MILITARY TECHNICAL COLLEGE

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# BEHAVIOUR OF FATIGUE CRACK PROPAGATION IN Cr - V SPUR GEAR MODEL .

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## ABSTRACT

*On single edge bend (SEB) specimens and spur gear models the fatigue crack propagtion rate at very low stress intnsity factor (SIF) was measured . The SIF for spur gear model was obtained by compliance measurements. The following expression which involves the threshold value of SIF was used to analyse the results .*

$$\frac{da}{dN} = A\left[\left\{\frac{K_a}{(1-R)^{\gamma}}\right\}^{\beta} - \left\{\frac{K_{at}}{(1-R)^{\gamma}}\right\}^{\beta}\right]$$

*The present results beside it adds to the experimental evidence supporting the independence of growth rate on geometry of tested body, it extends the conclusion to cover the uninvistigated region at very low SIF .*


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*INTRODUCTION*

*In the last decade a great effort has been devoted to the study of the fatigue crack propagation rate (FCPR) because this stage of the fatigue process represents a considerable part of the fatigue life of most engineering designs. The most progressive approach to this problem proved to be the fracture mechanics. On the basis of the fracture mechanics concepts both quantitative descriptions and models of crack propagation were developed (1-4) . It was shown that FCPR can be expressed as a simple power function of the stress intensity factor (SIF) in the range of medium rates. However, the valuable results of this enormous amount of effort have not been fully applied to the practical engineering problems due to their limitations for laboratory specimens .*

*Only a few papers deal with the practical applications of the quoted findings(1,5-7) Moreover, the articles were limited to the range of FCPR from $10^{-8}$ to $10^{-4}$ m/ cycle . The present state of art shows that no measurement was performed, which would prove the independence of growth rate vs. SIF, (V-K) curve of the loading conditons and structure geometry in the region of very low rates and threshold values of the SIF. Such investigations are required due to their importance from the practical point of view.*

*The submitted work beside it adds to the experimental evidence supporting the independence of growth rate on structure geometry or loading conditions, it extends the conclusion to cover the un-investigated region at very low rates and threshold values .*

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*The main goal of the work is to compare the fatigue crack propagation behaviour in Cr-V alloy steel specimens and in spur gear model teeth by analyzing the experimental data with a crack propagation expression that enables measuremets at very low SIF.*

*MATERIAL*

*Single edge bend (SEB) specimens and spur gear models were machined from Cr-V steel (CSN 15241) with carbon content 0,42 wt% ; Cr 1,87 wt% ; V 0,24 wt% and Ni 0,13 wt % .*

*Specimens and gear models were austenized at 840°c, quenched in oil and tempered at 550°c for 4hrs. The values of tensile strength* $\sigma_{ut}$ = *14360 Kp* $cm^{-2}$ *(1409*$MNm^{-2}$*) and yield stress* $\sigma_{0,2}$ = *12380 Kp* $cm^{-2}$ *(1214 MNm-2) were determined on a Zwick testing machine .*

*Edge notch was introduced in the loaded side of both specimens and gear teeth to locate and facilitate crack initiation. Specimens and gear model dimension are shown in Fig. 1 .*

*EXPERIMENTAL PROCEDURES*

*The scheme shown in Fig. 2 illustrates in a simple way the different procedures followed till reaching the final results . Tests were conducted at normal laboratory atmosphere and at room temperature . Fatigue tests were performed on the 2t-Amsler Pulsator (3-pointbending specimens) and on the Edy 2 machine (gear teeth). The crack starter notch was extended to fatigue crack by cycling the specimens (or a tooth of the gear model ) at high amplitude stress. Then the amplitude stress was reduced to a predetermined value for crack propagation.*

*The effect of remaining stresses resulting f m crack initiation and stress reduction were minimized by allowing a 0,001m crack extension between stress reductions to have the crack past the maximum plain strain plastic zone for the preceding stress conditons. Crack propagation was followed from both sides by two travelling light microscopes of magnification X 15 . A special arrangement was used in case of the gear model to enable measurements of a characteristic curved cracks at gear tooth root. The values of crack lengths were taken as the arithmatic means of readings on both faces of specimen ( or gear tooth ) . The experimental data were collected from 19 specimens and 13 gear teeth .*

