FUNDAMENTAL ASPECTS OF SHOT PEENING COVERAGE CONTROL PART THREE: COVERAGE CONTROL VERSUS FATIGUE

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ABSTRACT

Increasing coverage as shot peening progresses involves multiple impacting. Over-peening will induce cracking and reduce fatigue and corrosion-fatigue performance. Equations for multiple impacting [Abyaneh MY 'Fundamental Aspects of Shot Peening Coverage Control Part one: Formulation of Single and Multiple Impacting', ICSP6] is used here to demonstrate, quantitatively, how the proportion of the total coverage due to specific numbers of impacts changes as coverage increases. These changes have also been simulated using computer-generated drawings involving random-number coordinates for circular centres. The effect of multiple coverage on fatigue performance is discussed.

KEYWORDS

Shot Peening, Coverage, Multiple Impacting.

INTRODUCTION

Shot peening is an important mechanical surface treatment that is usually very effective in improving important service performance factors such as fatigue life. Detailed experimental analysis of actual peened surfaces is very difficult. Modelling of the process can, however, be readily achieved using computer-aided techniques. Fig.1 illustrates the situation in an early stage of peening when only a small proportion of the surface has been impacted. Even with the majority of the surface being unpeened it can be seen that several regions have received two or three impacts. During the shot peening of a component's surface an increasing proportion of that surface is said to be 'covered'.

Coverage is defined as the proportion of the exposed surface that has been impacted in a given time of shot peening. Control of this coverage is an essential feature of precision shot peening. Calculation of shot peening coverage [1], using the well-known Avrami postulate [2] or the less-known Evans approach [3], and the theoretical basis of its control [4] has already been dealt with in other papers [1,4].

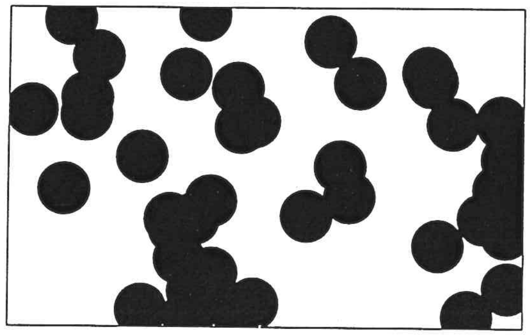


Fig.1 Simulated early stage of Shot Peening

As shot peening progresses a higher proportion of the peened area must, necessarily, be impacted more than once. This multiple impacting is a very important factor in the optimization of service performance enhancement. A very large proportion of shot peened materials are able to tolerate repeated impacting by the high velocity shot. Even tolerant materials will start to develop cracks if excessive shot peening times are used. These cracks then reduce the overall fatigue life. This phenomenon is known as 'over-peening'. A quantitative analysis of multiple impacting based on a geometrical model has been developed and the extent of coverage by one or more impacts is formulated [1]. This paper aims to show how the proportion of the total coverage due to specific numbers of impacts changes as coverage increases. These changes have been simulated using computer-generated drawings involving random-number coordinates for circular centres.

COVERAGE AS A FUNCTION OF TIME

As shown previously [1,4] the percentage of surface area that has been covered by impressions made by shot particles can easily be calculated using the Avrami [2] approach. Certain simplifying assumptions must, however, be made. These are that each shot particle arrives at the surface in a statistically random manner making the same size of circular impression and that the rate of impacting is uniform. Given these assumptions the following is an equation relating the percentage coverage, S, as a function of peening time, t.

$$S = 1 - \exp(-\pi r^2 At) \qquad (1)$$

where r is the radius of each impression, and A is the uniform rate of creation of impressions. The application of the Avrami postulate or that of Evans requires that an infinite area of surface is being considered (in order to obviate edge effects). This is a reasonable assumption for virtually all practical cases of shot peening for which the area being peened is very large compared with the size of the individual impressions. However, when looking, say, through a microscope to count either the number of shots or to calculate the coverage we are restricted to a confine area. In this case the edge effect has to be taken into account. The statistical formulation of coverage taking into account the edge effect is discussed in another paper [5]. For a shot peening situation in which r=0.5 mm and A=0.2 $mm^{-2}\ s^{-1}$, eq.(1) gives rise to the progressive coverage curve shown as Fig.2.

