

# Test Data Processing Use for Structural Fatigue Life Assessment

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## Abstract

Some technique and results of the strain-life fatigue analysis use test data digital processing of the wide-spray field sprayer's booms have been described in the paper under discussion. The test data were obtained from four channel of universal measuring system each of these represents a uniaxial strain gauge placed in some potentially critical locations on the test object. Two problems have been solved by fatigue analysis for each of the four channels, namely the direct calculation of the fatigue life and back calculation for a scale factor that gives the target fatigue life. The back calculation provides quantifiable stress or strain reduction targets for a redesign of the wide-spray field sprayer's booms.

## Keywords <sup>1</sup>

Test data, signal, processing, software, glyph, data correction, fatigue, strain-life

## 1. Introduction

The working conditions of the engineering structures are often complex and the operating environment is not always favorable. In the long-term operation, the strength of the structural elements keeps decreasing and it fails eventually. A perusal of the broken parts in almost any structure's elements will show that a high number of failures occur at stresses below the yield strength of their materials. This complex phenomenon is known as "Fatigue".

Fatigue failure is one of the most typical failure modes of the structural elements, especially for the mechanical structure under loads of random character. Fatigue is responsible for up to 90% of the in service part failure which occur in industry [1].

Therefore, an important engineering problem is to study the fatigue of materials and structural elements and predict the fatigue life of the structure. It makes possible to prevent fatigue failure of the material and ensure the safety and stability of engineering structure during the design life [2].

Nowadays, the research on the fatigue state of mechanical structure is primarily focused on two aspects: life prediction and reliability evaluation. The research on life prediction mainly targets the prediction theory and method of the remaining service life of the mechanical structure, and is relatively systematic.

The established life prediction methods predominantly include the stress-life fatigue theory (S-N fatigue analysis or High Cycle Fatigue – HCF), strain-life theory fatigue (E-N fatigue analysis or Low Cycle Fatigue – LCF), fracture mechanics theory, damage mechanics theory, and the probability statistics based on the life prediction method.

Different authors use divers methods and approach to evaluate the fatigue life of structures.

In particular, in the paper [1] a fatigue life evaluation model based on equivalent elastic modulus is proposed for in-service mechanical structure. In the proposed model, parameters that represent the operating conditions of the mechanical structure, such as load, vibration, and shaft torque, etc., are used as the generalized load. To replace the fatigue stress, the statistical method is used here, which is also used in the conventional fatigue analysis method.

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In the paper [3] the fatigue life calculation in operational load conditions is presented. The obtained load runs were so processed as to get a set of sinusoidal cycles by using the following methods: full cycles counting method and rainflow counting method. On the basis of such sets of cycles of load were prepared block load spectra of equivalent amplitudes, obtained with the use of an original method of these authors, in which two-parameter fatigue characteristics were applied. The work resulted in comparison of fatigue life results for load spectra determined by using the assumed cycles counting methods and the assumed two-parameter fatigue characteristics.

In the paper [4] the fatigue life is calculated for random loading with single overloads. There is used the spectral method of fatigue life assessment. The transformation of the power spectral density of the loading signal with the use of the correction factor based on the information obtained from the spectral kurtosis is used to modification of the fatigue life assessment algorithm. The proposed procedure is verified of the calculation results comparison with the results obtained by the rain cycle calculation method.

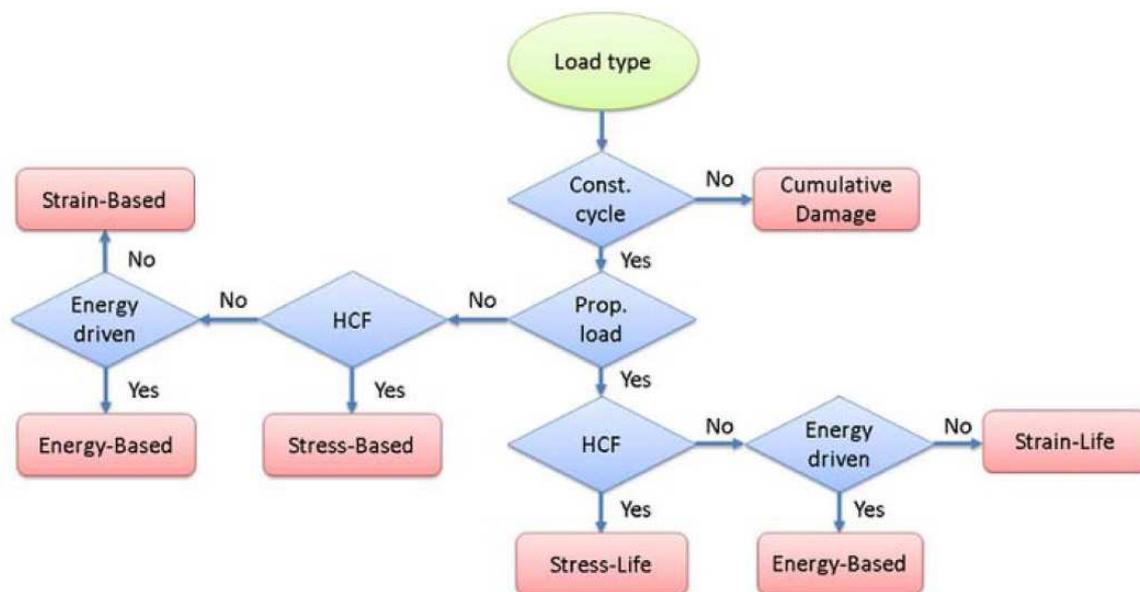
In the paper [5] based on the Miner rule, a new linear damage accumulation rule is proposed to consider the strengthening and damaging of low amplitude loads with different sequences using fuzzy sets theory.

In the paper [6] the average value of variable loads is taking into account by determining a substitute cycle characterized by mean value  $S_m = 0$  and amplitude  $S_{az} \neq S_a$ . Fatigue life calculations were carried out based on hybrid method. This method combines calculations in strain approach and in stress terms.

In the paper [7] has been considered the process of progressive localized permanent structural changes occurring in a material subjected to conditions that produce fluctuating stresses or strains at some points and that may culminate in fracture after a sufficient number of fluctuations when subjected to Bending, Axial, Torsion or combined equivalent stresses. Are defined the life of the machine components to determine the number of cycles to failure and Fatigue factor of safety.

In the paper [8] an energy-based approach was used to predict fatigue life under uniaxial and multiaxial random loads. Such a method uses time-based damage accumulation model compared to the classical cycle-based damage accumulation model.

A fatigue model can be selected in different ways. When there is no prior knowledge on the fatigue case, a suitable fatigue model can be choose based on a few questions regarding loading conditions and expected fatigue failure. In the diagram below are summarized the key questions which should ask when select method evaluating fatigue (fig. 1).



**Figure 1:** Selection of the fatigue model type

Fatigue life calculation of a varying load spectrum is a complex task. There are various approaches suggested to simplify the load spectrum into simple major and minor cycle. There are many different

methods are used for definition estimated number of equivalent load cycles, such as full cycle counting method (FCM), peak counting method (PCM), simple-range counting method (RCM), rainflow counting method (RFM), range-pair counting method (RPM), two-parametric fatigue characteristics (TFC), etc.

In practice, the most often used are methods that do not limit the schematic load process and allow processing any load mode. These include the methods: of maximums, of complete cycles, of ranges (amplitudes), of augmented ranges, and "rain flow" method.

In the paper [9] is an analysis of the influence of cycle counting methods on fatigue life calculations. Based on set of cycles, with variable parameters block load spectrums have been developed for substitute amplitude, designated using the author's method, which uses two-parametric fatigue characteristics.

In the paper [10] are examined the effect of cycle counting method on the estimated number of equivalent cycles. Authors evaluate four different a cycle counting method: peak counting, level-crossing, mean-crossing, and rainflow counting.

In the paper [11] a universally cycle counting procedure is presented that can be used to the simplest uniaxial experiment, to the most complex experiment, variable amplitude and frequency, and non-proportional multiaxial fatigue loading. Despite of its simplicity, the proposed cycle counting method has different advantages compared to the known procedures. Its completely independent of the damage criterion since the procedure standalone definition, allows to be combined it with any damage criterion. The method does not require periodicity of the loading cycle, and therefore can be directly used to analyze variable frequency and amplitude, multiaxial fatigue loading.

In the paper [12] a new algorithm for the Modified Graphical Rainflow counting method is presented. This method allows the application of Miner's rule in order to assess the fatigue life of a structure subject to complex loading.

The rainflow algorithms are one of the most popular counting methods used in fatigue and failure analysis in conjunction with lifetime estimation models despite the nascence of new methods. This method is also most often implemented in specialized software to analysis fatigue life.

Modern software makes it possible to analyze the fatigue failure of a structure under conditions of long-term action of loads that vary over time, opens up unique opportunities for designing and optimizing structures, including requirements for durability, product life under normal and extreme operating conditions.

The use of software allows reducing the time of product development and eliminates the cost of eliminating fatigue damage and destruction at an early stage of design. Also, during the operation of the product, when fatigue damage is detected, software allows you to analyze the impact of these damages on the structure life, preventing accidents and disasters.

The main source of input data for fatigue life analysis with the software is the previous results of structure finite element analysis or the results of field tests. The quality of a fatigue life analysis is thus directly dependent on the quality of the results (stress or strain) obtained from a structural analysis or experiment.

Currently, there is a lot of different software that allows perform structural analysis and implement the structure fatigue life analysis, in particular [13 - 17]: MSC Fatigue, AFGROW, SIMULIA fe-safe, SolidWorks, COMSOL Multiphysics, ANSYS, nCode.

ANSYS software is especially popular among researchers. In particular, in the paper [14] the principle of stochastic fatigue failure analysis is presented and the random vibration of a structure is analyzed using ANSYS software.

