Optimising the Double-Sided Simultaneous Shot Peen Forming

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1 Introduction

Shot peen forming is a flexible pressure forming procedure. According to the velocity and mass of the balls striking the components we can induce convex as well as concave curvatures. Hitherto, it has been solely usual to bring both methods of curvature generation to bear one after the other on both sides of a particular component. This study describes the new technology of double-sided shot peen forming.

The manufacturing of three-dimensional structural parts may serve as an example of how to identify the mechanisms which come into play during this double-peen technology in order to optimise the process as to both effectiveness and reproducibility.

Beside the experimental series of tests, the simulation of shot peen forming, which due to the many difficulties arising from the basic principle is still in its infancy, is being further developed, so that in future we will be able to apply this kind of simulation to rapid advance planning of the process strategy.

2 Principles of curvature Generation

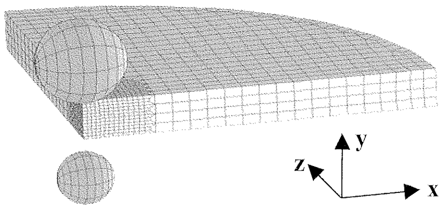
2.1 Single Sided Convex and Concave Shot Peen Forming

From the literature we are familiar with various models of describing the two possible types of curvature produced by single-sided shot peen forming, for instance the plane model of elementary theory [1] or the slip line model [2]. The former is only good for cases of convex forming however, the latter mainly for plain strain and for rigid ideal plastic material behaviour, which represents a considerable limitation.

To investigate the mechanisms which bring about a convex or a concave curvature simulations of individual ball hits at various ball velocities were carried out explicitly using the FEM-Software LS-DYNA3D (Figure 1). This model will be used in the further course of the experiments for the double-sided hitting of balls, one on the top side and one on the bottom side. In what follows we shall first present and discuss the results only. A further detailed discussion of the problems involved in simulating this technology will follow later in this paper.

Figure 2 shows the equivalent strain as well as the nodal displacements brought about in the sheet underneath an individual hit at various ball velocities. As expected, these are greater on the upper side of the component. The equivalent strain is reduced the deeper is the hit, and in the region of the bottom side it becomes larger again. This indicates that there is a dynamic bending effect with a short-term overextension of the fibres at the time of contact with the ball.

The zones on the bottom side which are affected by plastic strain increase more noticeably at higher ball velocity than are those on the top side, which to a greater extent is also true for the nodal displacements in the sheet (x-direction). At higher ball velocities the dynamic, short-term bending is more pronounced, which produces a greater plastic extension on the bottom side than on the top, and therefore also a concave curvature.



Side A:
Ball diameter $d_A = 6.4$ mm
Mass $m_A = 1.07$ g

Side B:
Ball diameter $d_B = 4.0$ mm
Mass $m_B = 0.26$ g

Model: 4892 Nodes, 5244 Elements,
Element length in forming zone 0.25 mm
Material law: Elasto-plastic, Balls rigid
Alloy: AlMg3 Flow curve at $d\varphi/dt=300\ s^{-1}$

Software: LS-DYNA3D
Geometry: Symmetry in x- and z-direction,
Sheet thickness 3 mm,
Work piece diameter 25 mm

Figure 1: Simulation of individual hits, single-sided and double-sided

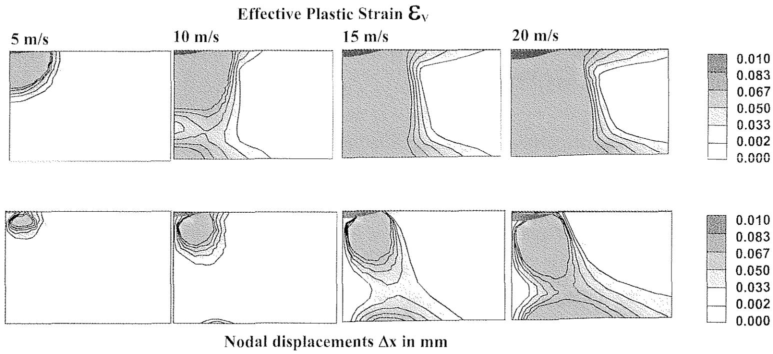


Figure 2: Effective strains (top) and displacements (bottom) in the sheet (x-direction)

2.2 Double-Sided Shot Peen Forming

The simulations described above were extended for double-sided shot peen forming. A second ball with the properties described in Figure 1 strikes the bottom side of the sheet, doing so however after a short interval of time so that positive countervailing effects caused by both balls striking at the same time may be avoided. A further simplifying assumption concerns the two hit locations, which in reality would hardly ever lie on one axis. A displacement to one side would, however, mean that one would not be able to assume any quarter symmetry. The results are shown in Figure 3.

It becomes clear that due to the effects of the balls double hits cause both sides of the component to become sufficiently plastically deformed, so that the high velocity of the balls on the top side will not be necessary to bring about plastification of the bottom side of the component. It accordingly appears from this that if we want to induce a concave curvature in a component, both single-sided and simultaneous double-sided shot peen forming may be used.

