REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE *(DD-MM-YYYY)*

2. REPORT TYPE
Technical Papers

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
2302

5e. TASK NUMBER
M1G2

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory (AFMC)
AFRL/PRS
5 Pollux Drive
Edwards AFB CA 93524-7048

8. PERFORMING ORGANIZATION REPORT

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory (AFMC)
AFRL/PRS
5 Pollux Drive
Edwards AFB CA 93524-7048

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

1119 112

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:

a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Leilani Richardson
Unclassified	**Unclassified**	**Unclassified**	A		**19b. TELEPHONE NUMBER** *(include area code)* (661) 275-5015

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18

36 separate items are enclosed

G2

MEMORANDUM FOR PR (Contractor/In-House Publication)

FROM: PROI (TI) (STINFO) 19 Apr 2000

SUBJECT: Authorization for Release of Technical Information, Control Number: **AFRL-PR-ED-TP-2000-080**
Liu, C.T., Yang, J.N., "Determination of Equivalent Initial Flaw Size in a Particulate Composite Material"

8th ASCE Conference on Probabilistic Mechanics and Structural Reliability (Statement A)
(Notre Dame, IN, 24-26 Jul 2000) (Submission Deadline: 12 May 2000)

1. This request has been reviewed by the Foreign Disclosure Office for: a.) appropriateness of distribution statement, b.) military/national critical technology, c.) export controls or distribution restrictions, d.) appropriateness for release to a foreign nation, and e.) technical sensitivity and/or economic sensitivity.
Comments:

Signature ______________________ Date ____________

2. This request has been reviewed by the Public Affairs Office for: a.) appropriateness for public release and/or b) possible higher headquarters review.
Comments:

Signature ______________________ Date ____________

3. This request has been reviewed by the STINFO for: a.) changes if approved as amended, b.) appropriateness of distribution statement, c.) military/national critical technology, d.) economic sensitivity, e.) parallel review completed if required, and f.) format and completion of meeting clearance form if required
Comments:

Signature ______________________ Date ____________

4. This request has been reviewed by PR for: a.) technical accuracy, b.) appropriateness for audience, c.) appropriateness of distribution statement, d.) technical sensitivity and economic sensitivity, e.) military/ national critical technology, and f.) data rights and patentability
Comments:

APPROVED/APPROVED AS AMENDED/DISAPPROVED

ROBERT C. CORLEY (Date)
Senior Scientist (Propulsion)
Propulsion Directorate

20021119 112

00-080

Determination of Equivalent Initial Flaw Size in a Particulate Composite Material

C. T. Liu
Air Force Research Laboratory
10 E. Saturn Blvd.Edwards AFB CA 93524-7680
chi_liu@ple.af.mil

J. N. Yang
Civil Engineering Department
University of California at Irvine Irvine, CA 92697

Abstract

In this study, a method for determining the initial flaw size in a particulate composite material is developed. The results of analyses indicate that the initial flaw length and the critical flaw size follow the second asymptotic distribution of maximum value. It also indicates that on the first approximation, it can be assumed that the initial flaw size and the critical flaw size is independent of specimen thickness.

Introduction

An important engineering problem in structural design is evaluating structural integrity and reliability. It is well known that structural strength may be degraded during its design life due to mechanical or chemical aging, or a combination of these two aging mechanisms. Depending on the structural design, material type, service loading, and environmental condition, the cause and degree of strength degradation due to the different aging mechanisms differs. One of the common causes of strength degradation is the result of crack development in the structure. When cracks occur, the effects of crack sizes and the rate of growth on the fracture resistance of the material need to be investigated.

Crack propagation in particulate composite materials has been an important subject of research for many years. It has been shown in recent literature that the crack propagation rate in particulate composites is a power function of the Mode I stress intensity factor (Liu,1990; Liu 1990; Liu and Yang, 1994). In order to predict the crack growth rate, it is necessary to determine the initial crack size.

It is well known in the aerospace industry that the initial flaw size in metals and superalloys is too small to be detected by any NDI techniques. Consequently, the initial flaw size in metals has been determined using experimental results, such as fractographic data or S-N data (Yang et. al,1995 and Yang et. al,1997). From the experimental S-N data, one can determine the terminal crack size (critical crack size) at the time of failure. The initial flaw size is then computed from the terminal crack size by conducting the crack growth analysis backwards.

