Strain Gauge Correlation of CAE & Test Results and Analyzing the Root Cause of Any Deviation

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Abstract

Driven by the need to continuously reduce the cost, CAE analyses are becoming more and more an integral part of today's product development cycle. Striving for a lightweight design while reducing the number of physical tests requires an accurate correlation between the measurements from the test lab and the CAE results, along with a detailed understanding of any deviations. The correlation can be challenging due to several reasons such as approximations in strain gauge location and orientation, realization of the boundary conditions, e.g. the correct combination of loads. In physical testing, tolerances of the measuring instruments and human errors are only some of the potential root causes for abnormalities. These uncertainties can make the correlation a tedious and time consuming process. The goal of this paper is to perform a root cause analysis of any deviations in the correlation and understand the effect of above factors on the correlation process with an example of a steel bracket.

Introduction

Altair's Product Design team investigated the structural integrity of a crucial bracket bearing the load of an entire assembly. When structural analysis was performed, the bracket showed some signs of bending around the central area. It became essential to verify these results by physical testing. Since the displacements were small, strain gauge correlation was an appropriate method to use. The results from the test lab showed differences compared to the simulation results which made further design recommendations difficult. Hence, it was important to understand these differences and measure their influence on the quality of the correlation, be it good or bad.

The Virtual Gauge Director (VGD), coupled with HyperStudy from Altair was used to perform design of experiments (DOE) and optimization studies to understand the effect of load variation as well as the robustness of the gauge placement and orientation. The combination of both presented more ways of analyzing the strain gauge correlation outcome.

The VGD is a customizable solution from Altair to correlate and verify simulation results with the test lab data. VGD enables engineers to extract the results at the exact position of the strain gauge as in the test lab, interpolate the results at the gauge locations in the simulation model, compute results in their local coordinate system, and give a correlation index confidence. VGD can interpolate stress or strain values at any placement in the model.

HyperStudy is a Multi-Disciplinary Design Exploration, Study and Optimization Software. Based on user defined design objectives and mathematically established methods such as design of experiments, metamodelling and optimization, it creates intelligent variants of designs, executes the simulations and collects performance data. It then guides the user to understand data trends, perform trade-off studies and optimize design performance and reliability.

Verifying the robustness of the strain gauge locations

A simple strain gauge and one rosette strain gauge were placed in the central area where the high stresses were observed. While measuring the strains, it is critical, to find a right balance between capturing the strains and placing the gauges in the stress gradient area. The feasibility to place the actual gauge on the bracket also needed to be considered. The first step in the process was to verify how sensitive the placement of the gauges was to these stresses.

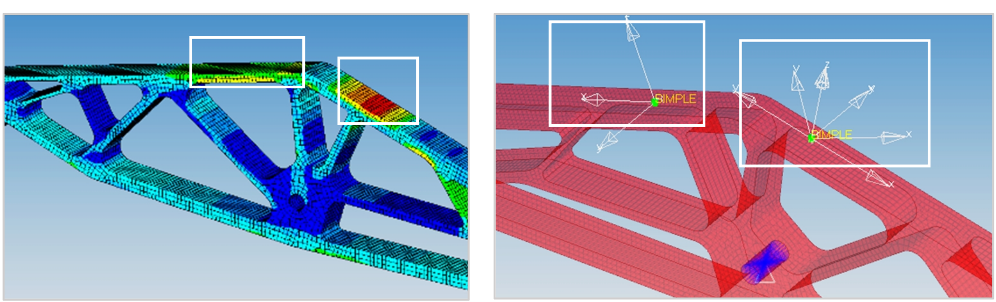

Figure 1: Stresses observed in simulation and placement of the virtual strain gauges created in VGD

A DOE study was performed to get the most sensitive direction and orientation of the gauges. For this analysis VGD was used as a solver driven by HyperStudy. The responses were set as the mean squared roots results of the gauges and a DOE was performed to estimate the responses around the ideal placement and orientation of the strain gauges.

