DARWIN® 9.0 Release Notes

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Southwest Research Institute®

Summary of New Capabilities

DARWIN 9.0 includes the following new features:

- Optimal Gaussian Process Pre-zoning
- 3D Sector Models
- SIF Solution for Angled Corner Cracks
- Formation Life Scaling
- Anomaly Distribution Tracking
- Micromechanical Initiation
- Enhancements for Large Finite Element Models

Optimal Gaussian Process Pre-zoning

DARWIN 8.2 expanded the exhaustive and optimal autozoning capabilities that were previously available for 2D axisymmetric geometries to 3D geometries with inherent anomalies. These techniques automatically build DARWIN zones (i.e., set material volume and locate cracks) based on user-defined property regions such as anomaly distributions, material parameters, and other factors. Autozoning leads to consistent results between users and reduces user intervention needed to define zones. For example, risk limiting locations defined by experienced and inexperienced users may differ drastically, leading to drastically differing risk values. Autozoning eliminates this issue by determining the expected risk limiting location without human intervention. However, the computational cost of autozoning increases dramatically for increasingly complex finite element models.

DARWIN 9.0 introduces a new optimal Gaussian Process (GP) pre-zoning capability to create DARWIN zones automatically and efficiently. Pre-zones are elements grouped by stress range, distance-to-surface, and temperature that have similar risk values. DARWIN 9.0 samples points within these pre-zones to build an approximate risk surface on local pre-zone domains using a response surface defined by training points. An iterative scheme determines the approximate risk limiting location within each pre-zone. DARWIN then employs the previously developed optimal autozoning methodology to determine the optimal zone break-up of the model. Pre-zones, instead of individual elements, define the minimum sizes for zones. For large models where the number of pre-zones is significantly smaller than the number of finite elements, the optimal pre-zoning capability can significantly reduce the computation time associated with risk assessment. Initial studies indicate that the new pre-zoning algorithm is up to three orders of magnitude faster than the previous optimal autozoning algorithm. The new pre-zoning algorithm is up to five orders of magnitude faster than the previous exhaustive algorithm. Furthermore, the pre-zoning method requires less memory than either the exhaustive or optimal methods. This feature enables the pre-zoning method to solve much larger models than either previous method. Note that the performance of the new algorithm may vary among different FE models.

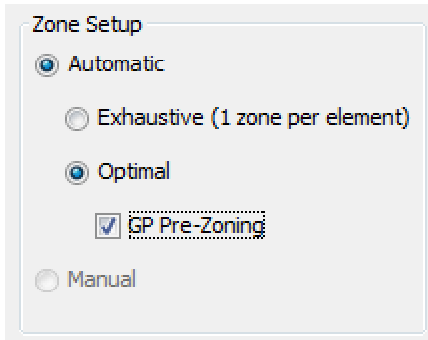


Figure 1: DARWIN features a new optimal Gaussian Process (GP) pre-zoning capability that significantly reduces the computation time associated with risk assessment of large finite element models.

