Siemens Digital Industries Software

Finding the longest lasting design, faster

Designing durable vehicles with simulation using Simcenter 3D

Executive summary

Siemens Digital Industries Software helps its customers in all steps of the vehicle design process to accelerate their time-to-market. The focus of the 3D computer-aided engineering (3D CAE) durability process presented in this white paper is the design optimization and virtual product validation stage. More specifically, this white paper presents how 3D simulation solutions can be used to assess a vehicle's structural durability for body-in-white and chassis and excludes the powertrain, for which the involved physics and process are very different.

Contents

Abstract

Every car owner expects their vehicle to be reliable. Unlike other performance criteria like dynamics, comfort or acoustics that can be directly experienced by the end-user, vehicle durability issues are perceived to occur only after long usage and a heavy odometer reading. This implies that creating a car brand known for long-lasting vehicles is a very hard and lengthy process. Conversely, the brand's image for durability can quickly be destroyed by a few recalls.

Increasing a vehicle structure's durability performance by material reinforcement comes at the cost of increased weight (and fuel consumption), which leads to higher carbon dioxide (CO_2) emissions and more expensive usage. Other design updates improving durability performance also affect other vehicle performance attributes. Therefore, designing a durable car is a multi-attribute optimization process. Weight and durability performance of structural components must be balanced, while being as cost effective as possible, and not negatively impact other performance attributes.

Using accurate and efficient simulation in the early stage of the vehicle design process to predict and optimize vehicle durability is crucial because that is when there is a wide range of design freedom at affordable cost. The earlier the better: creating models before prototypes exist and optimizing performance on these models is much cheaper and faster than applying fixes on the existing, physical vehicle, in particular when it is already released on the market.

The Simcenter™ software portfolio includes all the solutions to cover the standard durability engineering process in a vehicle development scenario (figure 1).

It all starts with an understanding of the loads that products will undergo during their anticipated lifetime. Strength and durability-specific characteristics are analyzed and a target is derived. Such data typically serves as input for the virtual and physical product validation and optimization process. The last two steps in the durability development process involve optimization and validation of the physical prototype before testing the final product on the road.

Simcenter™ 3D software is a comprehensive, fully integrated 3D CAE solution with connections to design, 1D simulation, test and data management[1]. It contains a central platform used to model, perform and evaluate multidiscipline simulations, thanks to the integration of fast and accurate solvers powering structural, acoustics, durability, flow, thermal, motion, materials, electromagnetic as well as optimization and multiphysics simulation.

The focus of this white paper is to explain how Simcenter 3D Specialist Durability, the application integrated in Simcenter 3D for durability analysis, together with the rest of the Simcenter portfolio provides durability engineers with the best tools to perform early durability assessments on a vehicle's comprehensive digital twin before the first prototype exists, from load data acquisition to advanced durability simulations.

Simcenter is part of Xcelerator, a comprehensive and integrated portfolio of software and services from Siemens Digital Industries Software.

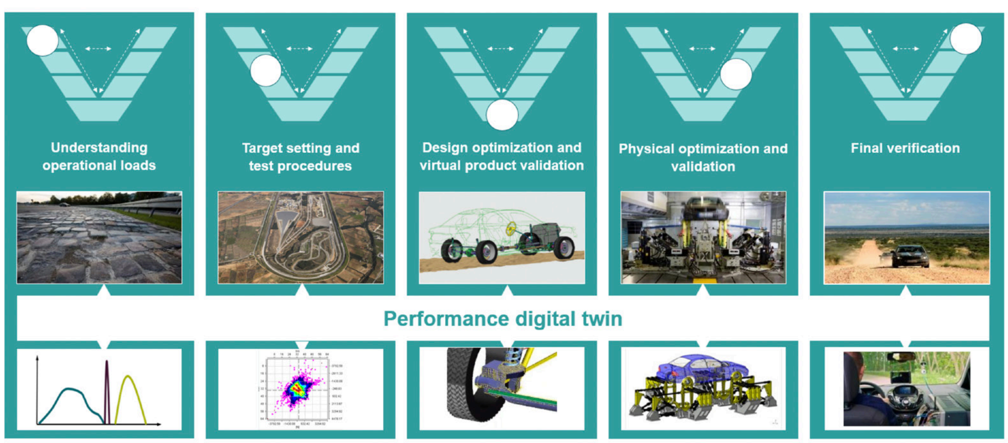

Figure 1: Durability engineering process in a vehicle development scenario.

