SHOT PEENING RETARDS " FRETTING"

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ABSTRACT

Controllled 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 metalic parts, in contact and under pressure and animated by minute relative movements is also called wear through micro-movements or (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 exerced 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 oxydize.

The phenomenon of metalic fragment dislocation will accelerate under the amplificating influence of the oxydized 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.

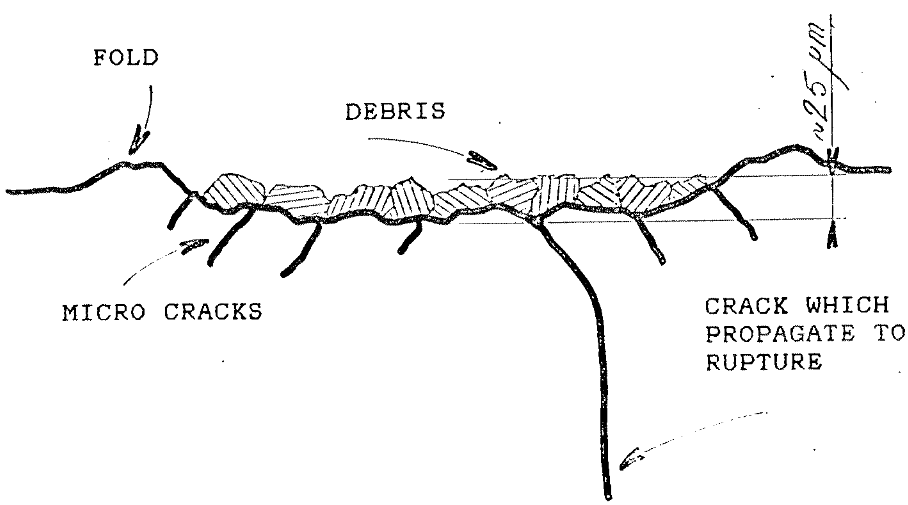


Fig. 1 : diagram of the damage process on aluminum alloys from CEAT

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 metalic surfaces from which they originated, because they have sustained extreme solicitations (welding, rupture temperature, pressure, oxydation). 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.

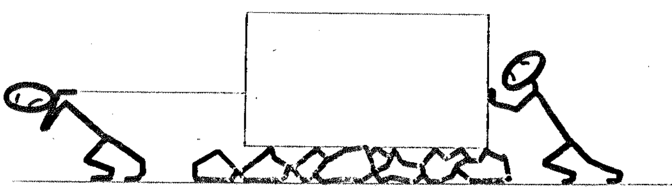


Fig. 2 : Hard Angular Debris

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 :

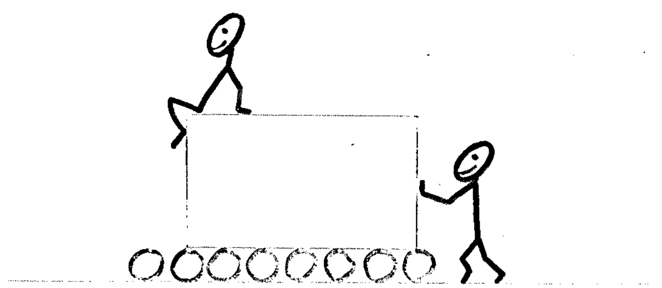


Fig 2 bis : Soft Rounded Debris

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

FRETTING MINIMIZATION	
FAVOURABLE PRINCIPLES	UNFAVORABLE PRINCIPLES
* Surface bearing characteristics	* High contact pressures
* Compressive residual stresses	* Lack of lubrification
* Lubrification retention	* Movement amplitude
* High material hardness	* Low material hardness

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 racers in the automobile industry which appeared during train and truck transport of new vehicules 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.

