



BEHAVIOUR OF ALUMINIUM-MAGNESIUM ALLOY
UNDER ROTATING BENDING FATIGUE TESTS

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ABSTRACT

Behaviour of materials under repeated application of loads of varying magnitude is an important problem in design aspect. Most structures and machine parts "which are made of aluminium-magnesium alloy" are subjected to more or less random fluctuations of loads. Therefore, the main purpose of this work is to obtain data which can be used as a guide for predicting the behaviour of aluminium-magnesium alloy in service.

Presented here are the results of endurance fatigue tests for the material. The specimens have been subjected to rotating bending stress, and also the staircase testing procedure was followed to determine the endurance strength of the material.

Two-step tests for cumulative fatigue damage were conducted to the material. A comparison between the experimental results with the cumulative fatigue damage rules is made. An agreement for the iso-damage rule with the experimental results.

The experimental results indicated that the amount of damage is more than unity for low-high sequences and less than unity for high-low sequences with the same different of magnitude of damage than unity.

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INTRODUCTION

The linear damage rule proposed by Miner [1] is widely used for its simplicity, but it does not reflect the true behaviour of the material "especially" in multilevel loading. The linear damage rule is :

$$\sum \frac{n_i}{N_i} = 1 \quad (1)$$

where :

n_i = number of cycles run at stress level S_i .
 N_i = " " " " to failure at stress level S_i .

Many experiments on cumulative fatigue damage have been carried out by Roylance [2], Schijve and Jacobs [3] to determine the effect of fluctuations in stress amplitude on fatigue life. The results have usually been compared with the linear damage rule. Gásner [4] carried out many program tests on aircraft structure and real vehicle components, claimed that the results agree with life in service. But the results of program tests in fluctuating tension are quite different from those in rotating bending for plain specimens. Therefore, the results on aluminium alloy are not in quite agreement.

Moreover, the cumulative damage rule based on the knee-point of the S-N curve is first suggested by Subramanyan [5] and confirmed by Kenawy [6, 7 and 8] with program tests on steel and aluminium. The concept is assumed that all the isodamage lines converge at the knee-point of the S-log N curve.

In this work, a program tests were applied on aluminium-magnesium alloy and the results compared with the other rules suggested by Wilkins [9], Henry [10] and Manson and others [11].

EXPERIMENTAL INVESTIGATION

The material used has the following chemical composition :

Si : 0,5 % ; Fe : 0,4 % ; Ti : 0,2 % ; Cu : 0,05 % ; Zn : 0,2 % ;
 Mg : 4,3 - 5,5 % and Al : remainder .

About 16 standard test specimens were prepared to determine the mechanical properties of the material, which give the following data :

- Ultimate tensile strength	$S_u = 270$ MPa.
- Yield strength	$S_y = 150$ MPa.
- Brinell Hardness Number	BHN = 70

The endurance life of the material is determined at five stress levels to obtain the basic S-N curve. The stress levels are 180, 160, 140, 130 and 120 MPa. respectively. Using about 15 test specimens for each stress level. The probability of failure with number of cycles to failure curves for every stress level are shown in Fig. 1. The S-logN curve for probability P_f of failure of 50 % is shown in Fig. 2 .

