

Material Properties and Theory for Structural Analysis (2)

R&D Center

Structural Analysis Material Properties and Theory Part 1 explained that the basic theory of essential solid mechanics and the mechanics of materials to understand structural analysis will be described as a section of input properties that enhance the accuracy of the analysis.

In understanding the theories in regards to S-S curves, engineering stress & engineering strain, true stress & true strain, strain rate, modulus, Poisson's Ratio, yield stress for structural analysis, one will come to understand how these properties function in actual analysis and whether they can provide a more accurate analysis result than real values.

Structural analysis is determined by the types of analysis.

As previously discussed, we need modulus, Poisson's Ratio, and the S-S curve in general static load structural analysis. When you consider only the linear elastic region of material, the S-S curve is not required yet it is imperative in structural analysis such as with KEP products.

Vibration analysis requires modulus, Poisson's Ratio, density and in the case of thermal analysis, thermal conductivity, specific heat, density, and the thermal expansion coefficient are necessary.

In addition, it is important to obtain the properties in advance because the physical properties of the material needed are different by fatigue analysis, creep analysis, and so on.

First of all, let's look at how to obtain the required properties based on static load analysis among others.

(2) To enhance the precision of the analysis, the section of input properties that engineers consider:

1) Correction of Elastic Modulus

Despite being an analysis using the S-S curve, modulus must be factored in because the first behavior of material is the linear elastic region. Modulus in analysis means gradient (stress/strain) within a proportional limit, which doesn't leave residual strain in the S-S curve. In other words, permanent deformation must not occur when the material, which is the gradient of a complete linear elastic region, acts upon this region. For that reason, it is very difficult to measure the actual modulus that agrees with this condition.



(Figure 1) Modulus and yield stress according to ISO

As such, there exists a generally defined method to find modulus via a tensile test in ISO.

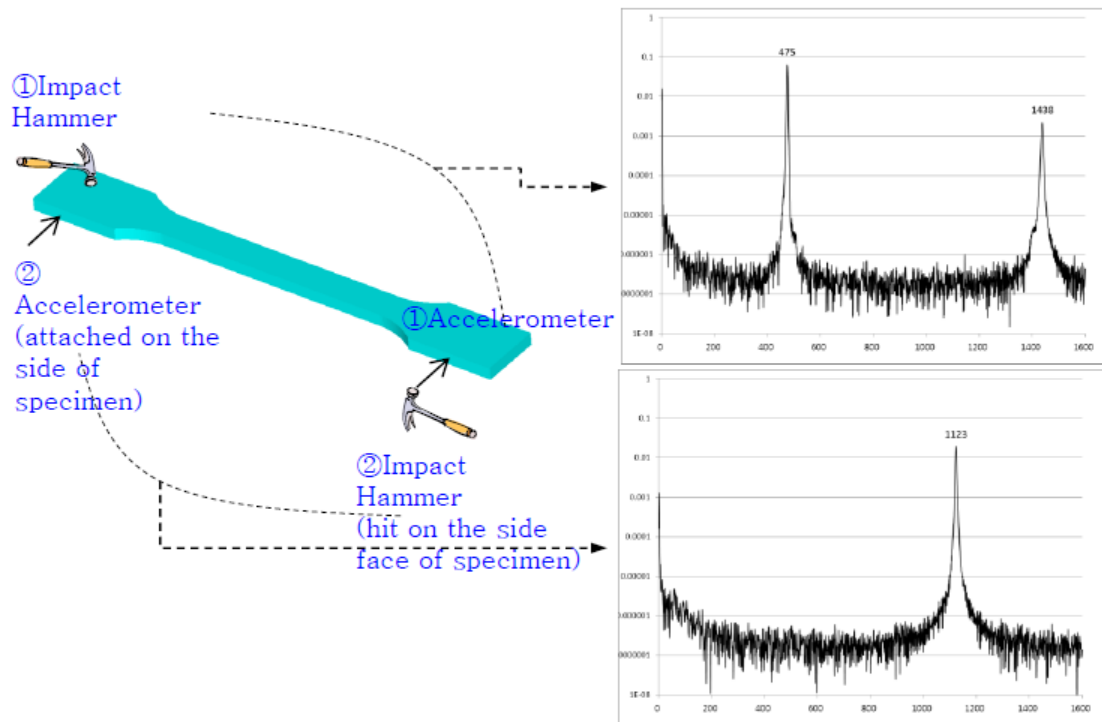
The gradient on the graph to the left that appears between 0.0005 to 0.0025 modulus in the S-S curve through a tensile test of specimen refers to modulus. This can be shown as a formula:

$$\text{Modulus} = (S2 - S1) / (E2 - E1) = (S2 - S1) / 0.002$$

The stress point where meet this line and the S-S curve after the modulus line moves to starting point becomes yield stress.

However, in most structural analysis, this expands to nonlinear regions beyond the elastic region, and the analysis conjugating modulus refers to vibration analysis.

Therefore understanding modulus is rational as the method to correlate the native mode through structural tests of specific figuration (specimen) and analysis. Since native mode changes depending on figuration, FRF can be determined by using an impact hammer, which in an ISO tensile specimen is easy to determine and extract the natural frequency of the first three.



When processing the normal mode analysis as making an FE model with the same ISO specimen, the first three natural frequencies and modes can be determined, which are able to change modulus with minimal errors in regards to the actual value of the earlier test.



	Experiment	Analysis	Error (%)
1 st mode	475	475	0.00
2 nd mode	1123	1140	1.49
3 rd mode	1438	1433	0.37

The analysis result, measured mode shape, and frequency value correspond to the above table and modulus used in analysis is the modulus of the material.

2) Correction of S-S curve:

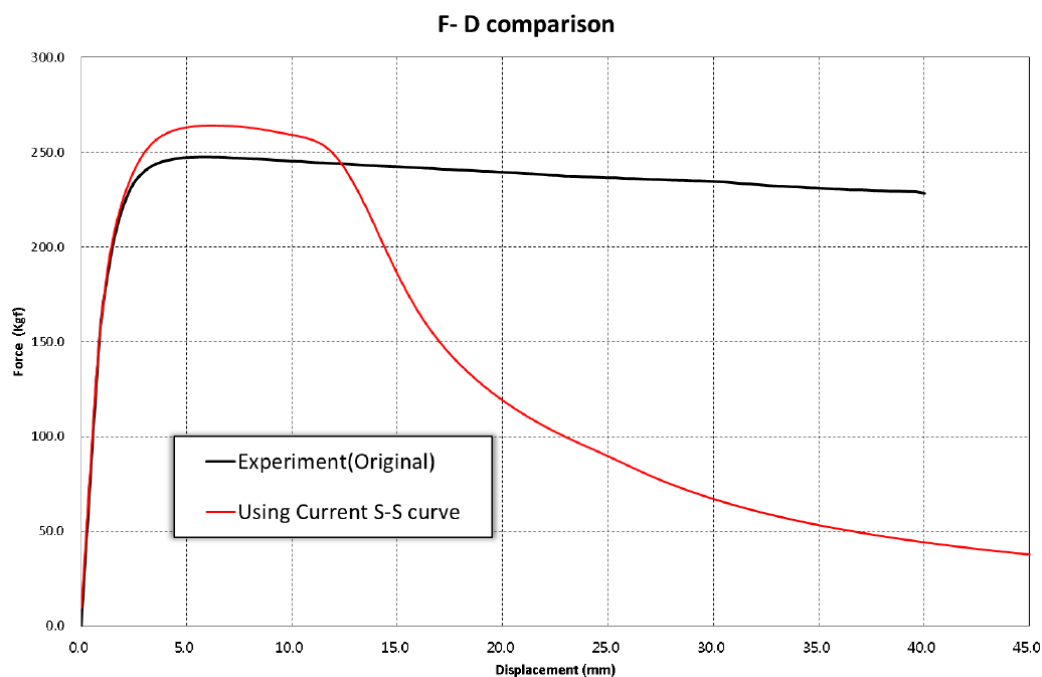
As previously mentioned, we need modulus, Poisson's Ratio, and the plastic strain - true stress curve (S-S curve) for structural analysis under static load. The modulus is drawn by the methods described above and Poisson's Ratio does not need to be corrected because there is no significant influence on the static analysis. Finally, the S-S curve can be use in analysis after finally transforming to the F-D curve step by applying the aforementioned formula.

