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CHEMICAL IMPURITY DATA ON SELECTED ARTIFICIAL GRAPHITES WITH COMMENTS ON THE CATALYTIC EFFECT OF IMPURITIES ON OXIDATION RATE

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SUMMARY

Forty grades of commercially available, nonpyrolytic, artificial graphite have been analyzed for individual elemental impurities and total ash content. Of the impurities detected, Ca and Fe occur frequently in the highest concentration. Sulfur, Ti, Si, and V also occur frequently in significant concentrations. Other elements are sometimes present, but usually in small concentrations or in only a few grades. For most grades investigated, ash content is approximately proportional to the total concentration of impurities.

A review of the literature has been made to determine the reported catalytic effects of various elemental impurities on the oxidation rate of carbon and graphite. Most elements are reported to accelerate oxidation, while only a limited number are reported to inhibit oxidation. Of the elements found in the 40 graphites investigated, the majority, including Ca, Fe, S, Si, and Ti, are reported in the literature to be weak to moderate accelerators. Only a few elements found in this investigation are reported to be strong accelerators, the most abundant being V. The only reported inhibitor found is B. The very strong accelerators, Bi and Pb, and the strong inhibitor, P, were virtually absent in all the grades studied.

The distribution of impurities of each type (i.e., accelerators or inhibitors) and degree of catalytic activity is similar among the 40 grades of graphite analyzed, with only a few exceptions. Since ash content for most grades is roughly proportional to total impurity content, ash content should, in general, be a convenient and approximate measure of the degree of catalytic acceleration. However, since atypical distributions of impurities occur in a few cases, concentrations of the strong accelerators and inhibitors should always be determined in addition to ash content.

Because the combined effect of the impurities occurring in most graphites is catalytic acceleration, it is obvious that in order to minimize acceleration of the inherent oxidation rate of a graphite, impurities should be reduced to, or maintained at, as low a concentration as possible. A few substances, particularly P and various compounds of P, offer promising possibilities as additives to inhibit oxidation.

INTRODUCTION

Graphite is a material of considerable interest for aerospace applications because of its high strength-to-mass ratio at elevated temperatures, its high emissivity, high sublimation point, and other desirable properties. Unfortunately, however, graphite erodes rapidly at high temperatures in oxidizing environments, such as might be encountered in supersonic and hypersonic vehicle reentry. This erosion rate is not the same for all artificial graphites, even in the same aerodynamic environment (see, for example, ref. 1). It is also not necessarily due to oxidation alone, since mechanical removal of unoxidized material may occur, as a result of aerodynamic shear forces provided the surface is sufficiently vulnerable, either inherently or as the result of uneven oxidation.

Thus, the erosion rate of a particular graphite in a given environment should be dependent on various physical and chemical properties of the graphite, acting either individually or in complex interaction with each other. The specific properties which are most important have not yet been established. One factor of potential importance is the extent to which chemical impurities catalyze[1] the oxidation rate. Such catalysis has been reported by many investigators (refs. 2 to 19). However, detailed chemical impurity data on a wide variety of commercially available, artificial graphites are lacking. These data are necessary for assessing the extent to which the oxidation rate of these graphites may be catalyzed. Furthermore, such data provide a necessary foundation for an investigation of the possible role of impurities in the erosion of graphite under aerospace conditions.

Presented in this report are the results of analyses of 40 selected grades of commercially available, nonpyrolytic, artificial graphite, for individual elemental impurities and for total ash content. Also included is a summary of the important literature on the catalytic influence of various impurities on the oxidation rate of graphite, with particular attention to those impurities found in the graphites analyzed. On the basis of this literature study and the chemical-impurity data of the present study, pertinent generalizations are drawn and recommendations offered for obtaining the lowest possible inherent oxidation rate of artificial graphite.

LITERATURE REVIEW OF CATALYTIC EFFECTS OF IMPURITIES

Many investigations of the catalytic effect of impurities on the rate of gas-solid oxidation of graphite and ungraphitized carbon have been made (refs. 2 to 19). The

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[1]In this report the concept of catalysis is used in its broadest sense to include both positive and negative effects. When the distinction between these two types of catalysis is important the terms "acceleration" or "inhibition" are used.

impurities studied include almost every naturally occurring element except the noble gases. Many of these elements have been studied in more than one form: as uncombined elements, as oxides, and as salts. It should be noted that the form in which an impurity is present at reaction conditions may differ from the form in which it is originally introduced because of possible reaction with the environment or with the carbon itself (refs. 2 to 4 and 20).

Although extensive data on the catalytic activity of various impurities are reported in the literature, the data from different investigations are not strictly comparable because such important test condition parameters as impurity concentration and method of introduction, reaction temperature and pressure, oxidizing gas, and type of graphite or carbon studied have varied from one investigation to the next. Furthermore, none of the theories advanced to date (refs. 3 to 6 and 20) enable data taken under different conditions to be correlated. Nevertheless, certain general observations can be made regarding these data:

1. Almost every impurity studied exhibits some catalytic effect, whether inhibiting or accelerating, under some set of test condition parameters. Of all the impurities which have been studied in the references cited in this report, only Be was reported to have no catalytic effect; however, it was studied only in reference 5.

2. Impurities which are noncatalytic at one test condition may become catalytic at another. For example, B was found to be noncatalytic by Amariglio and Duval (ref. 5), but at higher concentration and reaction temperature, and introduced by a different method, it was found to have a catalytic effect by Rakszawski and Parker (ref. 7). Iron was reported by Heintz and Parker (ref. 8) to be virtually noncatalytic at 600° C, but catalytic at 700° C. Other investigators have shown Fe and a number of its salts to be moderately effective catalysts under their experimental conditions (refs. 2 and 11).

3. A few impurities behave as either accelerators or inhibitors, depending upon the conditions of study. Examples are In, a weak accelerator at 700° C but a weak inhibitor at 800° C (ref. 7), and Ho, a weak inhibitor at 600° C and a weak accelerator at 700° C (ref. 8).

4. Many more impurities act as accelerators than as inhibitors. Almost all metallic impurities studied act as accelerators to some degree, and although most known inhibitors are nonmetallic, not all nonmetals are inhibitors. In fact, Rakszawski and Parker (ref. 7) found that at 700° C all solid nonmetallic and metalloid elements were accelerators except B and P which were inhibitors, and I and At, which were not studied.

5. Marked differences in degree of catalytic activity can occur among different impurities at the same test conditions, and for the same impurities at different test conditions. The extent of the differences in the activity which can occur between different

impurities at the same conditions is illustrated by Zr and Hf, which exhibit relative reaction rates[2] of 1.01 and 18.5, respectively, at 600° C as reported in reference 8. An example of the marked differences in activity which the same impurity can exhibit in the same investigation but at different temperatures is Pd, which is reported in reference 8 to have a relative reaction rate of 1.23 at 600° C and a relative reaction rate of 155.0 at 700° C. Many other examples of the effect of temperature on degree of catalytic activity are given in references 7 and 8. A dramatic example of the considerable difference in activity which a single impurity can exhibit is Pb, which is reported under the conditions of reference 5 to have a relative reaction rate of 470 000, whereas under the different conditions of another investigation (ref. 7), it was reported to have a relative reaction rate of only 13.8. In both investigations, however, Pb was either the strongest, or nearly the strongest, accelerator of all impurities studied.

