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A study on fatigue fracture under non-constant load

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불균일 하중을 받는 피로 파괴에 관한 연구

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Abstract There are fatigue fractures at the practical area. The fatigue load happens non- constantly. As it is impossible to be predicted, it can not be known when the fracture happens. Non -constant fatigue load is simulated in this study. The stability and the life of the material are analyzed theoretically by the program of Ansys workbench. These results are greatly applied as the practical structures to predict the prevention of failure and the endurance.

요 약 실무 현장에서 피로 파괴가 잘 일어나고 있는 상황이다. 그런데 그 하중도 불규칙적으로 일어나고 있어 예측이 불가능하여 언제 파괴가 일어나는지를 잘 알 수가 없는 상황이다. 본 연구에서는 그러한 불규칙적인 피로 하중을 시뮬레이션하여 그 재료의 안정성과 수명 관계를 Ansys workbench 프로그램을 이용하여 이론적으로 해석하여 보았다. 이러한 결과들을 실제 구조물에서 응용하면 그 파손 방지 및 내구성을 예측하는데 활용이 크다고 본다.

Key Words : available life, fatigue damage, design life, damage matrix

1. Introduction

In order to investigate the fatigue or fracture at automobile or structure, the studies of fatigue crack, compressive residual stress, and optimum stress are progressed very much nowadays. It is estimated that 50-90% of structural failure is due to fatigue. Among them, most of fatigue fractures are happened non-constantly and it is not possible to estimate without the theoretical analysis.

There are many programs about the analyzing programs usually. But the more accurate and effective analyzing results can be obtained by the program in this study [1-2] in comparison with other fatigue analysis programs. And the convergence about the analysis results of the stress and fatigue life becomes also good.

In this study, the fatigue tool is available in providing both flexibility and usefulness comparable to other types of analysis tools. This is why many designers and analysts use "in-house" fatigue programs which cost long time and much money to develop. It is hoped that these designers and analysts, given a proper library of fatigue tools could quickly and accurately conduct a fatigue analysis suited to their needs. Its focus is to provide useful information to the design engineer when fatigue failure may be a concern. Fatigue results can have a convergence attached. A stress-life approach has been adopted for conducting a fatigue analysis. Several options such as accounting for mean stress and loading conditions are available. And the simple model applied by the variable fatigue load is used in order to the simplicity of analysis. The material under the variable fatigue load is simulated and the safety and life of material is analyzed in this study. If the generalized results of this study are applied at the real structure, it is very useful to estimate and predict the prevention of fracture and the durability.

2. Simulation Model and Analysis

A fatigue analysis can be separated into 3 areas: model and material, analysis, and result of analysis. Each area will be discussed in more detail below:

2.1 Model and material

The dimensions of the specimen are shown in Fig.

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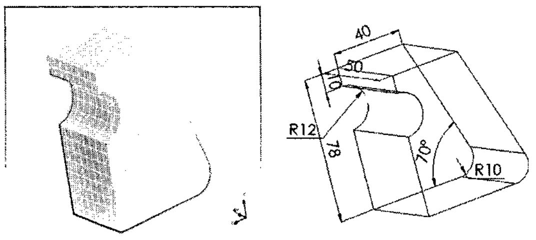


Fig. 1. The mesh and dimensions of the specimen (unit: mm)

Table 1. Material properties

Structural Properties	
Young's Modulus (MPa)	2×10^{-5}
Poisson's Ratio	0.3
Mass Density (kg/mm^3)	7.85×10^{-6}
Thermal Expansion Coefficient (/°C)	1.2×10^{-5}
Stress Limits	
Tensile Yield (MPa)	250
Compressive Yield (MPa)	250
Tensile Ultimate (MPa)	460
Compressive Ultimate (MPa)	0
Thermal Properties	
Specific Heat (J/kg · °C)	434
Fatigue Properties	
Interpolation	Log-Log
Mean Curve Type	mean stress

1 (unit; mm). Its mesh is also shown in Fig. 1. The numbers of nodes and elements are 4631 and 912. The material properties of the specimen are shown in Table 1. Its constraints are fixed at the upper, and the mean pressure is applied on the upper of the specimen by 100 MPa.

A large part of a fatigue analysis is getting an accurate description of the fatigue material properties. Since fatigue is so empirical, sample fatigue curves are included only for structural steel and aluminum materials [3]. These properties are included as a guide only with intent for the user to provide his own fatigue data for more accurate analysis [4-5].

