The 2015 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM15)
Incheon, Korea, August 25-29, 2015

Derivation of Fatigue Properties of Plastics and Life Prediction for Plastic Parts

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ABSTRACT

Plastics have been widely used to many external and mechanical components in electronic devices such as cover, coupler, gear and etc. due to relatively low cost, ease of manufacture and versatility. In order to assure the reliability of mechanical components, it is important to consider fatigue characteristics for plastics. In this study, Fatigue property of ABS is derived from tensile fatigue tests(R=0.1) with notched and un-notched specimens in order to find the influence of stress gradient. Fatigue simulations and jig tests are performed to estimate the life of mechanical components

1. INTRODUCTION

Fatigue occurs when a material is subjected to repeated loading and unloading. Many studies have been carried about the fatigue behaviour and life prediction of metal components, but there is not enough research on the fatigue characteristics of plastics in spite of large application of plastic components in many industries. To ensure the reliability of the plastic parts, there is a need for systematic study on fatigue properties of plastic materials.

There are 2 empirically-based design approaches about fatigue life prediction, the stress-life approach and the strain-life approach. The stress-life approach is applied to estimate the life of a mechanical component under cyclic loading in high cycle fatigue (above 10^3 or 10^4 cycles) with S-N curve. The S-N curve can be made by fatigue test with un-notched specimen at various stress levels, but mechanical components have geometrical features which can cause local stress concentration and multi-axial states of stress. Therefore, the influence of stress gradient must be considered to predict fatigue life of mechanical components.

2. INFLUENCE OF THE STRESS GRADIENT

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The notched specimen has the same endurance cycle with that of the smooth specimen in spite of higher peak stress at notch area as shown in Fig. 1. This is frequently said that the notch has a supporting effect, which means the material surface can endure higher stress with the support of the area below the material surface. This supporting effect explains smooth bending specimens always have higher fatigue limit than smooth, axially stressed specimens.

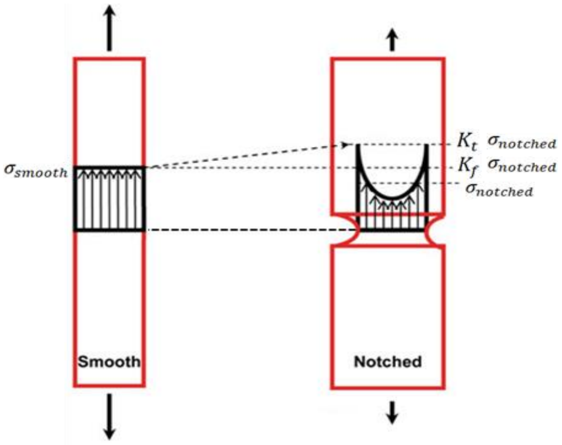


Fig. 1 Same endurance cycle for smooth and notched specimen

The fatkgue limit of notched specimen can be predicted with the fatigue notch factor K_f and K_f is smaller than the elastic concentration factor, K_t. (Yung-Li Lee, Mark E. Barkey, Hong-Tae Kang, 2012). The fatigue notch factor is defined as Eq. (1),

$$K_f = \frac{\sigma_{smooth}}{\sigma_{notched}} \tag{1}$$

where σ_{smooth} is the fatigue limit of a smooth specimen and $\sigma_{notched}$ is the fatigue limit of a notched specimen

According to FEMFAT method (*FEMFAT Theory manual*), the support factor n is calculated with the relative stress gradient χ' and the ratio of tensile/compressive fatigue limit $\sigma_{A,tsc}$ to the bending fatigue limit $\sigma_{A,b}$ as Eq. (2)

$$n = f_{GR,af} = 1 + \frac{(\sigma_{A,b}/\sigma_{A,tsc})-1}{(2/b)^{\nu}}\chi'^{\nu} \tag{2}$$

where b is specimen thickness, and ν is the material parameter. The relative stress gradient χ' indicating the stress concentration by a notch is defined with the equivalent von Mises stress σ_e as Eq. (3)

$$\chi = \frac{d\sigma_e}{dx} \qquad \chi' = \frac{\chi_{max}}{\sigma_e} \tag{3}$$