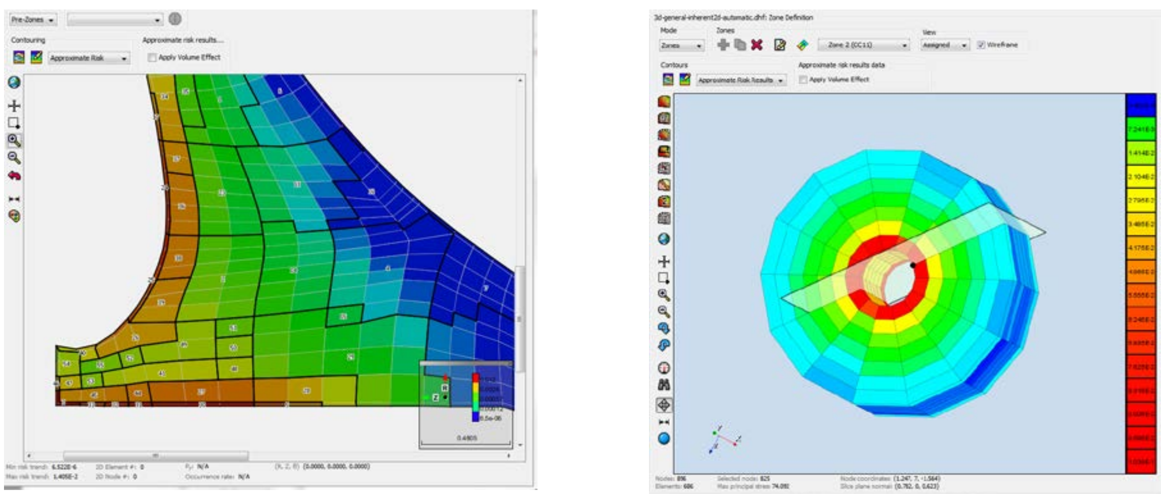


Figure 2: The new GP pre-zoning capability provides a display of the approximate risk surfaces associated with pre-zones in both 2D and 3D finite element geometries.

As shown in Figure 1, GP pre-zoning is an optional analysis type for optimal autozoning. Similar to previous autozoning implementations, users first define property regions via the GUI and then execute the analysis. Results from optimal pre-zoning include life predictions and accurate risk values at the zone level. DARWIN 9.0 supports new graphical features to display pre-zones, estimated risk surfaces from pre-zones, and uncertainty levels of the approximate risk surfaces. These tools are available for both 2D and 3D geometries (Figure 2).

3D Sector Models

Rotating engine components often have 3D geometric features that repeat cyclically around an axis. For example, a rotor might have eight “sectors” where the geometry remains identical between any two rays originating from the axis of rotation if these rays are separated by 45 degrees. Previously, DARWIN only supported full 3D models or axisymmetric geometries where the cross section was constant about the axis of rotation.

DARWIN 9.0 includes a new capability that enables users to import 3D sector models directly into DARWIN and to assess the life and fracture risk based on the complete component geometry (Figure 3). The finite element results file translator FE2NEU was enhanced to provide information regarding the number of sectors and the axis of rotation. When the sector model option is selected, DARWIN displays the original sector model and external boundaries based on cyclically repeating sectors (shown in Figure 4). For life and risk assessments, cracks and associated fracture plates are based on the full model geometry. For example, a crack location on a sector boundary would be treated correctly as an embedded crack rather than a surface crack. This capability is available for both manually and automatically zoned models.

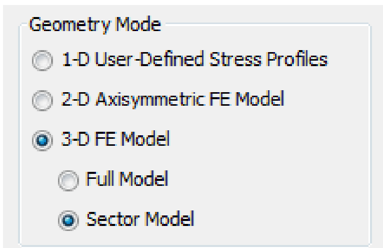


Figure 3: DARWIN 9.0 provides support for 3D sector models.

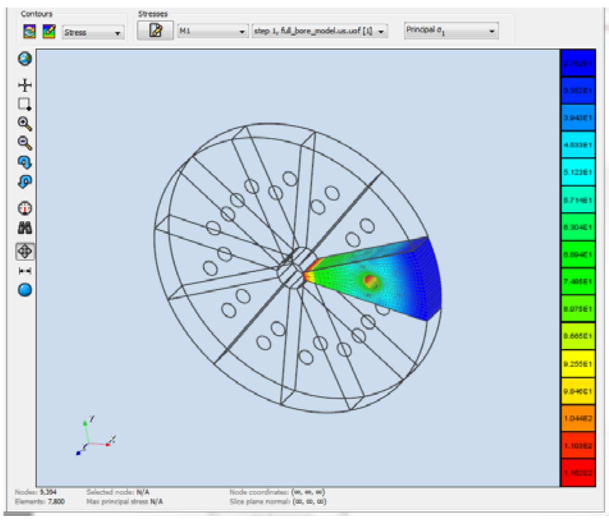


Figure 4: When the sector model option is selected, DARWIN displays the original sector model (colored portion) and external boundaries (solid lines) based on cyclically repeating sectors.