*The K-calibration of the gear teeth was performed by compliance measurements (8). Deflection measurements were done staticlay . From direct measurements of load-deflection diagrams , the compliance was calculated for different crack lengths. Each crack was cyclicly extended by a small increment between each pair of consecutive deflection measurements .*

## RESULTS

*The data obtained from fatigue tests were converted to the form of SIF amplitude "$K_a$" vs CPR "da/dN". Results are plotted in Fig. 3 on log-log scale.*

*The following expression of crack propagation rate (4) was used to analyse the results ;*

$$\frac{da}{dN} = A\left[\left\{\frac{k_a{}^{\beta}}{(1-R)^{\gamma}}\right\} - \left\{\frac{k_{at}{}^{\beta}}{(1-R)^{\gamma}}\right\}\right] \qquad (1)$$

*Where : A and $\beta$ are material constants, R is the stress ratio, $\gamma$ is an exponent and $K_{at}$ is the threshold amplitude of SIF.*

*The values of $K_{at}$ were obtained by sudden decrease of the stress amplitudes to lower values and the specimens were cycled again, if no propagation of the crack was not observed in about $1,5 \times 10^6$ cycles, the stress amplitude was increased step by step ( each step 10% more , and lasts about $1,5 \times 10^6$ cycles) until crack propagation occur .*

*The lowest value of $K_{at}$ , which is denoted as the basic threshold SIF amplitued $K_{atb}$ (3) is achieved when $K_a = K_{at}$ .*

*The values of $K_{atb}$ were obtained by extrapolating the experimental data obtained from that test. The dependence of $K_{at}$ on $K_a$ is shown in Fig. 4, also is given the corresponding values of $K_{atb}$ .*

*The dependence of $K_{at}$ on $K_a$ was found to be expressed as*

$$\log K_{at} = \log K_{atb} + \log K_a \log\left(\frac{Ka}{K_{atb}}\right)^{c_2} \qquad (2)$$

*where, for specimens $K_{atb} = 300$ kp cm $^{-3/2}$ (2940 MN m $^{-3/2}$ and $c_2 = 0,18$ while for the spur gear model $K_{atb} = 210$ kp cm $^{-3/2}$ (2058 MNm $^{-3/2}$) and $c_2 = 0,22$ .*

*Moreover, the experinemtal results show that the material is insensitive to the effect of mean stress, hence $\gamma = 0$ .*

*By least squares analysis, the experimental data were fitted by Eq. (1) the solid lines in Fig 3 are the computed ones. The material constants A and $\beta$ were computed, then for the specimens it holds :*

$$\frac{da}{dN} = 7,9 \times 10^{-14} \left[ K_a^{2,55} - K_{at}^{2,55} \right] \qquad (3)$$

while for the gear teeth it is valid that

$$da = 2,22 \ 10^{-14} \left[ K_a^{2,86} - K_{at}^{2,86} \right] \quad (4)$$

DISCUSSIONS

For the purpose of comparing FCPR in spur gears and single edge bending specimens the expression (1) was chosen among other various equations corelating CPR with the SIF. This expression satisfies the prerequisit that it should be applied to cover crack growth at very low rates ($10^{-7}$ up to $10^{-6}$ cm/cycle) . Such a prerequisit limits the selection among very few published expressions [6,9] . The shortcoming of the expressions [6,9] is the independence of $K_{at}$ on the immediate value of $K_a$ [3]. Moreover, beside the expression (1) satisfies the prerequisit put forward, the material constants $A, \beta, \gamma, \alpha$, and $K_{atb}$ could be obtained by simple experimentation and with very few number of specimens .

All the experimental resuts presented in Figs. 3 and 5 have shown that CPR in Cr-V steel specimens was insensitive to the effect of stress ratio change. This suggests that the exponent in Eq. (1) - within the limits of experimental accuracy - equals to zero. It means that the mean stress has no effect either at high CPR ($10^{-6}$ m/cycle) or at very low rates ($10^{-9}$ m/ cycle ) in Cr-V steel .

