Computer Simulation of Different Surface Topographies of Metals Produced by Blasting Processes

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1. Introduction

Widespread availability of electronic data processing equipment in recent years has led to an enormous increase in the use of simulation techniques. Such techniques already have an established role in the field of measurement and control technology, where they are used to analyse the behaviour of engineering systems but their application in the general field of materials science has to date been limited.

Simulation may be defined as a method in which a second system is created possessing the same abstract model structure in terms of the relvant variables as the original system. The second system is termed a real or simulation model.

Simulation comprises both the construction of the real model according to the data of the abstract model and experiments carried out with its aid (1).

The objective of using simulation models or algorithms may, for example, be to gain a deeper understanding of the real system in the process of constructing the model, or, in cases where a multi-parameter system is modelled, to study the effects of changes in single parameters simply, rapidly, cheaply and without excessive experimental effort.

Among their other applications, blasting processes have acquired considerable importance as a technique for roughening surfaces as a preliminary to coating. A surface prepared in this way is generally characterised by measuring the values for R_t and R_z, and relating them to the measured adhesions of the coatings. It is, however, apparent from the relationships established by this means that a characterisation of surface topography solely on the basis of the values listed above permits only an inadequate interpretation of the results, although mechanical cramping of the coating to the substrate surface must be regarded as the primary mechanism of adhesion.

With this problem in mind, a Monte Carlo simulation has been developed to generate further data on the surface topography produced by blasting processes in general and shot peening in particular. The calculated model and the results obtained from it form the subject of the present contribution.

2. Preliminary Observations on the Monte Carlo Method

Some discussion is first required of a term which will be used frequently in the following remarks, namely "random numbers". Random numbers are realisations of random variables which obey certain distributions. The simplest and most important case is that of the uniformly distributed random numbers in the interval (0,1), which may be considered as the realisation of a random variable with a density

$$f(x) = \begin{cases} 1 \text{ for } 0 \leqq x \leqq 1 \\ 0 \text{ else} \end{cases}$$

or of the distribution function

$$F(x) = \begin{cases} 0 \text{ for } x \leq 0 \\ x \text{ for } 0 < x \leq 1 \\ 1 \text{ for } x > 1 \end{cases}$$

The random numbers must therefore firstly constitute a sample of a population distributed in this way, and secondly must be randomly arranged. They must thus form a random sample of a population (2). Random numbers can be generated either physically or by the use of certain computer algorithms (pseudo-random numbers) (3).

The Monte-Carlo method is a numerical technique in which a stochastic model matched to a given problem is constructed, and the corresponding random variables simulated with the aid of random numbers. It may be used to address problems of a deterministic or - as here - of a stochastic nature. With problems of the latter kind, the difficulty is to establish the random processes associated with the problem and to model them in a suitable algorithm with the aid of random numbers (4). The fundamental simulation procedure is illustrated in Fig. 1.

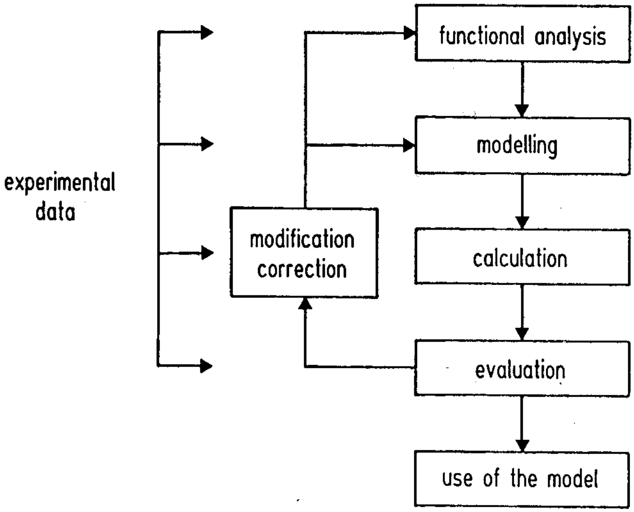

Fig. 1: General Sequence of a Simulation

The first step is to carry out a functional analysis establishing what influencing variables apply to the system and must or should be taken into account and what relationships exist between them. The second step, that of modelling, results in a flow chart of the system. At this stage at the latest, it is necessary to determine the interval in which the random numbers lie and the distribution which they obey. The third step of calculation or simulation consists of running a computer programme corresponding to the flow chart. Finally, the results obtained must be validated, for example by comparison with experimental data. If the results turn out to be incorrect or inaccurate, modification or correction of the model is required.

