SHOT PEENING RETARDS "FRETING"

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ABSTRACT

Controlled shot peening is well known to be very effective against metal fatigue. However, its effect in retarding or eliminating fretting is not as well understood. Fretting, a complex deterioration phenomenon caused by the small amplitude relative motion of two mating metallic surfaces against one another, is described and analysed.

Fretting corrosion, fretting wear and fretting fatigue are discussed.

Increases in contact area, compressive residual stresses, improved lubrication and high material hardness are beneficial to fretting performance whereas high contact pressures, lack of lubrication, increased motion amplitude and low harness are detrimental.

The effects of controlled shot peening along these lines are investigated:

1. effect on contact area  
2. residual compressive stress  
3. mating surface peak elasticity  
4. debris removal  
5. lubricant retention  
6. microcracks arrest  
7. cold work  
8. surface texture

The applicability of shot peening to improve the fretting performance of carbon steels, alloy steels, stainless steels, Titanium alloys and Aluminum alloys is investigated and several case histories and experimental data compiled from various sources serve to illustrate the effectiveness of the process.

KEYWORDS

Fretting corrosion, fretting wear, fretting fatigue, residual compressive stress, surface texture, mating surfaces, workhardening.
FRETTING

This type of surface destructive phenomenon of metallic parts, in contact and under pressure and animated by minute relative movements is also called wear through micro-movements (UIP) and cracking through micro-movements (FIP).

Fretting may be decomposed into two distinct phenomena:

* Fretting corrosion (UIP : usure induite par petits déplacements)
* Fretting fatigue (FIP : fissure induite par petits déplacements)

Fretting is caused by small amplitude cyclical movement of two solid bodies in close contact and under pressure. The exerted pressures are sufficiently high and the movement sufficiently small so that the debris produced may not escape from their point of origin.

The fretting causes shear peaks by friction between the contact zones and the non-contact zones onto which are superposed local plastic deformations of the asperities. There follows microwelds of these asperities under the influence of the high contact pressures and the temperatures due to the plastic deformations.

The minute relative displacements of the contact surfaces subsequently cause the rupture of the asperities, which then oxidize.

The phenomenon of metallic fragment dislocation will accelerate under the amplifying influence of the oxidized particles, often much harder than the base metal.

Score marks and severe surface damage will soon appear under the influence of the applied service stresses of the moving parts added to the shear stresses due to friction, fatigue microcracks will develop and propagate leading to eventual part rupture.

![Diagram of damage process on aluminum alloys from CEAT](image-url)
Fretting develops in three stages:

1. Surface corrosion
2. Wear
3. Fatigue

Contact corrosion and induced wear cause the appearance of the "third corps" which are called debris. These debris are of a different nature to the metallic surfaces from which they originated, because they have sustained extreme solicitations (welding, rupture temperature, pressure, oxidation). Depending on their hardness and form they will play a different role.

In the case where these particles are harder than the base metal surface, and irrespective of their form, we have wear acceleration by abrasion and increased friction.

![Fig. 2: Hard Angular Debris](image)

In the case where the particles are softer than the base metal surface, their form will progressively round-off, and we will see a decrease in friction as one surface rolls over the other:

![Fig. 2 bis: Soft Rounded Debris](image)

Various solutions generally used to combat fretting are: better dry or liquid lubrication; blockage of surface relative movements; interposed low-shear modulus materials or placings; surface grooving or roughening for debris escape routes; shot peening; cold rolling.
FRETting MINimIZATION

<table>
<thead>
<tr>
<th>FAvOURABLE PRINCIPLES</th>
<th>uNFAVOURABLE PRINCIPLES</th>
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<tbody>
<tr>
<td>* Surface bearing characteristics</td>
<td>* High contact pressures</td>
</tr>
<tr>
<td>* Compressive residual stresses</td>
<td>* Lack of lubrication</td>
</tr>
<tr>
<td>* Lubrification retention</td>
<td>* Movement amplitude</td>
</tr>
<tr>
<td>* High material hardness</td>
<td>* Low material hardness</td>
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</table>

One finds fretting in bolted structures, rivetted structures, ball bearing races, leaf spring assemblies, twisted cables, turbine-blade base connections, elastic pin connections, connecting rod bushings etc...

Certain well-known case have left their mark on industry:

* Fretting on ball bearing and races in the automobile industry which appeared during train and truck transport of new vehicles for delivery.

* Fretting under the conical screw heads of stainless steel surgical implants.

* Fretting of aluminum munitions casings during the second world war.

* Fretting of railway bogie, axle and hub connections in steel and iron.

CONTROLLED SHOT PEENING TO COMBAT FRETting

Shot peening or controlled impact prestressing is the science of hammering a surface through the aid of spherical shot.

![Diagram of shot peening process]

**Fig 3: Principle of controlled shot peening**
A shot peening surface is characterized by impact dimples like spherical dishes surrounded by a slight peak. The depth and diameter of these dimples are adjustable as a function of the treatment parameters; let us recall these parameters:

* Nature, size and hardness of the shot.
* Almen intensity.
* Amount of coverage.