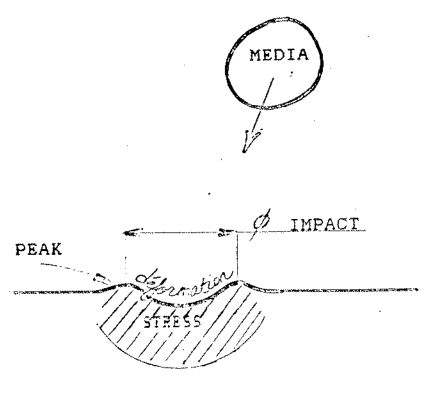


Fig 3 : Principle of controlled shot peening

A shot peening surface is characterized by impact dimples line 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.

EFFECTS OF CONTROLLED SHOT PEENING
* Creation of minute surface dimples
* Surface strain hardening
* Surface morphology and friction coefficient
* Compressive residual stress

Fig 4

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

FRETTING	SHOT PEENING
* contact pressure..................	* bearing capacity
* nominal stress.....................	* residual stress
* displacement amplitude............	* peak elasticity
* debris............................	* debris absorption
* lubrification.....................	* lubrificating agent retention
* microcracks.......................	* microcrack blocage
* hardness..........................	* microstructure
* friction..........................	* surface morphology

Fig 5

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 absorbe 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.

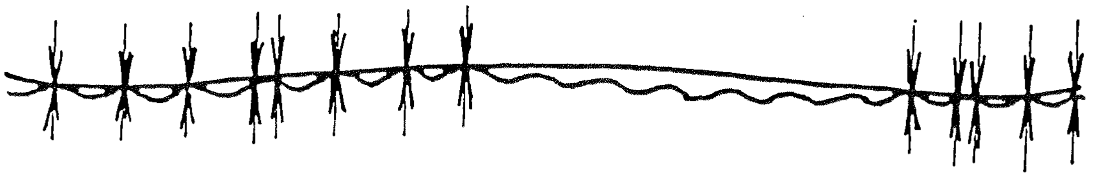


Fig 7

Residual Stress

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

- Cs - surface stress
- Cmax - maximum stress
- Cn - zero stress

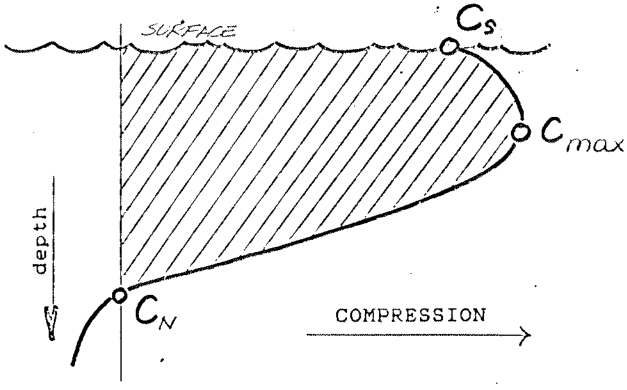


Fig. 8 : Residual stress distribution introduced by shot peening

These stresses are of a high magnitude. The maximum stress value equals 0.5 to 0.7 times the tensiles 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.

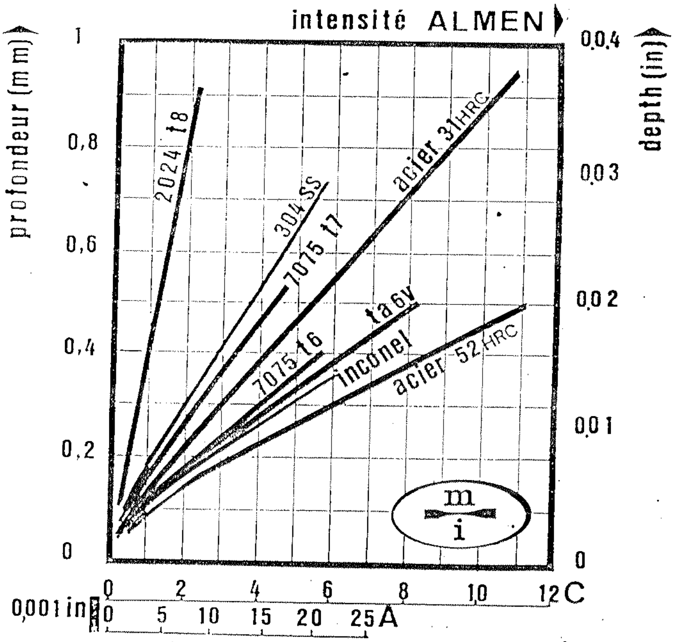


Fig 9

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.