SIF Solution for Angled Corner Cracks

DARWIN 9.0 features a new stress intensity factor solution (CC18) for a quarter-elliptical surface crack centered on an angled corner. In a previous solution (CC12), DARWIN required cracks at chamfers to span the enter chamfer edge. Large chamfers required large cracks as a result. The new solution (CC18) is designated for cracks that originate at a clipped end of a 45˚ chamfered corner. CC18 is a bivariant SIF solution that supports stress gradients that vary strongly in more than one direction. The CC18 SIF solution is available for life assessment analyses using 2D axisymmetric models that are manually zoned.

The DARWIN GUI has been enhanced to support the new crack type. During zone definition, users can select the new crack type (CC18) as shown in Figure 5. For circular crack fronts (*i.e.,* $a = c$), the crack is placed at the chamfer corner, and the GUI automatically positions the crack tips. Non-circular crack fronts (*i.e.,*$a < c$) require more information on the position of the crack front from the user. The GUI positions an arrow in the direction of the ellipse's major axis. The GUI includes a button that enables users to switch the chamfer leg where the long crack length is located. Similar to CC12, CC18 requires that the user input a chamfer dimension (as is already done for the previous chamfer solution, CC12). The chamfer dimension is indicated in the GUI screen as shown in Figure 6. Output from the RAC to the GUI is shown the crack state tab of the GUI as indicated by Figure 7.

Cracks defined using CC18 may transition to CC12 during the analysis. The transition occurs if the crack grows from one end of the chamfered corner to the opposite edge. A crack modeled with the CC18 SIF solution will transition to the CC12 SIF solution where the crack spans the entire length of the chamfered edge.

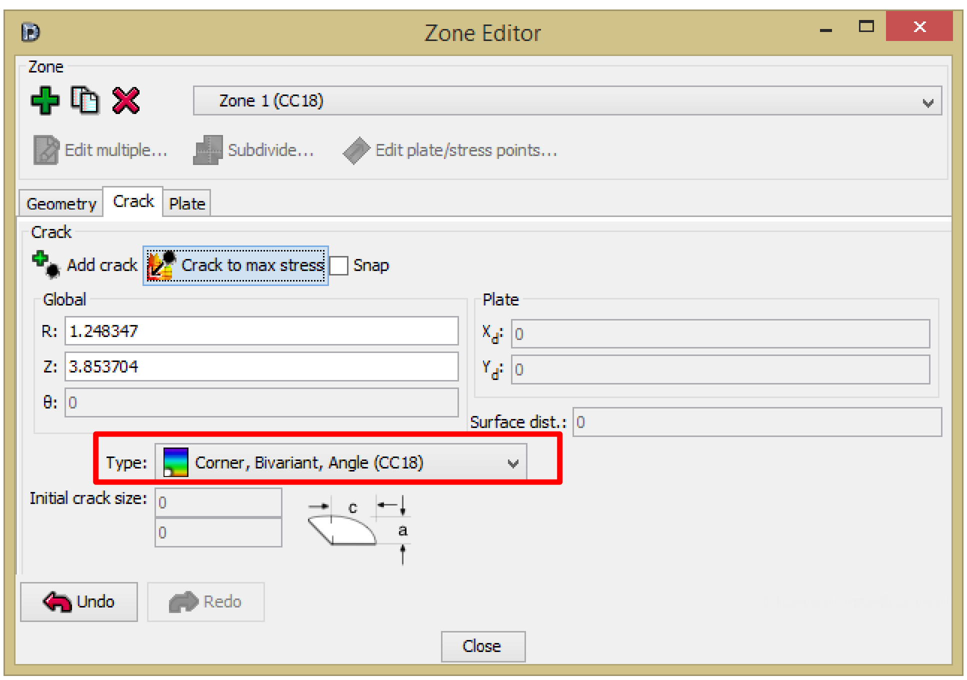


Figure 5: The zone editor has been enhanced to include the new angled-corner crack solution (CC18).

