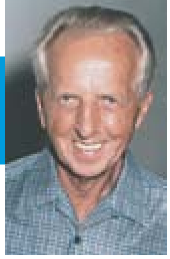

ACADEMIC STUDY
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Shot Stream Force Affects Thin Components

INTRODUCTION

The force exerted by a shot stream must always generate some degree of component bending. This bending may be so small as to be insignificant—as is the case with 'thick' components. With 'thin' components, however, component bending always induces an element of stress peening. The degree of bending depends on three factors:

Magnitude of applied force, F,
Thickness of component, t, and
Distance between supports, L.

Fig.1 illustrates the three controlling factors applied to, for example, a machined computer case. Sample calculations indicate that: for a force of 10 N applied centrally to an aluminum case 1mm thick, 200 mm wide by 300 mm long (.04" x 8" x 12"), the deflection would be 5 mm (.2"). At 0.78 mm (.03") thick the deflection would be 10 mm (.4").

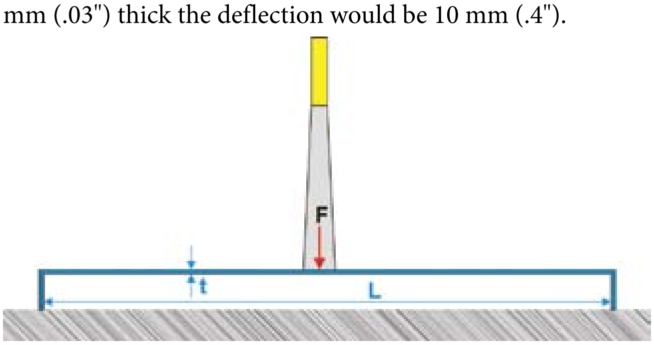

Fig.1 Schematic representation of factors affecting shot stream bending of a component.

It was shown, in the previous article in this series, that the magnitude of the shot stream force can be both predicted and measured. The force that an air-blast shot stream applies (to reasonably-flat surfaces) is in the region of tens of Newtons. Wheel-blast machines can impose hundreds of Newtons of force. Force is generated by a combination of the air stream and the high-velocity shot particles. Very large forces can be exerted when water is used, either on its own or as the accelerating fluid for shot particles. The thickness of a component determines its rigidity (resistance to bending) and the distance between supports determines the amount of 'bending moment' that a given force generates.

Component bending generates a stress distribution in the component with maximum stresses being at the surface. For the previous example, a surface stress of ±23 MPa can be predicted at 45% of the yield strength of pure aluminum.

This article is concerned with showing (a) how the effects of shot stream force can be quantified and (b) identifying whether or not these effects will significantly affect shot peening parameters—such as peening intensity, coverage and residual stress profile. Simple component shapes are used to minimize the mathematical complexities involved. As shot peening evolves there is an increasing interaction with other engineering disciplines. Several basic mechanical engineering principles are invoked in this article.

INDUCED BENDING

Rigidity

The amount of bending depends upon the component's rigidity. A simple demonstration is to press one finger on the center of Almen strips whilst they are mounted on an Almen gage. N strips will show a significant dial reading with even a gentle pressure. C strips, on the other hand, will not show a significant deflection - even with a high finger pressure.

For rectangular components the rigidity, **I**, is given by:

$$\mathbf{I = w{*}t^3/12} \qquad (1)$$

where **w** is strip width and **t** is strip thickness.

Equation (1) shows that the rigidity is proportional to the cube of the thickness. For N, A and C strips, **w** is constant but the strip thickness **t**, varies. The ratios of thickness cubed are: 1 to 4.5 to 28 for N, A and C strips respectively. Hence, C strips are 28 times as rigid as are N strips and A strips are 4.5 times as rigid as are N strips.

Deflection

Deflection, **d**, of a rectangular beam of length, **L**, with a centrally-applied load, **F**, is given by the 'textbook' equation:

$$\mathbf{d = F{*}L^3/(48{*}E{*}I)} \qquad (2)$$

where **E** is the elastic modulus of the component material.