6. In cases where impurities have been introduced into the graphite as oxides or salts rather than as uncombined elements, the nature and degree of catalysis are frequently dependent upon both the cation and the anion (refs. 3 and 9 to 12). The effects of different cations associated with a common anion have been demonstrated by Harker (ref. 3), who determined ignition temperatures[3] of a purified carbon with and without the addition of small amounts of alkali metal carbonates. Each of these carbonates caused a significant lowering of ignition temperature relative to the untreated carbon, and the extent of depression increased with increasing atomic number of the alkali metal. For example, the ignition-point depression for Li_2CO_3 (lithium carbonate) was 95° C, whereas for Cs_2CO_3 (cesium carbonate) it was 200° C.

The effect of different anions associated with a common cation has been demonstrated by Nebel and Cramer (ref. 9), who studied the effects of 21 compounds of Pb on the ignition temperature of carbon black. The observed ignition-point depression ranged from a high of 290° C for $Pb(C_2H_3O_2)_2$ (lead acetate) to no depression at all for $Pb_3(PO_4)_2$ (lead orthophosphate) and $Pb_2P_2O_7$ (lead pyrophosphate). This study therefore provides an ordering of the relative catalytic activity of various anions. On this basis, the orthophosphate and pyrophosphate ions must be good inhibitors, since they offset the strong accelerating effect of the lead ion (see table I). In fact, these results, together with those of Earp and Hill (ref. 10), suggest that phosphate ions are likely to be

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[2]Relative reaction rate is defined as the ratio of the rate of the catalyzed reaction to the rate of the uncatalyzed reaction for the same graphite or carbon.

[3]Ignition temperature has been used by several investigators (refs. 3, 9, and 11) as a convenient measure of oxidation reactivity, ignition temperature being assumed to be inversely related to oxidation rate. Such a relationship has been qualitatively confirmed by Earp and Hill (ref. 10) for seven carbons and graphites.

the most strongly inhibiting anions. Other anions which are moderately inhibiting include borate ions (ref. 10) and, possibly, sulfate and chromate ions (ref. 9).

7. Catalytic influence on the oxidation of graphite and carbon is not restricted to solid impurities. For example, Day, Walker, and Wright (ref. 13) found that small amounts of gaseous Cl_2 drastically reduced and even quenched the reaction of petroleum coke with oxygen. Wicke (ref. 14) found that 1 percent $POCl_3$ (phosphorus oxychloride) in air increased the ignition temperature of spectroscopic carbon by about 200° C. Frey (ref. 4) found that certain inorganic acids decrease the rate of oxidation of coconut-shell charcoal by a factor of about 10.

The catalytic effect of water vapor is less clear; Schoeppel (ref. 15) reports an accelerating effect of water vapor, whereas Hoynant (as quoted by Amariglio and Duval (ref. 5)) reports an inhibiting effect. Lang, Magnier, and May (ref. 16) observed both acceleration and inhibition due to water vapor, depending on the carbon or graphite studied. A resolution of these apparent discrepancies is offered by Amariglio and Duval (ref. 5), who suggest that water vapor acts as an inhibitor in the oxidation of high-purity graphite or carbon, but as an accelerator in the oxidation of impure graphite or carbon. Thomas and Roscoe (ref. 17) report that in the presence of water vapor even the inhibitor B_2O_3 (boric oxide) becomes an accelerator.

On the basis of the foregoing observations it should be obvious that no meaningful quantitative, or even semiquantitative, catalytic activity can be assigned to individual impurities. Nevertheless, sufficient trends are apparent in the data presented in the literature to permit assigning the various impurities to broad activity groups. Although differences in catalytic activity will exist among the impurities in any one group, such differences should, in general, be less than the differences between members of different groups.

Table I presents activity groupings for selected impurities along with the appropriate literature citations and the temperature ranges over which each impurity was studied. The impurities in each group are listed in order of increasing atomic or molecular weight. The groupings were formulated by comparing individual orderings of catalytic activity obtained from various reported investigations (refs. 2, 3, 5, 7 to 14, and 17). The assignment of a given impurity to a particular group is necessarily subjective, because some inconsistencies among the catalytic orderings of the impurities studied in the different investigations do exist, particularly between reference 8 and the other investigations in which the same impurities were studied. Such inconsistencies are probably due to the differences in test condition parameters noted earlier in this section. Despite these complications, it is felt that the groupings presented are both useful and valid.

In view of the fact, noted above and illustrated by table I, that many more impurities act as accelerators than inhibitors, the effect of a random collection of elemental impurities should be acceleration of oxidation rate, rather than inhibition or passivity. Furthermore, for such a collection of impurities, the degree of acceleration should be grossly related to the total concentration of impurities. This concentration, in turn, should be roughly related to ash content (i.e., the mass of residue remaining after removal of the carbon by combustion). Thus, other factors being equal, a graphite or carbon with a high ash content should oxidize more rapidly than one with a lower ash content, providing their distributions of impurities are similar. A relation between oxidation rate and ash content has been observed by Rusinko (ref. 18) and by Snow, Wallace, Lyon, and Crocker (ref. 19). It is apparent, however, that ash content cannot be expected to serve as a reliable guide to catalytic activity for grades of graphite whose distributions of impurities with regard to type and degree of catalysis are significantly different from each other.

In order to determine the general applicability of ash content as a guide to the catalytic activity of commercial graphites, both ash content and the concentrations of individual elemental impurities must be determined for a wide variety of grades of graphite. In the following sections of this paper such determinations, on 40 selected grades of commercial graphite, are presented and discussed.

EXPERIMENTAL DETERMINATION OF IMPURITIES AND ASH

A list of the 40 grades of commercially available, nonpyrolytic, artificial graphite investigated in this study is presented in table II. Also included in this table are certain properties of each of these grades furnished by the manufacturers at the time of purchase. All grades were graphitized above 2500° C with the possible exception of AHDG. All grades contain coal-tar pitch as the binder carbon with the exception of AHDG, which has a resin binder (ref. 21), and with the possible exception of the proprietary grades.

Two samples of each grade were analyzed for individual elemental impurities and total ash content. The concentrations of elemental impurities were determined spectrographically except for S, which was determined volumetrically as SO_2 by an iodometric technique. Ash determinations were performed according to the ASTM procedure for ash in graphite (ref. 22). All concentrations are expressed in parts of impurity per million parts of sample (ppm), by mass. All elemental analyses and ash determinations were performed by Speer Carbon Company Research Laboratory on samples furnished by NASA. The limit of detection and precision of measurement for each element and for ash are listed in table III.

RESULTS AND DISCUSSION

The results of the separate analyses are presented in table IV and summarized in tables V and VI. The elements listed are those which were detected in at least one of the 40 grades investigated. They are divided into four broad groups of catalytic activity: group I, those elements which are very strong accelerators; group II, those which are strong accelerators; group III, those which are weak to moderate accelerators; and group IV, those which are inhibitors. Differences in concentration of impurities determined between the two samples of each grade reflect both local variations in impurity concentration within the grade and imprecisions in the analyses, the latter being given in table III. Also presented in table IV is the percentage which each element in a grade contributes to the total impurities in that grade, based on its average concentration in the two samples analyzed. These percentages, separated into the four catalytic activity groupings, are summarized by grade in table VI.

From table V, which summarizes the results by impurity, it is seen that the most frequently occurring elements were Si, Fe, Ti, S, V, and Ca. Of these, Fe and Ca occur with the highest average concentrations. Iron occurred in 38 grades with an average concentration of 126.2 ppm in those grades in which it appeared, which included six of the seven grades with no detectable ash. Calcium occurred in 27 grades with an average concentration of 212.2 ppm in those grades in which it appeared. Calcium was not found in any grade that had no detectable ash. Silicon was the only impurity detected in every grade. Its average concentration was 21.3 ppm. Titanium occurred in 37 grades and S in 36, with average concentrations of 23.3 ppm and 50.8 ppm, respectively. Iron, Ca, Si, Ti, and S are all weak to moderate accelerators of the oxidation rate.

