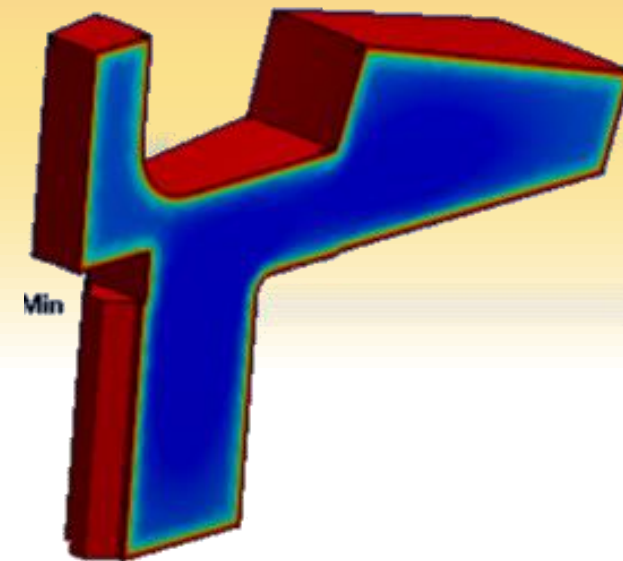
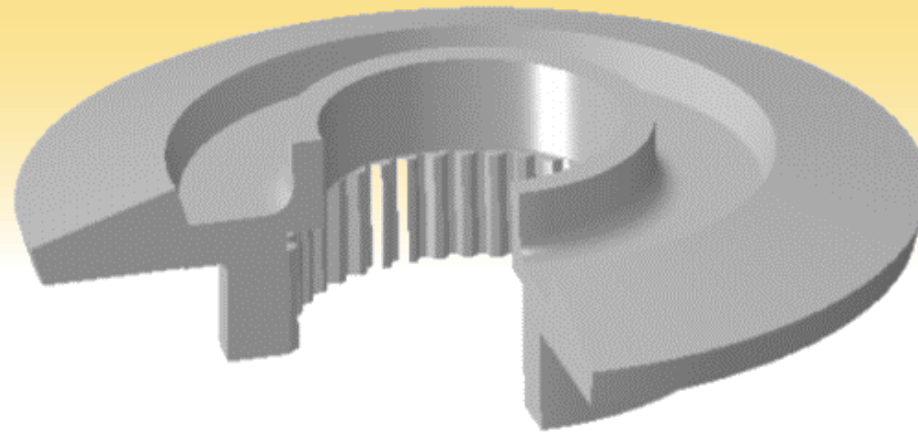
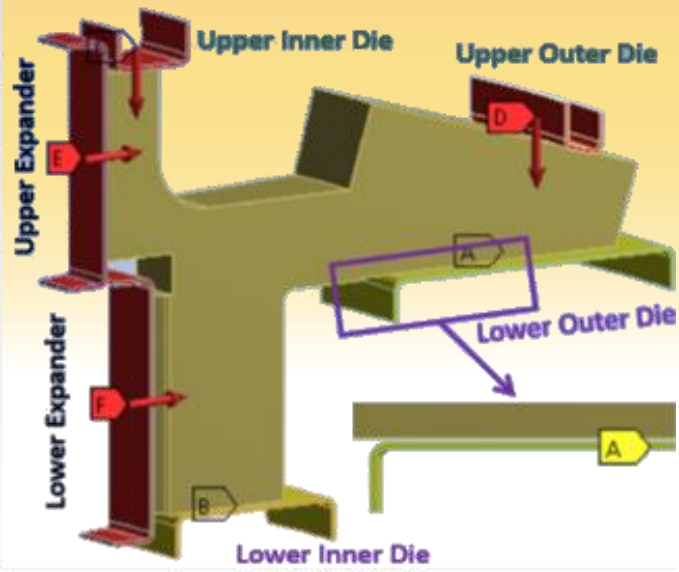




Distortion Minimization of a Press Quenched Bevel Gear

Using DANTE for Troubleshooting and Press Quench Process Design



A combination of carburization and quench hardening is often used to increase the strength and improve fatigue performance of steel parts. During quenching, stresses caused by the thermal gradient and phase transformations will generate plastic deformation, which will lead to distortion in hardened parts. Gear components with large distortion will increase gear noise and reduce fatigue life in service. Final machining of hardened gears often leads to nonuniform case depth distribution, so a maximum amount of distortion caused by hardening is often specified, and parts with distortion exceeding the specification will be scrapped. Press quenching is one effective way to reduce the distortion amount from a hardening process.

Quench hardening is a transient thermal stress process with phase transformations. The effect of various factors on distortion is nonlinear, and the distortion can only be measured after the process is done. Heat treatment results that are of common interest include the volume fractions of phases, hardness, residual stress, and part dimensional change. The thermal gradients during both heating and cooling work together with the phase transformations to continually change the internal stress and deformation of the part being heat treated. The material response of a specific part during the heat treatment process is difficult to document just using the final measurements. DANTE heat treatment simulation software makes it possible to understand the material response during the heat treatment process, including the evolution of internal stresses and the deformation, the phase transformation sequences, and the probability of cracking. Computer simulation has increased the level of understanding of heat treatment processes because the events that occur during heating and cooling can be accurately modeled.

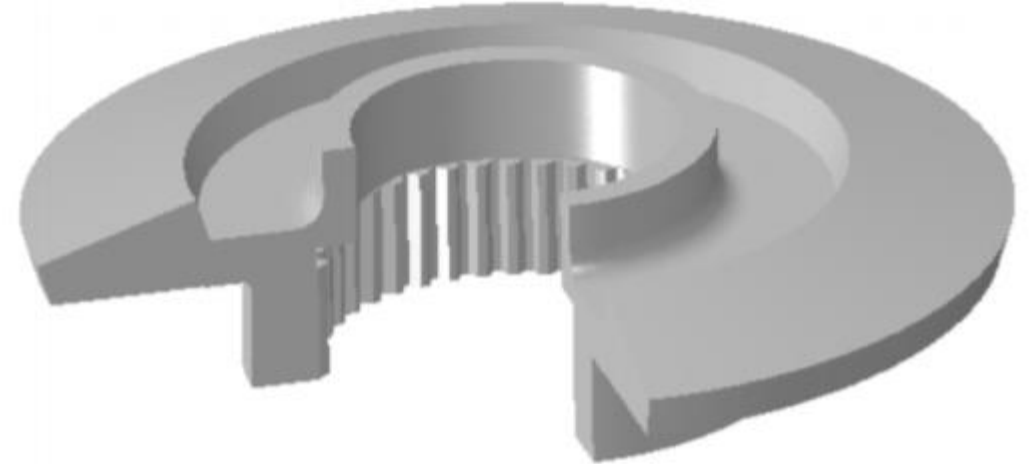
In this case study, DANTE is used to model the carburization and press quenching of a spiral bevel gear component. The modeling results are used to understand the causes of distortion, and further studies of the press quench models are used to improve the effectiveness of the press quench tooling design.

