A SIMPLE METHOD FOR MEASURING K_{IIIC} OF DUCTILE METALS AND ITS SOME APPLICATIONS

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In the past several years, circular torsion specimes were used to measure the tearing mode fracture toughness K_{IIIC} of ductile metals. In view of the fact that the fatigue precrack is not exactely concentric with the outside circle and also the disputable definition of critical torque, it is not quite positive that the problem has been entirely solved. In this paper, the author introduces an improved method for measuring K_{IIIC} of ductile metals. Here, a keeper is used as an additional part in order to get a fracture surface with axially symmetrical appearance and a corresponding torque. Then, we can calculate K_{IIIC} by using the diameter of the smooth core of the fracture surface, the outside diameter, and the fracture torque which is now used as a critical load. This method has many advantages, such as simple in equipment and accurate in results. Besides, there is no precrack and no definite limitation in specimen dimensions. The author extends this method to the tensile test to get K_{IC} of ductile metals. Meanwhile, the relationship $K_{IIIC}/K_{IC} = \sqrt{1-\nu}$ is experimentally proved to be correct.

I. MEASURING METHOD

1) Keeper

For the common circular torsion specimen, a keeper is used as shown in Fig. 1, with the two halves of it screwed together. Between the keeper and the specimen there is a slight contact pressure. The purpose of using the keeper is to keep the outside contact surface of the specimen on the same cylindrical surface throughout the whole testing process, in other words, the torsion center always remains coincident with that of the outer circle. Thus we can finally get an axially symmetrical fracture surface,

the diameter of instantaneous fracture region, the drop section of torque-angle diagram, and the corresponding fracture torque.

In general, a circumferential slot is made on the specimen so as to fix artificially the position of the fracture surface and, as a result, the lenght of the keeper may be made shorter, the maximum and fracture torques are lowered and the torsion angle is reduced.

2) Specimen

The torsion specimen is of circular cross-section, with or without a circumferential slot. The outside diameter of specimen may be chosen somewhat arbitrarily. The extended angle of the slot is usually taken small than 20°. No strict restrictions are imposed upon the slot depth and the root radius. The eccentricity between the outer circle and the slot circle should be as small as possible. But all these geometrical effects will not influence the final value of K_{IIIC}. The recommended sizes of a slotted specimen are shown in Fig. 2.

3) Testing Procedure

The testing procedure is just the same as for the ordinary torsion test except that a keeper is used. In Fig. 3, two typical torque-angle diagrams are shown for the slotted specimens. Torsion angle ϕ is based upon the specimen length between the grips. From the M_n-ϕ diagram we can easily determine the maximum and fracture torques, M_{nmax} and M_{nf}. After fracture, there are two regions to be seen on the fracture surface. The central smooth core is the instantaneous fracture region, See Fig. 4. With the data of M_{nf}, the core region diameter d and the outside diameter D, K_{IIIC} may be calculated by using the following formula[1]:

$$K_{IIIC} = F_1 \tau_n \sqrt{\pi d/2}$$

where, factor F_1 is a function of $\frac{d}{D}$. When $0<\frac{d}{D}<0.5$, $F_1=0.375$; for other values of $\frac{d}{D}$, see Fig. 5. And $\tau_n = 16M_{nf}/\pi d^3$.

II. RESULTS AND APPLICATIONS

The testing results for three kinds of steel (low-carbon steel, 9Cr and 50Cr steel) are listed in Table 1. The fracture surfaces shown in Fig.4 are for 9Cr and 50Cr steel specimens respectively. Due to similarity, K_{IC} for these steels are calculated from tensile tests with fracture loads and cup-cone diameters. The results are also listed in Table 1.

According to the results listed, we conclude as follows:

(1) It is noted that d is smaller than d_s, the slot diameter. The acute ring-shaped crack is developed by the keeper's action before instantaneous fracture taking place. Thus the fatigue precracking process for the specimen can be omitted.

