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Developments in fatigue peening

Paul Huyton, Managing Director of Surface Dynamics looks at applications and recent developments in surface treatment by peening.

Have you ever gazed through an aircraft window and considered the stresses occurring where the wings flex under the load of the fuselage? Or the repeated loads on the landing gear as up to 400 tonnes of airliner slams down onto the runway? And what of the thermal and mechanical stresses on jet engine parts that rotate up to one hundred thousand times per minute and at four-figure temperatures?

In these areas and many more, resistance to fatigue failure is enhanced by controlled peening.

The process is usually carried out by impacting the surface with shot, small round particles that are hard as or harder than the surface to be peened.

The plastic deformation of the surface layer resulting from the impact induces a residual compressive stress which will counter any tensile stresses near the surface.

It is cyclic tensile stresses that initiate cracking and, ultimately, fatigue failure.

Tensile stresses can be the result of in-flight loadings, thermal gradients, plating or other manufacturing processes.

The peening process is controlled by the correct selection of shot, maintenance of shot quality, regulating the shot velocity and ensuring the proper coverage.

Shot for fatigue life enhancement is typically 1mm or less in diameter, depending on the smallest radii to be peened and the required depth and intensity of processing.

The majority of peening is undertaken using ferrous shot which has high impact energy and good durability.

The chemical composition, microstructure and hardness of the shot will be defined within the process specification and associated documents.

Cut wire shot is made from wrought steel wire which is chopped into short cylindrical shape.

When the edges are rounded-off, or "conditioned", this provides top quality peening shot with uniform size and very low break-down rate.

Understandably, cut wire has a much higher initial cost than cast steel shot.

Glass beads can be used when lower peening intensities are permitted.

Using glass beads avoids having to decontaminate nonferrous parts after processing but glass has a higher breakdown rate and higher risk of irregular particles in the blast stream.

Ceramic bead is very hard but with much lower density than ferrous shot.

It is less prone to breakage than glass bead, but initial purchase costs are higher.

Process specifications normally define the sampling of delivered and in-process shot in order to maintain quality.

The tests conducted are typically for size, roundness and hardness.

The peening equipment should have some provision to maintain shot quality.

This can be in the form of air-washing, size screening, roundness separation and, for nonferrous shot, magnetic separation.

For accurately targeted peening the shot is delivered through a nozzle in a stream of compressed air.

The compressed air pressure determines the shot velocity and so, as the impact energy is proportional to the square of the velocity, pressure is a critical control parameter.

For large, flatter areas, the shot can be delivered by an electric motor driven turbine wheel.

This technique uses less energy to deliver high volumes of shot than the compressed air system.

The rotational speed determines the shot velocity and impact energy.

The intensity of the shot stream is measured using 1070 steel strips, called Almen strips.

When blasted on one side the plastic deformation causes a curvature which is measured on an Almen gauge.

A graphical process can be used to produce a saturation curve and hence determine the peening intensity.

To fully protect the component the residual compressive stress must be present over the entire surface designated for peening.

Gaps where there is no compressive stress layer within this designated area could be vulnerable to fatigue cracking.

For this reason, peening equipment should have automatic actuation, where possible.

The shot peening process leaves small dimples and these are required to fully obliterate the surface to ensure full (100%) coverage.

Some specifications require 200, 300 or 400% coverage, ie process for two, three or four times longer than for 100%.

Recent studies, particularly by Dr John Cammett of the US Navy, have shown this to be erroneous.

Residual compressive stresses peak as coverage approaches 100%, and may reduce with further processing.

But in all cases the fatigue life is higher than with unpeened components.

With the proper selection of shot and impact velocity the plastic deformation of the surface can induce curvature of panels and this is used to good effect in peen forming.

Wing and fuselage skins are peen formed to provide good fit with the structural airframe.

The Airbus A318 and A380 incorporate laser-welded structures to avoid the installation of thousands of rivets.

Peen forming of the components into the final contour is undertaken after laser welding.

Some aircraft wings, for instance that of a Boeing 737, have a complex "saddle-back" shape where the aerofoil curvature is opposite to the curvature along the length of the wing.

This shape can be achieved by initially peening to achieve the aerofoil shape then peening to a pattern of "darts", pointing inwards from leading and trailing edges, to provide the counter-curvature.

The nose and tank segments of the Ariane space rocket are peen formed, drastically reducing the time and cost previously taken on fabrication and inspection of welds.

Peen forming can reduce cost and provide better stress profiles within the component than alternative shaping technologies.

It can also be used for corrective action where the shape or alignment is incorrect.

Wing spars which have been machined out of solid aluminium will distort due to the release of internal stresses.

These types of components are realigned by shot peening.

Gas turbine main shafts are straightened by fixing a dial gauge on the convex side and peening the concave side.

The surface enlargement of the concave side will "pull" the shaft back into alignment.

Peening forming is undertaken with larger shot, some up to 10 millimetres in diameter.

Although the traditional means of undertaking shot peening will remain the industry norm for the foreseeable future, there are new technologies which are finding niche applications.

Pulsed laser processing can induce very deep residual stresses in a highly controlled fashion.

The component is covered in a light-absorbing ablative coating and deluged with water.

The dark ablative coating ensures that the light energy is not reflected and the coating vaporises under the pulse of the laser.

The resulting plasma shock is contained by the water layer and driven deeper into the surface layer.

Cost and component considerations are constraints to wider use of this technique.

Ultrasonic peening is undertaken by containing shot within a chamber which is closed on one side by the target surface and on the other side by an ultrasonic sonotrode.

The sonotrode causes the shot to impact the component and induce beneficial residual stress with lower surface roughness than traditional blasting.

To achieve the required intensities very hard tungsten carbide shot is used.

But there are targeting and containment issues to be considered which will not make this process applicable to all components.

Cavitation peening is a water immersion technique which uses the formation and collapse of vapour bubbles in a low pressure vortex to transmit shock waves into the surface.

This technique can induce residual compressive stresses with virtually no surface roughness.

The process is still in the experimental stage with Dr Hitoshi Soyama of Tohoku University in Japan.

These future technologies provide exciting possibilities and will help to expand the use of peening beyond its current applications.

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