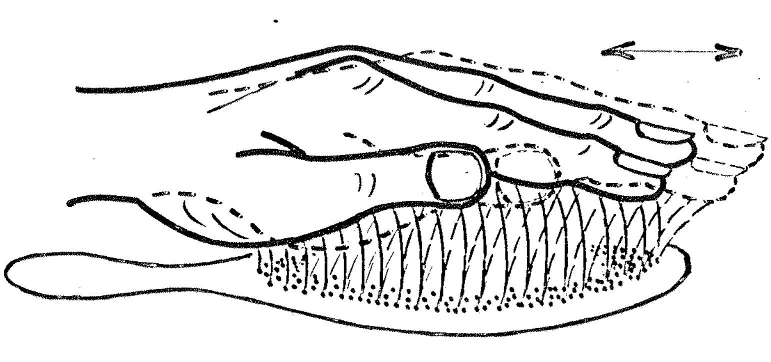


Fig 10

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.

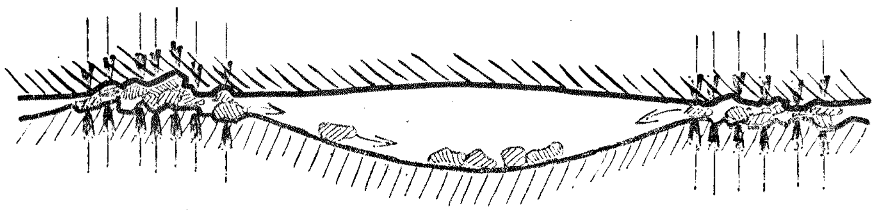


Fig 11

Retention of Lubrificating Agents

The very local contact pressures on the asperities often leads to rupture of the oil film or expulsion of the lubrificating 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.

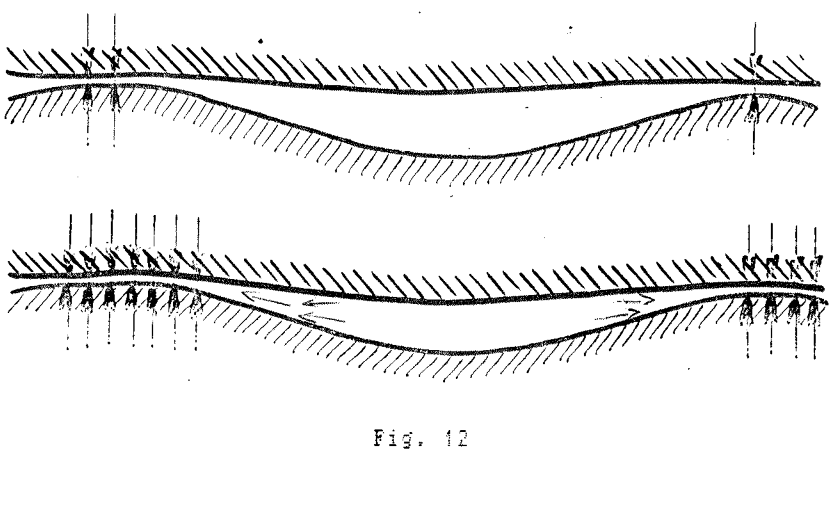


Fig. 12

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.

