BIAXIAL FATIGUE STRENGTH OF A FINE-GRAINED ISOTROPIC GRAPHITE FOR HTGR

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Introduction

The HTTR (High Temperature Engineering Test Reactor), a high temperarure gas-cooled reactor, has been under construction at JAERI Oarai Research Establishment since 1990 and is supposed to attain criticality by the end of 1997[1]. The core of this reactor consists of several kinds of graphite components such as fuel blocks, fuel sleeves, reflector blocks, core support posts, etc. During reactor operation or shut-down these components are subject to repeated stresses caused by the variation of the pressure of coolant helium, thermal gradient and neutron irradiation[2]. Therefore, the fatigue data are indispensable for the design and safety analysis of the components. It was convenntional in the past that the evaluation of the fatigue strength was carried out on the basis of the data on the uniaxial fatigue strength[3]. However , in reality, the components are used in the biaxial or, more generally, multi-axial stress state.

In this paper, the biaxial fatigue test is carried out on a fine-grained isotropic graphite to investigate the diffrence between the uniaxial and biaxial fatigue strengths from the aspect of design and safety evaluation of the graphite components in the core of HTGR.

Experimental

Tubular specimens, a schematic of which is shown in Fig. 1, are machined from a block of IG-11 graphite which is used for fuel sleeves, fuel blocks and core support posts of the HTTR. Biaxial fatigue tests were done at room temperature using a servohydraulic testing machine on the specimens the interior surface of which was coated with rubber to prevent oil from penetration[4, 5]. The biaxial stress state was realized by applying the longitudinal tension plus internal pressure for the tension-tension regime, and by the longitudinal compression plus circumferential torsion for the compression-tension regime. The applied stress in the longitudinal direction was 75% to 90% of the mean tensile or compressive strength whereas the secondary stress applied by internal pressure or tortion ranged from 53 to 74% of the mean tensile strength. The latter stress was applied in out-of-phase(Fig. 2, only for tension-tension regime) or in-phase. The number of specimens tested was 10 to 40 for each testing condition and the data were statistically analyzed..

Results and Discussion

An example of the results of the test is shown in Fig. 3 for the tension-tension regime in phase. The results of such biaxial fatigue tests are summarized in Table 1. Here, the equivalent stress level is defined as the stress level which corresponds to the normalized fatigue strength in the uniaxial loading mode. Let $\Delta\sigma$ represent as the difference between the uniaxial stress level and the the longitudinal stress level in the biaxial fatigue test. Then, the fatigue life N_f for the biaxial stress state is expressed as

$$\sigma_{max} / \sigma_{mean\ strength} + \Delta\sigma = A + B \log N_f \quad (1)$$

Eq.(1) means that the biaxial fatigue strength can be estimated by giving a parallel shift to the $\sigma_{max} / \sigma_{mean\ strength}$ versus N_f relationship in the case of uniaxial fatigue.

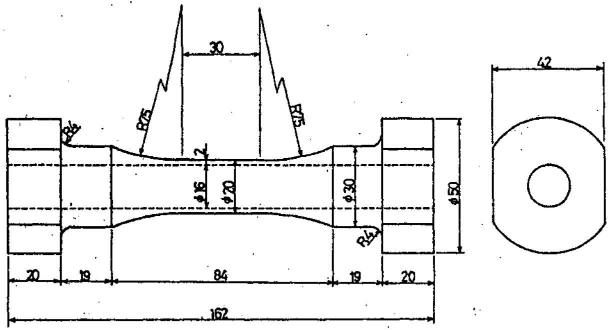

Fig. 1 Specimen dimensions for the biaxial fatigue test.

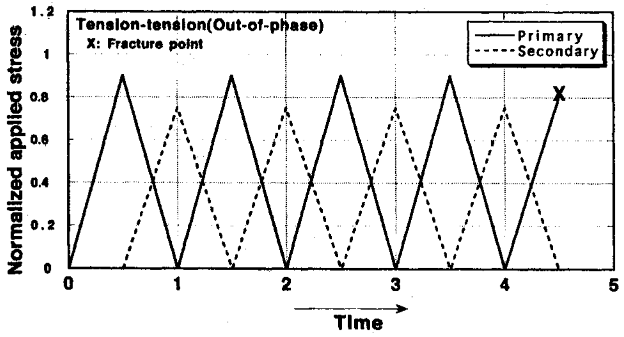

Fig. 2 Biaxial loading mode for the tension-tension in out-of-phase mode.