Vanadium, the only strong accelerator that occurred frequently, was detected in 32 grades with an average concentration of 24.8 ppm in those grades in which it appeared. With only one exception, the grades in which V was not detected are grades with very low impurity levels.

The only other strong accelerators detected, Na, K, Cu, Mn, and Co, were found in only a few grades (see table V) or at low concentrations.

The only very strong accelerator found, Pb, was detected in only one grade, ME 18.

The only inhibitor found was the weak to moderate inhibitor, B, which was detected in 20 grades but generally in low concentrations. However, in three relatively pure grades (ATL-GP, CDG, and CDG-GP), B accounted for more than 11 percent of the total impurities. The strong inhibitor, P, was not found in any grade, possibly because it has a relatively high limit of detection (see table III).

From table VI it is seen that the distribution of impurities among the catalytic activity groups is similar for most of the grades of graphite studied. For a typical grade, the impurities consist of a high percentage of weak to moderate accelerators, a small percentage of strong accelerators, and an even smaller percentage of the weak to moderate inhibitor, B. Virtually no very strong accelerators are present. The combined catalytic effect of these impurities should be acceleration of the oxidation rate, with the degree of acceleration roughly proportional to the total concentration of impurities.

Figure 1 indicates that ash content is also approximately proportional to the total concentration of impurities with a constant of proportionality of about 2.5. This correlation between ash content and total impurity content is good for most grades having an ash content of less than 2000 ppm, but is less clear for the few grades with ash content above this value. That ash content is larger than the total concentration of impurities is to be expected since ash consists of oxides of the impurities rather than the impurities themselves.

Because of the relationships just described, ash content should serve as a convenient and approximate measure of catalytic activity for graphites with similar distributions of impurities. A few grades, however, have atypical impurity distributions and for these, ash content alone is likely to be unreliable as such a measure. For example, ME 14 has more than 30 percent of its total impurities composed of strong accelerators, whereas most grades have less than 10 percent. Grade ME 14, therefore, may well exhibit greater catalytic activity than its ash content alone would indicate. As another example, ME 18 contains the very strong accelerator, Pb, in addition to a high concentration of strong accelerators. On this basis, ME 18 should oxidize more rapidly than other grades, such as 4007 and L31, even though its ash content is roughly the same as theirs. A third example is CDG-GP, which contains an unusually high percentage of the inhibitor B and no strong accelerators.

In spite of the fact that significant variations in impurity distribution sometimes exist between grades, the combined catalytic effect of impurities in most graphites should be acceleration of oxidation rate to some degree. It is apparent, therefore, that to minimize catalytic acceleration of the inherent oxidation rate of artificial graphite, impurities should be removed, or at least reduced to as low a concentration as possible. To what level the impurity concentration must be reduced before catalytic effects become insignificant has not been firmly established, although Amariglio and Duval (ref. 5) and Heuchamps and Duval (ref. 6) state that at even a few parts per million, some impurities produce a detectable catalytic effect.

Once a high degree of purification has been accomplished, further lowering of the oxidation rate of a graphite may possibly be achieved by introduction of inhibitors. The best inhibitors for this purpose are apparently P and various compounds of P (refs. 4, 7, 9, 10, and 14). Chlorine (ref. 13) is appealing as an inhibitor because of its very strong effect; however, its utilization imposes difficulties because it is a gas. For most situations, though, probably the most practical approach for obtaining a low oxidation rate is simply to remove impurities insofar as possible.

CONCLUDING REMARKS

Forty grades of commercially available, nonpyrolytic, artificial graphite have been analyzed for individual elemental impurities and total ash content. A review of the literature was made to determine the reported catalytic effects of various elemental impurities on the oxidation rate of carbon and graphite.

The main conclusions of this paper are summarized below. Items 1 and 2 are based upon both the literature review and the experimental impurity data generated in this investigation; items 3 and 4 are based solely on the literature review.

1. Most of the impurities contained in a typical commercial grade of nonpyrolytic, artificial graphite are weak to moderate accelerators of its oxidation rate. A small proportion of a few strong accelerators and an even smaller proportion of the inhibitor, B, are generally also present. Virtually no very strong accelerators are present. The combined effect of natural impurities should be catalytic acceleration of oxidation rate. Therefore, in order to minimize catalytic acceleration of the inherent oxidation rate of artificial graphite, impurities should be reduced to as low a concentration as possible.

2. The ash content of a graphite is, for most grades, approximately proportional to the total concentration of its impurities and should, with a few exceptions, be a convenient and approximate measure of the combined catalytic activity of its impurities. Some grades, however, have atypical distributions of impurities and, for these grades, ash content alone is likely to be unreliable as such a measure. The concentrations of the strong accelerators and inhibitors also need to be known.

3. The oxidation rate of a highly pure graphite may possibly be reduced by the introduction of P and various compounds of P, or by the introduction of gaseous chlorine or phosphorus oxychloride directly into the oxidizing environment.

4. Studies of the oxidation rate of graphite should include close attention to the water-vapor concentration in the gaseous oxidant because of its variable and pronounced catalytic effect.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., August 4, 1967,
129-03-12-05-23.

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TABLE I.- APPROXIMATE CATALYTIC ACTIVITY OF SELECTED IMPURITIES ON THE OXIDATION RATE OF CARBON AND GRAPHITE

Catalytic activity groupings[a]	Impurity	References	Temperature ranges of investigations, °C
I: Very strong accelerators	Pb	5, 7, 9, 10, 12	251 to 800
	Bi	7, 10	600 to 800
II: Strong accelerators	Li	3	395
	Na	3, 5, 10, 12	330 to 600
	K	3, 10, 12	296 to 600
	V	5, 8, 10	[b]600 to 700
	Mn	2, 5, 8	457.5 to 720
	Co	2, 8, 11	300 to 750
	Cu	5, 8, 12	[b]370 to 700
	Ag	2, 5, 8, 12	[b]413 to 700
III: Weak to moderate accelerators	Mg	3, 5	[b]490
	Al	7, 5	[b]700 to 800
	Si	7	700 to 800
	S	7	700 to 800
	Ca	3, 5, 10	[b]490 to 600
	Ti	8	600 to 700
	Cr	8	600 to 700
	Fe	2, 8, 11, 12	390 to 720
	Ni	2, 5, 8, 11	[b]390 to 700
	Zn	8	600 to 700
	Sr	3, 5, 10	[b]470 to 600
	Zr	8	600 to 700
	Mo	8	600 to 700
	Ba	3, 5, 10	[b]450 to 600
IV: Weak to moderate inhibitors	B	5, 7, 10, 17	[b]600 to 835
	Borates	10	600
V: Strong inhibitors	P	7, 9, 10	555 to 800
	Cl_2	13	1637 to 1760
	Phosphates	9, 10	555 to 600
	$POCl_3$	14	830 to 890

[a]See text for explanation of groupings.

[b]Temperature ranges of the data in reference 5 for this impurity are not available.