The surface morphology and the friction coefficient will, of course, be distinctly modified by the shot peening, as will be the local strain hardening effect which can attain 1 mm in depth.

This strain will also influence the materials microstructure causing a certain increase in surface hardness. In addition, a residual stress is introduced by the shot peening which plays an important role in fretting-fatigue life.

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**Fig 4**

Effects of controlled shot peening

- Creation of minute surface dimples
- Surface strain hardening
- Surface morphology and friction coefficient
- Compressive residual stress

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The complete interaction fretting / shot peening may be represented diagrammatically as follows:

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**Fig 5**

Fretting | Shot Peening
---|---
* contact pressure | * bearing capacity
* nominal stress | * residual stress
* displacement amplitude | * peak elasticity
* debris | * debris absorption
* lubrication | * lubricating agent retention
* microcracks | * microcrack blōcage
* hardness | * microstructure
* friction | * surface morphology
Bearing Capacity

Two machines surfaces together, in reality, have few contact points, causing very high contact pressures at these points.

![Fig 6]

When one of the two surfaces has been shot peened, the bearing capacity is considerably modified. Bearance is assured by a multitude of points or peaks which will each absorb a part of the contact pressure. Plastic deformation of the highest points will permit the initially lower peaks to subsequently participate in the bearance effort distribution over all the surface.

![Fig 7]

Residual Stress

The residual stress field introduced by shot peening is already well-known. It is characterized by three particular points:

- $C_s$ - surface stress
- $C_{\text{max}}$ - maximum stress
- $C_n$ - zero stress

![Fig 8: Residual stress distribution introduced by shot peening]
These stresses are of a high magnitude. The maximum stress value equals 0.5 to 0.7 times the tensile strength of the shot peened material and the depth varies from several thousands of an inch up to approximately 4/100 inch.

The graph in Fig. 9 allows us to estimate the depth of compression as a function of the Almen intensity for different materials such as aluminum alloys, various hardness steels, titanium and a nickel based alloy.

**Fig 9**

**Peak Elasticity**

When two surfaces are in contact and sustain a relative microscopic motion, the elasticity of the peaks or contact points on which the surface is carried plays an important role. In fact, at the limit, if the peak elasticity is such that it can accept relative movement without plastic deformation, then the capacity to "slide" disappears.

**Fig 10**
Take as an example a hair brush. When you place your hand on a brush and move it back and forth, the brush will move in relation to your hand without friction. The elasticity of the brush hairs have absorbed the movement amplitude.

We can easily imagine that if the peak created by shot peening absorb the relative movement amplitude of the two contacting surfaces, then the fretting condition disappears through lack friction.

Debris Absorption

We have seen why most debris are harder than the base metal from which they originated. The possibility of absorbing them in cavities is generally a favorable factor. The craters formed on the surface through the shot impacts permit this debris retention.

Retention of Lubricating Agents

The very local contact pressures on the asperities often leads to rupture of the oil film or expulsion of the lubricating agent. The weak cyclic amplitude of movement can sometimes amplify the phenomenon. The possibility of keeping pockets of lubricants in the immediate proximity to the maximum pressure permits a better lubrication of the compressed surfaces. The elastic deformation of the pressured surface leads to the elimination of the lubricant which would generally oppose the applied surface pressures.

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Fig. 11

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Fig. 12
Microcrack Blockage

A fatigue crack will not propagate if it is imprisoned in a compressively zone. Shot peening, by the introduction of residual compressive stresses, opposes crack propagation and considerably slows the rupture of a part through fretting.

Fig 13: The compressive stresses oppose the opening of microcracks and arrest their propagation.

Microstructure

Shot peening is a mechanical treatment that cold work hardens the metallic surfaces. This stress hardening can produce a considerable superficial hardness increase which will improve wear characteristics.

The increase in hardness as a function of depth on shot peened satellite is a classic example.

Surface Morphology

The very original surface aspect produced by controlled shot peening often causes a reduction in the friction coefficient especially when only one of the two contacting surfaces is treated.
If, on the contrary, a relative movement blockage is required, then shot peening of both surfaces would be necessary. In this case of micro-oscillations, this solution would appear to be the best.

**Carbon Steel Type XC18**

Fretting has a great influence on steels. In fact, in many cases a reduction in durability of a factor of 10 or more is quite frequent.

In general, the softer the steel the greater will be the damage through fretting.

The increase in hardness by the pronounced strain hardening effects of shot peening on soft steels is a major contributing factor in their durability improvements when faced with fretting corrosion phenomenon. The fretting fatigue limit, in durability tests, passes from 150 to 225 MPa through shot peening which is an increase of 50%.

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**Fig 16**: Fretting and fatigue life of shot peened XC18 steel
Lightly Alloy steel 42CD4

This test on a joined assembly of 42CD4 shows a gain of the same order as for the XC18 steel after shot peening.

