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Influence of Maximum Fatigue Load on Probabilistic Aspect of Fatigue Crack Propagation Life at Specified Grown Crack in Magnesium Alloys

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***Abstract*—**The principal purpose of this paper is to find the influence of maximum fatigue load on the probabilistic aspect of fatigue crack propagation life at a specified grown crack in magnesium alloys. The experiments of fatigue crack propagation are carried out in laboratory air under different conditions of the maximum fatigue loads to obtain the fatigue crack propagation data for the statistical analysis. In order to analyze the probabilistic aspect of fatigue crack propagation life, the goodness-of fit test for probability distribution of the fatigue crack propagation life at a specified grown crack is implemented through Anderson-Darling test. The good probability distribution of the fatigue crack propagation life is also verified under the conditions of the maximum fatigue loads.

***Keywords*—**Fatigue crack propagation life, magnesium alloys, maximum fatigue load, probability.

I. INTRODUCTION

MAGNESIUM alloy is one of the lightest materials in all metals used in structural parts. Magnesium alloys are increasingly adopted in automotive industry owing to the requirement of a weight reduction for an emission regulation. The uncertainty is essential in the behavior of the structure. It is necessary to consider the probabilistic aspect of the fatigue crack propagation (FCP) life at a specified grown crack for an estimation of structural integrity.

There are some studies on FCP behavior of a magnesium alloy. Xu et al. [1] investigated the FCP behavior of a forged Mg-Zn-Y-Zr alloy, and Zeng et al. [2] studied the FCP behavior of an extruded magnesium alloy. Tokaji et al. [3] investigated also the FCP and fracture mechanisms of wrought magnesium alloy in different environment and concluded that the relationship between FCP rate and stress intensity factor range for large cracks consisted of two sections with different slope, which became much more remarkable in the FCP behavior after allowing for crack closure, and so on. However, the study for stochastic FCP characteristic of a wrought magnesium alloy has been rarely reported [4]-[8].

In the present paper, the probabilistic FCP behaviors are investigated through the experiments and the statistical analyses to verify the influence of the maximum fatigue load on the probabilistic aspect of the FCP life at a specified crack.

II. EXPERIMENTAL METHODS

A. Test Specimen

The material of the specimen is a commercial wrought AZ31 magnesium alloy with the principal chemical components of Al 3.29% and Zn 0.95%. Its mechanical properties are yield strength of 198.3 MPa, tensile strength of 264.4 MPa, and elongation of 21.95%.

The specimens with a width of 50 mm and a thickness of 6.60 mm are prepared for three experimental cases of the maximum fatigue loads in as-rolled condition. The specimen type is Compact Tension (CT) complied with ASTM E647 [9].

B. FCP Experiment

The statistical FCP data have been obtained at a load ratio of 0.2 using servo-hydraulic test equipment operating at a frequency of 10 Hz with a wave form of sine. The FCP experiments have been performed on CT specimens of about 20 duplicates for three cases of the maximum fatigue loads, respectively. The conditions of the maximum fatigue loads are three cases of 2000 N, 2250 N, and 2500 N. The crack size is automatically calculated by the compliance method after measuring the crack opening length on the loading line through COD gauge.

III. STATISTICAL ANALYSIS

To find the influence of the maximum fatigue load on the probabilistic aspect of the FCP life at a specified grown crack, the statistical analysis is carried out for the probability density of the FCP life and its probability distribution.

In order to evaluate the goodness-of-fit for the probability distribution of the FCP life under different maximum fatigue loads, Anderson-Darling (A-D) test has been applied to the statistical analysis in this paper. A-D test statistics, A^2, of goodness-of-fit is obtained from the expression

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

where, i is a rank of observation, n is a number of observation and $F(\,)$ is a cumulative distribution function. The statistical package software of MINITAB 17 is used to analyze the probabilistic aspects of the FCP life.