Automotive durability simulation challenges

To efficiently perform early durability simulations, CAE engineers face well-identified challenges and need access to various data and use a range of tools:

- First, accurate road load data must be available. Durability loads are mostly coming from the road, transferred through the tires, the wheel's spindles, and then to the chassis and all of the vehicle's structural components. The main challenge is to have accurate load data to account for both critical scenarios (like paved roads, potholes and misuses) and more usual ones (smooth driving on highways), while the vehicle prototype does not exist yet. They can either come from measurements done on previous vehicles, or from simulations done on digital roads.
- Then, the CAE engineer will need tools for load data prediction at the component or subsystem level as an input to durability simulations and optimization.
- Access to up to date computer-aided design (CAD) data and an accelerated CAD-to-CAE process are necessary. In general, designers are not working in the same department as CAE analysts. They typically update the designs of their components daily to answer update requests from the manufacturing department or from another CAE analyst. Durability results typically come rather late, when the design has already been updated several times, so that less design freedom remains (as parts of the design may have been frozen for other attributes, and/or tooling has been started such that some changes are no longer allowed from the manufacturing perspective).
- Standard fatigue simulation methods can be different from one company to another and can change with time. They must be implemented in the durability solution and easily accessible. Moreover, due to the increasing complexity of vehicle assemblies and technologies, the variety of materials types, connections strategies, manufacturing processes, and old and well-known durability methods are not always enough. New advanced fatigue methods are necessary.
- Finally, fatigue-specific postprocessing tools must be available for CAE specialists to thoroughly analyze, visualize and interpret the results, and derive design updates. This drastically benefits the added value of the engineers on the final product.

Durability 3D CAE models preparation

Access to up-to-date CAD data and acceleration of the CAD-to-CAE process

In a typical CAE process, designers share CAD files with CAE analysts in a shared folder or an e-mail. The CAE analyst needs time to integrate the CAD in the CAE model, prepare

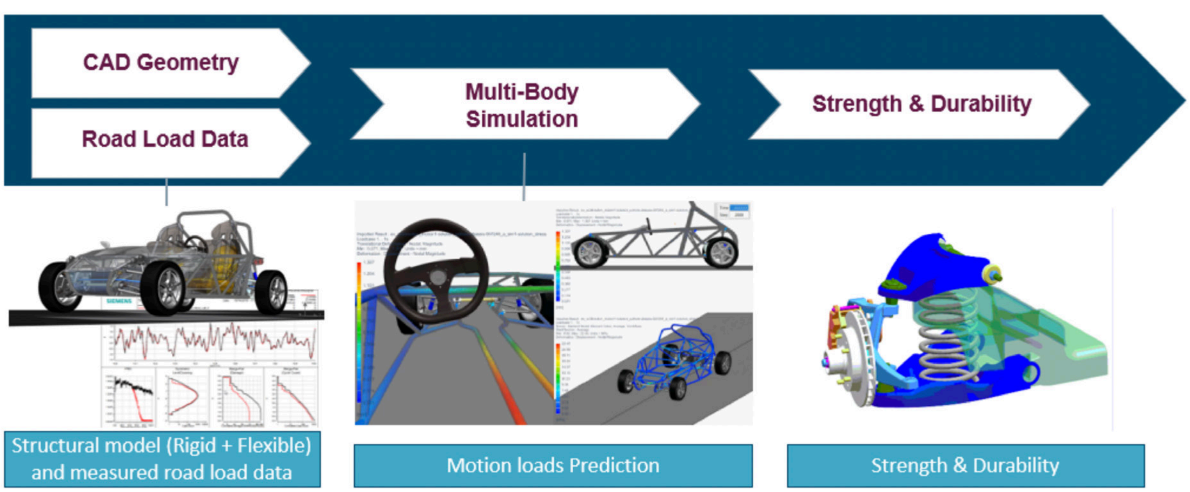

Figure 2: Typical 3D CAE durability process, from road load data to strength and durability assessment.

and run the simulation and postprocess the results. In the meantime, the designer updates the CAD several times based on feedback from other departments (analysts, manufacturing, program management, etc.).

The results of the CAE analysis quickly become obsolete. The entire CAD-to-CAE process must be accelerated to avoid this situation. This is why Siemens Digital Industries Software proposes, as part of its Simcenter 3D portfolio:

- A strong CAD integration, giving full access to CAD items, from a Siemens platform (NX™ software) or third-party ones
- Teamcenter for Simulation as a simulation-data management solution that automatically associates the most up-to-date CAD part to CAE analyses, and then link CAE results to CAD parts
- Automation and customization capabilities with NX Open to accelerate the CAD-to-CAE process and adapt it to customer needs
- Efficient and accurate durability analyses and postprocessing, as explained later in this white paper

Road load data prediction

In a "real-life" vehicle durability scenario, complex loads act on components and subsystems. These loads can only be measured when prototypes are produced. Therefore, a comprehensive digital twin is necessary to get the correct loads on the full system. This can be used to transfer the loads to the components.

The durability engineers first need to define the loads that will act on the whole vehicle, thus strongly influencing its lifetime. This depends on the type of vehicle, the driver and the type of roads on which the vehicle will be used. This definition helps define a test campaign or extract existing testing data on existing vehicles. The loads on new components are then simulated and the design of these components optimized to meet multiple performance targets.