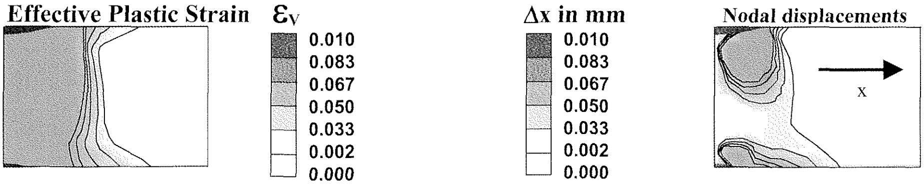


Figure 3: Results of simulation of double hits, $v_{B,\ upper\ ball} = 13$ m/s, $v_{B,\ lower\ ball} = 10$ m/s

3 Applications and Experiments

In the field of the air- and spacecraft industry shot peen forming has been successfully used for many years to form NC-milled components such as aeroplane wings, stringer-strengthened fuselages (Alpha Jet, Airbus) or for segments of the water tank of the ARIANE 4 [3,4,5]. As described in [6]the 1/8 segments of the bottom of the fuel container for the European ARIANE 5 rocket have been shot peened from both sides for several years now, albeit not simultaneously.

The numerically controlled shot peening apparatus installed at the Institute of Metal Forming has two independent peening systems, an Injector-Gravitation-Peening system (Side A, ball diameter of 6.4 mm) as well as an airpressure peening system (Side B, ball diameter of 4.0 mm). The conceptual construction accordingly provides for concave curvature of the components in the case of Side A and convex curvature in the case of Side B.

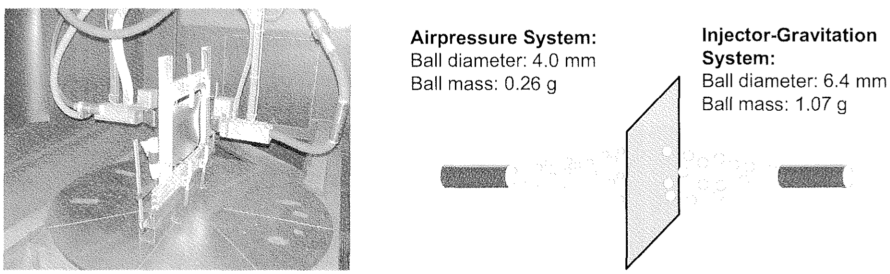


Figure 4: Configuration of the apparatus for double-sided simultaneous shot peen forming

3.1 Pre-Tests

In shot peen forming (given the ball dimensions noted above) it is the direct peening parameters - the mass flow dm/dt and the shot velocity v_B as well as the derived, indirect peening parameter represented by the degree of shot coverage A^* - that exercise a decisive influence on the result of the peening. Whereas the velocity v_B is essential for the direction of the curvature generated, the degree of coverage A^* is primarily a measure of the amount of curvature generation.

In double-sided shot peen forming these peening parameters have to be co-ordinated for both sides being peened, since they influence one another. Thus, it is not possible to determine the optimal parameters individually by means of pre-tests of the respective separate peening treatments. Figure 4 shows the configuration of the apparatus for double-sided shot peen forming.

3.2 Optimising the Peening Parameters

We thus undertook pre-tests, where the peening pressure and mass flow and thus, too, the peening parameters velocity and degree of coverage were varied on both sides and the curvatures generated subsequently measured.

To place these results in a mathematical context, two sine functions were selected in accordance with the considerations outlined above and superimposed in accordance with the form

$$f = -\left[A_A^* \cdot a_1 \cdot \sin\left(\frac{\left(v_{K,A} + a_2\right) \cdot \pi}{a_3} \right) \right] + A_B^* \cdot b_1 \cdot \sin\left(\frac{\left(v_{K,B} + b_2\right) \cdot \pi}{b_3} \right)$$

By means of an optimisation tool [7] the six correction factors a_1 to a_3 and b_1 to b_3, three of which respectively influence the form of one sine function per side, were optimised, until a minimum error quotient of calculated and measured values was obtained. Using this mathematical description, the peening parameters can be optimised and co-ordinated with one another.

3.3 Peening of Demonstrator Components

Using the optimised peening parameters we were now able successfully to form a number of demonstrator components.

By way of example, a number of contours were produced for a seat, such as a wave and a saddle contour (Figure 5). Simultaneous double-sided shot peen forming allows us to complete-

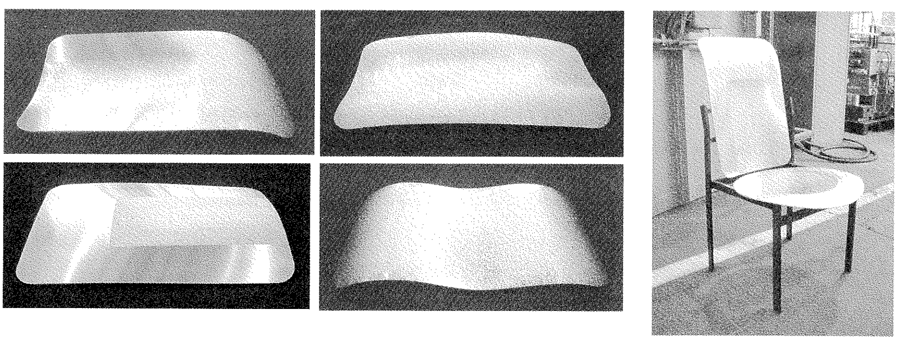


Figure 5: Various 3D-contours, produced by means of double-sided simultaneous shot peen forming

ly plastically deform the areas to be stretched in small local limits, which means that varyingly stretched areas such as we have in the case of a saddle contour may be fairly close to one another without strongly influencing one another.