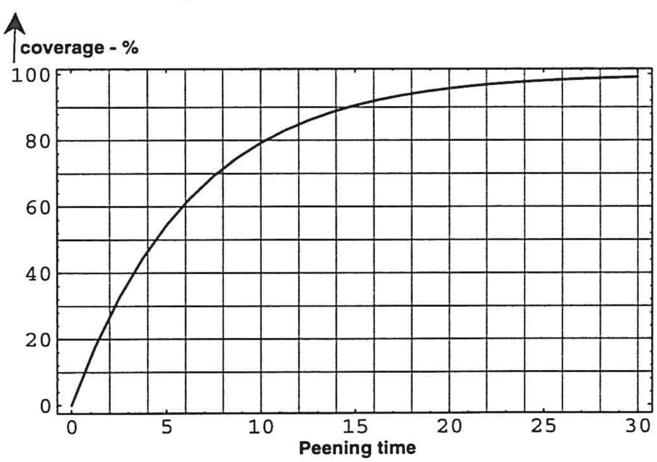


Fig.2 Coverage curve for r = 0.5 mm and R = 0.2 $mm^{-2}\ s^{-1}$

As the surface becomes increasingly covered the probability of overlapping impact areas increases. The rate of coverage must therefore decrease with increasing peening time. The approach to 100% coverage is exponential so that 100% coverage is theoretically impossible.

ANALYSIS OF MULTIPLE IMPACTS

Theoretical basis of calculating multiple impacting is given elsewhere [1]. In general the number of impacts received by a given area of the surface can be regarded as an integer, n. The contribution to the total coverage due to a particular value of n, S_n, can be expressed by [1]

$$S_n = \frac{(\pi r^2 At)^n}{n!} \exp(-\pi r^2 At) \quad (2)$$

where E, the expectation value, is shown to be equivalent to the 'extended area' of the Avrami equation, that is equal to $\pi r^2 At$, and ! is the factorial of the value of n. Equations (1) and (2) are plotted as Fig.3 for which n has values from 1 to 10, r = 0.5 mm and A = 0.293 . This value of A has been deliberately chosen since the resulting total coverage is 90% after 10 seconds, 99% after 20 seconds and 99.9% after 30 seconds.

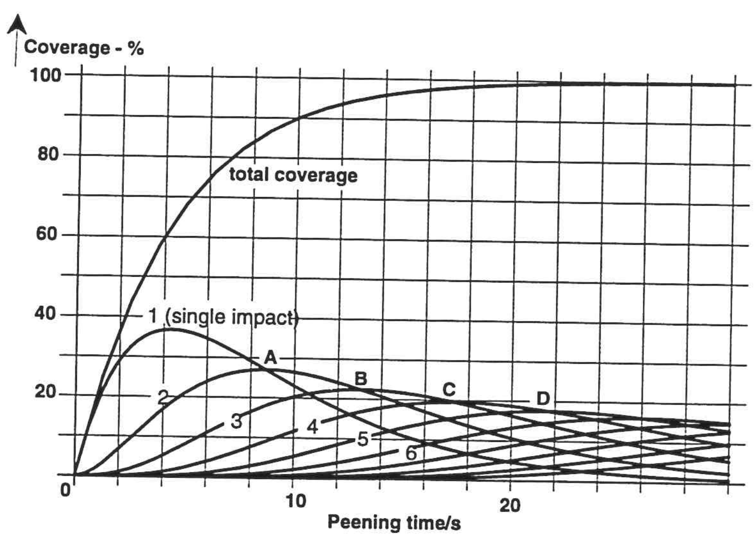


Fig.3 Contribution to the total coverage of single and multiple impacts.