Using the comprehensive digital twin, all you need to have is the test track and the driving maneuvers to get loads on the complete vehicle, on subsystems and components. The load schedules on a test rig can be tailored and optimized to the individual subsystems and components.

There are two typical approaches for performing this road load data prediction: the hybrid approach and the digital road approach.

Figure 3: Examples of extreme durability conditions.

Hybrid approach

The hybrid test/CAE approach combines tests with simulation. It allows engineers to apply measurements taken on test tracks and transfer this data to the CAE environment in a consistent and pragmatic way. This method provides a realistic road-load prediction, even for loads that cannot be measured.

More precisely, the input is the measurement of wheel spindle forces on existing vehicles applied to the multibody simulation model of the future vehicle. The model calculates spindle displacements for the new vehicle, from which loads on components and subsystems needed for durability CAE analyses are derived. One of the main benefits of this solution is that the model does not need to include advanced models for tires, the driver and the digital road as the loads are coming from real measurements done on predecessor vehicles.

Simcenter 3D Motion-TWR from Siemens is a unique, integrated application that captures the entire road load prediction process.

This application is not limited to full vehicles. Data from sensors used in test track measurements, including wheel force transducers, accelerations, strain gauges and displacements, are accepted. The loads on subsystems and components needed for durability CAE analyses can be back calculated from this type of data as well.

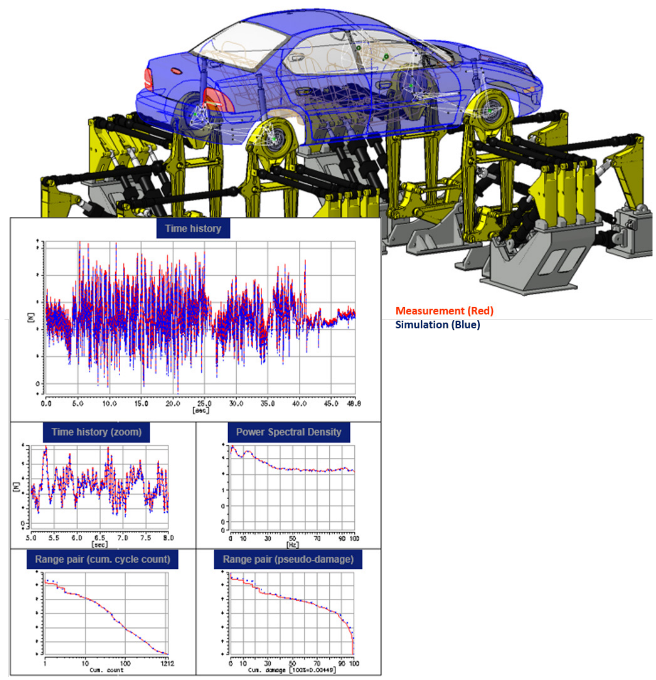

Figure 4: Hybrid test-CAE approach.

Digital road approach

The digital road approach is the method of choice when test data is unavailable. The road profile is measured and applied to the CAE model as a virtual road. The driving maneuvers are applied to the virtual vehicle, rolling on the virtual road.

While the hybrid approach needs measurements on a similar vehicle, the digital road approach needs some investments in the road measurements, an accurate tire model, a driver model and a good knowledge of driving maneuvers.

Definition of complex load events in the durability analysis

Simcenter 3D Specialist Durability handles a variety of complex time-based and frequency-based load events (figure 6).

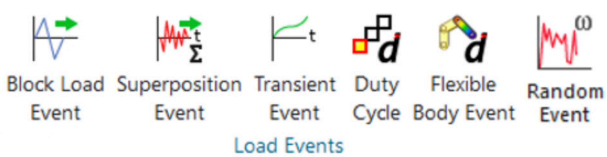

Figure 6: Load events in Simcenter 3D Specialist Durability.

Load events can directly use Simcenter 3D Motion results coming from the load data prediction phase described above. Stress results from Simcenter 3D Motion flexible bodies can be analyzed for durability performance with the flexible body events. Hundreds of measured or simulated load histories can be combined using superposition events, and duty cycles allow the designer to create an ordered list of events, including repetition factors.

In some cases, durability engineers need to work on a more reduced scope, for example, if the full vehicle multibody model, or testing data and digital road data, do not exist yet. Applied loads must still be sufficiently realistic to make the durability results valuable. Applying random events is a way to account for road load data when it is not available from tests or digital road analyses. These events are best represented in frequency domain, with power spectral density (PSD) functions.

Of course, basic load events like simple block loads or transient events are also available. Transient events can be defined directly by importing the transient load history data or by writing it.

