Degradation of the Fracture Mechanics Properties for Thermal Shock of Burned-Off Graphite in an Arc Steelmaking Furnace

S. Sato, K. Hirakawa
Faculty of Engineering, University of Ibaraki,
Hitachi, Ibaraki 316
S. Kiyono, Y. Inoue
Omachi Research Laboratory, Showa Denko K.K.
Omachi, Nagano 398, Japan

Abstract
Graphite electrode poles are oxidized as much as to be deformed to a spindly shape and disappeared from the pointed end in actual steelmaking arc furnace at high temperature. The degradations of fracture mechanics properties of the graphite cause reductions of the original performances of graphite. In this paper we evaluate experimentally the degradations of the thermal shock resistance and fracture toughness. These test pieces were cut from different positions of electrode which was connected to three poles by nipples. Other mechanical properties are also determined and their distributions are expressed as a function of the distance from the outer surface of graphite electrode.

A graphite electrode for steelmaking arc furnace is heated over 2000 °C at the pointed end during the practical work and is subjected to severe oxidation as it is called "burn-off". Changes of the fracture mechanics properties are taken account of very seriously by maker and user of grapahite electrode. In this paper, we have taken a left-over electrode, which was consisted of three electrode poles connected by two nipples and was used actually in an arc furnace. The specimens were cut from different positions in the electrode, the thermal shock resistance $\Delta(=\sigma_t k/E\alpha$, σ_t: tensile strength, k: thermal conductivity, E: Young's modulus, α: CTE)1,2 and the thermal shock fracture toughness ∇ (= $K_{IC}k/E\alpha$; K_{IC}: fracture toughness value of model)3 and the other physical and mechanical properties are determined as a function of the distance from he pointed end and the outer surface of electrode.

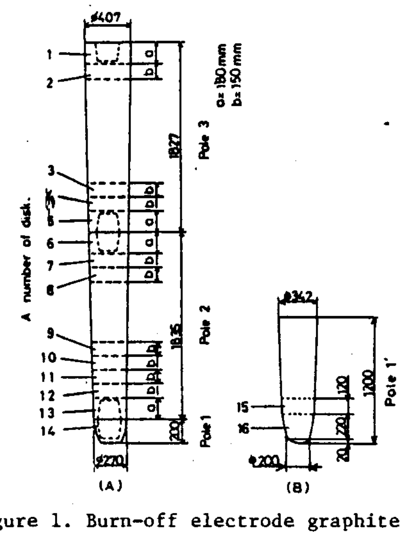

Figure 1. Burn-off electrode graphite and the cutting of disks.

Experiment
Fig.1 shows the graphite electrode and the position of disk for cut of specimen. Table 1 shows the physical and mechanical properties at the central area of each disk at different position of electrode(A). Fig.2 shows changes of bulk density along the central line of the oxidized electrode(A) and (B). Densities decrease slightly to near the pointed ends. Changes of other properties along the central line of the electrode are also very small as shown in Table 1. Vickers hardness was measured on the surface which was coated a liquid paper correction diluted fluid to survey the change on the radial direction from the outer surface of the electrode. Fig.3 shows the distributions of Vickers hardness of Disk 8 and 43 specimens as a function of distance x from the outer surface. Very large scatters are found, but the changes are almost limmited within x=10-15mm in spite of the electrode

Table 1. Physical properties of disks cut at different positions of burn-off graphite electrode (A).

Disk		2	7	9	10	11	12
(No.of sample)		(20)	(20)	(20)	(20)	(17)	(12)
Bulk densuty γ_b(g/cm)		1.69	1.70	1.69	1.69	1.68	1.68
True density γ_t(g/cm)		2.23	2.23	2.23	2.23	2.23	2.23
Elect.resistance $\rho(\times10^{-5}\Omega cm)$	L	46.2	48.3	48.2	47.8	47.6	47.1
	R	87.5	86.1	82.1	85.6	86.0	89.2
Young's modulus E(GPa)	L	11.5	11.7	11.0	11.0	11.2	11.1
	R	4.26	4.56	4.54	4.42	4.25	4.16
Bend.strength σ_b(MPa)	L	13.4	14.3	13.1	13.4	13.9	13.6
	R	8.26	8.93	9.10	8.80	8.82	7.92
(No.of sample)		(20)	(20)	(20)	(20)	(19)	(20)
Coef.therm.exp.* $\alpha(\times10^{-6}°C^{-1})$	L	1.85	1.98	1.88	1.84	1.83	1.89
	R	3.33	3.08	3.32	3.14	3.10	3.18
(No.of sample)		(2)	(2)	(2)	(2)	(2)	(2)
Therm.conductivity k(W/mK)	L	274	278	276	264	277	270
	R	148	144	155	154	149	152

L and R refer to the directions of with-grain and across grain, respectively.
*Mean linear coefficient of thermal expansion in 500°C-800°C.