Model and Process Description

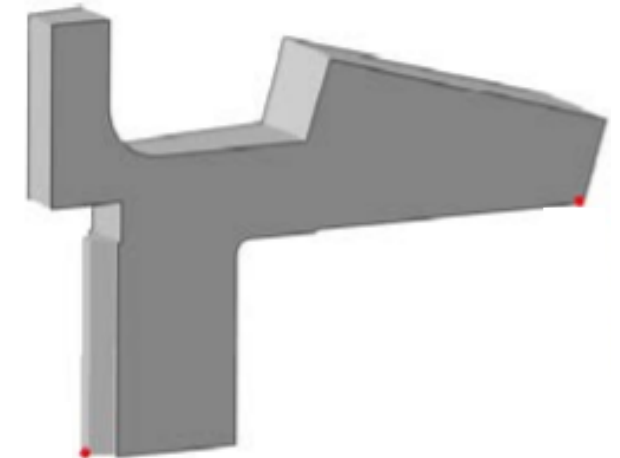
- Model Description:
- Bevel gear made of AISI 9310
- Outer diameter of approximately 420 mm and a bore diameter of approximately 140 mm
- Bevel teeth removed since bore distortion was main concern
 - Internal spline was modeled
- Single tooth sector was modeled
 - Assumes that cooling is uniform in the circumferential direction

Process Description:

- Part was carburized on all surfaces to a case depth of 1.3 mm
- Austenitized at 850° C for 3 hrs.
- Transferred to press quench unit and quenched for 10 min.
- Cooled to room temperature
- Tempering was not modeled for this study
 - Tempering usually has a negligible effect on distortion



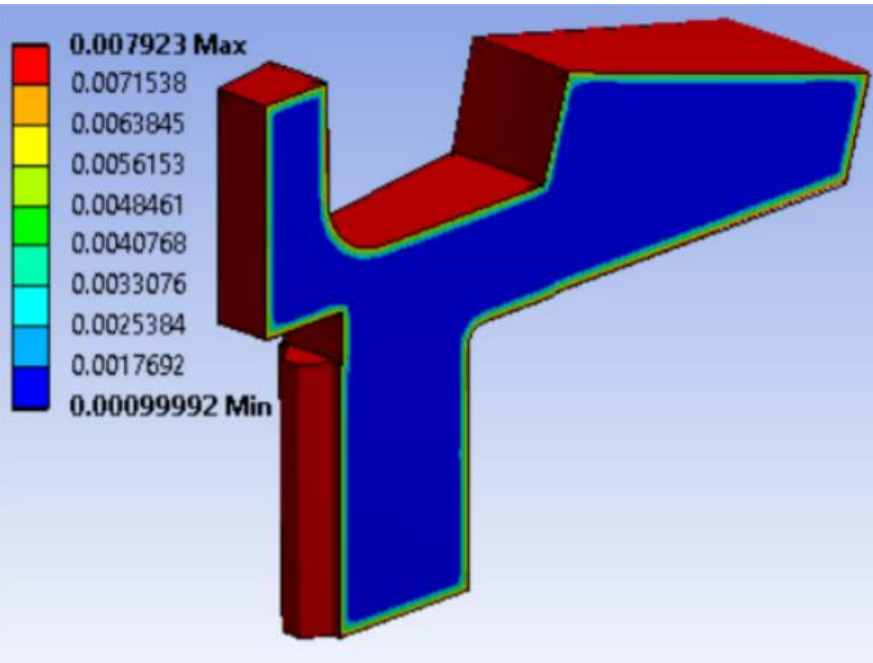
270° section of bevel gear with bevel teeth removed



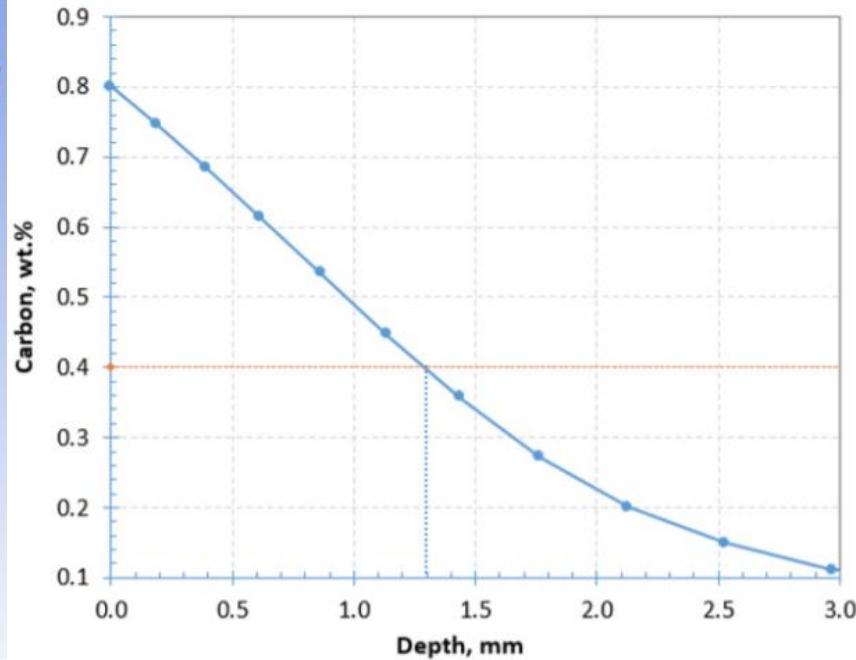
Single tooth model with bevel tooth removed