However, why does the S-S curve need to be corrected? This is because the Force-Displacement (F-D) curve obtained through the tensile test of specimen is not equal to the F-D curve obtained through analyzing the same tensile test. (See Figure 2)

In addition, if the S-S curve obtained after just the transforming tensile test is applied without the correction process, real deformation and simulated deformation will occur as demonstrated below.



Local necking severely occurs compared to the actual specimen transformed figuration when using the S-S curve, which is extracted via the formula like in the figures above.



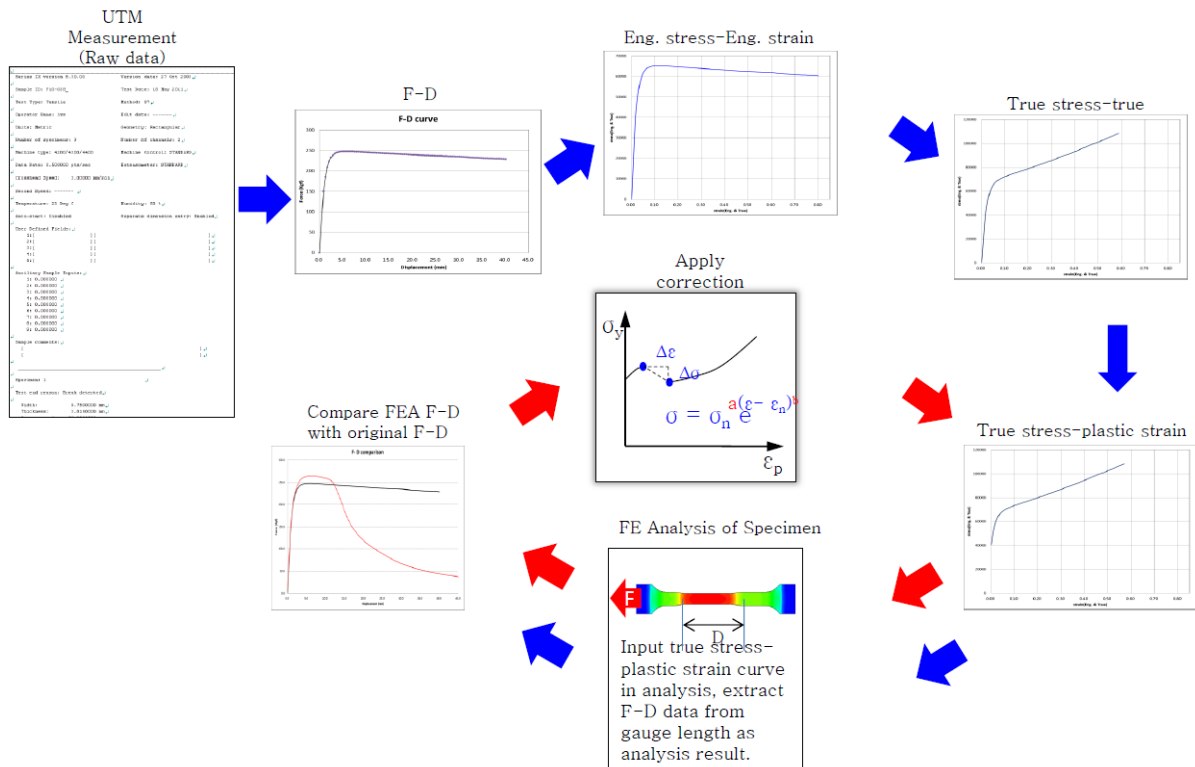
(Figure 2) Comparison test result and analysis result

This phenomenon occurs for several reasons;

- ① The strain re-homogenization phenomenon,
- ② UTM measured stress is 1 axis measurement, the actual specimen has 3-axis stress,
- ③ Measurement errors (slip of the specimen, measuring errors, and so on),
- ④ Yield surface \neq Von-Mises (Compression yield stress > tensile yield stress),
- ⑤ Non-Isochoric (Volume changes in Non-linear region),
- ⑥ Shear bands : negative slopes in the hardening curve.

