FUNDAMENTAL ASPECTS OF SHOT PEENING COVERAGE CONTROL PART TWO: SIMULATION OF SINGLE AND MULTIPLE IMPACTING

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ABSTRACT

The nature of some of the inaccuracies, which may be introduced in the calculation of coverage when a shot peening practice is substituted with a computer simulation, is discussed in detail. One source of inaccuracy is removed with the introduction of two concentric windows. Another source is shown to stem from the choice of the dimension, R, considered for simulation area, in comparison to the dimension, r, considered for each impression. For this reason coverage is formulated for all ratios of R/r. The effects of the overlap of impressions with the edge of the simulation area is fully accounted for in the formulation.

KEYWORDS

Simulation, Shot Peening, Coverage, Finite Surface

INTRODUCTION

In part one of this series [1], theoretical equations for predicting the coverage of a substrate by at least a single impact, or by multiple impacting, were derived. Given the rate of arrival of shots per unit area of the exposed surface, the equations are able to predict the coverage at any given time. These predictions are shown, in the present paper, to be correct if the size of the exposed surface is at least few hundred times greater than that of each impression, a condition which already exist in practical shot peening.

Another method of studying coverage as a function of peening time is through simulation. In any shot peening simulation impressions are produced by a set of two-dimensional random numbers, one for the x- and one for the y-coordinate of each impression. Fig.1 represents a simulated early stage of shot peening with 95 impressions formed within the outer rectangle

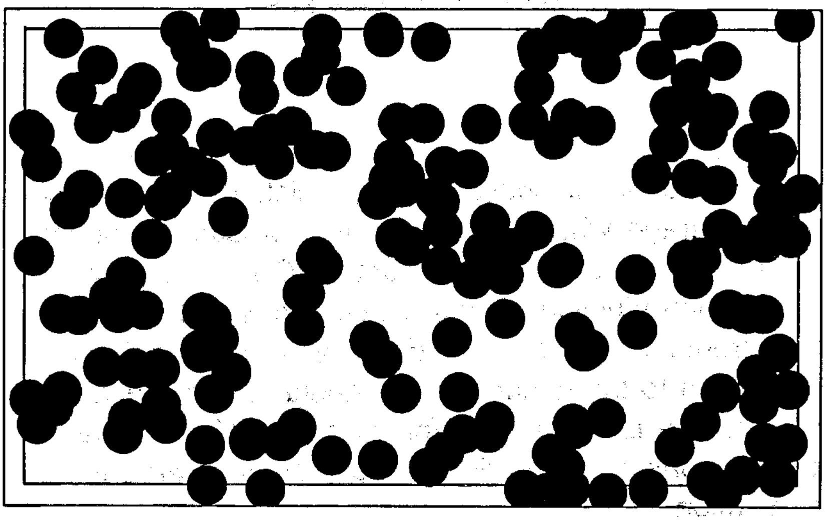

Fig.1 Simulated early stage of Shot Peening

To predict coverage with a simulation technique, it is necessary to know the rate of peening, A ($mm^{-2}s^{-1}$), and the average radius of impressions, r (mm). Furthermore in order for the simulation to represent reality correctly, the area of each simulated circular impression as a proportion of the total simulated area (the outer rectangle) must be the same as the ratio of the average size of each impression made by real shots to that of the exposed area. In practical shot peening the ratio of the area of each impression to that of the exposed area is so small that after an appreciable peening time the number of shots landed can be in the region of thousands. To reduce such huge numbers to a manageable size, the simulated area must be chosen to represent a fraction of the exposed area. This reduction in area would at least introduce two sources of inaccuracy. To understand the nature of these inaccuracies, and by doing so develop techniques to either eliminate them or take them into account, we analyse in more detail the simulation presented in Fig.1.

NATURE OF INACCURACIES INTRODUCED BY REDUCING SIMULATION AREA

Impressions produced within the outer rectangle in Fig.1 are usually intended to represent a section of the real surface which has been exposed to shots for a given period. The inner rectangle, which is separated from the outer one by a distance equivalent to the radius of an impression, is drawn here purposefully for the following reason.