Carbon and Hardness Profiles

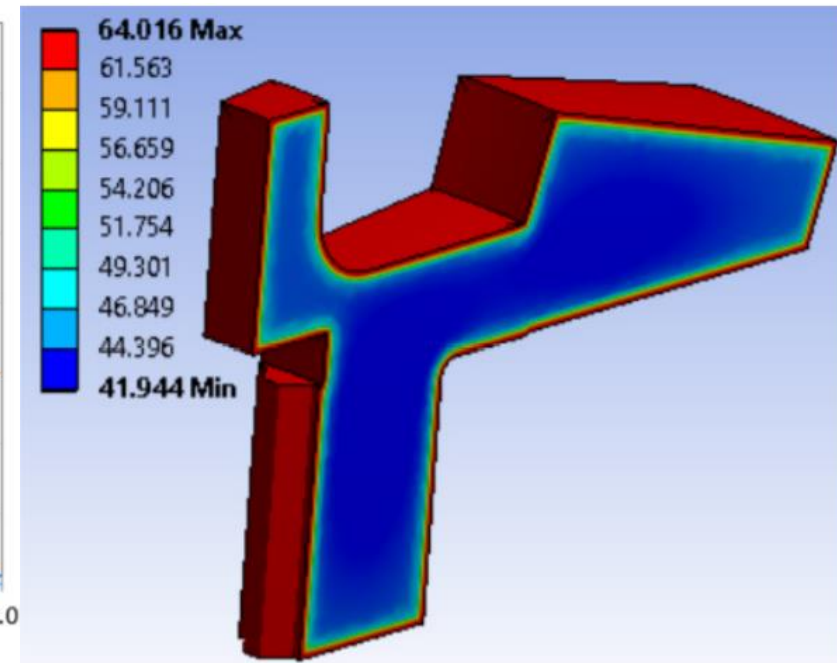
- All surfaces carburized
- Case depth is approximately 1.3 mm
- Hardness is directly after quenching, before tempering



Carbon Profile



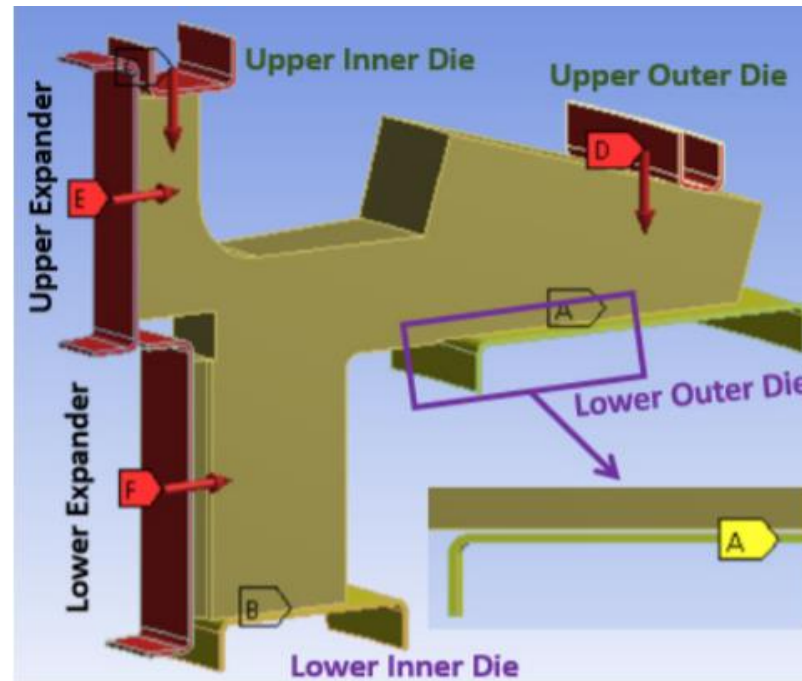
Carbon Profile as a function of Depth



Hardness Profile

Press Quench Tooling Setup

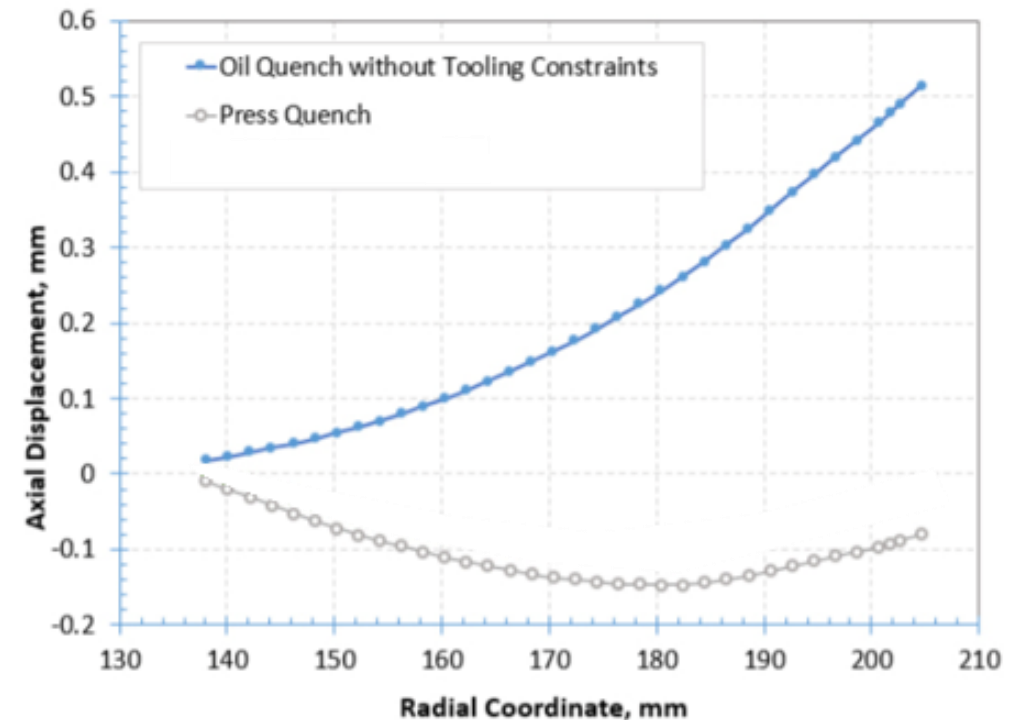
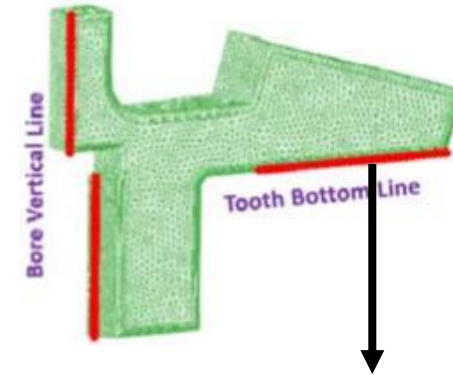
- Press quench tooling setup of the original process uses an expander with a load to control the bore dimension
- A load of 801 N was applied to the upper inner die
- A load of 1068 N was applied to the upper outer die
- A load of 245 N was applied to the upper and lower expander
- There is a gap between the lower outer die and the teeth of the gear



