Optimum Particle Size Distribution of Coke for Graphite Electrode Determined by Thermal Shock Testing

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Abstract

The thermal shock resistance,the thermal shock fracture toughness and other mechanics properties of two kinds of graphite electrode with three different particle size distribution of coal tar pitch coke and oil coke are measured.Experimental results are all expressed by Knudsen type formula:

$$S=SoG^{-m}exp(-nP)$$

where G and P are the mean particle diameter and porosity, and So,m and n are materials constants,respectively. Optimum coke particle size distribution is deduced to produce graphite electrode having the maximum thermal shock properties.

Usually artificial graphite is made by carbonizing and graphitizing a green mixture of coke and binder pitch.Particle size distribution of coke filler is considered to influence greatly the physical and mechanical properties of graphite. We examined the optimum particle size distribution of coke to make graphite electrode having high thermal resistance and fracture toughness.

Experiment

Graphite specimens were made from coal tar pitch coke(symbol"-C") and oil coke (-O) having respectively three types of cumulative weight distribution(Fig.1).Mean particle diameter(median diameter) G of G1,G2 and G3 have 381,84 and 34 μm,respectively. Table 1 shows physical and mechanical properties of the extruded rods of 60mm ϕ graphite specimens.The thermal shock resistance Δ $(=\sigma_{t} k/E\alpha$: σ_t: tensile strength, k:thermal condctivity, E:Young's modulus, α:CTE),and the thermal shock fracture toughness ∇ $(=k_{Ic} k/E\alpha$: k_{Ic}:fracture toughness value of modeI)were measured by arc discharge heating method for disk specimens[1].The disk specimens were 50mm ϕ and 5mm thick.Forthe diametral compressive testings, a thicker disk of 10mm was used. These disk specimens were also used for measurements[1] of the fracture toughness of modeI and modeII[3,4], K_{Ic} and k_{IIc}. Uniaxial tensile strength σ_t was deduced on the basis of the fracture crite-rion of graphite.[5]

Experimental Results and Discussion

In Fig.2 E decreases with the increase of G in with-grain direction.Data by Inagaki et al., by Kennedy et al. and by JAERI[6-8]are also compared in Fig.2.It is seemed that following expression by Knudsen is the most rational:

$$S = SoG^{-m} exp(-nP)$$

where So,m and n are empirical constants.

This implies in a general form the Petch's relationship for particle diameter effects of metallic material.In this study, experimental results of Δ and ∇ for thermal shock and other properties were all evaluated by the Knudsen's expression.Table2 shows the empirical constants for all experimental

Table 1. Physical and Mechanical Properties of Graphites of Coal Coke and Oil Coke.

Graphite	*	G1-C	G2-C	G3-C	G1-O	G2-O	G3-O
Apparent density	L	1.376	1.418	1.527	1.404	1.513	1.565
γ (g/cm)	R	1.358	1.410	1.516	1.394	1.512	1.574
Prosity p	-	0.395	0.373	0.327	0.381	0.331	0.306
Electric resist.	L	104	84	67	82.5	75	71
ρ ($\times 10^{-5}\Omega$cm)	R	170	145	130	129	131	131
Young's modulus	L	4.81	6.81	10.73	4.12	6.47	8.34
E (GPa)	R	1.81	2.55	3.29	1.77	2.56	3.14
Bend.strength	L	6.77	9.71	14.80	7.75	10.8	13.04
σ_b(MPa)	R	4.71	6.47	9.90	5.10	5.69	6.06
Coef.ther.exp.**	L	1.99	2.02	1.92	2.19	2.10	2.00
α ($\times 10^{-6}$°C^{-1})	R	3.30	3.50	4.00	3.18	3.60	3.90

*L and R: Longitudinal and perpendicular directions for the extrusion axis, respectively.
**Mean linear coefficient of thermal expansion in 500°C-800°C.

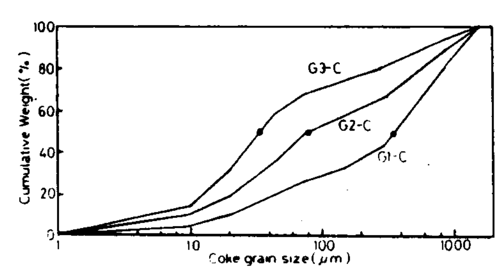

Figure 1. Cumulative weight percent of graphites.

