Special Applications of Shot Peening

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Shot peen forming has become an excellent procedure for forming sophisticated components in aircraft construction industries. The theory, recent developments, application and economy of the process have been described in brief. Experiments were conducted on thin spring steel strips to study the effect of elastic bending prestresses in peen forming to a given curvature. Results indicate that elastic prestress peen-forming was found to be advantageous and it reduces compound contour normally resulting from free state peening. The residual stress magnitude in pre-stress forming was also found to be higher than free state forming under similar conditions. It could be possible to peen form even hard strips and sheets without rebound and compound contour.

Nomenclature

P^C = Residual compressive stress into the work piece due to impact of the ball on it
σb = bending stress
dE = Indentation diameter
Mf = Mass of shots Kg/min.
R = Final radius of curvature, mm

1. INTRODUCTION

Shot peen forming is the technique to form an unformed skin panel or sheet metal by shot peening with round shots (steel, glass, ceramic). While the shot peening is a cold working process where round shots are thrown at a relatively high velocity over the metal surface. The impact of the shot causes a plastic flow of the surface fibers extending to a depth depending upon degree of impact of the shot and physical properties of the work. The surface metal is under compression and spreads in the place of the surface but the core is not, and so resists this spreading. The core is in a corresponding state of tensile stress but, as the compressive stress is of small depth compared to tensile stress, the later is of curved shape so as to balance these stresses (Tatton, 1986). The peened surface is convex as it needs to expand to achieve this balance. This phenomenon is shown in Fig. 1.

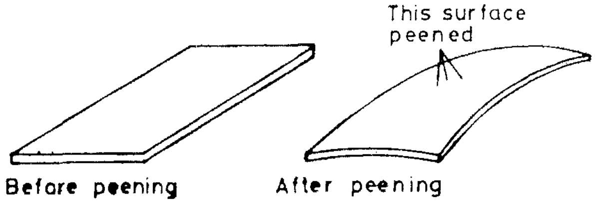

Fig. 1. If one side only is peened then that side will have convex shape (compound curved or bend shaped)

2. NATURE OF THE PROCESS

In peen-forming process the sheet volume is in general only partially plasticized. Elastic deformation cannot therefore be neglected, as in the case of many other forming process. The problem under consideration is consequently an elasticplastic one. As a result of the manufacturing process, the sheet metal to be formed usually has a rolling mill texture, so that the material may generally be regarded as in homogenous and anisotropic. \In addition, strain hardening of the material is induced by each shot impact. During the forming process, high kinetic energies are converted into heat, necessitating additional consideration of thermal phenomena. Strictly speaking, therefore, the problem is thermomechanically linked.

In addition, the exchange of energy often takes placed so rapidly that the process must be regarded as dynamic rather than static.

All these phenomena occur three dimensionally, making complete theoretical analysis an extremely complex, and indeed at present, an insoluble problem (Kopp and Ball, 1987).

3. THEORY

Shot peen forming works by either stretching one surface and so causing the metal to bend or by stretching a complete section in relation to another and so inducing a compound "barrel" or "saddle" double curvature. A barrel shape is one which is convex in both 'X' and 'Y' directions when viewed from one side and saddle shape in convex in one direction and concave in the other /3/.

The action of the shot striking the surface stretches the material beyond its yieldpoint. The material below the surface will be permanently stretched for a finite distance below the surface. The depth of stretched material will vary according to the work piece material composition and hardness, the shot media used (steel, glass, ceramic) the size and speed of the shot, etc. These factors will effect the size of the indentation which will give an indication of the depth compression. (Fig. 2).

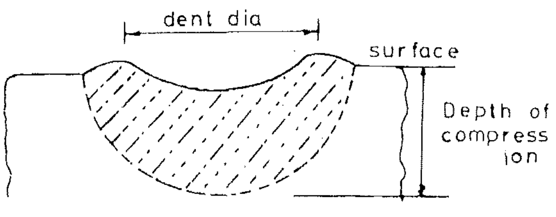

Fig. 2. Proportion of dent diameter and compressive depth

There is some evidence to suggest that, for some materials at least, the depth of compression is approximately equal to the indentation diameter. By careful selection of the shot media, size and striking energy in relation to the components size, thickness material and required shape the necessary depth of compression will be induced so that the metal bends as a result of the change in balance of the internal residual stressed. The residual stresses in a beam which has been shot peened on the upper surface is as shown in Fig. 3, it is assumed that there were no residual or

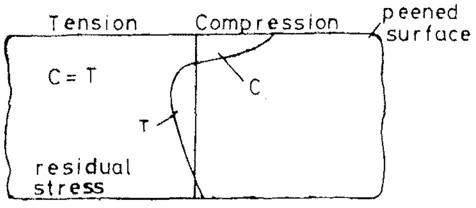

Fig. 3. Residual stress pattern in a shot peened beam

applied stresses in the beam is in equilibrium the areas between the curve and zero detum. That is, the compressive forces are balanced by tensile forces. The sum of moments about the neutral axis must also balance, for equilibrium to be maintained.