Each impression formed within the inner rectangle contributes a full circular area towards the extended area [1]. But an impression, the centre of which is formed within the area in between the two rectangles, contributes to the extended area only as much as a part circle (a circular-cap). As the centres of circular impressions are formed all within the outer window, the simulation would fail to account for the acute-angle circular-caps which in real shot peening would have resulted from those shots landed outside the section by a distance equivalent to a radius of an individual impression, r. Any coverage value obtained from this simulation would inevitably be an under-estimate by an amount equal to the area of acute-angle circular-caps. It is in order to rectify this error that the inner rectangular frame is introduced. If the impressions in the region between the two frames are wiped out, as in Fig.2, the measured coverage within this inner window will now include acute-angle circular-caps, such as those observed, particularly at the lower edge of the frame.

Another source of inaccuracy introduced, when a section of exposed surface is chosen as the simulated area, is the possibility that such an area may not statistically represent the exposed surface. This point can easily be demonstrated by choosing even smaller areas within the simulated area in Fig.1. Five areas, one from each corner and one from the centre of Fig.1 are chosen, as in Fig.3. Evidently there is an appreciable variation between the coverage estimated by each of these windows. This is because none of the windows chosen is large enough to be considered as a true representation of the coverage. To overcome this problem it is necessary to choose randomly a large number of such windows and to measure the average coverage over all chosen windows

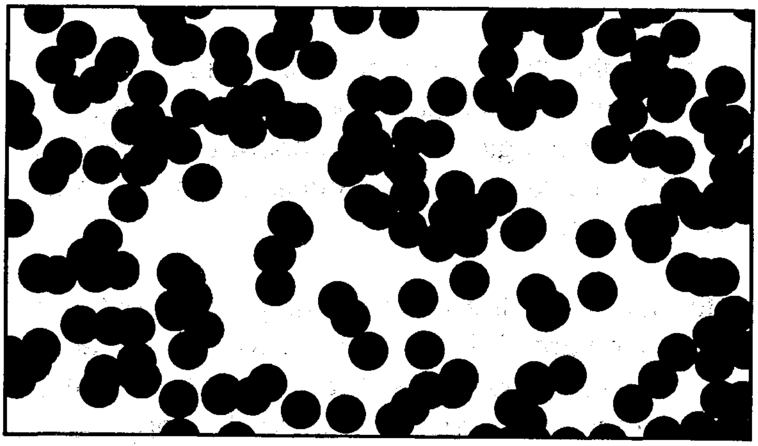

Fig.2 Simulated area to be used for calculation after wiping out the region between the two frames in Fig. 1

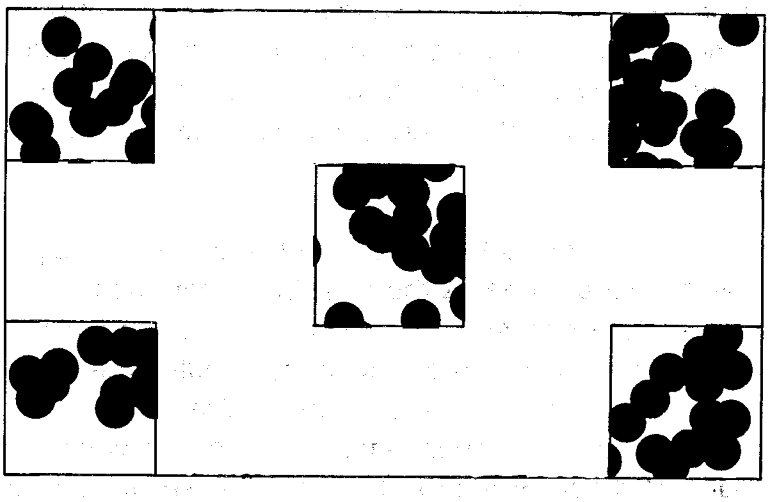

Fig.3 Introduction of 5 smaller observational windows, 4 at the corners and 1 in the centre of Fig.1.

STATISTICAL FORMULATION OF COVERAGE RESULTING FROM SHOTS ONTO A FINITE SURFACE

It was shown already that simulation of a reduced exposed area, though facilitating the practical measurement of the coverage, creates a statistical error in way of underestimation. A practical method of measuring the coverage is by using an image analyser. In this method the simulation region in Fig.2 is placed under a microscope. This restricts the field of viewing to a circular region. It is for this reason that in the following we will deal with statistical formulation of the coverage for a finite circular area. The comparison of this formulation with the one intended for an infinite area [1] will automatically lead to the values of underestimation.

