MECHANIKA TEORETYCZNA
I STOSOWANA
Journal of Theoretical
and Applied Mechanics
1, 32, 1994

FATIGUE CRACK PROPAGATION IN FLAT 18G2A AND St3SY STEEL WELDED SPECIMENS

Czesław Goss

Andrzej Likowski

Jan Leśniewski

Military Technical Academy, Warsaw

Sylwester Kłysz

Military Airforce Technical Institute, Warsaw

This paper confirms that at welded cyclic loaded specimens greater fatigue life is usualy met for those made of low strength steel rather than for those made of material revealing higher mechanical properties. Numerical investigation results also show a confirmation of this thesis, when tests are carried out on flat 18G2A and St3SY steel specimens butt welded single, overloaded every ΔN cycles and at $k_{ov} = 1.75$. The experimental results of those specimens have showed an approximately 80% higher fatigue life for St3SY steel.

1. Introduction

The fatigue crack growth retardation after overloadings affects in appreciable degree the fatigue life. The hitherto gathered investigation results of this problem allowed the determination of machine elements duty period in the presence of cracks under overloadings. To those working conditions one tries to adopt, despite of difficulties, the general lows ruling the crack mechanics. Determining the values describing the fatigue crack growth under overloadings we usualy assume considerable simplifications. So we take for example into account the same yield point before and after the overloading event, independent of the localisation of the crack front inside the plastic deformed zone, despite the hardening of material (Kocańda, 1978). Beside this, the hardening effects depend also on the kind of material used. Also the calculation formulas for crack propagation become inaccurate at high values of the overloading coefficient (Glinka, 1979). In some materials an inessential influence of a mean strain values and overloading coefficients has been stated (Sobczykiewicz and Rzeszot, 1980). On the other hand, in other materials, e.g 18G2A steel, in flat centre crack specimens the asymmetry cycle influence was found. Its increase was acompanied by the crack rate increase (Kocańda et al., 1976). In ductile steels, after the overloading event a transitional crack rate increment has been observed and afterwards a retarded crack propagation period, too. When the next overload event was applied before the crack reached the plastic deformed zone boundary a decrease in fatigue life was observed (Stephens, 1978). Experiments on aluminium alloys (Vardar and Vildrim, 1980), showed that the retardation becomes maximal when the next overload is periodicaly applied at a half of the fatigue cycle numbers adequate to the retarded crack growth after single overload test.

Basing on the aquired informations we can predict the retardation under further overloadings. The analysis is however limited to the cases, in which the ductile tearing during overload event can be neglected against this in the crack propagation between the overloads. In such a way one can predict the fatigue life for a given machine element as a base for renovation period determination in its maintenance.

2. Test conditions

Flat 18G2A and St3SY steel specimens were fatigue tested at an asymmetry coefficient equal to $R = 0.3$ (Fig.1).

The joints were welded in FUD (Handling Equipment Factory) after their welding technology. A copper pad with flux priming to get a oneside butt welded joint on steel sheet egdes without pretreatment, 8 mm thick at a distance of 4 mm between them was used. The following weld parameters were chosen – 500 A and 35 V, welding rate 0.33 m/min. The bare welding electrode of 4 mm in diameter was used

The tests were carried out on a servohydraulic fatigue test machine INSTRON equiped with an automatic control system. The test conditions were selected in such a way that the crack of the specimen took place within the range of low fatigue strength, i.e. $10^4 \div 5 \cdot 10^5$ cycles. It is the fatigue life of most heavy duty machine elements used under high cyclic loading stresses.

