X-Ray Study of Carbon Brushes

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Carbon brushes for electrical machines must have specific qualities requisite for their uses. There are quite a good many kinds of carbon brushes on the market made from various kinds of raw materials by different procedures, details of which, however, are generally kept secret. The properties of carbon brushes depend on their structures, such as the mode of aggregation and distribution of carbon particles, and the form, size and degree of distortion or

Table 1

Unit Cell Dimensions of Graphite Crystal

Name of brush	c Dimension from (004) A.	c Dimension from (006) A.	a Dimension from (110) A.	a Dimension from (112) A.	a Dimension from mean A.	$C=c/a$ from (004)	$C=c/a$ from (006)
HM-5	6.66_0	6.702	2.446	2.447	2.447	2.72_7	2.739
HM-6	6.71_2	6.708	2.461	2.462	2.462	2.72_6	2.725
PD-2	6.69_0	6.690	2.455	2.457	2.456	2.72_4	2.724
GE-D	6.72_4	6.699	2.460	2.461	2.460	2.73_3	2.723
8601-N	6.76_4	6.738	2.454	2.457	2.455	2.75_5	2.745
NCC-258	6.74_6	—	2.457	—	2.457	2.74_5	—
NCC-259	6.76_8	—	2.453	—	2.453	2.75_9	—
NCC-255	6.79_9	—	2.458	—	2.458	2.76_6	—
SA-45	6.79_6	—	2.455	—	2.455	2.76_6	—
E	6.71_2	6.720	2.458	—	2.458	2.73_3	2.736
Graphite							
Bacon[2]	6.708±0.001		2.4614			2.725_7	
Hofmann[3]	6.69 ±0.01		2.455 ±0.002			2.725	

imperfection of graphite crystallites in carbon particles. The structure may be divided into macroscopic, microscopic and submicroscopic ones. Although there are many studies concerning the macroscopic and microscopic structures, the apparent and true densities, the porosity, and other physical properties, no one has yet succeeded in making clear the relationship between the dynamic characteristics and the structure of brushes by having recourse to the macroscopic and microscopic observations alone. The authors now intend to make clear the submicroscopic structure of carbon brushes by X-ray and electronmicroscopic methods.

K. Hayashi and Y. Uto[1] measured the unit cell dimensions of graphite crystallites of several carbon brushes and divided them into three groups, *i. e.* (a) the natural graphite type, (b) the 2600 type or the pitch coke type, and (c) the SA-type or the soot type. The a dimension of graphite crystallite was constant for all kinds of brushes, but the c dimension was not uniform, being 6.72 A. for the natural graphite type, 6.78 A. for the 2600 type, and 6.85 A. for the SA-type. In the present paper, the results of the measurements of the unit cell dimensions and crystal sizes of graphite crystallites of several natural graphite and electrographite type of carbon brushes are reported.

Experimental

Specimens of carbon brush powder pulverized to pass 300 mesh per inch sieve and packed in a cellophane tube of about 0.3 mm inner diameter were employed, using FeK radiation in a 6.1 cm. camera. The diameter of the camera was calibrated by NaCl reflexions. Samples investigated were,

HM-5 (Morganite), natural graphite type,
HM-6 (Morganite), natural graphite type,
PD-2 (Hitachi), electrographitized pitch coke type (electrode for a vaccum tube),
GE-D (General Electric), electrographitized pitch coke type,
8601-N (Ringsdorff), electrographitized pitch coke type,
NCC-258 (National Carbon), electrographitized pitch coke type,
NCC-259 (National Carbon), electrographitized soot type,
NCC-255 (National Carbon), electrographitized soot type,
SA-45 (National Carbon), electrographitized soot type,
E (Nippon Carbon), electrographitized pitch coke type (Laboratory product).

Unit Cell Dimensions and Calculate Density.— The results of the meaurements of unit cell dimensions are shown in Table 1. The spacing values of HM-6, GE-D, 8601-N, NCC-255, and SA-45 were taken as the mean of those found from two films, but the others from one film.

The c dimensions were calculated from the (004) and (006) reflexions. For the a dimensions, the measurements were of the (110) and (112) reflexions. The c dimension from the (006) reflexion was used to calculate the a dimension from the (112) reflexion. The coincidence of the a dimensions from the (110) and (112) reflexions on the same film is satisfactory. The (006) and (112) reflexions could not be detected on films of some of the specimens, especially those of the soot type brushes. On the films of the soot type brushes, the (100) and (101) reflexions could not be resolved.