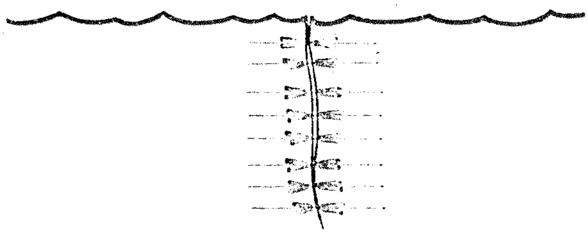
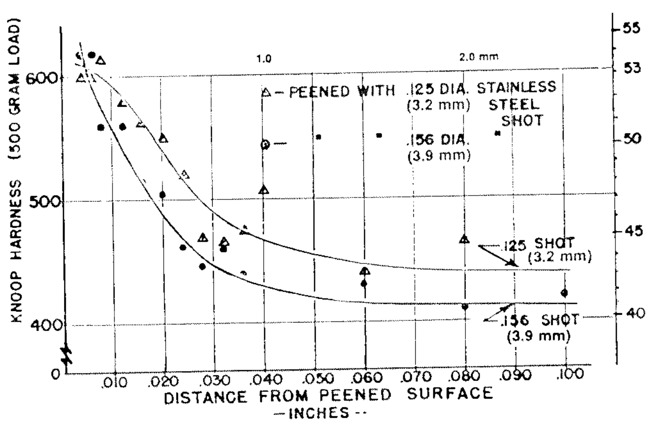


Fig 13 : The compressive stresses oppose the opening of microcracks and arrest their propagation

Microstructure

Shot peening is a mecanical treatment that cold work hardens the metalic 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.



–HARDNESS vs. DEPTH FOR SHOT-PEENED STELLITE THRUST RUNNER SEGMENT (Ref.50)

Fig 14

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 the both surfaces would be necessary. In the case of micro-oscillations, this solution would appear to be the best.

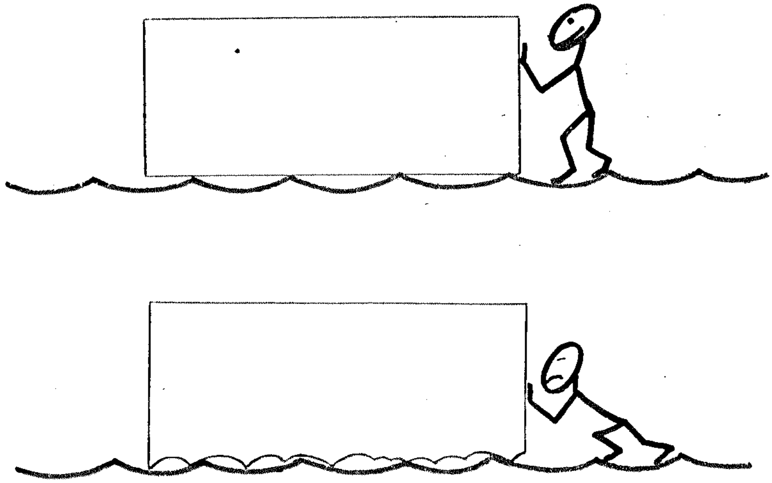


Fig 15

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 %.

Contact	Steel/Steel
contact pressure	68MPa
frequency	35Hz
SP MI 230	diam 0.84
intensity 8.12A	F20/30A
coverage	125%
control	Peenscan

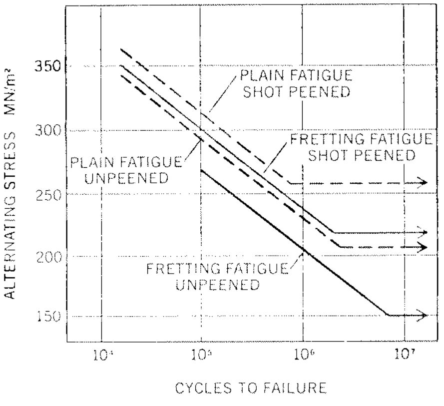


Fig 16 : fretting and fatigue life of shot peened XC18 steel

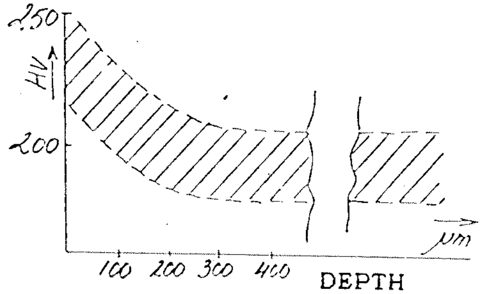


Fig 17 : increase in surface hardness due to shot peening

Lighty Allloy 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.