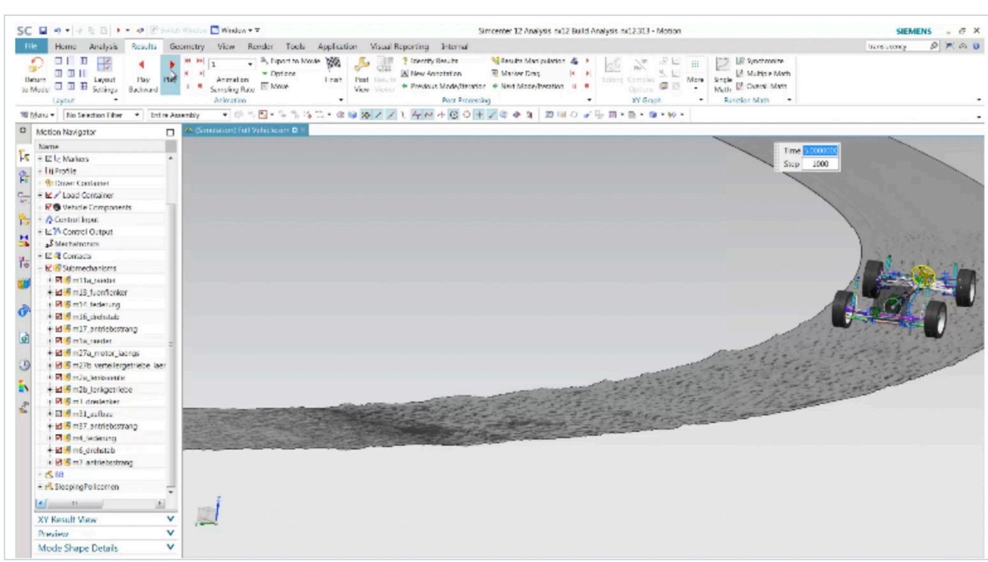

Figure 5: Digital road approach.

Finally, load events can be run backwards to consider loading but also unloading.

An important advantage of Simcenter 3D Specialist Durability is that the user interface efficiently processes the load event data, leaving the solver to handle the resource-intensive mesh processing.

Efficient and accurate durability simulations

Manage fatigue parameters and methods

The next step in the 3D CAE durability process is defining fatigue parameters and methods to be used in the CAE analyses. This is typically a challenge because the parameters (materials, loads, formulations, etc.) are numerous, complicated to select for non-experts, and because they depend on the general fatigue method, which also needs to be selected among numerous available options.

A major innovation in Simcenter 3D Specialist Durability to streamline the end-to-end CAE process is the management of durability-specific parameters and methods.

- The configurable setup of Simcenter 3D Specialist Durability leaves the full flexibility to the specialist to select methods among existing ones or create their own ones, and then define corresponding parameters.
- The CAE specialist can also configure default setups for the complete CAE community. The full configuration (method and parameters) will be automatically configured and the final users will only need to do a single selection, which is faster and more robust.

Moreover, any combination of materials, methods and parameters can be used in one single analysis, using local definitions in the model.

Efficient durability solver for components fatigue prediction and optimization

Access to an accurate and efficient durability solver is necessary to reduce fatigue analysis time and therefore explore multiple design options and optimize the design for fatigue performance.

Simcenter 3D Specialist Durability includes an industry standard fatigue-life solver with proven accuracy and speed. It may be run in sequential or parallel mode on the computer on which the model is prepared or independently in batch mode. It provides all standard durability methodologies but may easily be extended with any fatigue methodology due to unique openness via user-defined fatigue methods.

By combining component loads obtained with the methods described above, finite element (FE)-based stress results and cyclic fatigue material parameters, Simcenter 3D Specialist Durability allows engineers to predict fatigue hotspots and corresponding fatigue life and optimize the component design for fatigue performance.

Component fatigue analyses include the assessment of low-cycle fatigue, high-cycle fatigue and infinite life, stress gradient correction and below-surface fatigue. With dedicated postprocessing functionalities, engineers can quickly identify and solve fatigue life problems and experiment with multiple design options. The strong CAD integration of Simcenter 3D allows straightforward parametric studies, and Simcenter 3D Design Space exploration (powered by HEEDS™ software, part of the Simcenter portfolio) will help the durability engineer discover better component designs, faster.

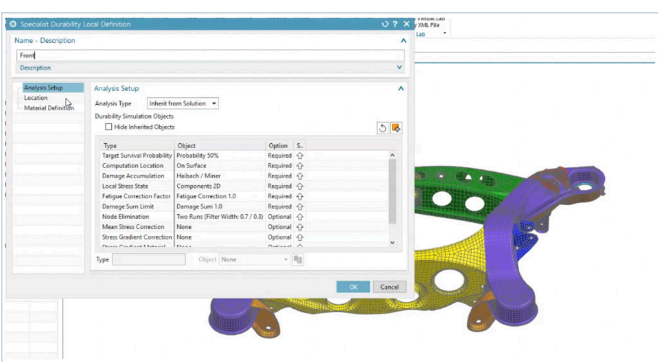

Figure 7: Durability analysis setup and material definition applied locally on the model.

