Peen forming by pointed ball shooting (Ball Shot Forming)

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1. Introduction

In the past more than once has been reported about the possibility of producing special component curvature [1 to 7]. This also was the subject at the 'First' and 'Second International Conference on Shot Peening'. Hence it is known, that for a reproducable fabrication of components it is essential to know about effects, which influence the shot peening process. The peening intensity and the guide of shot flow are of great importance for the resulting curvature of the components.

In the main, the peening intensity can be influenced by the choise of qualified shot medium (that is material, grain size, grain shape and grain hardness), by shot velocity, processing time, coverage and shot flow. Above all, the guide of shot flow influences the momentary shape of components with its influence on the resulting final shape. Remarkable is the possible relation between the guide of shot flow and the peening intensity by partial or total overlay of peened traces (enlargement of coverage).

Within the aircraft industries the use of peen forming is widespread because of its advantages at the production of curvatures on sheet metals for wings and cells. Thereby the process of manufacturing is controlled according to the different shapes, thicknesses, recesses and stringers. As for automatically working machines this means, that apart from guiding of shot flow the peening intensity has to be determined before beginning the peen forming process as well.

2. Disadvantages of conventional peen forming

As for the usual technique of air blast peen forming, the shot is continually distributed on the surface of the workpiece by means of a nozzle. That is how the workpiece is hit at each moment simultaneously by several grains, respectively balls, whereby the resulting indentations in the spread due to the nozzle are statistically distributed. The depths of indentations are of different size because of different kinetic energies of grains.

As for miner coverages (e.g. less than 50 %) there will be, apart from single indentations, still indentations at the surface of the workpiece which touch and thereby influence each other. It has to be pointed out, that these multiple indentations effect other lokal residual stresses and thereby local strains than several single indentations, which are side by side and don't touch each other. Also the visual impression is not favourable. The lower the coverage, the more irregular is the distribution of indentations respectively the distribution of induced local stresses with resulting inhomogenious distribution of extensions in the surface.

Since the generation of low curved components demands lower coverages, in view to these special demands it seems to be convenient to leave the conventional peening process for choosing a technology without the disadvantages mentioned above. Thus, a technique has been developed, which allows to place balls of low tolerances in shape and diameter (e.g. ball bearing balls) with defined energy not uncontrolled but pointed at the surface of workpieces.

3. Description of the peen forming test unit

By the use of a test unit to realize the technique mentioned above, it is possible to shoot ball bearing balls of different diameters with various speed pointed at the surface of workpieces, controlled by a program. The test unit consists of several components and allows automatical peening of specimens as well as automatical registration of total strain by measuring 24 * 24 = 576 surface-points in steps of 10 to 10 mm. The following components have to be distinguished:

- air blast accelerator for balls, including ball magazine, ball loader, changable accelerator tubes for different ball diameters, air blast boiler.
- workpiece fixture with changable pick up elements and a sensor to registrate the impact of balls.
- measuring instrument for registering ball velocity and thereby the kinetic energy of balls each.
- controller for workpiece location by the use of CNC and for process control.
- measurement component to register the total strain of workpieces by the use of an inductive displacement transducer, an amplifier,an A/D- transducer and a computer to investigate saved measurement data by analysis programs.

The figures 1 to 3 illustrate the surface of a peen formed workpiece by pointed ball shooting and show a computed measurement data listing of a strained specimen as well as a graphical demonstration of data by a grid size of 10 to 10 mm.

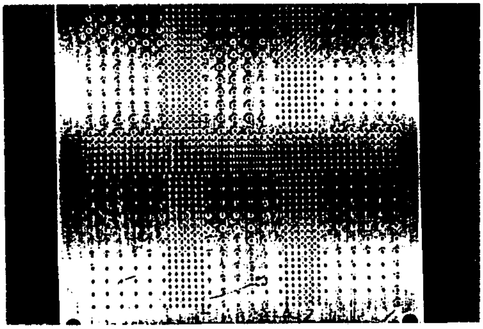

Fig. 1: An example for exakt positioning of balls (about ± 0.2 mm) at the surface of a workpiece by pointed ball shooting.