Press Quench Tooling Setup

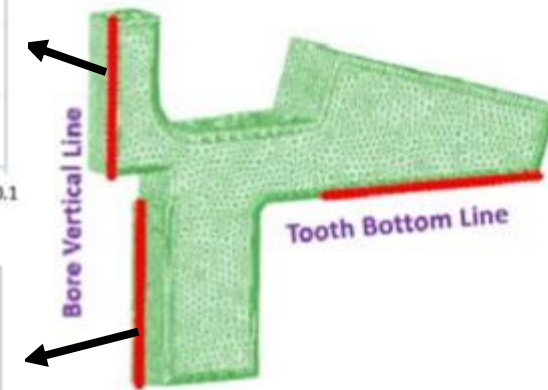
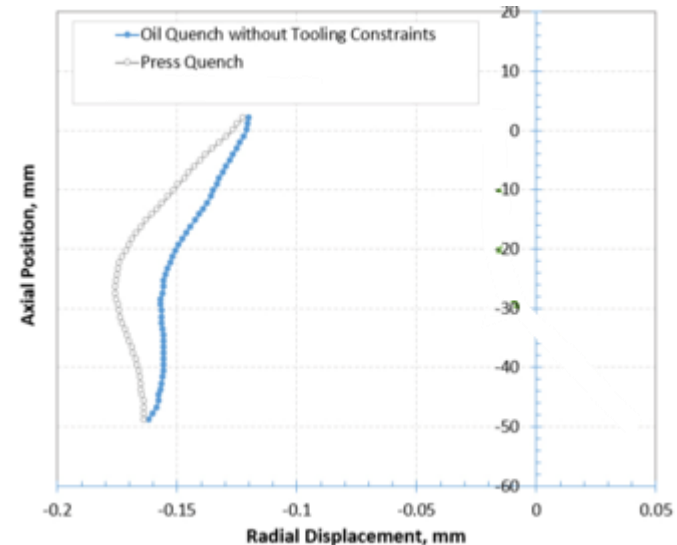
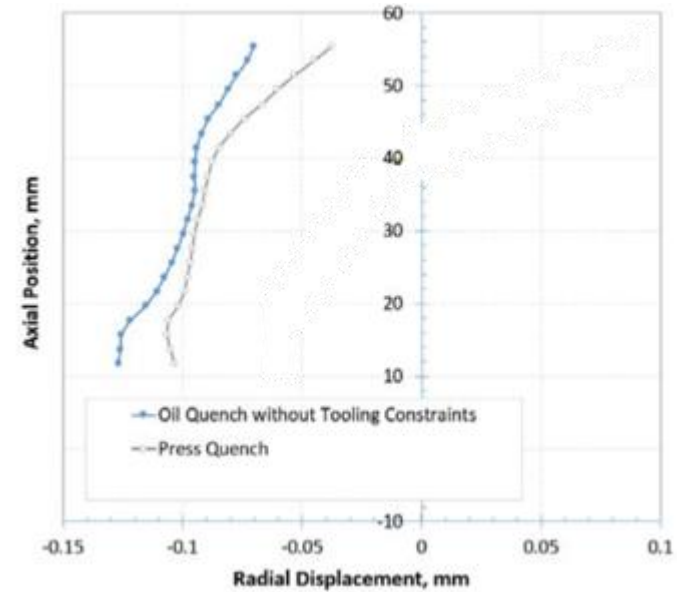
Comparison of the Bevel Tooth Distortion

- Distortion prediction for the bevel tooth shown for an oil quench with no tooling constraints and the press quench setup used for production (Press Quench)
- Tooling has a significant effect on the distortion of the bevel tooth
- In this case, the distortion was acceptable
 - No modifications were needed for the upper and lower dies or their loads



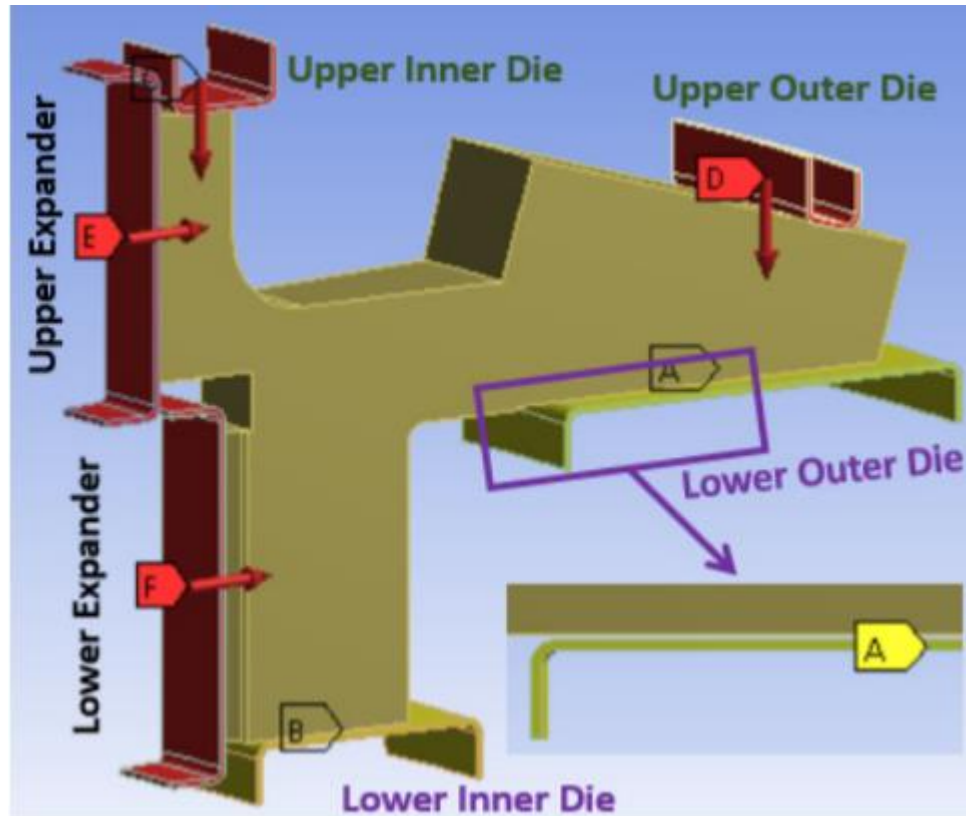
Comparison of Bore Distortion

- Distortion prediction for the bore shown for an oil quench with no tooling constraints and the press quench setup used for production (Press Quench)
- The production setup was creating more distortion of the bore than if no tooling constraints were used
- This amount of distortion was unacceptable, and a solution was sought
- It was determined that the expander was not creating enough resistance to restrict the shrinkage of the bore
- Two solutions are possible
 - Use a higher load on the expander to try and control the radial dimension of the bore
 - Use a plug to ensure the bore is the same size each run
- It was decided to use a plug to ensure a more consistent process