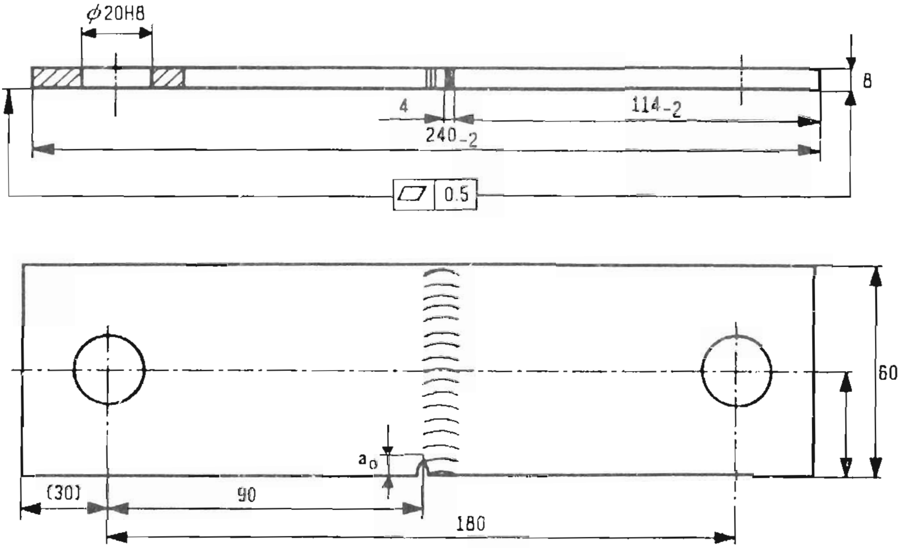


Fig. 1. Flat butwelded single edge cracked test specimen

The fatigue crack was initiated at the stress amplitude of 190 MPa and developed to some milimeters length from the bottom of the notch. The number of cycles to the end of initiation period was $20 \cdot 10^3 \div 40 \cdot 10^3$ cycles. The basic load was at the 160 MPa amplitude of tension stress. The overloading events took place at the overloading coefficient $k_{ov} = 1.75$ after every 10^4 cycles.

3. Test results and discussion

To show the parent and welded metal structures, the specimens were prepared in the cross-sections and etched in an ethyl nital solution. Macroscopic photographs of St3SY steel welded joint reveal a cristalisation welding zone contour (Fig.2).

Its sizeable width shows that a high line energy heat source was used. The direction of the longitudinal axis of the cristalities is peripendicular to the direction of the weld joint longitudinal axis. Dependent on the dihedral angle is the degree of removing the welded contaminations by the cristalisation area head during the material solidification process. The run of this process determines the degree of purity of the weld material and its mechanical properties (Hrivnak, 1989). It seems that the cross-section shape of the weld would be

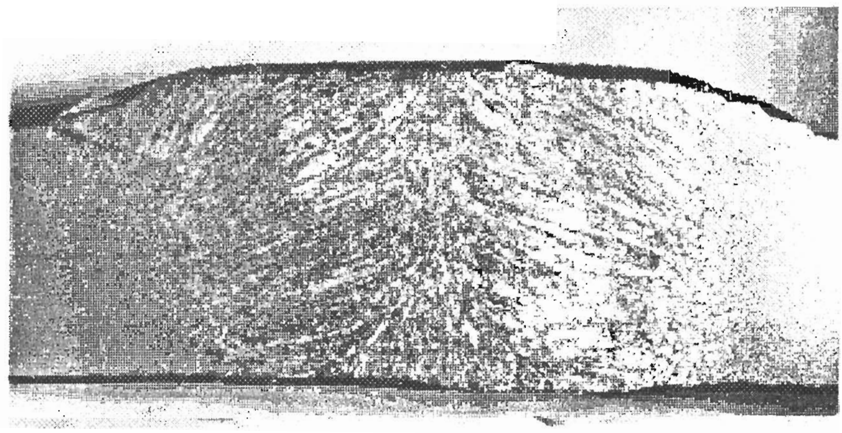


Fig. 2. Macrophotograph of St3SY steel welded joint

more suitable then the former one when additional coolers were used to form properly the weld face side.

Table 1. Single edge cracked unoverloaded (2KS, 1KS) and overloaded (2KSP, 1KSP) welded specimens fatigue test conditions and results

Steel	18G2A	18G2A	St3SY	St3SY
Specimen label	2KS	2KSP	1KS	1KSP
F_{min} [kN]	26	27	21	24
F_{max} [kN]	85	88	70	70
F_{ov} [kN]	-	154	-	125
t [mm]	8.20	7.80	7.95	7.90
a_0 [mm]	12.30	13.34	14.50	13.40
$a_{cr\ exp}$	49.10	32.30	49.20	33.40
$a_{cr\ cal}$	31.50	30.99	34.15	26.40
$2N_{f\ exp}$	152.706	290.000	301.102	530.000
$2N_{f\ cal}$	141.881	293.043	62.785	520.000

In Table 1 the fatigue tests results are presented, where:

F_{min} – minimal loading force

F_{max} – maximal loading force

$2N_f$ – halfcycle number to failure

t – specimen thickness

a_0 – initial crack length

$a_{cr\ exp}$ – experimental critical crack length
$a_{cr\ cal}$ – calculated critical crack length
$2N_{f\ exp}$ – experimental halfcycle number to failure.