The exponent was found to have the values from 0,53 to 0,95 for different steels [10] The value of $\gamma = 0$ is in disagreement with any value obtained before. More than one consideration introduces itself to account for this behaviour .

a) Any obtained value of $\gamma$ is influenced by the limit of threshold detectibility [10] and this may partially explains the large variation of $\gamma$ among different steels .

b) The range of investigated values did not cover most of the steels especially if it is considered its dependence on the microstructures [10] .

c) The possible similarity between notch sensitivity ,q, which is a material property of values from zero to unity , and the exponent describing the effect of mean stress (CPR) -$\gamma$ may be termed as mean stress sensitivity .

However, the experimental results of $\gamma = 0$ for Cr-V steel might be accepted, and more investigations are required to explain the wide variation of $\gamma$ for various materials . Results obtained from the threshold tests supports the evidence that $K_{at}$ depends on the preceding value of $K_a$ [3]. Furthermore, the function representing this dependence should be monotonically increasing in $K_a$ .
Fig. 5 shows slight difference in results exists at very high and very slow SIF amplitudes. The main argument of this behaviour is the different deformation modes in specimens and gear teeth. While in specimens it is purely mode-I , it is suspected to be a combined mode I and II in case of gear teeth that is changed to mode I during propagation of the crack . Also is must be taken into consideration the difference in accuracy and range of validity of the used K-calibrations.

The further two constants A and $\beta$ were computed from the least squares fitting of experimental points, it was found that the values of the constants are not consistent. However, the combined effect of A and $\beta$ on the growth rates, and it could be confirmed -within limits of engineering accuracy - that they lead to similar values of growth rates independent whether they were obtained from tests conducted with spur gear model or SEB specimens.

Nevertheless, Fig. 3 indicates that the CPR in gear model is slightyly higher than that in specimens. This is argued to be due to the different crack tip deforamtion modes. However, the results would be improved if one follows the suggession [11] that CPR in case of combined Mode I and II could be obtained from that of Mode - I increasing the later by 10 to 20 percent .

From the comparison of results in Fig.3, it emerges that fatigue growth data obtained from tests conducted with SEB specimens may be used with a certain degree of accuracy to predict fatigue behaviour of spur gear cracked teeth .

## CONCLUSIONS

The most significant conclusion is that the present results beside it adds to the experimental evidence supporting the independence of growth rate on geometry of tested body , it extends the conclusion to cover the uninvestigated region at very low $K_a$ . This allows one to draw a single important conclusion that the (V-K) curve is rather a material property which does not depend either on type of loading or body configuration . This conclusion can be utilized for the prediction of fatigue life of cracked bodies .

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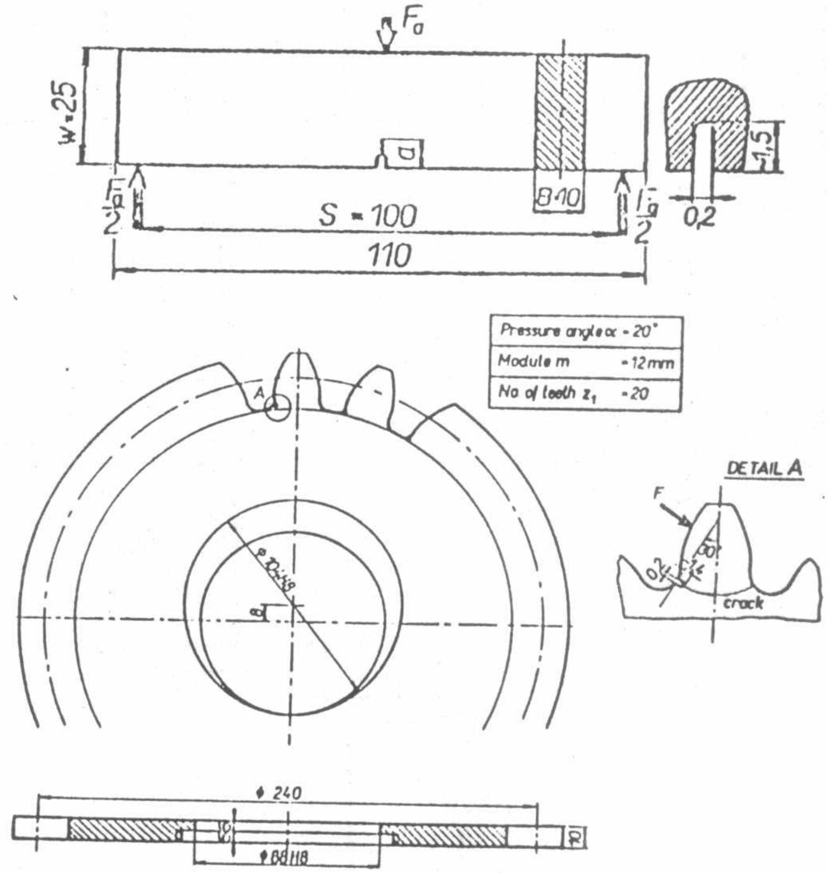



