DOI: 10.1017/S1431927605502113
Microsc Microanal 11(Suppl 2), 2005

Use of Statistics of Extremes for Microstructural Analysis: ASTM E2283

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Extreme value statistics is an analytical method of observing extremes and predicting further extremes. Historically this type of analysis was first used to predict what magnitude of river flooding could be expected to occur in a certain number of years. Major contributions to both the theory and practical applications of extreme value theory were made by Gumbel [1]. More recently, this analysis has been used to predict how large a nonmetallic inclusion could be expected to be found in a given volume of steel. The control areas used for these studies have ranged from 0.384 mm^2 through 100 mm^2, and the number of planes of observation has ranged from 19 through 80. This suggests a standardized test procedure is required for these types of tests. Commercially, this type of analysis is important because it can be used as a preliminary test procedure for predicting how large a nonmetallic inclusion may be contained in a given volume of steel. This information can be used in modeling component life. The lack of consistency in using this type of analysis has lead to the development of ASTM Standard E2283, "Standard Practice for Extreme Value Analysis of Nonmetallic Inclusions in Steel and other Microstructural Features," [2].

As outlined in E2283, the largest inclusion on 24 different polishing planes are measured, Fig 1. The individual lengths are then sorted in ascending order. Each inclusion is then assigned a probability plotting position based on the following equation: $P_i = i / (N + 1)$ where N is the total number of inclusions measured (24), and i represents the i^{th} inclusion; i.e.; the first is i = 1, the 7^{th} is i = 7, etc. The Reduced Variate is defined as $-\ln(-\ln(P_i))$. As shown by Gumbel, a linear relationship exists between the Reduced Variate and the length of the inclusions, Fig 2.

To establish a Precision and Bias statement for an ASTM standard, an interlaboratory, Round Robin test is used. For this investigation, hardened 4140 steel specimens approximately 20 mm thick and 56 mm in diameter were evaluated. The steel used for this Round Robin contained 0.001% Sulfur, 0.031% Aluminum, 16 ppm Calcium and 5 ppm Oxygen by weight. This material was selected so that all of the large inclusions contained in the steel would only be oxides. Test specimens were sent to 19 different laboratories for analysis. The test results were then analyzed in accordance with ASTM E691 [3]. By using this standard, statistical information regarding the test method can be obtained. Two statistics are used to evaluate the consistency of the data obtained in the interlaboratory study. The "k-value" is used to examine the consistency of the within-laboratory precision - Repeatability. The "h-value" is used to examine the consistency of the test results from laboratory to laboratory - Reproducibility.

Data from one laboratory was immediately rejected because the investigator was not able to properly prepare the specimens, and was not sure the Image Analysis system was properly calibrated when performing the test. A preliminary analysis of the results indicated that another laboratory seemed to have mean values of inclusion lengths that were greater than the critical values of both the h and k statistics. It was later determined that this laboratory did not perform the test in accordance with the furnished instructions; hence, their results were discarded. Thus the testing program was based on the results obtained from 17 laboratories. With regard to the k-statistic, two laboratories were slightly above the critical level, dotted line. For the h-statistic, the results from all the laboratories were below the critical value. This indicates that the testing program was successful.

References

[1] E. J. Gumbel, Statistics of Extremes, Columbia University Press, NYC, 1958.
[2] ASTM E2283, "Standard Practice for Extreme Value Analysis of Nonmetallic Inclusions in Steel and Other Microstructural Features," American Society for Testing and Materials, W. Conshohocken, Pa, 2004.
[3] ASTM E691, "Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method," American Society for Testing and Materials, W. Conshohocken, PA, 2004.

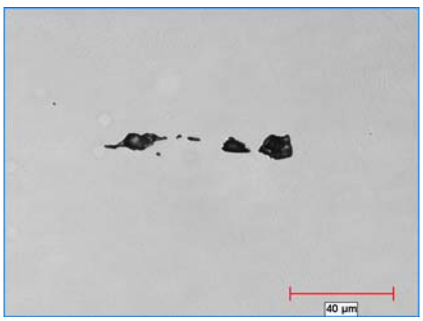

Fig. 1. Typical inclusions contained in the 4140 steel test specimens

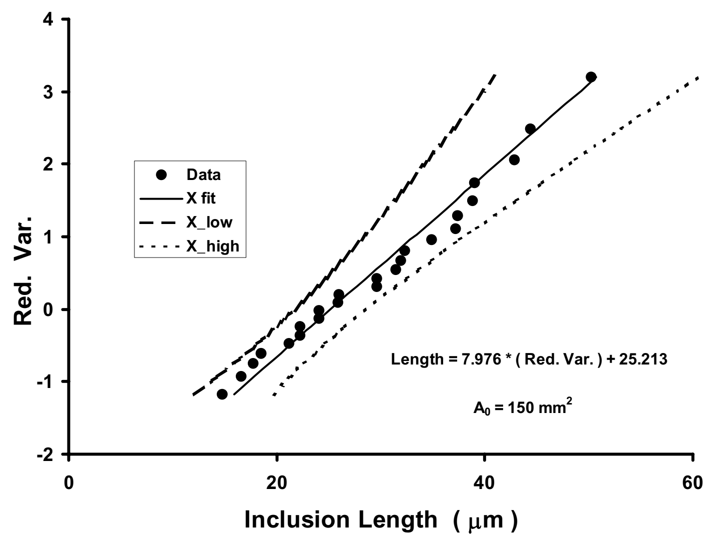

Fig. 2. Typical distribution of large inclusions in the 4140 steel specimens.

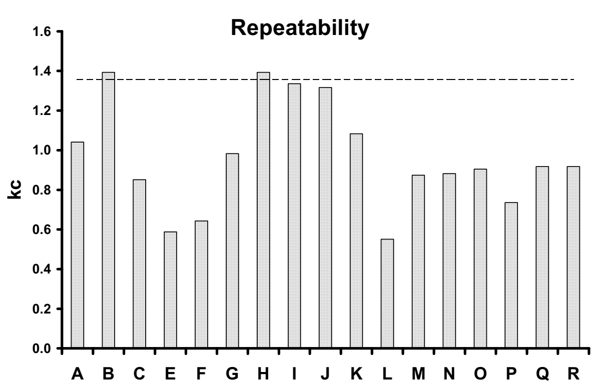

Fig 3. Round Robin test k-statistic.

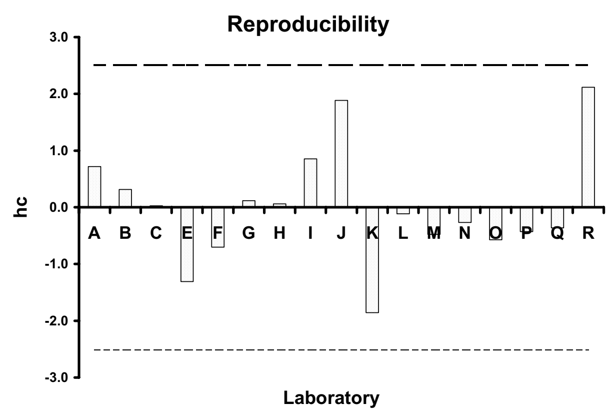

Fig. 4. Round Robin test h-statistic.

https://doi.org/10.1017/S1431927605502113 Published online by Cambridge University Press