In the paper [15] use ANSYS for fatigue life prediction rocket combustion chambers with finite element analysis. Fatigue life prediction is an important part of design studies and loading cycle optimization, but existing calculation methods based of a finite element method (FEM) are often numerically inefficient. The authors propose a procedure of training an artificial neural network to predict the number of cycles to failure based on the studying object geometry analysis. This publication is one of the first to apply machine learning to fatigue life prediction.

Among the whole amount of software to processing experimental data, the nCode software of HBM Prenscia [16, 17] is the most appropriate. It designed for working with large amounts of test data, for signal processing, and performing various studies, such as, for example, fatigue life analysis.

nCode GlyphWorks software has a convenient object-oriented graphical interface and it is optimized for the complex work with large volumes of multi-channel data. The software functional includes a wide range of tools for temporary, frequency and statistical analysis of signals. Moreover, some tools are available to assess both the resource and fatigue durability of the products and synchronized reproduction of GPS signals, video and other data obtained during the tests, and also a convenient mechanism for automated creation of reports has been implemented. nCode GlyphWorks software has a module system which enables us to create the required feature set either by means of large embedded libraries or by the use of language Python. Working templates in nCode GlyphWorks can be prepared in advance and can be found in the specified library to provide reliability and high speed of calculation [18].

## 2. Strain-life fatigue analysis

### 2.1. Test data obtaining and correcting

In this paper are implemented strain-life fatigue analysis use nCode GlyphWorks software's tools. The goal of this analysis is to use the strain gauge measured test data to predict wide-spray field sprayer booms fatigue life.

The test data were obtained using the methods, means and software presented in [19 - 22]. They were obtained from four channel of universal measuring system each of these represents a uniaxial strain gauge placed in some potentially critical locations on the test object.

In the paper [18] the test data have been corrected to remove the data drift effect by tools of the nCode GlyphWorks. The obtained in [18] the time series data output file contains the stress, which is the function in time. For low-cycle fatigue analyze the strain is decisive, therefore it is necessary to convert the stress into strain.

It is known that stress within the limits of linear elastic strain (Hooke's law) is determined by the formula [23]:

$$\sigma = \varepsilon \cdot E, \quad (1)$$

where  $\varepsilon$  - is strain and

$E$  – is modulus of elasticity (Young's modulus), MPa. For steel  $E$  is about  $2 \cdot 10^5$  MPa.

The input data must be converted into microstrain, therefore we will transform the data from the channels according to formula (1) taking into account a factor of  $10^{-6}$ :

$$\varepsilon = \left( \frac{\sigma}{E} \right) / 10^{-6}, \quad (2)$$

Converting the stress into strain and strain-life fatigue analysis are implemented by the nCode GlyphWorks - data processing system that contains a comprehensive set of standard and specialized tools for performing durability analysis and other insightful tasks such as digital signal processing.

### 2.2. Project development and setting

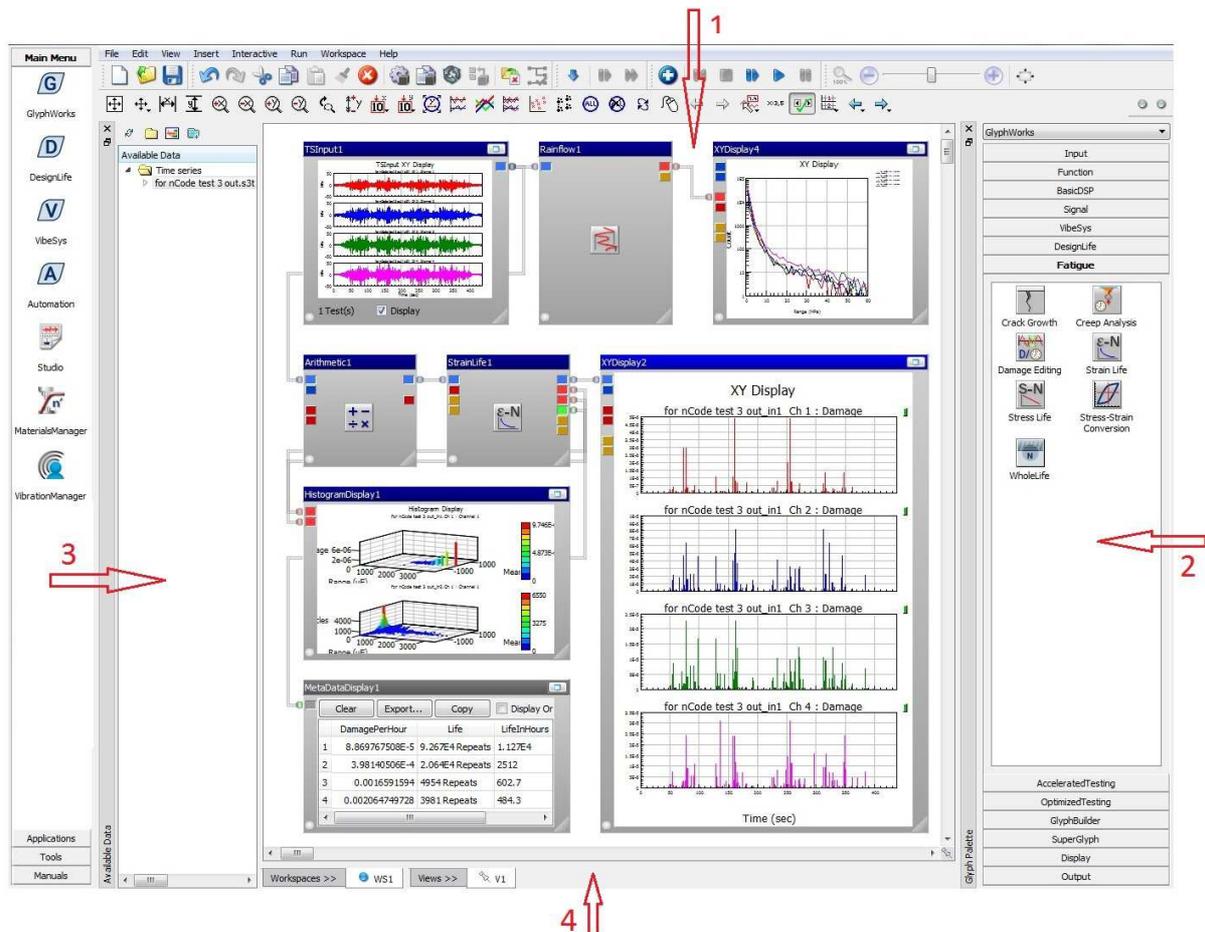
Under test data digital processing conditions by specialized software tools nCode GlyphWorks procedure of the strain-life fatigue assessment has been implemented.

GlyphWorks is a multi-channel, multi-file, multi-format environment for processing large amounts of data. GlyphWorks provides a graphical, process-oriented environment that contains leading analysis capabilities for research of various processes. GlyphWorks represents data analysis processes graphically and lets drag and drop graphical representations of interactive data analysis processes that allow create and save sophisticated working projects for later re-use [18].

The basic analysis building blocks used in GlyphWorks are termed glyphs. Glyphs are connected by pipes, which contain the data that passes between glyphs and attach at the glyph's pads (different types of I / O pads are marked with different colors). In fact, Glyph is a calculation module (template) with specified algorithms of certain functions performance and with possible setting of different parameters of its properties. A set of glyphs with functional connections is the detailed design of the research [18].

The main windows of the GlyphWorks interface are shown on fig. 2. The general view of Interface nCode GlyphWorks can be changed by turning on the several other windows using the View menu:

1. Analysis Workspace – Where the process is created
2. Glyph Palette – Glyphs available for processing
3. Available Data – Data that can be analyzed
4. Diagnostics – List of process, error messages, etc.



**Figure 2:** The main window of the GlyphWorks interface

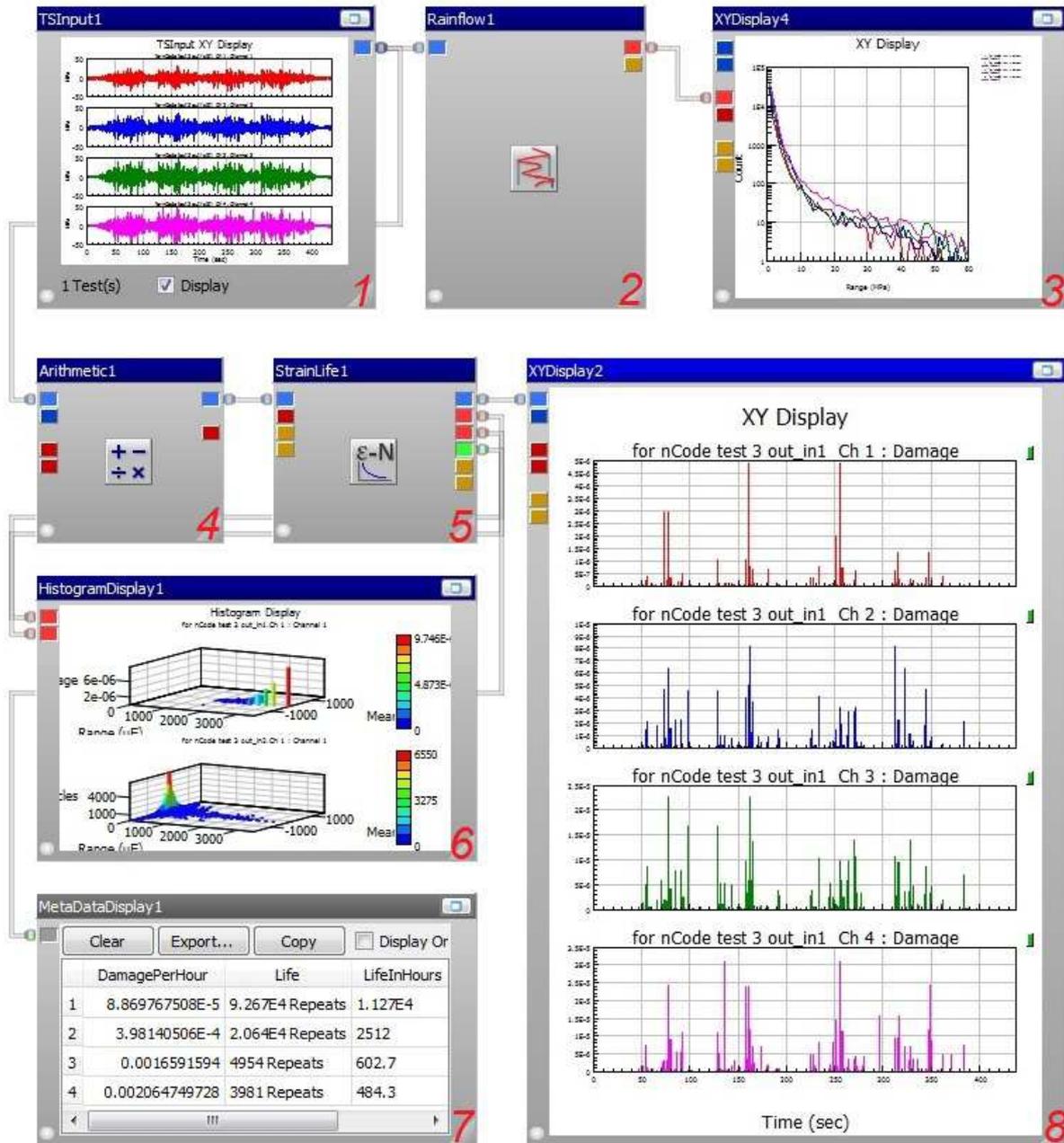
GlyphWorks glyphs are classified according to their functionality. The glyphs are available in the glyph palette (the window on the right side on fig. 2). There are sections in the glyph palette for glyphs that input data, perform basic digital signal processing (DSP), display results, and so on [18].