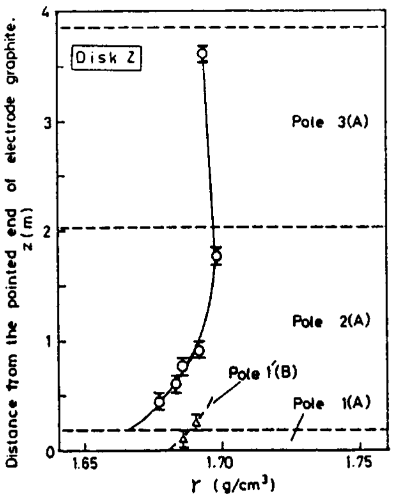

Figure 2. Bulk density along the center line of the burn-off electrode graphite.

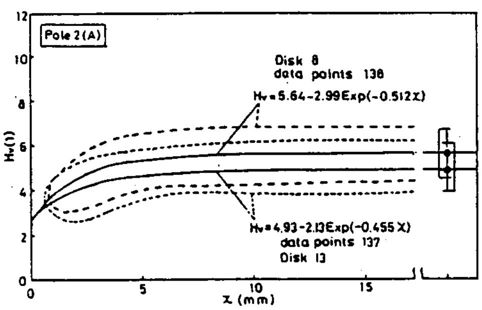

Figure 3. Distribution of Vickers hardness as a function of the distance from outer surface of the electrode graphite rod.

which was seriously sustained oxidation.Therefore the measurements are required to carry out by as small specimens as possible. In this study, disk specimens of two types for thermal shock tests were used such as 36mmϕ and 3.6mm thick Disk-R to measure the distribution in radial direction and the 80mmϕ and 5-8mm thick Disk-z to measure the distribution in axial direction of the electrode. Thermal shock resistance Δ and thermal shock fracture toughness ∇ were determined by arc discharge heating at the central area of disk specimens.

Results and discussion

Fig.4(a) and (b) show the distributions of Δ and ∇ measured by Disk-R.for instance.Data points in the figures are mean values which were obtained by disks in the specified ranges. Experimental formulas of Δ(W/mm) and ∇(W/mm$^{1/2}$) for Disk-R of electrode(A) were expressed as follows;

$$\Delta=(4.47-17.7\exp(-3.32\cdot10^{-3}z))(1-0.328\exp(-0.203x))$$

$$\nabla=(11.4-45.1\exp(-3.8\cdot10^{-3}z))(1-0.463\exp(-0.201x))$$

where x and z are distances from the outer surface

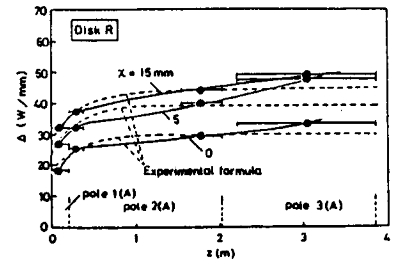

Figure 4a. Thermal shock resistance of burn-off electrode graphite (AG).

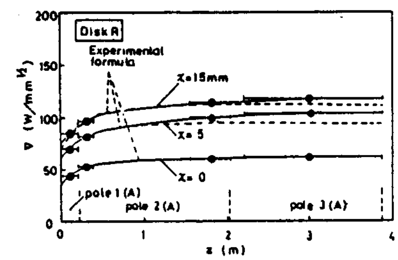

Figure 4b. Thermal shock fracture toughness of burn-off electrode graphite (AG).

and the pointed end of electrode,respectively. The accuracies of these formulas for areas at small x (<5mm) and z(<20mm) may be not high since the specimens could not take a suitable number for very narrow at the areas.

According to the above formulas on Δ and ∇ in this study, an equivalent crack length a_c in plate subjected to an uniform tensile stress σ_t is deduced from the fracture toughness value of the plate material as follows;

$$a_c=(K_{Ic}/\sigma_t)^2/\pi=(\nabla/\Delta)^2/\pi$$

The calculated value of a_c at different positions of electrode do not almost change by z, but increase from about 1.4mm at x=0 then saturate to about 2.1mm at x>15mm with the increase of x. Decrease of a_c at small values of x and z means that the decrease of K_{Ic} is larger in the ratio than the decrease of σ_t and the allowable margin of crack size to the final fracture decreases. In other words, the voids and/or cracks at near outer surface or the pointed end become more sensitive than those at the central area of the graphite electrode.

Conclusion

Degradation of thermal shock properties and other mechanical properties are expressed as a function of the distance from the outer surface of graphite electrode.

References

(1) S.Sato,et al.,Carbon,12,555 (1974)
(2) S.Sato, et al.,Carbon,13,309 (1975)
(3) S.Sato,et al.,Carbon,16,103 (1978)