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◉ 論 文

A Study on the Fatigue Strength Reduction Factor under the High Cycle Bending Fatigue

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高사이클 굽힘 疲勞에서의 疲勞强度 減少係數에 關한 研究

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Key Words : Fatigue Crack Initiation Life(疲勞龜裂發生壽命), Fatigue Strength Reduction Factor(疲勞强度減少係數), Fatigue Design(疲勞設計), Load Controlled Axial Force Test(荷重制御軸力試驗), Welding Joints(鎔接이음)

초 록

機械나 構造物의 疲勞壽命은 노치에서의 疲勞龜裂 發生壽命에 의하여 支配되기때문에 노치로 인한 疲勞强度減少係數 K_f는 疲勞設計上 대단히 重要한 因子이다.

노치 선단(Notch root)에서의 疲勞龜裂發生壽命 N_c를 基準으로 하면 彈性應力集中係數 K_t가 10 정도까지 K_f와 K_t간에는 거의 直線的인 關係가 있음이 이이다-고에 의하여 明確해 졌으나 이는 引張, 壓縮의 축력이 作用하였을 때이며 따라서 機械나 構造부재는 축력 외에도 굽힘 疲勞 荷重이 作用하였을때도 많으므로 本 研究에서는 굽힘 疲勞 荷重을 받았을때도 이이다-고의 結論이 適用되는지를 檢討코져 本 研究를 실시하였다.

NOMENCLATURE

K_f	Fatigue strength reduction factor
K_t	Elastic stress concentration factor
N_f	Fatigue life to failure
N_c	Fatigue crack initiation life
S_a	Stress amplitude

1. Introduction.

Generally, machinery and steel structures have a geometrical notch which is geometrically discontinous part.

The welding joints also have the notch due to the change of metallurgical structure.

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The fatigue life of the machinery and steel structures depends on the fatigue crack initiation life at the notch.

Therefore, the fatigue strength reduction factor K_f which is related to the notch is the most important factor in case of the fatigue design of machinery and steel structures.

The study on the fatigue strength reduction factor K_f in the high cycle range has been done by many authors.

Most of these researches K_f increase linearly to 2 of the elastic stress concentration factor K_t and the K_f was led to the saturated values from 3 to 5 in the relation of K_f and K_t. The above conclusion is because the cycle to failure N_f of specimens is taken as the basis of fatigue life, but in study by Iida and Koh[1),2)] the fatigue initiation life N_c is taken as the basis of fatigue life, and K_f increases linearly to 10 of K_t in the relation of K_f and K_t.

Iida and Koh made it clear on the theory and experiment by the hysteresis energy at the notch root under the pulsuating tension in the range of intermediate and high cycle.

They conducted the axial test under the load control, and used the specimens which are the plate with notch and hour-glass type, and made of KDK, HW 50 and HW 70. The fatigue strength reduction factor K_f of the electro-gas welding joints of KDK steel at $N_c=5\times10^5$ is 80% of elastic stress concentration factor.

K_t and K_f are almost same at $N_c=1\times10^6$, 2×10^5 in case of HW 50 and HW 70.

The research by Iida and Koh shows the case of the axial fatigue load with notch, but do not show the case of the bending load.

Therefore author will study on the fatigue strength reduction factor of the bending fatigue strength.

The purpose of this study is to compare the estimated formula by Iida and Koh with this study.

2. Test

2-1. Specimen

Specimen is hot-rolled steel plates SM50B with the thickness of 6mm.

The chemical components and the results of the static tensile test are shown in the Table 1. Fig. 1 shows specimens of the plate with one side notch. The longitudinal axes of specimens have the same direction as the rolled direction of steel.

Table 1. Chemical Composition and Mechanical Properties of Steel Used(SM50B)

Chemical Composition(%) Mill Sheet)				
C	Si	Mn	P	S
0.15	0.45	1.37	0.017	0.015

Mechanical Properties(Mill Sheet)		
Yield Stress (Kg_f/mm^2)	Ultimate Tensile Stress(Kg_f/mm^2)	Elongation (%)
43	57	26

