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Peen Forming—A Look under the Surface

Submitted on behalf of Vacu-Blast Ltd, United Kingdom

Controlled shot peening is widely accepted in the aerospace industry for fatigue life enhancement of critical aeroengine and airframe components. Less well known and little understood by many production engineers is the associated process of 'peen forming'. This uses the basic principle of shot peening to form or shape curved sheet metal geometries which would be difficult to create with conventional methods like die bending, stretch-forming or rolling. It is particularly cost-effective where the number of components involved is too small to justify expensive mass production processes. Here, Roger Brickwood of Vacu-Blast removes some of the mystique surrounding peen forming.

Like computer-controlled shot peening, peen forming is employed today at the forefront of aerospace production technology. This may come as something of a surprise to those who have either not heard of the process or who might associate it with its 'low-tech' historical image of shaping shields and armour by hitting them repeatedly with a hammer—a process thought to be employed by the ancient Romans. Even in the latest UK edition of 'Chambers Science & Technology Dictionary', peening is defined as "using hammer blows or shot blasting to cold work metal".

In essence, peen forming uses the established shot peening effect to shape sheet and thin section metal parts. It has been used and developed very successfully in the aerospace industry for many years to produce low-throughput high-integrity components such as wing and fuselage skins and airframe stringers.

Before describing a number of typical peen forming applications in detail, it may be helpful to 'go back to basics' to explain what happens to a metal surface during shot peening and how this effect is harnessed to shape a component.

Shot peening is a cold working, surface conditioning process employed primarily in the aerospace and automotive industries to improve the resistance to fatigue of critical components operating under stress - aeroengine fan discs, blades and shafts, and high performance vehicle transmission parts, for example.

Fatigue is the most common cause of engineering component failure today, normally brought about by the repeated loading/unloading of a component with a stress very much less than its tensile strength. Shot peening can increase the resistance of a component to fatigue failure by more than 50 percent.

The shot peening process uses a stream of spherical particles to bombard the surface of a part and the impact of each particle produces an indentation on its surface due to the plastic flow of material.

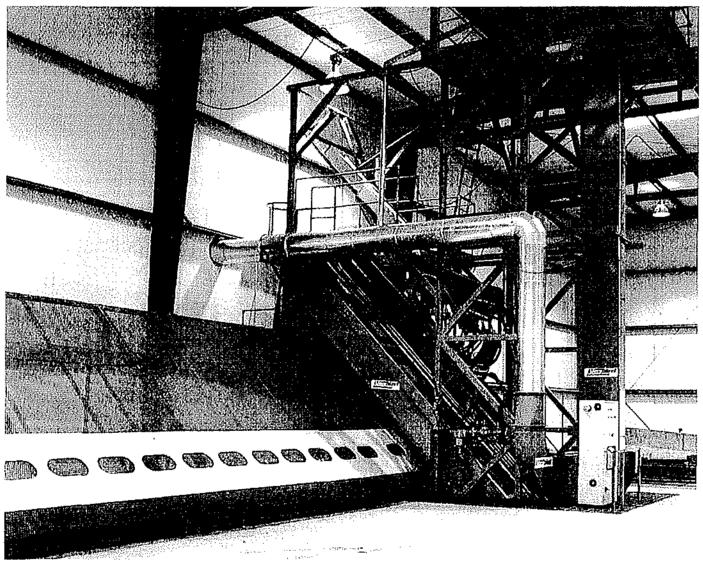
This indentation has a larger surface area than the original surface and, cumulatively, the indentations try to create a surface expansion. The elastically deformed sub-surface layers act to resist this surface expansion, inducing a compressive stress at the surface - balanced by a tensile stress of lower magnitude in the core of the material.

The magnitude of the compressive stress is dependent upon the kinetic energy of the impacting particles, the yield strength of the component material, and the relative hardnesses of the shot peening media and the component. All these factors are known and measurable, enabling the process to be controlled highly accurately to produce precise, consistent and reproduceable results.

The effect of shot peening is measured by representing the surface of a component with what is termed an 'Almen' strip (named after its inventor), a thin piece of metal, usually steel, of known hardness and dimensions, secured on an 'Almen' block. When this strip is peened on one side only and released from the block, the compressive stress at the surface causes the strip to curve.

Subsequent measurement of the amount of curvature indicates the extent of the peening effect, which can be pre-determined by production trials in line with component design requirements.

This curvature phenomenon is the basis of peen forming. When peen forming, the part is usually thin in section and is selectively peened on one side only, thus creating bi-axial curvature of the part in a similar way to the effect on the 'Almen' strip. Controlled adjustment of the processing parameters together with variation of the position of the part under the particle stream can produce simple shapes or complex, multi-axial geometries.



Production-line system for 'Gulfstream IV'

A classic example of the science of peen forming is the Vacu-Blast production-line 'saturation peening' system used in the manufacture of wings for the successful 'Gulfstream IV' executive aircraft. (Shown in photograph above.)

Built in conjunction with the US company, National Metal Finishers for Textron Aerostructures, the system is one of the most advanced of its kind in the world and handles the widest ever wing section to be peen formed - the single upper skin measures 12ft (3.5m) wide by 45ft (13.7m) long.

