CONTROLLED SHOT-PEENING FOR THE PREVENTION OF FATIGUE AND STRESS CORROSION CRACKING AND 'SEARCH PEENING' TO EXPOSE EXFOLIATION CORROSION.

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INTRODUCTION.

CONTROLLED SHOT-PEENING GENERATES A COMPRESSIVE STRESS WHICH IN MAGNITUDE IS APPROXIMATELY EQUAL OF 60% OF THE BASE MATERIALS ULTIMATE STRENGTH.

A LOAD MUST BE APPLIED WHICH RESULTS IN A STRESS IN EXCESS OF THIS LEVEL BEFORE SURFACE TENSION IS EXPERIENCED, HENCE ITS BENEFIT IN REDUCING FATIGUE.

STRESS CORROSION IS DEPENDANT ON A NUMBER OF FACTORS, THE ELIMINATION OF ANY ONE OF THEM WILL RESULT IN ITS AVOIDANCE. THE APPROACH TAKEN IS TO TACKLE THE PROBLEM BY KEEPING THE SURFACE STRESS BENEATH THE THRESHOLD LEVEL FOR S.C.C. OR USING THE TECHNIQUE IN ADDITION TO OTHERS AS A FURTHER SAFEGUARD.

NEW AIRCRAFT HAVE CONTROLLED SHOT-PEENING APPLIED AS PART OF THE DESIGN THEREFORE ON REPAIR AND OVERHAUL WHERE CORROSION/FRETTING/EROSION IE. METAL REMOVAL IS NOTED, THE COMPRESSIVE STRESS MUST BE RE-GENERATED OR ITS LIFE TO FAILURE MAY BE REDUCED.

"SEARCH PEENING" OF SURFACES WILL IDENTIFY IF EXFOLIATION CORROSION IS STILL PRESENT IN THAT SURFACE AFTER DRESSING TECHNIQUES HAVE BEEN APPLIED TO REMOVE VISIBLE CORROSION.

CONTROLLED SHOT-PEENING.

Controlled Surface Pre-Stressing can be achieved by different methods whether it is cold rolling, mechanical pre-stressing or controlled shot-peening. This paper is principally directed towards Controlled Shot-Peening because of the nature of aerospace components discussed, where their irregular shape/location preclude or make alternative methods unsuitable.

Controlled Shot-Peening is the cold working of a metal by bombarding its surface with shot. The result is that the surface yields but the core resists stretching and a residual compressive stress is induced.

The magnitude and depth of this compressive stress varies with materials, but generally a level of 50%-60% of the ultimate strength of the base metal is achieved and the depth varying from 0.1 to 2.5mm. See Figures 1 and 2. Shot used to achieve this level of cold work can be steel, glass, ceramic or stainless steel and these vary in size from 50 micron up to 3mm.
Each of these sizes and types are used for specific reasons. The problems commonly tackled by this method, are stress corrosion, corrosion fatigue, fatigue, fretting fatigue and galling. All of these situations are surface related and are linked to tensile stress, therefore consideration of this area will gain benefit.

To date in the field of stress corrosion and corrosion fatigue, this treatment has been applied on aluminium structural components, titanium and high strength steels and outside the aerospace field, to chemical storage tanks, heat exchangers, fabricated structures, pressure vessels, impellers, deaerators and associated piping.

The industries that have used Controlled Shot Peening to retard or prevent surface problems include aerospace, pharmaceutical, chemical, automotive, offshore oil and gas, brewing, food processing, sewage and the pulp and paper industries.

FATIGUE - Residual Stress.

Fatigue by definition is the result of stresses less than the ultimate strength of an alloy but sufficient after many cycles to cause premature failure. These stresses are not only from applied loads, they result from different manufacturing techniques which result in different residual stresses. This obviously has repercussions on the fatigue and stress corrosion resistance of materials.