TABLE II.- GRAPHITE GRADES INVESTIGATED

Grade[a]	Filler[b]	Approximate bulk density, g/cc	Maximum grain size, in.	Maximum grain size, mm	Experimental impurity data in table IV, part –
AHDG	AG[c]	[d]1.90	[d]0.033	0.84	1
ME 11	PC, LB, AG	1.65	.003	.076	2
ME 14	PC, LB, AG	1.78	.003	.076	3
ME 15	LB, PC, AG	1.77	.007	.18	4
ME 18	PC, LB, AG	1.65	.003	.076	5
H-205	Proprietary	1.80	.016	.41	6
H-205-85	Proprietary	1.82	.006	.15	7
MHLM	PC[c]	1.79	.033	.84	8
MHLM-85	PC[c]	1.83	.033	.84	9
2BE	PC	1.50	.006	.15	10
2D8D	LB	1.50	.007	.18	11
2D9B	LB, PC	1.62	.007	.18	12
W119	PC, NG	1.70	.010	.25	13
L-56	LB	1.62	.006	.15	14
L-56-GP[e]	LB	1.62	.006	.15	15
P-3W	PC	1.60	.006	.15	16
P-3W-GP[e]	PC	1.60	.006	.15	17
E-24	LB	1.53	.005	.13	18
3499	PC	1.68	.003	.076	19
3499-S	PC	1.65	.003	.076	20
39-RL	PC	1.64	.003	.076	21
4007	PC	1.70	.008	.20	22
8827	PC	1.77	.003	.076	23
9-RL	PC	1.68	.003	.076	24
9050	PC	1.80	.003	.076	25
L1	PC	1.59	.006	.15	26
L31	LB	1.66	.006	.15	27
331	PC	1.76	.003	.076	28
AGSX	PC[c]	[d]1.67	[d].016	.41	29
ATJ	PC	1.74	.006	.15	30
ATJ-GP[e]	PC	1.72	.006	.15	31
ATJS	PC	1.83	.006	.15	32
ATJS-GP[e]	PC	1.83	.006	.15	33
ATL	PC	1.78	.030	.76	34
ATL-GP[e]	PC	1.89	.030	.76	35
CDA	PC, LB	1.61	.006	.15	36
CDG	PC, LB	1.49	.016	.41	37
CDG-GP[e]	PC, LB	1.47	.016	.41	38
CMB	PC, LB	1.75	.003	.076	39
PGR	PC	1.68	.030	.76	40

[a]All grades are molded except AHDG and AGSX, which are extruded.

[b]Filler materials are: AG, artificial graphite; LB, lampblack; NG, natural graphite; PC, petroleum coke.

[c]From reference 21.

[d]From reference 1.

[e]Gas-purified version of base grade denoted by GP.

TABLE III.- LIMITS OF DETECTION AND PRECISION OF MEASUREMENTS

Impurity	Limit of detection,[a] ppm	Coefficient of variation, %
Li	0.5	50
B	1	50
Na	.5	50
Mg	1	20
Al	3	20
Si	1	20
P	25	50
S	1	20
K	.5	50
Ca	25	20
Ti	1	20
V	1	20
Cr	5	50
Mn	1	50
Fe	1	20
Co	10	50
Ni	10	50
Cu	1	20
Zn	10	50
Sr	25	50
Zr	5	50
Mo	5	50
Ag	1	50
Ba	25	50
Pb	1	50
Bi	5	50
Ash	5	20

[a]Other metallic elements have a limit of detection of about 25 ppm.

TABLE IV.- IMPURITY DATA FOR GRAPHITE GRADES INVESTIGATED

		(1) Grade AHDG			(2) Grade ME 11			(3) Grade ME 14			(4) Grade ME 15		
Group[a]	Impurity	Concentration,[b] ppm		Percent of total impurities	Concentration,[b] ppm		Percent of total impurities	Concentration,[b] ppm		Percent of total impurities	Concentration,[b] ppm		Percent of total impurities
		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2	
I	Pb	----	----	-----	---	---	-----	---	---	-----	---	---	-----
II	Na	----	----	-----	---	---	-----	---	---	-----	---	---	-----
	K	----	----	-----	---	---	-----	---	---	-----	---	---	-----
	V	84	83	15.7	16	51	19.6	25	46	33.3	4	11	12.2
	Mn	----	----	-----	---	---	-----	---	---	-----	---	---	-----
	Co	----	----	-----	---	---	-----	---	---	-----	---	---	-----
	Cu	----	----	-----	---	---	-----	---	---	-----	---	---	-----
III	Mg	----	----	-----	---	---	-----	---	---	-----	---	---	-----
	Al	14	16	2.8	---	---	-----	---	---	-----	---	---	-----
	Si	56	70	11.8	2	2	1.2	4	6	4.7	2	9	8.9
	S	----	----	-----	7	6	3.8	7	5	5.6	19	12	25.2
	Ca	110	115	21.2	29	34	18.4	---	---	-----	---	---	-----
	Ti	15	20	3.3	3	9	3.5	2	8	4.7	6	6	9.8
	Cr	----	----	-----	---	---	-----	---	---	-----	---	---	-----
	Fe	200	240	41.5	70	96	48.5	56	44	47.0	18	22	32.5
	Ni	40	----	3.8	15	---	4.4	---	10	4.7	---	10	8.1
	Zn	----	----	-----	---	---	-----	---	---	-----	---	---	-----
	Zr	----	----	-----	---	---	-----	---	---	-----	---	---	-----
	Mo	----	----	-----	---	---	-----	---	---	-----	---	---	-----
IV	B	----	----	-----	1	1	0.6	---	---	-----	2	2	3.3
	Total	519	544	100	143	199	100	94	119	100	51	72	100
	Ash	1118	1146	-----	404	430	-----	260	248	-----	104	142	-----

[a]The elements are divided into the following activity groups: I – Very strong accelerators; II – Strong accelerators; III – Weak to moderate accelerators; IV – Inhibitors.

[b]Dashes indicate that the particular impurity was not detected. See table III for limits of detection.

TABLE IV.- IMPURITY DATA FOR GRAPHITE GRADES INVESTIGATED – Continued

		(5) Grade ME 18			(6) Grade H-205			(7) Grade H-205-85			(8) Grade MHLM		
Group[a]	Impurity	Concentration,[b] ppm		Percent of total impurities	Concentration,[b] ppm		Percent of total impurities	Concentration,[b] ppm		Percent of total impurities	Concentration,[b] ppm		Percent of total impurities
		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2	
I	Pb	10	---	2.5	------	----	-----	------	----	-----	-----	---	-----
II	Na	---	1	0.3	------	----	-----	------	----	-----	-----	---	-----
	K	---	---	-----	------	----	-----	------	----	-----	-----	---	-----
	V	25	49	18.8	9.8	10	1.7	7.5	8	0.7	49	60	15.2
	Mn	---	---	-----	------	----	-----	------	----	-----	-----	---	-----
	Co	---	---	-----	------	10	.9	------	20	.9	-----	---	-----
	Cu	---	---	-----	------	----	-----	------	----	-----	-----	---	-----
III	Mg	---	---	-----	------	----	-----	------	----	-----	-----	---	-----
	Al	---	---	-----	11	14	2.2	5.8	25	1.4	3.8	---	0.5
	Si	4	4	2.0	160	170	28.9	84	160	11.0	12	13	3.5
	S	10	2	3.1	3	17	1.8	3	----	.1	-----	---	-----
	Ca	33	26	15.0	190	240	37.6	28	33	2.7	140	200	47.4
	Ti	5	8	3.3	11	14	2.2	31	25	2.5	65	120	25.8
	Cr	---	---	-----	------	15	1.3	------	10	.4	-----	---	-----
	Fe	74	85	40.5	88	100	16.5	240	300	24.2	3.1	2	.7
	Ni	15	15	7.6	25	30	4.8	25	90	5.2	-----	---	-----
	Zn	25	---	6.4	------	----	-----	------	----	-----	15	20	4.9
	Zr	---	---	-----	------	----	-----	550	550	49.4	-----	---	-----
	Mo	---	---	-----	10	15	2.2	10	20	1.3	-----	---	-----
IV	B	1	1	0.5	------	----	-----	1	1	0.1	5	10	2.1
	Total	202	191	100	507.8	635	100	985.3	1242	100	292.9	425	100
	Ash	352	372	-----	1549	1488	-----	3643	4657	-----	743	740	-----

[a]The elements are divided into the following activity groups: I – Very strong accelerators; II – Strong accelerators; III – Weak to moderate accelerators; IV – Inhibitors.