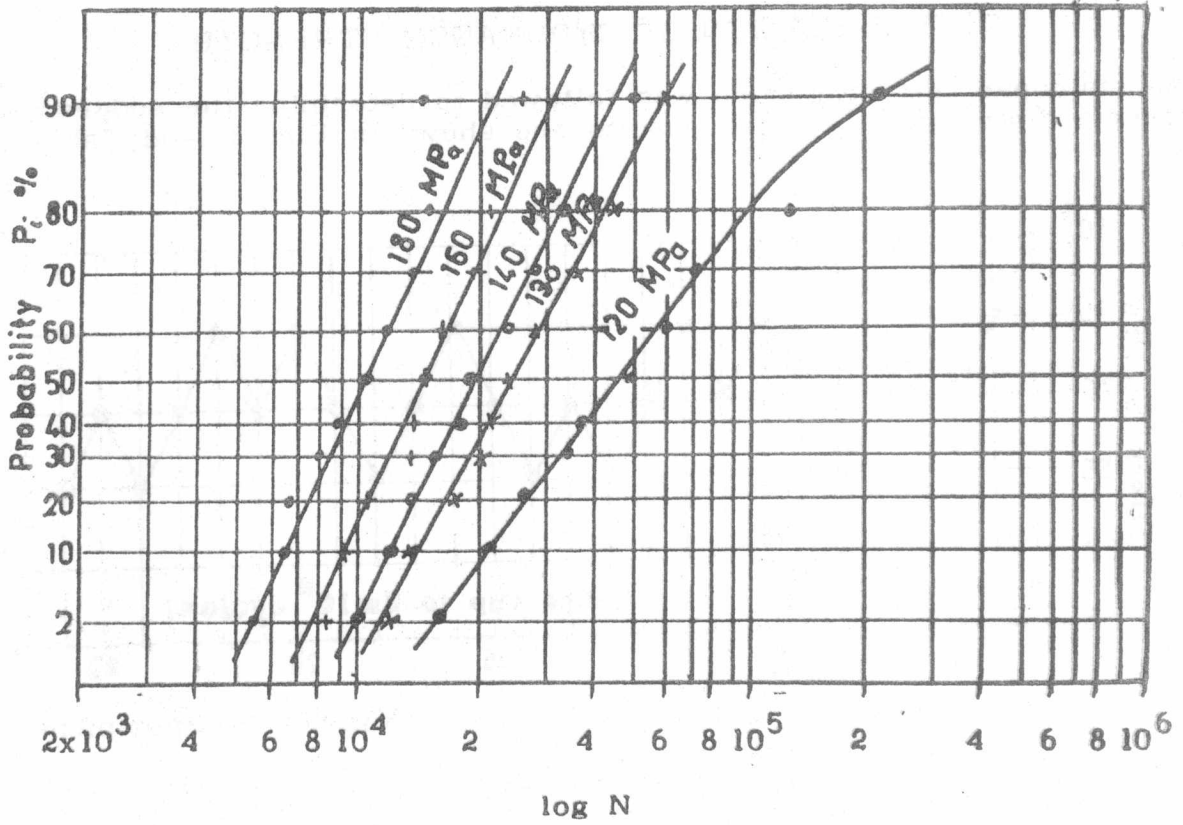


Fig. 1, P - S - log N curves.

