A PRACTICAL APPROACH TO FORMING AND STRENGTHENING OF METALLIC COMPONENTS USING IMPACT TREATMENT

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ABSTRACT

Development of shot-peening and peen-forming have so far been confined to the improvement of the machines producing the jet of shots. Little work has been carried out which is aimed at understanding the main parameters in the mechanics of the process. To provide helpful quantitative information about the process main parameters is the aim of the present article.

In this investigation, the experimental programme ultilised a combination of newly developed techniques to measure average jet velocity using phototransistors and arc-heights using strain gauges, as well as older methods using high speed photography and Almen gauge. Micro and Macro-structural analyses were conducted to determine the effect of a particular parameter upon the depth of the plastically deformed zone.

For the shot-peening and peen-forming processes, the influence of the shot size and material, the speed of the jet and its obliquity of impact, the intensity and time of exposure, are discussed with regard to their beneficial effects. The study also provides a detailed analysis of the effect of impact treatment upon the surface profile of target materials using an automated, fully-computerised, profile-tracing equipment.

INTRODUCTION

Impact treatment processes involve the bombardment of metallic components with high velocity shot or grit. These processes take several different forms and the main ones of interest to this study are referred to as shot-peening, stress-peening and peen-forming, and, together, have application in the manufacture of a wide range of components.

Shot-peening is used to improve the fatigue life of metallic components. The result is obtained by the use of relatively high velocity, small spherical shots of hardened iron, steel or glass. The outcome is the cold working of the exposed surface layers down to a depth of between 0.25 - 1.2 mm, and the presence of a compressively stressed layer which is highly effective in preventing premature failure under conditions of cyclic loading. An even greater improvement in the fatigue life is obtained if the component is preloaded at the time of peening. In this form it is called stress-peening. In peen-forming, the bombardment process is used to actively form panels to a specified curvature, i.e. to shape flat metal sheet and plate without resorting to conventional metal forming techniques. All three processes are well reviewed in (1) and (2).

From an economic viewpoint, the primary justification for impact treatment processes is that their use would allow engineering components to be employed at high stress levels under cyclic loading and aggressive environment. In the case of aircraft industry, this means a reduction in structural weight for a specified reliability level. In automotive applications, it means that relatively small, low-cost components can be upgraded for conservative operation at stress levels that would represent poor practice without shot-peening. Springs, torsion bars, connecting rods and gears are examples of components that can be upgraded without the use of costly alloys or increased sections. Indeed, the processes can also be used to enhance resistance to stress-corrosion.

The ability to upgrade the mechanical properties of a component by peening offers obvious opportunities in the correction of under-sized components, when fatigue failures occur after a product is standardized or in field service.

Although shot impingement methods have been employed for many years, very little is understood about the detailed mechanics of the process. A major problem frequently met in industry is how to choose particular peening conditions to obtain the required fatigue life and/or curvature in a component. In practice, the process users resort to the use of empirical methods (the Almen test strip) to determine the peening intensity and hence, the expected performance of the component. The main objective of the results reported here is to provide helpful quantitative guide lines of the effect of the process main parameters.

In particular, attention was given to the effect of shot-characteristics, average jet velocity and obliquity of impact, stand-off distance and exposure time with regard to their beneficial effects.

This study, which is an extension of the earlier work of Meguid (2, 3) also provides a detailed analysis of the effect of impact treatment upon the surface profile using an automated, fully-computerised profile tracing equipment (4). The experiments are described in the following Section. Results and discussion are given in Section 3.

EXPERIMENTAL ANALYSIS

Equipment and Specimen

The peening system used in the present investigation was a Vacu-Blast PB100 air-blast equipment, in which a compressor supplies high pressure-high temperature air to an after cooler where the temperature of the air is reduced. The air then passes to a receiver and on to an air dryer where any humidity is practically eliminated. The dry air takes away the spherical shots from the hopper of the peening cabinet and delivers them to the working chamber. Any dust from the process is taken away through the dust collector unit connected to the peening cabinet. Parts of the tests were carried out on a PB 80, and the details of this equipment can be seen in (2). The primary function of the system was to direct a "cylindrical" jet of high-speed air containing solid spherical steel shots at a flat target. The composition of the target material used is given in Appendix 1.