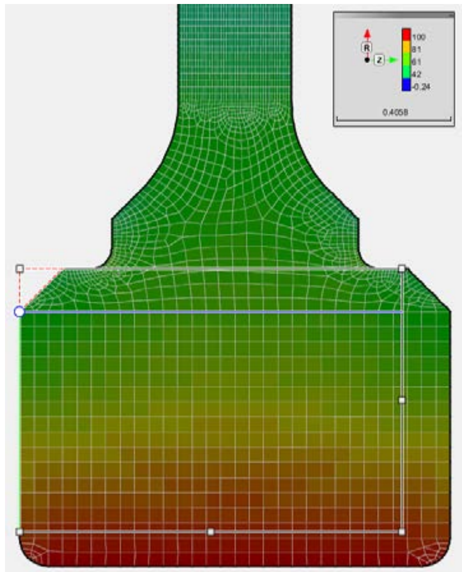


Figure 6: DARWIN 9.0 supports definitions of corner cracks at angled corners using enhanced visualization tools to place cracks, locate plates, and track chamfered corners.

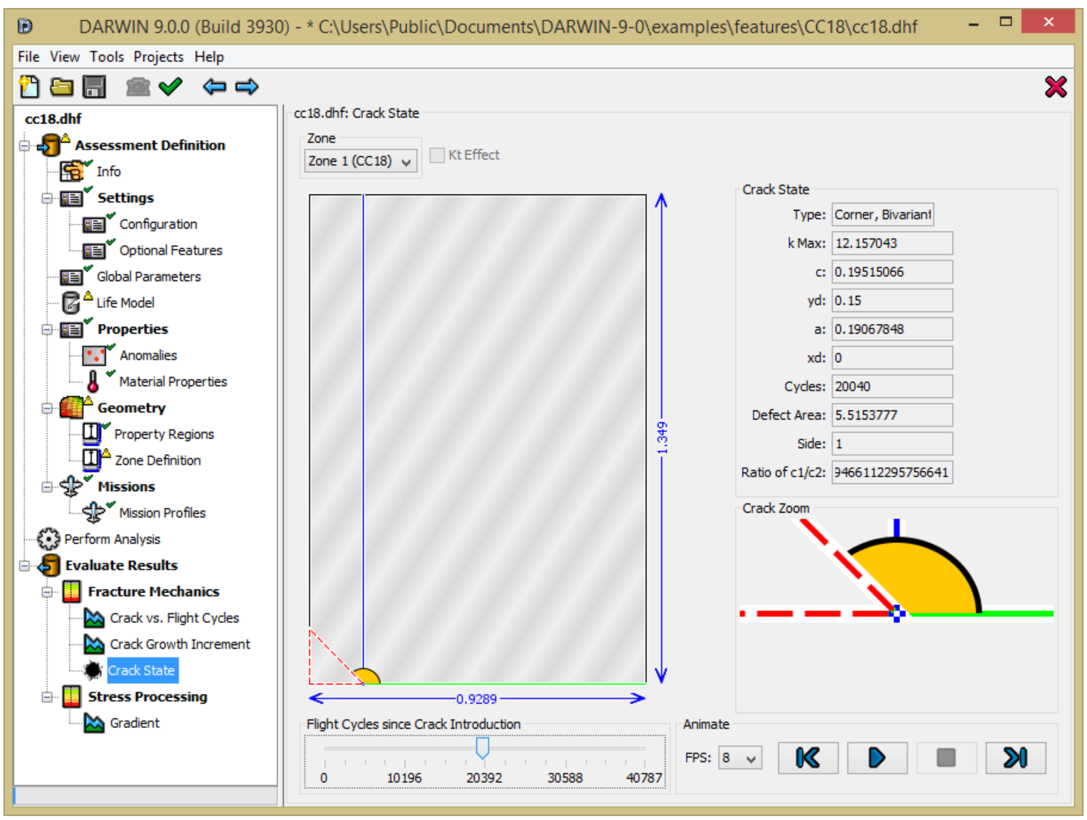


Figure 7: The updated crack state screen shows the elongated crack growing from a chamfer edge.

Formation Life Scaling

Local differences in the thermo-mechanical history of material during manufacturing processes (including forging, heat treatment, and machining) may lead to variable microstructural and material properties, even though the component has the same nominal material composition. If properly understood and managed, manufacturing-driven local variations in properties provide unique opportunities to optimize component integrity or reliability. Manufacturing process simulation software such as DEFORM™ can be used to predict location-specific variations in microstructure. Previous versions of DARWIN have provided a number of features to provide treatment for manufacturing processing effects, including a scaling module that scales fatigue crack growth rates based on location-specific average grain size values.