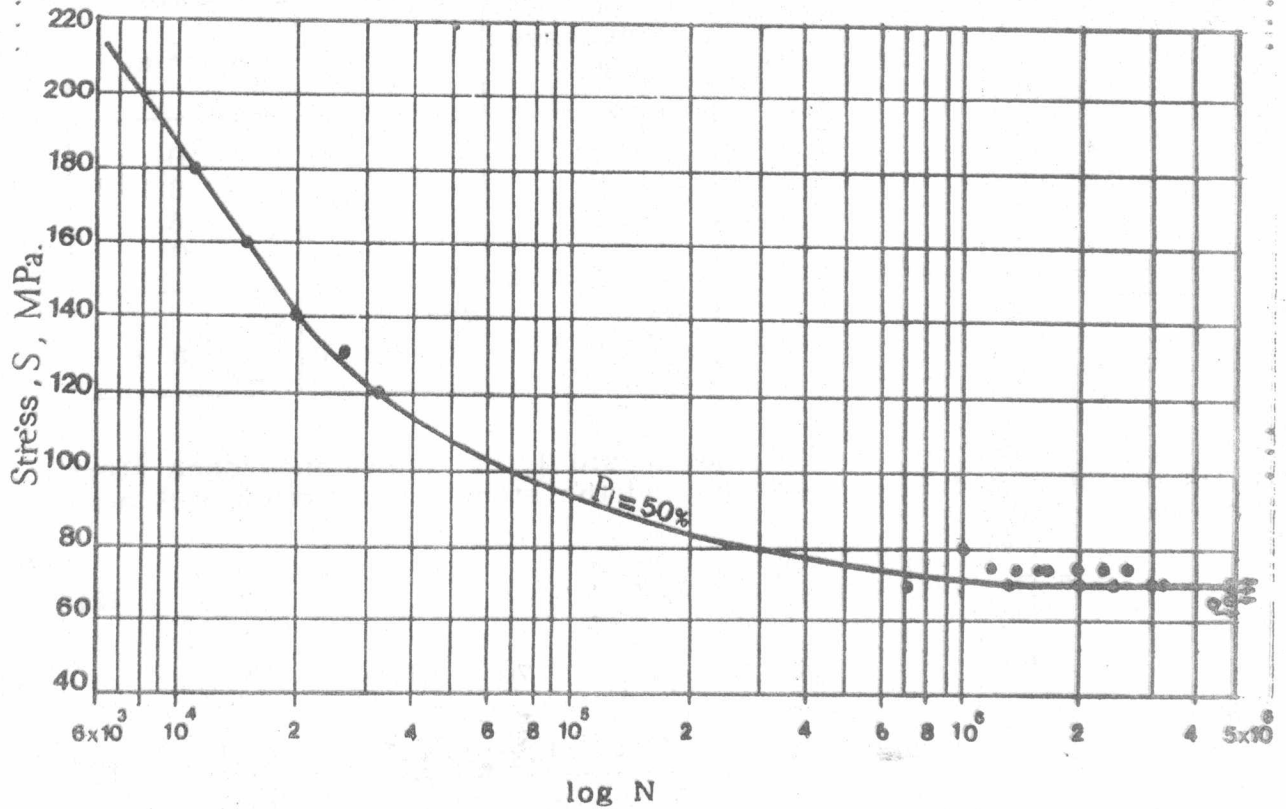


Fig. 2, S - log N curves.

DETERMINATION OF ENDURANCE STRENGTH

The staircase test procedure was followed to determine the endurance strength distribution, and its results are shown in Fig. 3, and Table 1.

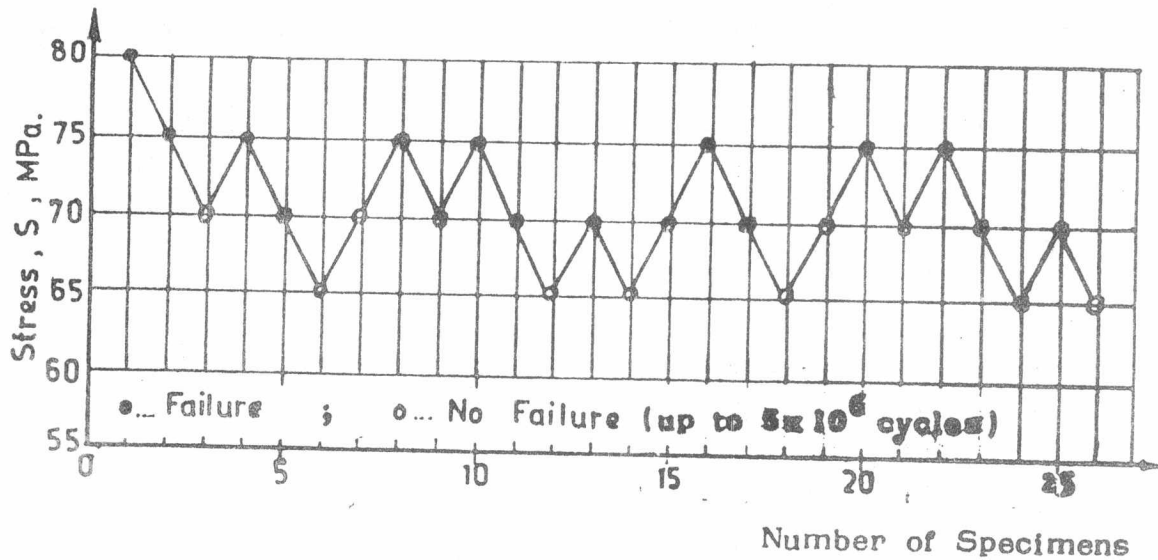


Fig. 3, Staircase Test.