Fig.1 - Specimen and spur gear model dimensions

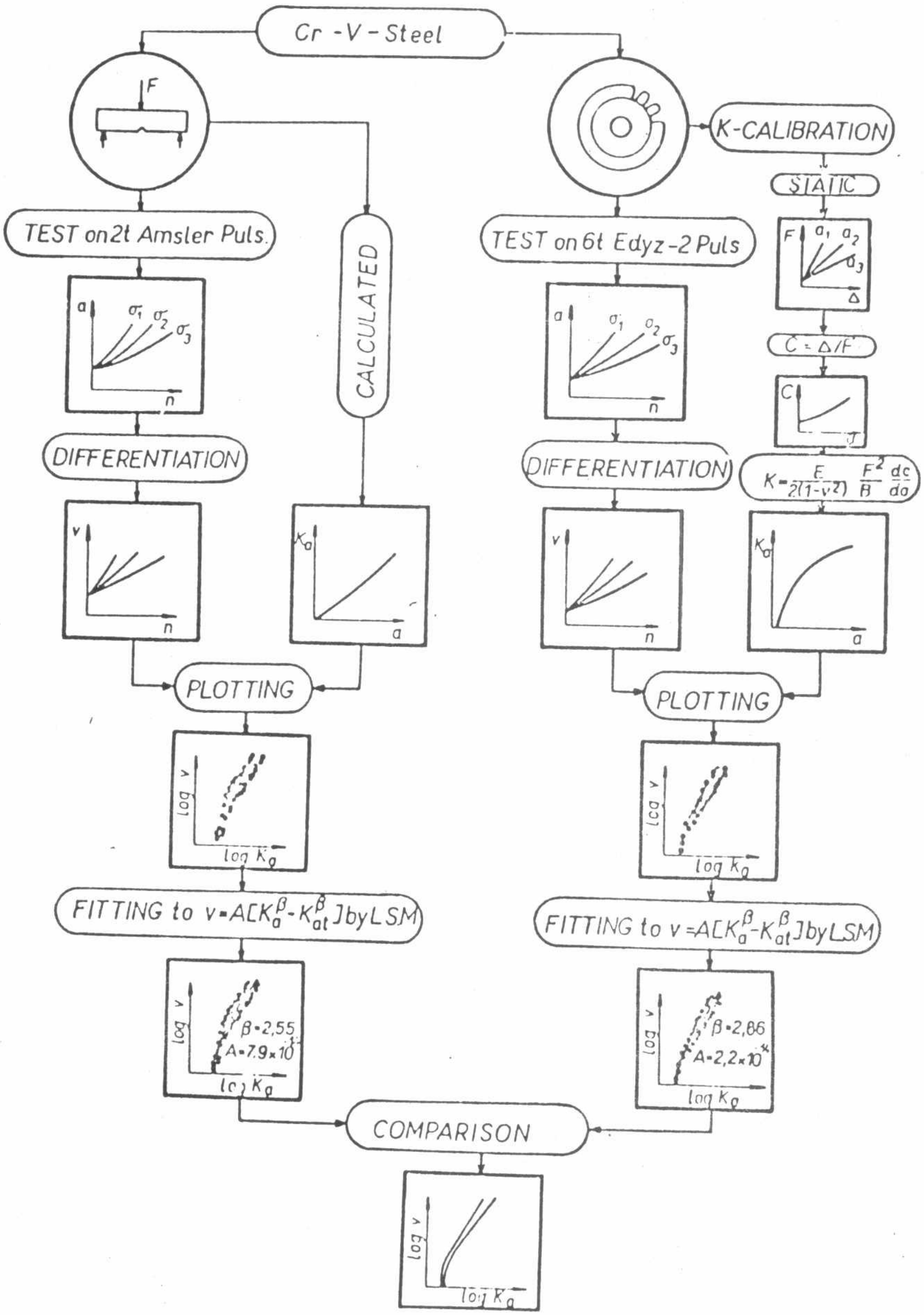
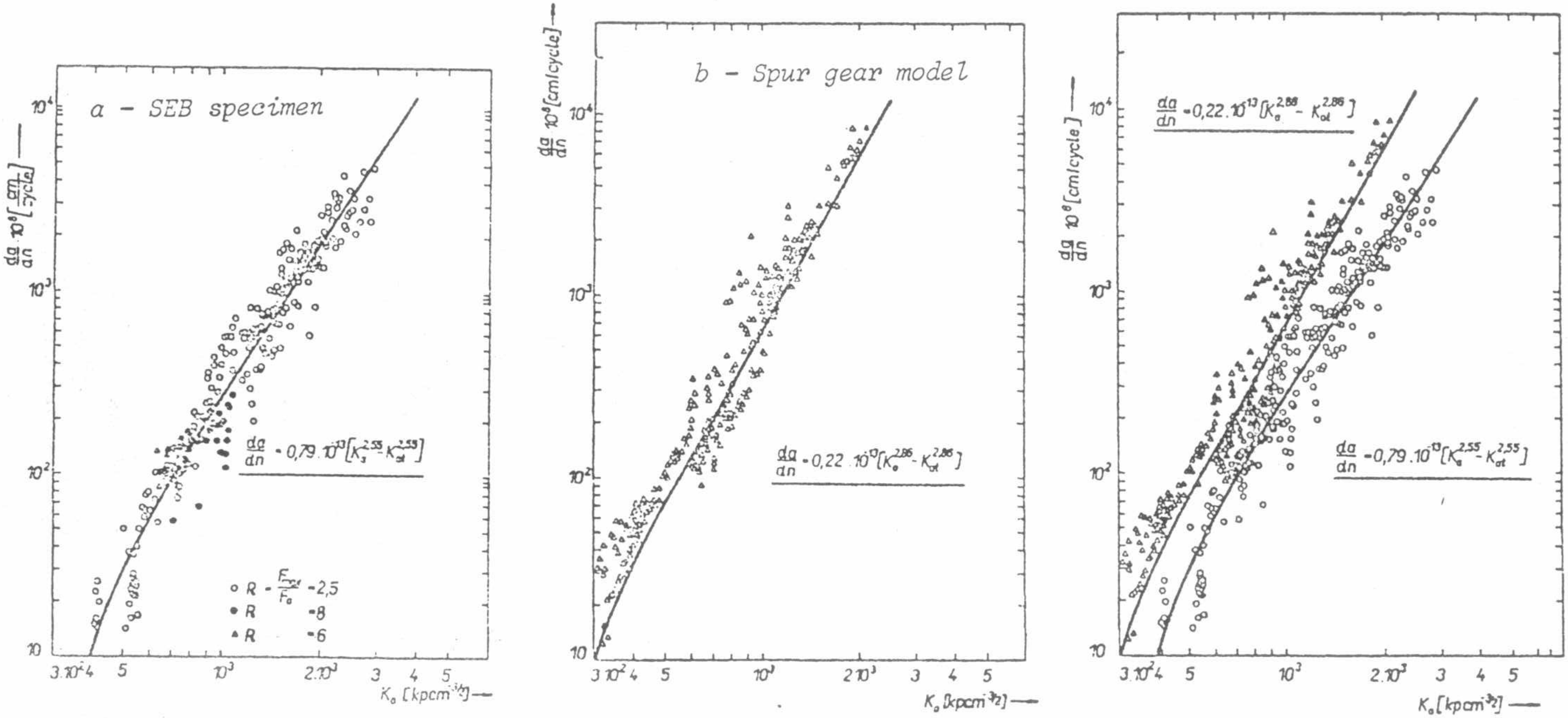



Fig. 2:Scheme of experimental procedure.




c - Ccmparison of CPR in specimen with spur gear model.

Fig. 3 Crack propagation rate vs stress intensity factor amplitude .