Therefore it is important here to study the effect of different manufacturing techniques, such that designers are aware of what they are using. It is not unusual for designers to pay particular attention to the surface roughness generated by the manufacturing process and ignore the resultant residual stress, which will vary according to the process used, and how it is applied.

Certain manufacturing processes can result in various residual stresses from levels approaching the ultimate strength of the material in compression, to high tensile stresses up to and over yield, hence in certain situations surface cracking. Clearly these are extremes, but achievable under quite normal production manufacturing techniques used in the manufacture of aircraft components.

The traditional methods of cutting metals (milling, turning, grinding) have been complimented over the years by several non-traditional methods which do not have mechanical or physical contact. These later processes use energy systems to achieve metal removal which involve, thermal, electrical or chemical reaction.
The resultant surface finish does not have machine lay as experienced by the traditional methods but a random non-directional finish that can be beneficial in eliminating the directional machine lines. However, the methods of achieving metal removal by non-traditional means, can leave the surface in a variety of residual stress states just as traditional methods.

In all of the above residual stress states mentioned, Controlled Shot-Peening will yield the surface and leave a residual compressive stress in line with that mentioned in the introduction.

**FATIGUE - Applied Stress.**

The applied surface stress in combination or otherwise with the residual stress need to be considered.

Shot-Peening the surface results in a residual compressive stress but the stress the surface witnesses is the algebraic sum of the applied and residual. In other words the applied tensile stress has been reduced by the residual compressive stress induced in the surface. Clearly this also applies to torsion and tensile stressed applications. See Figure 3.

The advantage of Shot-Peening is that it can be applied to flat surfaces as well as fillets, grooves, holes, in other words areas where the geometry of the surface generates a stress intensity problem. Therefore, one of the main objectives of shot-peening is to reduce the geometry sensitive nature of aerospace components.

**STRESS CORROSION CRACKING.**

Stress corrosion cracking of materials results from a combination of 1 of the 4 following conditions.

a. A susceptible alloy  
b. A corrosive environment  
c. A tensile stress  
d. Time.

It is therefore possible to influence the performance of any component by adjusting one of these variables. The effect shot-peening has on stress corrosion cracking is to eliminate or considerably reduce the tensile stress and therefore remove one of the conditions for initiation.

One area to immediately highlight is that design engineers do not always consider the combination of residual and applied stress. The approach therefore with Controlled Shot-Peening is to tackle the problem of S.C.C. by maintaining a surface working stress beneath the threshold level of stress needed to initiate stress corrosion cracking.
SHOT-PEENING APPLICATIONS ON AEROSPACE COMPONENTS.

It has been mentioned previously that Controlled Shot-Peening has been used on aluminium structural components, titanium and high strength steels. These materials are susceptible to stress corrosion cracking or fatigue and have been shot-peened to retard the problem. Specifications exist stipulating that all critical surfaces of structural forgings, machine plate and extrusions after final machining and heat treatment must be shot-peened or placed in compression by some suitable means for stress corrosion or fatigue resistance.

One of the forming techniques used by the aircraft industry is peen forming. This dieless forming method uses the principle that if one side of a relatively thin components is bombarded with spherical media, then stretching of the outer layers results, and a curved shape is induced see Figure no. 4.

This technique is used on aircraft skins and fuselage components where single or double curvature shapes are required on components of continuously changing thickness. Not only is this technique used in the shaping of parts, it is also used in straightening components. Many integrally machined parts, after machining, distort through a combination of internal billet stresses and machining induced stresses. The recognised and approved method of correcting these parts is peen straightening. The reason being that correction is achieved by inducing residual compressive stresses on both sides of the component.

Consequently the above method of Peen Forming/Correction and Shot Peening for Fatigue or Stress Corrosion Cracking will result in residual compressive stresses in the surface of aerospace alloys.

One of the major problems here is that on repair and overhaul many organisations do not appreciate why this process was conducted in the first place. With the result that should the surface become damaged or removed through corrosion, fretting, erosion, etc. a loss in stress corrosion and fatigue resistance will result. Fortunately some repair organisations are beginning to appreciate the significance of this treatment and many areas are been re-peened if the aforementioned problems arise.
EXFOLIATION CORROSION.