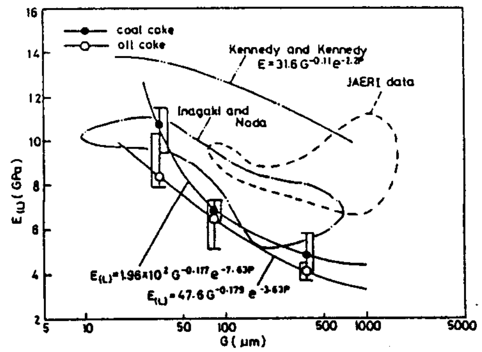

Figure 2. Young's modulus of graphites as a function of grain size.

Table 2. Empirical Constant Involving Knudsen's Expression for Graphite.

Graphite	*	Coal coke S_0	Coal coke $-m$	Coal coke $-n$	Oil coke S_0	Oil coke $-m$	Oil coke $-n$
Young's modulus E (GPa)	L	1.96×10^{2}	-0.117	-7.63	47.6	-0.179	-3.63
	R	11.09	-0.202	-1.54	18.8	-0.087	-4.86
Coef. therm. exp. α ($\times10^{-6}$ °C^{-1})	L	2.66	0.0367	-1.07	5.00	0.204	-5.35
	R	16.8	0.094	-5.4	5.03	-0.087	0.16
Elect. resist. ρ ($\times10^{-4}$ Ωcm)	L	1.77	0.096	3.04	5.49	0.0571	0.18
	R	7.96	0.098	0.43	17.7	0.0411	-1.56
Bend. strength σ_b (MPa)	L	197	-0.144	-6.37	43.4	-0.145	-2.27
	R	153	-0.103	-7.27	8.7	-0.05	-0.56
Dia. compr. strength σ_{HC} (MPa)	R	18.0	-0.166	-7.24	3.43	-0.020	-1.54
Compr. strength σ_C (MPa)	R	34.8	-0.166	-7.24	16.4	-0.077	-0.18
Uniax. tens. strength σ_t (MPa)	R	7.35	-0.114	-1.24	2.54	-0.042	-0.20
Fract. tough. of mode I K_{IC} (MPam$^{1/2}$)	R	1.52	-0.122	-3.87	0.36	-0.041	-1.06
Fract. tough. of mode II K_{IIC} (MPam$^{1/2}$)	R	2.35	-0.109	-4.16	0.51	-0.075	-0.40
Therm. shock resist. Δ (W/mm)	R	7.25	-0.016	5.60	2.77	-0.052	7.92
Therm. shock fract. tough. ∇ (W/mm$^{1/2}$)	R	61.9	0.038	3.19	40.6	0.027	3.21

* L and R; longitudinal and perpendicular directions for the extrusion axis, respectively .

results.The formulas in solid curves in Fig.2 show E of both coke graphites having trends to increase with the decrease of G and P. Such trends agree with the other reseacher's. Fig.4 and 5 show Δ and ∇ as a function of G,respectively.And optimum coke particle size distribution to obtain the maximum values of Δ and ∇ is seemed to be between G1 and G2 and can be calculated by followings:

$$Pc=-2.42\times10^{-6}G^{2}+1.20\times10^{-3}G+0.289$$

$$Po=-9.78\times10^{-6}G^{2}+6.22\times10^{-4}G+0.286$$

Substituting these relations into empirical formulas of Δ and ∇ in Fig.3 and 4, Δ and ∇ are expre-sed as a function of G only. The mean particle diameters of optimum particle size distribution are about 250 and 300 μm for Δ and ∇ of coaltar pitch coke and oil coke, respectively.Optimum conditions for other properties may be deduced similarly from the results listed in Table 2.

Conclusions

Optimum coke particle size distribution to make graphite electrode having high thermal shock resistance and fracture toughness can be calcullated by knudsen type formula.

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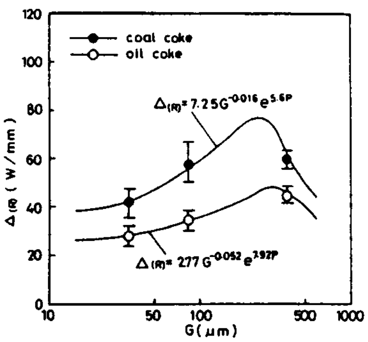

Figure 3. Thermal shock resistance of graphites as a function of grain size (across grain).

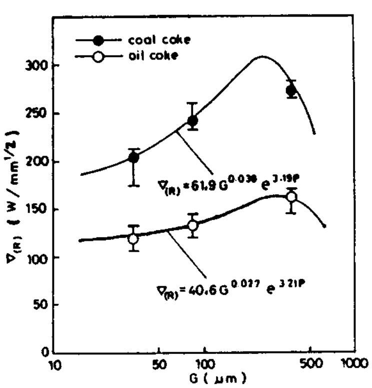

Figure 4. Thermal shock gracture toughness of graphites as a function of grain size (across grain).