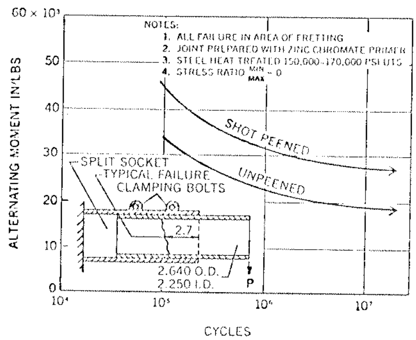


Fig 18

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 %.

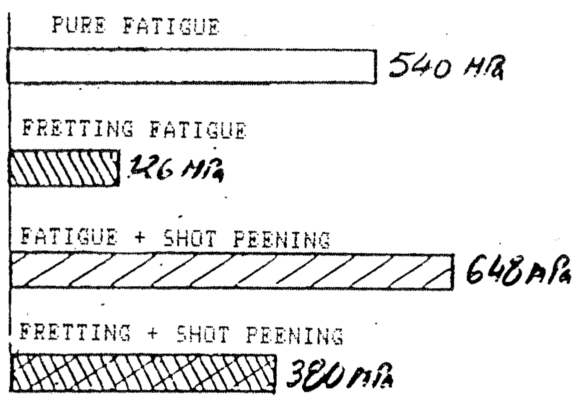


Fig 19

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.

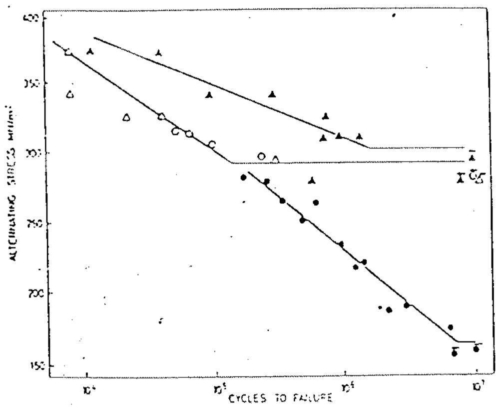


Fig. 20

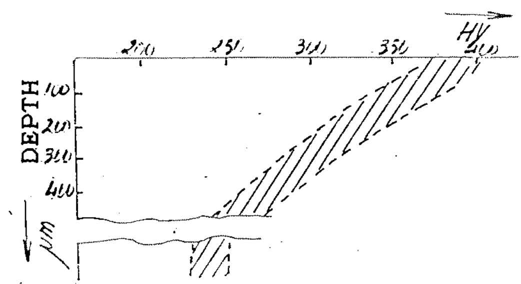


Fig 21

On the other hand, the stainless steels natural sensitivity to "gripping" is a factor of agravation 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 resitance to surface damage.

Tests on titamiun 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.

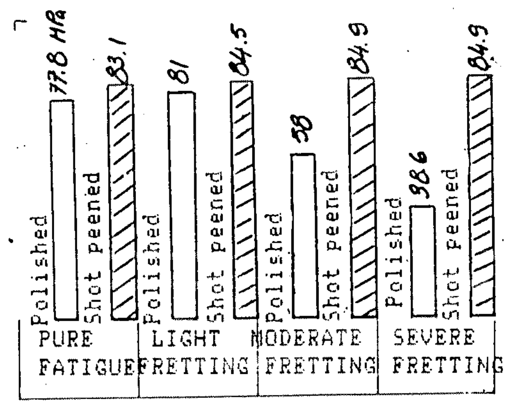
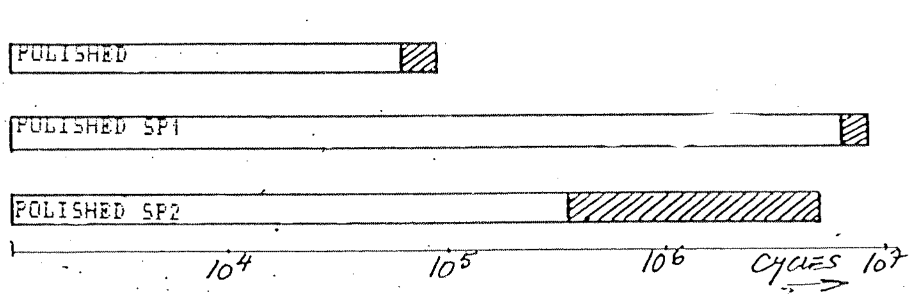