Measuring Devices

A method of utilising two TIL-65 Phototransistors and a two-channel storage oscilloscope was developed in order to facilitate measurements of the average shot velocity. The equipment, shown diagramatically in Fig. 1, contains two phototransistors secured on Perspex tubes and mounted in an aluminium holder.

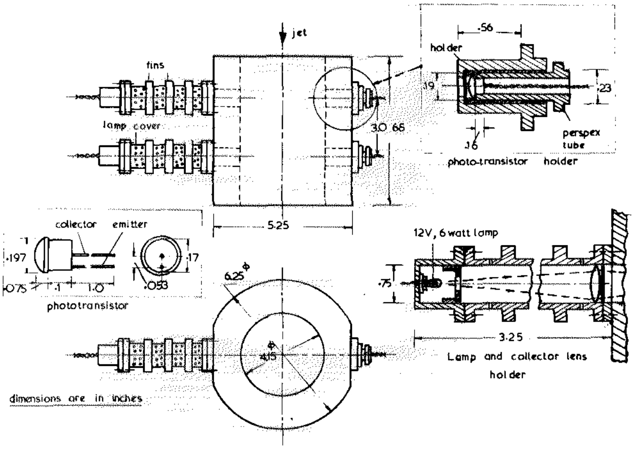


Fig. 1. Apparatus for measuring average shot-velocity.

They are spaced 3 inches apart in a hollow steel cylinder which permits the passage of the jet. The light source consisted of two 12 V, 6 watt bulbs with focusing lenses, positioned to give minimum thickness, to a converging beam of light. Alignment of each phototransistor with the light source was made to minimise the resistance of the illuminated phototransistors.

The sequence of operation was for the jet to interrupt the first light beam causing a high resistance at the phototransistor, thus changing the output potential of the phototransistor circuit, shown in Fig. 2.

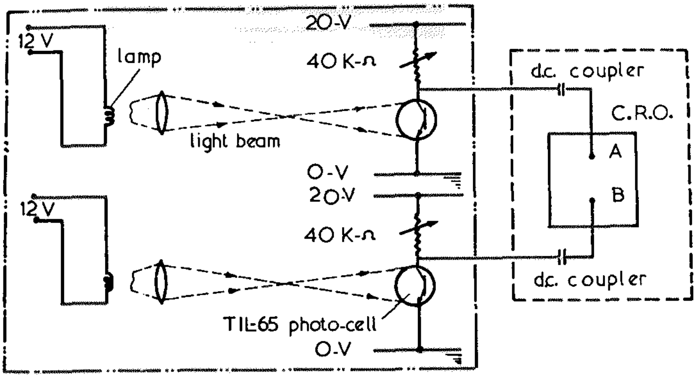
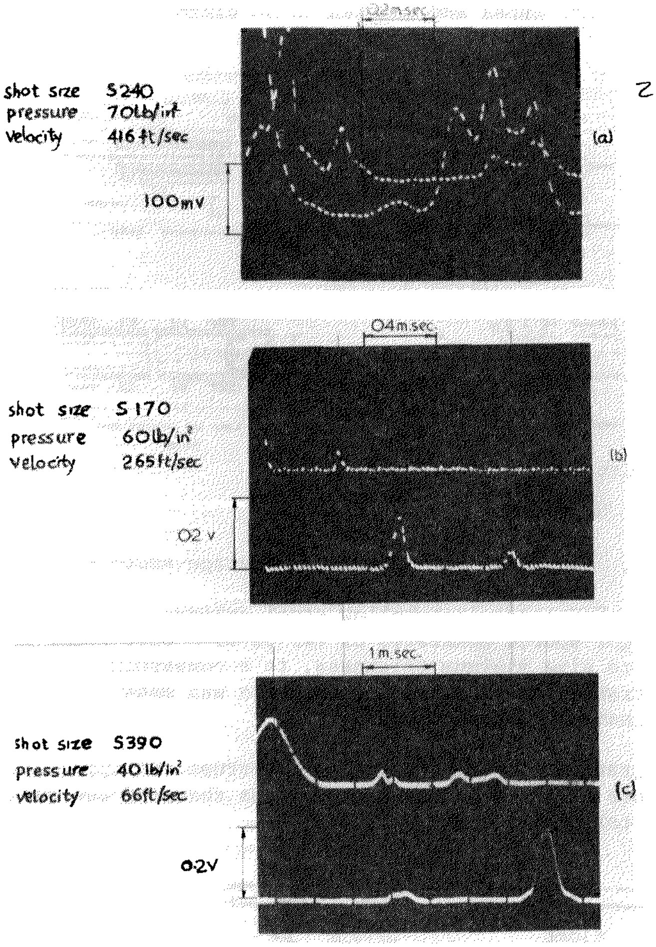