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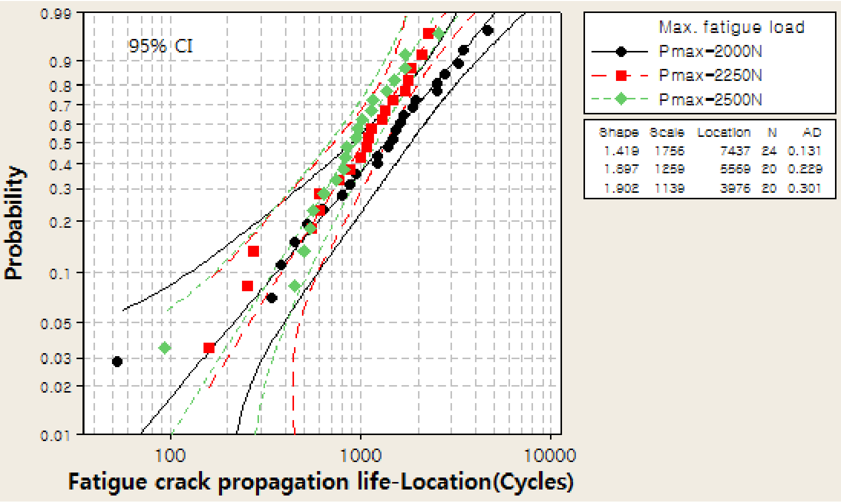
IV. RESULTS AND DISCUSSIONS

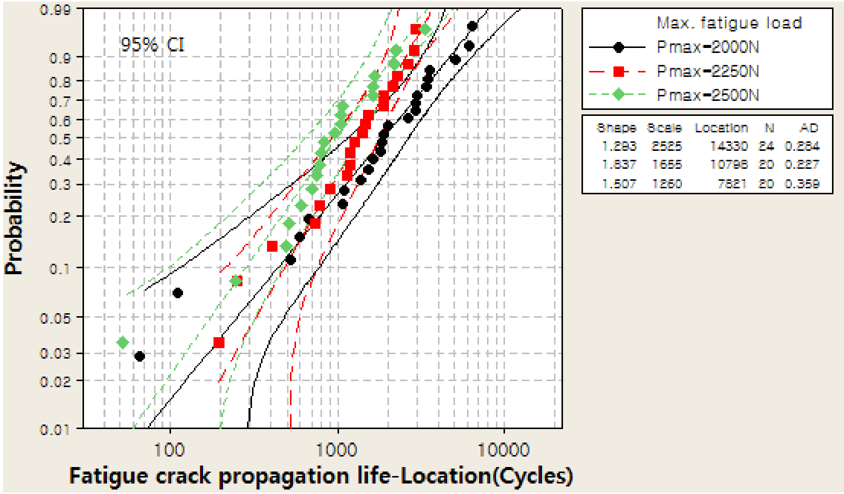
A. Goodness-of-Fit Test of Probability Distribution of FCP Life at Specified Crack

The A-D test has been used for a goodness-of-fit test of the probability distribution of the FCP life under the maximum fatigue load conditions. There are two criteria for a goodness-of-fit of a probability distribution. One is to compare A-D statistics, A^2, calculated to its critical value. Its critical value is 0.744 in case of 5% significant level and 20 observations [10]. The other one is to verify an existence of an experimental data in confidence interval (CI) bounds of a probability distribution plot. The straight line in a probability distribution plot represents a goodness-of-fit line and the curves on both sides of it indicate the CI level. Although the experimental data deviate from goodness-of-fit line, the probability distribution having those plotted in CI bounds is accepted as available.

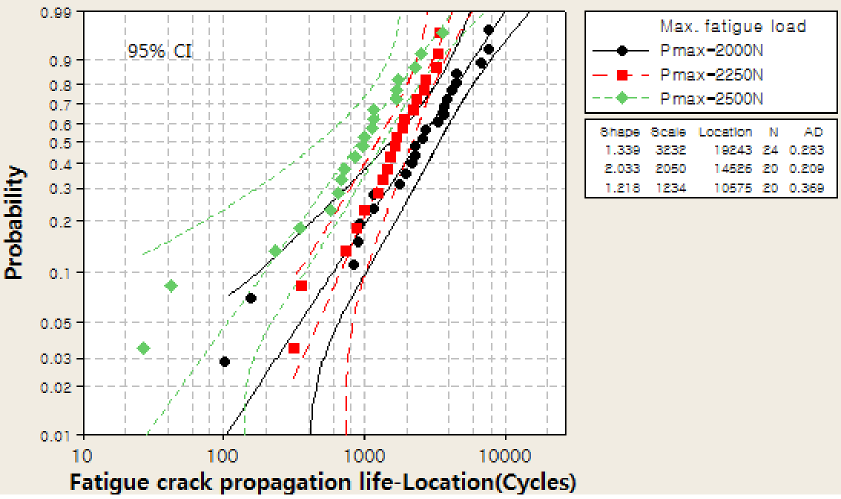
Fig. 1 shows the goodness-of-fit test for the probability distribution of the FCP life at a specified crack, depending on each maximum fatigue load through A-D test. The goodness-of-fit test in Fig. 1 has been implemented for a 3-parameter Weibull distribution and in 95% CI level. Because the FCP life data of each crack propagation exist in CI bounds of 3-parameter Weibull distribution, this distribution is able to be used for a probabilistic prediction of the FCP life.