DARWIN 9.0 extends the scaling module to scale formation lives based on As-Large-As (ALA) grain size (unrecrystallized grain size) values from manufacturing process simulation software. DARWIN enables users to select multiple files with ALA grain size information, view ALA grain size contours associated with each file, and define random parameters associated with the manufacturing process input variables (Figure 8).

During probabilistic assessments, an ALA grain size response surface is created based on the ALA grain size files. Random variables associated with the manufacturing process variables are propagated through the response surface to obtain random ALA grain sizes. The crack formation lives are then scaled based on the random ALA grain sizes. DARWIN displays contour plots of the computed random ALA grain sizes and associated scaling factors (Figure 9) as probability distribution percentile values.

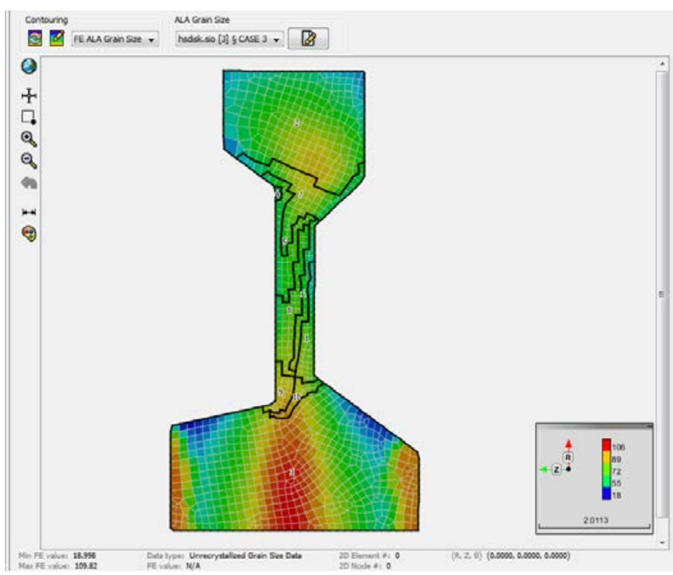
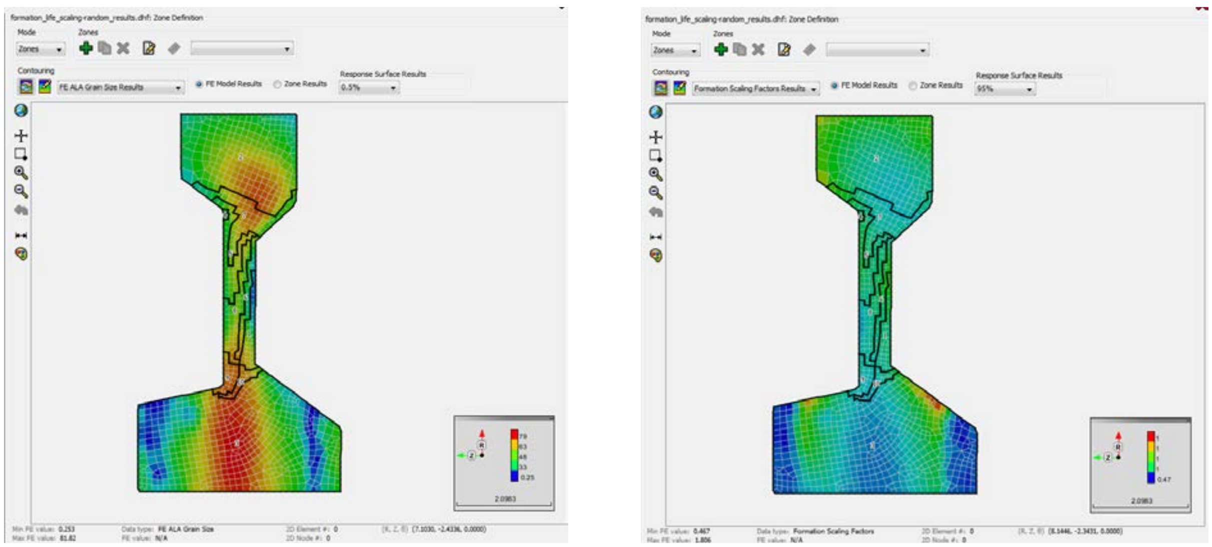


Figure 8: DARWIN 9.0 enables users to view ALA grain size contours associated with multiple finite element results from manufacturing process simulation software such as DEFORM.



