



Title	The Role of Microstructure on the Fracture Behaviour and Statistics of Advanced Ceramics
Authors(s)	McNamara, Declan, Alveen, Patricia, Carolan, Declan, et al.
Publication date	2013-09
Publication information	McNamara, Declan, Patricia Alveen, Declan Carolan, and et al. "The Role of Microstructure on the Fracture Behaviour and Statistics of Advanced Ceramics." Trans Tech Publications, September 2013. https://doi.org/10.4028/www.scientific.net/KEM.577-578.57 .
Publisher	Trans Tech Publications
Item record/more information	http://hdl.handle.net/10197/5960
Publisher's version (DOI)	10.4028/www.scientific.net/KEM.577-578.57

Downloaded 2026-05-01 23:35:12

The UCD community has made this article openly available. Please share how this access benefits you. Your story matters! (@ucd_oa)



© Some rights reserved. For more information

The Role of Microstructure on the Fracture Behaviour and Statistics of Advanced Ceramics

Declan McNamara^{1,a}, Patricia Alveen^{2,b}, Declan Carolan^{3,c}, Neal Murphy^{4,d}, Alojz Ivanković^{5,e}

^{1,2,3,4,5} School of Mechanical and Materials Engineering, University College Dublin, Ireland
^a declan.mc-namara@ucdconnect.ie, ^b patricia.alveen@ucdconnect.ie,
^c declan.carolan@ucd.ie, ^d neal.murphy@ucd.ie, ^e alozj.ivankovic@ucd.ie

Keywords: advanced ceramics, fracture, strength statistics

Abstract. Strength data of three advanced ceramics were fitted to the Weibull, normal and lognormal distributions. The three ceramics had similar grain size and varied in binder content. The role of microstructure in the failure mechanism of such ceramics was analysed in terms of the chosen strength distributions. The best-fit distributions were determined using the maximum log-likelihood criteria and a comparison between the best and worst fit was conducted using the Akaike Information Criteria (AIC). Both large and small samples were tested to investigate possible scaling effects for these ceramics. It was found that for two of the three ceramics tested that a lognormal distribution rather than the conventionally used Weibull distribution was preferable in characterising the strength data. A small drop in strength was noticed between large and small samples but this trend was not thought to be a result of scaling rather due to the decrease in binder content.

Introduction

Advanced ceramics are frequently used in the machining of hardened steels and other abrasive alloys. While such materials have favourable qualities such as high hardness and abrasive resistance they are prone to premature failure due to brittle fracture. An understanding of the role of microstructure and the structure property relationship in advanced ceramic materials is vital in determining dominant failure mechanisms under working conditions. Correct statistical characterisation is essential therefore in order to avoid misleading strength measurements and establish reliable information in order to improve such materials.

In general the strength of ceramics is caused by small crack like flaws, which are homogeneously distributed within the specimen. These flaws are the cause of large scatter in the maximum strength distribution among ceramics and have been commonly described by the Weibull strength distribution function. This theory assumes a direct correlation between the density of flaws distributed throughout the specimen and strength distribution [1]. However increasing evidence has shown that this distribution may not always be the most suitable to describe experimentally measured strength data [2,3]. In light of this a statistical analysis incorporating Weibull, normal and lognormal distribution functions has been carried out on the strength data of a number of advanced ceramics.

Experimental Setup

Flexural Strength. Three-point bend flexural strength test were performed on three grades of advanced ceramics. The materials had a two-phase microstructure composed of extremely hard grains and a small amount (<10%) of metallic binder.

The three grades had a constant grain size with varying binder content. Tests were done on both large and small samples with dimensions of 14 mm x 5 mm x 2 mm and 6 mm x 3 mm x 0.5 mm respectively. Ceramic A and B were the large test specimens and Ceramic C was the smaller dimensioned specimen. Tests were conducted at a crosshead speed of 0.5mm/min and at least 14 specimens of each material were tested. Small-scale tests were performed on a novel miniature three-point bend rig.