One of the most common reasons is that there must be errors because all data converted to this formula even though at engineering S-S curve \rightarrow true S-S curve conversion formula, as previously described, is not applicable as it fails to remain isochoric not only in non-linear regions but also linear regions when compared to metal.

Therefore when analyzing, we must correct the S-S curve continually so it is also important that F-D curve obtained by analysis of the same tensile specimen coincides with the actual observed F-D curve.

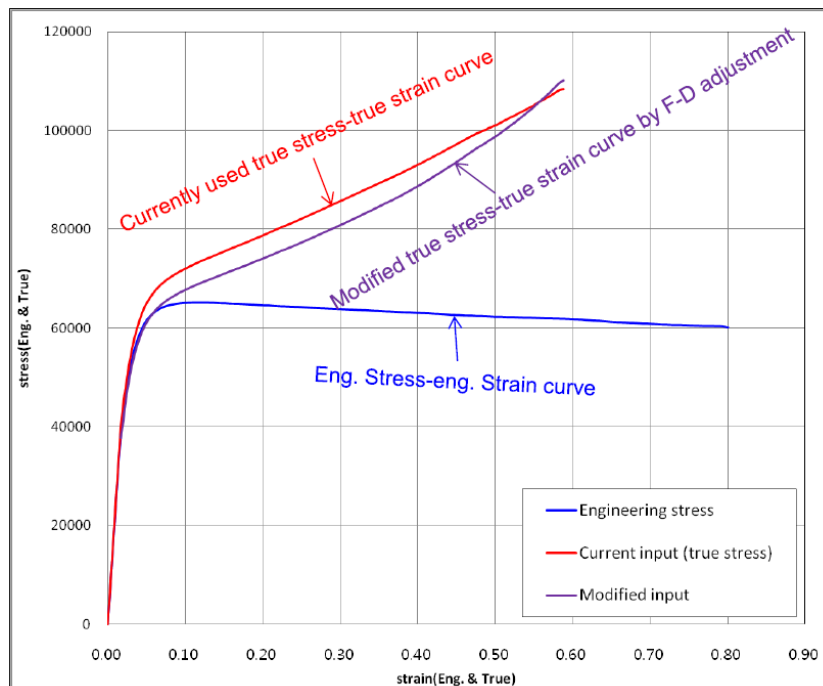


(Figure 3) S-S curve correction process

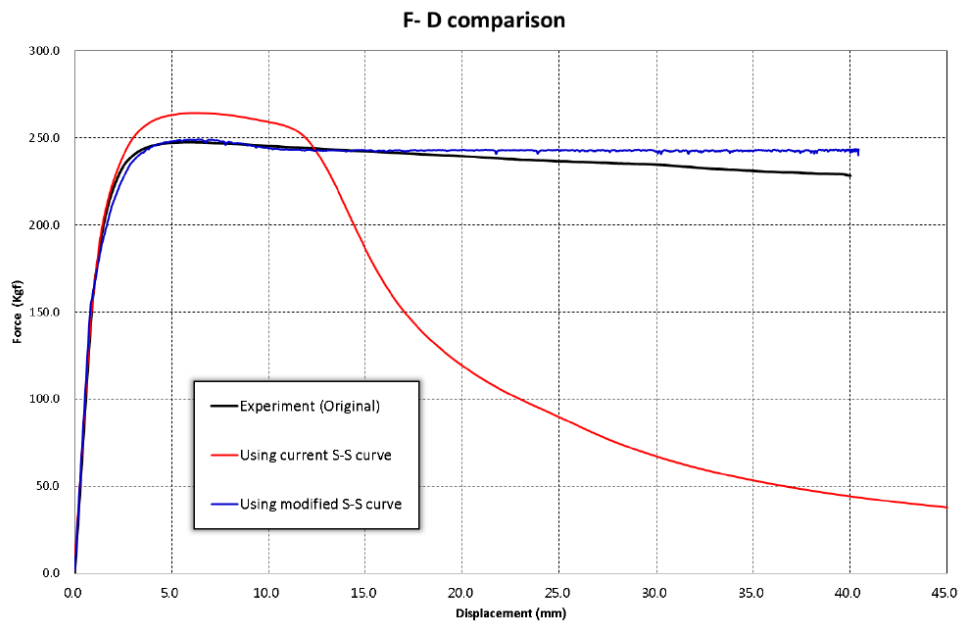
The correction equation applies to the region of all data points after analyzing the S-S curve necking point as in Figure 3

