Strength Weibull Distribution Analysis for the NBG-18 Graphite in HTR

Li Hongwei[1)], Gao Mingshan [1)], Sun Libin [1)]

1) Institute of Nuclear and New Energy Technology, Tsinghua University, Beijing, China

ABSTRACT

A serial of tensile strength experiments and assessment for the NBG-18 graphite, developed by SGL Carbon Group in Germany, are described in this paper. Both the normal strength distribution and the minimum ultimate strength for this graphite are given to provide reliable data for stress analysis of graphite components. Finally the presented is the Weibull distribution for the NBG-18 graphite material strength.

INTRODUCTION

Graphite is a kind perfect reactor material for HTGR and has been widely used in the reactor core for its good mechanical properties, excellent thermal properties and lower neutrons absorption. The safety of HTGRs is closely bound up with the stabilization and integrity of the graphite structures. The safety estimation for the graphite structures is very important in designing these reactors. This estimation needs to know the specified minimum ultimate strength and the strength distribution density function of the used graphite [1-2].

The NBG-18 nuclear graphite, developed by SGL Carbon Group in Germany, is a new product for High Temperature Gas-cooled Reactors. To obtain the strength property of this kind graphite, the tensile strength experiment was carried out on a block of NBG-18 graphite brick.

TENSILE STRENGTH EXPERIMENTS

The NBG-18 graphite brick is shown as Fig. 1. Specimens are cut in different positions and along different directions of the brick. According to the sample positions (shown as Fig. 2), the specimens are divided into three groups in the tensile strength experiments. According to the standard DIN51914-1985 [3], the specimens were machined in standard figure and dimension, as shown in Fig. 3.

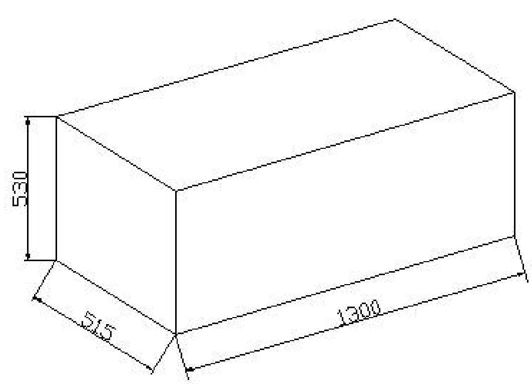

Fig. 1 Graphite brick's shape

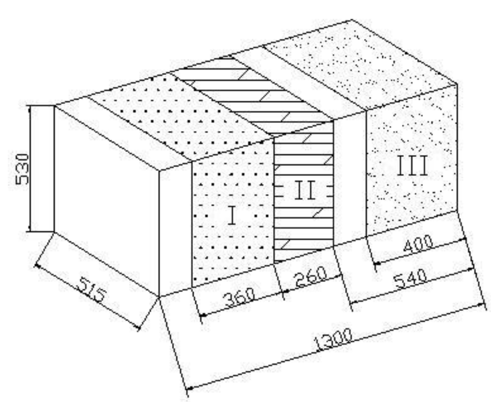

Fig. 2 Positions of three groups of specimens

In the experiments, the special material testing machines pulled the graphite specimens evenly along the axes till the crack and now recorded the break load. The used material testing machines and the load speeds are different for the three groups. The detailed information is shown in Table 1.

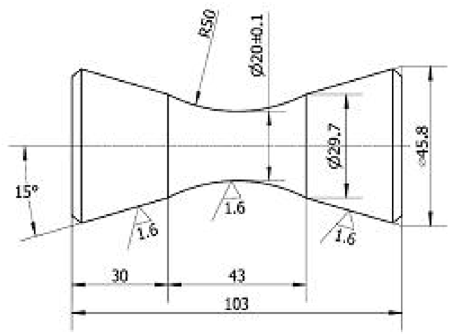

Fig. 3 Specimen's shape

Table 1. the material testing machines and load speeds for three groups

Group	Material testing machine	Load speed
I	DLy-6 universal material testing machine	150N/min
II	SANS CMT5504 universal material testing machine	3 N/s
III	DLy-10 universal material testing machine	150N/min

RESULTS AND ANALYSIS

The distribution of tensile stress is assumed equality in the section of specimen with the uniaxial experiment. So the stress in the time of crack is:

$$\sigma_p = \frac{F}{S} \tag{1}$$

F: the break load;

S: the least section area.

According to the equation (1), 108, 140 and 56 effective experiment data are achieved respectively for the Group I, II and III. Some important statistics of the experiment results are shown in table 2.

Table 2. Some important statistics of the tensile strength results

Statistic \ Group	I	II	III	Total
Specimen capacity	108	140	56	304
Mean (MPa)	19.11	21.09	18.90	19.98
Variance (MPa)	1.68	1.58	1.81	1.95
Maximum (MPa)	23.71	25.24	23.44	25.24
Minimum (MPa)	14.96	16.79	15.43	14.96
Extreme difference (MPa)	8.75	8.45	6.92	10.28
Asymmetry coefficient	0.36	-0.20	0.44	0.00
Coefficient of kurtosis	2.82	2.72	2.26	2.36
Coefficient of variation	0.088	0.075	0.096	0.097

From table 2, regardless the difference of the three groups, the conclusion can be drawn that the tensile strength of

NBG-18 graphite has a lower scatter character, which is good to the graphite components. The distribution of the tensile strength is symmetric and approximately fits the normal distribution.