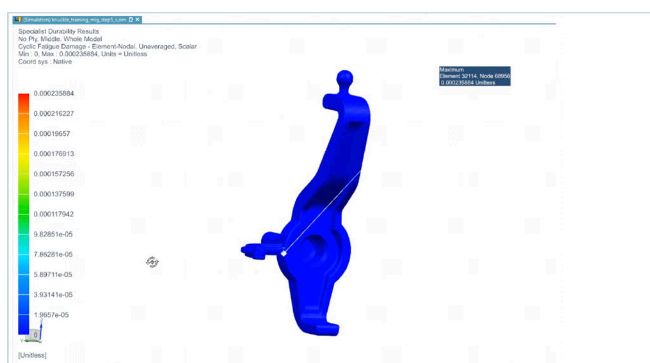

Figure 8: Maximum fatigue damage detection.

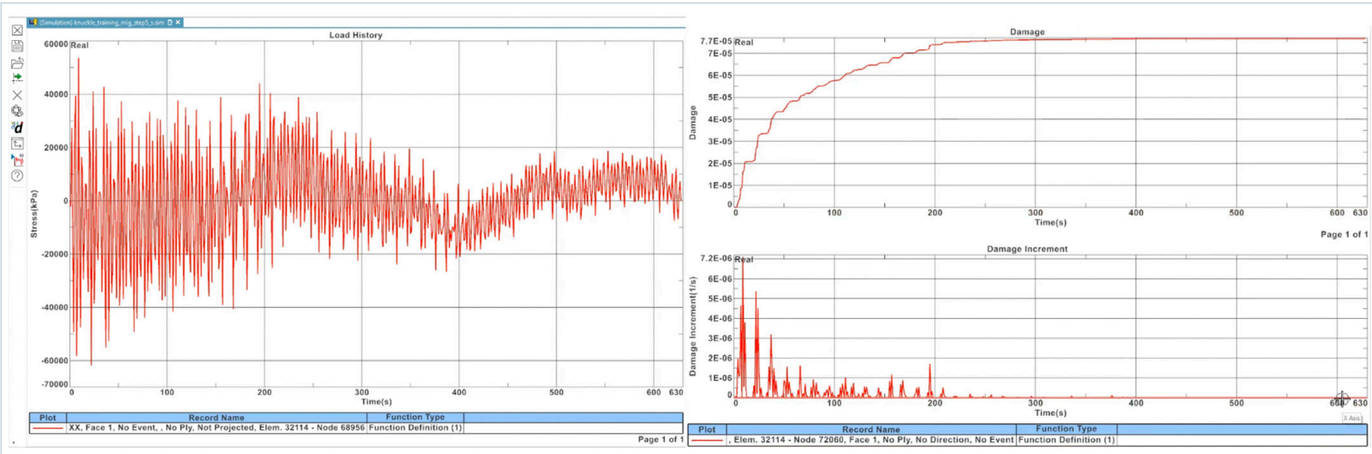

Figure 9: Transient results at hotspot location: stress, fatigue damage and fatigue damage incremental evolution.

In the example above, the fatigue critical area, corresponding to the maximum cyclic fatigue damage, is identified (figure 8) and the transient results at this location are automatically postprocessed (figure 9).

The CAD component can be fully parametric, and any of these results may be used as an input of an optimization process to iterate on the design and discover lighter and more durable designs.

Ensure reliable connections

Welds are often the first connections where durability failure occurs. Estimating the fatigue life of welds is imperative in the vehicle development process. However, this also comes with significant challenges.

By definition, a large load level passes through the welds. The main challenge is their complex and very variable geometry, and the huge effect of this geometry on the load distribution and therefore on the durability performance. A typical vehicle contains thousands of spot welds and seam welds with different geometries and different fatigue behavior. The durability solution needs to efficiently detect and define these thousands of welds in the model and then automatically assign the correct durability properties (geometry, material, fatigue methods) before running the durability analyses.

On top of weld geometry, a lot of factors coming from the manufacturing process influence the welds' durability performance:

- The base material (porosity, composition)
- The chemistry of the base material (carbon, manganese, hydrogen)
- The geometry of the connected components (surface finishing, alignment, warpage)
- The temperature during manufacturing process (weld, preheat, cooling)
- The uniformity of the zone affected by heat

Computing the stress in the welds leads to costly analyses, while traditional methods with an approximate stress evaluation around the welds followed by correlation with existing tests are too conservative. Simcenter 3D Specialist Durability combines solution accuracy and efficiency; the proposed compromise is to automatically detect welds and combine the accuracy of the notch stress approach with the usability of traditional nominal or structural stress methods.