In the above discussion the longitudinal, or primary, applied stress has mainly been considered for the evaluation of the biaxial fatigue strength. However, to be more precise, both longitudinal and secondary applied stresses should be taken into account for the evaluation of the biaxial fatigue strength. Here, it has become essential to refer to the biaxial static strength.

For the biaxial static strength of the graphite tested in the present experiment the following wquation was obtained:

$$(\sigma_{1f})^2 + (\sigma_{2f})^2 = 1 \qquad (2)$$

Here, σ_{1f} is the ratio of the longitudinal fracture stress to the mean fracture strength and σ_{2f}, the ratio of the circumferential fracture stress to the mean fracture strength. From the analogy with Eq.(2) M-value is defined to evaluate the biaxial fatigue strength:

$$(\sigma_1)^2 + (\sigma_2)^2 = M^2 \qquad (3)$$

Here, σ_1 is the longitudinal applied stress normarized to the mean fracture strength, and σ_2, normalized applied circumferential stress

Fig. 4 shows plots of M-value versus the equivalent uniaxial fatigue strength, i.e., normalized applied stress which gives a number of cycles to failure equal to that for the biaxial fatigue. It is indicated here that the biaxial fatigue strength is apparently larger than that for the uniaxial fatigue strength. The amount of increase in the fatigue strength was in the order of tension-tension(out-of-phase) < Tension-tension(In-phase) < Compression-tension (In-phase). The tendency that the amount was the smallest for the case of tension-tension(out-of-phase) would be probably caused by the fact that the secondary stress, even if it is much smaller than the primary stress, can be counted as an independent fatigue cycles.

It is concluded from the data obtained here that the design and safety evaluation of graphite components in the HTTR is to be conservative on the basis of the data on the uniaxial fatigue strength.

References

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Table 1 Mean value of biaxial fatigue life and the stress level equivalent to the uniaxial fatigue test.

Normalized applied stress σ_1	σ_2	Mean fatigue life	Equivalent stress level	$\Delta\sigma$	M
Tension-tension, In-phase					
0.90	0.74	61	0.91	0.01	1.17
0.80	0.56	612	0.87	0.08	0.97
0.75	0.53	684	0.86	0.13	0.91
Tension-tension, Out-of-phase					
0.85	0.74	2	0.96	0.12	1.13
0.80	0.69	20	0.93	0.14	1.06
0.75	0.65	11	0.93	0.19	0.99
Compression-tension, In-phase					
0.85	0.81	442	0.90	0.06	1.17
0.90	0.87	249	0.91	0.01	1.25

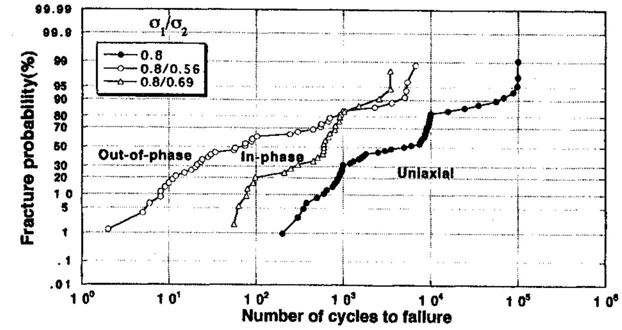

Fig. 3 An example of the results of biaxial faigue test.

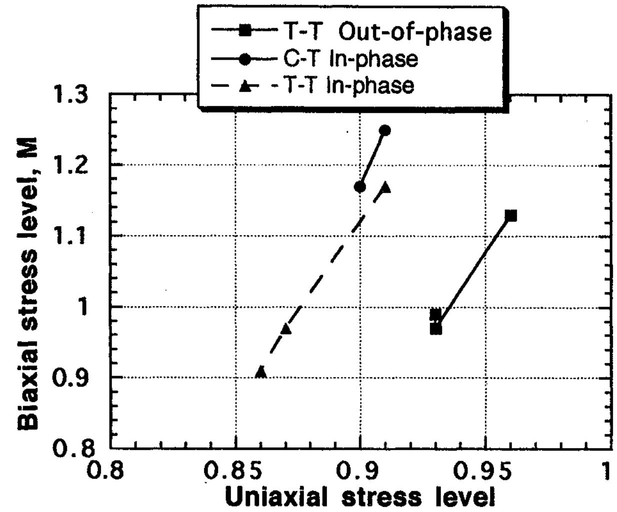

Fig. 4 Plots of M-value vs. the equivalent uniaxial fatigue strength.