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# Effect of Load Ratio on Probability Distribution of Fatigue Crack Propagation Life in Magnesium Alloys

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***Abstract*****—**It is necessary to predict a fatigue crack propagation life for estimation of structural integrity. Because of an uncertainty and a randomness of a structural behavior, it is also required to analyze stochastic characteristics of the fatigue crack propagation life at a specified fatigue crack size.

The essential purpose of this study is to find the effect of load ratio on probability distribution of the fatigue crack propagation life at a specified grown crack size and to confirm the good probability distribution in magnesium alloys under various fatigue load ratio conditions. To investigate a stochastic crack growth behavior, fatigue crack propagation experiments are performed in laboratory air under several conditions of fatigue load ratio using AZ31.

By Anderson-Darling test, a goodness-of-fit test for probability distribution of the fatigue crack propagation life is performed. The effect of load ratio on variability of fatigue crack propagation life is also investigated.

***Keywords*****—**Load ratio, fatigue crack propagation life, Magnesium alloys, probability distribution.

## I. Introduction

MAGNESIUM alloy is the attractive structural material in an automobile industry, an aerospace industry and an electronic industry due to its excellent property such as specific strength, machinability, and vibrational absorption and environmental requirement for reduction in air pollution. As the wrought magnesium alloy is better than the cast one, the former has more attention than the latter. Therefore it is of primary importance to investigate the fatigue crack propagation (FCP) behavior of a wrought magnesium alloy as structural material.

There are many studies on FCP behavior of magnesium alloy [1]-[4]. However the study for stochastic FCP characteristic of a wrought magnesium alloy has been rarely reported [5]-[7].

The stochastic fatigue crack propagation behaviors are investigated through the experiments and the statistical analyses to find the effect of load ratio on probability distribution of the FCP life at a specified grown crack size.

## II. Experimental Methods

### A. Material and Specimen

The material used for this study is a commercial wrought AZ31 magnesium alloy. Its chemical composition is shown in Table I and the mechanical properties determined by tensile test are listed in Table II.

The specimen is CT (Compact Tension) type with a width of 50mm complied with ASTM E647 [8]. CT specimens with a thickness of 6.60mm are prepared for four cases of load ratio, respectively.

TABLE I
Chemical Composition of Magnesium Alloy (Wt, %)

| Al | Zn | Si | Mn | Cu | Fe | Mg |
|---|---|---|---|---|---|---|
| 3.29 | 0.95 | 0.04 | 0.31 | 0.003 | 0.01 | Bal. |

TABLE II
Mechanical Properties of Magnesium Alloy

| Tensile strength (MPa) | Yield strength (MPa) | Elongation (%) |
|---|---|---|
| 264.4 | 198.3 | 21.95 |

### B. Fatigue Crack Propagation Experiment

The FCP experiments have been carried out on CT specimens of 20 duplicates for each load ratio prepared according to ASTM E647. The load ratio conditions are four cases of 0.05, 0.10, 0.20, 0.30. The details of the fatigue experiment conditions are as Table III.

The CT specimens are subjected to fatigue experiments using servo-hydraulic axial testing machine. After measuring the crack opening length on the loading line, the grown crack size is computed by the compliance technique.

TABLE III
Fatigue Experiment Conditions

| Test condition | Value |
|---|---|
| Load ratio | 0.05, 0.10, 0.20, 0.30 |
| Specimen thickness | 6.60mm |
| Maximum fatigue load | 2.00 kN |
| Frequency | 10 Hz |
| Wave form | Sine |

## III. Statistical Analysis

The statistical analysis for the probability density and the probability distribution of the FCP life is performed in order to find the effect of the load ratio on the probability distribution of the FCP life at a specified grown crack size. The statistical package software of MINITAB 15 is used to analyze the statistical aspects.

Anderson-Darling (A-D) test has been adopted in the statistical analysis of this study to estimate the probability distribution of the FCP life under various load ratio conditions. A-D test statistics, A2, is obtained from (1).

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$$A^2 = -\sum_{i=1}^{n}\left\{\frac{(2i-1)}{n}\left[\ln(F(x_i)) + \ln(1 - F(x_{n+1-i}))\right]\right\} - n \qquad (1)$$

where, $i$ is a rank of observation, $n$ is a number of observation and $F(\,)$ is a cumulative distribution function. The criteria for the goodness-of-fit of probability distribution is to compare A-D statistics, $A^2$, computed to critical value of $A^2$ according to the conditions such as a number of observation and a significant level. The critical value of $A^2$ is 0.744 in case of 20 observations and 5% significant level [9], [10].