Table 1, Staircase Test Results

Stress MPa.	i	Specimens Failed	Successes n_i	$i n_i$	$i^2 n_i$
80	3	1	0	0	0
75	2	7	0	0	0
70	1	6	6	6	6
65	0	0	6	0	0
Σ		14	$\Sigma n_i = 12$	$\Sigma i n_i = 6$	$\Sigma i^2 n_i = 6$

By using the data from Fig. 3, and Table 1, the mean endurance strength S_e is calculated from equ. (2) and the standard deviation ΔS also from equ. (3) as follow :

$$S_e = S_0 + d \left[\frac{\sum i n_i}{\sum n_i} + \frac{1}{2} \right] \quad (2)$$

$$= 65 + 5 \left[\frac{6}{12} + \frac{1}{2} \right] = 70 \text{ MPa.}$$

and

$$\Delta S = 1,62 d \left[\frac{\sum n_i \sum i^2 n_i - (\sum i n_i)^2}{(\sum n_i)^2} + 0,029 \right] \quad (3)$$

$$\Delta S = 1,62 \times 5 \left[\frac{12 \times 6 - (6)^2}{(12)^2} + 0,029 \right] = 2,26 \text{ MPa.}$$

CUMULATIVE FATIGUE DAMAGE TESTS

Two-step tests were applied on the specimens by using three stress levels with symbols A, B and C, have the following data :

level A :	$S_a = 180 \text{ MPa.}$;	$N_a = 10500 \text{ cycle.}$
level B :	$S_b = 160 \text{ MPa.}$;	$N_b = 14000 \text{ cycle.}$
level C :	$S_c = 140 \text{ MPa.}$;	$N_c = 20000 \text{ cycle.}$

The experiments conducted according to the schedule given in Table 2, using five specimens for each stress sequence and for prestress cycle ratio β_1 .

Table 2.

Level sequence	Prestress level S_1 , MPa.	Second stress level, S_2 , MPa.	Initial cycle ratio β_1
A → B	180	160	0,2 ; 0,4 ; 0,6 and 0,8
A → C	180	140	" " " " "
B → C	160	140	" " " " "
B → A	160	180	" " " " "
C → B	140	160	" " " " "
C → A	140	180	" " " " "

The cumulative fatigue damage models for different sequences of two step tests are designated in Fig. 4.