In the numerical analysis the following FORMAN equation coefficients for 18G2A steel were accepted (Glinka, 1979)

$$C = 1.69 \cdot 10^{-6} \qquad m = 2.54 \qquad K_{IC} = 108.5\mathrm{MPa}\sqrt{\mathrm{m}}$$

and also the stress intensity factor in the form

$$K_I = \sigma\sqrt{\pi a}F_1(\alpha)$$

where

$$\alpha = \frac{a}{W}$$

$$F_1(\alpha) = 1.12 - 0.231\alpha + 10.55\alpha^2 - 21.72\alpha^3 + 30.39\alpha^4$$

In fatigue life estimation $2N_{f\ cal}$ the retardation Wheeler model was accepted. The values are gathered in Table 1.

For St3SY steel it was accepted accordingly

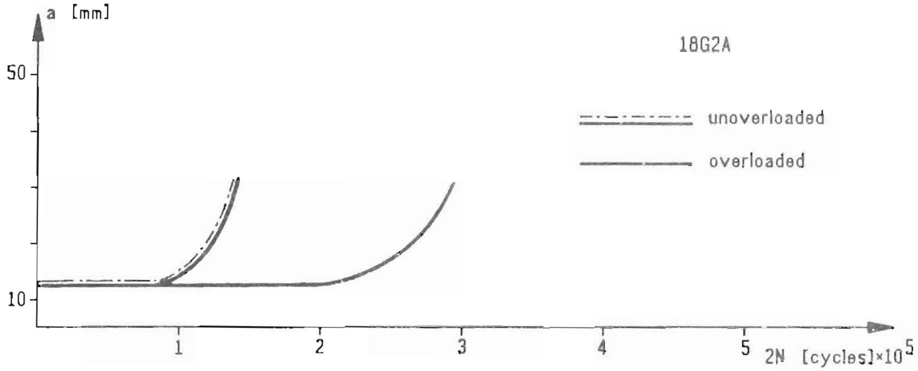
$$C = 2.35 \cdot 10^{-9} \qquad m = 3.3 \qquad K_{IC} = 40.9\mathrm{MPa}\sqrt{\mathrm{m}}$$

An acceptable correlation between the experiment and calculation results was achieved. A propagation alghoritm making easier the theoretical fatigue crack propagation model analysis, a cycle counting method and analytical crack propagation relations verification were elaborated (Klysz, 1991). Also the acceptable approximations of the used propagation equation coefficients determining the alghoritm have been achieved. In Fig.3 the relation $a = f(N)$ of single edge cracked welded 18G2A and St3SY steel specimens is presented.

The fatigue life of specimens depends also on the number of cycles between the overloading events. The greatest fatigue life has been achieved at a given overloading coefficient when the single tensile overload was applied before the fatigue crack reaches the cyclic ductile zone boundary.

In Fig.4 the relative fatigue life of specimens N_{rel} versus the number of cycles between the overloading events ΔN is presented. The relative fatigue life N_{rel} is the ratio of life at overload to life without overload at a constant amplitude.

As one can see from the figures, for a given overloading coefficient k_{ov}, as the cycle number between the overloads ΔN increases, a fatigue life increment



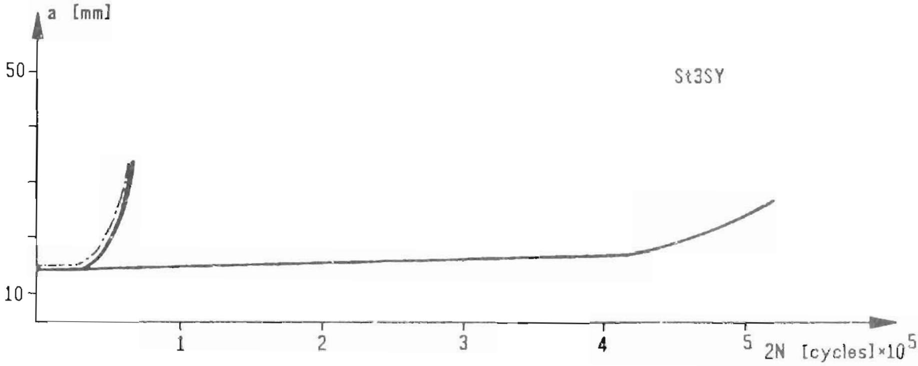


Fig. 3. Fatigue crack propagation theoretical analysis results of single egde crack 18G2A and St3SY steel specimens