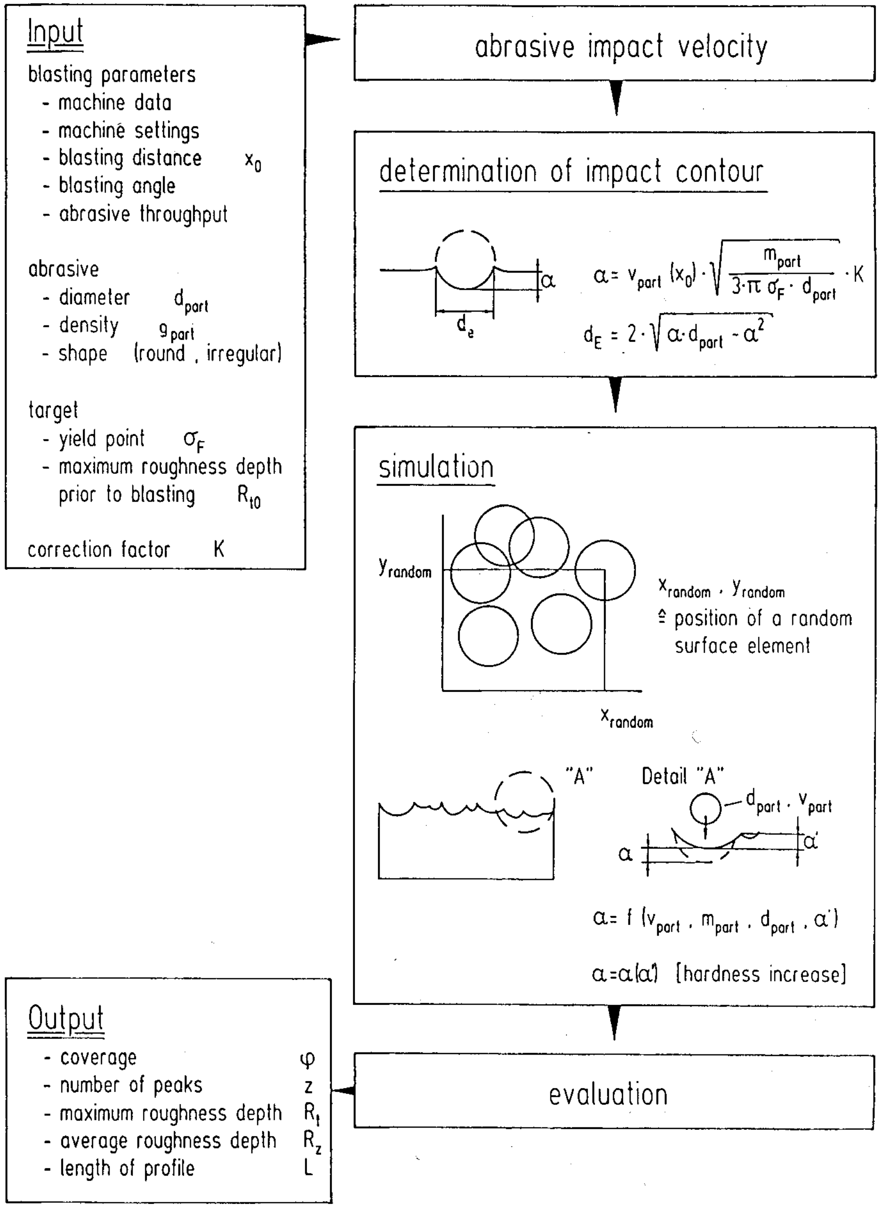

Fig. 2: Mode of Operation of the Simulation Programme

A study of recent literature on the application of simulation techniques leaves one with the initial impression that materials and production technology and engineering make little use of simulation methods in general and the Monte-Carlo method in particular. Certain examples demonstrate, however, that useful applications are also possible in these sectors. Deterministic problems such as diffusion equations can be solved with the aid of the Monte-Carlo method (2), and neutron transit through flat plates (2), material transport in PVD processes (5) and the growth of thin films (6) have, for example, been investigated as problems of a stochastic nature. The authors of the present paper have presented a Monte-Carlo simulation of the lamellar structure of thermally-sprayed coatings (7).