Substituting the value for **I** given in equation (1) gives that:

$$\mathbf{d = F{*}L^3/(4{*}E{*}w{*}t^3)} \qquad (3)$$

Equation (3) gives us a quantitative 'feel' for the magnitude of deflection. Doubling the force doubles the deflection whereas doubling either the modulus or the width halves the deflection.

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Far more significant are the unsupported length, **L**, and the thickness, **t**. Doubling the length multiplies the deflection by a factor of 8 (2^3) whereas doubling the thickness reduces the deflection, also by a factor of 8. The assumption of the load being centrally applied is reasonable provided that the shot stream diameter is much less than the unsupported length. If the shot stream diameter is such that the load is 'uniformly applied' then the deflection is 40% less than that predicted by equation (3). The relevant equation now becomes:

$$\mathbf{d = F^*L^3/(6.4^*E^*w^*t^3)} \qquad (4)$$

Fig.2 illustrates how deflection of the component shown in fig.1 could be virtually eliminated by using a support block. In effect, the unsupported length has been reduced to zero. An alternative would be to shot peen both major surfaces simultaneously.

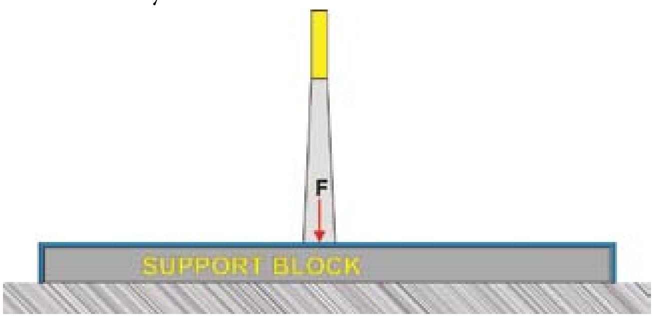

Fig.2. Deflection reduction by use of a support block.

Minimizing the deflection also minimizes the bending stress distribution.

Bending Stress Distribution

Bending of a component, caused by the force of a shot stream, produces a stress distribution. This is additive to the residual stress distribution produced by plastic deformation. The magnitude of the bending stress distribution therefore has practical consequences.

Fig.3 shows the terms involved in stress estimation. A centrally-applied force, **F**, has induced a radius of curvature, **R**, in a strip of length, **L**. The degree of bending, **1/R**, varies from zero at each end of the strip to a maximum at the center-point. Compressive stress is induced on the upper surface and tensile stress on the lower surface. The linear variation of stress between upper and lower surfaces is indicated in the 'call-out' in fig.3.

The induced surface stress, σ, which is generated by a load centrally-applied to a rectangular beam, is given by:

$$\boldsymbol{\sigma = \pm 1.5^*F^*L/(w^*t^2)} \qquad (5)$$

It is noteworthy that the induced stress is independent of the material's elastic modulus.

Equation (5) can be used to predict the induced surface stress provided that we know any three of the variables (**F, L, w and t**). Fig.4 is a typical example using the known dimensions of Almen strips and assuming that the distance, **L**, is 40 mm (1.6") (this being the distance between hold-down screws/ bolts). This shows that significant surface stress levels can be induced in N strips – whereas only low levels of surface stress are induced in thicker strips.

Fig.4 predicts that with an applied force of 20 N there will be an induced surface stress of -100 MPa in an N strip. Equation (3) predicts that the corresponding deflection would be 0.166 mm (.006").

The sign of the surface stress (compressive or tensile) depends on the way that a component is supported. Simple end support (as shown in fig.3) will induce compressive stress

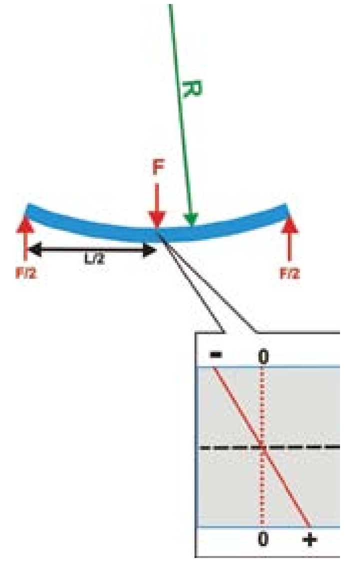

Fig.3 Induced bending stress distribution.