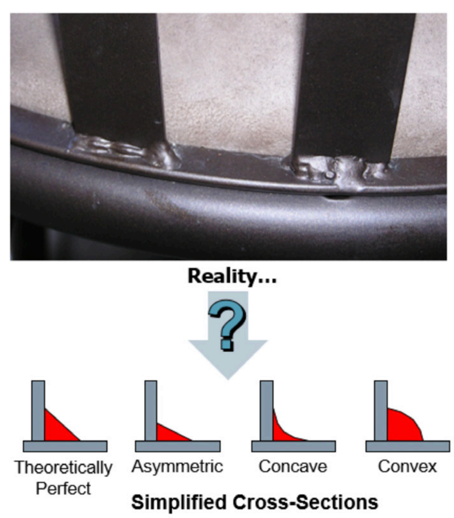

Figure 10: Complexity of weld geometry.

Welds are automatically taken from connections modeled in Simcenter 3D, defined either in an extended Master Connection File (xMCF), an open standard on the automotive industry with Siemens' active participation, or detected in existing meshes. They are grouped based on joint types, penetration grade and sheet thickness. Then, forces and moments applied to each weld are transferred into the surrogate FE result corresponding to its group. The surrogate model contains stress results for unit loads, so the applied loads are transformed into stress results with a linear transformation. Finally, durability results are deducted from stress.

Seam welds are the most challenging types of welds as they contain meters of complex, local weld geometries that cannot be generated directly in FE models of an industrial structure: this is an impractical, manual process and results in too heavy models.

Many different weld modeling methods are supported (shell-shell, shell-solid, solid-solid with simplified geometry). The strong connection with CAD, CAE and computer-aided manufacturing (CAM) data is handled through the xMCF file. All certified calculation methods (nominal stress, notch stress, effective stress) are supported.

Lighter and more durable vehicles with new materials and manufacturing process

Original equipment manufacturers (OEM) strive for more durable vehicles, but this should not have to result in a heavier vehicle. Designing lighter vehicles helps reduce CO_2 emissions of traditional vehicles, increases the range of electric vehicles and improves sports car performance. As a result, intensive research is dedicated to developing and using new materials and new manufacturing processes. Innovative fatigue simulation methods must be in place to virtually predict and optimize the impact of new materials in the vehicle durability design.

To account for the influence of the manufacturing process, the typical and conservative approach is to use fatigue data for the base material and introduce a large safety factor to include all uncertainties from manufacturing. The methodologies to further investigate the influence of manufacturing are especially important for new materials like composites and additive manufactured parts, where each manufacturing process defines a new material; traditional methods become impossible to apply.

Let's analyze some influence factors and methods needed for new materials in a little more detail.

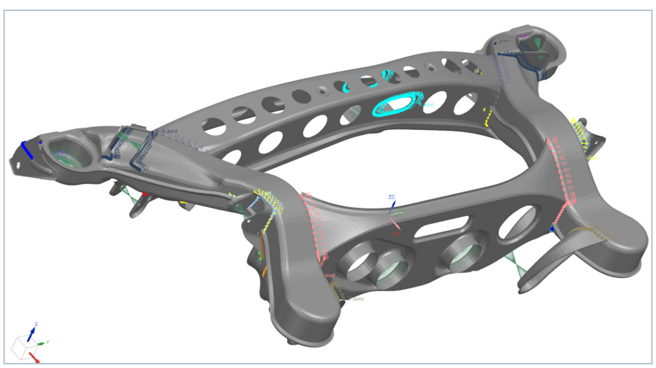

Figure 11: Seam welds definition.

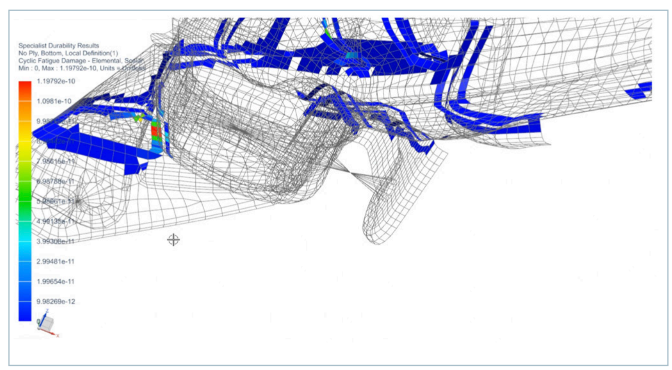

Figure 12: Cyclic fatigue damage of seam welds.

Composite materials

Due to their lack of accuracy, typical durability methods for composites lead to overdesign, removing the advantage of lightweight material usage. Siemens participated in several research projects to implement and validate new fatigue methods.