3. Basic features of a Computer Programme for the Simulation of Different Surface Topographies

Instruments for measuring surface topography use feelers which are drawn over a defined measuring distance on the surface. The path described by the feelers in the horizontal and vertical axes is recorded and evaluated according to certain criteria. This procedure establishes the parameters for the surface roughness of the workpiece being measured, which depends, for example, on the previous mechanical treatment of the workpiece surface.

A computer programme which simulates different surface topographies of the type produced by blasting processes should therefore include two phases: a first phase, in which the treated surface is modelled in the computer on the basis of the process parameters and material characteristics, and a second, evaluation phase in which the modelled surface is measured. Fig. 2 shows the fundamental principles on which the programme operates.

3.1 Modelling a Blasted Surface

The surface of the workpiece is represented in the computer by a two-dimensional matrix. Each element of the matrix corresponds to an element of the surface measuring 25 x 25 µm. This resolution has proved fine enough for the simulation of blasting processes using conventional abrasives with a grain size of at least several tenths of a mm. The value of the matrix element indicates the deformation of the corresponding area of the surface.

A blasting process essentially consists of abrasive particles scoring random hits within a delimited area and producing various effects, e.g. the setting up of residual stresses, the removal of particles from the workpiece surface and deformation. In this instance, only the latter influence is of interest. The deformation caused by the impact of an abrasive particle on a workpiece surface is dependent on its size, shape, mass, composition, strength properties, angle of impact and impact velocity, and on the characteristics of the existing workpiece surface at the point and moment of impact, for example the hardeness increase produced by previous impact of an abrasive particle at the same spot.

These mechanisms are taken into account in Phase 1 of the programme. A random element of the matrix is selcted (by the uniformly-distributed random-number generator) as the central point of impact of the abrasive particle. The "surface" (matrix element) and an area around it, whose size is determined by calculating the diameter of impact, is "deformed". The next random point of impact is then selected. This process continues until a set number of impacts has taken place. This number depends on the blasting time and abrasive throughput being simulated.

3.2 Measurement of Surface Topography

It will be evident that the simulated surface topography can be evaluated with the aid of appropriate algorithms, just as a real surface is evaluated by a measuring device. Suitable algorithms are built into the programme. The surface parameters R_t and R_z normally measured by conventional surface measuring devices can be determined. It is also possible to determine the coverage and the number of peaks. A feature currently being developed will likewise enable the actual size of the surface to be determined. Owing to its modular structure, new algorithms can easily be incorporated in the programme, and this is envisaged in the course of future developments.

3.3 Calculation with the Computation Programme

When the programme is run (on a personal computer), the input data shown in Fig. 2 are required. The impact velocity of the abrasive depends, among other factors, on the type of blasting process employed (wet blasting, centrifugal blasting), different machine data and machine settings being entered for each process.

A corrective factor is also entered. This corrective factor is used to compensate for modelling inaccuracies. It is determined by a single comparison of the calculated result for one particular abrasive/target pairing with a reliable measured value, e.g. for R_z. The corrective factor is altered to make the calculated and measured values coincide. It then remains valid for any variation of blasting parameters.

		specimen no.							
		1	2	3	4	5	6	7	8
nozzle-diameter	mm	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
pressure	bar	2	2	4	4	2	2	4	4
blasting distance	mm	150	150	150	150	150	150	150	150
-"- angle	°	90	90	90	90	90	90	90	90
abrasive	g/mm^2	0.008	0.056	0.008	0.056	0.02	0.14	0.02	0.14
abrasive-diameter	mm	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
density	g/cm^3	3.92 1)	3.92 1)	3.92 1)	3.92 1)	7.8 2)	7.8 2)	7.8 2)	7.8 2)
shape (round, irregular)		i	i	i	i	i	i	i	i
target material		1.4301, HV1= 199 ± 5; X 5 CrNi 18 9							
yield-point	N/mm^2	200	200	200	200	200	200	200	200
maximum roughness depth prior to blasting R_{t0}	μm	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4

1) abrasive : Al_2O_3 (MKE)
2) abrasive : (austenitic) steel grit

Table 1: Parameters for the Experimental and Simulated Generation of Differing Surface Topographies (Wet Blasting)

4. Results

This section presents some results already obtained with the model. Table 1 shows the input parameters used. The corrective factor was based on experimental results for R_z obtained using the same abrasives, blasting times, machine settings and target material in a wet blasting process. Figures 3 and 4 compare calculated results for R_t and R_z with the corresponding experimental values. In each case, the scatters for 6 measurements of real surfaces and 20 evaluations of simulated surfaces are shown. It will be seen that there is excellent agreement between the theoretical and experimental values.