(a) (b)

Figure 9: DARWIN 9.0 provides 2D contour plots of computed random (a) ALA grain sizes and (b) formation life scaling values at selected probability distribution percentiles.

Anomaly Distribution Tracking

Material forging processes may lead to different distributions of anomaly sizes in different regions of a component. Manufacturing process simulation software (e.g., DEFORM) has the capability to predict anomaly regions based on the process history.

DARWIN 9.0 features a new capability called anomaly distribution tracking (Figure 10) to assign anomaly distributions based on results from a manufacturing process simulation. When this feature is enabled, anomaly distributions can be assigned to the finite element model based on data from manufacturing processing simulation software. The DEFORM manufacturing process simulation software has the capability to track anomaly distributions throughout the material forming process Each node in the finite element model associated with the manufacturing process simulation is assigned a distribution identifier. DEFORM tracks the nodes and records the results in a material processing file (*.sio) that is readable by DARWIN. DARWIN maps the results to anomaly regions in the DARWIN geometry. Figure 11 shows the result of the mapping between the DEFORM results and geometry. Users set the appropriate anomaly distributions to the spatially-variant anomaly regions. The computational engine employs the assigned anomaly distributions to determine property regions used in life and risk calculations.

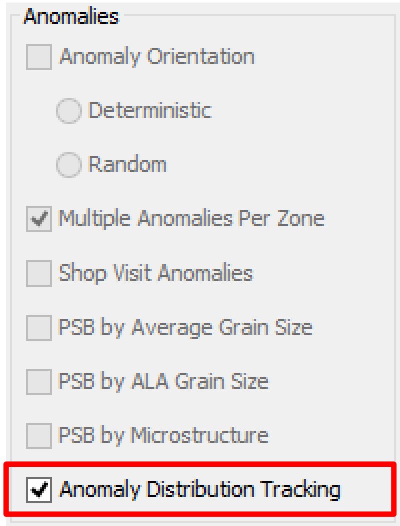


Figure 10: Enabling the anomaly distribution tracking optional feature

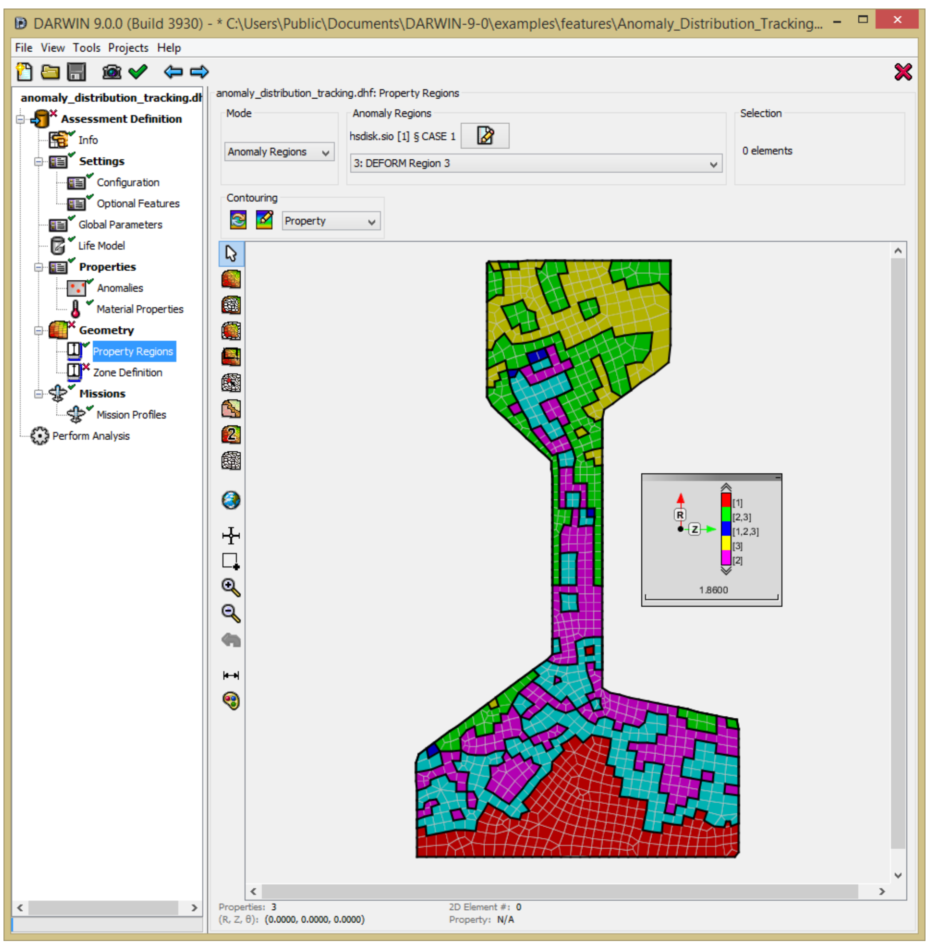


Figure 11: Enhanced GUI window displaying the button to import anomaly distribution identifier data. This example displays the anomaly distributions mapped from a manufacturing processing simulation.

Micromechanical Initiation

