Finite Element Analysis (FEA) to predict stress and strain

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Finite element analysis (FEA) is established in modern design to predict component response to forces and environmental conditions. With material properties, geometry, mechanical and thermal loads as inputs, FEAs determine failure points. CWST has developed an FEA model using input measurements of peened material to virtually design optimal peening that extends component fatigue lifetime and fatigue strength.

In the FEA analysis the component is modelled in 3D using a linear continuum approach dividing the volume into a grid of very small or finite elements to enable greater accuracy of predication. The programme then calculates the individual behaviour of each element to predict the overall behaviour of the component or structure. In particular the FEA code can predict areas of high stress loading, areas most susceptible to fatigue failure, stress corrosion cracking, thermal creep and/or erosion failure.

FEA prediction for peening

Curtiss-Wright Surface Technologies has developed a front end input and back end processor for the ABAQUS FEA code that describes the peening process and allows prediction in relatively high resolution of the stresses and strains developed by the peening process.

This FEA model of peening is then combined with the component's mechanical and thermal loads to iteratively design a peening process and pattern that best reduces high stress loading, minimizes any resulting tensile stress and predicts component strain. The code is normalized by peening and measuring the induced strain in respective materials by means of a crack compliance slitting technique.

FEA prediction of stress and strain lets us work hand-in-hand with customer stress analysists to identify high stress and failure prone areas of system components and to provide solutions that can quickly progress from concept to deployment.

Increasing fatigue life

When components are in service they are subject to many physical loads which induce fatigue cracking, fretting, stress corrosion cracking, erosion and cracking due to stress induced by thermal gradients plus loading. All of these mechanisms contribute to shortened fatigue life and/or lowered fatigue strength.

Component failure can be attributed to existing tensile stresses which are often generated during manufacturing or loading stresses generated under heavy in-service operating conditions. Biasing out these manufactured residual tensile stresses and pre-biasing known loading stresses with beneficial residual compressive stress is known to protect components from premature failure due to fatigue, stress corrosion cracking and erosion.

Desirable compressive stress can be generated with the application of a peening surface treatment either prior to manufacturing, during the manufacturing process or in fielded parts.

COMPANY PROFILE

Curtiss-Wright Surface Technologies (CWST) offers a single source solution and point of contact for all your surface treatments. We can reduce your turnaround times and costs through our network of over 75 worldwide facilities.

Our proven surface treatments meet industry demands for lighter materials, improved performance and life extension in key markets such as Aerospace, Automotive, Energy and Medical. We can prevent premature failures due to fatigue, corrosion, wear, galling and fretting.

Surface Technologies is a Division of Curtiss-Wright (NYSE:CW) a global innovative company that delivers highly engineered, critical function products and services to the commercial, industrial, defense and energy markets. Building on the heritage of Glenn Curtiss and the Wright brothers, Curtiss-Wright has a long tradition of providing reliable solutions through trusted customer relationships.

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Controlled shot peening and laser peening

Controlled shot peening is a proven technique to increase the life of a product by preventing or delaying common failure mechanisms such as fatigue, fretting, stress corrosion cracking, galling and spalling.

Shot peening impinges the surface, plastically deforming the material predominantly in the normal direction resulting in plastic expansion in the transverse directions. Pushback of the surrounding material which resists the expansion builds a compressive field biasing out the unwanted tensile stresses.

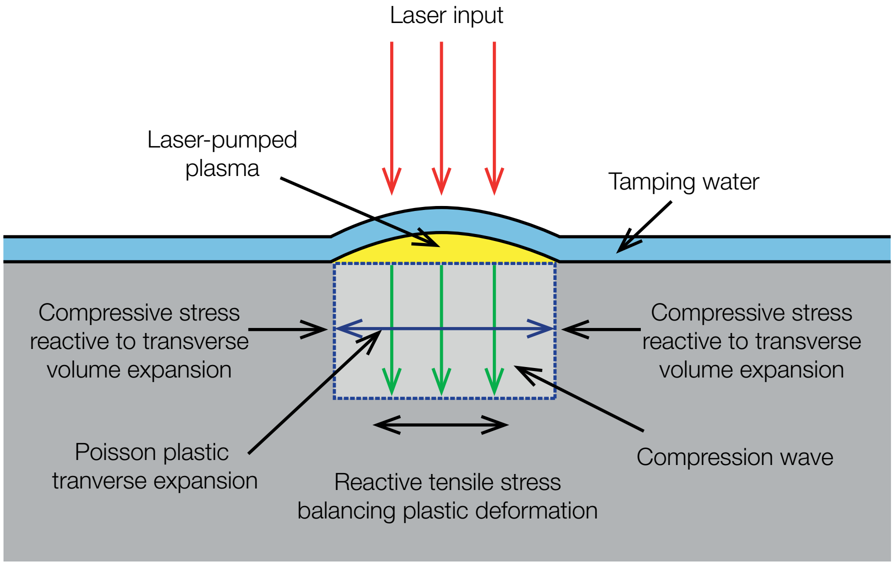
Laser peening is a production qualified technique where a laser pulse is used to create a controlled shock wave which imparts a precise and much deeper plastic deformation resulting in deeper levels of residual compressive stress and strain into the material substrate.