4 Simulating the Shot Peen Forming Process

4.1 Basic Considerations due to the FEM of Shot Peen Forming

Due to the complex processes involved in shot peening and the great number of parameters affecting the process, it is not possible at present to simulate this process sufficiently precisely by means of the Finite Element Method.

The number of balls, the interactions occurring between the balls and the fact that the actual forming process can take several minutes, whereas the individual ball hits occur within a period of 10^{-4} to10^{-5} s, cause an extremely high computing effort. In view of the work piece description the large dimensions of the components require a very rough mesh. In order, however, to be able to portray the ball impressions on the peened surface the lengths of the element edges should be very small. To describe the material behaviour simplifying material laws where the material is regarded as a continuum are usually used. Discontinuities present in the material, influenced by the "forming history" of the initial material, instances of elastic stress caused by clamping or preloading and the flow curve description that has to take account of the high strain rates which occur, have a great inluence on the result.

Nevertheless, the FEM can still make a contribution to a greater understanding of the mechanisms operating during shot peening.

4.2 Simulation

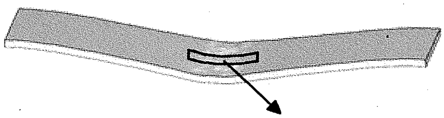
In simulations the ball hits are first simulated by means of an explicit program module. There then follows an implicit static calculation of springback [8].

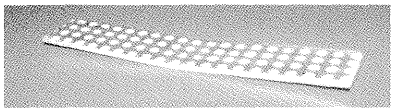
For the reasons explained above, the simulations are limited to a fairly small component (Figure 6: Simulation of multiple hits (upper left) and real component (upper right)). Real tests were carried out on sample strips with the dimensions $100 \times 20 \times 2$ mm^3 and whose parameters attracted ball velocities and numbers for the simulations. The final curvature achieved after spring-back is greater when simulating than it is in reality. One of the main reasons for this is that the flow curve description applies to a considerably lower strain rate of 300 1/s than that found in reality.

Figure 6 shows the equivalent plastic strain and the progression of the residual stress in the sheet. On both surfaces compressive stresses occur, the tensile stresses in the cross section being displaced in the direction of the bottom side of the component.

Model: 28101 nodes, 23460 elements,
Element length in forming zone 0.5 mm
Material law: Elasto-plastic, balls rigid
Alloy: AlMg3 Flow curve at $d\varphi/dt=300\ s^{-1}$

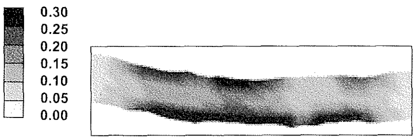
Software: LS-DYNA3D
Geometry: $100 \times 20 \times 2\ mm^3$ **Tools:**
70 balls diameter 6,4 mm, $v_B = 17$ m/s
140 balls diameter 4,0 mm, $v_B = 6.1$ m/s



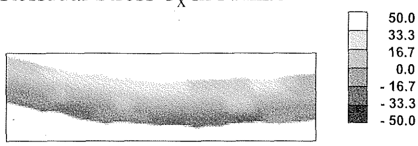


Simulation Real sample part

Equivalent Plastic Strain ε_v



Residual Stress σ_x in N/mm^2



5 Conclusions

With convex curvature only a small layer in the region of the surface is plastically deformed, whereas in cases of concave curvature it is the whole cross section. Simulations of individual hits show that due to a short term, superimposed deflection effect at the time of the hit with greater kinetic energy of the shot brings about greater plastic deformation on the side facing away from the ball. These hit effects can likewise be substituted by means of a peening treatment on both sides. A plastic deformation of the whole cross-section takes place in this case at lower kinetic ball energies than it would be the case with single-sided peening. The degree of shot coverage and the ball velocity have a determining effect on the peening result on both sides and have to be co-ordinated with one another. Knowing the optimised peening parameters, it was possible to manufacture reproducible 3D-contours. The overall plastic deformation brought about by double-sided simultaneous peening makes narrow curvature radii possible, which may be varied as to form and direction in local areas lying close to one another.

Simulations are presented, which use several hundred balls to produce deformation energy. Using this concept the first deformation processes can be simulated by using fundamental mechanisms of ball hits, which allow us to reach conclusions about plastic strains and the state of residual stress.

6 Acknowledgements

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7 References

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