Fatigue material data stored as tabular alternating stress vs. life points. Fig. 2 is a screen shot showing a fatigue material data graphically.

2.2 Analysis

Fatigue results can be added before or after a stress solution has been performed. To create fatigue results, a fatigue tool must first be inserted into the tree. This can be done through the solution toolbar or through context menu. The detailed view of the fatigue tool is used to define the various aspects of a fatigue analysis such as loading type, handling of mean stress effects and more.

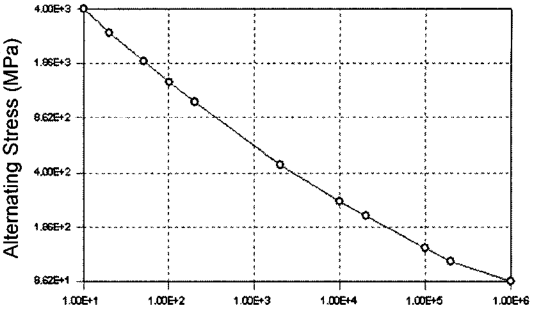


Fig. 2. S-N curves in fatigue

2.2.1 Loading types

Fatigue by definition is caused by changing the load on a component over time. Thus, unlike the static stress safety tools, which perform calculations for a single stress, fatigue damage occurs when the stress at a point changes over time. The fatigue calculations can be performed for either constant amplitude loading or proportional non-constant amplitude loading. In this study, the method loading of non constant amplitude is adopted.

A scale factor can be applied to the base loading if desired. This scale factor is 0.003. In this case, 1 set of results are only needed. In this study, instead of using a single load ratio to calculate the alternating and mean stress, the load ratio varies over time. Cumulative damage calculations including cycle counting and damage summation need to be done. The load scaling comes from an external data file provided by the user, (such as the one in Fig. 3) and is simply a list of scale factors. Several sample load histories can be found in the "Load Histories" directory under the "Engineering Data" folder. Setting the loading type to "History Data" in the fatigue tool specifies non-constant amplitude loading. Several analysis options are available for non-constant amplitude loading.

The value of infinite life will be used if the alternating stress is beyond the limit of the SN curve. Setting a higher value will make small stress cycles less damaging if they occur many times. An infinite

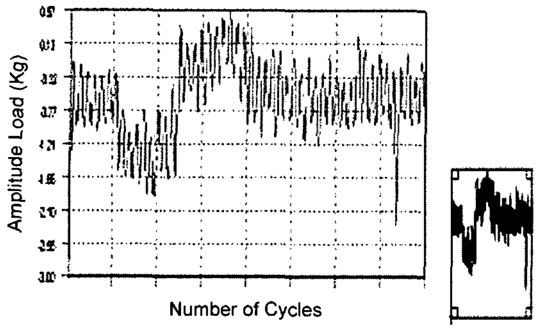
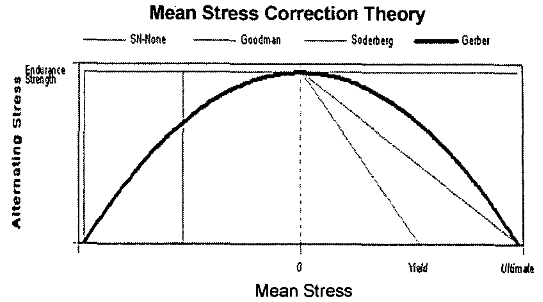


Fig. 3. Non-constant amplitude load history data

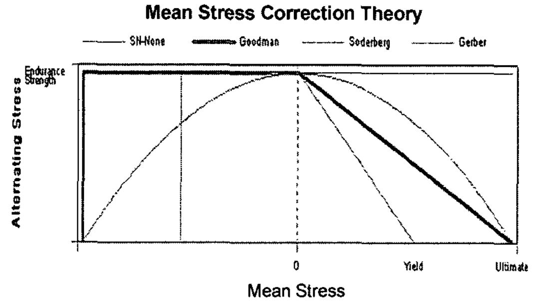
life is 10^9 cycles in this study.