Glyphs are organized into the following categories (palettes), according to their functionality: Input; Function; Basic DSP; Signal; Design Life; Frequency; Fatigue; Accelerated Testing; Optimized Testing; Glyph Builder; SuperGlyph; Display and Output. Glyphs and input files, etc., can be dragged onto the workspace from their respective palettes [18].

In GlyphWorks, a process is defined as a combination of glyphs that define a data flow. A process typically starts with an input glyph to define the data to be processed. Additional glyphs define subsequent steps in the process for calculation, display, or writing output [18].

The procedure of strain-life fatigue analysis is implemented according to the developed detailed design (fig. 3) that contains the following glyphs:

- 1 – Time Series Input,           5 – Strain Life,
- 2 – RainFlow,                   6 – Histogram Display,
- 3 – XY Display,
- 4 – Arithmetic,
- 7 – MetaData Display and
- 8 – XY Display.

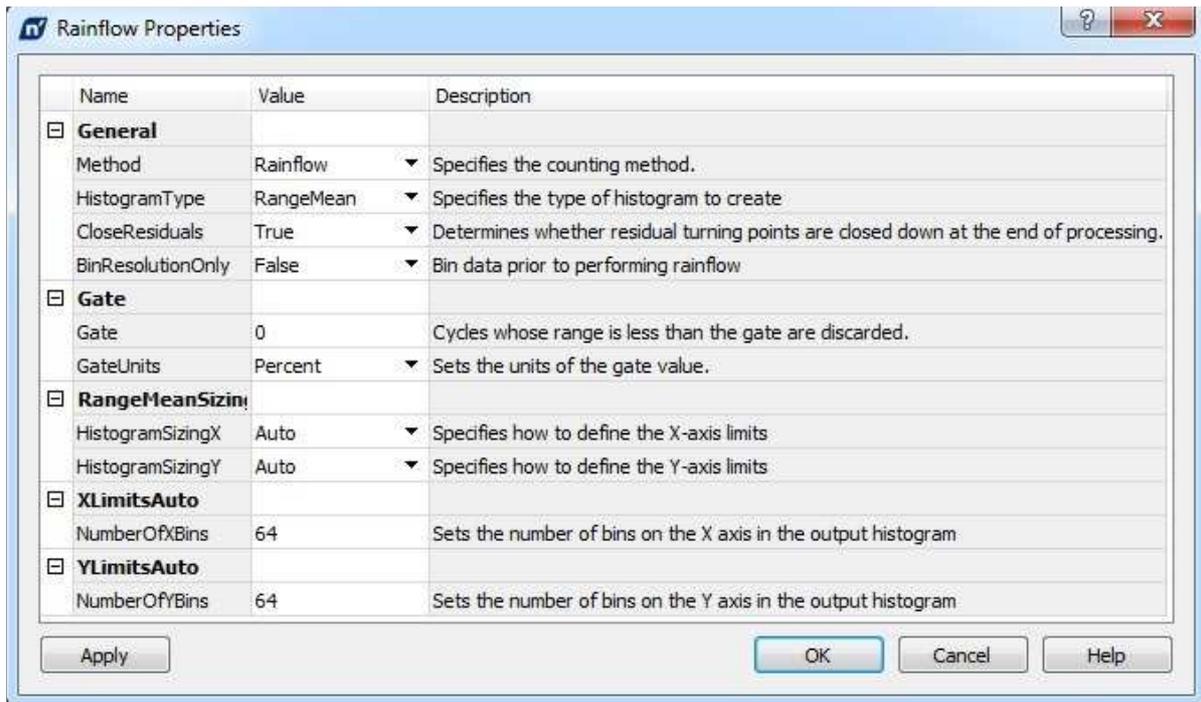


**Figure 3:** The process strain-life fatigue analysis (completed)

Functional purpose of these glyphs, structural relations between glyphs and their parameters settings are described below.

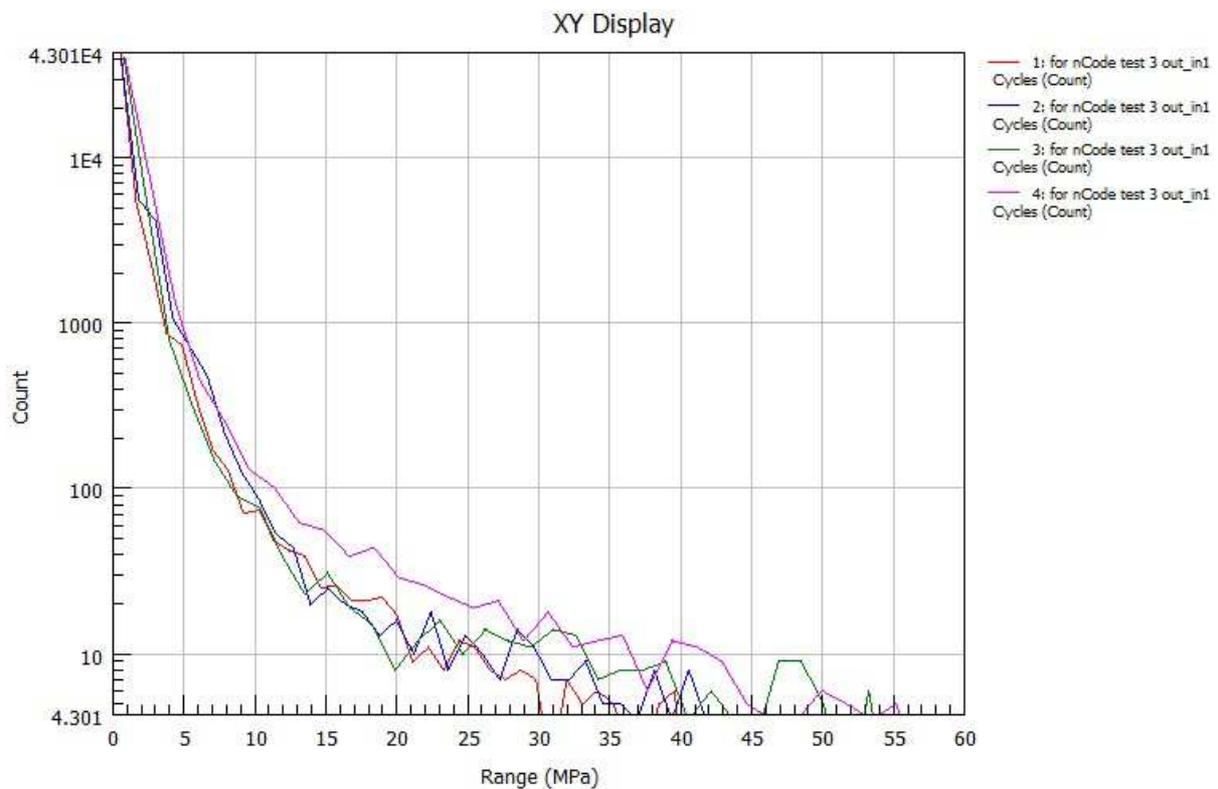
The obtained in [18] the time series data output file was uploaded to the glyph TimeSeriesInput (fig.3, glyph 1). These time series graphs are displayed in the central window of the glyph.

The settings of calculation template Rainflow (fig. 4) is left as default.



**Figure 4:** Rainflow properties

Rainflow glyph (fig.3, glyph 2) counting results are a correlation between of the load cycles number and stress. The glyph Rainflow output is connected with the XY Display glyph input (fig.3, glyph 1). The XY Display glyph has been used to show the output data from Rainflow glyph (fig. 5).



**Figure 5:** Rainflow glyph counting result view in XY Display glyph

A special glyph Arithmetic (fig.3, glyph 4) makes possible to perform mathematical operations on the data prepared in advance. This glyph input is connected with the output TimeSeriesInput glyph.

Setting of the Arithmetic1 glyph properties is shown on fig. 6. In the tab General in section Operator must be choose the type of arithmetical operation Equation. In section EquationDefinition is necessary to write the parameter Equation as « (Test1/2e5)\*10e6 » in accordance with equation (2).