Exfoliation is a particularly insidious form of intergranular corrosion that can extend well below visible evidence on the surface. It is more commonly noted on certain aerospace aluminium alloys and normally, but not exclusively, associated with the ageing aircraft problem.

Exfoliation corrosion can exist on a surface, although it is not obvious to the naked eye. Exfoliation corrosion can appear relatively light on a surface but can be 3-5mm into the material. The standard approach for removing this type of corrosion is to dress the surface by some means until visible traces have gone and in some cases to remove a further 0.25 - 0.5mm with the idea of playing safe.

Metal Improvement have worked on many areas of exfoliation corrosion to note that this may not be enough or may be excessive. The technique we have adopted is to 'search peen' the surface and expose further exfoliated material.

The technique is to:

a. Aluminium oxide blast the surface to remove visible oxides from aluminium areas and steel fastener heads in close proximity.

b. Dress the area to remove visible corrosion maintaining a width to depth ratio of 20:1.

c. Controlled Shot Peen the dressed areas and at least 10mm beyond any dressed area, using preferably ceramic shot to avoid ferrous contamination and examine the surface for further evidence of exfoliation. If evident that showing is dressed to remove all visible signs. Controlled Shot Peen with ceramic material is conducted once more and if no visible blistering or flaking of the surface is noted, then exfoliation attacking the grain structure causing its separation has been exposed and removed. Should further blistering or flaking be evident then the dressing and peening operations continue until no flaking or blistering occurs.

d. A final aluminium oxide blast is conducted to remove ferrous smearing from any steel fastener heads onto the aluminium structure.

The principle upon which "Search Peening" operates, uses the principle upon which Controlled Shot Peening operates. The action of peening any metallic material is to physically stretch and yield the outer layers of the material. This is highlighted in one of the principal controls of the shot peening process, the Almen strip.
The Almen strip described in more detail later, is a relatively thin standardised section of spring steel which when shot peened, the outer surface stretches with the result that the strip raises towards the peening action. The more heavily you peen the greater the lift, the less you peen the less the lift. This lift or curvature or arc height of the Almen strip, is measured via a dial gauge and gives an indication of the peening intensity.

The same effect is experienced by the exfoliated material, ie thin sections of aluminium alloy, separated by intergranular attack beneath the surface, stretch and lift up away from the parent metal. This is visibly noted as flaking or blistering of the surface. No blistering will be noted when sound material has been reached.

Experience to date has shown that this problem of exfoliation corrosion is more widespread than commonly believed. Cases have been experienced where the search peening technique has been used along steel fastener runs and panel edges where the dressing/peening action has been repeated up to 15 times. In one case through the aircraft skin. Another case of removing fretting corrosion products on a relatively new aircraft, resulted in search peening up to 10 times.

The present recognised techniques of removing visible corrosion and a further percentage of the surface, would not have been adequate in these and many other cases.

Removal of a percentage of material will result in a drop of fatigue/stress corrosion resistance. It may therefore be essential, particularly in those cases shot peened from new, that they are shot peened in a controlled manner as a final finishing technique. Indeed it is further recommended particularly on areas of steel fastener runs and panel edges that the complete fastener runs be "Search Peened" at major overhaul periods and not just those where visible surface corrosion exists. Experience has shown that exfoliation has been exposed in sections where no visible surface evidence was noted.

STEEL FASTENERS.