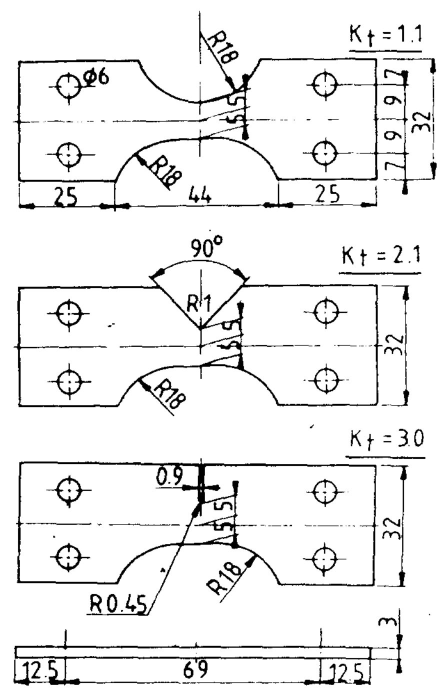

Fig. 1 Configuration of Specimens

The specimens are cut off the center part steel plate thickness, and the steel plate is machined for the use of specimens. The elastic stress concentration formula of the revised angle is as follows.[3),4)]

$$K_\theta = 1 + \frac{1-\exp\{-0.90\sqrt{B/d}(\pi-2\theta\}}{1-\exp\{-0.90\pi\sqrt{B/d}\}}(K_0-1) \quad \cdots\cdots(1)$$

where

K_0, K_θ : elastic stress concentration factor when the notch angle is 0° and θ°.

θ : notch angle

B : breadth

d : depth of notch

2−2. Fatigue test

A tester is the 4 kg_f-m capacity SCHENCK type fatigue testing machine and the specimens are used the completely reversed stress condition (R = −1). While the tester was operated, author sometimes stopped it and searched the fatigue crack with a magnifying glass to confirm the crack initiation.

In this study the crack initiation length of about 2mm was defined as the cycle of the crack initiation life N_c, and in case of over the 2mm, the crack initiation life N_c was estimated from the crack propagated behaviour.

The repeated velocity was always 3000 cpm and whenever the tester was started, it was operated by hands until some cycles to control the range of stress amplitude, and the effect of the characteristic difference of tester and specimens was disregarded. Experiments were conducted in air.

3. The test results and discussions

3−1. S-N diagrams of the smooth and notched specimens

Fig. 1 shows the fatigue strength diagram of plate specimen with one side notch under completely reversed stress control. The horizontal axis expresses the crack initiation life and the vertical axis the nominal stress amplitude S_a.(in Fig. 2)

The experimental data shows that S_a has linear relation with N_c on logarithmic scale and the fatigue strength can be expressed as follows.

$$Sa = CN_c^{-k} \quad \cdots\cdots(2)$$

$$N_c = C'S_a^{-k'} \quad \cdots\cdots(3)$$

Table 2. represents the constants for K_t = 1.1, 2.1, and 3.0 which is obtained from the experimental results calculated by the least-squares curve fitting. To decide the fatigue limit, five specimens for K_t = 1.1, five specimens for K_t = 2.1, and eight specimens for K_t = 3.0 were used under stress control with the stress between 0.5 Kgf/mm² and 1 Kgf/mm², and 3000 cpm of the repeated velocity.

Table 2. Constants in S_a−N_c relations

K_t	$S_a = C\ N_c^{-k}$		$N_a = C'S_a^{-k'}$	
	C	k	C'	k'
1.1	1.277E+2	0.092	8.669E+22	10.890
2.1	2.305E+2	0.196	1.068E+12	5.091
3.0	6.176E+2	0.300	2.041E+9	3.336

The experiment was considered as the non-rupture without crack to the number of 10^7 cycles. While the experiment was conducted, the stationary crack occured in one specimen and this specimen was considered as a rupture on the point of view of crack initiation.

Generally the starecase method is used for the fatigue limit dicision method, but in this case the number of data is few, so that the fatigue limit in the Fig. 2 was drawn by the eye-measurement.

