

Fatigue factor of safety at  
a specified design life

# Calculating and Displaying Fatigue Results

The ANSYS Fatigue Module has a wide range of features for performing calculations and presenting analysis data.

By Raymond Browell  
Product Manager  
ANSYS, Inc.

Al Hancq  
Development Engineer  
ANSYS, Inc.

In the last issue of *ANSYS Solutions*, we reviewed decisions required to perform a stress life or strain life fatigue analysis and covered supported features of the ANSYS Fatigue Module with respect to input quantities. This follow-up article deals with fatigue calculation types and ways of displaying results available in the ANSYS Fatigue Module.

## Types of Results

Just as some input decisions change depending on whether you're performing a stress life or a strain life analysis, calculations and results can be dependent on the type of fatigue analysis. Results can range from contour plots of a specific result over the whole model to information about the most damaged point in the model (or the most damaged point in the scope of the

result). Results that are common to both types of fatigue analysis are listed below:

- Fatigue life
- Fatigue damage at a specified design life
- Fatigue factor of safety at a specified design life
- Stress biaxiality
- Fatigue sensitivity chart
- Rainflow matrix output (beta for strain life at 10.0)
- Damage matrix output (beta for strain life at 10.0)

The results that are available only for stress life are:

- Equivalent alternating stress

The results that are available only for strain life are:

- Hysteresis (beta at 10.0)

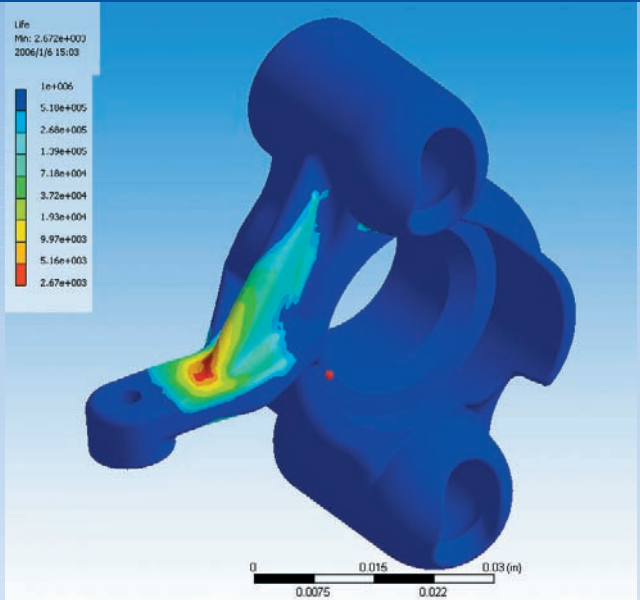
## General Fatigue

**Fatigue life** — This result can be over the whole model or scoped just like any other contour result in ANSYS Workbench (that is, parts, surfaces, edges and vertices). In addition, this and any contour result may be exported to a tab-delimited text file by a right-mouse-button click on the result. This result 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 hour of loading and the life was found to be 24,000, the expected model life would be 1,000 days. In a stress life analysis with constant amplitude, if the equivalent alternating stress is lower than the lowest alternating stress defined in the SN curve, the life at that point will be used.

**Fatigue damage** — This is a contour plot of the fatigue damage at a given design life. 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. For fatigue damage, values greater than 1 indicate failure before the design life is reached.

**Fatigue safety factor** — This is a contour plot of the factor of safety with respect to a fatigue failure at a given design life. The maximum factor of safety displayed is 15. Like damage and life, this result may be scoped. For fatigue safety factor, values less than 1 indicate failure before the design life is reached.

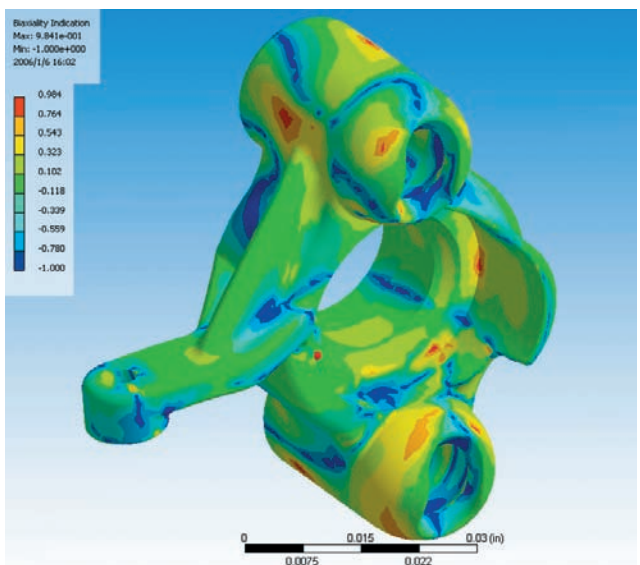
**Biaxiality indication** — As mentioned previously, fatigue material properties are based on uniaxial stresses, but real world stress states are usually multi-axial. This result gives the user some idea of the stress state over the model and how to interpret the results. Biaxiality indication is defined as the principal stress smaller in magnitude divided by the larger principal stress, with the principal stress nearest zero ignored. A biaxiality of zero corresponds to uniaxial stress, a value of  $-1$  corresponds to pure shear, and a value of  $1$  corresponds to a pure biaxial state. As you can see in the figure illustrating biaxiality, the majority of this model is under a pure uniaxial stress, with parts exhibiting both pure shear and nearly pure biaxiality. When using the biaxiality plot along with the safety factor plot (described above), it can be seen that the



Fatigue life

most damaged point occurs at a point of mostly uniaxial stress. If the most damaged spot was under pure shear, then it would be desirable to use SN data collected through torsional loading, if such data was available. Of course, collecting experimental data under different loading conditions is cost-prohibitive and not often done.