To date, the concept of predicting the crack growth rate based on the initial flaw size and the determination of the initial flaw size in highly filled polymeric materials has not been studied yet. Therefore, it is the objective of this study to investigate the concept of predicting the crack growth rate based on the initial flaw size and to determine the initial flaw size existing in a particulate composite material.

In this study, the equivalent initial flaw size (EIFS) in a particulate composite material, containing hard particles embedded in a rubber matrix, was determined using constant strain rate crack propagation test data. Uniaxial tensile specimens with and without pre-crack were tested at a constant strain rate of 0.067 in/in/min. Four different specimen thicknesses (0.2 in., 0.5 in., 1.0 in,. and 1.5 in.) were considered. The effect of specimen thickness on the EIFS was investigated and the results are discussed.

Analytical Analysis

To determine the EIFS, the following information is needed: (1) crack growth rate parameters, (2) critical stress intensity K_{IC} and threshold stress intensity factor K_{th} under which crack will not grow, and (3) time to failure data under constant strain rate. Crack growth rate parameters as well as K_{IC} and K_{th} are determined experimentally using pre-flawed specimens.Time to failure data are also obtained experimentally using specimens without a pre-flaw.

For pre-flawed specimens, the stress intensity factor K_I is given by

$$K_I = \sigma (\pi a)^{1/2} f(a/w) \qquad (1)$$

In which ,σ is the applied stress, f(a/w) is the geometric correction factor, a is the crack length, and w is the width of the specimen. The functional relationship between f(a/w) and a/w is shown below.

$$f(a/w) = 0.5854(a/w)^3+1.099(a/w)^2+0.8672(a/w)+1.049 \qquad (2)$$

For a specimen subject to a constant strain rate, the stress intensity factor K_I reaches the critical stress intensity factor K_{IC} at the instant of fracture, and the corresponding flaw size is denoted by a_c, referred to as the critical flaw size or the terminal flaw size. It follows from Eq. (1) that

$$K_{IC} = \sigma_c (\pi a_c)^{1/2} f(a_c/w) \qquad (3)$$

Where σ_c is the critical stress at fracture.

The crack growth rate da/dt has been shown to be a power function of the stress intensity factor K_I, i.e.,

$$da/dt = Q K_I^m \qquad (4)$$

in which m and Q are crack growth rate parameters.

When a specimen without pre-flaw is subjected to a constant rate, the entire loading history and hence the stress history $\sigma = \sigma(t)$ can be measured, including the critical stress σ_c at the time of fracture, t_c. For a given critical stress intensity factor K_{IC} (material constant), the critical flaw size a_c can be computed from Eq. (3).Consequently, the initial flaw size a_o at t=0 can be obtained by integrating Eq. (4), based on the terminal condition (a_c, t_c) and the stress history $\sigma(t)$.

Experimental Analysis

Constant strain rate tests were conducted on specimens with and without pre-flaws at a strain rate of 0.067 in/in/min.The critical stress σ_c and the time to failure t_c were determined from the specimen without pre-flaw. The crack growth parameters m and Q were determined form the specimens with pre-flaw. The results are: m = 2.084 and Q = $9.3325\text{x}10^{-7}$ in which the units are force in pound, length in inch, and time in minute. Further, the critical stress intensity factor and the threshold stress intensity factor are 78.3 psi $(\text{in})^{1/2}$ and 52 psi $(\text{in})^{1/2}$, respectively.

Statistical Distribution of Equivalent Initial Flaw Size and Critical Flaw Size

The results of the analysis show that the equivalent initial flaw size a_o as well as the critical flaw size ac vary from specimen to specimen. Hence, the statistical distribution of these quantities should be determined. In this study, four statistical distribution functions , (1) normal distribution, (2) two parameter Lognormal distribution, (3) two parameter Weibull distribution and (4) second asymptotic distribution of maximum values, were considered. The goodness of fit for different distributions has been conducted using the Kolomogorov-Smirov test. The results indicate that the second asymptotic distribution of the maximum value has the best fit for the distribution of a_o and a_c.

Results

Based on the constant strain rate test results for specimens with and without preflaws, a method for determining the equivalent initial flaw size existing in the particulate composite material has been presented. The method is based on a backward crack growth analysis starting from the given terminal flaw size to determine the equivalent initial flaw size.

Equivalent initial flaw sizes were computed for the cases in which the effect of K_{th} is ignored.Typical plots of statistical distributions of a_o are shown in Figs.1-4.For a comparison purpose, experimental data, shown as circles, are also included in these figures. It is seen that the second asymptotic distribution of maximum value fits the experimental data the best that is consistent with the results of the goodness of fit analyses.The results of statistical analyses of a_c are similar to that of a_o.