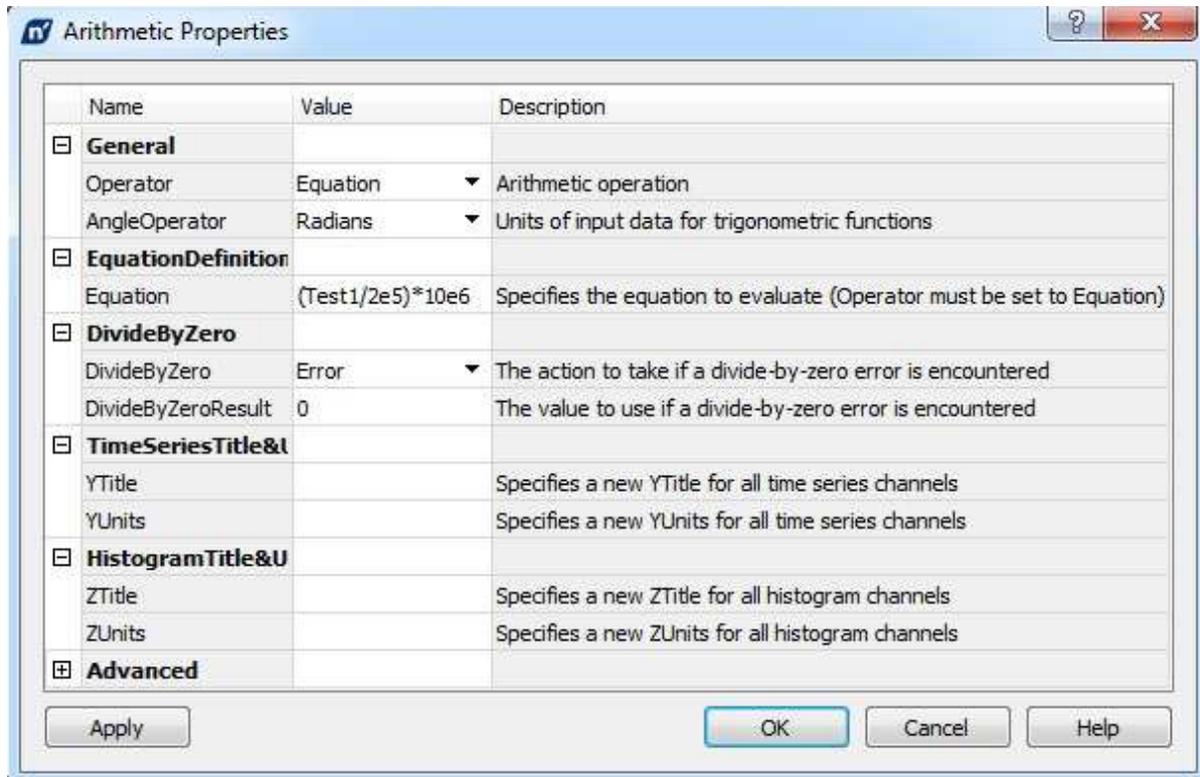


Figure 6: Arithmetic glyph properties

We have connected a Strain Life glyph (fig.3, glyph 5) from the Fatigue palette to Time Series Input glyph (TSInput1). The Strain Life glyph has six outputs, as detailed on fig 7.

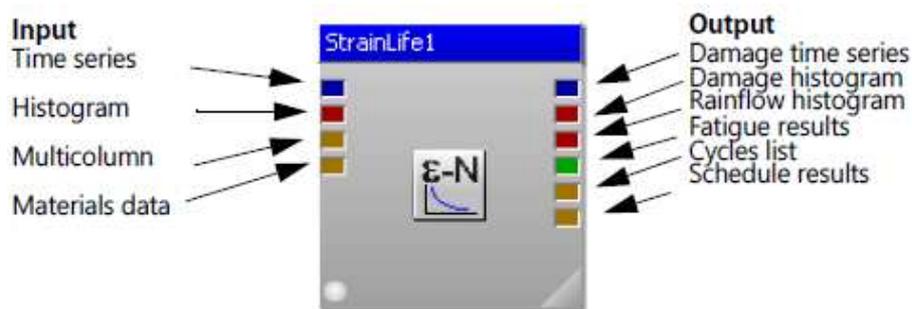


Figure 7: Strain Life glyph inputs and outputs

Two of the outputs are for histogram data (red pads). The upper pad is for the histogram of damage per bin, and the lower pad is for the corresponding rainflow cycle count matrix.

We will be connecting to these outputs the next glyphs (see the fig. 2):

- XY Display glyph input is connecting to the time series output (blue pads).
- Histogram Display glyph two inputs are connecting to the both Histogram outputs (red pads).
- Metadata Display glyph input is connecting to Fatigue Results output (green pads).

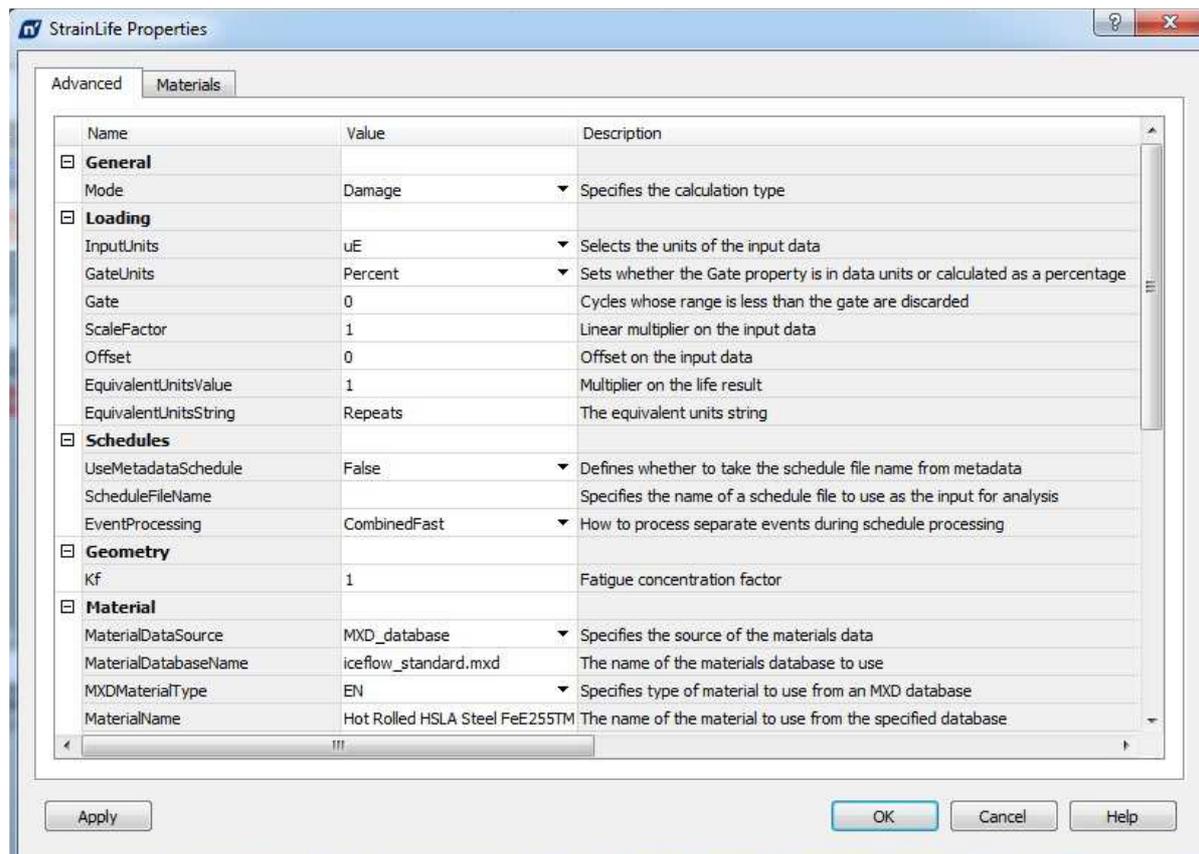
We connecting to the outputs but we don't always need to do this - we can use only the pads we want, and leave the others blank.

Before running the process, the properties of the strain life analysis need to be set; in this case, the material properties need to be defined.

The StrainLife1 glyph property dialog has two tabs: Advanced and Materials. The Advanced tab shows the glyph properties. The Mode property defines the type of calculation to be performed. In this case, we will be using the Damage mode, which performs a fatigue damage calculation.

The other Mode options are “*K<sub>f</sub>*”, which performs a back calculation to determine for each channel the *K<sub>f</sub>* required to achieve a certain desired fatigue life determined by the property TargetLife. Similarly, the “ScaleFactor” mode performs a back calculation on scale factor on the input to achieve a target life.

Under the Loading category (fig. 8), the InputUnits property = Auto that will attempt to sensibly interpret the channel Y axis unit string. We set the units of the channels as *uE*, which the Strain Life glyph will interpret correctly as microstrain. If is necessary to enforce other unit of strain can select one from the InputUnits pull down menu.



**Figure 8:** The Advanced tab of the Strain Life glyph properties

Under the Material category (fig. 8), the MaterialDataSource is by default = MXD\_database. This requires the strain-life material parameters to be entered under the MaterialData category.

This can be a convenient way of enforcing certain material data in the process. However, we will be selecting a material from the provided materials database file.

The default database is provided in the GlyphWorks installation and is of the nCode MXD format used in other nCode software such as DesignLife. There are to pick and browse different materials databases. The available sets of strain-life data are listed in the GUI.

The Materials tab window to choose a material is show on the fig. 9.

We select Hot Rolled HSLA Steel FeE255TM in the list by clicking it, or highlight it and click the Apply button. This material name has now been entered the Advanced tab under MaterialName: Hot Rolled HSLA Steel FeE255TM (fig. 8).

The other properties on this glyph were left at their defaults.

We used MaterialsManager to review the material data parameters selected. For this is necessary to select the MaterialsManager in the Main Menu (see the fig. 2).

