EFFECT OF SPECIMEN CHARACTERISTICS ON FLEXURAL STRENGTH

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Introduction

Flexural strength is a key property frequently used to indicate the strength of the artificial graphite products [1]. It combines the tensile and compressive strengths and is a quick inexpensive testing method. Interpretation of flexural testing data involves the consideration of several testing variables. The primary variables include cross-sectional shape of the test specimen (square, rectangular, circular), specimen dimensions (width-to-thickness ratio) and type of loading (i.e., three-point or four-point). These variables influence the stress-field generated within the sample upon loading, and, hence, are expected to yield significantly different flexural strength values.

In this study, the effect of specimen dimensions and cross-section shape on the measured flexural strength of the new high strength isomolded superfine (see [2] for definition) grain graphite, DURACAST® 20 was examined. This grade was selected as it is proving to be successful in non-ferrous metal continuous casting applications.

Experimental

The flexural testing specimens were obtained from an 8" x 8" x 6" block of DURACAST® 20. The specimens were machined to the given dimensions, the surfaces polished to a 120 grit finish, and the edges were beveled by polishing to remove the sharp corners. In this study, the specimens are identified by their smallest dimension and their cross-sectional shape. Therefore, a 1" x 1" x 5" specimen is identified as 1S, where S = square, C = circular, and R = rectangular cross-section. Ten samples were tested for each specimen geometry. Statistical analysis of the data performed included, mean, coefficient of variance, standard deviation, and Weibull analysis [3].

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Results and Discussion

The flexural strengths for the various specimen sizes show a clear variation depending upon the specimen size. The mean values, the coefficient of variance and Weibull modulus obtained for each specimen are shown in Table I. It is clear from Table I, that for the specimens with square and rectangular cross-sections, a decrease in the dimensions leads to an increase in the measured flexural strength. It is well known that the volume and (or) surface area of material under maximum tensile stress is greater for a four-point test specimen than that for the three-point test specimen, and approaches the uniaxial test specimen. This implies that if the surface area (or) volume of the material under maximum tensile stress is smaller, the strength will increase as the probability of a larger flaw under the maximum tensile stress decreases. Therefore, decreasing dimensions will lead to higher flexural strengths, which is indeed the case (see Table I).

The calculated standard deviation and coefficient of variation are lower for the smaller dimensions. This is primarily an indicator of the uniformity of the DURACAST® 20 superfine grain graphite material. Additionally, the smaller square cross-sectioned samples yield the lowest coefficient of variation (or higher Weibull modulus). On the other hand, rectangular cross-section specimens have nearly twice the coefficient of variation compared to the square cross-section. Such low coefficients of variation are essential for development of high strength isotropic graphites for structural applications.

The flexural strength depends on the volume of the material under tension. During four-point flexural testing, the volume of material below the neutral axis is under maximum tensile stress and is where the failure will be initiated. Since isotropic graphite exhibits near-perfect, brittle behavior, which implies instantaneous crack propagation, the crack initiation is the critical step in flexural testing of high strength graphites. This means that material in the immediate vicinity of the lower surface would influence the failure initiation. Thus, the flexural strength was also plotted as a function of the tensile stress volume (TSV), calculated as TSV = Width x Span length-to-thickness ratio x $(\text{Thickness})^2$. Figure 1 is a plot of FS and TSV and corroborates the dependence of flexural strength on the tensile volume. It can be seen that there exists an inverse power law dependence given by the following equation below:

$$FS = 8191*[TSV]^{-0.0275}$$

On the basis of the above results, it is clear that the 0.5S (0.5" x 0.5" x 4") specimen is a suitable specimen for flexural testing of superfine grain graphites. The 0.5S specimen has the lowest coefficient of variation among all the specimen types tested. Additionally, it is smaller in size than 1S (1" x 1" x 5") leading to material savings, large enough to be a representative sample, and does not pose any handling problems.

Conclusions

DURACAST® 20 graphite flexural test specimens of various sizes have high Weibull moduli, which imply a very uniform microstructure. Also, it was observed that a decrease in specimen dimensions leads to a higher mean value. Square cross-section specimens yield higher mean values compared to rectangular cross-section. Also, the scatter in the data for square cross-section specimens is lower than that for the rectangular. There appears to be an inverse power law dependence between the four-point flexural strength and the tensile volume.

References

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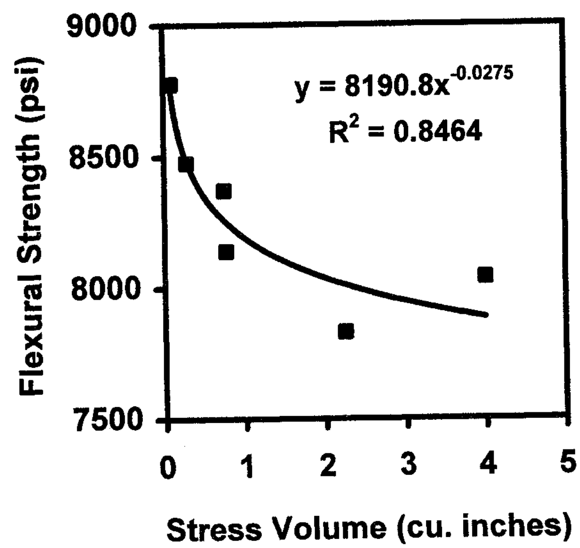

Figure 1. Dependence of flexural strength on the tensile volume for specimens of various sizes from the same material.

Table I. Summary of the Measured and Calculated Data on the Various Flexural Strength Specimens

Specimen I. D.	Span-to-Thickness Ratio (Type of Loading)	Mean Value (psi)	Std. Deviation (psi)	Coeff. Variation (%)	Weibull Modulus
1S	4 (4)	8038	317	3.95	23
0.5S	6 (4)	8371	134	1.60	58
0.25S	6 (4)	8775	144	1.64	59
0.5R	9 (4)	7831	280	3.57	27
0.4R	6 (4)	8139	506	6.22	15
0.25R	9 (4)	8476	283	3.32	30
0.5C	6 (4)	8805	297	3.37	29
0.5S	6 (3)	8898	285	3.20	30