Fig. 2. The phototransistor circuit.

As the jet proceeds and interrupts the second light beam, the output voltage of the duplicate phototransistor circuit is similarly increased. The result from a single sweep trace chopped beam will be two similar traces from the phototransistors, one being delayed by an interval depending upon the speed of the jet, as depicted in Fig. 3.



$\frac{3}{58} \times \frac{1}{12} = 1130$

2.9 x .2 = .58 m

580 μsec

$\frac{3}{.9} \times \frac{1}{12} : \underline{277}$ ft/sec

2.23 × .4 .9 m

900 μsec

$\frac{3 \text{ IN}}{3.7 \text{ msec}} \times \frac{1 \text{ FT}}{12 \text{ IN}} =$

$\underline{68 \text{ FT/SEC}}$

3,700 μsec

Fig. 3. Typical Oscilloscope Traces.

It is worth noting that the velocities given in this study are tip-nozzle velocities, and the impact velocity will depend upon the relative position of the nozzle and target. The oscilloscope traces, given in Fig. 3, show clearly the delay time between the two signals, and, hence, it was not felt necessary to use a cross-correlator in order to obtain the average jet speed. However, the technique was compared with high speed photography, and the results were in agreement to within ± 5%. The results of the phototransistors' technique are shown in Fig. 4. They demonstrate that there exists an approximately linear relationship between pressure and speed for all the three shot sizes used, of between about 100 and 900 ft/sec for pressures of 40 and 120 psi, respectively.

1087 = [illegible]

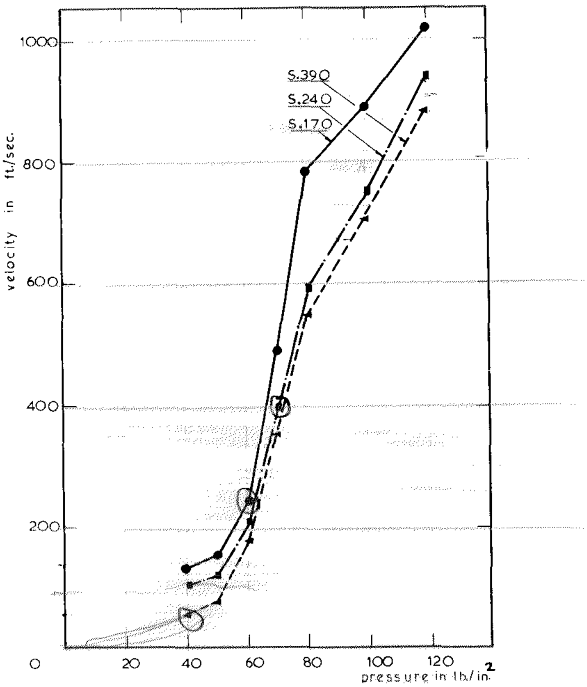


Fig. 4. Velocity-Pressure Relationship.

Curvature measurements were made using the conventional Almen Strip and using strain gauges. In the latter method, strain gauges were mounted on the unexposed surface of the target. As the assumption that plane sections remain plane could not be met at and near the exposed areas, use was made of an Araldite pad of 1/8 in stuck firmly on the unexposed surface, using epoxy resin to define the neutral axis. These gauges were then connected to a data logger, and the results of each gauge were recorded and printed on paper tape. Curvature of the specimen was then determined. The details of this technique can be found in References (2, 5).