[b]Dashes indicate that the particular impurity was not detected. See table III for limits of detection.

TABLE IV.- IMPURITY DATA FOR GRAPHITE GRADES INVESTIGATED – Continued

Group[a]	Impurity	(9) Grade MHLM-85 Concentration,[b] ppm		(9) Grade MHLM-85 Percent of total impurities	(10) Grade 2BE Concentration,[b] ppm		(10) Grade 2BE Percent of total impurities	(11) Grade 2D8D Concentration,[b] ppm		(11) Grade 2D8D Percent of total impurities	(12) Grade 2D9B Concentration,[b] ppm		(12) Grade 2D9B Percent of total impurities
		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2	
I	Pb	-----	---	-----	----	----	-----	----	----	-----	----	----	-----
II	Na	-----	---	-----	----	2	0.2	7	5	0.5	----	2	0.1
	K	-----	---	-----	----	----	-----	15	15	1.2	2	5	.2
	V	51	43	17.0	44	14	7.1	2	5	.3	7	15	.6
	Mn	-----	---	-----	----	----	-----	10	10	.8	----	----	-----
	Co	-----	---	-----	----	----	-----	----	----	-----	----	----	-----
	Cu	-----	---	-----	----	----	-----	29	36	2.5	----	----	-----
III	Mg	-----	---	-----	----	----	-----	5	6	0.4	----	----	-----
	Al	5.6	---	1.0	----	5	0.6	54	260	12.3	----	6	0.2
	Si	20	15	6.3	2	5	.9	18	18	1.4	4	9	.3
	S	6	7	2.4	6	7	1.6	532	560	42.7	30	45	2.0
	Ca	130	160	52.6	370	310	83.6	220	190	16.1	1400	2100	93.0
	Ti	38	34	13.1	15	15	3.7	10	18	1.1	13	14	.7
	Cr	-----	---	-----	----	----	-----	----	----	-----	----	----	-----
	Fe	3	4	1.3	3	6	1.1	280	230	20.0	9	14	.6
	Ni	-----	---	-----	----	10	1.2	20	----	.8	15	15	.8
	Zn	-----	15	2.7	----	----	-----	----	----	-----	20	15	.9
	Zr	-----	---	-----	----	----	-----	----	----	-----	----	----	-----
	Mo	-----	---	-----	----	----	-----	----	----	-----	10	10	.5
IV	B	10	10	3.6	----	----	-----	----	----	-----	2	1	0.1
	Total	263.6	288	100	440	374	100	1202	1353	100	1512	2251	100
	Ash	684	700	-----	1180	1058	-----	2558	2424	-----	2953	3440	-----

[a]The elements are divided into the following activity groups: I – Very strong accelerators; II – Strong accelerators; III – Weak to moderate accelerators; IV – Inhibitors.

[b]Dashes indicate that the particular impurity was not detected. See table III for limits of detection.

TABLE IV.- IMPURITY DATA FOR GRAPHITE GRADES INVESTIGATED – Continued

Group[a]	Impurity	(13) Grade W119			(14) Grade L-56			(15) Grade L-56-GP			(16) Grade P-3W		
		Concentration,[b] ppm		Percent of total impurities	Concentration,[b] ppm		Percent of total impurities	Concentration,[b] ppm		Percent of total impurities	Concentration,[b] ppm		Percent of total impurities
		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2	
I	Pb	----	----	-----	-	-	-----	-	-	-----	--	-	-----
II	Na	----	----	-----	-	-	-----	-	-	-----	--	-	-----
	K	----	----	-----	-	-	-----	-	-	-----	--	-	-----
	V	23	80	3.1	-	-	-----	-	-	-----	--	-	-----
	Mn	----	----	-----	-	-	-----	-	-	-----	--	-	-----
	Co	----	----	-----	-	-	-----	-	-	-----	--	-	-----
	Cu	----	----	-----	-	-	-----	-	-	-----	--	-	-----
III	Mg	----	----	-----	-	-	-----	-	-	-----	--	-	-----
	Al	47	----	1.4	-	-	-----	-	-	-----	--	-	-----
	Si	8	4	.4	4	2	60.0	1	2	16.7	2	1	17.7
	S	86	----	2.6	-	-	-----	4	7	61.1	10	1	64.7
	Ca	1300	610	56.5	-	-	-----	-	-	-----	--	-	-----
	Ti	93	160	7.5	2	-	20.0	2	-	11.1	1	-	5.9
	Cr	20	----	.6	-	-	-----	-	-	-----	--	-	-----
	Fe	780	56	24.8	2	-	20.0	2	-	11.1	2	-	11.8
	Ni	35	15	1.5	-	-	-----	-	-	-----	--	-	-----
	Zn	25	----	.7	-	-	-----	-	-	-----	--	-	-----
	Zr	10	10	.6	-	-	-----	-	-	-----	--	-	-----
	Mo	----	----	-----	-	-	-----	-	-	-----	--	-	-----
IV	B	5	8	0.4	-	-	-----	-	-	-----	--	-	-----
	Total	2432	943	100	8	2	100	9	9	100	15	2	100
	Ash	6229	2222	-----	-	-	-----	-	-	-----	--	-	-----

[a]The elements are divided into the following activity groups: I – Very strong accelerators; II – Strong accelerators; III – Weak to moderate accelerators; IV – Inhibitors.

[b]Dashes indicate that the particular impurity was not detected. See table III for limits of detection.

TABLE IV.- IMPURITY DATA FOR GRAPHITE GRADES INVESTIGATED – Continued

Group[a]	Impurity	(17) Grade P-3W-GP			(18) Grade E-24			(19) Grade 3499			(20) Grade 3499-S		
		Concentration,[b] ppm		Percent of total impurities	Concentration,[b] ppm		Percent of total impurities	Concentration,[b] ppm		Percent of total impurities	Concentration,[b] ppm		Percent of total impurities
		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2	
I	Pb	-	-	-----	---	----	-----	---	---	-----	---	---	-----
II	Na	-	-	-----	---	----	-----	1	---	0.3	---	---	-----
	K	-	-	-----	---	----	-----	1	---	.3	---	---	-----
	V	-	-	-----	12	10	2.9	17	10	7.7	20	14	9.9
	Mn	-	-	-----	---	----	-----	---	---	-----	---	---	-----
	Co	-	-	-----	---	----	-----	---	---	-----	---	---	-----
	Cu	-	-	-----	---	----	-----	---	---	-----	---	---	-----
III	Mg	-	-	-----	---	----	-----	---	---	-----	---	---	-----
	Al	-	-	-----	---	----	-----	---	---	-----	---	---	-----
	Si	1	3	50.0	90	54	18.9	17	12	8.2	18	21	11.3
	S	1	-	12.5	81	83	21.6	32	23	15.6	35	22	16.6
	Ca	-	-	-----	150	115	34.8	94	84	50.6	58	65	35.8
	Ti	1	-	12.5	74	56	17.1	37	17	15.3	27	40	19.5
	Cr	-	-	-----	---	----	-----	---	---	-----	---	---	-----
	Fe	2	-	25.0	---	----	-----	4	3	2.0	2	2	1.2
	Ni	-	-	-----	---	----	-----	---	---	-----	---	---	-----
	Zn	-	-	-----	15	20	4.6	---	---	-----	---	20	5.8
	Zr	-	-	-----	---	----	-----	---	---	-----	---	---	-----
	Mo	-	-	-----	---	----	-----	---	---	-----	---	---	-----
IV	B	-	-	-----	---	1	0.1	---	---	-----	---	---	-----
	Total	5	3	100	422	339	100	203	149	100	160	184	100
	Ash	6	-	-----	733	1131	-----	448	484	-----	456	464	-----