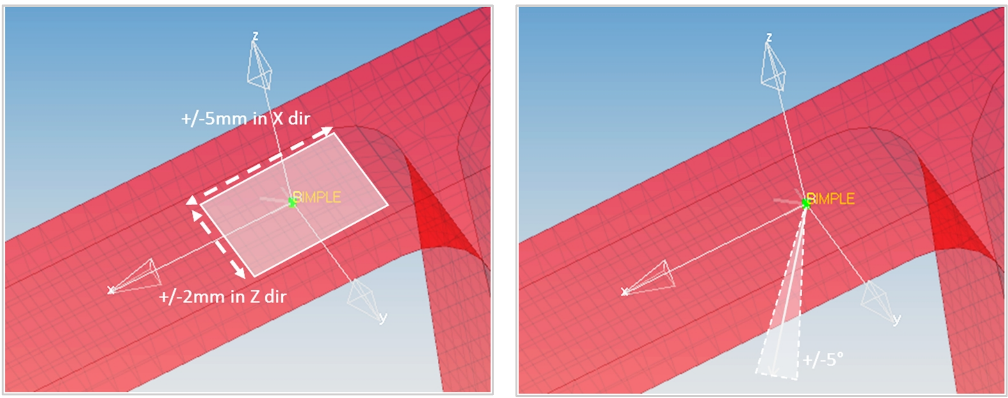

Figure 2: The following parameter were used as the input into the DOE study: +/- 5 mm in local X direction, +/- 2 mm in local Y direction, +/- 5° in local X orientation

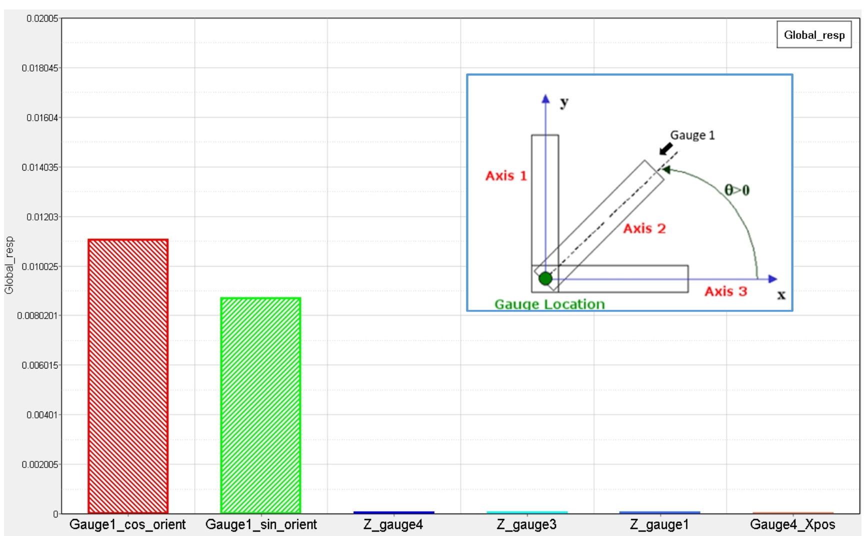

Figure 3: Rosette strain gauge placement parameters & Pareto plot of the DOE results

The DOE showed that the results of Gauge 1 is sensitive to its placement around local Z-axis. From the above recommendations, the test-lab engineer placed the gauges on bracket and measured strains for the given loading.

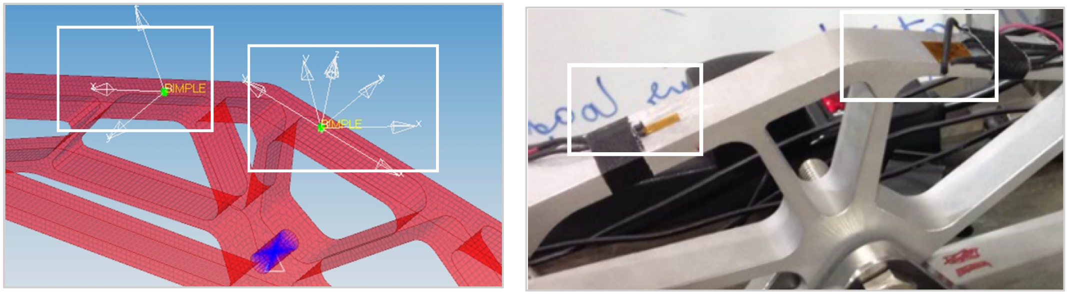

Figure 4: Test-lab strain gauge set-up

Strain Gauge Correlation

Test measurement data is not always in a CAE readable format. VGD ported this data into CAE environment through an automated script, which is useful to the team beyond this project. After brining the test results and the actual coordinates from the test lab the correlations process started. As the strains were measured in the local coordinate system in the test, VGD was used to automatically interpolate the strains from the analysis, which have been in the global coordinate system at the exact same gauge locations.