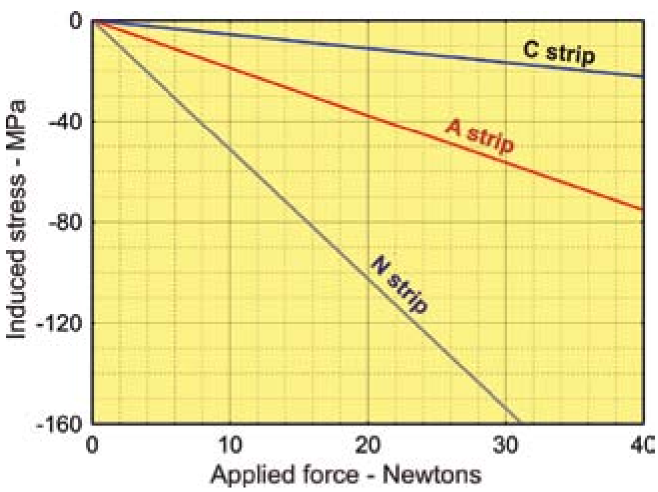

Fig.4 Surface stress induced by force applied centrally to Almen strips when L is 40mm (1.57").

in the surface being peened. If, however, we have just one end being clamped then the bending will induce tensile surface stresses in the surface being peened. This is illustrated in fig.5.

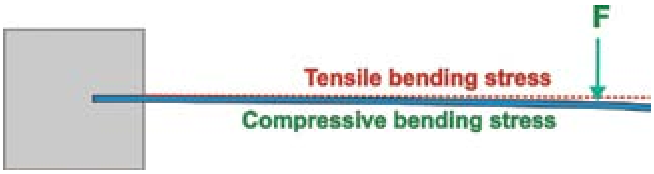

Fig.5. Shot stream applying a force, F, to an end-clamped strip.

COMBINATIONS OF RESISTANCE, BENDING AND RESIDUAL STRESSES

The first shot particles that indent a surface only have to contend with resistance stresses around each indent, see fig.6. These resisting stresses, - **q**, are compressive and account for very high component ductility (as discussed in a previous article in this series). For plastic deformation to occur, the shot particle has to exert a compressive stress, - **i**, that equals the yield strength of the component plus the resistance stress. Hence the stress system is given by:

$$-\mathbf{i} = \mathbf{Y} + \mathbf{q} \qquad (6)$$

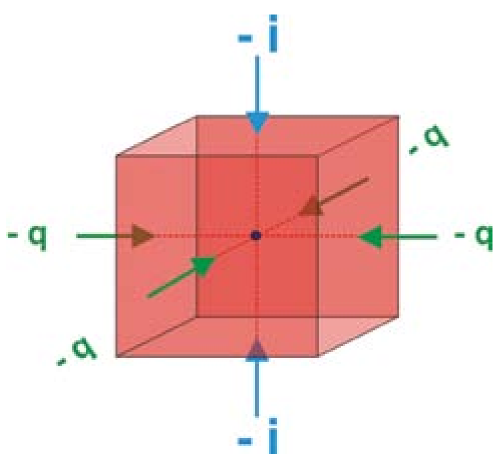

Fig.6. Stress system for initial shot peening indentations.

The stress that has to be imparted by subsequent impacts also depends on whether or not there is a bending stress element. With no bending, subsequent impacts have to overcome a combination of yield strength, resistance stress and the developing surface compressive residual stress, - **rs**. Hence we have the stress system:

$$\mathbf{i} = \mathbf{Y} + \mathbf{q} + \mathbf{rs} \qquad (7)$$

This stress system is illustrated in fig.7.

When there is also a compressive bending component, subsequent impacts then have to overcome the quadruple combination of yield strength, resistance stress, the developing surface compressive residual stress, - **rs**, and the bending stress component, **bs**. Hence the stress system is now given by:

$$-\mathbf{i} = \mathbf{Y} + \mathbf{q} + \mathbf{rs} - \mathbf{bs} \qquad (8)$$

Fig.8 illustrates the stress system incorporating all three compressive stress components.

