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Effect of Specimen Thickness on Probability Distribution of Grown Crack Size in Magnesium Alloys

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***Abstract*—**The fatigue crack growth is stochastic because of the fatigue behavior having an uncertainty and a randomness. Therefore, it is necessary to determine the probability distribution of a grown crack size at a specific fatigue crack propagation life for maintenance of structure as well as reliability estimation. The essential purpose of this study is to present the good probability distribution fit for the grown crack size at a specified fatigue life in a rolled magnesium alloy under different specimen thickness conditions. Fatigue crack propagation experiments are carried out in laboratory air under three conditions of specimen thickness using AZ31 to investigate a stochastic crack growth behavior. The goodness-of-fit test for probability distribution of a grown crack size under different specimen thickness conditions is performed by Anderson-Darling test. The effect of a specimen thickness on variability of a grown crack size is also investigated.

***Keywords*—**Crack size, Fatigue crack propagation, Magnesium alloys, Probability distribution, Specimen thickness.

I. Introduction

MAGNESIUM alloy is the lightest among the practical metals used as the basis for structural alloys. It has an excellent property such as specific strength, electromagnetic shielding, machinability and vibrational absorption. 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 FCP (Fatigue Crack Propagation) behavior of a wrought magnesium alloy as structural material. There are some studies on FCP behavior of magnesium alloy [1]-[3]. However the study for stochastic FCP characteristic of a wrought magnesium alloy has been rarely reported [4], [5].

In the present study, the stochastic fatigue crack growth behaviors are carefully investigated through the experiments and the statistical analyses to present the good probability distribution fit for the grown crack size at a specified fatigue crack propagation stage under different specimen thickness conditions.

II. Experimental Methods

A. Material and Specimen

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

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The specimen prepared for the experiment is CT (Compact Tension) type with a width of 50mm complied with ASTM E647 [6]. CT specimens with three kinds of thicknesses of 4.75mm, 6.60mm and 9.45mm are prepared for this study.

TABLE I
Mechanical Properties of Magnesium Alloy

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

TABLE II
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.

B. Fatigue Crack Propagation Experiment

The fatigue crack propagation experiments have been performed on CT specimens of the wrought AZ31 magnesium alloys. The specimens are subjected to fatigue tests using servo-hydraulic axial testing machine.

The crack length is automatically computed by the compliance technique after measuring the crack opening length on the loading line. The details of the fatigue test conditions are as follows.

TABLE III
Fatigue Test Conditions

Test condition	Value
Specimen thickness	4.75 mm, 6.60 mm, 9.45 mm
Maximum fatigue load	2.00 kN
Load ratio	0.20
Frequency	10 Hz
Wave form	Sine

III. Statistical Analysis

In order to estimate the goodness-of-fit of the probability distribution of a grown crack size under different specimen thickness conditions, A-D (Anderson-Darling) test has been adopted in the statistical analysis of this study. A-D test statistics, A^2, is obtained from (1) [7].

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

where, $F(\,)$ is a cumulative distribution function and n is a number of observation.

The criteria for the goodness-of-fit of probability distribution is to compare A-D statistics, A^2, computed to critical value of

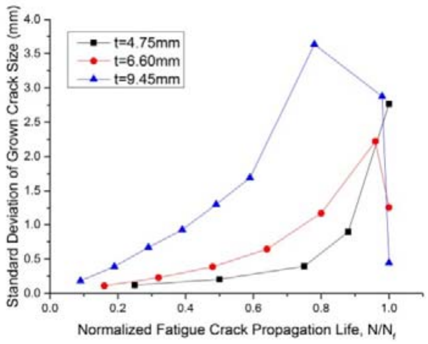
A^2 according to the conditions such as a number of observation and a significant level. The critical value of A^2 is 0.744 in case of 20 observations and 5% significant level [7].

IV. Results and Discussions

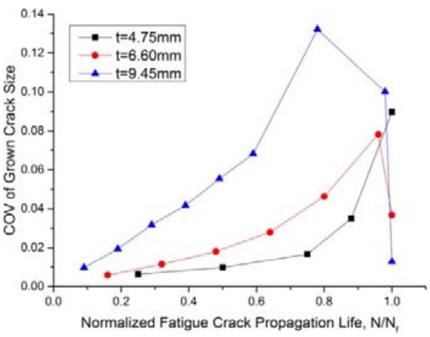
A. Statistical Behaviors

Standard deviation and COV (coefficient of variation) of grown crack size are shown in Fig. 1, depending on normalized FCP life. In the early crack propagation stage, variability of grown crack size is very small. On the contrary, it becomes large toward final stage. This trend is especially severe in thicker specimen. But, in failure stage ($N/N_f=1$), the variability of grown crack size becomes small in thicker specimen.