## IV. Results and Discussions

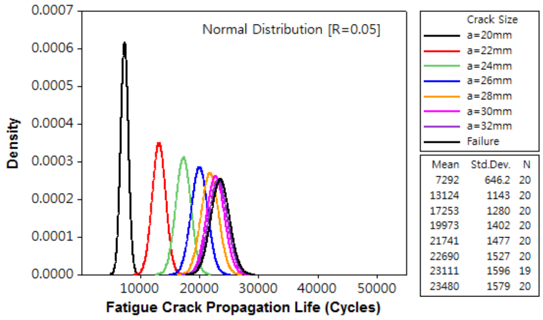
### *A. Statistical Characteristics*

The probability density of the FCP life for each load ratio(R) conditions is shown in Fig. 1, depending on the specified grown crack size.

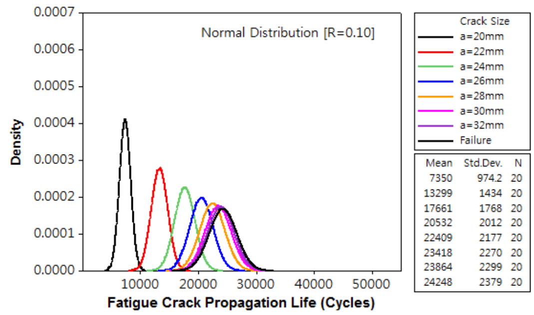
In Fig. 1 (a), the dispersion of the FCP life at a crack size of 20mm is very small. On the contrary, it becomes large as the crack grows. This tendency is similar in other load ratios in Figs. 1 (b)-(d) and 2. Especially, the dispersion of the FCP life becomes large in the larger load ratio.

The prediction of a fatigue life is not easy because the dispersion of the FCP life becomes large as the load ratio is large. It is found that the statistical aspect of the FCP life in magnesium alloy is affected by the load ratio condition.

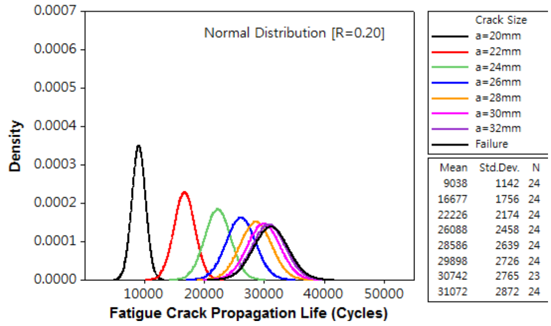
Therefore, the probabilistic approach is required to predict a safe fatigue life taking account of the load ratio.