2.2.2 Load effects

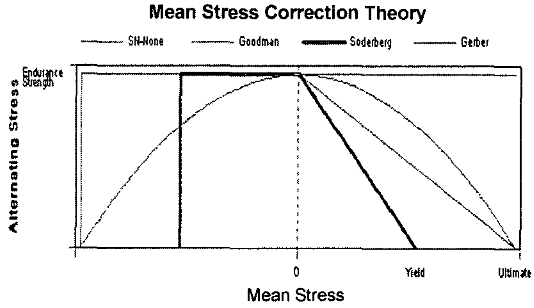
Fatigue material tests are usually conducted in a uniaxial loading under a fixed or zero mean stress state. It is cost-prohibitive to conduct experiments that capture all mean stress, loading, and surface conditions. Thus, empirical relations are available if there is no the fatigue data. If the loading is other than fully reversed, a mean stress exists and should be accounted. Methods for handling mean stress effects can be found in the "Options" section. If experimental data at different mean stresses or r-ratios exist, mean stress can be accounted for directly through interpolation between material curves. If experimental data is not available, several empirical options may be chosen including Gerber, Goodman and Soderberg theories which use static material properties (yield stress, tensile strength) along with S-N data to account for any mean stress. In general, most of experimental data fall between the Goodman and Gerber theories with the Soderberg theory usually being over conservative. The Goodman theory can be a good choice for brittle materials with the Gerber theory for ductile materials. As the screen shots in Fig. 4 can be seen, the Gerber theory treats the same negative and positive mean stresses whereas Goodman and Soderberg do not apply any correction for negative mean stresses. Although a compressive mean stress can retard fatigue crack growth, ignoring a negative mean is usually more conservative. The selected mean stress theory is shown graphically in the display window as Fig. 4. Note that if an empirical mean stress theory is chosen and multiple SN curves are defined, any mean stresses that may exist will be ignored when querying the material data since an empirical theory was chosen. Thus if you have multiple r-ratio SN curves and use the Goodman theory, the SN curve at r=-1 will be used. In



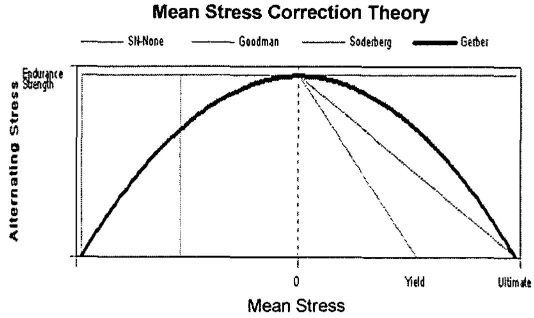
(a) SN-None



(b) Goodman



(c) Soderberg



(d) Gerber

Fig. 4. Mean stress correction theory

general it is not advisable to use an empirical mean stress theory if multiple mean stress data exists.

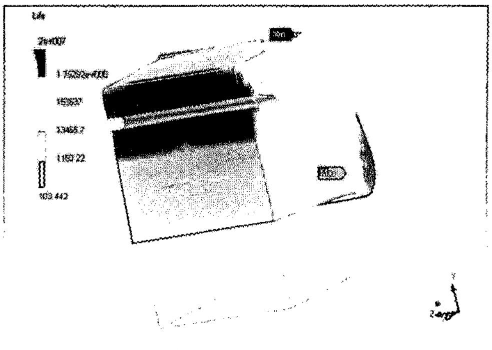
As seen in Fig. 4, a graphical representation of the loading and mean stress effects is displayed when a fatigue tool is selected by the user.

Fatigue material property tests are usually conducted under very specific and controlled conditions (eg. axial loading, polished specimens, 0.5 inch gauge diameter). If the conditions of service parts differ from as tested, modification factors can be applied to try to account for the difference. The fatigue alternating stress is usually divided by this modification factor and can be found in design handbooks. (Dividing the alternating stress is equivalent to multiplying the fatigue strength by K_f.) The fatigue strength reduction factor is defined by setting "Fatigue Strength Factor (K_f)" in the details view for the fatigue tool. Note that this factor is applied to the alternating stress only and does not affect the mean stress. This factor is 0.8.

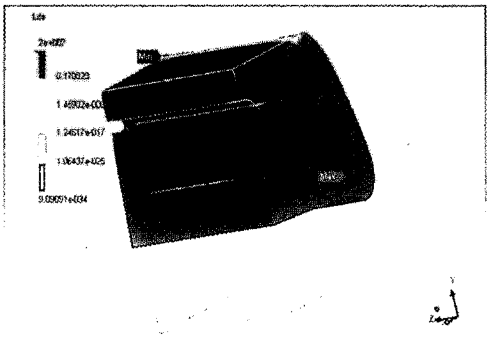
3. Result of Analysis

Several results for evaluating fatigue are available to the user. Some are contour plots of a specific result over the model while others give information about the most damaged point in the model (or the most damaged point in the scope of the result). Outputs include fatigue life, damage and damage matrix output. Each output will now be described and compared in the loads of SN-None, Goodman, Soderberg, and Gerber.