Fig. 2 shows the scattering of grown crack size in a wrought magnesium alloy. In the middle propagation stage, the grown crack size is widely scattered in thicker specimen and narrowly in the thinner. In contrast, the grown crack size at the failure stage is widely scattered in thinner specimen. It is found that the statistical aspect of grown crack size in magnesium alloy is affected by specimen thickness condition.

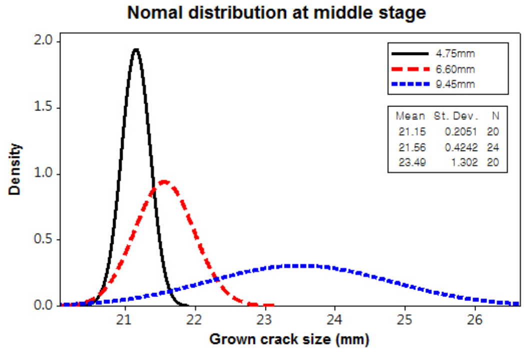


(a) Standard deviation

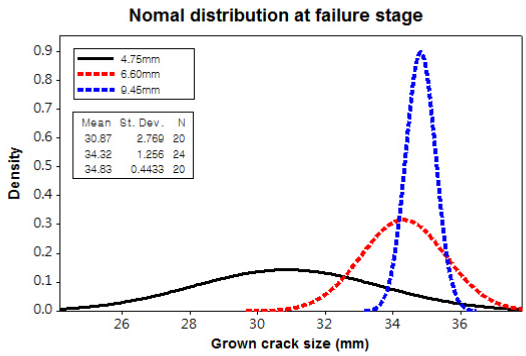


(b) Coefficient of Variation

Fig. 1 Statistical aspects of grown crack size at normalized fatigue crack propagation life, N/N_f



(a) Middle crack propagation stage



(b) Failure stage

Fig. 2 Comparison of dispersion of grown crack size between specimen thickness conditions

B. Probability Distribution Fit for Grown Crack Size

The goodness-of-fit test of the probability distribution of grown crack size is performed by Anderson-Darling test.

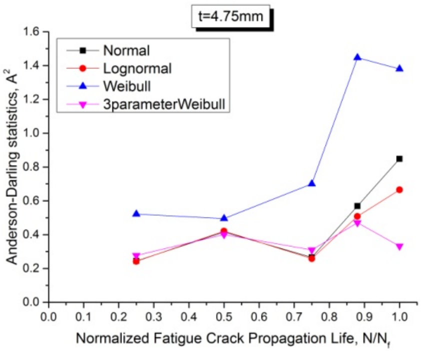
Fig. 3 shows the goodness-of-fit of probability distribution of grown crack size obtained from A-D test applied to four distributions such as Normal distribution, Lognormal distribution, Weibull distribution and 3-parameter Weibull distribution.

In case of specimen thickness of 4.75mm, Fig. 3 (a) shows that the good probability distributions are Lognormal and 3-parameter Weibull and the best probability distribution of grown crack size is 3-parameter Weibull.

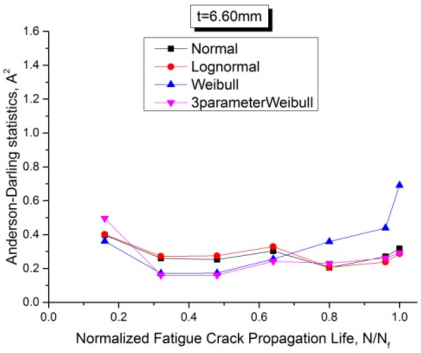
In Fig. 3 (b), the good distributions fit for grown crack size in specimen thickness of 6.60mm are Normal, Lognormal and 3-parameter Weibull except Weibull distribution.

Fig. 3 (c) shows that in case of specimen thickness of 9.45mm, the good probability distributions are Normal, Lognormal and Weibull distribution.