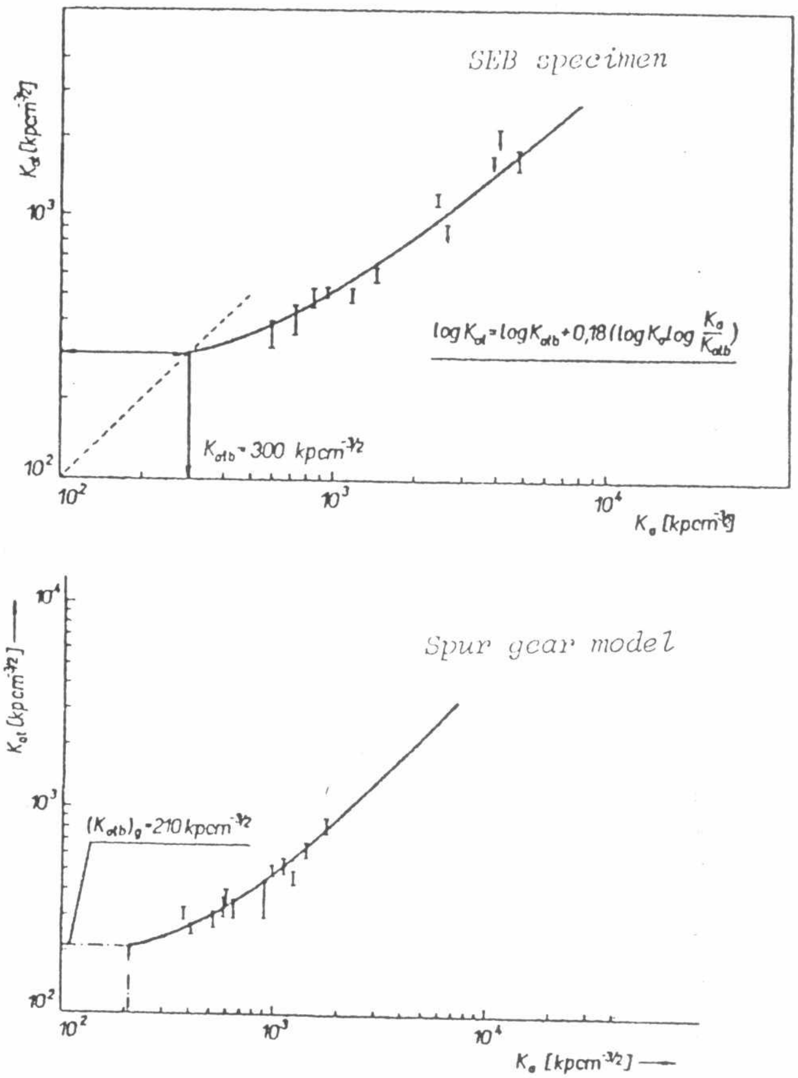



*Fig. 4 Dependence of $K_{at}$ on $K_a$ for Cr - steel (SEB specimens and spur gear model ) .*

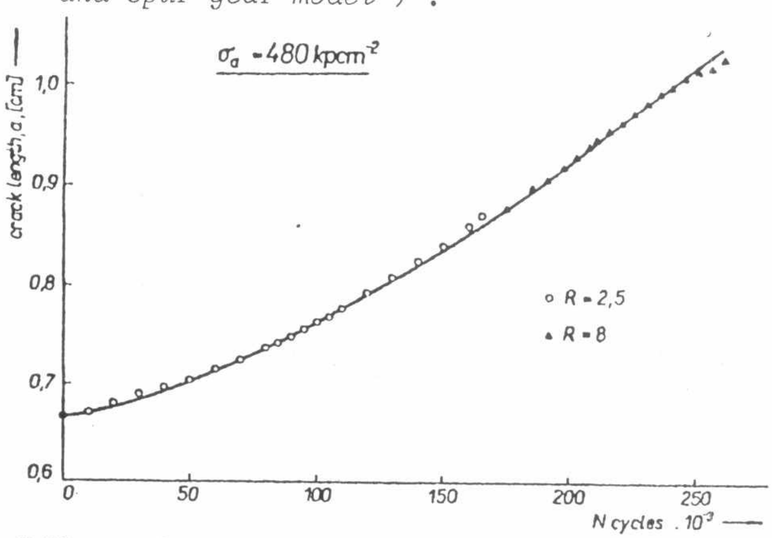



*Fig. 5 Effect of stress ratio jump on propagation rate in Cr-V steel specimen.*