Referring to Fig.3 it can be seen that single impacts give the largest contribution to the total coverage for peening times up to the point of intersection shown as A. For peening times equivalent to the range from A to B the largest contribution is from double impacts, from B to C triple impacts, C to D quadruple impacts, D to E quintuple impacts and E to F sextuple impacts. The single impact curve shows a maximum at about 4 seconds and then falls away as more and more of the single-impacted area receives additional impacts. Multiple impact contributions reach maxima at longer peening times such that at 30 seconds, equivalent to 99.9% total coverage, impacting values for n up to 4 have passed their maxima. At 30 seconds of peening it can be seen that a much larger proportion of the peened area has received ten impacts than a single impact. Alternative representations of the relative contributions of different degrees of impacting are shown in Fig.4.

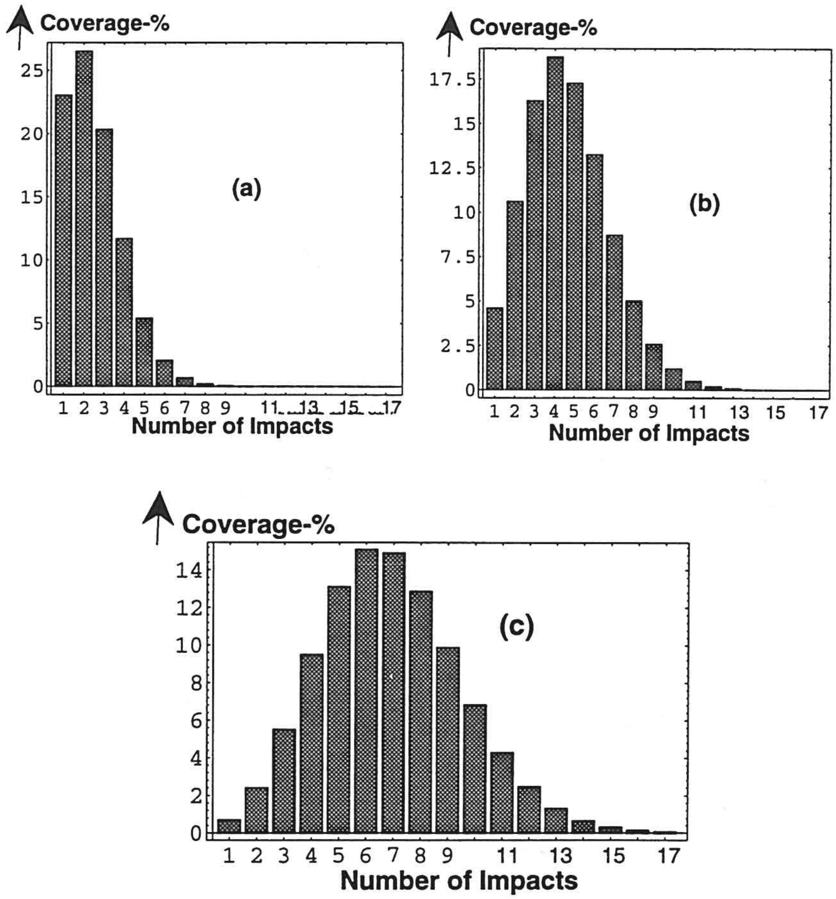
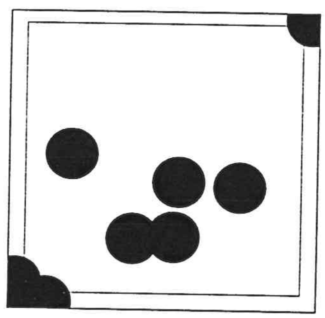


Fig.4 Contribution to total coverage of (a) 90%, (b) 99% and (c) 99.9%, due to single and multiple impacts.

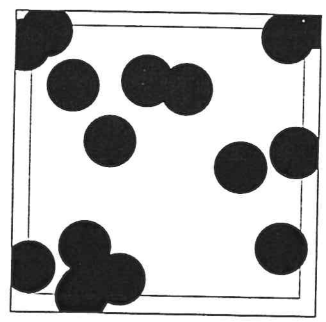
For 90% coverage most of the total coverage is made up from impacts in the range 1 to 4 with an insignificant contribution from multiple impacts greater than 8. For 99% coverage impacts in the range 1 to 8 make up most of the coverage with an insignificant contribution from multiple impacts greater than 13. For 99.9% coverage the range is broader still with 2 to 12 impacts making up most of the coverage and insignificant contributions from multiple impacts greater than 16. It is this last example that is nearest to the coverage aimed for in commercial shot peening. Numerical values for the relative contribution, S_n, can readily be determined by substitution into equation (2).

