From Printing

DR 2084

CONF-701105

MASTER

THIS DOCUMENT CONFIRMED AS
UNCLASSIFIED
DIVISION OF CLASSIFICATION
BY JHK/RLG/amb
DATE 3/17/72

Proceedings of THE CONFERENCE ON CONTINUUM ASPECTS OF GRAPHITE DESIGN

November 9-12, 1970
Gatlinburg, Tennessee

United States
Atomic Energy Commission

Technical Information Center

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

R3514

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

CHARACTERIZATION OF SEVERAL TYPICAL POLYGRAPHITES
WITH SOME CONVERGENCE ON SOLID BILLET ATJ-S

C. D. Pears
Southern Research Institute

ABSTRACT

Several typical fine, medium, and relatively coarse grain graphites are characterized in terms of thermal and mechanical properties, variations in property, correlations of these properties with porosities and other monitors, and their typical flaws and inspectability. These graphites include nominal AXM-5Q, AXF-5Q, ATJ, G90, and solid billet ATJ-S.

The need to characterize the material for a specific application is emphasized. Essentially, the argument is that proper characterization involves, first, the determination of the general property levels for a generic type, then a more intensive look at the critical properties involved in an application, and finally a screening of the uniformity and reproducibility that can be expected. A record of macrostructure and of inspectability by nondestructive test methods must be kept for each specimen, with the record of its properties. Such records enable judgments to be made on the properties of subsequently received large pieces that cannot be destructively tested and from which specimens for extensive testing cannot be cut. Judgments on the properties of such large pieces can be made by comparison of their macrostructure, the results of nondestructive tests, and a few property tests on specimens from selected locations where property "profiles" are known.

The data and observations also should provide interest for those people who are designing hardware or parameter studies for biaxial tests, temperature stress tests, fracture mechanics tests, or impulse loading.

PROPERTIES IN GENERAL

Figure 1 shows a family of stress-strain curves for various graphites at 2000°F to 2500°F. Generally the stiffness, yield, and ultimate strength increase with decreasing maximum grain size for either the with or across grain direction.

Figure 2 shows the 3500°F envelopes, which is where most of the polygraphites seem to obtain maximum stiffness though not necessarily maximum yield or ultimate. ATJ-S becomes a little stiffer than the AXF-5Q or AXM-5Q, and G90 is gaining on the others in terms of strain at failure.

At 4500°F, the envelopes as shown in Figure 3 have changed character considerably. AXF-5Q has extensive "plastic" behavior; ATJ-S has lost a little stiffness relative to AXF-5Q; ATJ has gained in strain at failure in relation to ATJ-S; and G90 has now fallen relatively well behind these other materials in strain at failure. Yield seems to depart from a rather common "elastic" envelope.

Some of the properties of interest to the designer are shown as a function of temperature in Figure 4. Fracture strength at this strain rate is a fairly uniform function of temperature, increasing continuously to 5000°F.

The 0.02 percent yield of these graphites is about 40 percent of ultimate, and again observe the same order, although there is a temperature peak at about 3500°F.

Strain at failure for three graphites follows a fairly uniform pattern, decreasing at first with increasing temperature and then increasing drastically at a strain threshold temperature. The threshold saddle is moving progressively to the left toward a lower temperature for the finer grained graphites. The elastic moduli

for these three graphites are of the same order though in general smaller for the coarser graphites where one suspects more internal accommodation.

Poisson's ratio does provide a nice spread in values with those for AXF-5Q being quite high and those for G90 quite low. In biaxial and in temperature stress tests, Poisson's ratio may be a good parameter to help design tests to study constitutive relations. Recall that graphites are typically transversely isotropic so that, in fact, there are three values of Poisson's ratio and that they are different.