(2) The value of K_{IIIC} for each steel may be considered the same for the different sizes of specimen. The outside diameter D and the slot depth h have influence on the magnitudes of M_{nf} and d, and would not finally influence the value K_{IIIC} calculated from them. Increasing D or decreasing h makes both M_{nf} and d larger. h may be zero (specimen No. 3) and D may be very large, though it is often unpractical.

(3) The values of K_{IIIC} (tor.)/K_{IC} (ten.) coincide well with those of $\sqrt{1-\nu}$ as shown in the table. So the formula $K_{IIIC}/K_{IC} = \sqrt{1-\nu}$ is established.

(4) Using the relationship $K_{IIIC}/K_{IC} = \sqrt{1-\nu}$, we can obtain both K_{IC} and K_{IIIC} from the tensile test which is in fact simpler than the torsional one for the absense of a keeper.

(5) In these two tests, it is shown to be reasonable to take the fracture as the critical state in calculations for this type of specimen.

III. CONCLUSIONS

The simplest test, tensile or torsional, is used to get the important material data, K_{IC} and K_{IIIC}. The equipment used is quite simple, the procedure is short and easy, the specimen may be of small size and without precracking, and the results are accurate and stable. The tensile test may be carried out more easily in high-and low-temperature environments, as well as under various strain rates. The measuring method introduced here is of great value in practice.

No much attention has been paid to the fracture load P_f of the tensile test before. And no one has ever imagined that there exists a fracture torque M_{nf}, similar to P_f. Because M_{nf} or P_f is needed for measuring K_{IIIC} and K_{IC}, the two fracture loads will doubtless become important testing data from now on.

Table 1

Torsional Test

Material	No.	d (mm)	D (mm)	h (mm)	M_{nmax} (kg-m)	M_{nf} (kg-m)	F_1	τ_n (kg/mm²)	K_{IIIC}(tor.) (kg/mm$^{3/2}$)	K_{IC} (kg/mm$^{3/2}$)
	1	4.70	10.00	1.27	3.53	3.10	0.375	152.1	155.0	185.2
low-	2	4.77	10.00	1.28	3.55	3.10	0.375	145.5	149.4	178.5
carbon	3	6.20	10.00	0.00	6.80	5.95	0.360	127.1	142.8	170.6
steel	4									
	5									
	6	4.80	10.00	0.70	7.70	5.10	0.375	234.9	241.8	283.0
	7	5.20	10.10	0.73	8.22	6.10	0.375	221.0	236.8	277.1
9Cr	8	7.00	12.82	0.55	20.20	13.30	0.370	197.5	242.3	283.7
steel	9	9.12	16.13	0.78	38.25	26.50	0.366	177.9	246.4	288.5
	10									
	11									
	12	4.80	9.74	0.67	8.03	5.47	0.375	251.7	259.1	310.2
	13	5.20	10.20	0.30	9.05	7.20	9.375	246.3	266.5	319.0
50Cr	14	7.00	13.60	1.25	19.35	14.10	0.375	209.4	260.3	311.2
steel	15	9.61	16.85	1.03	42.60	34.00	0.365	195.1	276.7	330.6
	16									
	17									

1. Except specimen No. 3, each with a circumferential slot.
2. Specimens No. 1 and 2 are longer in length, with a slot near one end. First in torsional test, then in tensile test for the longer remained part.
3. Low-carbon steel, ν=0.30 (assumed); 9Cr steel, ν=0.27 (measured); 50Cr steel, ν=0.30 (measured).
4. Testing temperature, 25°C.

Table 1 (cont.)