Consultation with various shot-peening firms revealed that there exists no convenient method to measure arc-heights of peened discs. The only available method is the Almen gauge which is suitable for intermittent measurements of curvatures resulting in peened strips. Therefore, it was thought desirable to attempt to devise a new technique to enable the continuous measurements of arc-heights in peened discs and strips. In this technique, a method utilising a dial gauge carefully positioned in a precision built housing was used. The spindle of the gauge was fitted through a rigid case and centred in the middle of a hollow cylinder, Fig. 5, and pressed against the unexposed surface of disc. The multiple impingement of the spherical shots will result in vibratory effects, thus making it difficult to obtain a precise reading during exposure. In industrial use, however, continuous reading will be taken during temporary shut-off without the removal of the disc.

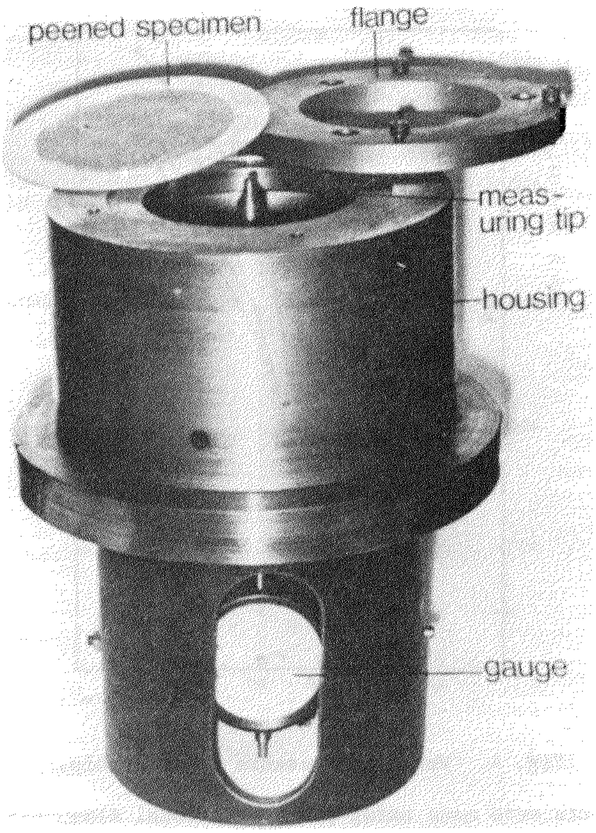


Fig. 5. Apparatus for measuring arc-heights in peened discs and plates.

The gauge measures the arc-height on the concave-side of the disc. The discs were partially restrained at the edges using the flange shown in the same figure. In order to eliminate the effect of the edge restraint, a constant torque of 10 N.m. was applied to the securing screw.

The appropriate mapping of the shot-peened surfaces was achieved using a basic stylus profilometer, supplemented by an automatic (or manually) controlled, three-dimensional traversing relocation stage developed at Cranfield Institute of Technology, and a microprocessor-based data-handling unit. The details of the system are given in Reference (4).

This technique differs from that used for basic commercially available profilometers in that the stylus arm is stationary and the specimen is moved under the stylus on a motorised traversing table. This table runs on a very accurate slideway. The speed of this movement is 1 mm/s and positioning of the table in the traverse direction to within ± 0.1μm is achieved using an optical encoder. The parallel-profile tracing sequence is completed by means of a stylus-arm lifting mechanism.

RESULTS AND DISCUSSION

The performance of a peened component can be related to the peening conditions by an expression of the form :

$$\text{Fatigue life and/or curvature} = f(\text{peening conditions})$$
$$= f(\rho, D, V, ND, T, \phi, h)$$

where the function f varies with the target material characteristics; ρ, D, V and ND are the shot density, diameter, velocity and number density, respectively. T is the exposure time, ϕ represents the angle at which the shot impinges the target and h is the stand-off distance. The main task of this study is to relate these factors in a quantitative manner. The experimental programme comprised of four series of tests, each having as its primary objective the determination of the influence of one of the process variables, referred to above, on the resulting arc-height (peening intensity).