Figure 5 provides a plot of the wide range of values for thermal conductivity that one can obtain for different graphites. The major point here would be that at the lower temperatures, one can have a rather large range of values for conductivity. One can get the impression that this is indeed a parameter that one can control or select; but at the higher temperatures, or the temperatures that control many designs, the range is reduced. AXM-5Q almost uniquely falls outside of the envelope suggesting relatively less graphitization as is indicated by some of its other properties. The thermal conductivities of three typical graphites often used for parameter tests are shown in Figure 6. Some flexibility is provided by the quite lower values for AXF-5Q at the lower temperatures. For a given graphite, density does correlate with thermal conductivity at least statistically. There is not a one on one correlation between specimens from different billets.

There is a rather broad range of values of thermal expansion available as shown in Figure 7 where the value for AXF-5Q is quite high, and the value for the "original" G90 was quite low. The original G90 logs had quite low expansions that have not been

duplicated yet to the author's knowledge. For a given graphite, there does not seem to be a correlation between density variations and thermal expansion.

SPECIFIC PROPERTIES OF SOLID BILLET ATJ-S

Some typical stress-strain curves are shown in Figures 9, 10, and 11 to provide a feel for the scatter typically seen in a given solid billet of ATJ-S. At a given temperature, a given specimen seems to follow the envelope to its failure site rather than systematically be stiffer, more compliant, or otherwise depart from the envelope. Secant modulus at fracture stays somewhat close to unity, but there is a trend for a given scatter in strength to provide a larger scatter in strain at failure. A composite plot of the averages of the stress-strain curves is shown in Figure 12 with similar curves for ATJ. In the composite, it is striking that ATJ-S is quite stiffer than ATJ at the higher temperatures. At above 4500°F, the stiffnesses of both graphites are quite dependent on stress rates over the range of 10 to 500 psi per second. Below 4000°F, there is not much effect.

The compressive behaviors of ATJ-S at different temperatures as shown in Figures 13 and 14 for with and across grain are important in many applications, particularly where a higher stiffness can convert the thermal expansion into higher tensile strains. In compression, as tension, the material gets stiffer up to about 3500°F or 4000°F, and then becomes more compliant and dependent on stress rate.

The 0.02 percent yield in compression is, perhaps, two times the value in tension, and of course the strains at failure, even at room temperature, are an order of magnitude higher.

One can obtain a reasonably good shear modulus from a torsion test although the fracture value probably is no more than a minimum value. Fracture inevitably is a tensile mode. It is quite difficult in the laboratory to apply shear on a specimen without putting an equal or higher tension some place, and the fracture will be at tensile mode. In spite of these limitations, such torsion curves as those shown in Figures 15 and 16 do have an engineering value.

VARIABILITY IN SOLID BILLET ATJ-S

Now consider variability and the problems it brings to the tester, designer, and experimenter in parameter studies. Figure 17 shows the range of average strengths for 20 billets as reported by four different testers in a recent compilation, the range of average strengths for eight typical billets from one tester, and the range of the individual values for each one of seven individual billets from the latter tester. It is apparent that designing to a 99 percent confidence level reduces the design allowable down to below 3200 psi if one cannot truncate bad testing and bad billets.

Figure 18 shows the density and strength profiles that occur within a billet; these are somewhat worse or more systematic than typical. In the upper part of this billet, there is one density and strength profile across the billet on a radius. Lower in the billet, there is another density and strength profile; and at still another level (axial position) of the billet, there is another density and strength profile.

Certainly there are reasons traceable to the original warm pressing as to why these profiles should vary down the billets. There is nothing strange at all about that. The question is whether or not these variabilities are reproducible and the result of

macrostructure. Figure 19 shows typical macrostructures at 100X from various locations in a solid billet indicating high porosity zones that do match the profiles. The property variations, particularly the strength and strain at failure, do relate to these macrostructures as indicated by other extensive work by the author.

Figure 20 is a plot of open porosity (1 to 6 mils in size for ATJ-S) versus strength for some 200 data points and provides a quantitative measure of what one sees under the microscope. Larger open porosity reduces strength. One standard deviation for all of the data truncates every specimen that upon subsequent inspection either had a disparate flaw or high open porosity that would fall within 95 percent confidence limits on the regression of strength versus open porosity. This is a powerful observation if inevitably true, since it means that better inspection of disparates plus a tighter control or inspection of open porosity would permit raising the design allowable from the 3200 psi mentioned earlier to 4200 psi with no loss in confidence.