30 NCD 16 Steel

This steel is utilised extremely in the aeronautical industry. An example of fretting is frequently encountered under the bearing cage contact surface on transmission shafts.

Shot peening allows an important gain. In the test conditions shown in fig 19 the fretting fatigue life increase is more than 200%.
Austenitic Stainless Steel

The influence of fretting is much greater on stainless steels of type 304 than on soft steels. Fretting fatigue life deterioration is from 280 to 165 MPa, a decrease of approximately 40%. Shot peening allows a gain under fretting conditions, such that it will equal the non-shot peened pure fatigue test results. The test conditions and shot peening parameters are the same as for those in the carbon steel tests. The increase in hardness after shot peening of austenitic stainless steels is certainly on the fretting behavior.

![Graphical representation of fretting behavior](image)

Fig. 20

![Graphical representation of depth](image)

Fig. 21

On the other hand, the stainless steels natural sensitivity to "gripping" is a factor of aggravation on the microwelds and thus to fretting corrosion.

Titanium

Titanium is a material sensitive to fretting, even more so than steels. The loss of endurance of titanium through notch sensitivity is well known. In this case, shot peening has shown, since long ago, a great effectiveness in "desensitising" titanium, and increasing its resistance to surface damage.

Tests on titanium specimens under three different levels of contact pressures have shown an increase degradation of the fretting behavior, in a polished conditions, as a function of the increased pressure. The shot peening, when applied to the same specimens under the same test conditions again proves its high effectiveness.
Fig 22: Fatigue limit at 107 cycles

<table>
<thead>
<tr>
<th>TITANIUM - TI 140A</th>
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<tbody>
<tr>
<td>Surface state ........ polisher</td>
</tr>
<tr>
<td>Contact pressure for</td>
</tr>
<tr>
<td>light fretting .......... 45 MPa</td>
</tr>
<tr>
<td>moderate fretting ......... 60 MPa</td>
</tr>
<tr>
<td>severe fretting .......... 70 MPa</td>
</tr>
<tr>
<td>Shot peening :</td>
</tr>
<tr>
<td>shot: ......................... M1 330</td>
</tr>
<tr>
<td>Almen intensity ........... 18A (F45A)</td>
</tr>
<tr>
<td>Coverage ...................... 125%</td>
</tr>
<tr>
<td>Control coverage ........ Peenscan</td>
</tr>
</tbody>
</table>

The shot peening parameters should be judiciously chosen so as to obtain the best compromise between residual stress and surface morphology. The diagram below shows us the risk of dispersion in results due to badly adapted parameters.

* Material TA 6V; polished conditions
* Shot peening SP1 intensity 3/5A (F10A)
* Shot peening SP2 intensity 8/10A (F 22A)
Aluminum Alloy 2014

This material is also very sensitive to fretting. The fretting phenomena can reduce, by a factor of three, the admissible fatigue stress of a polished test specimen. In this case also, shot peening will regenerate the fretting-fatigue limit to the same level as that of a polished specimen submitted to a pure fatigue endurance test.

![Graph showing alternating stress vs. number of cycles for different conditions.](image)

**Fig. 24**

<table>
<thead>
<tr>
<th>ALUMINUM 2014</th>
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<tbody>
<tr>
<td>Contact pressure........MPa</td>
</tr>
<tr>
<td>contact type..........alu/alu</td>
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<tr>
<td>S.P. parameters :</td>
</tr>
<tr>
<td>shot....................MI330</td>
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<tr>
<td>intensity.............12/16 A (F36A)</td>
</tr>
<tr>
<td>coverage.............125%</td>
</tr>
<tr>
<td>control................Peenscan</td>
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<tr>
<td>frequency.............50 Hz</td>
</tr>
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The induced residual stresses play an important role in the shot peening effectiveness. The Wohler curves below show us that the shot peened state is far better than the unpeened polished state.

On the other hand, when these residual stresses are relaxed by stretching, the shot peening loses all its effectiveness.

![Graph showing alternating stress vs. number of cycles for different stretched conditions.](image)

**Fig. 25**
Aluminum Alloy 7075

Tests on aluminum alloy 7075 show a perfect desensitization to fretting through shot peening. In fact, the fatigue and fretting durability are the same after shot peening. In the case of untreated test samples, the loss of endurance through fretting is in the order of 50%.

<table>
<thead>
<tr>
<th>ALUMINUM 7075</th>
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<tbody>
<tr>
<td>Contact pressure.............32 MPa</td>
</tr>
<tr>
<td>Shot peening parameters :</td>
</tr>
<tr>
<td>shot..........................MI 330</td>
</tr>
<tr>
<td>Almen intensity.............12/16A(F35A)</td>
</tr>
<tr>
<td>coverage .....................125 %</td>
</tr>
<tr>
<td>control .....................Peenscan</td>
</tr>
<tr>
<td>frequency ...................25Hz</td>
</tr>
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</table>

Fig 26
REFERENCES


