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Discussion of data on the modulus of rupture of alumina ceramic disks☆

T.P. Hutchinson*

Department of Psychology, Macquarie University, Sydney, NSW 2109, Australia

Abstract

Three comments are made about statistical issues in a paper by Cruz Fernandes et al. [Ceram. Int. 26 (2000) 203–206]. They concern: (i) graphical presentation of cumulative distributions, (ii) the contrast between data exploration and hypothesis testing, and (iii) factors affecting the modulus of rupture.

Cruz Fernandes et al. [1] reported experiments on the modulus of rupture (MOR) of alumina ceramic disks prepared by using either an electric furnace or a solar furnace. The chief interest lay in whether the solar furnace was a satisfactory method. The MOR of disks prepared in the solar furnace was found to be similar to (on average, just a little lower than) that of those prepared conventionally. I have three comments on statistical issues.

1. Graphical presentation

When two or more sets of observations are being compared by plotting their cumulative distributions, it is helpful to show them on the same graph, rather than use separate graphs having different scales, as Cruz Fernandes et al. did. The reason is that it permits a visual judgment to be made of similarities between them. If they are straight lines, this visual judgment is likely to be unimportant. But quite often, there is some degree of curvature. In this case, one may wish to consider the possibility that they have the same shape, in the sense that one could be superposed on another merely by a shift in the horizontal direction. When the horizontal axis is logarithm of time—i.e., the experiment is concerned with the time of survival under certain conditions, rather than with measuring the stress that causes immediate failure—this is termed the "accelerated life" hypothesis [2].

In passing, it may be mentioned that fitting curves that differ by a horizontal shift may be carried out using multiple regression packages, as follows. Regress x on y rather than vice versa; if there seems to be curvature, include y^2 and possibly further terms as necessary. Include dummy variables to indicate which set each observation belongs to, and select the "no constant" ("zero intercept") option of the regression program. The output will include coefficients of y, y^2, etc., that are common to all sets of points, plus a further coefficient for each set that specifies its horizontal location.

Fig. 1 compares the two sets of observations; the smooth curves shown are cubic in y.

2. Data exploration versus hypothesis testing

Scientists typically have a mixture of motives when conducting a statistical analysis. But it is worth making a contrast between (a) the planned testing of a hypothesis, and (b) data exploration.

When the testing of a hypothesis has been planned in advance of seeing the data, the result of the test can be taken at face value. (For example that, if the null hypothesis is true, then in fewer than five occasions per hundred would a difference at least as large as the observed one be found.)

However, driven by curiosity, the scientist may look for features in the data that were never considered at the start of the investigation. (Differences between means

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* Tel.: +61-2-9850-8013; fax: +61-2-9850-8062.
E-mail address: phutchin@bunyip.bhs.mq.edu.au (T.P. Hutchinson).

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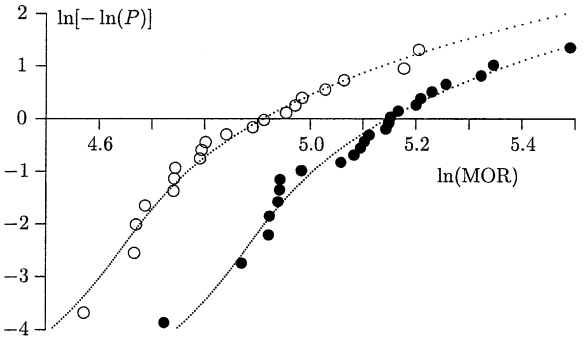

Fig. 1. The cumulative distributions of the two sets of observations.

may be examined, then attention may turn to differences between variabilities. Linear associations between pairs of variables may be looked for, then attention may turn to curvilinear associations. Associations between pairs of variables conditional on the value of some third variable may be the next thing examined. The effect of transformations of single variables might be investigated, and then the calculation of combinations of the original variables. It might be arguable that some data points should be considered to be outliers, and excluded from the analysis. And so the list of variations goes on.) Exploration of this kind is perfectly appropriate—having gone to a lot of trouble to collect the data, it would be wasteful not to squeeze the most out of it. But it is important to be clear that the output from such exploration is a set of ideas or hypotheses, that may be worth testing in a new dataset. It is unlikely that significance tests, performed because the data suggested them, can be taken at face value.

What some investigators like to do, if they have a lot of data, is to split the dataset and explore part of it. Having generated some new ideas by doing that, they use the other part of the dataset for statistical testing of those ideas.

3. Explaining the MOR

The aim in the experiments seems to have been to keep the conditions of preparing the disks in the solar furnace as constant as possible. Thus any variability in the properties of the disks is likely to be difficult to explain or eliminate. There was no intention to vary the conditions of preparation and relate these to the properties resulting. However, slight variations did occur (e.g., in the heating and cooling rates), and are recorded in Table 1 of [1].

Results of exploring these variations:

- A correlation of 0.52 was found between the MOR and t1500, the period of time the specimen temperature was above 1500 °C. See Fig. 2. Further, the correlation is 0.77 if specimen 5 is excluded—and there is some justification for this, as something unusual evidently happened on this occasion, the period of time the temperature was held at 1600 °C having been exceptionally short. There is a hint that a temperature of between 1500 and 1600 °C may be more favourable than 1600 °C, as the time the temperature was held at 1600 °C was not strongly correlated with MOR.
- Cruz Fernandes et al. speculated that excessive heating and cooling rates were responsible for the MOR being slightly lower in the disks prepared in the solar furnace. However, the correlations of MOR with heating rate and cooling rate were negligible.

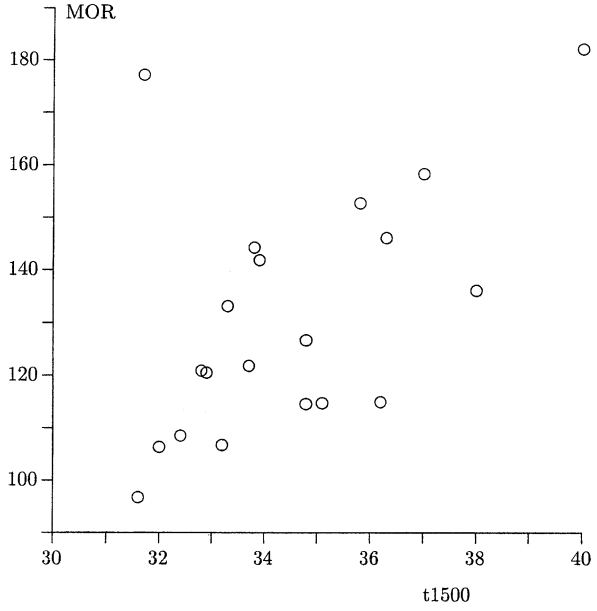

Fig. 2. For disks sintered in the solar furnace, scatterplot of modulus of rupture (MPa) versus length of time (min) the specimen temperature was above 1500 °C.

In view of what has been said above, "statistical significance" cannot be claimed for the correlation between MOR and t1500. The importance of t1500 must be merely a hypothesis for future study.

References

[1] J. Cruz Fernandes, P.M. Amaral, L. Guerra Rosa, N. Shohoji, Weibull statistical analysis of flexure breaking performance for alumina ceramic disks sintered by solar radiation heating, Ceramics International 26 (2000) 203–206.

[2] J.H. Hooper, S.J. Amster, Analysis and presentation of reliability data, in: H.M. Wadsworth (Ed.), Handbook of Statistical Methods for Engineers and Scientists, McGraw-Hill, New York, 1998 (Chapter 9).