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.54	2.01	2.44	2.83	3.17	3.47	3.73	3.95	4.12	4.25	4.33	4.38
2	1.96	2.45	2.88	3.29	3.64	3.95	4.19	4.42	4.59	4.72	4.81	4.85
3	2.33	2.82	3.27	3.66	4.02	4.32	4.59	4.80	4.98	5.11	5.19	5.24
4	2.68	3.18	3.64	4.03	4.39	4.70	4.96	5.18	5.33	5.48	5.54	5.61
5	2.96	3.46	3.92	4.32	4.68	4.98	5.25	5.47	5.65	5.77	5.86	5.90
6	3.25	3.73	4.21	4.61	4.96	5.27	5.53	5.75	5.92	6.05	6.14	6.18
7	3.47	3.96	4.41	4.81	5.17	5.47	5.73	5.95	6.12	6.25	6.35	6.39
8	3.68	4.18	4.63	5.02	5.36	5.67	5.93	6.15	6.32	6.44	6.53	6.58
9	3.81	4.31	4.74	5.14	5.49	5.80	6.04	6.27	6.44	6.56	6.66	6.70
10	3.93	4.44	4.88	5.28	5.62	5.91	6.16	6.38	6.55	6.68	6.77	6.80

Fig. 2: Computer listing of the measured strain data (shown is only 1/4 of the total data list).

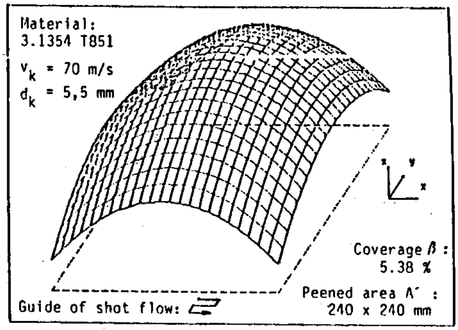

Fig. 3: Graphical presentation of a peen formed specimen (576 measurement points) at v_K = 70 m/s.

4. Advantages of the process

Opposite to conventional peen forming the following adventages by use of the test unit mentioned above are:

- Any patterns of indentations can be produced in respect to the exact positioning of balls, adapted to material, thickness, stringers and required curvature of workpieces. Hence it follows, that

  a. there are no difficulties in generating constant distributions of indentations by lower coverages as well,

  b. the touching of indentations is avoidable respectively produced only when required,

  c. there are lowest tolerances in reproduction of total strain when material, treatment and pre-shape of workpieces are equal,

  d. the visual impression of peened surface is well.

- The position of single indentations respectively of indentation patterns can be fixed by CNC programs. Eventually needed corrections are possible by variation or changing terms of programs without difficulties.
- The ball speed of single balls is measurable and variable. So the kinetic energy of single balls can be varied, too.
- There are no collisions between balls before touching the surface of the workpiece. Due to this fact, there is no loss of energy.
- Using oil as lubricant and sealant between ball and accelerator tube, abrasion of balls is very low. By machining alloys out of Al-Cu-Mg the balls are reusable.
- It is possible, working with different ball diameters simultaneously.
- To increase economy respectively to reduce processing time, balls with equal or different diameters could be shot simultaneously by using several accelerator tubes in a row or block.
- In total there are better conditions for basic research. The influence of peening parameters, especially the coverage, can be exactly registered and investigated in detail.
- The possibility of creating mathematical models to predict the total strain of workpieces in dependance on peening conditions increases.

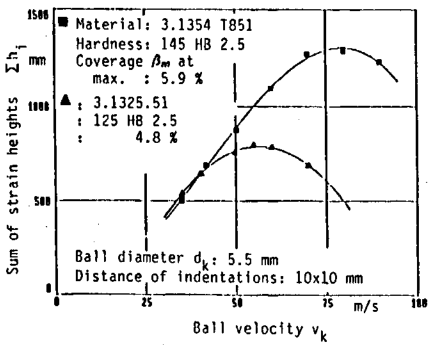

Fig. 4: 'Sum of strain heights' (based on 576 data) in dependance on ball velocity v_K at different aluminium alloys.