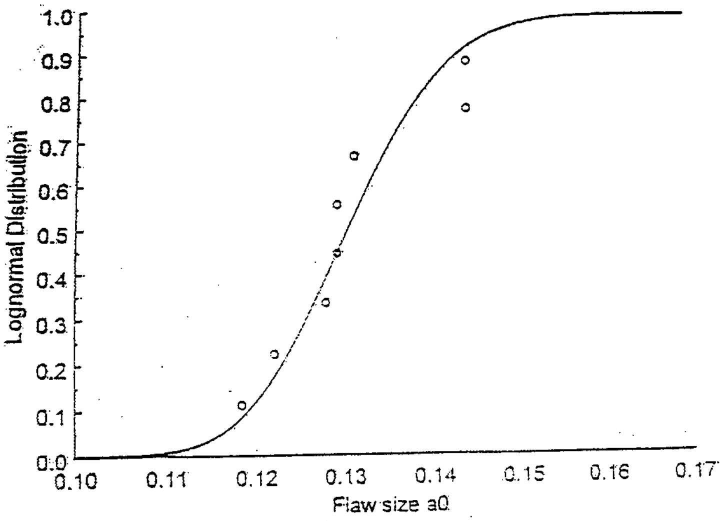

Fig 1: Lognormal Distribution Plot for a_0

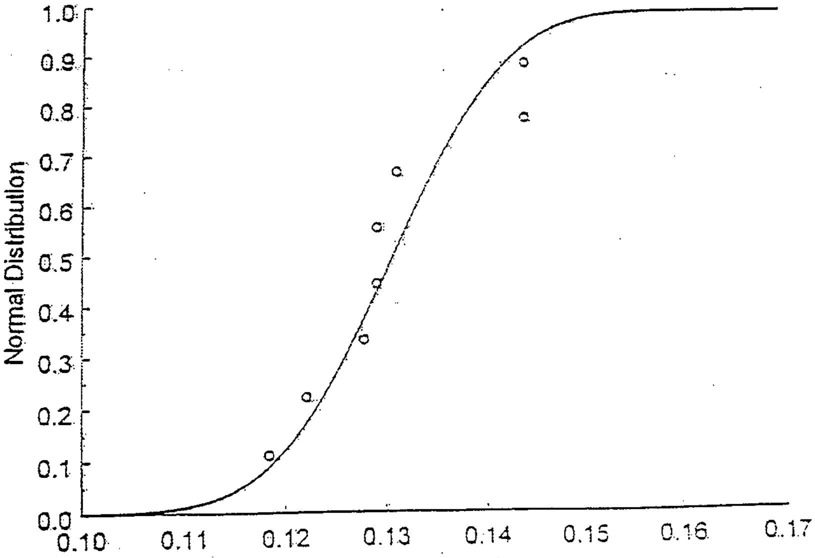

Fig 2: Normal Distribution Plot for a_0

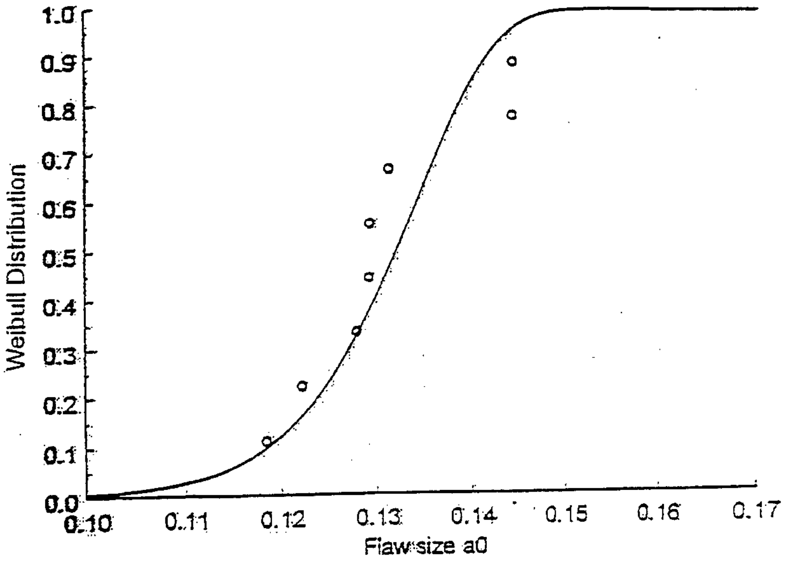

Fig 3: Weibull Distribution Plot for a_0

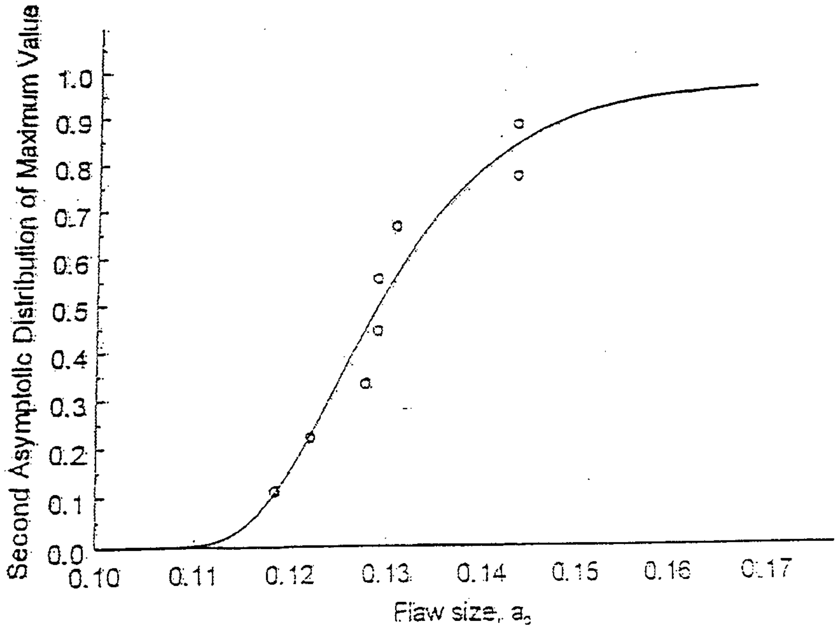

Fig. 4 Second Asymptotic Distribution Plot for a_0

The effect of specimen thickness on the initial flaw size and the critical flaw size were investigated.The results of analyses show that for specimen thicknesses equal to 0.2 in., 0.5 in., and 1.0 in., the variations among a_0 and a_c are small and the average values a_0 and a_c are 0.126 in. and 0.132 in. For specimen thickness equal to 1.5 in. the average values of a_0 and a_c are 0.144 in. and 0.158 in., and they are 14% and 20% higher than that when the specimen thickness is equal to or less than 1.0 in. The increase in a_0 and a_c in thicker specimen is probably due to the size effect of this material. Unlike the brittle metallic materials, this high toughness particulate composite material shows higher strength when the size of the specimen is increased. The size effect of this material is a subject of further research. Considering the highly nonhomogeneous nature of the highly filled particulate composite and for the engineering application purpose, it is reasonable to assume that a_0 and a_c are independent of the specimen thickness. Under this assumption, the average value and the coefficient of variation of a_0 (a_c) are 0.131 in. (0.146 in.) and 0.0703 (0.054), respectively.

