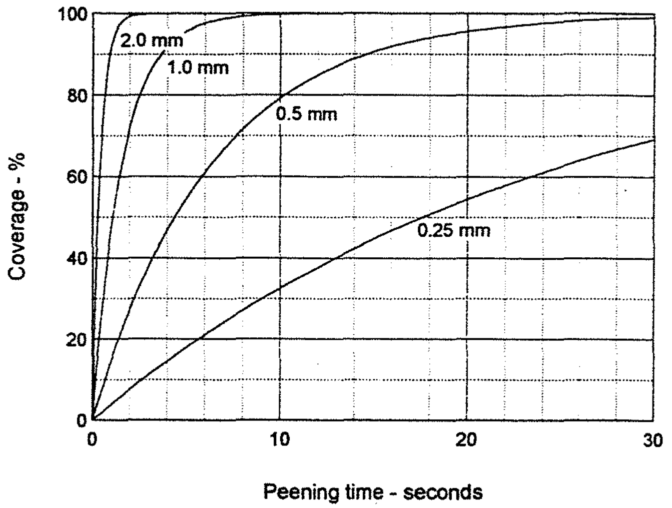

Fig. 3. Effect of varying impression radius, r, at given peening rate, R

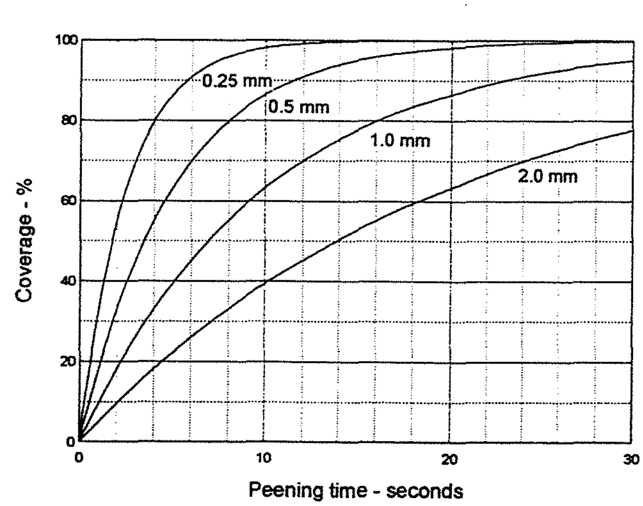

Fig. 4. Effect of varying impression size for fixed shot throwing rate, M

then consider the situation in which shot is being delivered at a fixed known rate, M, in terms of mass of shot delivered per unit time per unit area, and then examine the effect of varying the impression size. Equation (1) can easily be modified to accommodate this situation. Since the mass of a particle, m, is given by:

$m = 4/3.\ \pi r'^3.p$. where r' is the particle radius and p is the density

then R = M/m where M is the mass of shot thrown per unit area per unit time so that:

$R = M/(4/3\pi r'^3.p)$ (2)

We can substitute impression radius, r, for shot radius, r', in (2) if we know the relationship between them. This relationship can be determined experimentally but will vary according to the characteristics of the shot itself and of the material being peened. If, for a given situation, we know that r' - 2r then substituting in (2) gives that

$R = 3M/(32\pi r^3.p)$ (3)

If we now substitute the value of R given by (3) into (1) we get that

$C = 100\{1 - \exp\{-\pi r^2.3M/(32\pi r^3 p).t\}\}$ which reduces to

$C = 100\ \{1 - \exp.\ \{-3M/(32p).1/r.t\}\}$ (4)

If we take as an example steel shot with a density of 7800 kgm^{-3} thrown at a rate of 8.32 $kgm^{-2}s^{-1}$ then the term -3M/32p becomes -0.1 mms^{-1}. If we now substitute this value into equation (4) for different values of r we get the result shown as Fig. 4.

We now have the reverse of the situation shown in Fig. 3 where faster coverage was effected for larger impression sizes. In practice, of course, we do not have a fixed throwing rate irrespective of the shot size. With larger shot sizes for compressed air driven shot the nozzle diameter is necessarily increased for larger shot with a corresponding increase in the throwing rate. The ratio of nozzle diameter/shot size should normally be fixed to allow optimum shot flow without blockage leading. For centrifugal wheel type machines the throwing rate would also increase with the shot size.

Effect of Constant Ratio of Throwing Rate to Shot Size

If we examine equation (4) we see that constant coverage characteristics can be achieved if the ratio M/r is kept constant for a given type of shot. Hence we get

$C\ 100\{1 - \exp(-K.t)\}$ (5)

where K is the constant corresponding to the ratio M/r. If we do have this constancy then for a given value of K the coverage would be represented by a single curve such as that shown as Fig. 1. This would be an ideal situation. A constant value for K can be achieved in air-blast shot-peening by utilizing commercial devices that have been developed to continuously monitor the mass per unit time flowing through a feed pipe. We must still control M as the mass of shot arriving per unit area per unit time will depend on such factors as the distance between the nozzle and the workpiece. A schematic representation of the effect of nozzle-to-workpiece distance is shown in Fig. 5. For a circular nozzle diameter, D, giving rise to a circular cross-section shot stream the area of cross-section, A, will increase with the distance, d, from the nozzle. This area is given by:

$A = \{\pi(D + 2d\tan ø)^2.\}/4$ (6)

The divergence angle, ø, will depend upon the design and condition of the particular nozzle involved and it is obviously important that this is maintained if proper control is to be exercised. Given this situation we can then control the distance, d, so as to ensure a known peening rate, R, and hence a controlled ration of M/r.