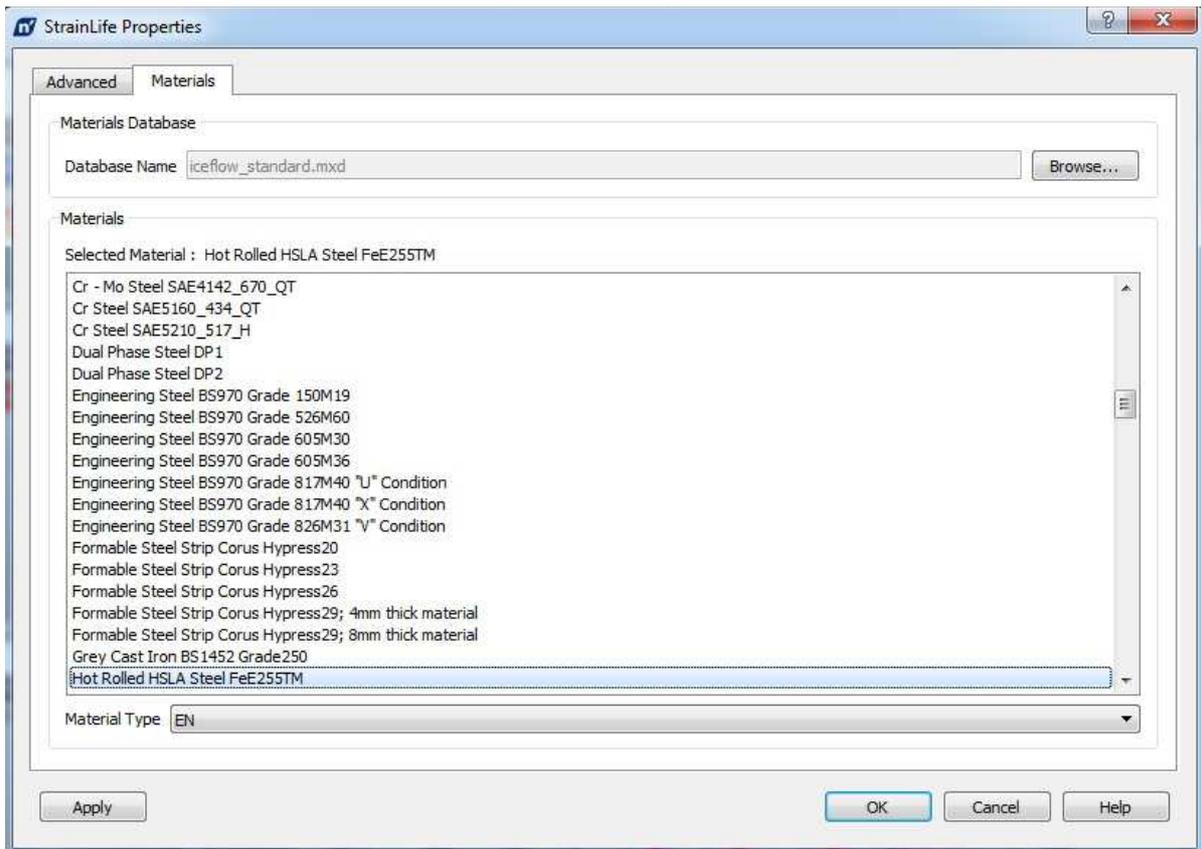


Figure 9: Selecting material

This will display a dialog for connecting to a materials database. In our case, we need to select the nCode materials file «iceflow\_standard.mxd». For the Database Type is necessary to select nCode MXD Material Database (fig. 10).

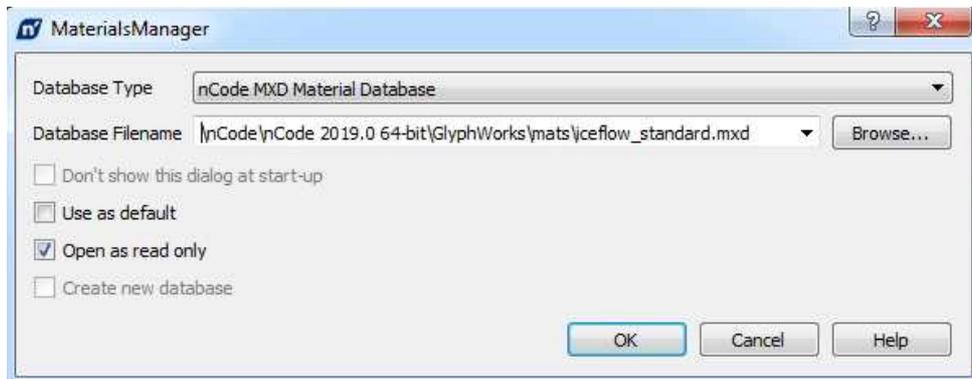


Figure 10: Materials Manager

On the fig.11 is showed a list of all available materials in this database. The default view of this set of materials is a tree view. The basic material properties of the selected Hot Rolled HSLA Steel FeE255TM are listed on the right side of the screen. These are static material properties like elastic modulus and tensile strength.

In addition to static material properties, this database also contains material fatigue curves. The expanded contents under Hot Rolled HSLA Steel FeE255TM shows any fatigue properties assigned to this material. In this case, this FeE255TM material has a strain-life curve (fig. 12).

It could have any number of different types of fatigue curves.