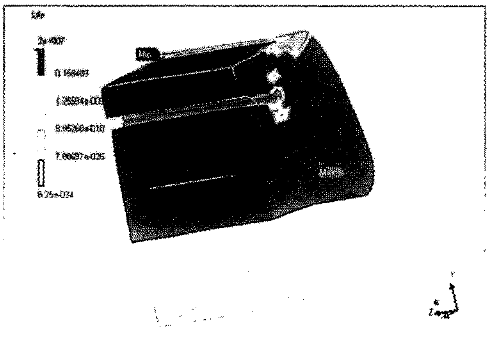
The contour plots of available life over the model are drawn as Fig. 5. This result can be over the whole model or scoped to a given part or surface. This result of contour plot shows the available life for the given fatigue analysis. If loading is of constant amplitude, this represents the number of cycles until the part will fail due to fatigue. If loading is non-constant, this represents the number of loading blocks until failure. Thus if the given load history represents one month of loading and the life was found to be 120, the expected model life would be 120 months. In a constant amplitude analysis, if the alternating stress is lower than the lowest alternating stress defined in the S-N curve, the life at that point



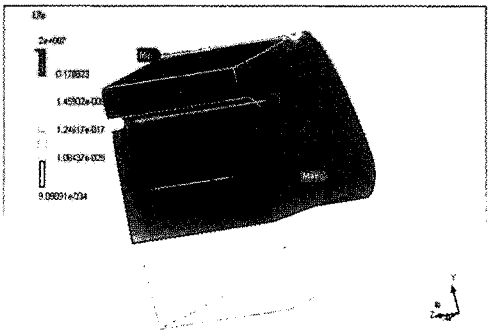
(a) SN-None



(b) Goodman

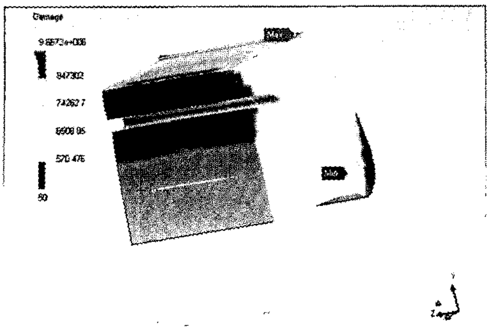


(c) Soderberg

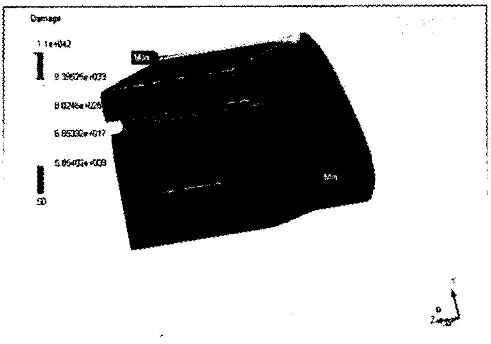


(d) Gerber

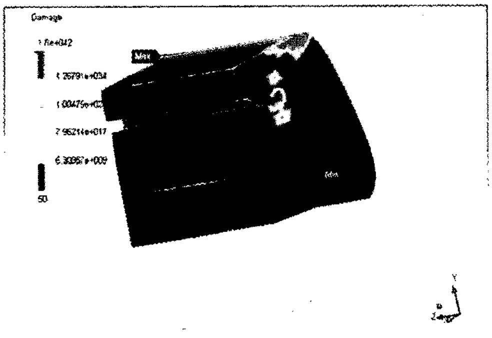
Fig. 5. Contour plots of available lives



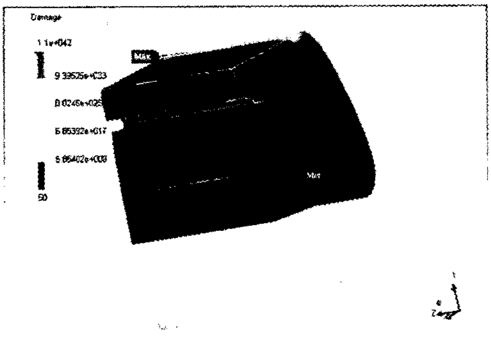
(a) SN-None



(b) Goodman



(c) Soderberg



(d) Gerber

Fig. 6. Contour plots of the fatigue damages

will be used. We can compare with 4 cases. The life in case of (a) is shorter than any other cases. The life in case of (c) becomes somewhat shorter.