(1) K. Hayashi and Y. Uto, *Journ. Inst. Elec. Engrs., Japan*, **63**, 452, 592 (1943).
(2) G. E Bacon, *Acta Cryst.*, **3**, 137 (1950).
(3) U. Hofmann und D. Wilm, *Z. Elektrochem.*, **42**, 504 (1936).

The accurate measurement of the graphite unit cell dimensions of Bacon[2] (1950) showed that the value of the c dimension increased inversely proportionally with the thickness of graphite crystal, and that the value of the a dimension showed no change for graphite samples investigated, whose thicknesses of graphite crystals were larger than *ca.* 100 A. According to Taylor's paper[4] (1942), there was no genuine change of the a dimension for carbon layers having widths greater than a few tens of Ångstron unit. As shown later, graphite crystallites of our samples have width larger than 100 A. and overall height H larger than a few tens of Ångstron unit, it may reasonably be assumed that the a dimension of all the samples has the same value as that of the natural graphite. As all the spacings of HM-5 have smaller values than the other samples, there must be a systematic error due to the film treatment. Mean value of the a dimension of the eight samples except HM-5 is 2.457± 0.001 A. This value is almost equal to Hofmann's value 2.455 A., but smaller than the more accurate value of Bacon by 0.004 A. The main source of the error came from the camera diameter determination, as the camera diameter was calculated from NaCl reflexions on a separate film. We can eliminate the film error and compare the degree of graphitization of each sample by taking the axial ratio $C=c/a$. The (004) and (006) reflexions occur at 35° and 60° respectively. As the mean error of the a dimensions calculated from the (110) ($\theta=52°$) and (112) reflexions ($\theta=57°$) is ±0.0001 A., the mean error of the c dimension from the (006) reflexions may be the same as or less than that of the a dimensions. Therefore the mean error of the C (006), the axial ratio calculated from the (006) reflexions and the a dimension, was assumed to be ±0.001. The accuracy of the C (004) may be less than the C (006). From the standard deviation of the C (004) to the C (006) and the mean error of the C (006), the mean error of the C (004) was calculated to be ±0.008.

Among five specimens of which the values of C were obtained from the (006) reflexions, the values of C (006) of HM-6, PD-2, and GE-D should be looked upon as equal to the value of the natural graphite of Hofmann and Bacon. These brushes could be regarded as being composed of well crystallized graphite crystallites. The C (006) value of HM-5 is greater than the above three values, but smaller than that of 8601-N. The C (006) value of E is smaller than that of 8601-N, but larger than that of GE-D. The larger value of C indicates the smallness of graphite crystallite. From the C (004) values, it is difficult to tell the difference between HM-6, PD-2, GE-D, E and HM-5. The C (004) value of NCC-258 can be distinguished from that of PD-2, but not from that of GE-D. The C (004) value of 8601-N can be distinguished from that of GE-D, but not from that of NCC-258. The value of NCC-259 can barely be distinguished from that of NCC-258, but it cannot be distinguished at all from that of 8601-N. The value of NCC-255 is equal to those of SA-45 and NCC-259, but can clearly be distinguished from that of NCC-258. Summarizing the above observation, the order of the value of C of the brushes can be shown by the following inequality.

$$\text{HM-6}=\text{PD-2}=\text{GE-D}<\text{E}\leq\text{HM-5}<\text{8601-N},$$
$$\text{GE-D}\leq\text{NCC-258}\leq\text{8601-N}\leq\text{NCC-259}\leq$$
$$\text{NCC-255}=\text{SA-45}.$$

Densities d (X) of the graphite crystallites were calculated from the C (004) or C (006) values taking the a dimension as 2.461_4 A. from Bacon's paper. This value is also very near to the value 2.461_2 A., previously obtained by Nelson and Riley[5]. Both values are shown in Table 2 with densities d(p) measured by the picnometer method. Calculated *Kryptoporen*[6] are also shown in the table.