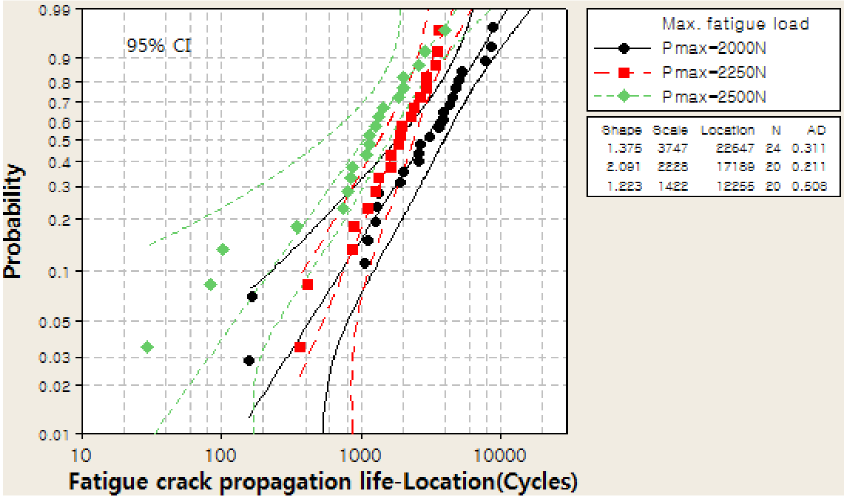
(a) a= 20 mm



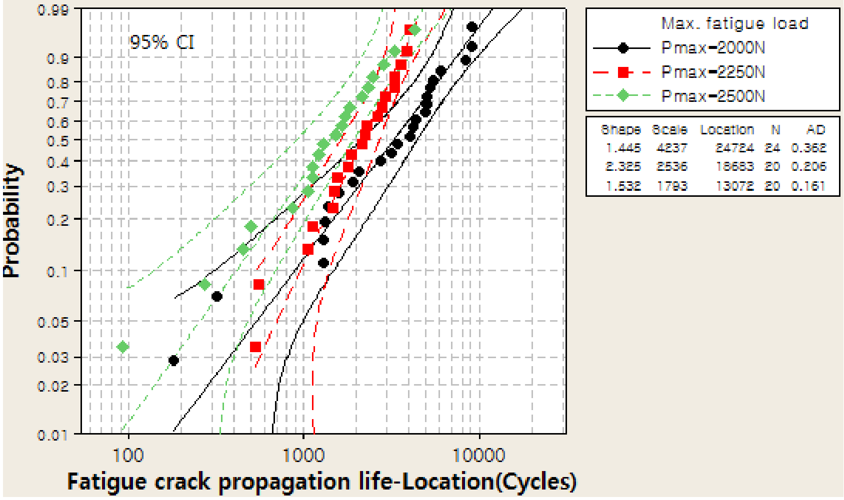
(b) a= 22 mm



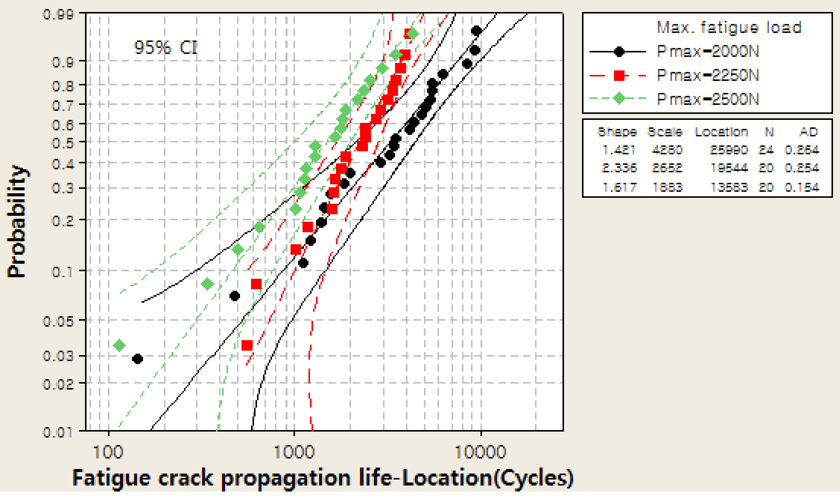
(c) a= 24 mm



(d) a= 26 mm

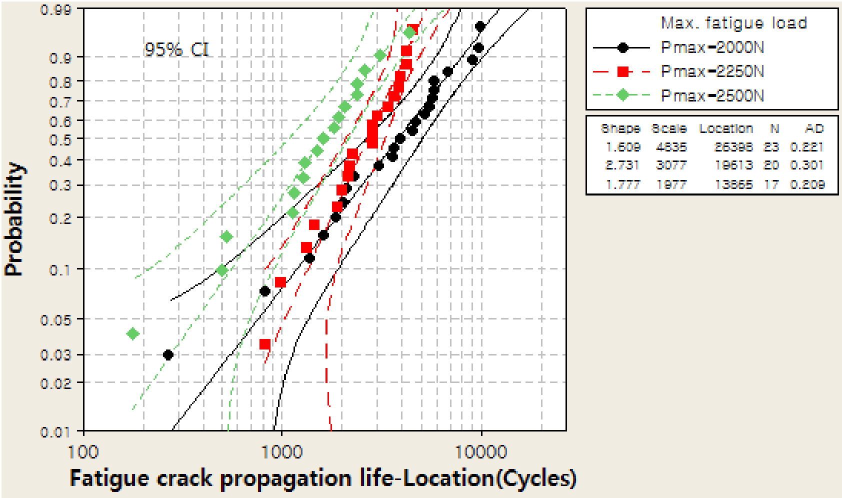


(e) a= 28 mm



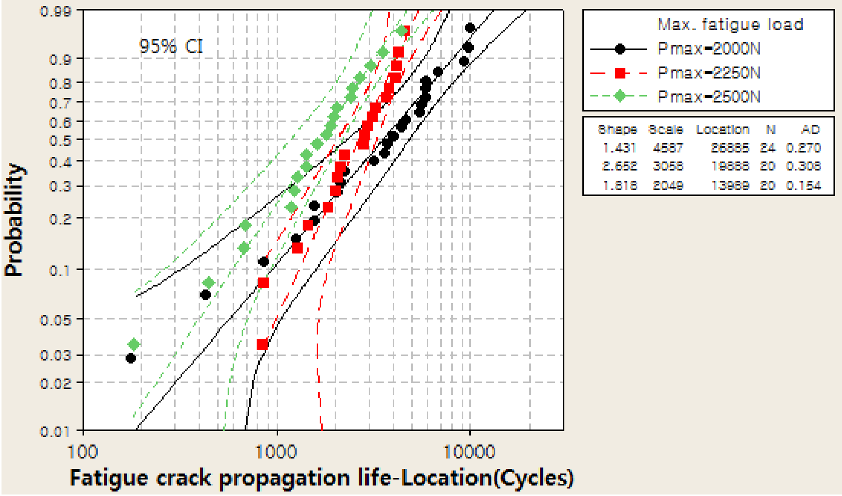
Shape	Scale	Location	N	AD
1.421	4280	25990	24	0.264
2.336	2652	19544	20	0.254
1.617	1883	13583	20	0.154

(f) a= 30 mm



Shape	Scale	Location	N	AD
1.609	4835	26398	23	0.221
2.731	3077	19613	20	0.301
1.777	1977	13865	17	0.209

(g) a= 32 mm



Shape	Scale	Location	N	AD
1.431	4587	26885	24	0.270
2.652	3058	19686	20	0.306
1.818	2049	13969	20	0.154