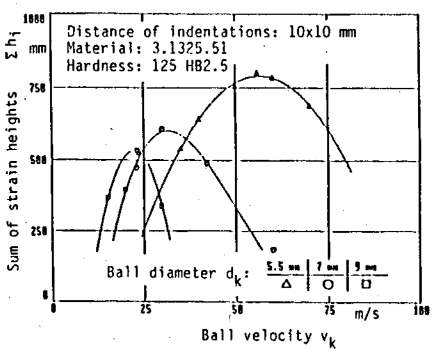

Fig. 5: 'Sum of strain heights' (based on 576 data) in dependance on ball velocity v_K at different ball diameters d_K.

5. Results of investigations

The following discourse presents selected results of basic researches. These refer to the influence of ball velocity, ball diameter, coverage and guide of shot flow. The experiments were realized with ball bearing balls and specimens out of alloys like Al-Cu-Mg 1 and Al-Cu-Mg 2 with the material numbers 3.1325.51 and 3.1354 T 851. The square specimens out of sheet metal by a size of 280 * 280 * 5 mm were carefully fixed in the workpiece fixture by the use of rubber elements to avoid stresses due to external forces. The peening process happened regularly with a distance of indentations of 10 to 10 mm. Selected peening parameters and data of experiments are shown in the following figures.

To describe the total strain of workpiece due to the peening parameters an abstract auxiliary parameter was created, called 'sum of strain heights'. It is composed by the sum of data on local measured heights of strain (576 measurement points) across the curved surface of peened workpieces.

Figure 4 shows the 'sum of strain heights' of two different aluminium alloys in dependance of ball velocity v_K . It can be recognized, that there is a certain ball velocity for each material which effects a maximum of total strain of the specimens. In the figure shown, the values of these ball velocities are at v_K = 80 m/s and about v_K = 60 m/s. The material with higher tensile strenght and hardness shows under similar test conditions a 40 % higher 'sum of strain heights'.

Figure 5 shows the 'sum of strain heights' for different ball diameters depending on ball velocity. Besides maximum values by certain ball velocities it is visuable, that smaller balls reach a better strain rate than using bigger balls. The reason of this fact is a better lateral extension in the surface of the specimens as a result of different shapes of indentations. Certainly a gradual reduction of ball diameters do not implicate continuous increasing of the total strain. Hence in addition to optimal ball velocity there must be an optimum of ball diameter.

The figures 6 to 11 e.g. demonstrate results about the investigated influences of different guides of shot flow by varied coverages. After finishing lots of experiments it was proved, that on one hand in case of low coverages the final strain is independant on the guide of shot flow but, on the other hand, if coverages reach values greater than 30 %, it is substantially not. The reason to the latter is based on enlarged momentary strains and resulting stronger modification of moments of resistance.

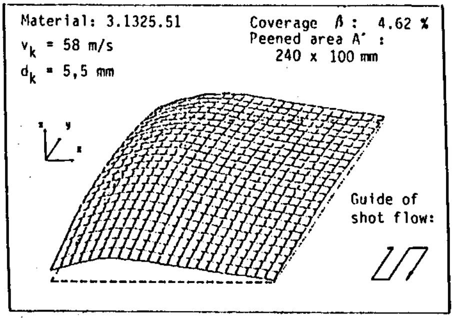

Fig. 6: Shape of specimen after a partial peened surface about 40 % (Maximal height of strain about 1.1 mm).

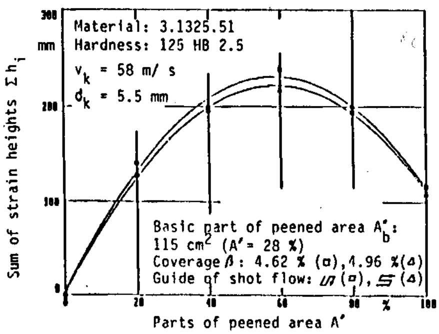

Fig. 7: 'Sum of strain heights' in dependance on parts of peened surface at a coverage of about 5 %.