There are disparate flaws in graphite larger than the larger voids (background voids) associated with the normal porosity. A radiograph of a disparate void is shown in Figure 21. Pulse-echo would not permit the preselection of this disparate as shown in Figure 22 because of the noise or other signals.

In the fracture face of the broken tensile specimen, this disparate is seen in Figure 23 as a void cluster covering perhaps 12 x 40 mils. Its influence on strength is seen in Table 1 where the value for this specimen was 20 percent low for strength and about 40 percent low for strain at failure. Remember that differences seen in strength are magnified in strain at failure because of the nature of the stress-strain curve. The electrical resistiv-

ity of the gage length of the disparate specimen was about the same as that for the average, as was the velocity, so it was not an odd material other than for the disparate void.

CONCLUSIONS

Graphites are continuum in their bulk behavior and have engineering properties. They also have nominal properties for given ranges of grain size. Different graphites have different characteristic flaws and inspectability.

For a given graphite it is necessary to recognize and properly handle both uniformity and reproducibility, particularly if a small factor of safety is required; this is possible by the judicious profiling of properties and monitors coupled with NDT inspection. Both the typical properties and the variability are observed as differences in the macrostructure.

As a final observation, the designer should never use handbook or typical values as given here to design hardware where low factors of safety are involved. This type of design process demands close iteration between the producer, the characterizer, and the systems group conducting the design, particularly in terms of applicable constitutive relations, reproducibility, and judgments on profiles and truncations.

TABLE 1
INFLUENCE OF DISPARATE VOID IN SPECIMEN A, ATJ-S

	Temp	Density	Strength	Modulus	Strain	Electrical Resistivity	Velocity
Average	4000°F	1.827	7460	1.70	7.6	738	0.1049
Spec A	4000°F	1.823	6040	1.80	4.6	740	0.1045

Fig. 1. Typical Stress-Strain Curves for Several Polygraphites.

Fig. 2. Typical Tensile Stress-Strain Curves for Various Graphites.

Fig. 3. Typical Tensile Stress-Strain Curves for Various Graphites With Grain.

Fig. 4. Mechanical Properties of Various Types of Graphites.

Fig. 5. Thermal Conductivity of Various Graphites.

Fig. 6. Thermal Conductivity of Selected Graphites.

Fig. 7. Thermal Expansion of Selected Graphites.

Fig. 8. Tensile Stress-Strain of ATJ-S at 70°F.

Fig. 11. Tensile Stress-Strain of ATJ-S at 3500°F.

Fig. 12. Comparison of Tensile Stress/Strain, With Grain, at Various Temperatures, of ATJ and ATJ-S.

Fig. 13. Compressive Stress/Axial Strain Curves for ATJ-S, Across Grain.

Fig. 14. Compressive Stress/Axial Strain Curves for ATJ-S, With Grain.

Fig. 15. Torsion of ATJ-S, With Grain.

Fig. 16. Torsion of ATJ-S, Across Grain.

Fig. 17. Ranges of Fracture Strengths for ATJ-S Specimens With Grain at 70°F.

Fig. 18. Comparison of Strength and Density Profiles, Radially and Axially, for ATJ-S Billet L-4-6 (With Grain).

Fig. 19. Macrostructure of Billet ATJ-S. 100X. Reduced 5%.

Fig. 20. Strength as a Function of Open Porosity for ATJ-S, With Grain.

Fig. 21. Radiographic Results (0° and 90° Orientations) for Specimen A, Showing Single-Void Strength Reducer.

Fig. 22. Pulse-Echo Smears and Standing Signal for Specimen A.

Short End

Long End

Fig. 23. 10X Photographs of 0.012-inch $\times$ 0.040-inch Void in Specimen A.