FEA modelling is currently used for laser peening in a virtual mode to predict the plastic deformation and resulting stress and strain developed by a particular set of processing parameters. The parameters can then be iteratively adjusted to find an optimum solution that builds beneficial compressive stress into the failure point of components while minimizing any tensile stresses that are consequently generated.

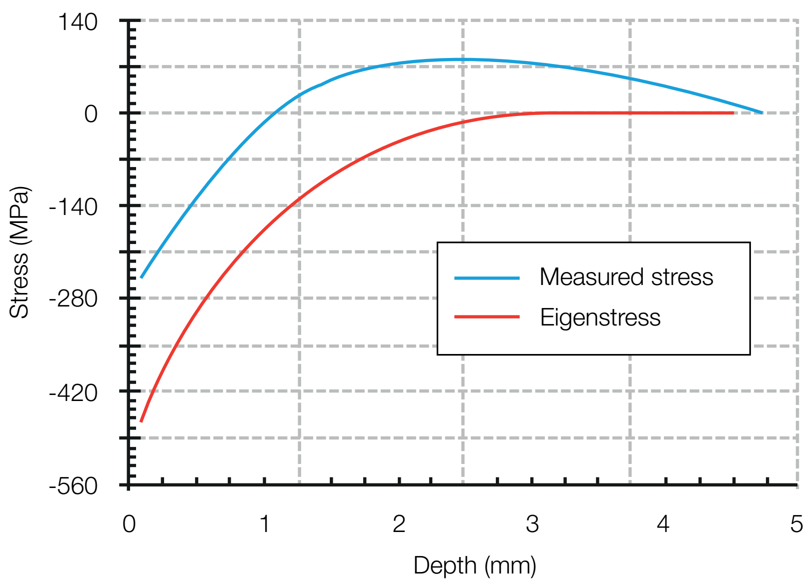
We are currently also developing the FEA modelling for use with our controlled shot peening technique.

Overview of modelling concept for stress mitigation application

- Laser peening is uniformly applied with a specific set of laser peening parameters to a 50 mm x 50 mm x 12 mm block (size optional) of the material of interest.

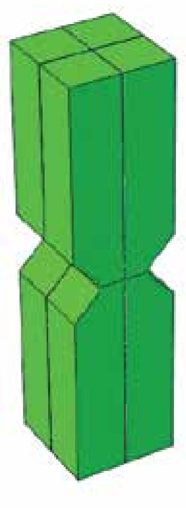


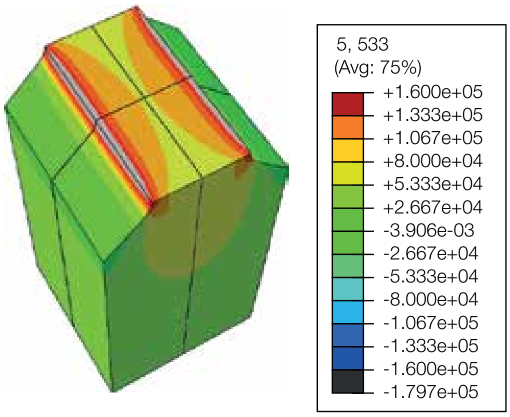
- Plastic strain induced by peening with the specific set of laser peening parameters is measured by strain gauges as the block is EDM cut and eigenstrain computed. Multiple blocks are treated to obtain material response for a range of peening parameters.



- Component is modeled using continuum (3D) elements in ABAQUS. High stress areas specifically identified for treatment.