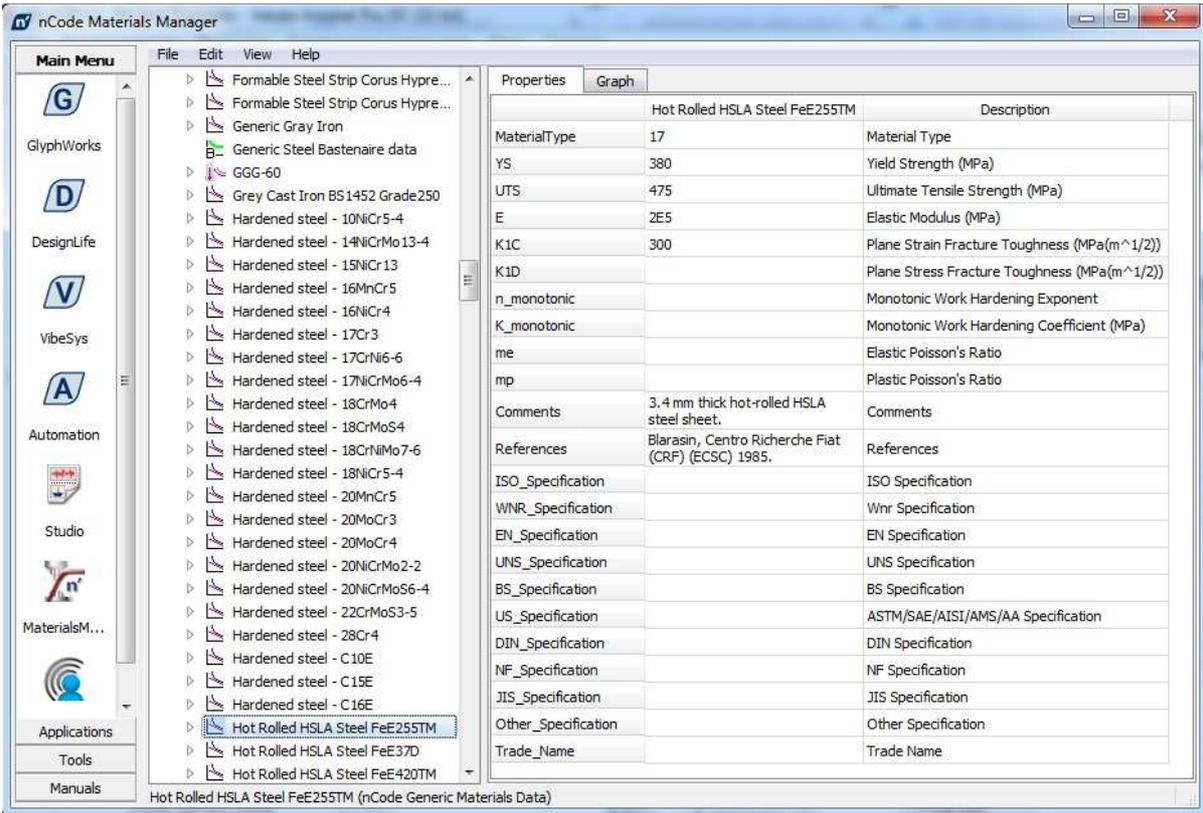


Figure 11: Static material properties

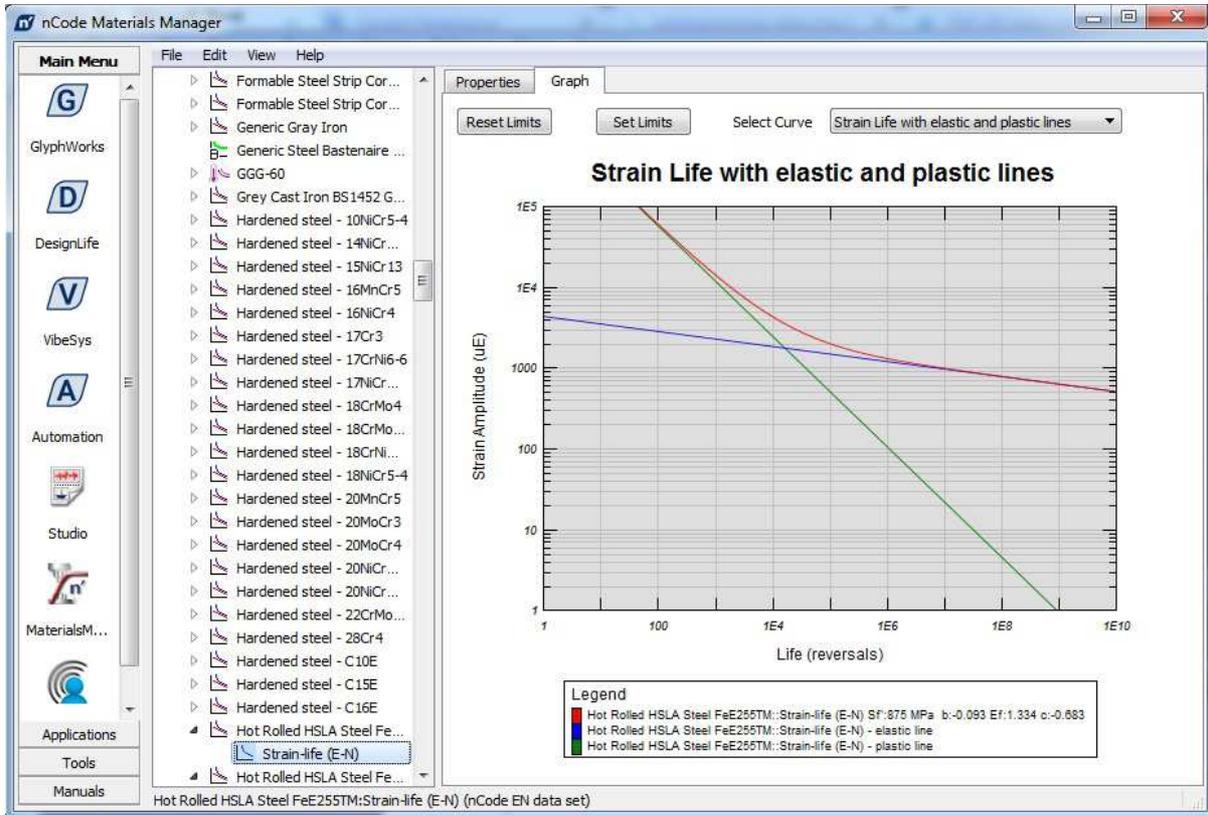


Figure 12: Displaying fatigue curve with elastic and plastic lines

In addition to reviewing data, MaterialsManager provides also the ability to add new materials data, edit existing materials data, delete existing materials data and view a plot of the data.

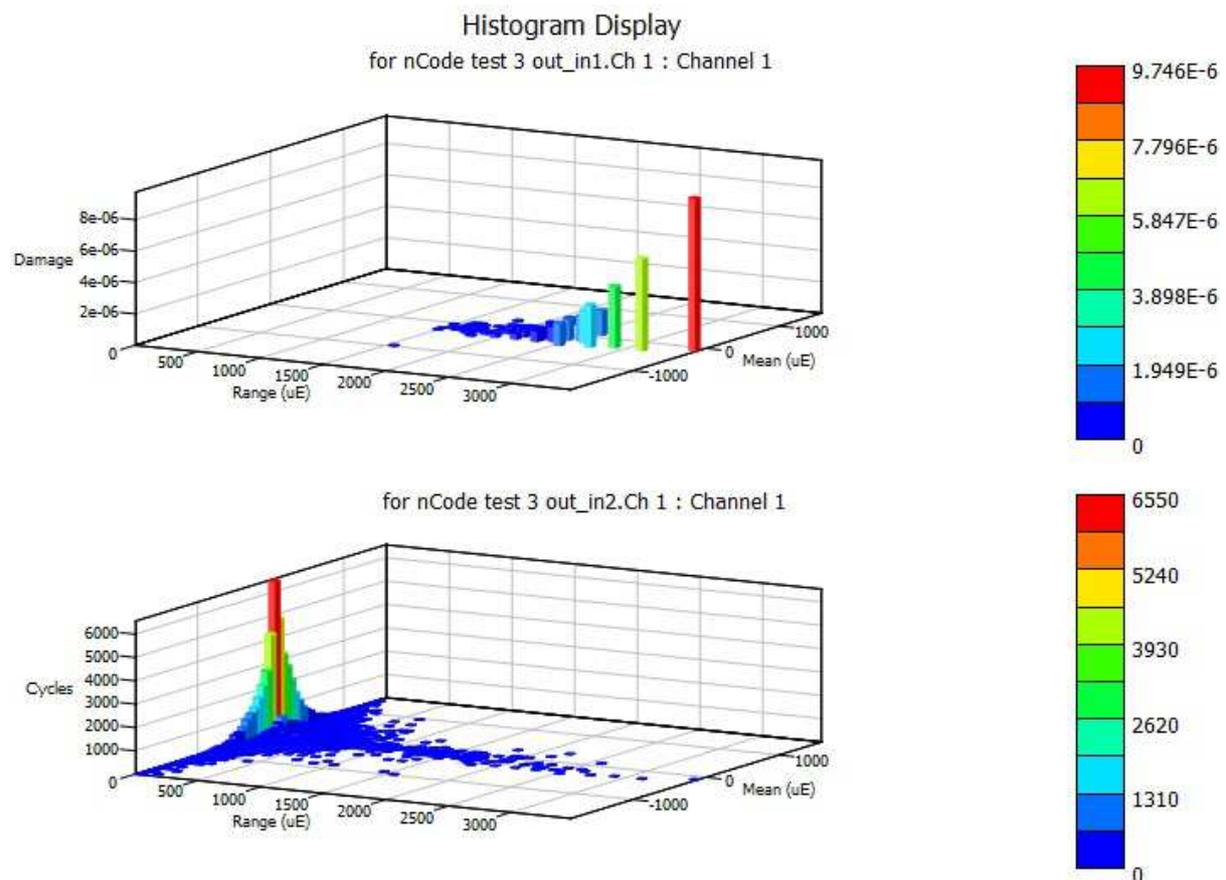
### 2.3. Strain-life fatigue analysis

The strain-life fatigue computation is carried out by starting the implementation of the developed process using the button Run on the toolbar (see the fig. 2)

The available metadata from the calculation are defined as follows:

Metadata Name	Description
DamageStatus	Value set to 0 for a successful calculation. The value will be set to 1 if the calculation failed or static failure occurred.
Duration	Length of input time history.
Life	Calculated life value. This value will be given as either a numerical value in the equivalent units or as “Beyond cutoff” or “Static failure”.
MaxStrainLocal	Maximum local strain (uE) including effect of $K_f$
MaxStrainNominal	Maximum nominal strain (uE).
MinStrainLocal	Minimum local strain (uE) including effect of $K_f$ .
MinStrainNominal	Minimum nominal strain (uE).
NumCyclesCounted	The number of cycles counted.
TotalDamage	Total calculated damage.

After the startup is complete we can analyze the computation results, in particular to review the cyclic content by looking at the rainflow and damage histograms (fig. 13).



**Figure 13:** Damage and rainflow histograms

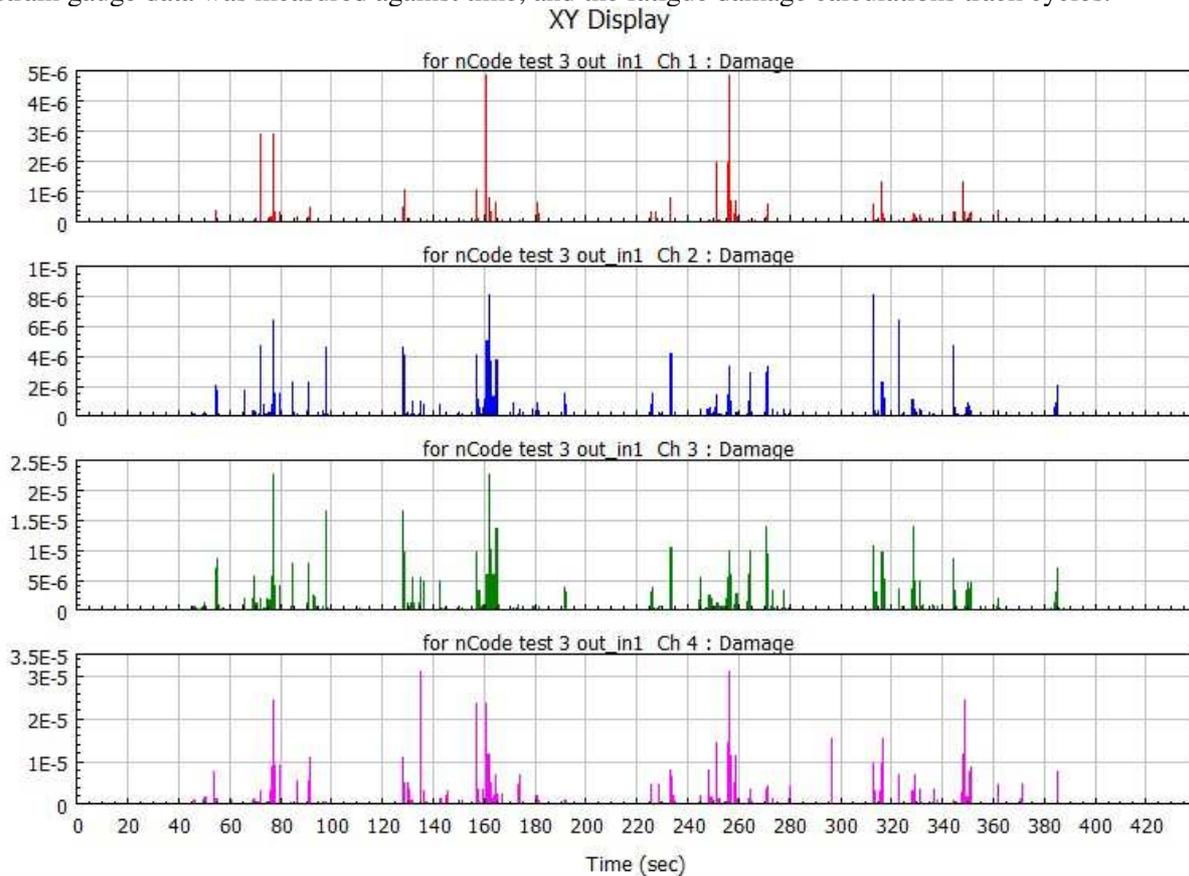
At the top and bottom there are the damage and rainflow histograms, respectively. The rainflow histogram shows the number of cycles counts on the vertical axis, plotted against those cycles' ranges and means. The largest number of cycles is seen on the left, where range is near zero – these are small fatigue cycles. The biggest fatigue cycles are to the right. Fortunately, there are very few of these occurrences. This is often typical of strain gauge data, which may have many small cycles and a few large ones.