Damage mechanisms occurring in fiber-reinforced parts are much more complex than in parts with more traditional materials. If metallic parts tend to have a limited fatigue life, composites typically behave much better. However, before fatigue failure, some local stiffness reduction may occur, which can have some macroscopic influence on the mechanical behavior of a component and then on the vehicle's macroscopic performance. A punctual event like a low-energy impact or a misuse can also lead to a deterioration of the composite material and act as a predamage in durability analyses.

Simcenter 3D Specialist Durability provides unique methodologies for analyzing short and continuous-fiber composites. It can incorporate stiffness reduction and stress redistribution during the fatigue life of composites under complex load situations. Furthermore, new technologies reduce the effort it takes to test for material characterization.

Of course, the solutions proposed for short-fiber composites are different from the ones proposed for continuous fibers.

For short-fiber reinforced components, typically used for non-structural parts, the production process defines the orientation of the fibers in the structure, which significantly influences its strength and durability. So the fatigue material parameters must be local: a master S-N curve approach is used [3,4].

For continuous fibers reinforced components, typically used for structural parts, different material phenomena occur in different material directions (in ply longitudinal, transverse, shear, and out-of-plane directions) and will have a different influence on material local stiffness. Ply-level degradation laws are applied in different directions to account for these local phenomena [5.6]. Damage laws to estimate delamination due to fatigue loads are also available [7]. These laws include methods to assess in the same analysis both static damage phenomena (misuse, low-energy impact, pothole, sidewalk) and fatigue damage (coming from usual vehicle usage, in particular road load).

These innovative laws have been validated in an industrial context along extended research programs that include industrial knowledge and test procedures to characterize material data. This is strengthened by the current integration of engineering solutions for new materials in Simcenter 3D[8] powered by Simcenter Multimech, enabling true multiscale simulation and as a result integrating advanced material engineering knowledge in the composites structural simulation process.

Another challenge to the development process for continuous fiber composites is the how to prepare and postprocess the FE model. Simcenter 3D Laminate Composites is a specific product module dedicated to the pre and postprocessing of laminate composite structures. Easy-to-use ply and laminate definition tools enable analysts to quickly create FE models representing a design composed of laminate composite materials. With this product module, engineers can optimize and validate composite structures and generate graphical and spreadsheet ply results from shell stress resultants and envelopes ply stresses, strains and failure metrics on elements and over multiple loads cases.

Figure 13: Short-fibers composites.

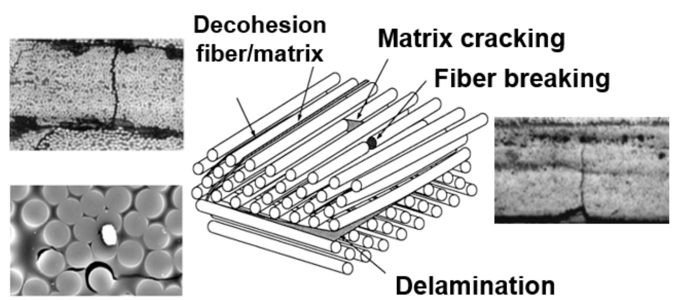

Figure 14: Continuous fibers composites: progressive failure phenomena.

Additive manufacturing

Additive manufacturing is an opportunity to design shapes that would have never been possible before. New challenges are coming related to the performance prediction of these parts.

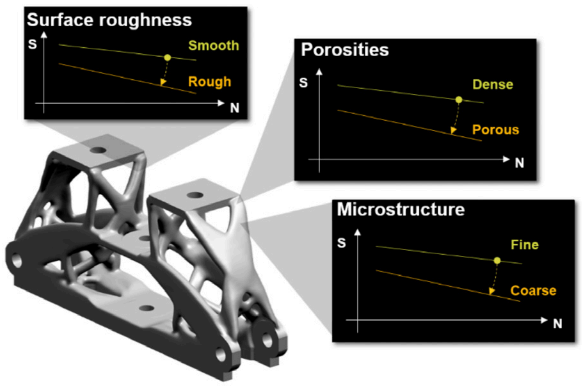

Figure 15: Variability of S-N curves across an additive manufacturing component geometry.

The main challenge in the fatigue analyses of parts built by additive manufacturing is that the S-N curves vary across a geometry. Due to this manufacturing process, different surface roughness, different levels of porosities and different refinements of the microstructures appear at different locations. These factors have a strong influence on the S-N curves. A rough surface will result in a short fatigue life. This is also true for a structure with a lot of porosities, or for coarse microstructures.

The issue is that these factors are very hard to control. They highly depend on the geometry, so they are very variable on one single component. It is impossible to physically test all possible parameter combinations.