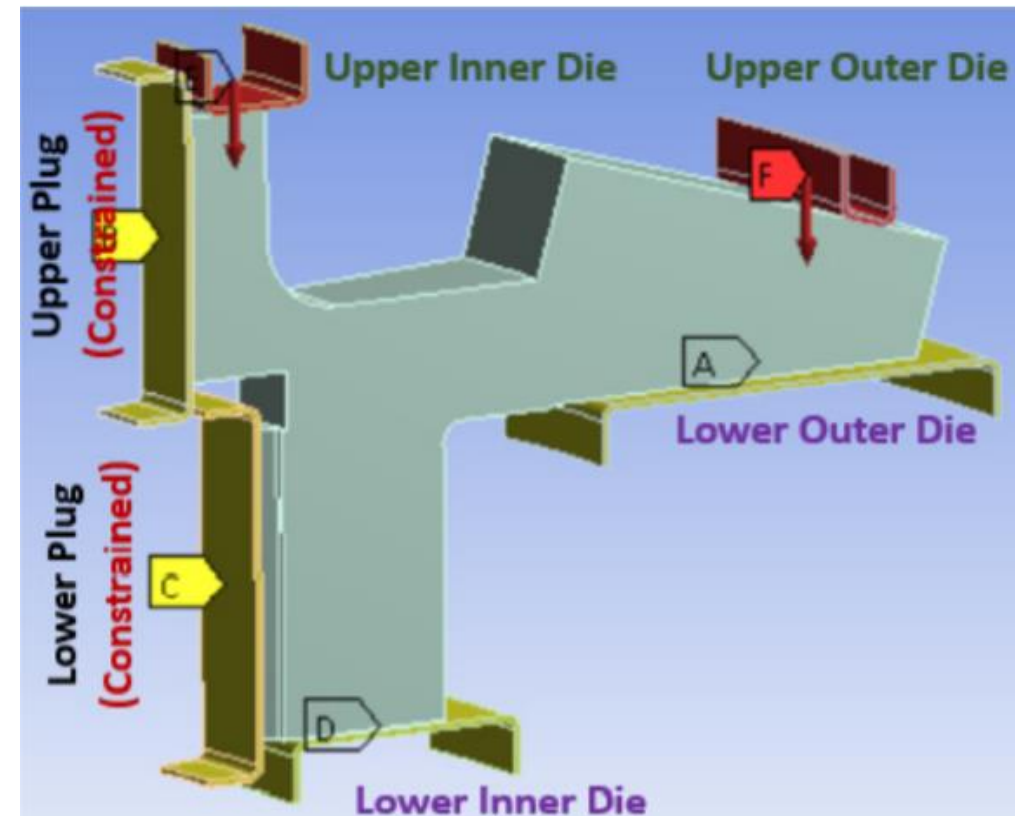


Press Quench Tooling Setup using a Plug

- Press quench tooling setup uses an expander with a load to control the bore dimension
- Modified press quench tooling uses a plug to control the bore dimension instead of an expander
- Upper and lower die positions and loads are the same between the two models