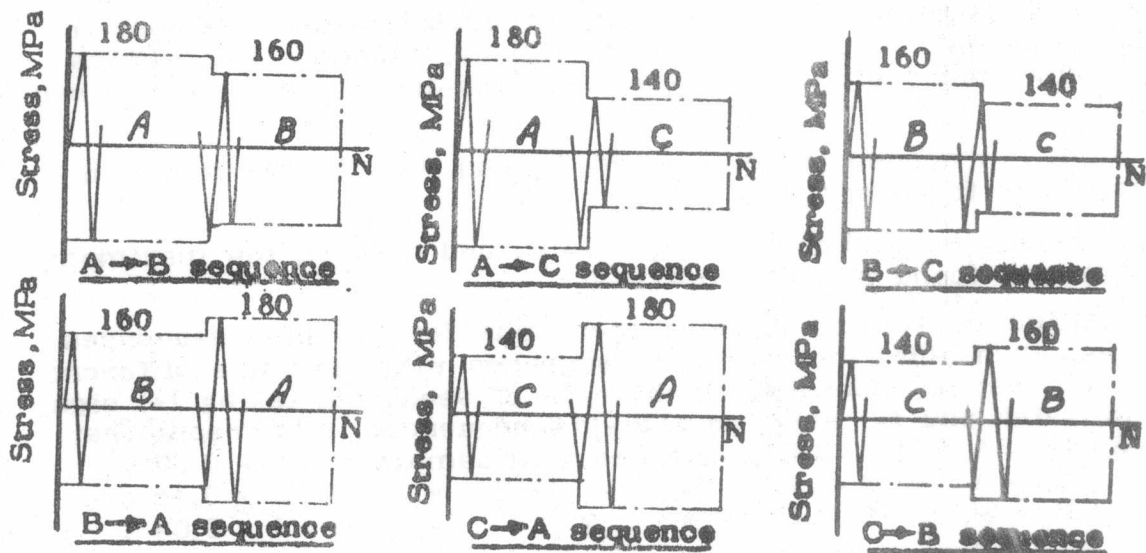


Fig. 4, Cumulative Damage Models.



ANALYSIS AND DISCUSSION OF RESULTS

A full investigation of different sequences for two-step tests is observed in Fig. 4, through the three stress levels A, B and C, either for high-low or for low-high sequences. A comparison in cycle ratio to failure are given in Fig. 5, between the experimental results and the rules proposed by Subramanyan, Henry, Manson, Wilkins and Miner, which showed clearly that the agreement of Subramanyan's rule with the experimental results is more than the other rules.

Fig. 6, shows a comparison between the experimental results and the same cumulative damage rules about the fatigue damage accumulation, which observed also the agreement of the isodamage rule with the experimental results than the other rules.

It can be noted (from Fig. 6) that the experimental results and Subramanyan's rule give minimum damage for high-low sequences ($A \rightarrow B$, $A \rightarrow C$ and $B \rightarrow C$) at initial cycle ratio β_1 about 0,3. But the minimum damage for Henry's rule and Wilkins's rule are found at $\beta_1 = 0,5$ with different in magnitude of the amount of damage. While Manson's rule indicates that the minimum damage occurs at $\beta_1 = 0,6$.

For low-high sequences ($C \rightarrow B$, $C \rightarrow A$ and $B \rightarrow A$), the maximum damage is found at $\beta_1 = 0,4$ for both the experimental results and Subramanyan's rule. While it is occurred at cycle ratio $\beta_1 = 0,5$ for both Henry's rule and Wilkins's rule. At the same time, the maximum damage is obtained at $\beta_1 = 0,6$ for Manson's rule, with difference in magnitude of the damage accumulation.

CONCLUSIONS

- 1- All the experiments indicate clearly the agreement of Subramanyan's rule which gives a close results to the experiments. Whereas the other rules that proposed by Miner, Henry, Manson, and Wilkins, have shown some deviations either for high-low or for low-high sequences.
- 2- For high-low sequences ($A \rightarrow B$, $B \rightarrow C$, and $A \rightarrow C$), the minimum damage was found at $\beta_1 = 0,3$.
- 3- For low-high sequences ($B \rightarrow A$, $C \rightarrow B$, and $C \rightarrow A$), the maximum damage was found at $\beta_1 = 0,4$.
- 4- The amount of damage is more than unity for low-high sequences and less than unity for high-low sequences with the same different ($\pm \Delta D$), that is depending on the type of sequence, taking (+) sign for low-high and (-) sign for high-low sequences, this means that :
 - a) For $B \rightarrow A$ and $A \rightarrow B$ sequences, the damage $D = 1 \pm 0,075$.
 - b) " $C \rightarrow A$ " $A \rightarrow C$ " " " " $D = 1 \pm 0,16$.
 - c) " $C \rightarrow B$ " $B \rightarrow C$ " " " " $D = 1 \pm 0,09$.
- 5- Wilkins's rule give the same trend and values for different sequences either for high-low or for low-high.
- 6- Manson's rule give results near to unity as that of Miner's rule.