As the contour plot of fatigue damage at a given design life, the fatigue damage is defined as the design life divided by the available life. This result may be scoped. The default design life may be set through the control Panel. We can compare with 4 cases in Fig. 6. The damage in case of (a) happens earlier than in any other cases. The damage in case of (c) happens somewhat earlier.

The plots of the damage matrices at the critical location on the model are shown in Fig. 7. This result is only applicable for non-constant amplitude loading. This result may be scoped. In this 3-D histogram, alternating and mean stress is divided into relative damages and plotted. The Z-axis corresponds to the relative damage for infinite life at a given alternating and mean stress.

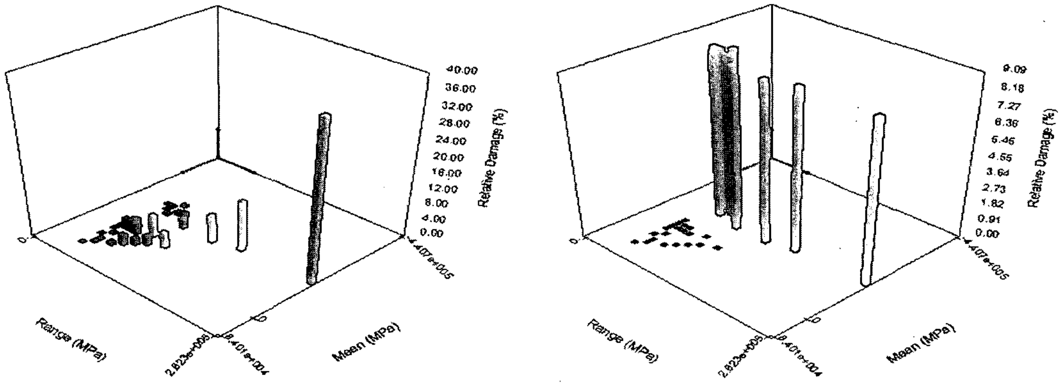
If most of the alternating stress cycles occur at a negative mean stress, this result gives the user a measure of the composition of a loading history.

As these figures can be seen from the damage matrices, although most of the damages occur at the lower stress amplitudes in this particular case, most of the damages occur at the higher stress amplitudes. We can compare relative damages with 4 cases. Most of relative damages occur at the uniform stress amplitude. But the counts of relative damages in case of (a) happen at higher stress amplitude more than in any other cases. The counts of relative damages happen in case of (c) happens somewhat at lower stress amplitude.

4. Conclusions

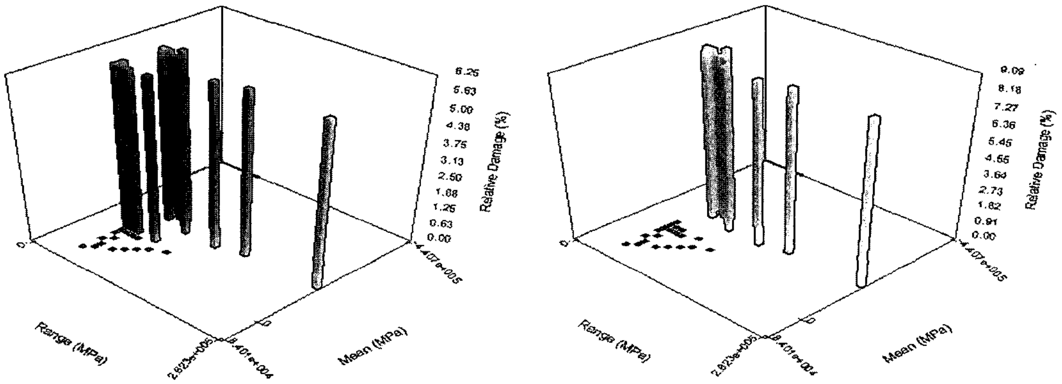
The conclusions of computer simulation in fatigue analysis of this study are as follows;

1. The life and damage of on the every part of the fatigue specimen can be known.
2. The available lives are compared with every loading variation type.
3. The damage matrix results can be helpful in determining the effects of small stress cycles in any loading history. The damage matrices also illustrate the possible effects of infinite life.



(a) SN-None

(b) Goodman



(c) Soderberg

(d) Gerber

Fig. 7. The plots of damage matrices

4. The safety and the stability of fatigue specimen according to the non-constant loading can be estimated by fatigue tools of Ansys workbench.

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