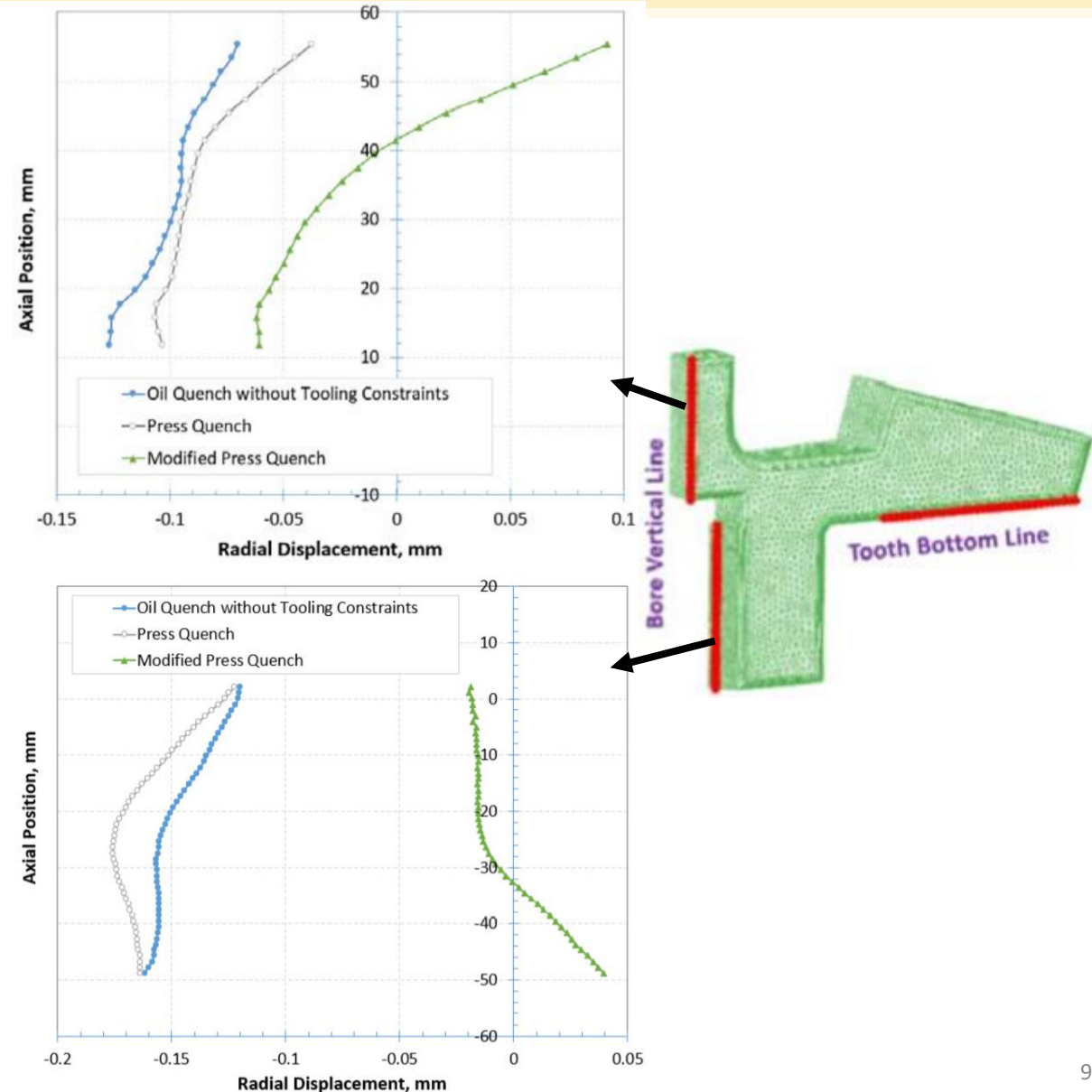
Press Quench Tooling Setup



Modified Press Quench Tooling Setup

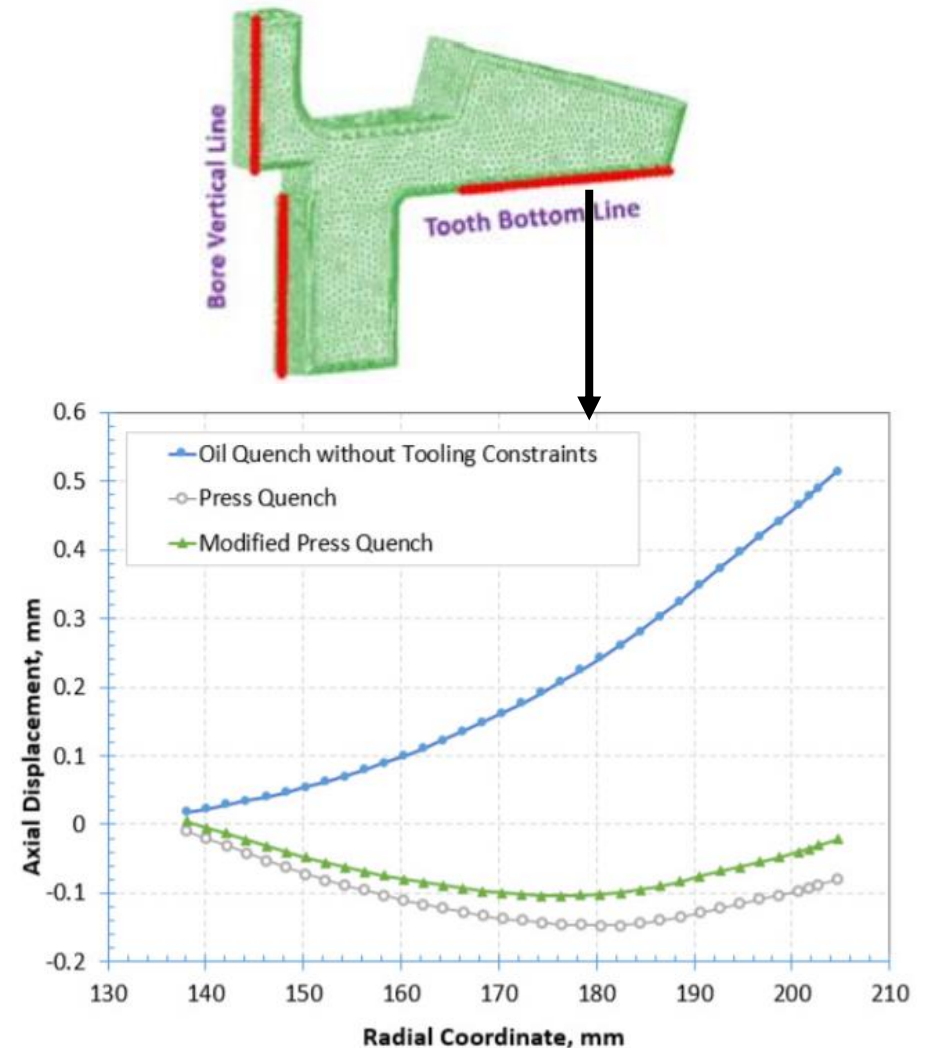
Comparison of Bore Distortion using a Plug

- Distortion prediction for the bore shown for an oil quench with no tooling constraints, the press quench setup used for production (Press Quench), and the press quench using a plug instead of an expander (Modified Press Quench)
- Using a plug reduced the overall magnitude of the distortion, but introduced a significant taper
- Using a plug can help make the process more consistent by forcing the bore to the same size for each part, regardless of the initial starting size
 - An expander uses pressure to simply try and hold the shape of the current size, which will vary slightly part to part
 - This variation will lead to variations in bore size of the final parts
 - A plug forces the bore to the same size for each part before the martensite transformation
 - This leads to a more consistent process