[a]The elements are divided into the following activity groups: I – Very strong accelerators; II – Strong accelerators; III – Weak to moderate accelerators; IV – Inhibitors.

[b]Dashes indicate that the particular impurity was not detected. See table III for limits of detection.

TABLE IV.- IMPURITY DATA FOR GRAPHITE GRADES INVESTIGATED – Continued

Group[a]	Impurity	(21) Grade 39-RL: Concentration,[b] ppm		(21) Grade 39-RL: Percent of total impurities	(22) Grade 4007: Concentration,[b] ppm		(22) Grade 4007: Percent of total impurities	(23) Grade 8827: Concentration,[b] ppm		(23) Grade 8827: Percent of total impurities	(24) Grade 9-RL: Concentration,[b] ppm		(24) Grade 9-RL: Percent of total impurities
		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2	
I	Pb	-	-	-----	---	---	-----	---	---	-----	--	-	-----
II	Na	-	-	-----	---	---	-----	---	---	-----	--	-	-----
	K	-	-	-----	---	---	-----	---	---	-----	--	-	-----
	V	-	-	-----	11	10	6.3	16	12	9.8	--	-	-----
	Mn	-	-	-----	---	---	-----	---	---	-----	--	-	-----
	Co	-	-	-----	---	---	-----	---	---	-----	--	-	-----
	Cu	-	-	-----	---	---	-----	---	---	-----	--	-	-----
III	Mg	-	-	-----	---	---	-----	---	---	-----	--	-	-----
	Al	-	-	-----	---	---	-----	---	---	-----	--	-	-----
	Si	3	1	57.1	36	13	14.6	23	12	12.2	2	-	6.3
	S	-	-	-----	11	39	14.9	35	14	17.1	25	5	93.8
	Ca	-	-	-----	33	33	19.7	66	51	40.8	--	-	-----
	Ti	-	-	-----	72	36	32.2	16	32	16.7	--	-	-----
	Cr	-	-	-----	---	---	-----	---	---	-----	--	-	-----
	Fe	3	-	42.9	4	2	1.8	7	3	3.5	--	-	-----
	Ni	-	-	-----	---	---	-----	---	---	-----	--	-	-----
	Zn	-	-	-----	15	20	10.4	---	---	-----	--	-	-----
	Zr	-	-	-----	---	---	-----	---	---	-----	--	-	-----
	Mo	-	-	-----	---	---	-----	---	---	-----	--	-	-----
IV	B	-	-	-----	---	---	-----	---	---	-----	--	-	-----
	Total	6	1	100	182	153	100	163	124	100	27	5	100
	Ash	-	-	-----	377	382	-----	428	410	-----	--	-	-----

[a]The elements are divided into the following activity groups: I – Very strong accelerators; II – Strong accelerators; III – Weak to moderate accelerators; IV – Inhibitors.

[b]Dashes indicate that the particular impurity was not detected. See table III for limits of detection.

TABLE IV.- IMPURITY DATA FOR GRAPHITE GRADES INVESTIGATED – Continued

Group[a]	Impurity	(25) Grade 9050			(26) Grade L1			(27) Grade L31			(28) Grade 331		
		Concentration,[b] ppm		Percent of total impurities	Concentration,[b] ppm		Percent of total impurities	Concentration,[b] ppm		Percent of total impurities	Concentration,[b] ppm		Percent of total impurities
		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2	
I	Pb	---	---	-----	---	---	-----	---	---	-----	----	----	-----
II	Na	2	---	0.7	5	3	1.0	5	5	2.0	1	----	0.1
	K	---	---	-----	---	---	-----	---	1	.2	1	2	.3
	V	16	12	10.3	16	35	6.2	1	---	.2	19	23	4.4
	Mn	---	---	-----	---	---	-----	---	---	-----	----	----	-----
	Co	---	---	-----	---	---	-----	---	---	-----	----	----	-----
	Cu	---	---	-----	32	34	8.1	---	3	.6	----	----	-----
III	Mg	---	---	-----	---	---	-----	---	2	0.4	----	----	-----
	Al	---	---	-----	6	7	1.6	6	5	2.2	17	17	3.5
	Si	18	16	12.5	3	3	.7	9	9	3.5	67	44	11.6
	S	17	16	12.1	102	156	31.6	63	109	33.9	43	7	5.2
	Ca	56	65	44.3	33	34	8.2	23	33	11.0	240	320	58.3
	Ti	31	16	17.2	2	3	.6	8	6	2.8	15	20	3.6
	Cr	---	---	-----	---	---	-----	---	---	-----	----	----	-----
	Fe	4	4	2.9	150	180	40.3	110	110	43.3	64	60	12.9
	Ni	---	---	-----	15	---	1.8	---	---	-----	----	----	-----
	Zn	---	---	-----	---	---	-----	---	---	-----	----	----	-----
	Zr	---	---	-----	---	---	-----	---	---	-----	----	----	-----
	Mo	---	---	-----	---	---	-----	---	---	-----	----	----	-----
IV	B	---	---	-----	---	---	-----	---	---	-----	----	1	0.1
	Total	144	129	100	364	455	100	225	283	100	467	494	100
	Ash	408	374	-----	704	714	-----	396	358	-----	1482	1470	-----

[a]The elements are divided into the following activity groups: I – Very strong accelerators; II – Strong accelerators; III – Weak to moderate accelerators; IV – Inhibitors.

[b]Dashes indicate that the particular impurity was not detected. See table III for limits of detection.