Let us denote the radius of the observational region, for which we are to examine the coverage at a given time t, by R, Fig.4.

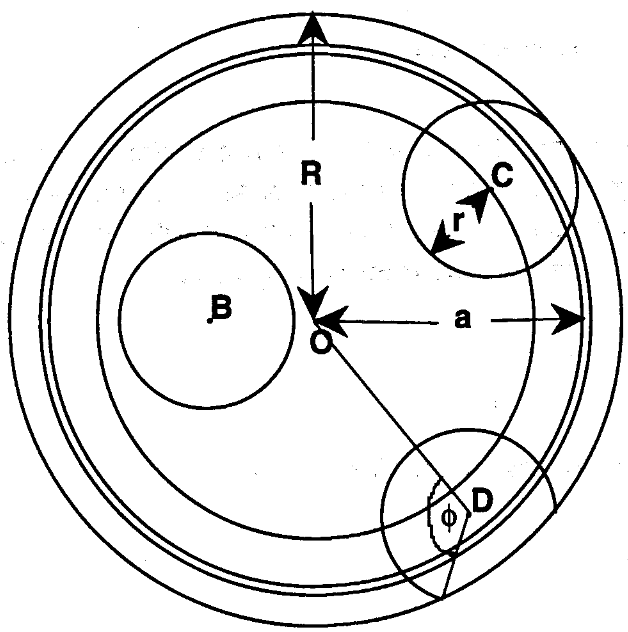

Fig.4 Geometrical representation of the method of calculating coverage for a finite area

The coverage, S, for an infinitely large exposed area is given by [1]

$$S = 1 - \exp(-E) = 1 - \exp(-\pi r^2 At) \tag{1}$$

where E is the expectation value and A is the uniform rate at which shots are fired. For a finite surface, E is not uniform everywhere and hence for these regions, we calculate dE for an annulus of thickness da, a distance a from O.

Evidently impressions, such as B, the centres of which are formed anywhere within the inner circle of radius R-r, including those such as C, formed at the boundary of the inner circle, will cover the substrate as though as the observational area had no boundary. Therefore for this region, that is for the proportion $(R-r)^2/R^2$, E is uniform and the coverage is calculated from eq.(1). The contribution to the total coverage arising from this region is then given by

$$S_1 = \left(\frac{R-r}{R}\right)^2 [1 - \exp(-\pi r^2 At)] \tag{2}$$

However, for the range R-r < a < R, E is not uniform and must therefore be obtained by integration. The form of any observed impression in this region is circular-cap and one such impression is shown with its centre at D, Fig.5. The area of any circular-cap is $2\phi r$, where ϕ is given by

$$\phi = \cos^{-1}\left(\frac{a^2 + r^2 - R^2}{2ar}\right) \tag{3}$$

The expectation E for the region R-r < a < R is

$$E = At \int_{R-r}^{R} \phi r^2 da \tag{4}$$

The contribution to the total coverage arising from this region is then given by

$$S_2 = \frac{2Rr - r^2}{R^2}\left\{1 - \exp\left[-At \int_{R-r}^{R} \phi r^2 a da\right]\right] \tag{5}$$

The coverage of a finite surface is, therefore, obtained from

$$S = \left(\frac{R-r}{R}\right)^2 [1-\exp(-\pi r^2 At)] + \frac{2Rr-r^2}{R^2}\left\{1-\exp\left[-At\int_{R-r}^{R} \phi r^2 a\,da\right]\right\} \quad (6)$$

DISCUSSION

In this paper the need for introducing two frames within one another for simulation of shot peening practice is shown. An outer frame within which shots are randomly introduced and an inner frame within which the coverage is calculated. The gap between the two frames is to be at least equal to the radius of each individual shot. Next we formulated the coverage for any given ratio of R/r, eq. (6). The following figures show the dependence of coverage on peening time for r=0.5 mm, A=0.293 $mm^{-2}s^{-1}$ and R/r=6, 20, 60 and 200.