But the mean value of the experiment results could not be adopted as the design intensity of graphite owing to the dissipation of strength distribution. Generally, the stated least strength is computed under the 95% confidence and 99% reliability level. The computing method is as equation (2).

$$S_u = \mu - (2.326 + \frac{1.645}{\sqrt{n}})\sigma \tag{2}$$

μ is the least value of all the mean values of all groups, and σ is the total variance of all experiment data.

Table 3. the minimum ultimate strength of the NBG-18 graphite

	Tst	Tnd	Trd	T
Mean (MPa)	19.11	21.09	18.90	19.98
Variance (MPa)	1.68	1.58	1.81	1.95
Minimum ultimate strength (MPa)	14.94	17.19	14.30	15.27

The recommended minimum ultimate strength of the NBG-18 graphite is 15.27MPa with regard to the difference of sampling positions, the negative system error and the safety factor in the practical design.

Knowing the Weibull distribution of the graphite strength is the precondition to make safety evaluation for graphite components with probability method. Generally speaking, the tensile strength of graphite satisfies the two parameters Weibull distribution. The lapse probability is shown as equation (3).

$$F(X) = 1 - e \times p\left\{ -\left(\frac{\sigma}{\eta}\right)^m \right\} \tag{3}$$

Make twice logarithm, then get:

$$\ln\ln\left(\frac{1}{1-F(X)}\right) = m\ln\sigma - m\ln\eta \tag{4}$$

Refer to equation (4), the scale parameter η and the shape parameter m can be obtained. The Weibull parameters of graphite tensile strength are shown in table 4. And the probability density distribution of the strength is shown as Fig. 4.

Table 4. Weibull parameters of graphite strength

	η	m
Tst	19.89	11.54
Tnd	21.81	14.77
Trd	19.73	10.73
T	20.87	11.24

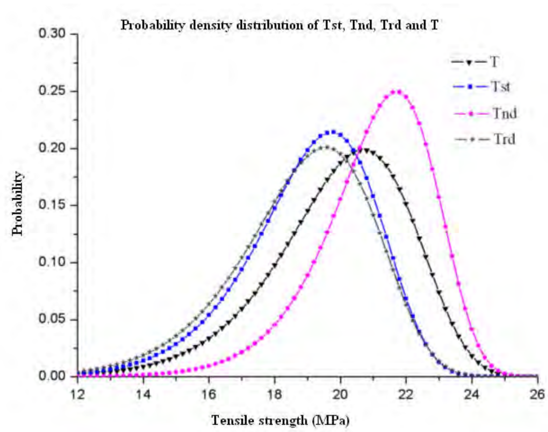

Fig. 4 the Weibull distribution of tensile strength

According to Germany HTGR design criterion KTA3232 [4], to make sure that the result has 0.95 confidence level, the Weibull parameters should be modified. The modify method is as equation (5).

$$m_t = \frac{m}{t(n;0.95)}, \quad \eta_t = \eta \times EXP\left\{-t^*(n;0.95)/m_t\right\} \tag{5}$$

But if the sample capacity is more than 120, the design criterion KTA3232 doesn't directly give the value of *t*(n,95%) and *t**(n,95%). In this paper the fitting method is applied to solve this problem according to the criterion data. Table 5 gives the modified Weibull parameters of graphite tensile strength.

Table 5 Modified Weibull parameters of graphite tensile strength

Parameter	Tst	Tnd	Trd	T
t(n,95%)	1.175	1.151	1.277	1.127
*t**(n,95%)	0.223	0.19	0.324	0.164
η_t	19.45	21.49	18.98	20.52
m_t	9.82	12.83	8.40	9.97

CONCLUSION

To obtain the strength characteristics of the NBG-18 graphite, a serial of tensile strength experiments and assessment are carried out and gets the following results.

(1) Under the 95% confidence and 99% reliability level, the minimum ultimate strength of the NBG-18 experimental graphite is 15.27MPa.

(2) All the experiment data from the three groups subordinates the two parameters Weibull distribution. The scale parameter is 20.87 and the shape parameter is 11.24. According to the German High Temperature Gas-cooled Reactor Design Norm KTA3232, the scale parameter is modified to 20.52 and the shape parameter is modified to 9.97, to ensure the 0.95 confidence level for the strength evaluation of the graphite structure.

REFERENCES

1. Wang Chaoyang. Probability Assessment Of the Graphite Block in High Tempreture Gas-cooled Reactor: [Dissertation for Master]. Beijing: Tsinghua University, 2002.
2. Zhang Zhongjie. Life Assessment of Graphite Structure under Irradiation in HTR-PM: [Dissertation for Master]. Beijing: Tsinghua University, 2006.
3. DIN. DIN51914-1985. Testing of Carbon Materials; Determination of Tensile Strength; Solid Matters. Berlin: DIN, 1985.
4. KTA 3232 Keramische Einbauten in HTR-Reacktordruckbehälten, sicherheits -technische Regel des KTA, 1992.