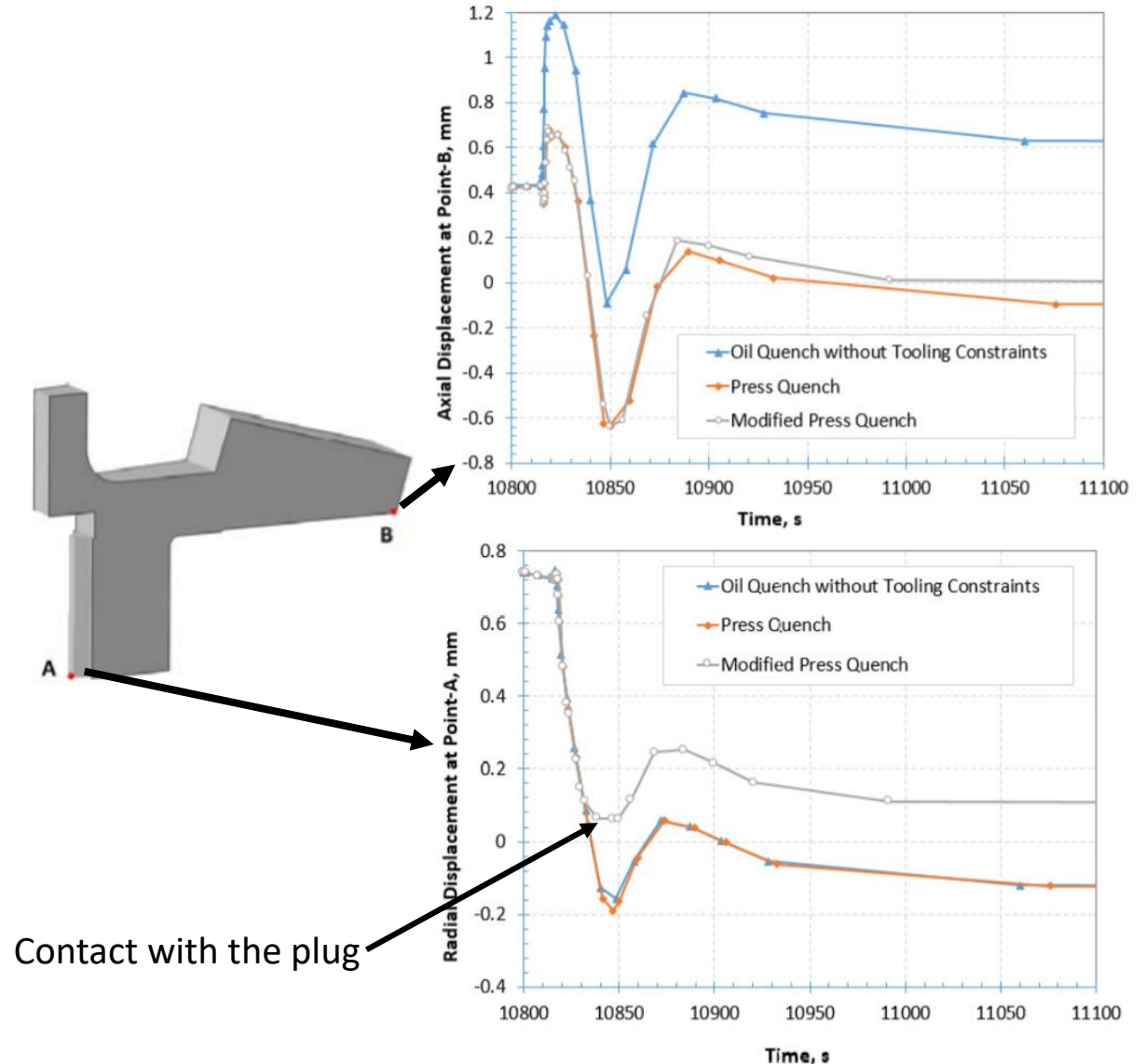
Comparison of Bevel Tooth Distortion using a Plug

- Distortion prediction for the bevel tooth shown for an oil quench with no tooling constraints, the press quench setup used for production (Press Quench), and the press quench using a plug instead of an expander (Modified Press Quench)
- Using a plug instead of an expander does not have a significant effect on the bevel tooth distortion
 - Slightly less distortion of the bevel tooth is predicted using a plug
 - No changes to tooling or loads controlling the other modes of distortion, only the expander controlling bore distortion was altered



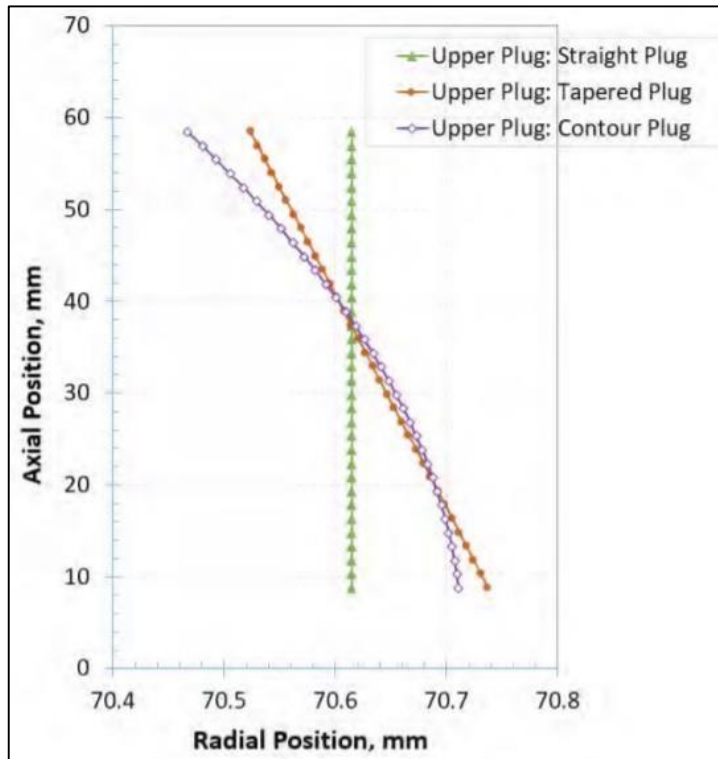
Comparison of Deformation History using a Plug

- Plots show that the plug can effectively control the distortion of the bore
 - Plug restricts shrinkage of the bore before the martensite transformation begins
 - Part then expands off the plug when the martensite transformation occurs
 - Bore ends larger than the plug, so the plug may be easily removed
- Plug helps make the process more consistent by having the part shrink to the same size before the martensite transformation for each part
 - An expander only resists shrinkage, it does not force the bore to be the same size for each part
- A higher load may also have worked in this case, though the process may not be as consistent

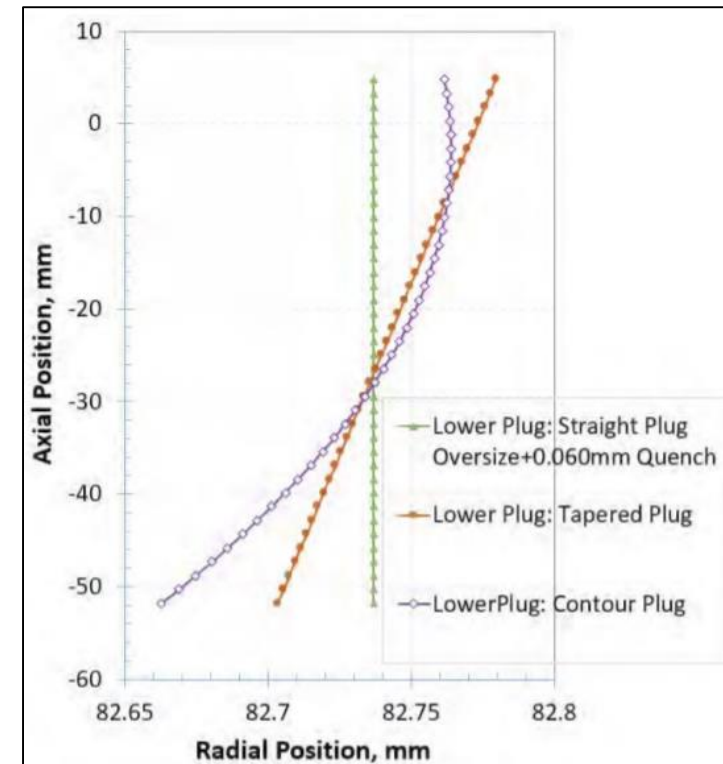


Plug Design Improvement

- It is usually possible to eliminate taper of a bore by using an inverse taper for the plug or expander
- It may also be possible to eliminate a nonlinear taper by using an inverse of the final distortion, or a contoured plug
- Both designs were compared to the straight plug that was used to reduce the distortion of the bore