The damage histogram shows a similar plot, but the vertical axis shows fatigue damage. The relationship between the number of cycles and fatigue life (and hence damage) is defined by the material's EN curve. It is worth notice that all of those numerous small cycles seen in the rainflow histogram don't contribute any fatigue damage, and that most of the fatigue content comes from those few big cycles.

These plots are useful as diagnostic tools when trying to interpret fatigue results. These histograms can help us understand the types of fatigue cycles seen in use and answered such questions as: how big are the biggest cycles? How often do they occur? Are these cycles statistically representative of actual usage, or are they outliers? How damaging are these big cycles? How sensitive are the fatigue answers to the distribution of cycles?

These plots can also view as a top-down color map by selecting the TopView button in the toolbar.

We can also look at how damage accumulates over time (fig. 14). We can do this because the strain gauge data was measured against time, and the fatigue damage calculations track cycles.

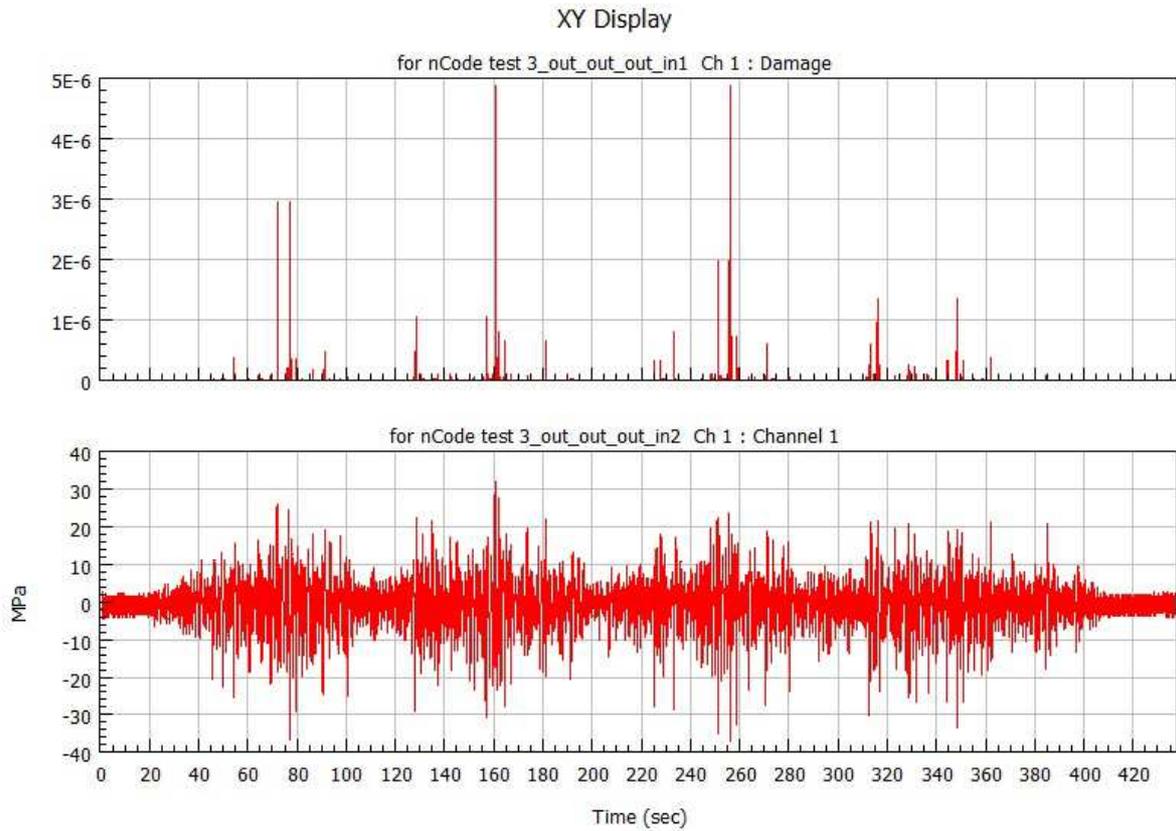


**Figure 14:** Time series of damage (XYDisplay1)

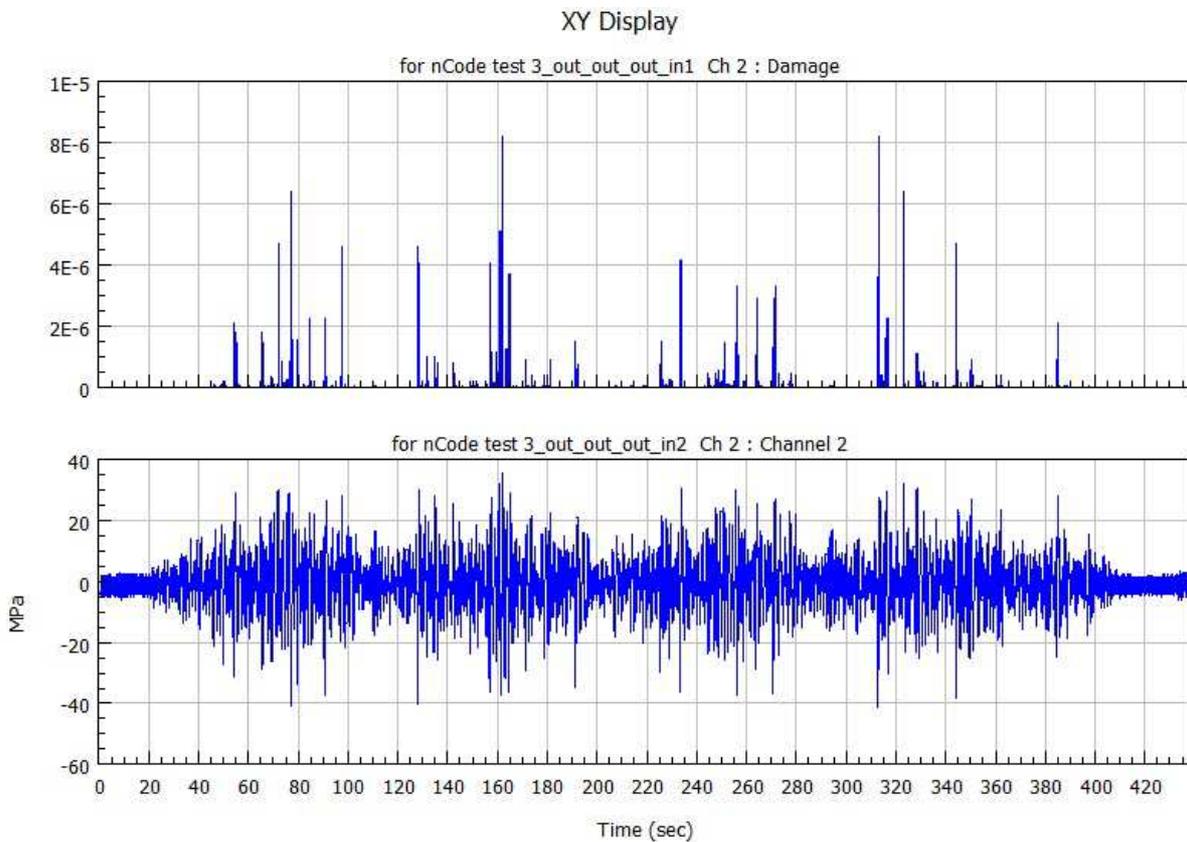
The XYDisplay1 glyph displays time histories of when damage occurred in the time domain for each channel. As we saw earlier, the strain time history is rainflow cycle counted to understand cyclic fatigue content. Each counted cycle's starting and ending times are recorded, and the amount of fatigue damage caused by that cycle is calculated.

Half of the damage calculated for this cycle is assigned to the cycle's starting time and half the damage to the ending time. This creates a time series with the same number of points as the original channel, but the Y-axis value is now damage. This can be used to visualize damage accumulation in the time domain – anywhere there's a damage spike, there must have been an important fatigue cycle.

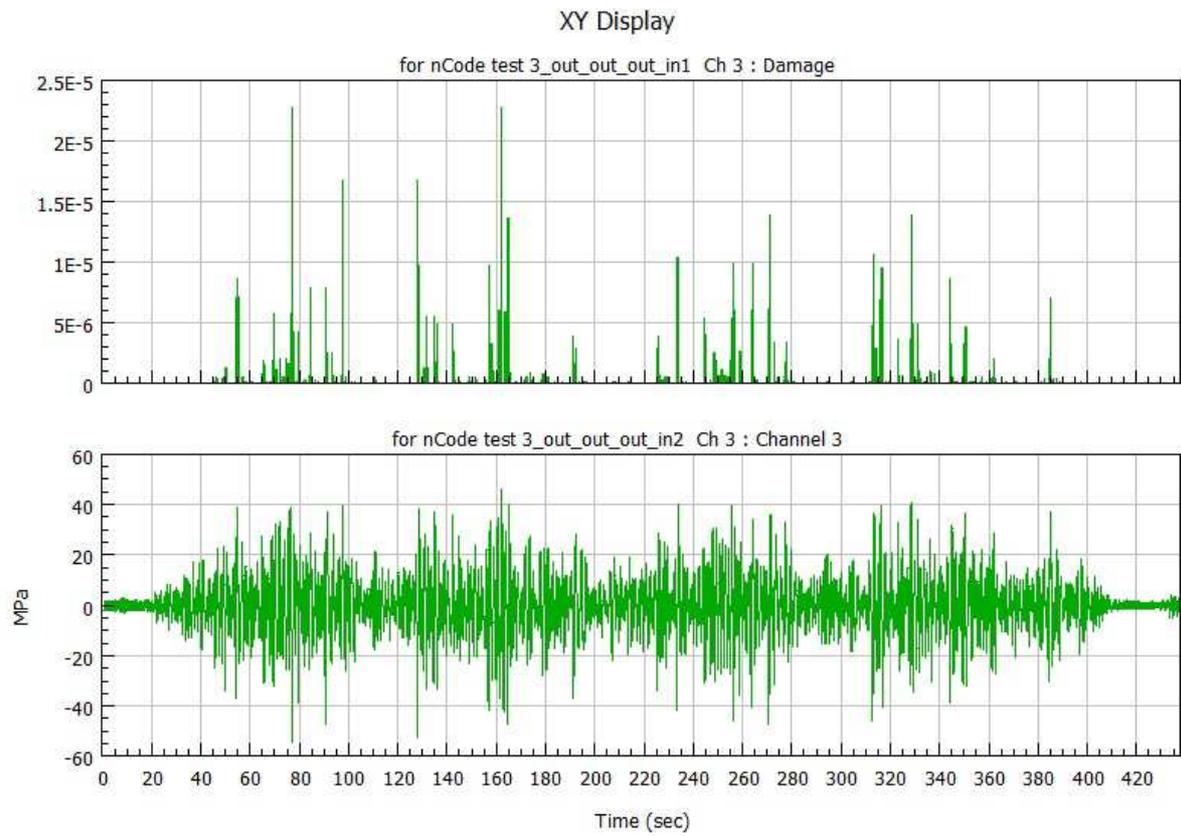
We added the original strain gauge time histories to this plot by connecting TSInput1's blue output pad (its only pad) to the second blue input pad on XYDisplay1. Then the glyph automatically changed from showing four channels' damage to showing damage and strain for a single channel. The rest of the strain gauge channels can be browse using the blue arrow NextChannel button in the toolbar. We can also view these damage channels with a logarithmic Y axis, since damage values tend to vary over orders of magnitude (fig. 15 - fig. 18).