TABLE IV.- IMPURITY DATA FOR GRAPHITE GRADES INVESTIGATED – *Continued*

Group[a]	Impurity	(29) Grade AGSX: Concentration,[b] ppm		(29) Grade AGSX: Percent of total impurities	(30) Grade ATJ: Concentration,[b] ppm		(30) Grade ATJ: Percent of total impurities	(31) Grade ATJ-GP: Concentration,[b] ppm		(31) Grade ATJ-GP: Percent of total impurities	(32) Grade ATJS: Concentration,[b] ppm		(32) Grade ATJS: Percent of total impurities
		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2	
I	Pb	---	---	-----	----	----	-----	--	--	-----	---	----	-----
II	Na	---	---	-----	----	----	-----	--	--	-----	---	----	-----
	K	---	---	-----	----	1	0.2	--	--	-----	---	----	-----
	V	18	32	10.6	19	12	3.4	1	2	5.0	34	20	8.8
	Mn	---	---	-----	----	----	-----	--	--	-----	---	----	-----
	Co	---	---	-----	----	----	-----	--	--	-----	---	----	-----
	Cu	---	---	-----	----	----	-----	--	--	-----	---	----	-----
III	Mg	---	---	-----	----	----	-----	--	--	-----	---	----	-----
	Al	6	8	3.0	12	8	2.2	--	--	-----	6	6	2.0
	Si	25	21	9.7	68	41	11.8	4	8	20.0	2	----	.3
	S	6	5	2.3	----	9	1.0	18	--	30.0	5	2	1.1
	Ca	59	72	27.8	260	250	55.4	--	--	-----	56	66	19.9
	Ti	80	69	31.6	9	5	1.5	3	7	16.7	14	11	4.1
	Cr	---	---	-----	----	10	1.1	--	--	-----	---	----	-----
	Fe	21	20	8.7	110	90	21.7	--	17	28.3	180	200	61.9
	Ni	---	---	-----	----	----	-----	--	--	-----	---	10	1.6
	Zn	15	15	6.4	----	15	1.6	--	--	-----	---	----	-----
	Zr	---	---	-----	----	----	-----	--	--	-----	---	----	-----
	Mo	---	---	-----	----	----	-----	--	--	-----	---	----	-----
IV	B	---	---	-----	----	1	0.1	--	--	-----	---	2	0.3
	Total	230	242	100	478	442	100	26	34	100	297	317	100
	Ash	540	620	-----	1194	1224	-----	20	30	-----	550	2700	-----

[a]The elements are divided into the following activity groups: I – Very strong accelerators; II – Strong accelerators; III – Weak to moderate accelerators; IV – Inhibitors.

[b]Dashes indicate that the particular impurity was not detected. See table III for limits of detection.

TABLE IV.- IMPURITY DATA FOR GRAPHITE GRADES INVESTIGATED – Continued

Group[a]	Impurity	(33) Grade ATJS-GP			(34) Grade ATL			(35) Grade ATL-GP			(36) Grade CDA		
		Concentration,[b] ppm		Percent of total impurities	Concentration,[b] ppm		Percent of total impurities	Concentration,[b] ppm		Percent of total impurities	Concentration,[b] ppm		Percent of total impurities
		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2	
I	Pb	--	-	-----	----	----	-----	--	--	-----	-----	---	-----
II	Na	--	-	-----	1	----	0.0	--	--	-----	-----	---	-----
	K	--	-	-----	2	2	.1	--	--	-----	-----	---	-----
	V	--	-	-----	56	45	1.4	2	2	9.1	34	49	14.6
	Mn	--	-	-----	5	10	.2	--	--	-----	-----	---	-----
	Co	--	-	-----	----	----	-----	--	--	-----	-----	---	-----
	Cu	--	-	-----	6	8	.2	--	--	-----	-----	---	-----
III	Mg	--	-	-----	----	3	0.0	--	--	-----	-----	---	-----
	Al	--	-	-----	22	160	2.5	--	--	-----	-----	---	-----
	Si	3	-	6.8	17	15	.4	3	2	11.4	23	18	7.2
	S	30	-	68.2	592	567	16.2	10	2	27.3	1	---	.2
	Ca	--	-	-----	270	290	7.8	--	--	-----	195	160	62.3
	Ti	2	5	15.9	22	26	.7	5	9	31.8	44	37	14.2
	Cr	--	-	-----	20	20	.6	--	--	-----	-----	---	-----
	Fe	2	-	4.6	2600	2300	68.3	--	3	6.8	1.9	2	.7
	Ni	--	-	-----	20	20	.6	--	--	-----	-----	---	-----
	Zn	--	-	-----	----	----	-----	--	--	-----	-----	---	-----
	Zr	--	-	-----	----	----	-----	--	--	-----	-----	---	-----
	Mo	--	-	-----	----	----	-----	--	--	-----	-----	---	-----
IV	B	1	1	4.6	30	40	1.0	5	1	13.6	3	2	0.9
	Total	38	6	100	3663	3506	100	25	19	100	301.9	268	100
	Ash	--	-	-----	5900	5719	-----	34	--	-----	700	718	-----

[a]The elements are divided into the following activity groups: I – Very strong accelerators; II – Strong accelerators; III – Weak to moderate accelerators; IV – Inhibitors.

[b]Dashes indicate that the particular impurity was not detected. See table III for limits of detection.

TABLE IV.- IMPURITY DATA FOR GRAPHITE GRADES INVESTIGATED – Concluded

Group[a]	Impurity	(37) Grade CDG Concentration,[b] ppm		(37) Grade CDG Percent of total impurities	(38) Grade CDG-GP Concentration,[b] ppm		(38) Grade CDG-GP Percent of total impurities	(39) Grade CMB Concentration,[b] ppm		(39) Grade CMB Percent of total impurities	(40) Grade PGR Concentration,[b] ppm		(40) Grade PGR Percent of total impurities
		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2		Sample 1	Sample 2	
I	Pb	-----	-----	-----	--	--	-----	--	--	-----	---	---	-----
II	Na	-----	-----	-----	--	--	-----	--	--	-----	---	1	0.1
	K	-----	-----	-----	--	--	-----	--	--	-----	---	---	-----
	V	23	18	11.5	--	--	-----	4	4	13.8	84	51	19.6
	Mn	-----	-----	-----	--	--	-----	--	--	-----	---	---	-----
	Co	-----	-----	-----	--	--	-----	--	--	-----	---	---	-----
	Cu	-----	-----	-----	--	--	-----	--	--	-----	---	---	-----
III	Mg	-----	-----	-----	--	--	-----	--	--	-----	---	---	-----
	Al	-----	-----	-----	--	--	-----	--	4	6.9	---	---	-----
	Si	46	27	20.4	1	2	7.0	3	2	8.6	10	18	4.1
	S	22	31	14.8	16	--	37.2	15	--	25.9	---	16	2.3
	Ca	65	56	33.8	--	--	-----	--	--	-----	56	85	20.5
	Ti	16	9	7.0	--	--	-----	3	3	10.3	43	32	10.9
	Cr	-----	-----	-----	--	--	-----	--	--	-----	---	---	-----
	Fe	1.6	3	1.3	4	--	9.3	10	9	32.8	35	240	40.0
	Ni	-----	-----	-----	--	--	-----	--	--	-----	---	---	-----
	Zn	-----	-----	-----	--	--	-----	--	--	-----	15	---	2.2
	Zr	-----	-----	-----	--	--	-----	--	--	-----	---	---	-----
	Mo	-----	-----	-----	--	--	-----	--	--	-----	---	---	-----
IV	B	20	20	11.2	10	10	46.5	1	--	1.7	1	1	0.3
	Total	193.6	164.0	100	31	12	100	36	22	100	244	444	100
	Ash	530	532	-----	--	--	-----	70	58	-----	446	930	-----

[a]The elements are divided into the following activity groups: I – Very strong accelerators; II – Strong accelerators; III – Weak to moderate accelerators; IV – Inhibitors.

[b]Dashes indicate that the particular impurity was not detected. See table III for limits of detection.