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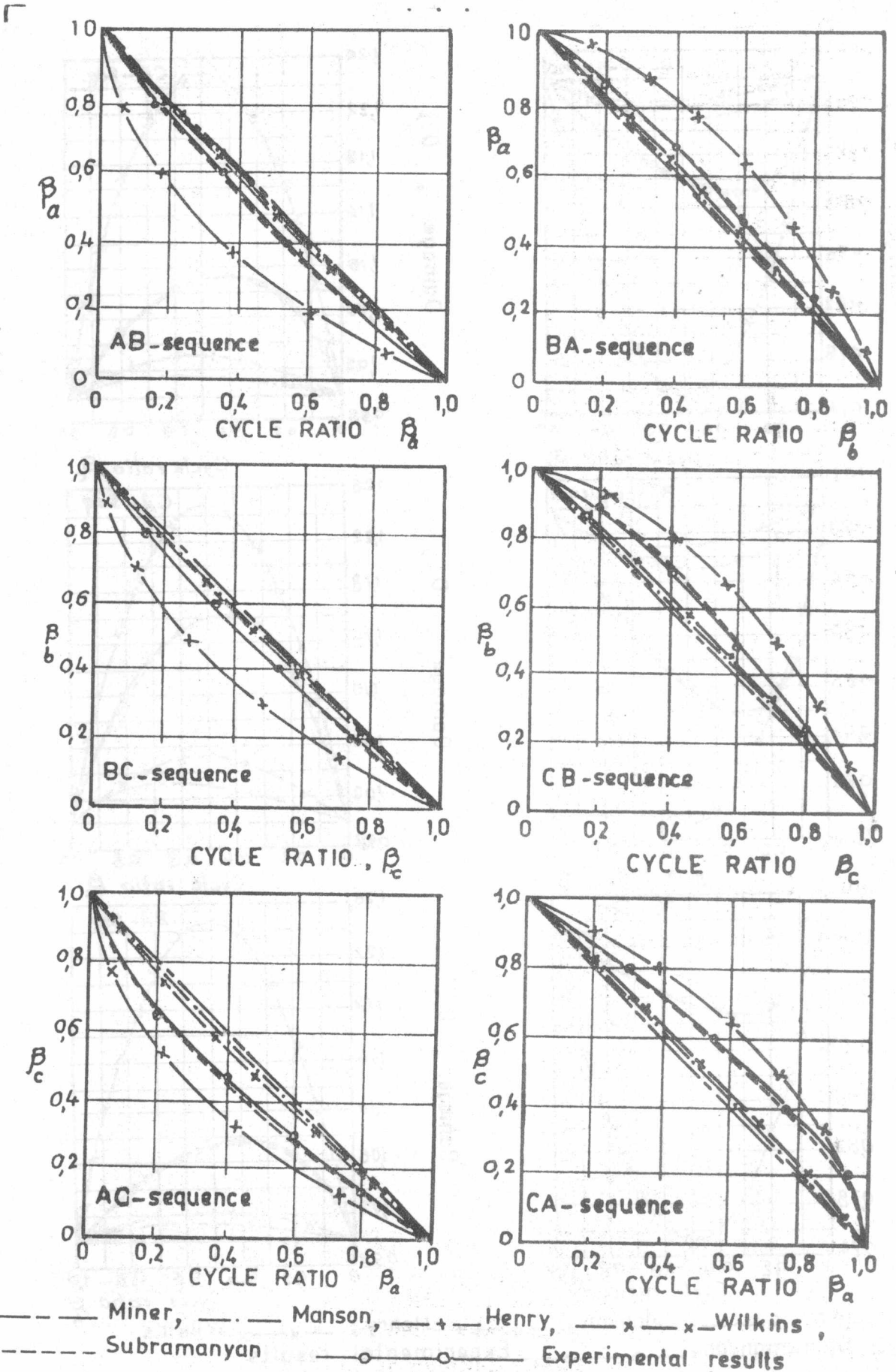


Fig. 5, Comparison between cycle ratio to failure in two-step tests.