The ageing aircraft problem has resulted in the breakdown of the treatments of steel fastener heads on wing and fuselage areas resulting in corrosion. This has to be removed but care must be taken as some techniques are more successful than others. The suggested method is aluminium oxide blasting which will cut the surface and abrade off any oxide or ferrous stain from the surface.
Critical shot-peening specifications stipulate 100% coverage as a minimum and more commonly 200% giving a 2-1 safety factor. Poor or partial coverage may result in areas of surface compressive stress of lower magnitude, or worse no effect at all on poorly covered areas. Inspection for adequate coverage is conducted using 2 methods. Both are acceptable but each has particular benefits. The standard method for many years has been visual checking using a 10 or 30 times magnifying glass which is excellent on small, less intricate components of relatively soft material. However, problems of quality assurance are raised on large structures, hard surfaces, and complex shapes where visual inspection with a magnifying glass is called for. Especially when large numbers of components are requiring inspection or complex areas and the chance of human error increased.

Hence the introduction of fluorescent tracers or dyes where the subjective element of inspection is considerably reduced. These dyes specially formulated for this task, are sprayed or brushed onto the surface and allowed to dry. A hard, thin, brittle film is left which when examined under ultra violet light, appears white.

Shot-Peening is then conducted and the thin film is eroded from the component in direct relation to the level of coverage. After shot-peening the part is examined under UV light and areas inadequately covered appear white or speckled white. Certain critical specifications now highlight this technique as an assurance of shot-peening coverage.

c. Intensity.

The intensity of shot-peening is an indication of the kinetic energy, (mass and particle velocity) transferred to the surface of the part, and is demonstrated using the Almen strip. The Almen strip works on a principle that if a flat piece of metal is clamped to a solid block and exposed to a degree of shot-peening it would be curved upon removal from the block. The height of the curve, measured on a special gauge, namely an Almen gauge serves as a measure of intensity. Different strips are available for different intensity ranges.

The test strips are mounted on a holding block, which will be supported on a fixture to simulate the actual production component and area being shot-peened. For a more complicated part a number of test strips may be needed on the same fixture.

d. Mechanisation.

To ensure repeatable and consistent shot-peening it is necessary to mechanise the process. As expressed earlier, variations on how the process is controlled result in variations in magnitude and depth of residual stress.
Therefore the only means of consistent processing is to mechanise the component and all nozzles/wheels such their relative motions can be repeated. Unfortunately some processing still exists today where the parts are "hosed down" by hand with little control of shot quality.

Fortunately knowledge of the critical features of the process are being better understood and practices which not only may give fluctuating performance but may reduce life, are slowly being eradicated. Mechanisation has developed to such an extent that computer controlled shot-peening machines are in use. The relative motions of the peening stream and components are controlled, monitored and recorded in addition to the shot flow, pressure, media level, etc.

e. Designation.

It is important that when specifying the process all critical parameters are designated. An analogy is that many years ago designers used to specify "heat treatment" or "hardened" on a drawing. Today they are very detailed in their requirement because it has been recognised that "harden" is unspecific and a considerable fluctuation in performance will result. It is not uncommon to see shot-peening specifications on a drawing simply state "shot peen". This, as in heat treatment, is totally unacceptable.

CONCLUSIONS.

Fatigue, Stress Corrosion Cracking and Fretting can result from tensile stresses induced in the surface of a component. If a residual compressive stress of predictable magnitude and depth is induced these problems can be considerably reduced. This can be achieved by shot-peening in a thoroughly controlled manner.

However, it is equally important that repair organisations understand that Controlled Shot-Peening is there for specific reasons and should the surface be removed for any reason during repair and overhaul periods then Controlled Shot-Peening must be repeated in the same well controlled manner.

"Search Peening" when applied to areas where Exfoliation Corrosion is seen or believed to be will result in its exposure. Dressing techniques are adequate for removing the problem but not for finding it.
FIG 1. RESIDUAL STRESS PRODUCED BY SHOT-PEENING VS. TENSILE STRENGTH OF STEEL

FIG 2. DEPTH OF COMPRESSION VS. ALMEN ARC HEIGHT

FIG 3. STRESS DISTRIBUTION IN A PEENED SHEET WITH BENDING LOAD.

FIG 4. COMPOUND CURVATURE RESULT OF TRI-AXIAL FORCES INDUCED BY SHOT PEENING.