Note that for non-proportional fatigue loading, there are multiple stress states and, therefore, there is no single stress biaxiality at each node. Thus, if the fatigue tool has non-proportional loading, the user may select either the average or the standard deviation of stress biaxiality. The average value may be interpreted as above, and, in combination with the standard deviation, the user can get a measure of how the stress state changes at a given location. Thus, a small standard deviation indicates a condition in which the loading is near proportional while a larger deviation



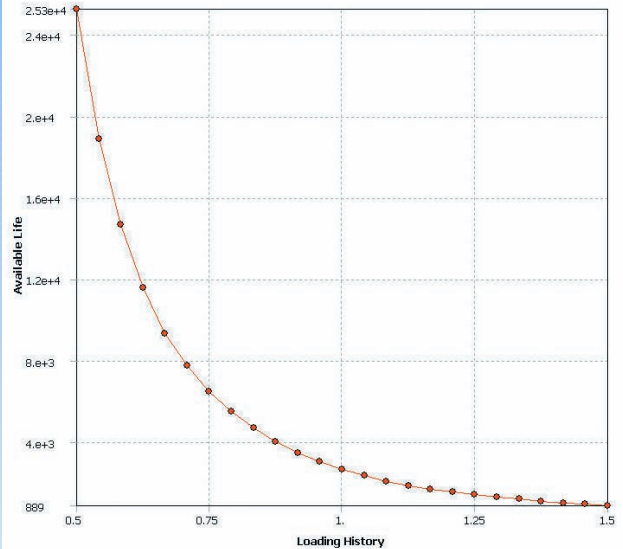
Stress biaxiality

indicates change in the direction of the principal stress vectors. This information can be used to give the user additional confidence in his results or to determine if more in-depth fatigue analysis is needed to account for non-proportionality.

**Fatigue sensitivity** — This shows how the fatigue results change as a function of the loading at the critical location on the model. This result may be scoped. Sensitivity may be found for life, damage or factor of safety. The user may set the number of fill points as well as the load variation limits. For example, the user may wish to see the sensitivity of the model's life in which the FE load is 50 percent of the current load through to where the load is 150 percent of the current load. A value of 100 percent corresponds to the life at the current loading on the model. Negative variations are allowed in order to see the effects of a possible negative mean stress if the loading is not totally reversed. Linear, log-x, log-y or log-log scaling can be chosen for chart display. Default values for the sensitivity options may be set through the control panel.

**Rainflow matrix chart (beta for strain life at 10.0)** — This is a plot of the rainflow matrix at the critical location. This result is applicable only for non-constant amplitude loading in which rainflow counting is needed. This result may be scoped. In this 3-D histogram, alternating and mean stress is divided into bins and plotted. The z-axis corresponds to the number of counts for a given alternating and mean stress bin. This result gives the user a measure of the composition of a loading history (such as, if most of the alternating stress cycles occur at a negative mean stress). In the rainflow matrix figure, the user can see that most of the alternating stresses have a positive mean stress and that, in this case, the majority of alternating stresses are quite low.

**Damage matrix chart (beta for strain life at 10.0)** — This is a plot of the damage matrix at the critical location on the model. This result is applicable only for non-constant amplitude loading in which rainflow counting is needed. This result may be scoped. This result is similar to the rainflow matrix, except that the percent of damage that each rainflow bin causes is plotted as the z-axis. For this particular case, as can be seen from the corresponding damage matrix (see next page) for the above-mentioned rainflow matrix, although most of the counts occur at the lower stress amplitudes, most of the damage occurs at the higher stress amplitudes.

