CORRELATION OF FRACTURE PARAMETERS WITH GRAPHITE ELECTRODE PERFORMANCE ON AN ARC FURNACE

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Introduction

Butt loss in graphite electrodes under severe Electric Arc Furnace (EAF) conditions is of serious concern to the steel producer. From the fracture standpoint, butt loss in graphite electrodes is due to crack propagation. Therefore electrodes with superior crack growth resistance are desirable as far as butt loss performance is concerned.

The present work involves the use of fracture mechanics testing in predicting the crack growth resistance, and possibly butt loss performance, of electrode materials made with various processing conditions and raw materials. The results of fracture tests are then compared with actual field observations of butt loss performance of a series of graphite electrodes used in a large scale industrial designed experiment. An outline of the experiment is shown in Table 1. As seen in this table, the effects of coke type, mix coarseness, densification and graphitization temperature on electrode performance were considered.

Experimental

Figure 1 shows a schematic of the fracture test utilized in this work. The specimen and loading condition as shown in this figure is a compact tensile type with Mode-I (crack opening) loading in the with-grain (WG) direction resulting in crack growth in the against-grain (AG) direction. We have found that for extruded graphite, the AG growth fracture results are more discriminating with respect to raw materials and graphite processing parameters. For the evaluation of of typical fracture parameters, Sakai's [2] energy approach with cyclic loading-unloading was adopted. This method has been successfully used by others [3] for fracture characterization of graphite materials. For the present work, the sample is initially loaded up to the peak load at which point (see Figure 1) the initial starter notch is believed to start growing. When the crack has grown to a new length (a1) at point B, the sample is completely unloaded (point A) and then reloaded. The reloading is continued beyond previous unloading point with the crack growing to a new length (a2) at point C. This cyclic loading-unloading is repeated 15 times. A compliance calibration is used [4] to estimate new crack lengths given previous ones. A computer program was developed to calculate various fracture energy parameters shown in Figure 1.

A new parameter , called 'Brittleness Index' was also defined and added to the fracture parameters as shown in Figure 1. This parameter simply reflects the rate of decay of the load-COD curve in the crack propagation region. Therefore, higher brittleness index indicates faster crack propagation.

Results and Discussion

Corresponding to each of the 18 categories of graphite materials 5-6 specimens were tested. Table 2 summarizes the results for the main effects and also the field observations of the large butt losses. The butt loss observations basically indicate that i) cokes And B are better than coke C, ii) the fine mix is undesirable and that the coarser mix the better, iii) no major advantage is achieved with the high density material and iv) higher graphitization temperature results in better butt loss performance. Considering the agreement of field observations and the fracture parameters, it appears that the brittleness index is the discriminating parameter. The major exception is the graphitization effect which is not seen to be detected by any of the fracture parameters at a significant level. Further work to improve the discrimination of this fracture test by increasing the specimen size has provided encouraging results. Also note that if one is mainly interested in the brittleness index, monotonic loading may yield similar results as cyclic loading-unloading.

Conclusions

The brittleness index as defined in this work appears to provide a useful predictive tool to evaluate trends in the electrode butt loss performance under EAF conditions with respect to coke type, mix coarseness and densification. None of the fracture parameters studied in this work appear to discriminate the graphitization temperature effect as far as electrode butt loss is concerned.

		COKE A	COKE B	COKE C	GRAPH
MIX	Fine	N	I	H	Low T
	Medium	I	H	N	Low T
	Coarse	H	N	I	Low T
	Fine	N	I	H	High T
	Medium	H	N	I	High T
	Coarse	I	H	N	High T

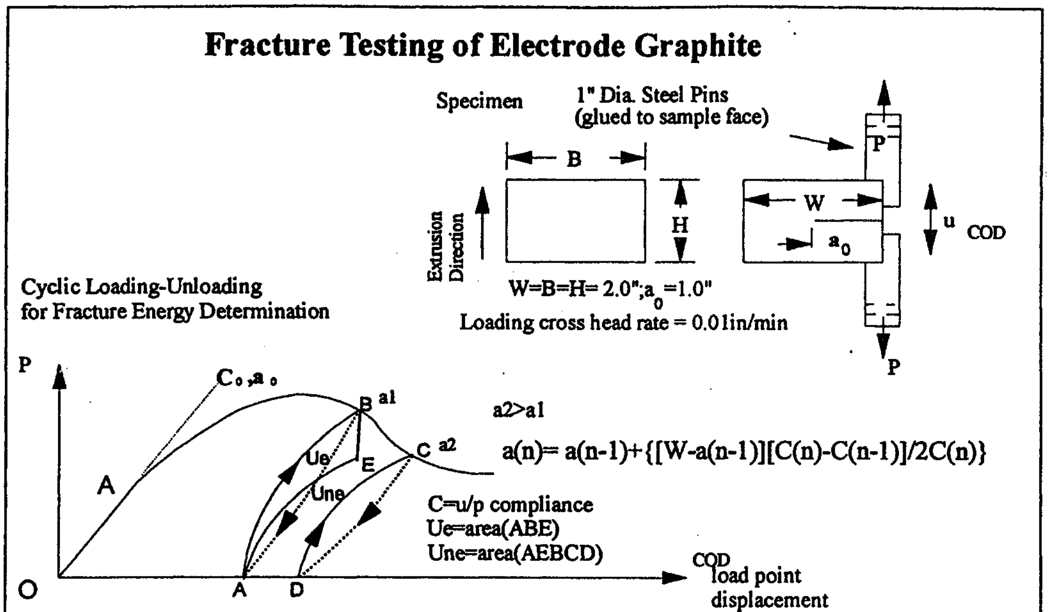
N, I, H : (N)ormal, (I)ntermediate and (H)igh density levels
Coke CTEs: A=0.12, B=0.18 and C=0.33x10^-6/C

Table 1. Experimental Design Matrix

Effect	Levels	N	Rt (J/m^2)	Rne/Re	Brittleness Index	Observed large butt loss frequency
Coke	C	36	426	0.750	51.0	9
	B	34	438	0.710	49.6	3
	A	35	447	0.776	47.0	6
Mix	Fine	33	426	0.770	52.2	10
	Medium	36	438	0.726	50.3	5
	Coarse	36	446	0.743	45.3	3
Density	N	37	411	0.732	47.4	7
	I	32	423	0.778	47.4	4
	H	36	476	0.730	52.7	7
Graph.	Low	53	444	0.733	49.2	14
	High	52	430	0.758	49.2	4

Average standard errors are: SE(Rt)=10, SE(Rne/Re)=0.026 and SE(britt.)=1.4

Table 2. Fracture results and observed large butt loss frequencies



Elastic fracture energy:	Re= Ue/B[a(n)-a(n-1)]
Inelastic fracture energy:	Rne= Une/B[a(n)-a(n-1)]
Total fracture energy:	Rt=Re+Rne
Inelastic dissipation factor:	Rne/Re
Brittleness Index =	%load drop at COD=0.009 in from COD @Pmax

Figure 1. Fracture test configuration and parameters

References

1. Wise, F.E. and Smith, R.E. in Carbon '94 Extended Abstracts and Programme, 1994, pp. 766-767.
2. Sakai, M., Urashima, K. and Inagaki, M., Journal of the American Ceramic Society, Vol. 66, No. 12, 1983, 868.
3. Rouby, D., Allard, B., Tahon, B. and Dreyfus, J. M. in Carbon '90, Extended Abstracts and Programme, 1990, pp. 280-281.
4. R'Mili, M, Rouby, D. and Fantozzi, G., Composite Science and Technology, 1990, 37, pp. 207-221.