Table 2

Density and *Kryptoporen* of Carbon Brushes

Name of brush	d (X) from (006)	d (X) from (004)	d (P)	*Kryptoporen* from (006)	*Kryptoporen* from (004)
HM-5	2.240	2.24_9	2.101	6.20	6.6
HM-6	2.251	2.25_0	2.229	0.98	0.9
PD-2	2.252	2.25_2	2.254	0.00	0.0
GE-D	2.253	2.24_4	2.210	5.90	5.5
8601-N	2.235	2.22_6	1.999	10.5	$10._6$
NCC-258	—	2.23_5	2.120	—	5.1
NCC-259	—	2.22_3	2.068	—	7.0
NCC-255	—	2.21_8	2.000	—	9.8
SA-45	—	2.21_8	1.990	—	$10._3$
Graphite					
Bacon	2.250_8				
Hofmann	2.251				

Crystallite Size and Intensity Ratio of Reflexions.—Relative intensities of the (100), (101), (110) and (112) reflexions and widths at half intensity of the (004), (110) and (112) reflexions were measured from the microphotometric curves of the X-ray photographs. Sizes of graphite crystallites were calculated from the widths at half intensity by Laue's equation. Sizes of crystallites larger than 200 A. could not be determined and it was possible to compare sizes smaller than 100 A. The true thickness of the graphite crystal t ($=m_3c$) was calculated from the (112) reflexion, the width of the crystal w ($=m_1a$) from the (110) reflexion, and the overall height of the crystal H from the (004) reflexion. The results are shown in Table 3 with the values of $I(101)/I(100)$ and $I(112)/I(110)$. The t value and the intensity ratio of reflexions of the soot type brushes could not be obtained, as their (112) reflexions were not observed, and their (100) and

(4) A. Taylor, *Nature*, **152**, 462 (1942).

(5) J. B. Nelson and D. P. Riley, *Proc. Phys. Soc., London*, **57**, 477 (1945).

(6) $Kryptoporen=[d(\text{X})-d(\text{p})]\times 100/d(\text{X})$.

Table 3

Crystal Size and Intensity Ratio

Name of brush	Crystal Size×10 A. H	t $(=m_3c)$	w $(=m_1a)$	Intensity Ratio I (101)/I(100	I (112)/I(110)
HM-5	>20	15	>20	1.8	0.9
HM-6	>20	12	>20	4.3	1.8
PD-2	>20	10	>20	3.2	1.6
GE-D	>20	7	>20	2.5	1.2
8601-N	7	2	15	1.6	0.6
NCC-258	10	7	>20	1.6	0.9
NCC-259	10	—	15~20	—	—
NCC-255	10	—	15~20	—	—
SA-45	10	—	10	—	—
Natural graphite (Hofmann)				4.9	1.6

(101) reflexions could not be resolved.

Discussion

HM-6 and HN-5 are the natural graphite-carbon type brushes. From the C value or the calculated density and the value of the *Kryptoporen* of HM-5, it was shown that HM-5 must contain α considerable amount fo amorphous (or ungraphitized) carbon. By the influence of the presence of amorphous carbon, calculated thicknesses of crystallites of HM-5 and HM-6 appeared to be too small. Intensity ratios of the reflexions of HM-6 are approximately the same as those of the natural graphite, but those of HM-5 are far smaller. The content of amorphous carbon of HM-5 must be large enough to influence the intensities of reflexions. The fact that the C value or the calculated density of PD-2 is equal to the values of the natural graphite and that the value of *Kryptoporen* is zero shows the completeness of the graphitization of PD-2, the electrographitized pitch coke. The C value of GE-D is equal to that of the natural graphite, but the value of *Kryptoporen*, 6 %, shows that the degree of graphitization is not yet sufficient. But among the electrographitized pitch coke type brushes, GE-D is the most highly graphitized one. Judging from the C values, the crystallite sizes, and the intensity ratios of the reflexions, NCC-258 is next to GE-D in the graphitization. 8601-N is the least graphitized one among these three piteh coke type brushes. Among the electrographitized soot type brushes, the degree of graphitization of NCC-259 is larger than the degrees of NCC-255 and SA-45. The thickness of crystallites of the soot type brushes must be very small, though the *(hkl)* reflexions of these brushes could not be observed on the films. SA-45 appeared to be composed of graphite crystallites of the smallest size among the above three soot type brushes.

The X-ray study of carbon brushes may be said to be useful, and a finer conclusion may be obtained by improving the experimental method.

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