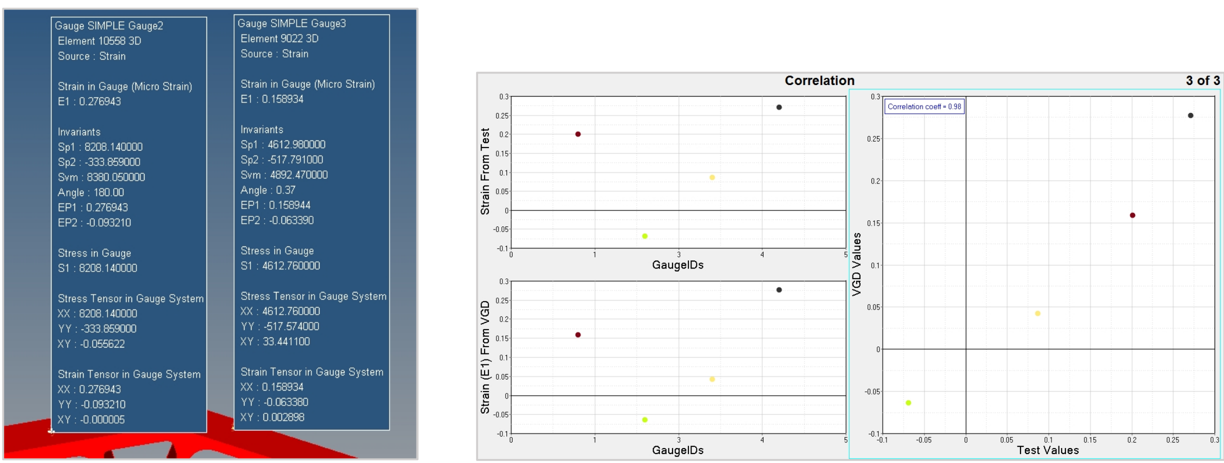

Figure 5: Interpolated strains at the gauge locations and correlation

Gauge	Strains Measured (in Micro Strain) from the Lab	Strains Measured (in Micro Strain) from the simulation	Deviation
Gauge1	0.087	0.0573	34%
Gauge2	0.271	0.311	15%
Gauge3	0.201	0.175	13%
Gauge4	-0.069	-0.063	9%

Table 1: Strains from results interpolation in VGD

The result of Gauge 4 was the closest match. Gauge 1 was quite far from the test and needed investigation to understand the root cause.

Results comparison exploration

Even though the initial conditions such as loading, material, gauge positions and so on have been the same in the lab as well as in the simulation, the final results showed still a difference. Since most of the gauge results were a close match, the issue was not a global one meaning that the global parameters such as loading and material were matching. Hence the issue was with one of the local parameters such as location or orientation of the gauge. This was confirmed by performing a sensitivity analysis with another DOE study.

A range of loads were specified as parameters to check how the results varied with the varying loads. VGD, in the background, interpolated the strain results for each load iteration at the gauge locations. Below are the plots from DOE study showing linear effects of loads on the gauge results.