The relevant stress system determines both the size of the consequent indentation and the reigning level of ductility. Indent diameter, for an individual impact, will be smaller with increased residual- and bending-stress components and with increasing yield strength. Component ductility, on the other hand, will increase with greater residual- and bending-stress components.

CASE STUDY – ALMEN STRIP PEENING

One type of thin component that is familiar to all shot peeners is the Almen strip. For that reason, peening of Almen strips provides an appropriate subject for a case study. This case study starts with a qualitative analysis of what happens to

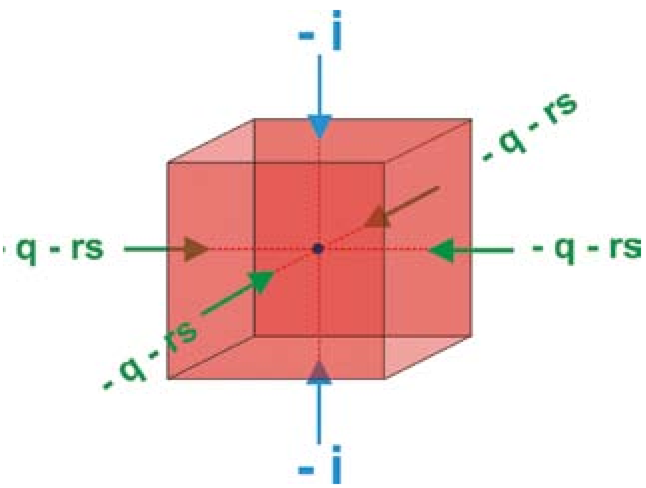

Fig.7. Stress system with residual stress component added.

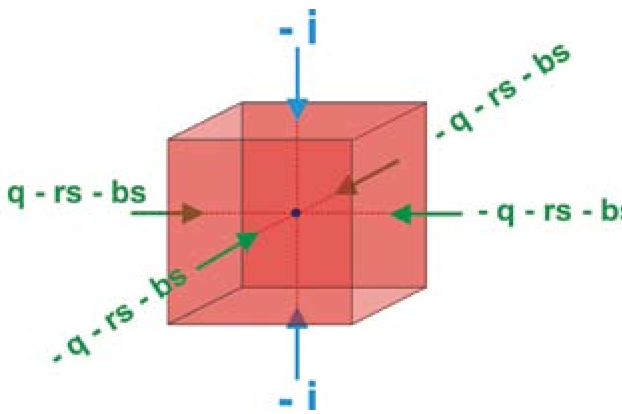

Fig.8. Stress system with both residual stress and bending stress components.

an Almen strip during peening and is followed by quantitative illustrations.

Qualitative Analysis
When peening of a flat Almen strip begins, the strip cannot bend regardless of the shot stream force. That is because the strip is being supported all along its length. Equation (6) then governs the relevant stress system. After further peening, the strip begins to adopt a convex curvature (see fig.9). Curvature occurs even though the strip is being restrained by four screws/bolts. The strip also develops surface compressive residual stress. During peening, this curvature will be opposed by the bending force being applied by the shot stream, inducing compressive bending stress in the surface being peened. For relatively low levels of coverage, the convex curvature will be completely overcome by the force of the shot stream. Equation (8) now defines the relevant stress system. Further peening may generate a curvature greater than that which can be overcome by the flattening-effect of the shot stream.

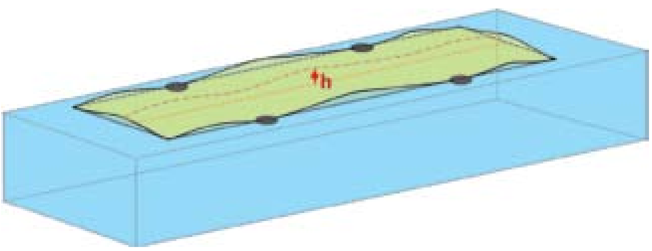

Fig.9. Complex curvature adopted by clamped, peened, Almen strip.

This qualitative analysis indicates that indentation becomes increasingly difficult as peening progresses. That means that coverage rates would be expected to decrease to a corresponding degree. The actual extent of this decrease can only be determined experimentally.