	Tensile Test									
No.	d_c (mm)	D_c (mm)	P_b (kg)	P_f (kg)	F_2	σ_n (kg/mm²)	K_{IC}(ten.) (kg/mm$^{3/2}$)	K_{IIIC} (Kg/mm$^{3/2}$)	K_{IIIC}(tor.) / K_{IC}(ten.)	$\sqrt{1-\nu}$
1	3.83	5.60	3150	2400	0.410	183.1	184.1	154.0	0.842	0.837
2	3.67	5.47	3070	2300	0.415	178.0	177.4	148.3	0.842	
3										
4	3.20	5.30	3200	2500	0.465	178.3	185.9	155.5	0.814	
5	3.50	5.60	3175	2575	0.460	171.6	185.1	154.9		
6										0.854
7									0.841	
8										
9										
10	4.35	6.05	5030	3750	0.405	270.1	285.9	244.3		
11	4.45	6.02	5230	3950	0.405	269.9	288.9	246.9		
12										0.837
13										
14									0.825	
15										
16	5.60	7.19	5690	4830	0.360	302.1	322.6	269.5		
17	5.65	7.37	5910	5130	0.370	291.4	321.2	268.3		

d_c— cup-cone inner diameter, D_c— cup-cone outside diameter,

$\sigma_n=4P_f/\pi(D_c^2-d_c^2)$ — nominal stress, $K_{IC}=F_2\sigma_n\sqrt{\pi d_c/2}$, F_2— correction factor (see [1]).

REFERENCES

[1] Hiroshi Tada, The Stress Analysis of Cracks, Del Research Corporation, Hellertown, Pennsylvania (1973).

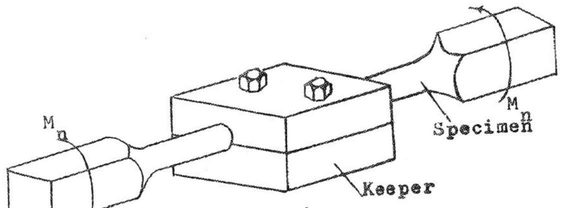

Fig.1

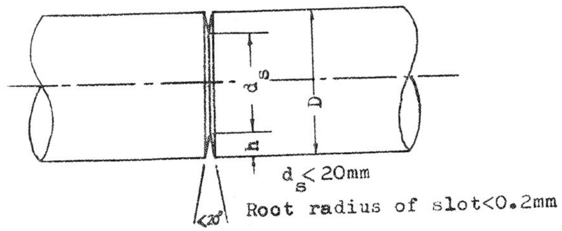

Fig.2

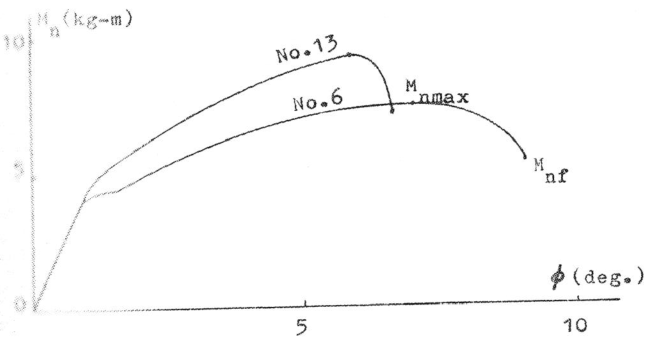

Fig.3

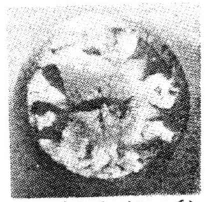

Fig.4(a) (No.6)

Fig.4(b) (No.13)

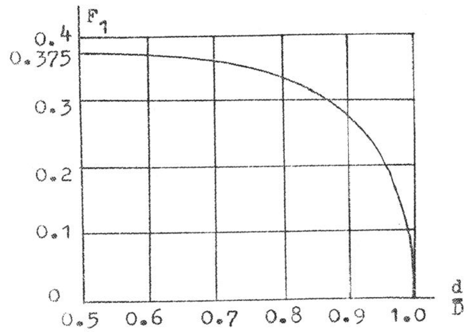

Fig.5