Repeat analysis until the F-D curve from the measured F-D curve and interpretation changing coefficient of this corrected equation returns a minimum error.

Through this process when the S-S curve is corrected, an F-D curve nearly similar to the actual tensile test result can be determined (Figure 5) and as for the S-S curve used by the traditional conversion formula, the corrected curve reveals many differences in same plasticity region as with Figure 4.



(Figure 4) Compare input of S-S curve

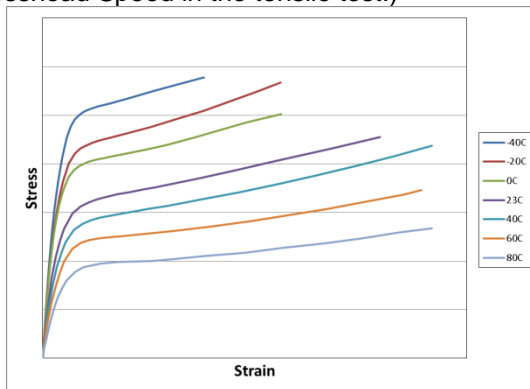


(Figure 5) Compare input S-S curve according to F-D curve result

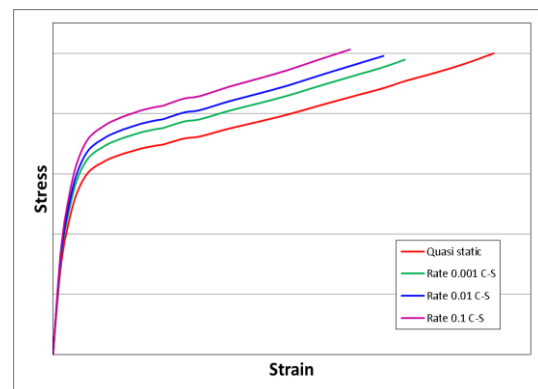
3) Use of S-S curve classified by temperature & strain rate

Generally, perform analysis using only one S-S curve because a room temperature of 23 degrees Celsius is standard.

However, if there is fluctuation in temperature, a proper S-S curve must be used because general polymers have significant changes in stiffness and elongation depending on temperature, different from metal. In addition, assume that there is almost no strain rate change in usual static load analysis but if the strain rate is high and changeable such as with impact analysis, an accurate analysis result can be determined as the S-S curve is classified by strain rate. (Strain rate is the speed at which deformation occurs, which is value of strain per unit time. Simply speaking, it is proportional to the Crosshead Speed in the tensile test.)



(Figure 6) S-S curve by temperature of F20-03



(Figure 7) S-S curve by Strain rate of F10-03H

This tends to return a lower S-S curve gradient and longer elongation as the temperature increases and strain rate decreases, such as in Figures 6 and 7, respectively.

The S-S curve by temperature is relatively easy to extract but S-S curve data by strain rate is neither easy to obtain nor construct because a high strain rate is difficult to be implemented using a general tensile tester.