That's why the baseline of the Simcenter 3D Specialist Durability solution is machine learning [9, 10]. A large database of S-N curves with different combinations of influencing factors is used as a starting point; it can be completed with customer data. From this database, the level of surface roughness, porosities and microstructures on every mesh of the geometry can be predicted, resulting in a lifetime estimation on the full component. Critical areas are easily visualized, and design iterations can be operated.

Determine the reason for fatigue failure

Obtaining accurate results is extremely important to learn from a simulation. Understanding not only if and where there is a problem, but also why and when helps improve the structures. Useful CAE results in early stages of the vehicle development process also help optimize the definition of the tests program when the prototype will be produced. This eliminates the need to perform long and expensive tests to assess scenarios that will have been predicted as safe.

On top of efficiently finding the critical regions (figure 8), Simcenter 3D Specialist Durability supports the user in analyzing which loads are having an influence on the critical regions (figure 16). This may be used for optimizing the component design by improving the load flow from the load application points that have the highest influence to the critical areas, which is a much better solution than just reinforcing the critical area with additional material. Another possibility is to define more efficient and simple tests for the component; for example, testing samples out of production.

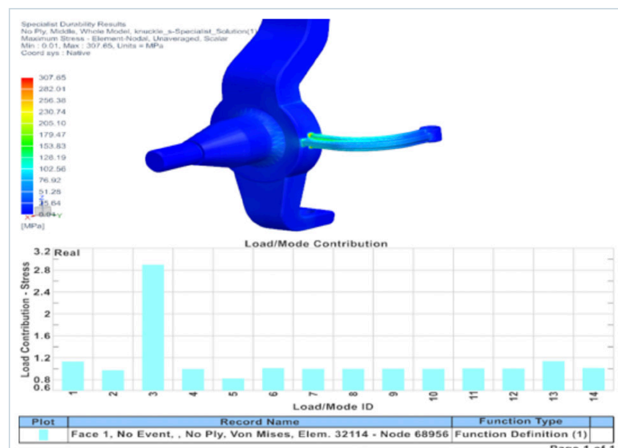

Figure 16: Load and mode contribution.

Specialized postprocessing scenarios are also proposed. A CAE analyst can access an intelligent failure-driven and event-based filtering for a better understanding of their results. Filtering on events, materials, groups, durability parameters, formulations, composites layers, etc., enables the possibility to get the right result that makes sense for the design optimization.

Finally, this easy access to specific results, together with the strong design space exploration capabilities provided by Simcenter 3D Design Space Exploration (powered by HEEDS), increases the efficiency of multi-attribute balancing and the opportunity to find the best possible design, faster.

Conclusion

The comprehensive digital twin concept proposed by Simcenter 3D enables a highly accurate and efficient end-to-end 3D CAE durability process in an integrated environment.

It all starts with getting access to road load data and predicting loads at components levels thanks to a hybrid approach that combines intelligent test data processing and a direct link with multibody simulation. Another option is to directly run multibody simulation from a digital road, virtual driver and accurate tire models.

The durability CAE model is efficiently created thanks to a fully integrated and managed environment that keeps simulation models in sync with the latest design revision. Durability engineers can then select the analysis parameters they prefer, either among a very extensive library available in the standard product, or by easily implementing their own methods. They can also create templates to make durability analyses more accessible to a wider community that may include CAE generalists or design engineers.

An efficient, industry-proven durability solver is integrated in the solution, including best-in-class solutions for component fatigue and connections fatigue. A range of advanced methodologies validated in the context of research and technology development (RTD) projects with leading academia and industrial end-users delivers innovative solutions in terms of materials engineering.

Finally, postprocessing allows you to identify critical areas, load events and situations to improve the vehicle (component) structure in terms of durability performance while reducing the cost of tests.

With Simcenter 3D Specialist Durability, the durability targets can be efficiently balanced with other attributes, like vehicle weight, noise, vibration and harshness (NVH), comfort, stiffness and safety, all before the first vehicle prototype has been created.

Case studies

Solutions presented in this white paper can be even better described by Siemens customers themselves.

Learn how Fiat uses Simcenter 3D and Simcenter Tecware[11] to verify and validate durability virtually:

https://www.plm.automation.siemens.com/global/en/our-story/customers/fiat/69071/

Learn how China FAW Co., Ltd. R&D Center significantly cuts vehicle development time and costs using Simcenter solutions and services for durability engineering:

https://www.plm.automation.siemens.com/global/en/our-story/customers/china-faw/16790/

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About Siemens Digital Industries Software

Siemens Digital Industries Software is driving transformation to enable a digital enterprise where engineering, manufacturing and electronics design meet tomorrow. The Xcelerator portfolio helps companies of all sizes create and leverage digital twins that provide organizations with new insights, opportunities and levels of automation to drive innovation. For more information on Siemens Digital Industries Software products and services, visit siemens.com/software or follow us on LinkedIn, Twitter, Facebook and Instagram. Siemens Digital Industries Software – Where today meets tomorrow.

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