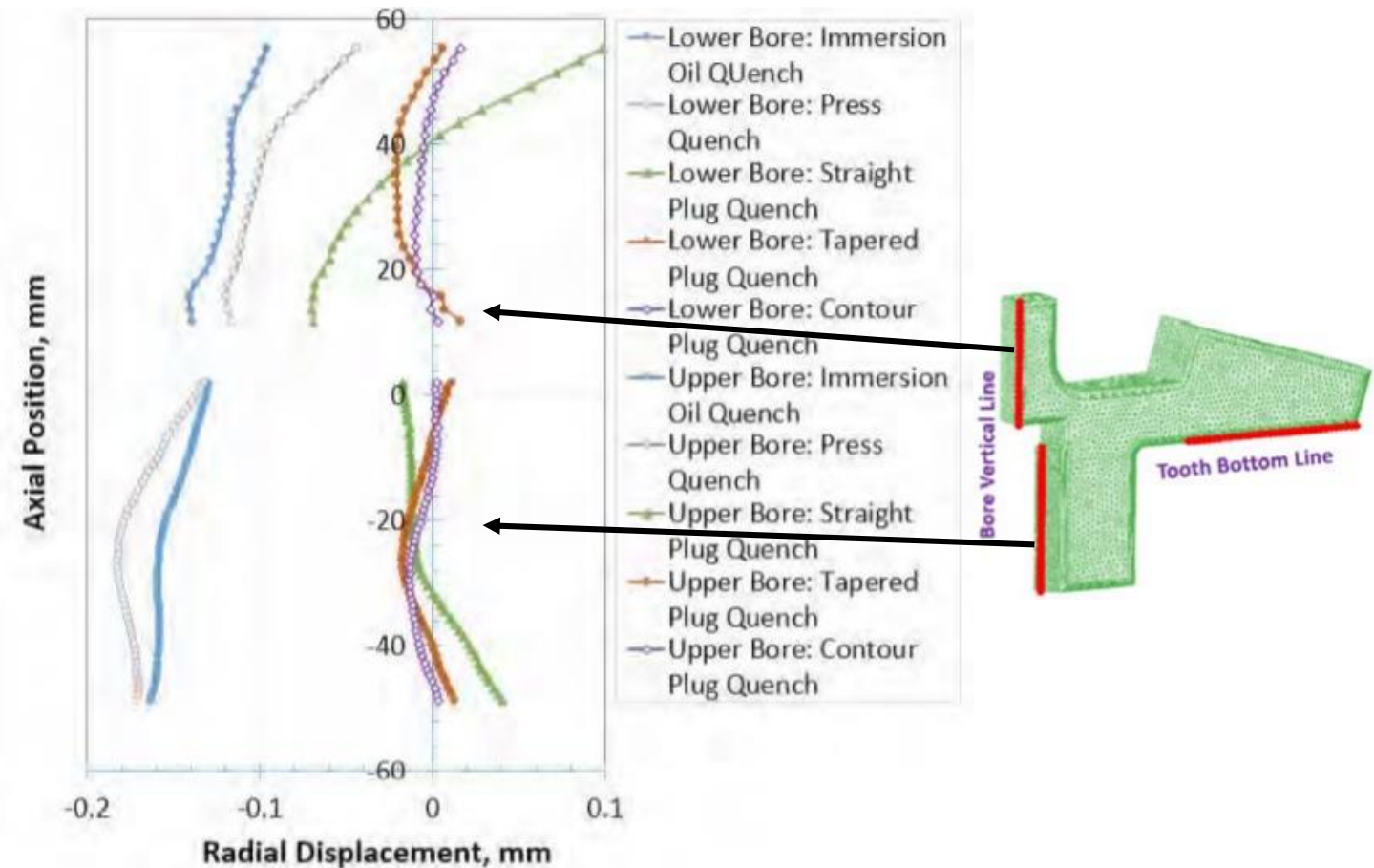
Upper Plug Shapes



Lower (Spline) Plug Shapes

Comparison of Distortion using Improved Plug Design

- The tapered and counted plugs both reduced the overall taper of the upper and lower sections of the bore
- The contour plug did not remove the slight bow in the upper and lower sections of the bore
 - The bow is small; approximately 15 μm
- Using a simple, linearly tapered plug is enough to reduce the total distortion, radial size and bore taper, to manageable levels
- The use of a plug also means the distortion of the bore will be more consistent from part to part than if an expander was used



Summary

- Press quenching process of a bevel gear modeled using the DANTE heat treatment simulation software
- Using DANTE, it was determined that the expander was ineffective in controlling the radial dimension of the bore
- Using DANTE, it was determined that the upper and lower dies were effective in controlling the dimension of the bevel teeth
- A plug was used in place of the expander
 - Using DANTE, the plug was shown to be effective in controlling the radial dimension of the bore
 - A straight plug caused a taper of the bore
- Two additional plug shapes were compared to eliminate the taper
 - Inverse taper plug
 - Inverse contoured plug
- It was shown that the inverse taper plug was effective in removing the taper, but caused a slight bow of the bore
 - The inverse contour was designed to eliminate this bow distortion, but was ineffective in doing so
- It was shown that DANTE can be used to successfully determine the cause of distortion in the bore of a bevel gear
- It was also shown that DANTE can be used to effectively redesign the press quench tooling to eliminate or reduce the distortion to manageable levels



Links to Relevant Case Study Material

Material related to this Case Study

[Press Quench Process Design for a Bevel Gear using Computer Modeling \(2016\)](#)

[Distortion Minimization of Bevel Gear Press Quench Hardening Process Using Computer Modeling \(2019\)](#)

Additional DANTE Aerospace Case Studies

<https://dante-solutions.com/aerospace>