The wing skins are processed on the system by means of sixteen peening nozzles mounted on programmable reciprocating nozzle manipulators. The skin sections pass through the system automatically under continuous computer control and monitoring, guaranteeing that critical design parameters to ensure optimum wing geometry are strictly adhered to. The flow of shot is also monitored continuously to check the feed rate against pre-determined values.

At the time of its introduction the design of the GIV wing was a radical departure from conventional approaches, allowing a substantially enhanced strength-to-weight ratio to provide extra fuel-carrying capacity for the aircraft.

Controlled peen forming was the only practicable method of shaping the wing, at the same time providing the required designed-in layer of uniform compressive stress across its surface - as well as ensuring that the same precise result could be achieved every time. Added to this, inherent in the peen forming process is the benefit of increased resistance to stress cracking of the outer surface.

Shaping 'Ariane' body panels

At the other end of the peen forming spectrum is the technique applied by the Belgian aerospace company, SABCA, which manufactures a number of components under licence for Aerospatiale's 'Ariane' programme, employs peen forming for the accurate shaping of the external housings of liquid fuel boosters.

The technique utilises a Vacu-Blast 'Closed-Circuit' mobile peening system and replaces mechanical rolling. It has cut production time from 24 to 16 hours, reduced the number of operatives needed and removed the danger of surface damage - totally eliminating rejects.

The sculpture-machined aluminium alloy body panels house the three major sections of the 2.2 metre diameter first-stage Ariane IV rocket motor. The panels vary in thickness from 2mm to 6mm and are peen formed manually from the flat to achieve the necessary highly-accurate profile.

One operator applies the Closed-Circuit peening head to the external surface, working to a profile gauge positioned by an operator on the internal surface. The process uses large diameter steel shot, with precise control of blasting pressure.

Using peen forming rather than the previous rolling or stretching method has another major advantage. It is generally understood that fatigue cracks propagate from surfaces under tensile stress. Any radial rolling technique induces tensile stress on the outer surface and compressive stress on the inner one.

In contrast, peen forming creates compressive stresses on both sides of the panel, making a vital contribution to improved crack resistance. Maintaining the optimum surface condition in this way also reduces the risk of premature failure, caused by high tensile stress zones around any area which may subsequently become damaged.

High precision

The degree of precision possible using peen forming is demonstrated by the specially developed technique employed at the Aerospatiale plant in Nantes, in the production of wing/fuselage components for the Airbus A320 and A310 aircraft.

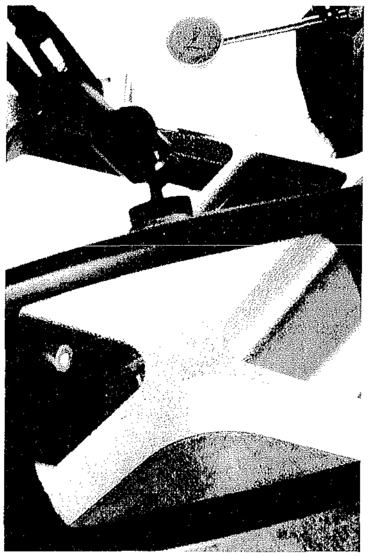
Aerospatiale have installed a purpose-designed Vacu-Blast Closed-Circuit system with four peening heads, suspended individually with extra-long supply hoses from overhead gantries. The system is used for the high-precision peen forming of the five special alloy components which make up the two end sections of the wing centre box.

The components are processed on special jigs to an accuracy of 0.2mm, using 2mm diameter steel shot at 4 bar pressure, thus ensuring perfect interfacing with each other and the centre box. The system incorporates a continuously cycling power-pack so that operators can carry on working without interruption. It is also equipped with Instantaneous Blast Cut-Off (IBCO) to enable very brief bursts of shot to be applied. This device is necessary in order to 'fine tune' the profile.

The most complex of the five items processed are the two main end ribs - precision-machined sections weighing 38Kg, the longest of which measures 2.9 metres. All the components are decontaminated after peen forming and prior to final assembly to remove any residual 'smear' from the steel shot.

Peen straightening

A variation of peen forming is 'peen straightening'. This process is often used to correct distortion of a component caused by machining or heat treatment. Under controlled conditions, the residual compressive stresses produced gently straighten a component to meet the original required dimensional tolerances.



This close-up view through a magnifier shows the surface effect of peen straightening, which not only corrects distortion but also prolongs fatigue life by inducing residual stresses in the component.

Typical examples are aircraft wing spars and other structural parts, where peen straightening leaves fatigue-resisting residual compressive stresses on both sides of the component. Conventional mechanical straightening, by contrast, leaves tensile stresses on one side of the component only, thereby introducing fatigue and stress corrosion problems.

As with peen forming, an additional benefit of peen straightening is that it also prolongs the fatigue life of the part and inhibits stress corrosion cracking. This is due to the residual compressive stresses produced in the surface of the metal by the peening effect.

All the applications described highlight the importance of peen forming in today's aerospace industry. It is a process which continues to be developed in line with other manufacturing techniques - this has been the case since one of the earliest uses of the process to shape wing panels for the Lockheed 'Constellation'. It is interesting to note that through its use in the 'Ariane' programme, peen forming still figures large in man's continuing quest to reach the stars! ○