Conclusion

In this study, a method is developed to predict the initial crack length and its statistical distribution function of a particulate composite material subjected to a constant strain rate loading condition. The results of analyses indicate that the equivalent initial flaw size and the critical flaw size follow the second asymptotic distribution of maximum value .It also indicates that, on the first approximation and for the engineering application purpose, it can be assumed that the initial crack length is independent of specimen thickness.

References

Liu, C.T. (1990),Crack Growth Behavior in a Composite Propellant with Strain Gradient-PartII, Journal of Spacecraft and Rockets, 27 (6) 647-652.

Liu, C.T. (1990), Crack Propagation in a Composite Solid Propellant, Proceeding of the Soceity for Experimental Mechanics, Spring Conference, Bethel, CT, 614-620.

Liu, C.T. and Yang, J.N., (1994), Probabilistic Crack Growth Model for Application to Composite Solid Propellant, Journal of Spacecraft and Rockets, 31 (1), 79-84.

Yang, J.N., Manning, S.D., Rudd, J.L., and Bader, R.M. (1995), Investigation of Mechanistic-Based Equivalent Initial Flaw Size Distribution, Proceeding of the 18th Symposium of ICAF, Melbourne, Australia, 385-403.

Yang, J.N., Manning, S.D., and Newman, J.C., Jr., (1997), Equivalent Initial Flaw Size Distribution for Notches in 2024-T3 Aluminum, Accounting for Short Crack Effect, Proceeding of 1997 International Conference on Structural Safety and Reliability, Kyoto, Japan