The parameter $f_{GR,af}$ is the stress gradient factor to determine the fatigue limit of the local S-N curve and the slope of the local S-N curve, $k_{C,GR}$, is defined with the stress gradient factor on the slope of the local S-N curve, $f_{GR,sf}$, as Eq. (4)

$$f_{GR,sf} = 1 + \frac{1.8 \cdot {\chi'}^{1.2}}{f_{GR,af}} {\chi'}^{\nu} \qquad k_{C,GR} = \frac{(k_M - IFK2)}{{f_{GR,sf}}^{IFK3}} + IFK2 \tag{4}$$

where k_m is the slope of the material S-N curve at R=-1, $IFK2$ is the slope exponent, and $IFK3$ is the material group-dependent exponent.

3. FATIGUE PROPERTIES OF PLASTICS

ABS plastics are used largely for mechanical purposes because of impact resistance and toughness. Basic static material properties of ABS are shown in Table (1) and S-N curve for un-notched specimen (ASTM D-638 type I) with pulsating tensile loading (stress ratio R=0.1) is shown in Fig. (2)

Young's modulus	Poisson coefficient	Tensile strength	Elongation at fracture
2160 MPa	0.38	44 MPa	19%

Table 1 Static material properties of ABS

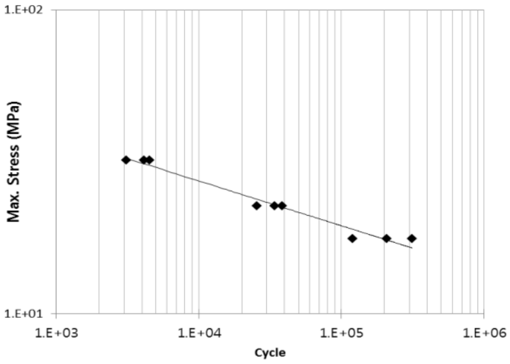


Fig. 2 S-N curve of ABS (R=0.1, Temp.=23℃, Frequency = 5Hz)

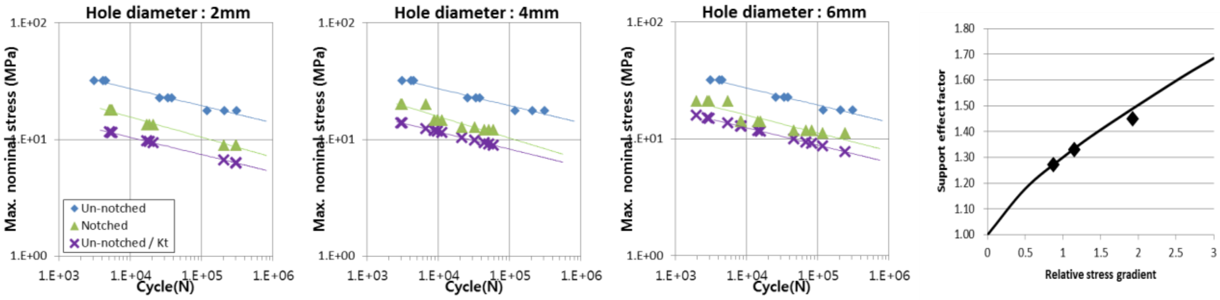


Fig. 3 Fatigue tensile test with notched specimen

In order to investigate the relationship between the support factor and relative stress gradient about ABS, tensile fatigue tests with 3 kinds of notched specimens are performed. The relative stress gradient is introduced with the hole in the middle of un-notched specimen (ASTM D-638 type I) and hole diameter is 2, 4 and 6mm to control the relative stress gradient. The test results with notched specimens are shown in Fig.