Effect of Shot Characteristics

The quality of shot for peening is dependent upon uniformity of size, shape, hardness, density and fatigue durability of the shot. Indeed, in a peening operation, the quality of shot must be carefully maintained if the peening system is to produce a uniform and consistent peening effect.

Uniformity of the shot hardness is of particular importance, although it is frequently overlooked. Recent measurements indicate that the hardness of the cast steel shots can vary from 45 to 65 RC, resulting in residual stress levels, which can vary considerably along the exposed surface. The greater the relative hardness of the shot to the test piece, the greater the depth of effective peening. Typical peening media are steel, iron or stainless steel shots, glass or ceramic beads, and chopped wire.

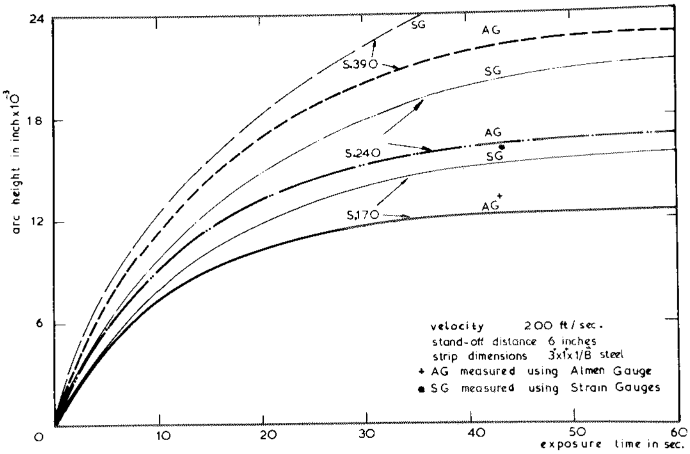


Fig. 6. Effect of shot size upon saturation curve.

Fig. 6, shows how the arc-height varies with the exposure time for a given shot size. The curves demonstrate that the change in arc-height with time starts off steeply and decreases rapidly until reaching saturation. The difference between each pair of curves arises because one was measured during loading using the strain gauge system (marked SG), and the other after unloading using the Almen gauge (marked AG).

In order to examine the effect of shot-size upon the resulting curvature, cast shots of different sizes, S 170, S 240 and S 390, having, practically, the same average speed were used. The saturation curves for larger size shots showed delay in reaching saturation. This is to be expected as the number of the shots projected is fewer (less coverage). Features similar to those observed above were noticed using the newly developed technique of continuously measuring arc-heights in peened components (3). Micro-structural analysis of the peened surfaces revealed the following. Bigger size shots, i.e. S 550 produce larger depth of plastically deformed surface and are associated with greatly varying distortion of the grain structure. The smaller size shots, i.e. S 120, gave rise to a smaller but more uniform depth of plastically deformed zone. Distorted and fractured shots are capable of cutting and causing damage to the area exposed for peening. Thus the shot must be examined.

For delicate use, such as aircraft engine parts, spherical glass beads are preferred to the steel shots. For a glass shot and a steel shot of the same diameter and same impact speed, the maximum force resulting from the impact of the steel shot is about 4 times that resulting from the glass beads. Stainless steel shot is also used for a few specialised applications, where ferrous contamination of the workpiece must be avoided.

Effect of Average Jet Speed

The results of the phototransistor and the chopped beam of a storage oscilloscope as described earlier, and by high speed photography indicate the following. Higher velocity shots, keeping other parameters unchanged, cause a deeper penetration of the target metal than the lower velocity shots, as would be expected, resulting in larger arc-height values, as seen in Fig. 7.