Repeated stress cycling of structural components composed of metallic alloys may trigger the formation of cracks along persistent slip bands, *i.e.,* slip systems that accumulate intensive cyclic plastic strain. Several factors determine the critical grain where formation occurs including the grain size, the critical slip system, slip systems of neighboring grains, the orientation and magnitude of the applied stress state, and bulk material properties. Low-angle grain boundaries may enable the critical grain to span multiple grains, further reducing formation life. DARWIN 9.0 includes a new capability to compute crack formation lives based on the microstructure and loading history.

The new persistent slip band feature in DARWIN 9.0 employs microstructural information that can be determined from manufacturing process simulation software such as DEFORM. In a small local region limited to a few hundred grains, DEFORM provides grain locations, dimensions of the major and minor axes for each grain, and the three Euler angles for each grain that denote crystallographic orientation. DEFORM also can provide average and ALA grain size values over the entire component. DARWIN computes formation lives at persistent slip bands using average sized grains, ALA sized grains, or multiple grains with similar slip systems within a local region. The user-accessible crack formation module has been enhanced to determine crack initiation life based on the persistent slip band mechanism.

Figure 12 shows the enhanced GUI Configuration preprocessing screen that displays the new "Persistent Slip Bands (PSB)" anomaly type. The PSB anomaly type is available for 2D axisymmetric finite element models using the life assessment analysis method and manual zoning. Figure 13 displays the optional methods to determine the persistent slip band using the average grain size, ALA grain size, and microstructure. Figure 14 presents the updated anomalies mixer that enables users to select the appropriate formation case. In Figure 14, the user has set three formation cases for persistent slip bands. When the full microstructure is available, DARWIN sets the crack location based on the microstructural location. DARWIN reports the formation lives on a zone-by-zone basis and shows the variation of lives computed using critical grains based on average grain size, ALA grain size, and multiple grains with similar slip systems.

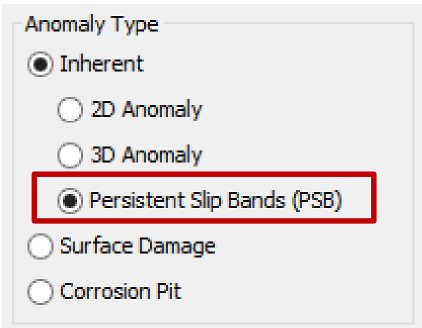


Figure 12: New "Persistent Slip Bands (PSB)" anomaly type available in the DARWIN configuration screen.