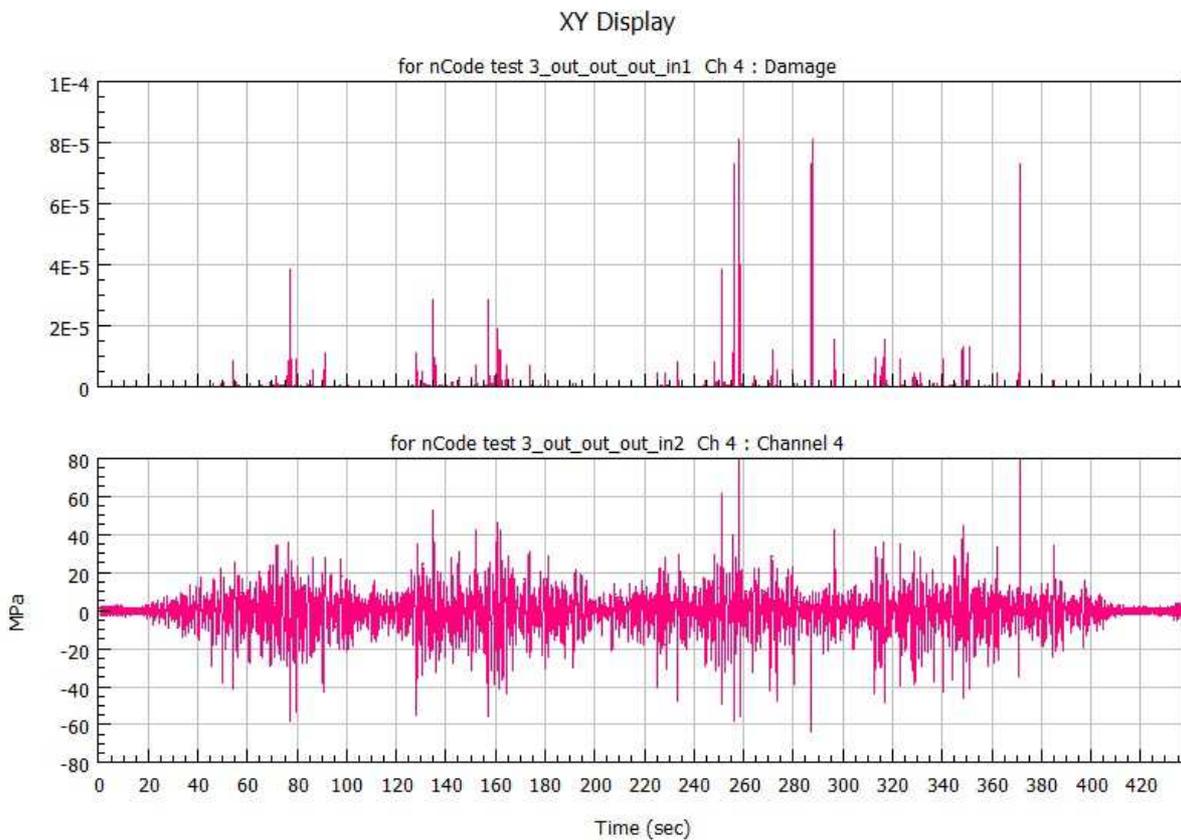
**Figure 15:** Plotting damage and strain gauge data in the time domain for channel 1



**Figure 16:** Plotting damage and strain gauge data in the time domain for channel 2



**Figure 17:** Plotting damage and strain gauge data in the time domain for channel 3



**Figure 18:** Plotting damage and strain gauge data in the time domain for channel 4

The damage and strain gauge versus time plots we can see that the large strain magnitudes contribute to fatigue damage. This can be helpful in diagnosing fatigue problems and can help to answer the question: What causes the damage? What's happening when damaging fatigue cycles occur? How is the part being used at that time?

The channel in this display could be anything that was recorded synchronously with the strain gauge data – speed, temperature, acceleration, etc. – so it's easy to cross-reference fatigue accumulation with other usage parameters. We can even link these damage time histories to GPS data and see where the test article was when it was damaged.

A more thorough browse all the fatigue analysis results allow Metadata Display glyph. In this glyph under StrainLife1\_Results section we can see fatigue results for the each channel.

The Metadata Display glyph allows setting the Display Type to Custom the creation of a custom table with different column content. The each channel now has its own row (fig. 19). This tabular display is easier to view than the tree views that been earlier. Also there are Export and Copy buttons that allow easy export results to other software programs such as Excel.

	DamagePerHour	Life	LifeInHours	Duration
1	8.870010532E-5	9.267E4 Repeats	1.127E4	437.97
2	3.981514147E-4	2.064E4 Repeats	2512	437.97
3	0.001659204859	4954 Repeats	602.7	437.97
4	0.0020648063	3981 Repeats	484.3	437.97

**Figure 19:** Simplified table of fatigue results

The longest fatigue life is 92670 time history repeats (for channel number 1). These repeats mean repetitions of the entire input signal, with all the cycles that it contained.

The shortest fatigue life is 3981 time history repeats (for channel number 4). The fatigue life in hours in this case is only about 484 hours.

The number of cycles per hour can be defined as  $3981 / 484.3 \approx 8.2$ .

Standard operating time of sprayers is 350 hours per season. For a service life of 7 years, this amounts to 2450 hours of operation or about  $2450 * 8.2 \approx 20000$  load cycles.

Thus, fatigue life is need to last about 20000 repeats in order to meet exploitation requirements.

In the current design, among the investigated hotspots are one over and two under-designed relative to this life target.

The under-designed areas need some attention to improve their fatigue performance.

We can use the Strain Life glyph's back calculation capabilities to assess how the stress should be increased or decreased to meet this target life. This is called a back calculation because we know the fatigue life and want to calculate what would normally be an input parameter – the stress level.

This type of back calculation provides quantifiable stress or strain reduction targets for a redesign or countermeasures. For this we set the StrainLife glyph's properties (fig. 8) as follows:

Mode = ScaleFactor and

TargetLife = 20000.

After running the process, can noticed that the calculation time increases because it has to iteratively solve for a scale factor that gives the target fatigue life for each channel.

The Metadata Display hasn't showed yet any new answers because its column content doesn't include them. To see the back calculated scale factors, need to edit Metadata Display properties, adding StrainLife1\_Results.ScaleFactor. The results table looks like in fig. 20.

Each channel's fatigue life is 20000 repeats +/- 1%. The last column is the back calculated scale factor that results in the target life.

This scale factor answer is very important. It says that if channel 4 strain time history were multiplied by 0.753, the fatigue life would increase to 20000 repeats.

	DamagePerHour	Life	LifeInHours	ScaleFactor
1	4.103532619E-4	2.003E4 Repeats	2437	1.233327627
2	4.086488642E-4	2.011E4 Repeats	2447	1.003713369
3	4.120521033E-4	1.995E4 Repeats	2427	0.799356699
4	4.074807222E-4	2.017E4 Repeats	2454	0.7534338236

**Figure 20:** Scale factor results from back calculation

In other words, a strain reduction of about 25% for channel 4 is required to meet the 20000 repeat durability targets. Likewise, a 20% strain reduction is required for channel 3.

For the channel 1 show scale factors > 1, indicating that the element's area is currently over designed and strain levels can be increase to meet the target life.

### 3. Conclusion

The developed procedure of the strain-life fatigue analysis under test data digital processing by nCode GlyphWorks software's tools made it possible to calculate of the fatigue life for each of the four channels and to study about what causes fatigue cycles and damage by viewing them in the histogram and time domains.

Analysis of the time histories that display when damage occurred in the time domain for each channel, made it possible to establish that the small fatigue cycles have the largest number but make small damage. While the biggest fatigue cycles have small number but they create damage spike that is the large strain magnitudes contribute to fatigue damage.

The results of the strain - life fatigue calculation show that load cycles number of the channels 3 and 4 do not provide required meeting the 20000 repeat durability targets (or 2450 hours).

The channels 4 and 3 are needed a strain reduction of about 25% and 20% respectively are required to meet the needed durability targets.

The channel 2 strain level completely provide required to meet the durability targets.

The channel 1 strain level it is advisable to increase of about 23% to meet the target life.

The results of the strain-life fatigue analysis are preliminary and need to be clarified taking into account structural, technological and operational features, such as, for example, stress concentrators, technological defects, the presence of an aggressive environment, etc.

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