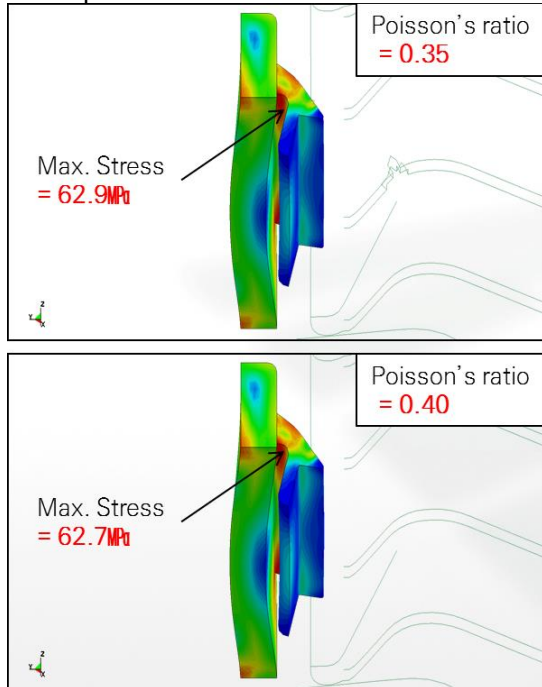
4) Result of analysis according to Poisson's Ratio

As described earlier, Poisson's Ratio doesn't influence as much impact on structural analysis result as modulus or the S-S curve in most of cases (but it does in vibration analysis). In high stiffness material cases, Poisson's Ratio tends to be low but is not always like that.

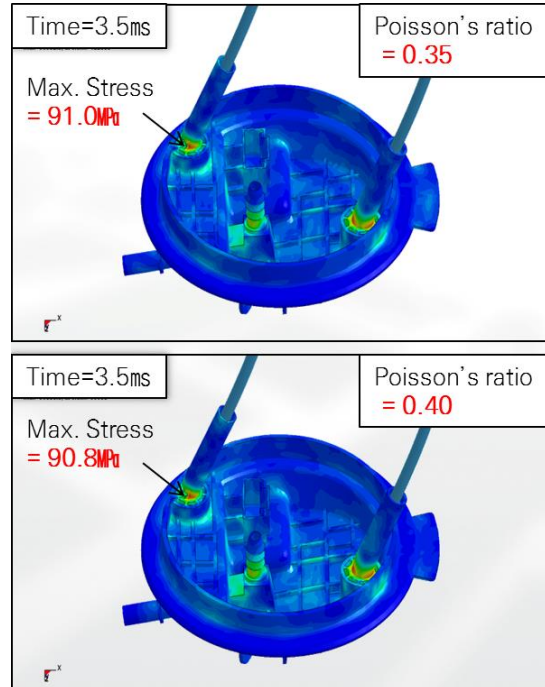
Poisson's Ratio doesn't exceed more than 0.5 in theory, with rubber at almost 0.5, and metal around

0.3. POM, the KEP flagship product, is about 0.39.

When Poisson's Ratio differs, significant differences cannot be observed as static analysis carries out and compares these values such as below in Figures 8 and 9.



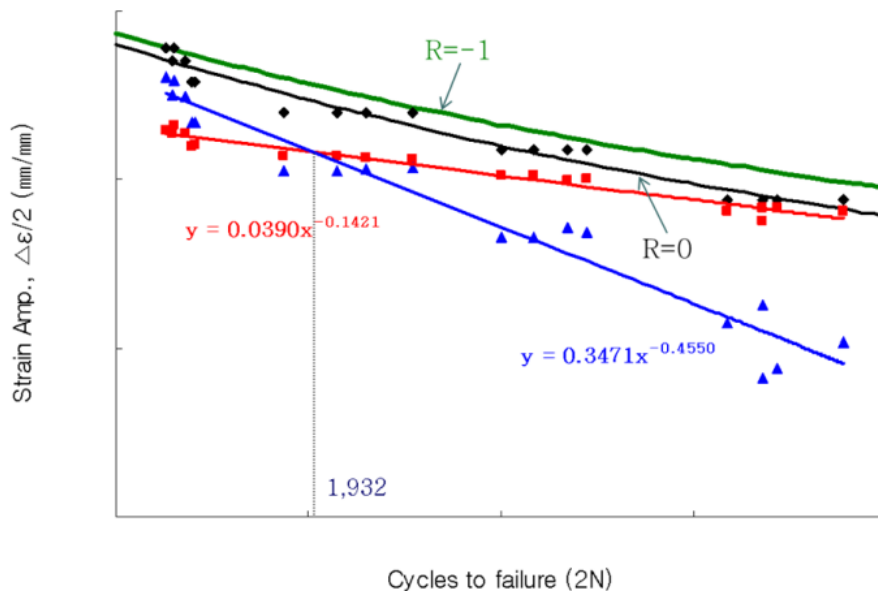
(Figure 8) Static analysis result by Poisson's Ratio