SIMULATION OF MULTIPLE IMPACTING

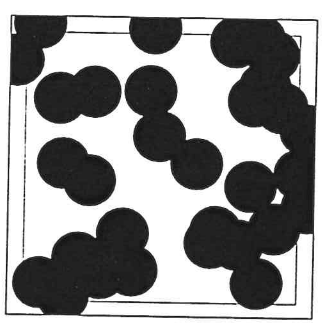
Figs.5(a) to 5(d) are simulations designed to illustrate the effects of increasing coverage on the distribution of multiple impacts.



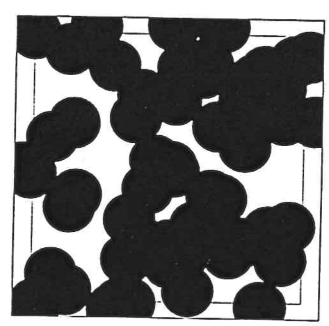
(a) Eight impacts



(b) Sixteen impacts



(c) tgirty-two impacts



(d) Sixty-four impacts

Fig.5 Simulation of impacts at four points in time.

The basis of simulating shots or correctly evaluating coverage is discussed in detail elsewhere [5]. The above figures have been generated such that the shots are landed anywhere within the larger squares. The inner squares represent areas within which coverage is to be measured. Visual inspection of the simulations confirms that with the lowest simulated coverage, (a), multiple impacts are only a minor contribution to the total coverage. With higher simulated coverages the proportion of multiple impacting increases. For the highest simulated coverage, (d), single impacting only contributes a minority of the total coverage.

DISCUSSION

The raison d'etre for shot peening is to improve the service performance of engineering components. This improvement stems mainly from the peened surface having an induced layer of highly-compressed residual stress. Any normal combination of applied stress and residual stress will therefore be reduced at the surface which is the most vulnerable in terms of manufacturing defects and maximum applied stress. The analysis of multiple impacting that has been presented here reveals the danger of over-peening. In an attempt to achieve maximum improvement in service performance too much coverage may be applied. Terms such as "three hundred percent coverage" are used in the shot peening industry. This loose terminology has no firm scientific foundation and relates simply to peening for three times that for which no more than an extra ten percentage increase in Almen gauge height will be affected.

One of the main assumptions made in this analysis was that individual impacts are statistically random. In practical shot peening there are two factors that are relevant. One factor is that individual shot particles cannot occupy the same space at the same time. This factor will favour a more uniform coverage of the shot-peened surface. The second factor is that the devices used to produce the shot stream cannot induce a perfectly random distribution of shot within the stream. This factor will favour a less uniform coverage of the shot-peened surface. This factor will have a small effect unless combined with poor control of the shot stream as it is applied to different parts of a component's surface. With computer-controlled shot peening equipment good control is generally exercised. Taken together it is believed that the assumption of statistically-random impacting is a reasonable approximation to practical situations.

The assumptions of uniform, perfectly-circular, impact areas facilitates the theoretical analysis. Non-uniform, perfectly-circular, impacts can be analyzed with more difficulty based on observed types of shot size distribution. Industrial shot specifications require close sieve size distributions. Modern methods of steel shot production can produce near-spherical particles which would make near-circular impact areas.

During shot peening individual high-velocity shot particles plastically deform regions of the surface in a manner similar to that of a Brinell hardness indentor. The material under the indentor deforms and work hardens. Multiple impacting will increase the work hardening until the ductility is exhausted. At that point cracks will develop at the surface. It would be expected that there will be a relationship between the incidence of cracking and a critical percentage of a given degree of multiple impacting. This would then enable a prediction to be made of the optimum degree of shot peening coverage based on the known ductility of a given material.

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