(3). There are 3 curves in each plot, S-N curve from un-notched specimen, notched specimen, and S-N curve calculated with the elastic concentration factor, K_t. Stress levels from S-N curve of “Notched” are higher than those of S-N curve of “Un-notched / K_t”, which shows the support effect near the notch. 3 data points for relative stress gradient vs support factor are derived from each test results shown as Fig. (3). The material parameter ν is determined from curve fitting of these data points with Eq. (2). It is possible to estimate the fatigue life of mechanical components with various geometrical features, using this fitted curve for relative stress gradient vs support factor.

Numerical analysis in ABAQUS 13.1 and fatigue calculation in FEMFAT 5.0 for notched specimen with tensile loading are done to check the accuracy of ABS fatigue property as shown in Fig. (4).

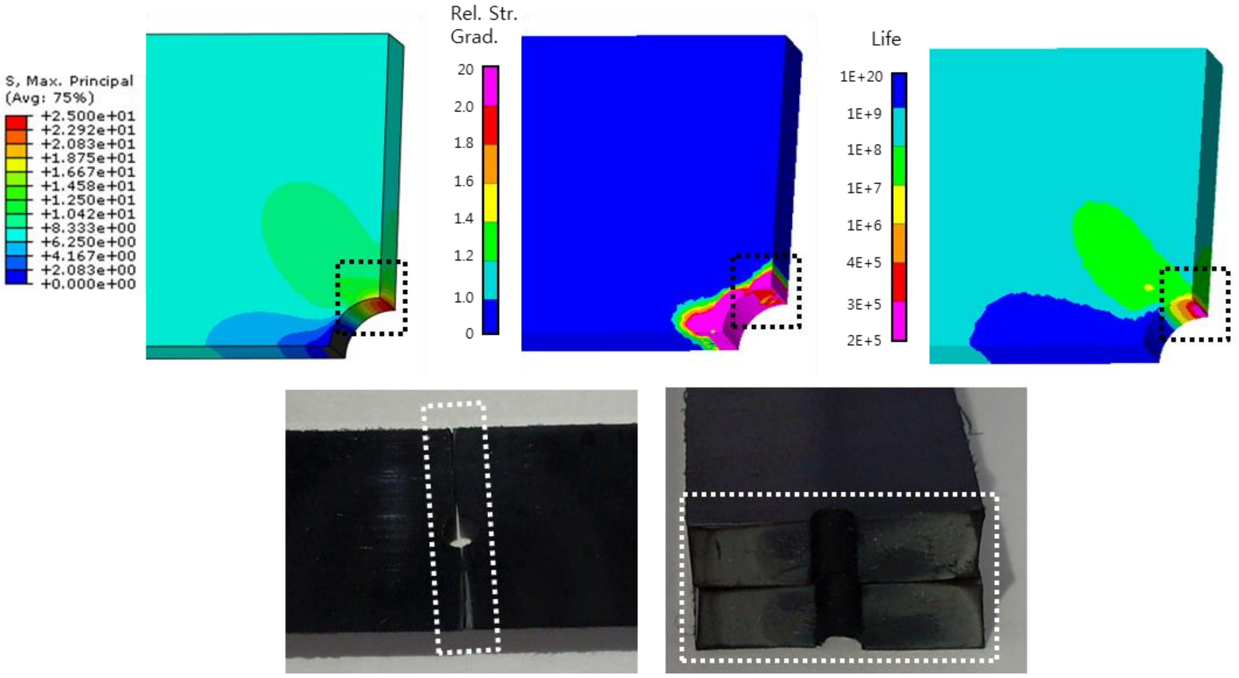


Fig. 4 Numerical analysis result for D=2mm specimen

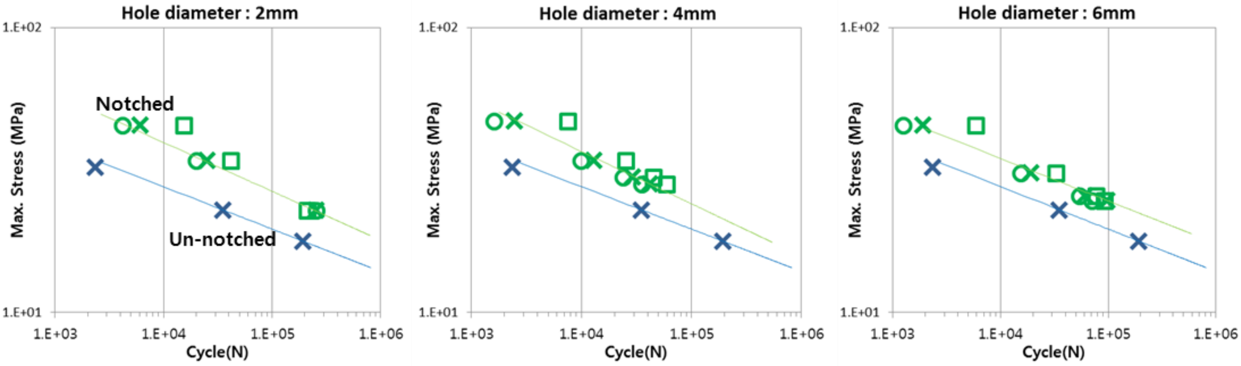
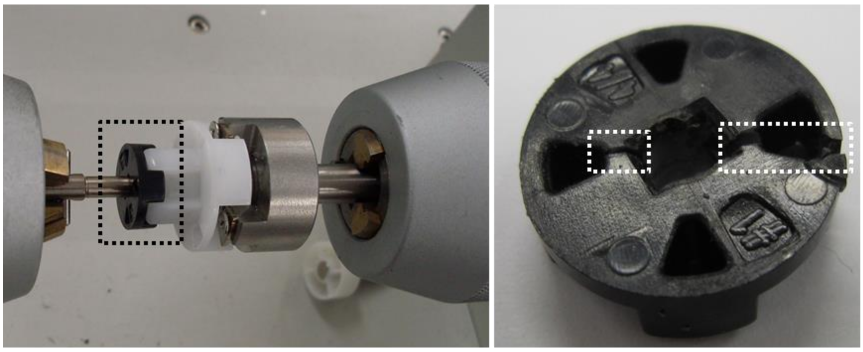


Fig. 5 Failure cycle from test and numerical analysis result for notched specimen

Material exponent *IFK2* and *IFK3* are used to determine the slope of local S-N curve. Fig. (5) gives the predicted life of un-notched and notched specimen as marks in the plots. Material exponents are defined with comparison of failure cycle between test and numerical analysis result for each case.

4. LIFE PREDICTION OF PLASTIC PARTS

Coupler is a mechanical part which transfers torque and rotation. Fatigue life of coupler is derived from coupler testing device as shown in Fig. (6). Coupler testing device can control rotation speed and torque same as actual condition for several types of couplers. Failure cycle of coupler under 3kgf.cm torque is between 20,000 and 30,000 and average failure cycle 24,447. Crack is initiated from contact area with the edge of D-cut shaft. Static analysis result for life prediction of coupler is shown as Fig. (7). Highest stress concentration occurs at the contact area with shaft.



Test No.	Failure cycle
#1	27,841
#2	25,000
#3	20,500
#4	29,500
#5	30,000
#6	28,500
Average	24,447