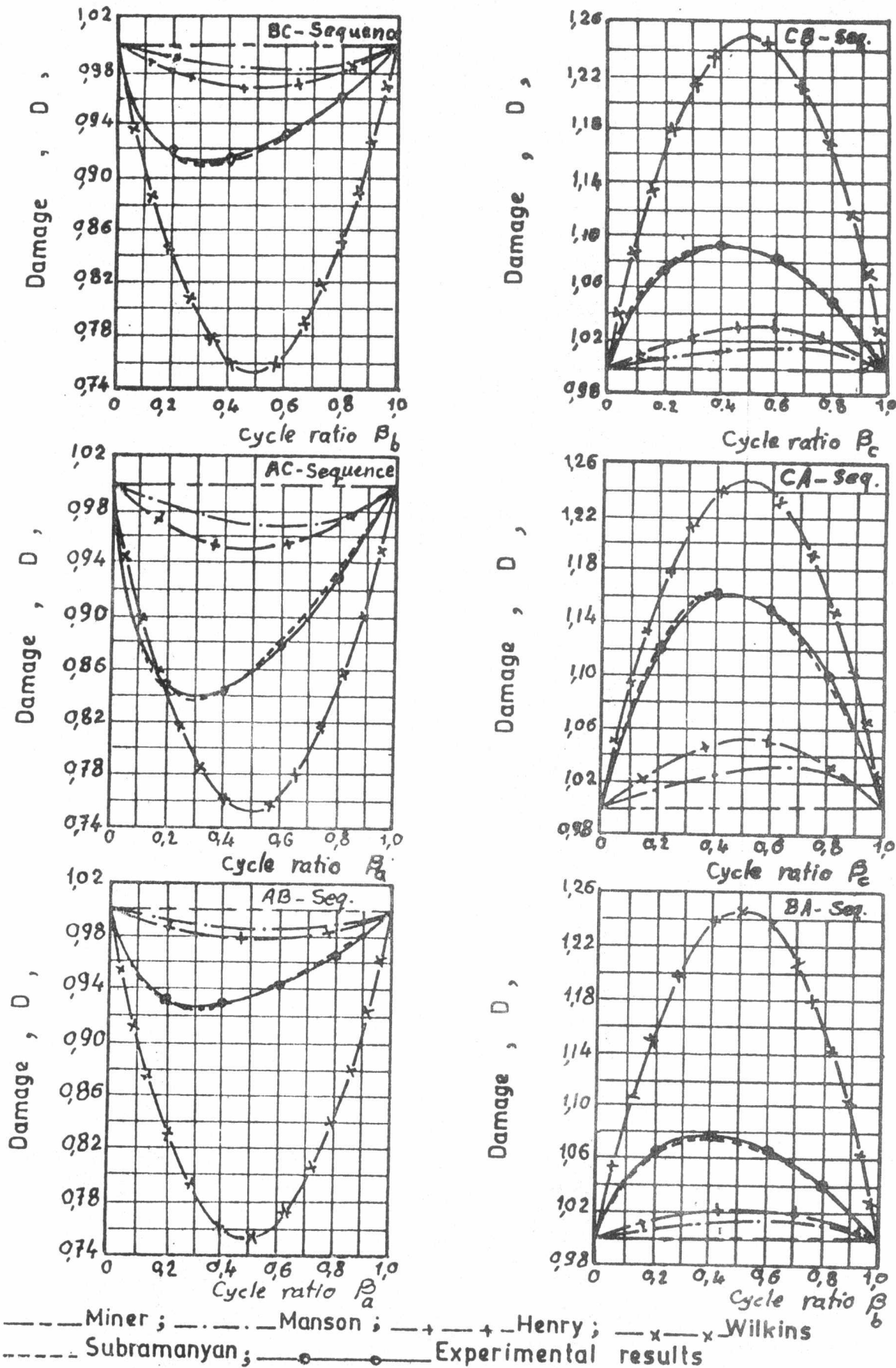


Fig. 6, Comparison between fatigue damage accumulation in two-step tests,



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NOMENCLATURE

- D = amount of damage . ($D = n/N$) .
 d = stress increment (in staircase test) .
 S_e = endurance strength .
 S_0 = lowest stress (in staircase test) .
 ΔS = standard deviation.
 β_i = n_i/N_i = cycle ratio at stress level S_i .