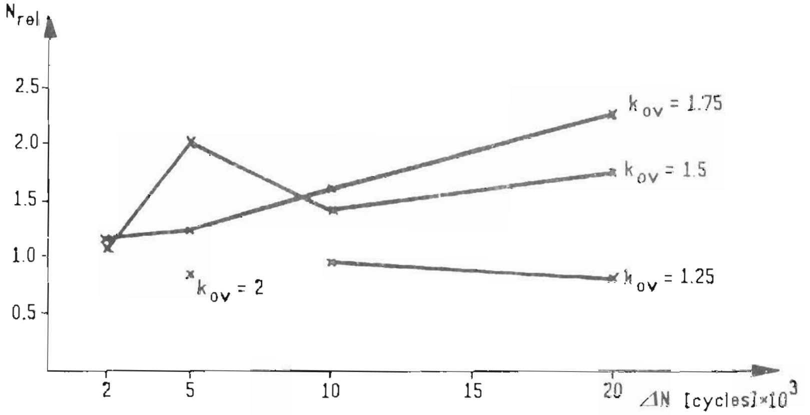


Fig. 4. The relative fatigue life N_{rel} versus cycle numbers between the overloading events for 18G2A steel single edge cracked specimens

takes place. This life reaches its maximum value as the ΔN becomes apposite to the location of the crack front at the cyclic plastified zone made during the previous overload event. One can expect that for greater ΔN a decrease in the fatigue life will be observed.

Fatigue life increase in the range before achieving its maximum value is an effect of the material "recovery" in essence beeing a change in line and point deffects, respectively, distribution and also their partial anihilation. The energy stored during the overloading event around the plastificied zone is a driving force of those processes. At greater overloading coefficients the energy stored in the material potentialy assures a longer "recovery" period and the maximum value of fatigue life is reached at greater ΔN values. For $k_{ov} = 1.5$ the fatigue life increases in the range of $\Delta N = 2000 \div 5000$ cycles, on the other hand in the range of $\Delta N = 5000 \div 20000$ cycles a decrease is seen. At $k_{ov} = 1.75$ in the range of $\Delta N = 2000 \div 20000$ cycles an fatigue life increase can also be seen. To determine the exact location of this maximum further experiment results are required.

The plots in Fig.4 are drawn for 18G2A steel specimens. The experimental results for 18G2A and St3SY steels are collected in Table 1, they were acquired at $\Delta N = 10000$ cycles. Evidently for St3SY steel this result was closer to its maximum life value then for 18G2A steel, for which a maximum has not been reached at $\Delta N = 20000$ cycles. Beside this, their hardening mechanism potentials are different and also changes of mechanical properties after plastic deformation are observed.

References

1. GLINKA G., 1979, *The fatigue cracks growth, in the presence of residual weld stresses, theoretical and experimental analysis,* Journal of Theoretical and Applied Mechanics, **17**, 4, Warsaw, 479-496
2. HRIVNAK J., 1989, *The metals and alloys welding ability theory,* Veda Bratislava (in slovak)
3. KŁYSZ S., 1991, *Modelling of fatigue crack propagation in stress concentration zone,* Doctor's dissertation (in Polish), WAT, Warsaw
4. KOCAŃDA S., 1978, *Fatigue failure of metals,* Sijthoff & Noordhoff International Publishers
5. KOCAŃDA S., LIKOWSKI A., SADOWSKI J., 1976, *About the possibility of reproducing the crack growth rate of higher strength 18G2A steels based on micrographic investigations,* VII Symposium of Experimental Tests in Solid Body Mechanics, PTMTS at al., Warsaw, 292-303

6. SOBCZYKIEWICZ W., RZESZOT J., 1980, *Fatigue crack growth rate in steels of advanced and high strength and their welded joints*, IX Symposium of Experimental Tests in Solid Body Mechanics, PTMTS at al., Warsaw, 321-324

7. STEPHENS R.I., 1978, *The overloading effect on fatigue crack growth*, Journal of Theoretical and Applied Mechanics, **16**, 2, Warsaw, 123-150

8. VARDAR O., VILDIRIM N., 1980, *Crack growth retardation due to intermittent overloads*, Int.J.Fract., 12, 283-287

Rozwój pęknięć zmęczeniowych w płaskich próbkach spawanych ze stali 18G2A i St3SY

Streszczenie

Uzyskano potwierdzenie tezy, że przy obciążeniach cyklicznych połączeń spawanych większą trwałość wykazują połączenia wykonane ze stali o niższych własnościach wytrzymałościowych niż podobne ze stali o podwyższonej wytrzymałości. Badania numeryczne, potwierdzające tę tezę przeprowadzono dla próbekpłaskich wykonanych ze stali 18G2A i St3SY ze spoiną czołową przeciążanych jednokrotnie co ΔN cykli, przy $k_{ov} = 1.75$. Wyniki badań doświadczalnych próbek tego typu wykazały o około 80% wyższą trwałość zmęczeniową dla stali St3SY.

Manuscript received October 1, 1993; accepted for print October 14, 1993