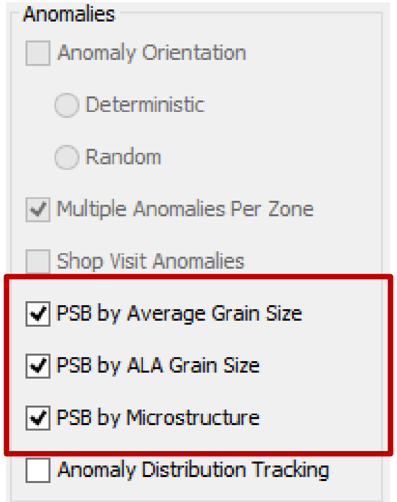


Figure 13: Microstructural information available to drive persistent slip bands.

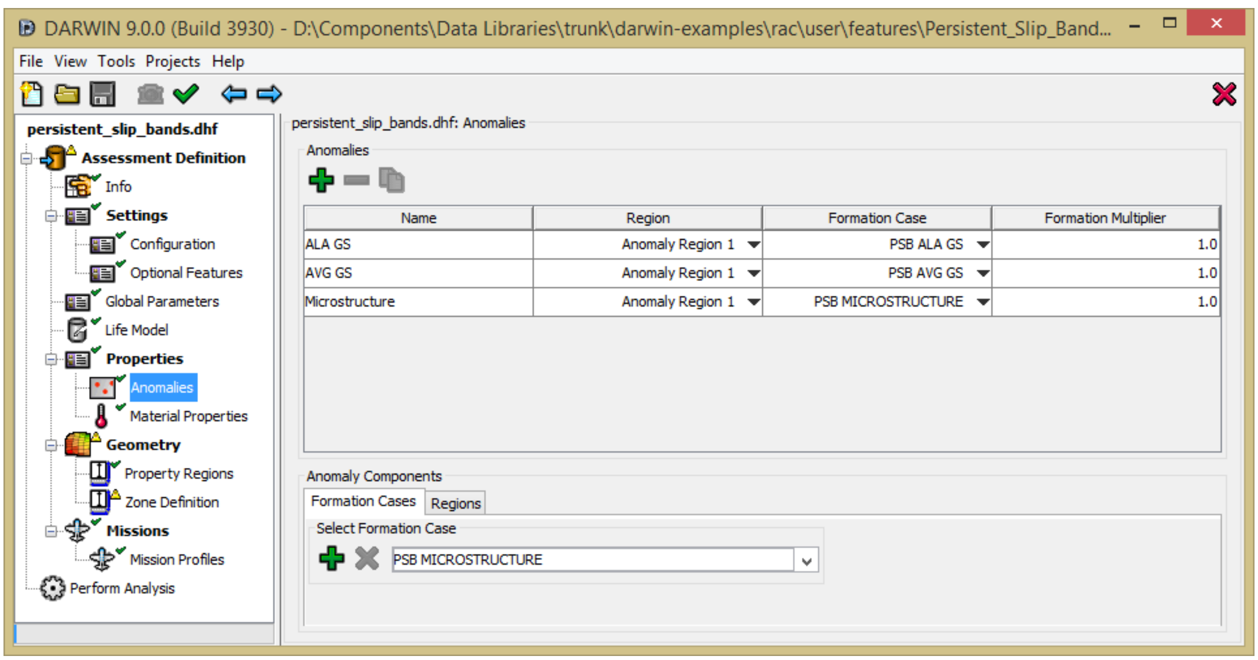


Figure 14: Available formation cases for persistent slip band methodologies that are available with the supplied user formation module.

Enhancements for Large Finite Element Models

Current versions of DARWIN store all of the data associated with imported finite element (FE) model results directly in memory. For large FE models, the memory required to store the FE model results can exceed the available system memory. SwRI is in the process of making extensive enhancements to DARWIN to accommodate large FE models. These enhancements will be provided in future releases of DARWIN. Version 9.0 provides new features to assist users who are performing risk analyses using large FE models. The GUI has been enhanced to enable users to disable the visualization of stress contours. This enhancement significantly improves the responsiveness of the GUI during mission definition. This optional feature may be enabled or disabled via the GUI preferences menu. The DARWIN computational engine has also been enhanced to warn users when the memory required to execute an analysis will exceed the available system memory.