Best-Fit Procedures

In order to choose the distribution that represents the empirical data the closest some ‘goodness-of-fit’ test must be performed. To determine a best fit the maximum likelihood criteria was used, [4]. This method used the likelihood of a distributions density function to determine the best model. The distribution that yields the largest likelihood function is chosen. The likelihood of a probability density function is defined as,

$$L = \prod_{i=1}^N f(\sigma_i), \quad (1)$$

and for a given function its log-likelihood is given by,

$$\ln L = \sum_{i=1}^N \ln f(\sigma_i). \quad (2)$$

This method can further be extended to make comparisons between competing models. This is done using the Akaike Information Criteria (AIC), [5]. The AIC is defined by,

$$AIC = -2 \ln \hat{L} + 2k, \quad (3)$$

where, $\ln \hat{L}$ is the maximum log-likelihood for a given distribution. The best distribution is that one with the minimum value of AIC. Determining the ΔAIC ($\max\{AIC\} - \min\{AIC\}$), between models demonstrates the ‘goodness of fit’ between the distributions. For a significantly better-fit $\Delta AIC \geq 2$ must be demonstrated, [2].

Results and Discussion

Table 1. presents the parameters of each of the fitted distributions from the experimentally determined strength data for 3 different advanced ceramic material.

Material	Weibull		Normal		Log-normal	
	m	σ_0 [MPa]	μ [MPa]	σ [MPa]	m[MPa]	v[MPa]
Ceramic A	8.28	1034.30	980.15	121.79	980.45	120.25
Ceramic B	13.35	1074.70	1033	100.85	1033.50	106.78
Ceramic C	5.98	1010.30	941.31	161.81	941.70	154.88

Table 1: Fitted parameters for Weibull, normal and lognormal distributions

Ceramic A and B were the samples with the larger dimensions. From Table 1,

Ceramic B exhibited the highest strength across all distributions. Ceramic B was the material with the highest percentage binder content, with Ceramic A having the second highest binder content and Ceramic C having the least. The data shows that a decrease in the binder within the microstructure results in a drop in overall cohesive and average strength. Ceramic B also shows the lowest strength scatter, having the largest Weibull moduli and the lowest additive and multiplicative normal and lognormal standard deviations respectively.

Ceramic C was tested using the smaller sample size to investigate possible scaling effects. From the data presented the strength of both the large and small samples is quite similar showing little size effect. The drop in strength between the three grades seems likely to be only a consequence of the decreasing binder content. For Weibull distributed data smaller specimens will fail at lower loads due to an increased critical flaw size density, [6]. No apparent size effect exists for the strength of the tested ceramic material, a results that has been noted previously on similar material, [7]. The effect of scaling on the failure strength of brittle materials is a direct result of the data being a Weibull distribution. Other than the strength decrease associated with the varying binder content, no size effect was observed between the samples, this suggests that the Weibull distribution may not be the most reliable statistical characterisation of strength for these ceramics and other distributions must be considered.

Other evidence against the use of Weibull analysis for the tested materials is the large variation in the measured moduli, an indication of the scatter of the strength values. While Ceramic B has a high modulus common to materials characterised well by the Weibull distribution, Ceramics A and C have low moduli indicating a large scatter in the data. A low modulus indicates a low reliability in the strength data as describes by the Weibull distribution.

Table 2 shows the maximum log-likelihood for each ceramic and their corresponding AIC values.

Material	Weibull log-likelihood	Normal log-likelihood	Lognormal log-likelihood	ΔAIC
Ceramic A	-401.74	-400.23	-399.75	3.97
Ceramic B	-395.03	-396.46	-397.44	4.83
Ceramic C	-325.78	-324.63	-323.61	4.33

Table.2 Log-likelihood values for Weibull, normal and lognormal distributions. $\Delta AIC = \max\{AIC\} - \min\{AIC\}$

Based on the maximum log-likelihood criteria the lognormal distribution is the best-fitted model for both Ceramic A and C. In the case of Ceramic B the scatter was shown to be small from Table 1, and therefore it is not surprising that the Weibull model fits the best in this case.

The ΔAIC for between the best and worst fit models is also shown in Table 2. In each case where Weibull is not the best-fit distribution the ΔAIC is greater than 2 which indicates the lognormal distribution characterises the strength data significantly better. These results are further illustrated in Fig.1, where the empirical survival functions and the fitted survival functions are plotted for each material.

