Transactions of the Korean Nuclear Society Autumn Meeting
Busan, Korea, October 27-28, 2005

Relation of Microstructure and Fracture Strength in IG-11 Nuclear Graphite

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1. Introduction

Graphite is a technologically important material that has been intensely studied for over 100 years [1]. Elastically, graphite is a strongly anistropic solid; an anisotropy that stems from the very strong covalent bonding within the basal planes, and the weak van der Waals forces between them. At 1060 GPa, the elastic modulus along the basal planes (c_{11}) is one of the highest known. In contrast, at 36.5 GPa, the modulus along the c-axis (c_{33}) is significantly lower. The true value of c_{44} (4-4.5 GPa) is nontrivial to measure accurately because it is reduced by one or two orders of magnitude when mobile dislocations are present [1].

Graphite is a composite material consisting of a coke filler and a carbonized pitch or resin binder. The graphite structure is porous, typically containing between 15-25 % porosity [2]. A microstructural study of fracture in graphite has revealed the manner in which certain microstructural features influence the process of crack initiation and propagation in graphite. Two important roles of porosity in the fracture process have been identified [2]. First, the interaction between the applied stress field and the pores will cause localized stress intensification, promoting crack initiation from favorably oriented high aspect ratio pores at low applied stresses. Second, propagating cracks can be drawn toward pores in their vicinity, presumably under the influence of the stress field around the pore. Two arbitrarily defined types of microstructure can be identified in the binder phase: (i) domains, which are regions of common basal plane alignment extending over linear dimensions greater than 100 ㎛, and (ii) mosaic, which are regions of small randomly-oriented pseudo-crystallites with linear dimensions of common basal plane orientation of less than about 10 ㎛. Cleavage of domains can be occur at stresses well below the fracture stress, and such regions can act as sites for crack initiation, particularly when in the vicinity of pores. Fracture of mosaic region is usually only observed at stresses close to the fracture stress. At lower stresses, propagating cracks which encounter such regions are arrested or deflected [2]. Coke filler particles with good basal plane alignment are highly susceptible to microcracking along basal planes at low stresses. This cleavage is facilitated by the needle-like cracks which lie parallel to the basal planes, and are formed by anisotropic contraction of the filler-coke particles during the calcination process.

Polycrystalline graphite is used in UK gas-cooled reactors because it is an effective moderator for fast neutrons, has good resistance to high temperatures and can act as a major structural component [2-3]. On the negative side, during operation, fast neutron irradiation and radiolytic oxidation produce dimensional and material property changes that can generate significant component stresses, promoting cracking and damage accumulation, and which may lead ultimately to failure [3]. Nuclear graphite is a polygranular graphite material with very high chemical purity to avoid absorption of low-energy neutrons and activation of the impurities [4]. High dimensional stability is also required for nuclear graphite to withstand the material at high temperatures and in a high flux of neutrons [4].

Fracture strength data in graphite is currently understood in terms of the independent influences of radiolytic oxidation on microstructure (e.g. porosity, density) and the effect on neutron irradiation on mechanical properties (e.g. elastic moduli, intrinsic toughness) [2].

Six commonly used models of graphite failure are described in tension and bending by Tucker, Rose and Burchell [5]. The simpler models based on (i) critical stress, (ii) critical strain and (iii) critical strain energy density criteria are shown shown to be remarkably unsuccessful in describing the experimental results. The (iv) Weibull model, though versatile in its application to geometry-related effects, is far less useful in treating the influence of microstructural variations. The final two treatments considered, the so-called (v) Rose/Tucker and (vi) fracture mechanics models, are much wider selected in their usefulness [5].

2. Experimental

2.1 Material

IG-11 graphite was chosen for the study. This type of graphite is a cold isostatic pressed, fine textured graphite containing a mixture of petroleum pitch binder and filler coke phase.

2.2 Fracture Toughness

IG-11 was machined into rectangular 4-point bend samples and tested to failure. The IG-11 was not irradiated. The samples were tested in a universal testing machine at a constant crosshead displacement rate of 0.5 mm/min. For the sample the distance between the support points was 40 mm and the loading span was 20 mm. The K_{IC} value of the samples was measured by 4-point bend test with SEVNB.