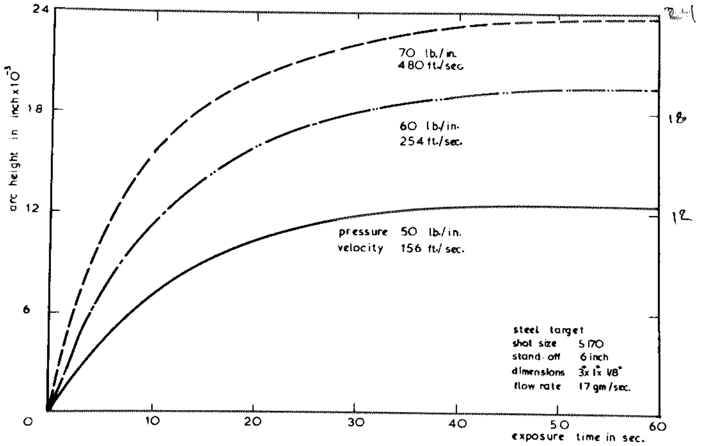


Fig. 7. Effect of average jet velocity upon saturation curve.

Pressure drop behind each shot decreases the drag force for the following shots, so that some shots may overtake others; this phenomenon was observed in the very high speed photographic studies.

Effect of Jet Obliquity

If a particle strikes the target at an impact angle θ, then its resultant velocity V can be resolved into two components, one normal to body surface V_n and the other tangential to it V_t. As a result of V_n the particle penetrates into the body, while V_t is responsible for a scratching action. The effect of V_t will be to produce non-symmetrical plastic zones and consequently a non-uniform residual stress pattern. This effect is clearly demonstrated by the single ball investigations carried out by Meguid (2), and depicted in Fig. 8.

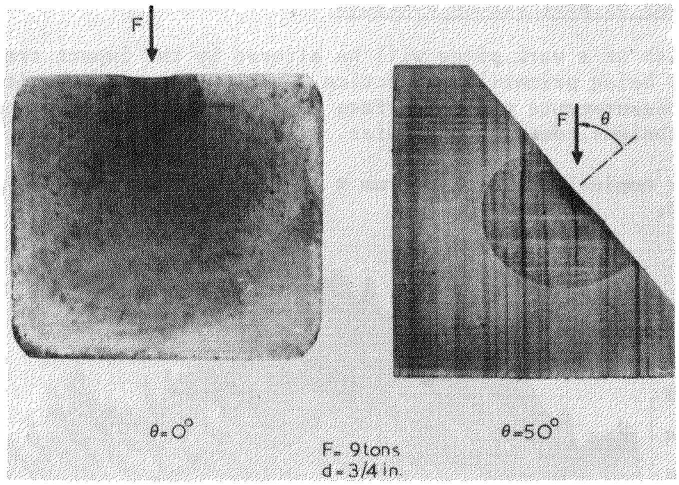


Fig. 8. Effect of load obliquity upon the resulting plastic zone.

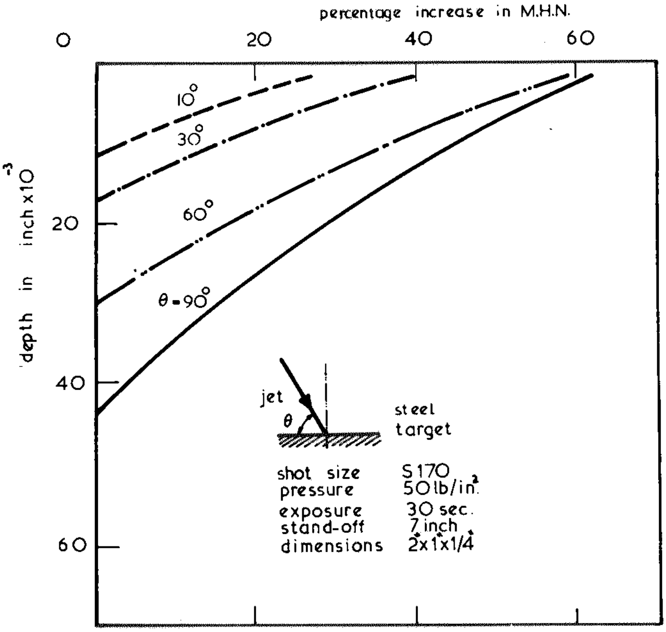


Fig. 9. Effect of jet obliquity upon the Micro-Hardness Number (M.H.N.) of steel specimens.

Fig. 9, shows how the obliquity of the jet determines the increase in the microhardness value for the steel tested. The curves (which are an average of only three trials) relate the percentage increase of the microhardness number to its original value. They indicated a greatest increase in hardness at normal impact and minimum at grazing impact, as would be expected.