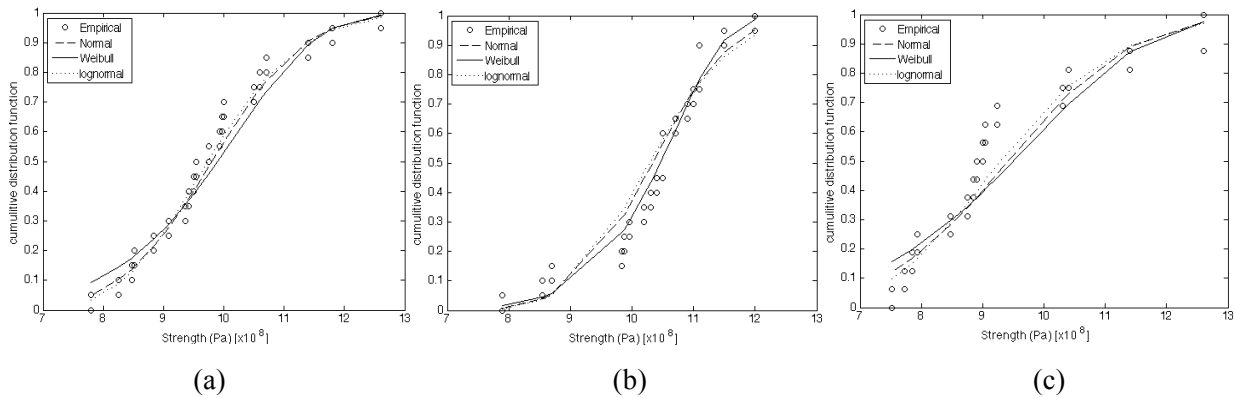


Figure 1. Empirical and fitted survival functions for (a), Ceramic A, (b) Ceramic B, and (c) Ceramic C.

The Weibull distribution is based on the weakest link hypothesis, that is that the microstructure contains sparsely distributed flaws and it is the largest of these flaws that initiate failure. Weibull analysis assumes that there is no interaction of flaws before failure. For ceramics whose microstructures are very complex this may not be the case.

When microstructures contain grains and pores it is often difficult to distinguish where initiation takes place, from a grain boundary or from a pool. Failure from one or the other will result in a different strain distribution within the microstructure and therefore fracture will occur at varying loads. It is likely that over a number of tests failure will initiate from both these flaw types and that interaction between the grains and pores will cause deviation in the strength distribution throughout a particular test set. It is therefore necessary to perform such statistical test as above in order to achieve the most accurate strength data. It is noted however that when sample sizes are small (<30) the values of maximum log-likelihood are very close and it can become difficult to distinguish which model is preferable for a given strength distribution.

Conclusion

Strength data of three advanced ceramics with constant grain size and varying binder content have been analysed using three common statistical distributions. The fitted distribution with the best fit to the empirical data was chosen by means of the maximum likelihood criteria. A comparison between models was performed using the Akaike Information Criteria. It has been shown that the Weibull distribution is not necessarily the most appropriate model to characterise the experimental strength data. For two of the three ceramics tested the lognormal distribution was found to describe the data better. This could be due to the complex interaction between the grains and binder pools within the materials microstructure.

References

- [1] W. Weibull, *Journal of applied mechanics* 18.3 (1951), p. 293-297.
- [2] L. Chunsheng, R. Danzer, and F.D. Fischer, *Physical Review* 65.6 (2002), 067102.
- [3] B. Bikramjit, et al., *Ceramics International* 35.1 (2009), p. 237-246.
- [4] D.R. Cox, D. Oakes. *Analysis of survival data*. Vol. 21. Chapman & Hall/CRC 1(984).
- [5] H. Akaike, in *Applications of Statistics*, edited by P.R. Krishnaiah (1977).
- [6] R. Danzer, et al. *Engineering Fracture Mechanics* 74.18 (2007), p. 2919-2932.
- [7] L. Chunsheng, R. Danzer, and F.D. Fischer, *Journal of the European Ceramic Society* 24.14 (2004): p. 3643-3651.