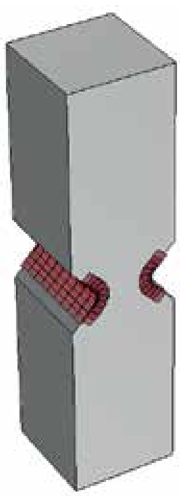
Without peening, under load



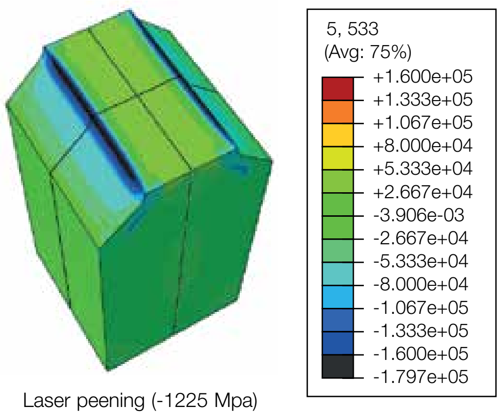


Without peening – Peak axial stress is 1281 MPa

- Laser peening process developed using FEA model in an iterative manner. Each square in notched area of the component represents one laser peening pulse. For each spot a thermal initial condition is set based on Eigenstrain and the model equilibrated – result shows the shape and stress state of the component after peening but without loading.

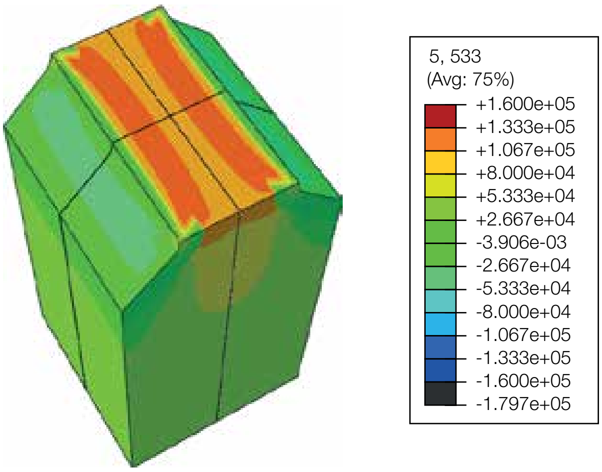


Laser peening pattern



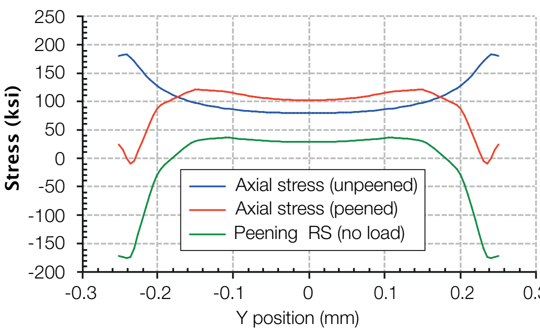
Laser peening (-1225 Mpa) (without load)

- FEA model is employed to sum loaded component plus laser peening of component to generate shape and stress state of the treated component. Note that peak tensile stress is reduced by 28% and stress at surface where cracks initiate is reduced by 83%.

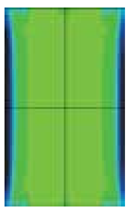


With laser peening – Peak axial stress is 924 MPa

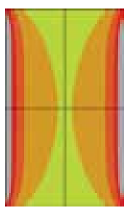
- **Summary:** FEA model is employed to analyze fatigue problem and through a rapid iterative process provide an optimum solution for reducing tensile stress and improving fatigue performance. Note that peak tensile stress is reduced by 28% and stress at surface where cracks initiate is reduced by 83%. Expectation for lifetime improvement is greater than 10-fold.



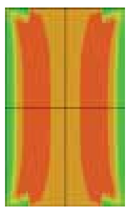
86% reduction in peak surface stress



Effect of laser peening (without load)



Without peening – Peak axial stress is 1281 MPa



With laser peening – Peak axial stress is 924 MPa

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Key benefits and applications

- FEA is an established method to predict the effect of physical forces and environmental conditions on materials and structures
- FEA analysis can determine the ultimate failure point of a component or structure
- Components are modelled in 3(D) using a linear continuum approach
- FEA can identify and predict areas of high stress loading, areas susceptible to fatigue failures, stress corrosion cracking, thermal creep and/or erosion failure
- FEA programme has been adapted and developed by Curtiss-Wright Surface Technologies to predict outcomes related to peening surface treatments
- Parameters can be adjusted to find an optimum solution to prevent premature failure of components or structures

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