Quantitative Analysis
The deflection of a clamped Almen strip can be estimated using a combination of equations (3) and (4). A combination is needed because the shot stream can no longer be regarded as applying a load at one particular point. The divisor parameter lies somewhere between 4 and 6.4. Fig.10 shows the estimated flattening that can be predicted for three thicknesses of Almen strip and assuming a divisor value of 5.2 (average of 4 and 6.4). Note that the deflection developed during peening of clamped Almen strips is about one-third of the deflection on release from the holding bolts.

Consider first an N strip being peened by a shot stream exerting a force of 10 Newtons. The shot stream will fully flatten the N strip against its block until the as-clamped deflection reaches 0.06 mm (.002"). (The prediction is given in fig.10.) With greater as-clamped deflections, the shot stream will only partially flatten the N strip. The strip will then be suffering a compressive surface stress throughout further peening. This will reach a maximum of some 50 MPa as indicated by fig.4.

When A strips are being peened it is reasonable to suppose that the shot stream will be exerting a greater force than that used for N strips. The maximum as-clamped deflection for a (larger) 20 Newton shot stream is 0.03 mm (.001") with an induced compressive surface bending stress of 40 MPa. With C strips and a 30 N shot stream the values would be 0.007 mm (.0003") and 17MPa.

Equation (8) predicts that it becomes progressively more difficult to generate indents as shot peening progresses. The effect would be greater for N strips than for A and C strips. This should be reflected in it taking longer to achieve a given level of coverage. Verification can be obtained by comparing the time, T, which it takes to reach the peening intensity point on a saturation curve – using a fixed intensity of shot stream. Figs. 11 and 12 are examples of saturation curves produced using such fixed shot stream conditions. The 'fixed conditions' used in producing the data for figs.10 and 11

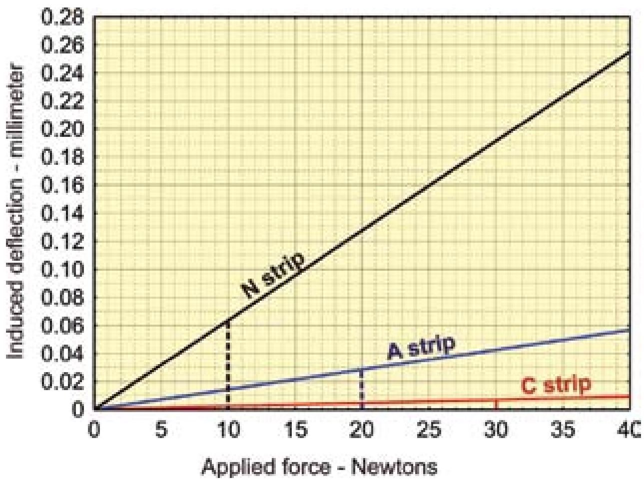

Fig.10. Estimated as-clamped deflection of Almen strips as a function of applied force.

Fig.11. Analyzed Saturation curve for N strips using fixed peening conditions.

Fig.12. Analyzed Saturation curve for A strips using same peening conditions as for fig.10.

were: S70 shot, 10 lb/min feed rate, 25 psi air pressure, 0.36" nozzle 12" above strips, 90˚ blast angle. For N strips the time, T, was 50% longer than when using A strips - 0.47 cf 0.31. This finding is in agreement with the proposed bending stress effect.

DISCUSSION

It has been shown that shot stream force can induce significant deflections and surface stress during peening. The magnitude of these effects depends primarily on the component thickness and on the distance between supports. If the induced surface stress is substantial, then the primary effect will be on the size of the peening indents. Inducing a compressive surface bending stress will reduce the size of a given indent. An induced tensile surface bending stress will have the opposite effect.

If the size of peening indents has been significantly affected, then there will be corresponding effects on the measured peening intensity, coverage rate and residual stress profile.

Real components will require the application of more complicated equations than those used in this article. Such analysis lies in the province of mechanical engineers for whom mechanics of bending is a core interest. Nevertheless the equations used here do allow estimates to be made for a range of components.

Finally, the effects of shot stream force should not be ignored if peeners are confronted with components that are only a few millimeters thick.