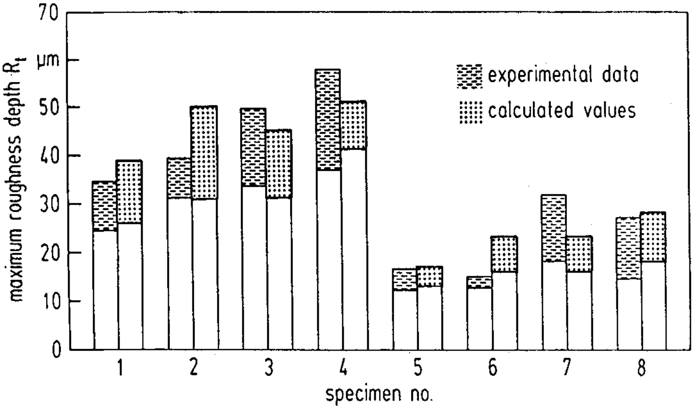

Fig. 3: Comparison of Experimental and Calculated R_t values (see Table 1 for target, abrasive and processing parameters)

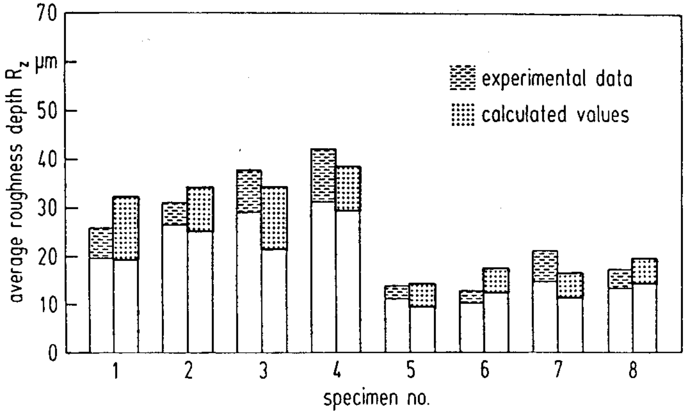

Fig. 4: Comparison of Experimental and Calculated R_z values (see Table 1 for target, abrasive and processing parameters)

Fig. 5 shows the coverage for different amounts of abrasive impacting with the target. A comparison with data in the literature (8) (using the same experimental procedure and input data as in the simulation) again shows exceptionally good agreement.

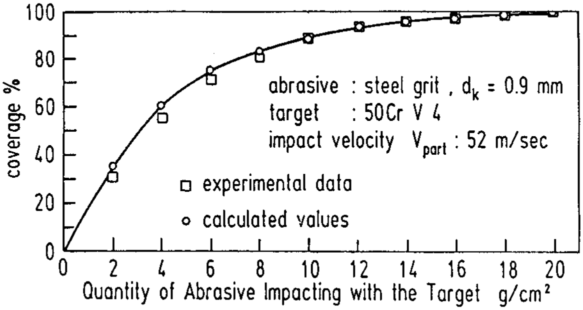

Fig. 5: Comparison of Experimental and Calculated Values; Dependence of Coverage on Quantity of Abrasive Impacting with the Target (Centrifugal Blasting)

5. Summary

A brief definition of the term simulation is followed by an account of the principle and applications of Monte-Carlo methods. The significance of the term random number in this context is discussed. The basic sequence for a Monte-Carlo simulation is indicated and examples of a number of applications for Monte-Carlo methods in materials technology are given.

A model which can be used for the computer simulation of a surface treated by a blasting process is described. The main feature of the programme is a matrix, each of whose discrete elements represents a single discrete element of a real surface. Deformations of the kind produced by the impact of abrasive particles unter particular determining parameters are calculated for randomly-selected elements of the matrix. The topography of the "surface" generated in the model can be evaluated using any criteria and related to the input data.

The results of calculation are compared with experimental data. Agreement may be described as excellent. The model thus constitutes a computer programme capable of characterising different surface topographies of the type produced by blasting processes according to given material and processing data.

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