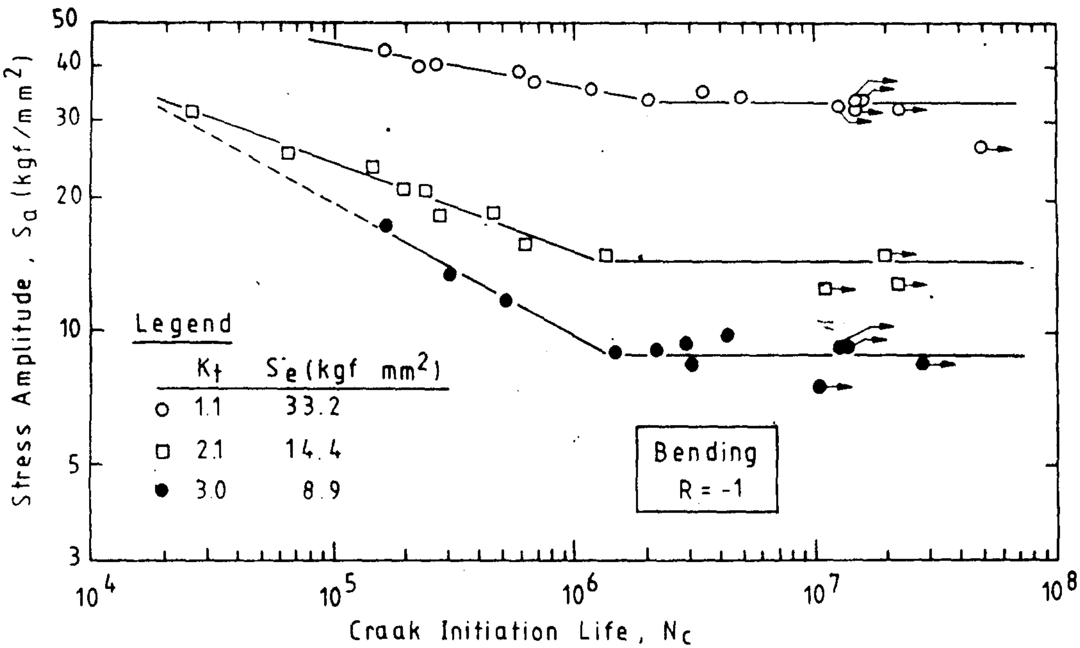

Fig. 2 Sa-Nc Diagrams

3−2. Relation between K_t and K_f

Substituing the value to each K_t of Table 2. into Equ.(3), and plotting the relation of stress amplitude S_a and fatigue limit S_e to K_t, the result is shown in the Fig. 3 for the condition of the $N_c=1\times10^5$, 2×10^5, 5×10^5, and 1×10^6.

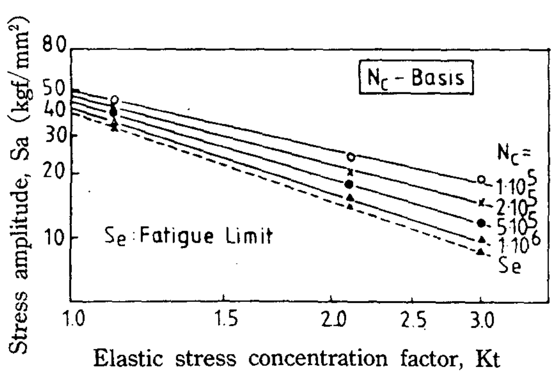

Fig. 3 Relation between Kt and Sa

Both horizontal and vertical axes represent logarithmic plots, and on the assumption that each point was on the straight line of N_c as parameter, the assumed value was obtained under $K_t=1.0$.

Now the K_f is defined as follows :

$$K_f=\frac{S_a \text{ of the specimen for } K_t=1.0 \text{ under the arbitrary } N_c}{S_a \text{ of the specimen for } K_t=K_t \text{ under the same } N_c}$$

Hence the relation between K_t and K_f is plotted on N_c as parameter, which is represented in Fig. 4.

As N_c increases, the inclination of $(K_f-1)/(K_t-1)$ has the tendency of increasing. This fact is the same as that of Iida and Koh's paper, which concluded as $K_f \leq K_t$ on the tensile loading fatigue. On the contrary, the Fig. 4 represents $K_f > K_t$ except the case of $N_c=1\times10^5$.

This result expresses greater bending fatigue strength under the same value of K_t.

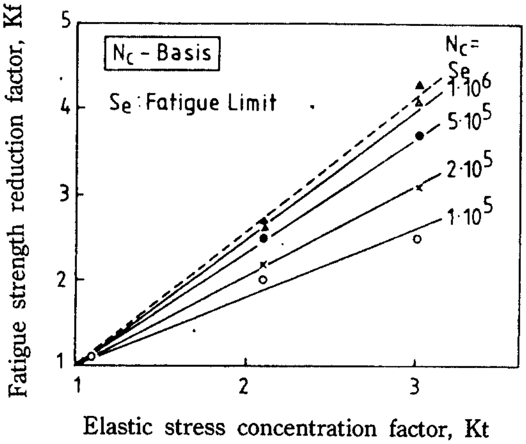

Fig. 4Kt-Kf Relations

4. Conclusion

The obtained results as follows :

"Fatigue strength reduction factor of the bending fatigue strength is greater than that of the axial fatigue strength."

5. References

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