TABLE V.- SUMMARY OF RESULTS BY INDIVIDUAL IMPURITIES

FOR THE GRAPHITES INVESTIGATED

Group[a]	Impurity	Number of grades in which present	Maximum concentration[b] in any grade, ppm	Average concentration[b] in grades in which impurity appears, ppm
I	Pb	1	5	5.0
II	Na	11	6	1.9
	K	7	15	3.4
	V	32	83.5	24.8
	Mn	2	10	8.8
	Co	2	10	7.5
	Cu	4	33	18.5
III	Mg	3	5.5	2.7
	Al	17	157	22.3
	Si	40	165	21.3
	S	36	579.5	50.8
	Ca	27	1750	212.2
	Ti	37	126.5	23.3
	Cr	5	20	9.5
	Fe	38	2450	126.2
	Ni	14	57.5	16.1
	Zn	11	17.5	13.0
	Zr	2	550	280.0
	Mo	3	15	12.5
IV	B	20	35	5.3
	Ash	33	5810	1130.1

[a]The elements are divided into the following activity groups: I – Very strong accelerators; II – Strong accelerators; III – Weak to moderate accelerators; IV – Inhibitors.

[b]The concentration of an impurity in any given grade is defined as the average of the concentrations of the impurity in the two samples of that grade.

TABLE VI.- SUMMARY OF RESULTS BY GRADES INVESTIGATED

Grade	Average ash, ppm	Average total impurities, ppm	Percent of impurities in activity group[a] –		
			II	III	IV
AHDG	1132.0	531.5	15.7	84.4	----
ME 11	417.0	171.0	19.6	79.8	0.6
ME 14	254.0	106.5	33.3	66.7	----
ME 15	123.0	61.5	12.2	84.5	3.3
ME 18	362.0	196.5	[b]21.6	77.9	.5
H-205	1518.5	571.4	2.6	97.5	----
H-205-85	4150.0	1113.7	1.6	98.2	.1
MHLM	741.5	359.0	15.2	82.8	2.1
MHLM-85	692.0	275.8	17.0	79.4	3.6
2BE	1119.0	407.0	7.3	92.7	----
2D8D	2491.0	1277.5	5.3	94.8	----
2D9B	3196.5	1881.5	.9	99.0	.1
W119	4225.5	1687.5	3.1	96.6	.4
L-56	------	5.0	-----	100	----
L-56-GP	------	9.0	-----	100	----
P-3W	------	8.5	-----	100	----
P-3W-GP	3.0	4.0	-----	100	----
E-24	932.0	380.5	2.9	97.0	.1
3499	466.0	176.0	8.3	91.7	----
3499-S	460.0	172.0	9.9	90.2	----
39-RL	------	3.5	-----	100	----
4007	379.5	167.5	6.3	93.6	----
8827	419.0	143.5	9.8	90.3	----
9-RL	------	16.0	-----	100	----
9050	391.0	136.5	11.0	89.0	----
L1	709.0	409.5	15.3	84.8	----
L31	377.0	254.0	3.0	97.1	----
331	1476.0	480.5	4.8	95.1	.1
AGSX	580.0	236.0	10.6	89.5	----
ATJ	1209.0	460.0	3.6	96.3	.1
ATJ-GP	25.0	30.0	5.0	95.0	----
ATJS	1625.0	307.0	8.8	90.9	.3
ATJS-GP	------	22.0	-----	95.5	4.6
ATL	5809.5	3584.5	1.9	97.1	1.0
ATL-GP	17.0	22.0	9.1	77.3	13.6
CDA	709.0	285.0	14.6	84.6	.9
CDG	531.0	178.8	11.5	77.3	11.2
CDG-GP	------	21.5	-----	53.5	46.5
CMB	64.0	29.0	13.8	84.5	1.7
PGR	688.0	344.0	19.7	80.0	.3
Average	932.3	413.2	8.1	89.6	2.3

[a]The elements are divided into the following activity groups: II – Strong accelerators; III – Weak to moderate accelerators; IV – Inhibitors.

[b]Includes 2.5 percent in group I (very strong accelerators) and 19.1 percent in group II.

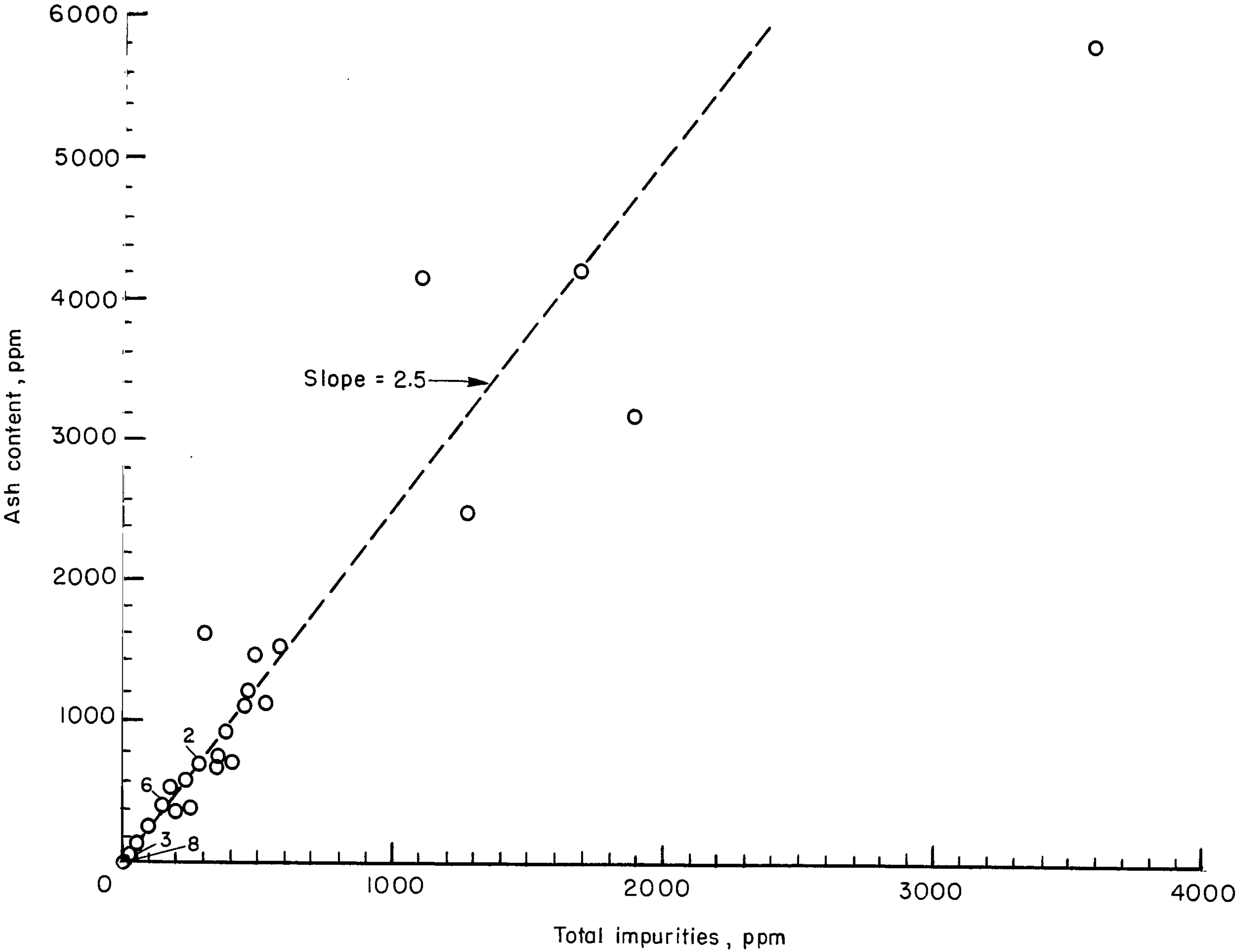

Figure 1.- Relation between ash content and total impurities.

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