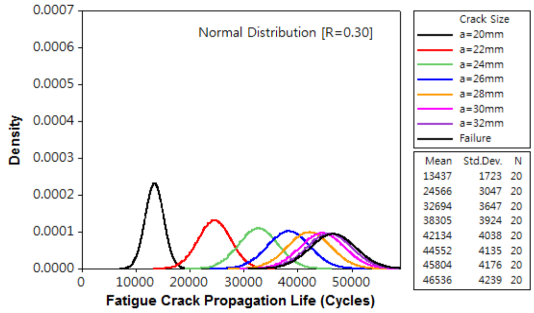

(a) R=0.05




(b) R=0.10

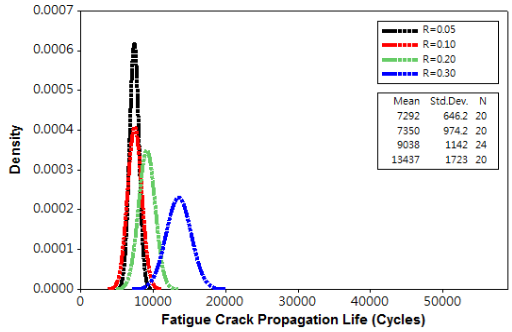



(c) R=0.20

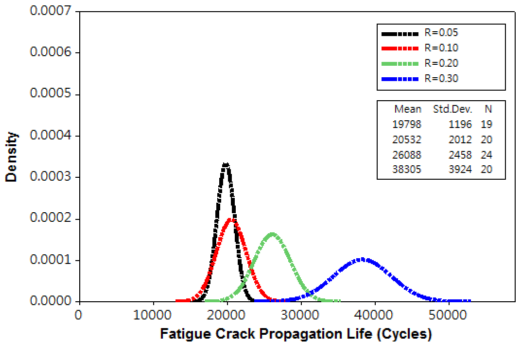



(d) R=0.30

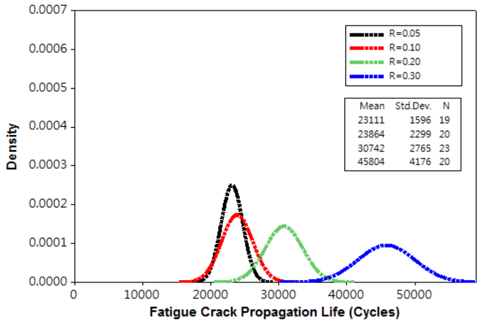
Fig. 1 Probability density of fatigue crack propagation life depending on specified grown crack size



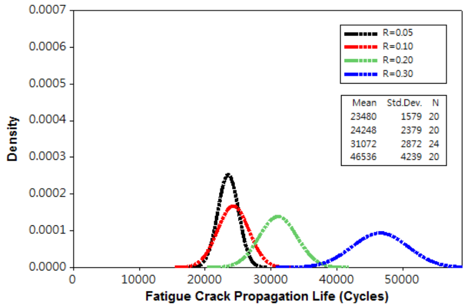

(a) Normalized Grown Crack Size, $a/a_f$=0.5




(b) Normalized Grown Crack Size, $a/a_f$=0.7




(c) Normalized Grown Crack Size, $a/a_f$=0.9

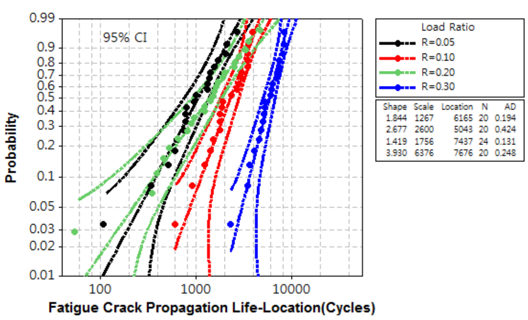



(d) Normalized Grown Crack Size, $a/a_f$=1.0

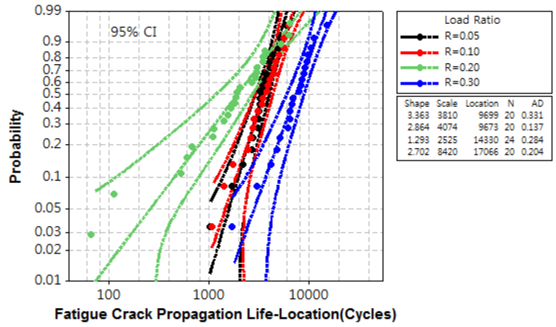
Fig. 2 Comparison of dispersion of fatigue crack propagation life between load ratio conditions

*B. Probability Distribution of Fatigue Crack Propagation Life*

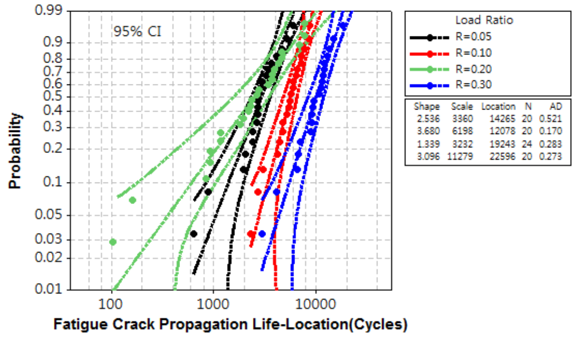
Fig. 3 shows the probability distribution of the FCP life for each load ratio condition, depending on the specified crack size. In Fig. 3, the straight line is the goodness-of-fit line and the curves on both sides of the straight line represent the confidence interval (CI) of 95%. If the statistical data may exist in CI bounds but they go off the goodness-of-fit line, the probability distribution can be accepted as valid for the statistical data. The goodness-of-fit test of the probability distribution of the FCP life is also performed by Anderson-Darling test. Through A-D test for four load ratio conditions, the goodness-of-fit of probability distribution of the FCP life is also obtained as following Fig. 3. It is reconfirmed that the 3-parameter Weibull distribution is useful for the prediction of the FCP life at the specified crack size in probabilistic approach.