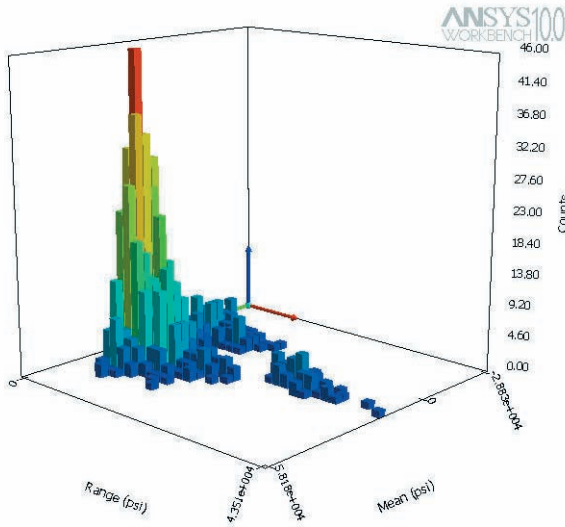


Fatigue sensitivity chart

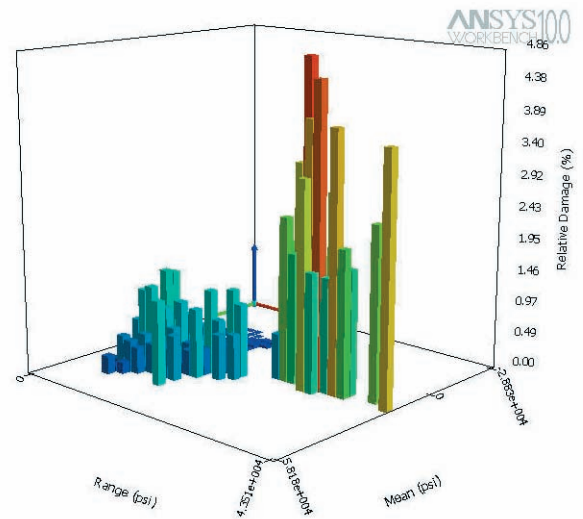
## Stress Life

**Equivalent alternating stress** — In a stress life fatigue analysis, one always needs to query an SN curve to relate the fatigue life to the stress state. Thus, the equivalent alternating stress is the stress used to query the fatigue SN curve after accounting for fatigue loading type, mean stress effects, multiaxial effects and any other factors in the fatigue analysis. Therefore, in a fatigue analysis, the equivalent alternating stress can be considered the last-calculated quantity before fatigue life is determined. The usefulness of this result is that, in general, it contains all fatigue-related calculations independent of any fatigue material properties. As discussed in *ANSYS Solutions Volume 7 Issue 1*, some mean stress theories use static material properties — such as tensile strength — so equivalent alternating stress may not be totally devoid of material properties. A quantity such as equivalent alternating stress may be useful in a variety of situations:

- To avoid possible security issues with proprietary material stress life properties, an engineer may be given equivalent alternating stress design criteria.
- The equivalent alternating stress may be exported to a third-party or in-house fatigue code that performs specialized fatigue calculations based on industry-specific knowledge.
- An engineer can perform a comparative analysis among a variety of designs using a result type (stress) that he or she may feel more comfortable with.



Rainflow matrix output



Damage matrix

- A part can be geometrically optimized with respect to fatigue without regard to the specific material or finishing operations that will be used for the final product.

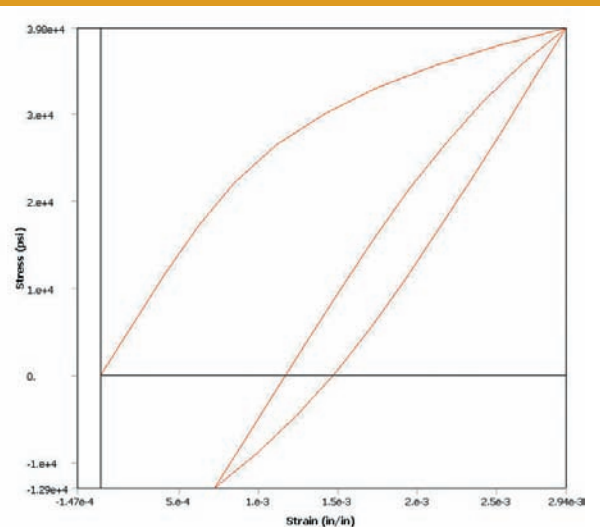
This result is not applicable to strain life or stress life with non-constant amplitude fatigue loading due to the fact that multiple SN queries per location are required and, thus, no single equivalent alternating stress exists.

### Strain Life

**Hysteresis (beta at 10.0)** — In a strain-life fatigue analysis, although the finite element response may be linear, the local elastic-plastic response may not be linear. The Neuber correction is used to determine the local elastic-plastic response given a linear elastic input. Repeated loading will form closed hysteresis loops as a result of this nonlinear local response. In a constant amplitude analysis, a single hysteresis loop is created, although numerous loops may be created via rainflow counting in a non-constant amplitude analysis. The hysteresis result plots the local elastic-plastic response at the critical location of the scoped result. (The hysteresis result can be scoped, similar to all result items.) Hysteresis is a good result to help you understand the true local response that may not be easy to infer. Notice in the hysteresis example that, although the loading-elastic result is tensile, the local response does venture into the compressive region.

### Conclusion

The ANSYS Fatigue Module supports a wide variety of fatigue analyses. The comprehensive calculations and results enable engineers to evaluate their designs for avoiding failures under real-world conditions. As a module that is integrated into the ANSYS Workbench environment, the ANSYS Fatigue Module can further leverage advances in CAD support, including bi-directional parameters, solid modeling, virtual topology, robust meshing, hex-dominant meshing, automatic contact detection, optimization, Design for Six Sigma and Robust Design. ■



Hysteresis