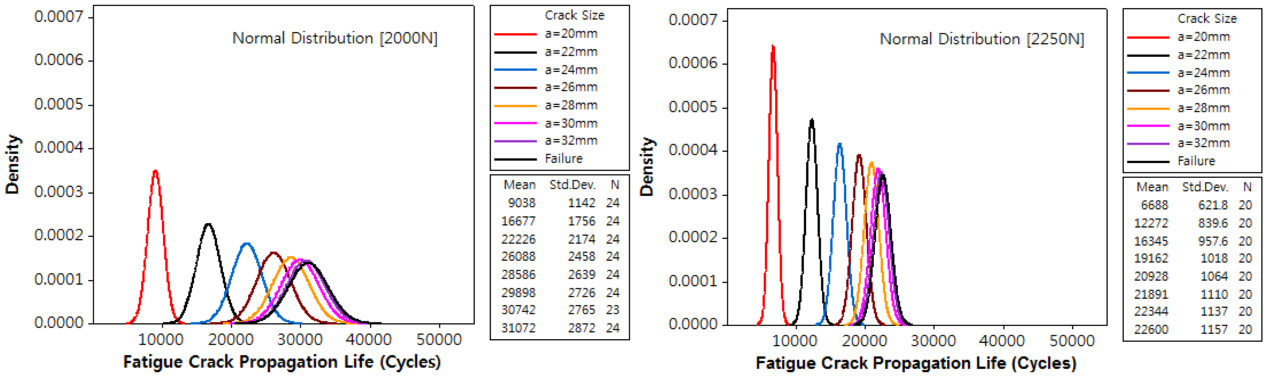
(h) Failure

Fig. 1 Goodness-of-fit of 3-parameter Weibull distribution of FCP life at a specified crack (symbol, a)

B. Statistical Aspects

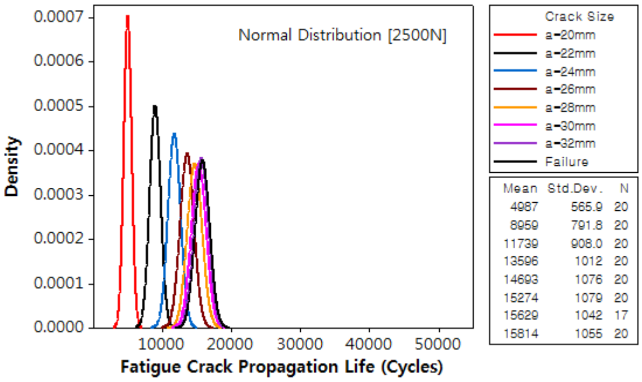
Figs. 2 and 3 show the statistical aspects of the FCP life for each maximum fatigue load condition, depending on the specified grown crack size.

In Fig. 2, the dispersion of the FCP life becomes larger as crack grows and becomes largest in failure stage. It means that the prediction of the FCP life is not easy because of its statistical uncertainty. Especially, the dispersion of the FCP life becomes large in the smaller maximum fatigue load. It is considered that the small maximum fatigue load condition has small mean stress and stress amplitude. It is found that the maximum fatigue load condition has a reasonable influence on the statistical aspect of the FCP life.