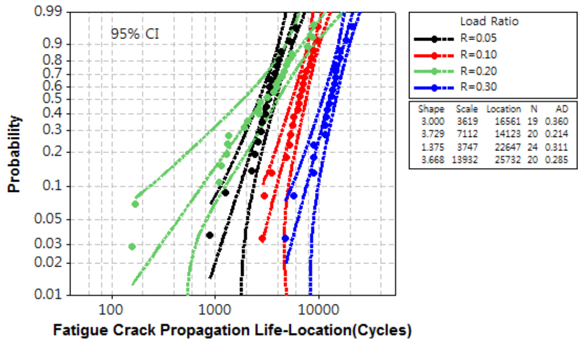

(a) at grown crack size of 20mm



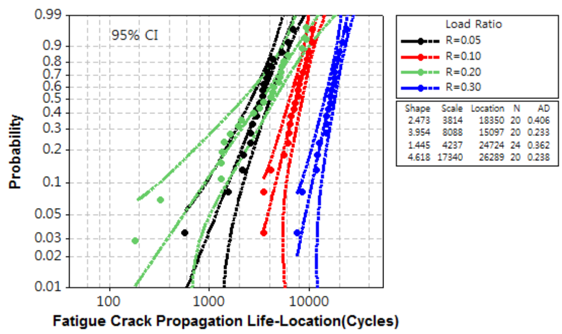

(b) at grown crack size of 22mm




(c) at grown crack size of 24mm




(d) at grown crack size of 26mm




(e) at grown crack size of 28mm

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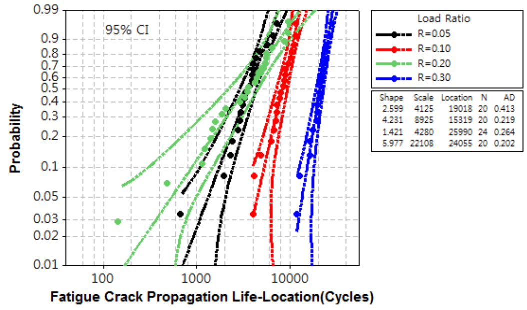
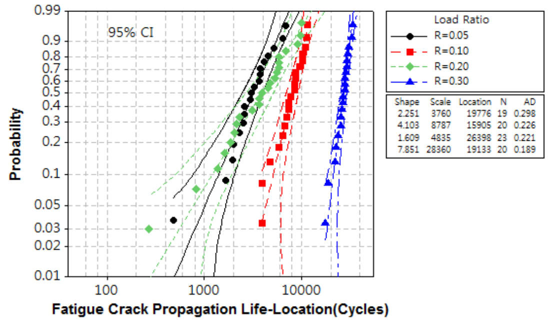
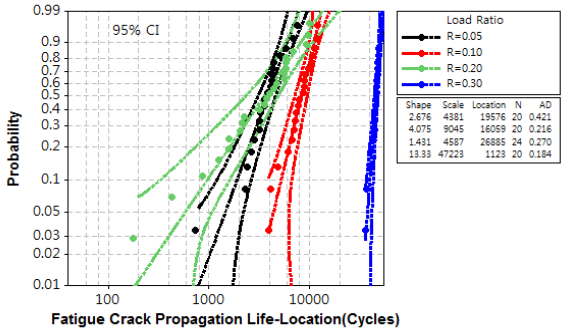



(f) at grown crack size of 30mm




(g) at grown crack size of 32mm




(h) at Failure

Fig. 3 Probability distribution of FCP life at a specified crack size (3-parameter Weibull distribution)

## V. CONCLUSION

The conclusions obtained can be summarized as follows:

1) It is found that the statistical aspect of the FCP life in magnesium alloy is affected by the load ratio condition.
2) The probabilistic approach is required to predict a safe fatigue life taking account of the load ratio.
3) It is reconfirmed that the 3-parameter Weibull distribution is useful for the prediction of the FCP life at a specified crack size in probabilistic approach.

## ACKNOWLEDGEMENT

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