sympozjum Mechaniki Eksperymentalnej Ciała Stałego, Oficyna Wydawnicza Politechniki Warszawskiej, 13-16 października, Jachranka, 2004, s. 117-122.
3. Bonnen J. J. F., Conle F. A., Topper T., H., The role of in-phase and out-of-phase overloads on the torsional fatigue of normalized SAE-1045 steel, International Journal of Fatigue vol. 23, 2001, s. 385-394.
4. Bonnen J. J. F., Topper T. H., The effect of bending overloads on torsional fatigue in normalized 1045 steel, International Journal of Fatigue vol. 21, 1999, s. 23-33.
5. Cempel G., Gasiak G., Robak G., Badanie trwałości zmęczeniowej stali konstrukcyjnej po jednokrotnym przeciążeniu w przypadku płaskiego zginania, XXI Sympozjum Mechaniki Eksperymentalnej Ciała Stałego, Oficyna Wydawnicza Politechniki Warszawskiej, 13-16 października, Jachranka, 2004, s. 159-163.
6. Kocańda S., Zmęczeniowe pękanie metali, WNT Warszawa 1978.
7. Neimitz A., Mechanika pękania, PWN, Warszawa, 1998.
8. Tsukuda H., Ogiyama H., Shiraishi T., Transient fatigue growth behaviour following single overloads AT high stress ratios, Fatigue Fract. Engng. Mater. Struct., 1996, Vol. 19, No7, pp.879-891.
9. Gasiak G., Grzelak J., Forecarting the fatigue crack growth in 10HNAP steel after single overloadning while tension, Archiwum Budowy Maszyn,1996, Vol.XLIII, No 2-3, pp. 168-171.
10. 10. Gasiak G., Modelowanie prędkości pękania zmęczeniowego w stalach konstrukcyjnych w przypadku jednocyklowego przeciążenia przy zmiennym rozciąganiu, Zeszyty Naukowe Politechniki Świętokrzyskiej, Mechanika 78, Kielce, 2003, ss. 143-151.
11. Changqing Z., Yucheng J., Guangli Y., Effect of a single peak overload on physically short fatigue crack retardation in an axle-steel, Fatigue Fract. Engng. Mater. Struct., Vol. 19, No 2/3, 1996, pp. 201-206.