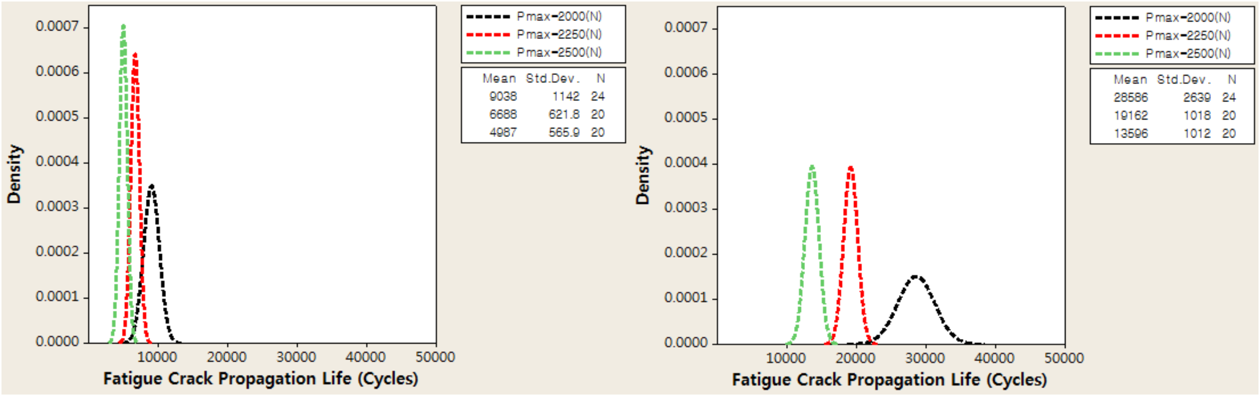
(a) Pmax=2000 N

(b) Pmax=2250 N



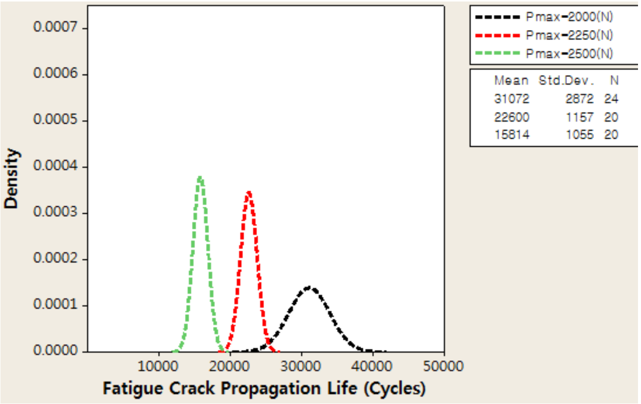
(c) Pmax=2500 N

Fig. 2 Statistical behavior of FCP life depending on specified grown crack



(a) Early crack propagation stage, a/a_f=0.6

(b) Middle crack propagation stage, a/a_f=0.8



(c) Failure stage, a/a_f=1.0

Fig. 3 Statistical behavior of FCP life between maximum fatigue load conditions

The symbol of a_f in Fig. 3 is the grown crack size of failure stage. Fig. 3 shows that the dispersion of the FCP life is small in early stage of the crack propagation. But, its dispersion becomes large toward the failure stage. This tendency is similar in all cases of the maximum fatigue loads. Owing to the statistical dispersion of the FCP life in each crack propagation stage, the probabilistic method is necessary to predict the FCP life at a specified grown crack.

V. CONCLUSION

The study of the influence of the maximum fatigue load on the FCP life reveals that the maximum fatigue load condition has a reasonable influence on the probabilistic aspects of the FCP life in magnesium alloy. Because the FCP life at a specified grown crack has a stochastic behavior under the maximum fatigue load condition, the probabilistic method using the 3-parameter Weibull distribution is necessary to predict the FCP life.

REFERENCES

[1] D. X. Xu, L. Liu, Y. B. Xu, E. H. Han, "The fatigue crack propagation behavior of the forged Mg-Zn-Y-Zr alloy," *Journal of Alloys and Compounds,* Vol. 431, pp. 107~111, 2007.

[2] R. C. Zeng, Y. B. Xu, W. Ke, E. H. Han, "Fatigue crack propagation behavior of an as-extruded magnesium alloy AZ80," *Materials Science and Engineering,* Vol. 509, Issue 1-2, pp. 1~7, 2009.

[3] K. Tokaji, M. Nakajima, and Y. Uematsu, "Fatigue crack propagation and fracture mechanisms of wrought magnesium alloys in different environments," *International Journal of Fatigue,* Vol. 31, Issue 7, pp. 1137~1143, 2009.

[4] M. Sivapragash, P.R. Lakshminarayanan, R. Karthikeyan, "Fatigue life prediction of ZE41A magnesium alloy using Weibull distribution," *Materials and Design*, Vol.29, pp. 1549-1553, 2008.

[5] S. S. Choi, "Estimation of probability distribution fit for fatigue propagation life of AZ31 Magnesium alloy," *Transactions of the KSME(A)*, Vol. 33, No. 8, pp. 707-719, 2009.

[6] Y. Liu, S. Mahadevan, "Probabilistic fatigue life prediction using an equivalent initial flaw size distribution," *International Journal of Fatigue,* Vol. 31, pp. 476~487, 2009.

[7] S. S. Choi, "Effect of specimen thickness on probability distribution on grown crack size in magnesium alloys," *International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering*, Vol.8, No. 6, pp. 440-443, 2014.

[8] S. S. Choi, "Effect of load ratio on probability distribution of fatigue crack propagation life in magnesium alloys," *International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering*, Vol.9, No. 8, pp. 1002-1005, 2015.

[9] ASTM E647-00, *Standard Test Method of Fatigue Crack Growth Rates*. Pennsylvania: ASTM International, 2000.

[10] B. Dodson, *the Weibull Analysis Handbook*. Wisconsin: ASQ Quality Press, pp. 115-117.