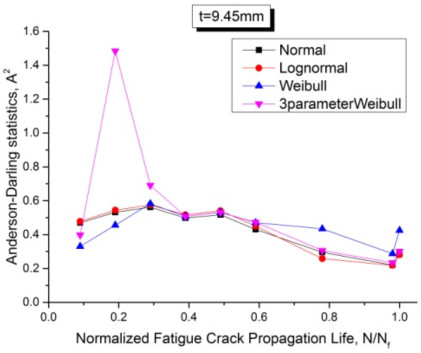
3-parameter Weibull distribution is good for specimen thickness of 4.75mm and 6.60mm. Normal distribution is good for specimen thickness of 6.60mm and 9.45mm. It is found that the probability distribution of grown crack size suitable for all cases of specimen thickness is Lognormal distribution.



(a)



(b)



(c)

Fig. 3 A-D goodness-of-fit test statistics of probability distribution of grown crack size at normalized FCP life

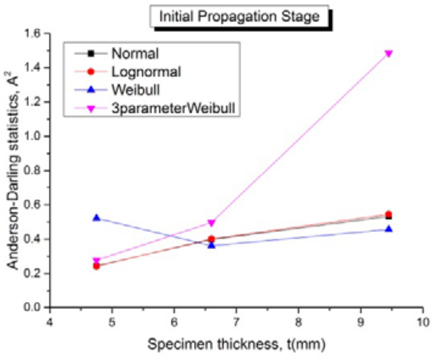
Through A-D test for four crack propagation stage, the goodness-of-fit of probability distribution of grown crack size is obtained as following Fig. 4.

Fig. 4 (a) shows Normal and Lognormal distribution are suitable for probability distribution of grown crack size at the initial crack propagation stage.

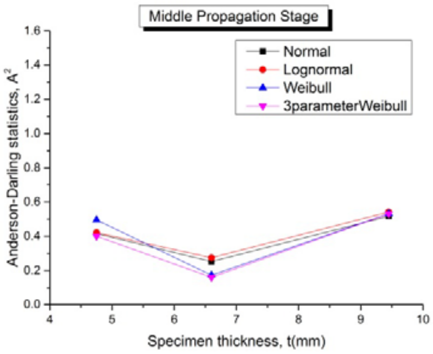
In Fig. 4 (b), the probability distributions fit for grown crack size at the middle crack propagation stage are Normal, Lognormal, Weibull and 3-parameter Weibull distribution.

For the final stage, the good probability distributions are Normal, Lognormal and 3-parameter Weibull except Weibull distribution.

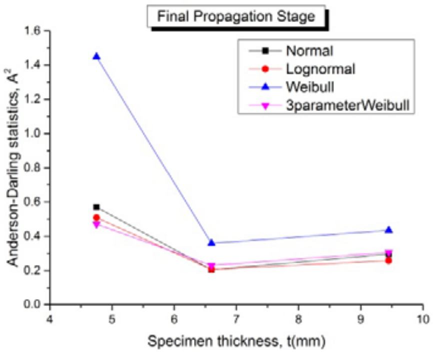
Fig. 4 (d) shows the best probability distribution fit for grown crack size is 3-parameter Weibull distribution. In order to predict the crack size at the failure stage, it is necessary to use 3-parameter Weibull distribution.



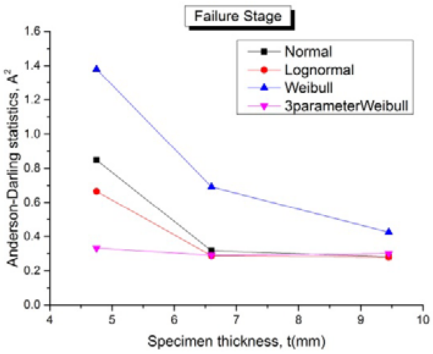
(a)



(b)



(c)



(d)

Fig. 4 A-D goodness-of-fit test statistics of probability distribution of grown crack size under different specimen thickness conditions

V. Conclusion

The conclusions obtained can be summarized as follows:

1) The best probability distribution fit for the grown crack size at a specified fatigue crack propagation stage under different specimen thickness conditions is Lognormal distribution. 3parameter-Weibull is also good distribution describing probability distribution of a grown crack size except an initial propagation stage.
2) In order to predict the crack size at the failure stage, it is necessary to use 3-parameter Weibull distribution.
3) It is found that the statistical aspect of grown crack size in magnesium alloy is affected by specimen thickness condition.

Acknowledgement

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