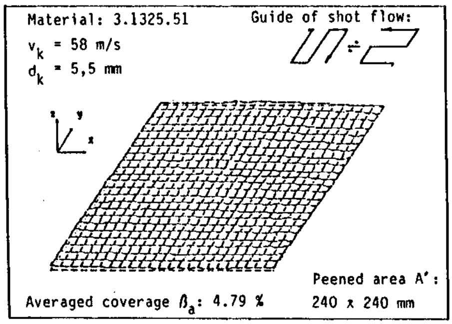

Fig. 8: Difference of final strain of two specimens, produced at different guides of shot flow at a coverage of about 5 %.

Figure 6 as an example shows the strain of a specimen (sheet metal component) after peening 40 % of its total surface by a constant coverage from about β = 5 % (gridscale 10 mm). The guide of shot flow was to and fro. After total peening of surface the result was a symmetrical curved shape with a globular radius of about r = 7.5 m. Different guides of shot flow produce at similar coverages similar final shapes. This result can also be seen in the figures 7 and 8.

Figure 7 shows the development of the 'sum of strain heights' at increasing parts of peened surface by different guides of shot flow. Figure 8 graphical presents the resulting difference of the final shape. There are no important differences in the 'sum of strain heights' to be seen. The difference of final strains is described by a constant level, that means the final strains are out of the same shape.

On the contrary with higher coverages there are totally different characteristics to be found. The value of each 'sum of strain heights' strongly differs dependent on the guide of shot flow (see Figure 9). Analogous the resulting mathematic level of the difference of both final strains is not constant (see Figure 10). Compared are two surfaces with a coverage of about ß = 55 %, which are worked on the one hand to and fro and on the other hand by helical guide of shot flow.

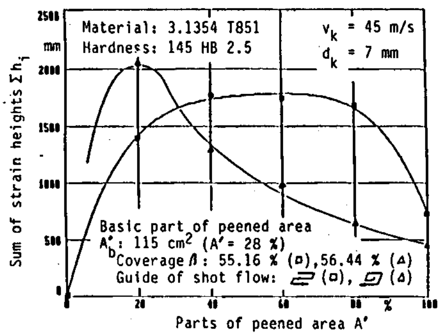

Fig. 9: 'Sum of strain heights' in dependance on parts of peened surface at a coverage of about 55 %.

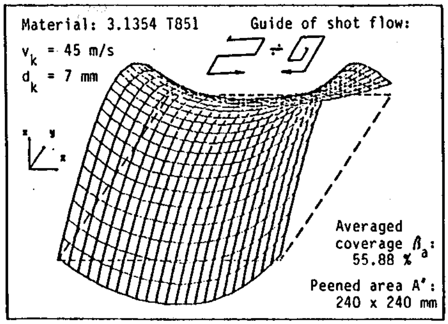

Fig.10: Difference of final strain of two specimens, produced at different guides of shot flow at a coverage of about 55 %.

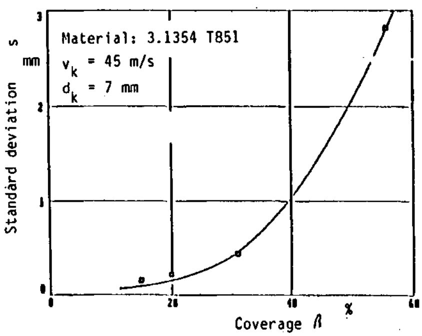

Fig.11: Standard deviation for differences in total strain due to the guide of shot flow in dependance on coverage.

By calculating the standard deviation of differences in the total strain due to the guide of shot flow for the examples mentioned above, one will find a value from about s ≈ 3 mm (coverage β > 50 %, see Figure 11). Opposite, for a coverage less than 30 % the standard deviation is smaller than s ≈ 0.5 mm.

Based on the results of experimental tests now it is tried to find mathematical models to predetermine the total strain of the sheet metal specimens considering restricted conditions. One model is based on the approximation of measured total strains by plains of second order with the aim to find a functional relation between the peening parameters and the coefficients of prepared systems of equations. Up to now worked out approximations show good results. The computed data show deviations to measured data from about 4%.

6. References

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