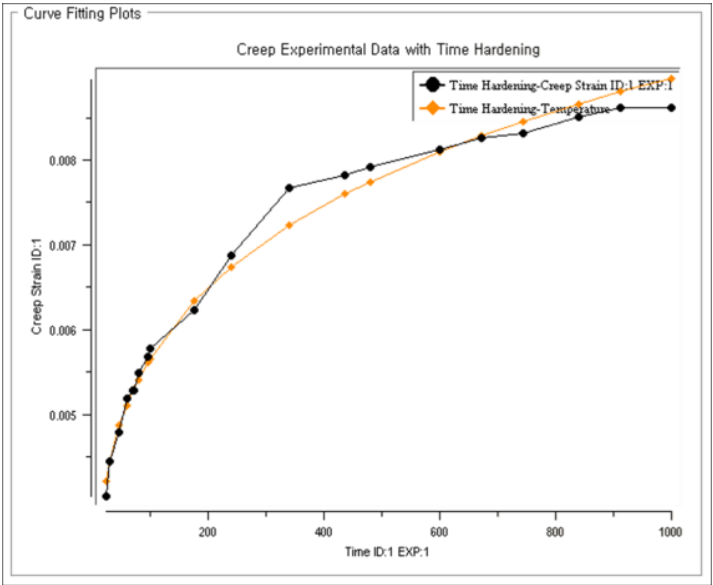
(Figure 9) Impact analysis result by Poisson's Ratio

5) Other properties of fatigue, creep, and thermal analysis

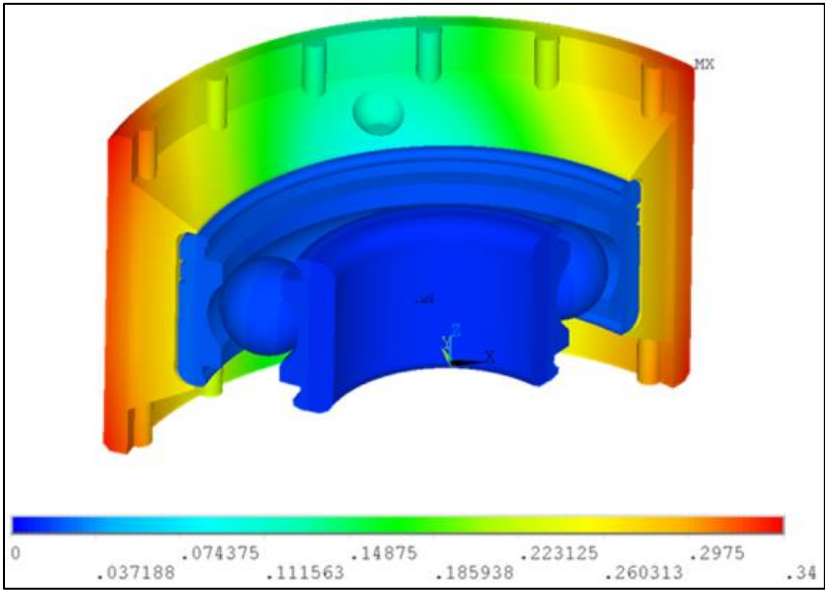
In addition to fatigue properties to predict product life time under repeated load condition, creep properties exist for analyzing this phenomenon, which is changeable strain by time in terms specific weight. There are also thermal properties (specific heat, heat transfer coefficient) for analyzing a product's temperature distribution by heat sources and conduction, convection, and radiation. This can be discussed in detail at another time, as it is beyond the scope of this paper.



(Figure 10) Strain leading life of F20-03 (Fatigue properties)



(Figure 11) Creep properties of F20-03 (Equation)



(Figure 12) Temperature distribution analysis result by using thermal properties

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