Surface Topography of Shot-Peened Surfaces

The surface finish of a work piece will be altered by the impact treatment process, the exact amount being primarily a function of shot size and velocity, its obliquity and material. Measurements of the surface quality were carried out using the stylus profilometry technique, described earlier.

In this study, a nominal area of (3.2 mm x 3.2 mm) of a shot-peened surface is shown in Fig. 10.

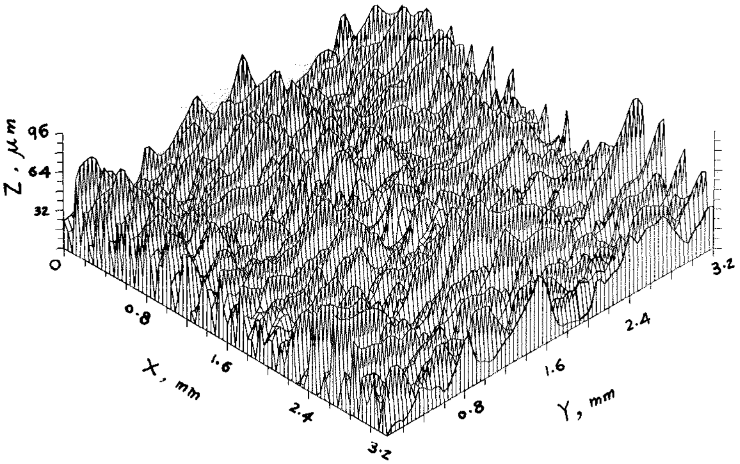


Fig. 10. Isometric view of a shot-peened steel surface. Peening conditions : p = 60 psi; Shot-size S 170; Stand-off distance 8 in.

The representations are built up from one hundred, parallel-profile traces taken in incremental steps of 40μm, and 100 samples per trace. Statistical and auto-correlation analyses of the shot peened surfaces indicated that the ratio between the centre line average value R_1 and the root mean square roughness value R_2 varied between 0.785 and 0.824, thus approximating randomly distributed surface indentations. (It is worth noting that the ratio R_1/R_2 must equal 0.8 for randomly generated surfaces). Fig. 11, shows an isometric representation of a grit blasted surface. The figure demonstrates that abrasive blast cleaning processes also generate random profile to the exposed surface prior to protective coating. Such profiles need only be of a small magnitude (R_1= 40 - 50μm) as large profiles inevitably require additional protective coating to fill the valleys between the peaks, and may trap air in them (6). This surface analysis is a preliminary study and further work is currently in progress.

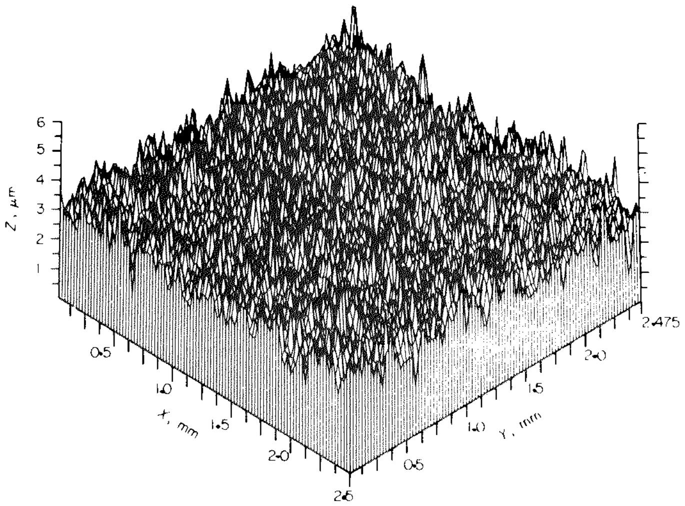


Fig. 11. Isometric view of a grit-blasted stainless steel surface (4). (Courtesy of Precision Engineering).

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APPENDIX 1.

Chemical Composition of the Steel Tested

% C	$\% S_i$	$\% M_n$	% S (max)	% p (max)
0.4	0.05	0.6	0.06	0.06