Fig 22 : Fatigue limit at 10^7 cycles

TITANIUM - TI 140A	
Surface state	polished
Contact pressure for :	
light fretting	45 MPa
moderate fretting	60 MPa
severe fretting	70 MPa
Shot peening :	
shot	MI 330
Almen intensity	18A(F45A)
coverage	125 %
control coverage	Peenscan

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.

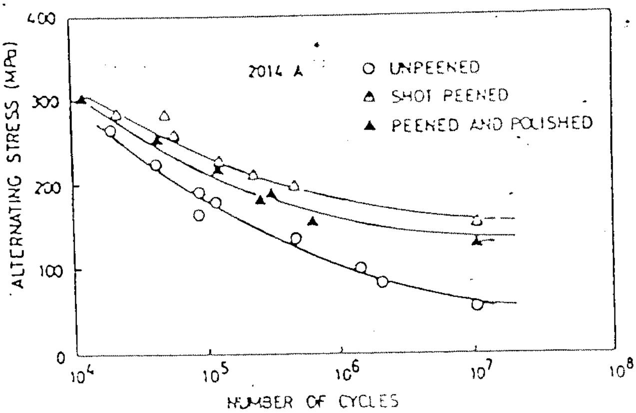


* Material TA 6V ; polished conditions
* Shot peening SP1 intensity 3/5A (F10A)
* Shot peening SP2 intensity 8/10A (F 22A)

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.

Fig. 24



ALUMINUM 2014	
Contact pressure	......MPa
contact type	.........alu/alu
S.P. parameters :	
shot.	................MI330
intensity	............12/16 A(F35A)
coverage	.............125%
control	...............Peenscan
frequency	............50 Hz

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 looses all its effectiveness.

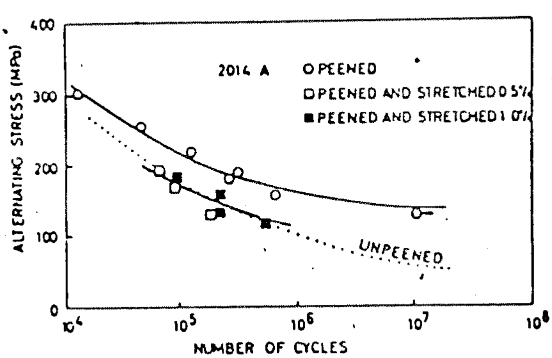


Fig. 25

Alunimun Alloy 7075

Tests on aluminum alloy 7075 show a perfect desensitizationto 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 %.

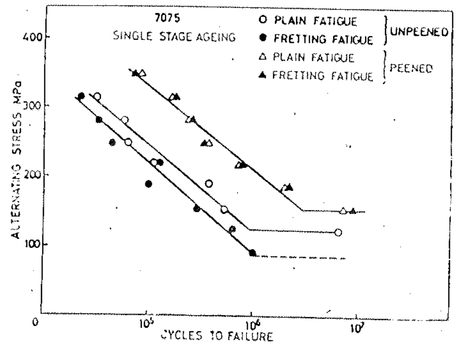


Fig 26

ALUMINUM 7075
Contact pressure..........32 MPa
Shot peening parameters :
shot.....................MI 330
Almen intensity...........12/16A(F35A)
coverage.................125 %
control..................Peenscan
frequency................25Hz

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