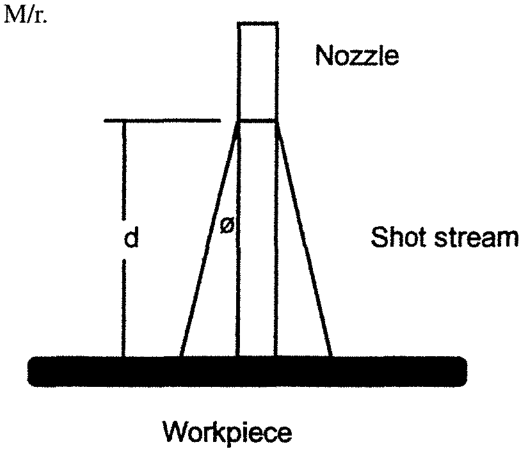

Fig. 5. Schematic representation of shot stream diverging by an angle ø.

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Discussion

We have assumed throughout that uniform circular impressions are being created in a random manner during shot peening. This is a simplification of the practical situation. Sophisticated techniques are available, for example those proposed by Knotek and Elsing (2), which enable computer predictions to be made of the shot peened surface topography. These techniques themselves often contain simplifications. For example the diameter of an impression may have been calculated using the "Intersecting Chord Theorem". This is illustrated in Fig. 6.

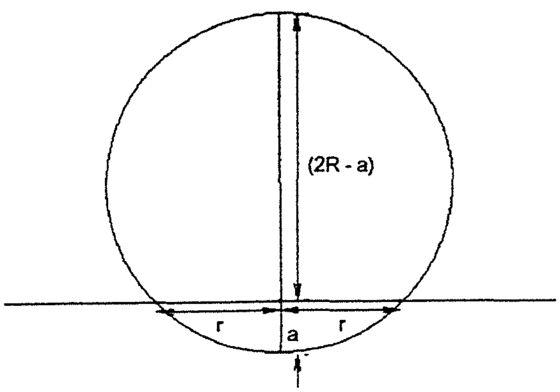

Fig. 6. Intersecting chords for circle of radius R

The intersecting chord theorem gives that $r^2 = (2R - a).a$ for the two chords shown as intersecting at right angles so that the impression radius r is given by:

$r = \{(2R-a).a\}^{1/2}$ (7)

Fig. 6 does not represent the actual situation accurately for indentation by a spherical particle. A better model would be one which allows for the displacement of the material from the indentation to produce an annulet of the same volume, as shown in Fig. 7.

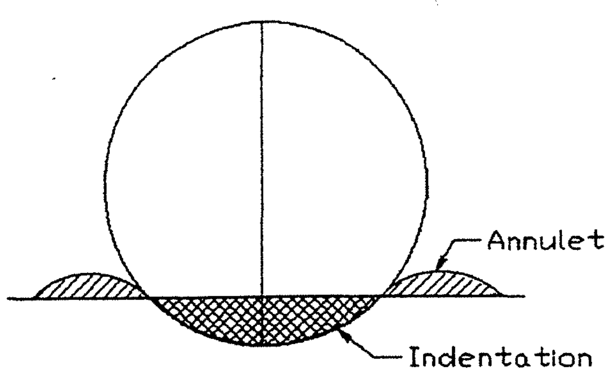

Fig. 7 Model of indentation with annulet of transposed material

The diameter of the impression may then be taken as either the diameter at the level of the original surface (when the intersecting chord theorem is valid) or as the diameter of the annulet. A search of the literature shows that there is some ambiguity as to which is taken as the impression diameter.

With respect to the validity of using the Avrami-type equation a comparison of the shape of this curve with published curves shows excellent agreement. Published curves, by their very nature, tend to derive from carefully-controlled shot peening situations. A feature of curve-fitting procedures is that, provided the model is sound, one can determine the nature of practical variations. Fig. 8 shows a situation in which the peening rate has been deliberately varied and the corresponding coverage rates determined experimentally using the assumption that displacement is directly proportional to coverage.

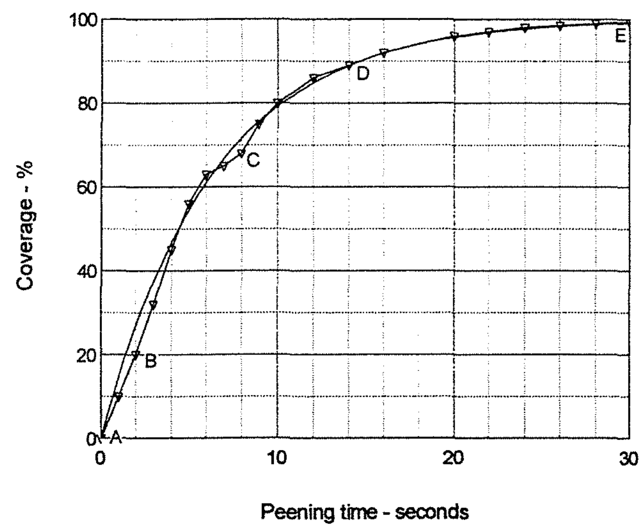

Fig. 8. Variable peening rate giving deviation from Avrami-shaped curve

In the example shown in Fig. 8 the section A-B corresponds to a relatively slow initial peening rate. Between B and C the peening rate increases and then falls followed by another increase at C falling again to D. A constant peening rate is indicated between D and E.

A set of Avrami curves can be matched against particular parts of the observed data curve in order to determine the corresponding peening rates.

Conclusions

The theoretical basis of coverage control has been analyzed using simple Avrami equations. This analysis has concluded that effective control can be based on employing a constant ratio of throwing rate/shot size. ❍

References

1. Avrami M., *J. Chem. Phys.*, **7**, 1103, 1939; Ibid., **8**, 212, 1940; Ibid., **9**, 177, 1941.

2. Knotek O., and Elsing R., *Computer Simulation of Different Surface Topographies of Metals Produced by Blasting Processes*, Proceedings of ICSP3, 361-368, 1987.