3. Results and Discussion

After the fracture test by 4-point bending test by UTM, IG-11graphite showed about 36.2 MPa. The deviation of strength value may be come from the pore in the graphite. Fig. 2 showed the pore in the graphite. Despite of cold isostatic pressed fine textured graphite, IG-11 has the porosity of about 20%.

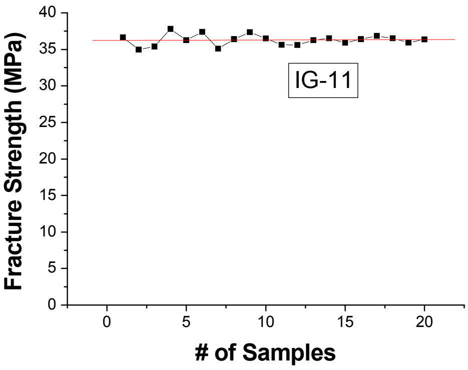

Fig. 1. Fracture strength of IG-11 graphite

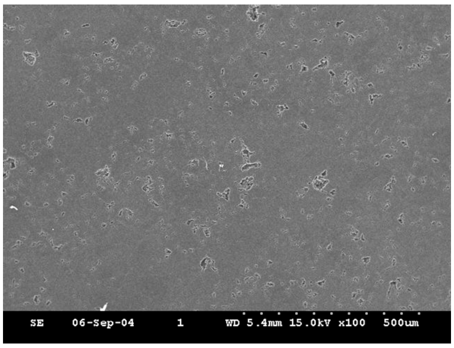

Fig. 2. Pore of IG-11 graphite

Fig. 3 showed the crack propagation path. The path was not straight. The bend of the crack path may happened by pore in the graphite.

Fig. 4 showed the K_{IC} of IG-11 graphite. K_{IC} were measured by 4-point bending test method with SEVNB. K_{IC} of 0.88 MPa was obtained from theIG-11 graphite. The K_{IC} value of the graphite has no relation to crack length in this work. This phenomenon was related with pore in the graphite.

4. Conclusion

The IG-11 graphite was chosen in this work to measure the relation with microstructure and fracture. The pore in the graphite affected the fracture strength. However, the K_{IC} of the IG-11 was not affected by crack length with SEVNB method.

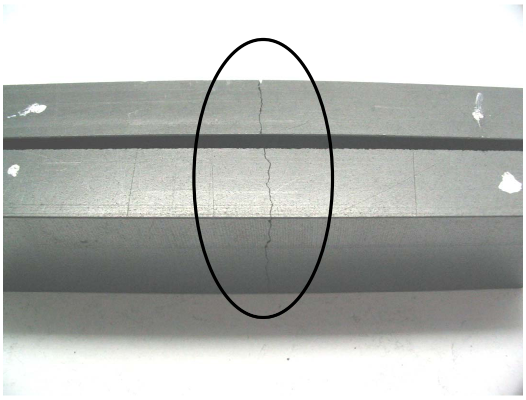

Fig. 3. Crack propagation of IG-11 graphite

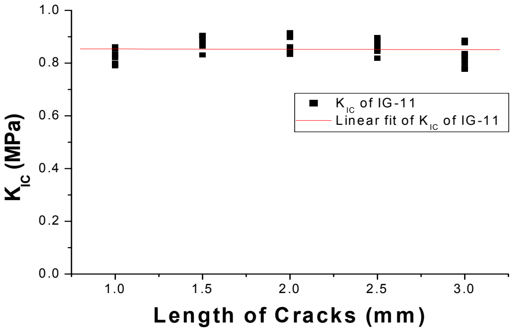

Fig. 4. K_{IC} of IG-11 graphite

Acknowledgement

This work was supported by a grant from the KAERI. The authors specially thank to Dr. S.W. Chi, Dr. E.S. Kim, and Dr. J. K. Hong of the KAERI.

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