Fig. 6 Fatigue test result with coupler testing device

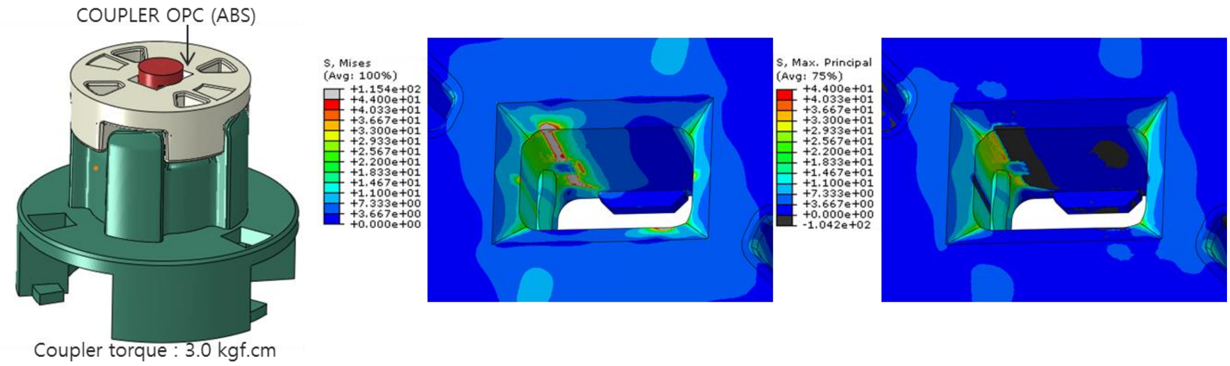


Fig. 7 Stress distribution near crack initiation area

Fatigue result of coupler is calculated to take into account the influence of stress gradient of ABS plastic. According to fatigue calculation result of coupler shown in Fig (8), fatigue life at the contact area with D-cut shaft edge is between 20,000 and 30,000 and fatigue life at the contact area with D-cut shaft vertex is below 10,000. Fatigue life of coupler can be determined with the damage at the contact area with D-cut shaft edge because the crack at the contact area with D-cut shaft edge can grow to the fracture of coupler under torsional loading. Fatigue life prediction of coupler agrees with test result.

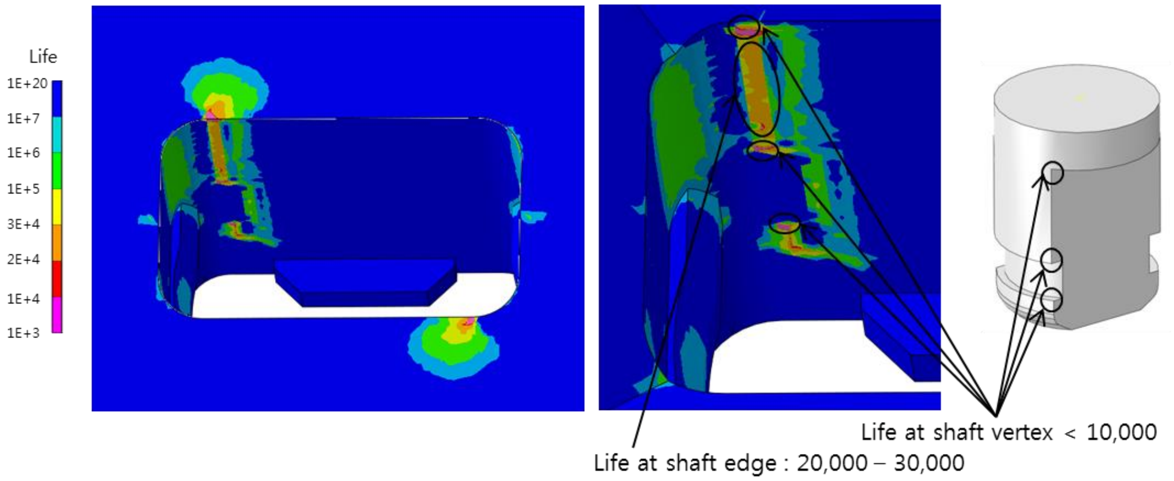


Fig. 8 Life prediction of coupler

5. CONCLUSION

In this paper fatigue property of plastic is derived to take into account the influence of stress gradient and fatigue life of coupler is predicted using this fatigue property. This fatigue property is determined to perform fatigue test and numerical analysis of un-notched and notched specimens. Life prediction to take into account the influence of stress gradient is implemented in FEMFAT. Life predictions for notched specimen and coupler are in good agreement with test result.

In order to apply this method to predict the fatigue life of mechanical component, much more tests with different types of notched specimens are needed as future work because mechanical components have many kinds of geometrical features which have wide range of the relative stress gradient.

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FEMFAT Theory manual