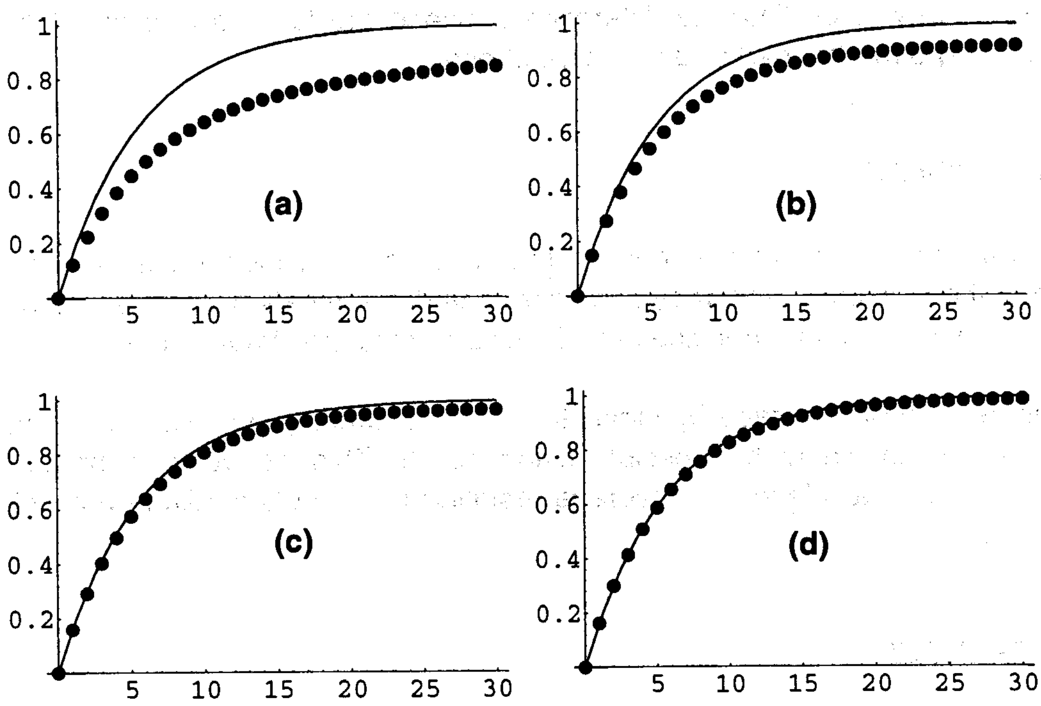

Fig.5 Comparison of coverage obtained for an infinite surface, ____, with those obtained for finite surfaces, ... (a) R=3mm, (b) R=10mm, (c) R=30mm and (d) R=100mm.

These curves are drawn for simulation areas with different values of R/r, shown by points, and for the case of R/r equal to infinity [1] drawn by full lines. It can be seen that as simulation area increases, that is, as the ratio of R to r increases, the coverage calculated for shots thrown on finite areas, eq.(6), approaches that predicted by shots thrown on an infinitely large area, equation (1). The ratio of R/r for a near perfect fit of eq.(6) with (1) is 200, Fig.6(d). In addition to having two windows for simulation purposes, it is therefore necessary to choose a simulation area with at at least a radius 200 times larger than the average radius of individual shots.

In practice it is easier to choose smaller ratios of R/r for simulation. This is partly because measurement of coverage may become unmanageable at long times due to the huge number of shots expected to fall on areas with large R/r ratio. Eq.(6) can then be of great value in that when coverage is measured over all relevant times for a given A and for small R/r, it must be corrected by adding at any given time the difference between the full line and the dotted lines in Fig.5 for that particular R/r ratio chosen.

CONCLUSIONS

The introduction of two concentric windows in a simulation have shown to correct the possible inaccuracy arising from under-estimation of coverage due to shots which would otherwise have landed outside the simulation area.

Measurement of coverage by simulation of shots landing on areas with small R/r ratio is shown to be possible using eq.(6). This equation is primarily developed for calculation of coverage resulting from shots landing on a finite substrate.

REFERENCES

1. Abyaneh MY 'Fundamental Aspects of Shot Peening Coverage Control Part one: Formulation of Single and Multiple Impacting', ICSP6, San Francisco.