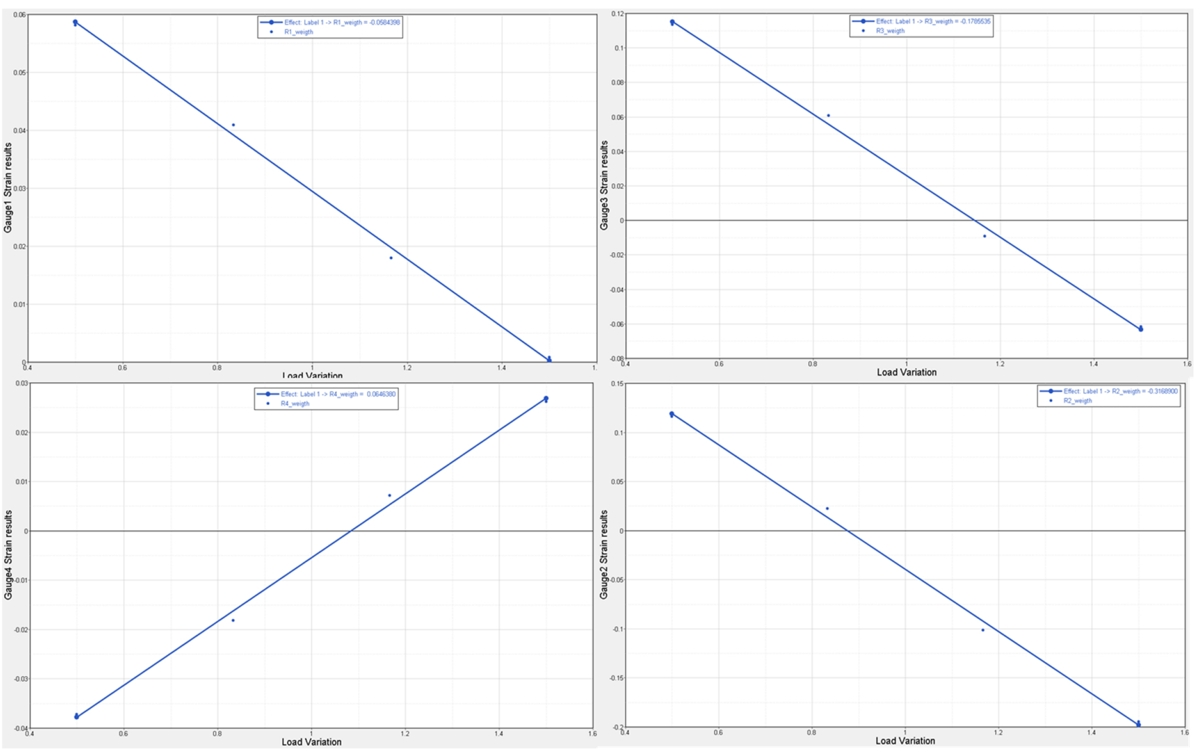

Figure 6: Linear effects of load variation on the strains at each gauge location

The plot above shows that the Gauge 1 deviated the most while other gauges were much closer. This confirmed the earlier conclusion from CAE-test correlation and the previous DOE that the loading was not the root cause of the difference between CAE results and test-lab measurements.

Optimization

After confirming with the test lab engineer that indeed the proposed locations was used, and thus eliminate human error, an optimization was performed to find the best possible combination of the location and orientation for Gauge 1.

Below is the example of the optimization of Gauge 1, the 45º branch of the rosette gauge. A GRSM based algorithm was used for this optimization with range of +/- 10° of local X orientation. VGD serves as an engine in background to calculate the results at the gauge location in each iteration.

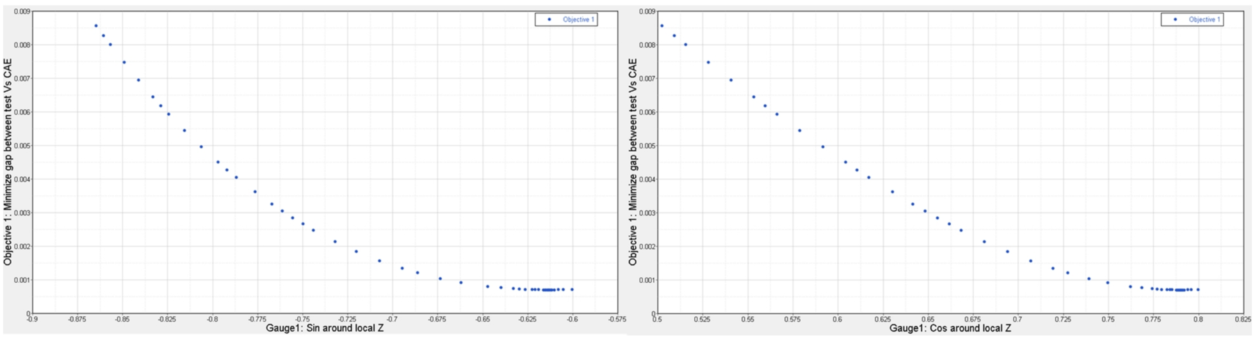

Figure 7: Scatter 2D plot of the optimization global response vs cos & sin orientation angle around local Z axis

It was concluded that a 7.2º rotation of X direction from the current location would give the same results in the simulation and test. This new orientation was imported in VGD and results were recalculated. Below were the strains in the rosette gauge. It was seen that the optimizer proposes a better compromise of results for the 3 branches of the Rosette.

Gauge	Test Strain Measured	Initial Strains Measured (in Micro Strain)	Optimized Strains Measured (in Micro Strain)
Gauge1	0.0867	0.0573	0.0869
Gauge3	0.2009	0.175	0.171
Gauge4	-0.0688	-0.063	-0.0599

Table 2: Results comparison between test, initial CAE and optimized results

Conclusion

A right balance between capturing the strains and placing the strain gauges in a stress gradient area is important in a correlation process. The DOE performed by coupling VGD with HyperStudy helped the engineers to understand the robustness of the gauge placement. Engineers were able to estimate the risk on the strain measurements from the test-lab and the reliability on the initial assumptions. Since the correlation was good for most of the gauges except for one, a global factor was predicted to be the root cause. With VGD, another DOE was performed to narrow down the most influential global factors.

Finally to verify the accuracy of the test set-up, an optimization was carried out and the best possible strain gauge placement was found. With this project, the correlation process became more reliable, and accurate. VGD made it possible to reduce the efforts in physical testing and made the each lab-test count by providing initial suggestions and recommendations from CAE, thus saving both time and money for the company. The knowledge gained during the process was useful to the team beyond this project.

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If you would like to find out more about Altair's services and technologies for strain gauge correlation, or if you'd like to speak to us about any of the technologies or processes featured in this paper; please visit us at altair.com