If the thickness of the beam is very large in relation to the depth of compression, then no measurable bending will occur. For thinner sections,where the depth of compression is in the order of 10% of the total thickness, a useful change in shape can occur.

The stress distribution described above in Fig. 3 will tend to apply in all places perpendicular to the component surface. Consequently a panel which is wide and long in relation to its thickness will initially tend to have a barrel shape when shot peened uniformly on one side only (Fig. 4).

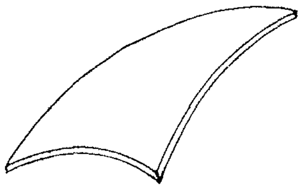

Fig. 4. Compound shape induced by low level shot peening

A point may be reached however, when the depth of the induced shape becomes large enough to cause it to be too stiff to take this compound shape. When this point is reached the pane will tend towards single curvature (Fig. 5). The double and single curvatures described above are, however, uncontrolled with regard to the relationship of the induced radii in the 'X' and 'Y' directions and would rarely match that desired in practice. The necessary control can be gained by stretching the fill thickness of the metal in specific areas to induce the required compound shapes. By varying the shot energy when it strikes the parts surface, the depth and intensity of the compressive stress can be varied accordingly. If both surfaces of the panel are shot peened so that residual stress are symmetrical, or near to symmetrical, about the neutral axis an overall increase in area will result with any asymmetry causing a bending action. If the area so worked is restricted to a specific area then a compound shape is induced.

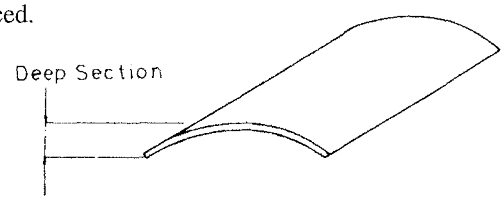

Fig. 5. Single curvature from heavier shot peening

4. SHOT PEEN FORMING WITHOUT PRE-STRESSING

The shot peen forming without pre-stressing is a pure compression forming operation where the impact of ball forms an axisymmetric zone of deformation caused essentially depend on component geometry (eg. length, width ratio or stiffening due to thickness discontinuities), the direction of rolling, the shot size and velocity and the properties of the work piece material. An approximate peening strategy, for example line-by-linecoverage of the component, enables certain uni or multi axial curvature to be generated (Kopp et al, 1982 and 1984; Martin, 1980; and Kopp et al, 1987).

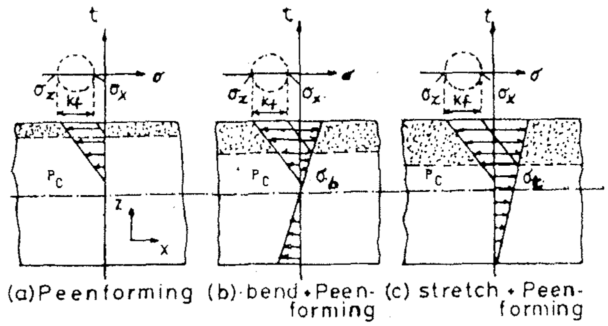

Fig. 6. Stress states and plastic zones for different shot peen forming variants

Fig. 6a shows an idealized distribution of the compressive stress Pc produced by the impact of a ball on the work piece, the depth of the plastic zone for an assumed yield and the Mohr's circle for the work piece surface.

Depending on the intensity of energy of the ball, either convex or concave shot peen forming will result. Convex peening occurs when the impact of the ball causes the work piece to deform against the direction of peening. If kinetic energy of the ball is increased to a point at which the work piece is highly plasticized and deforms in the direction of blasting, the process is termed as convex peening.

5. SHOT PEEN FORMING WITH ELASTIC BENDING PRE-STRESSES

A significant development in controlling the direction and degree of stretching action of shot peening has been "Pre-stress shot peening". It has been established that if the component surface is subjected to a tensile stress whilst it is shot peened then the depth of the resultant residual compressive stress but also the resultant residual compressive stress but also of its direction and thus control of the magnitude and direction and thus control of the magnitude and direction of the degree of stretch is obvious in the panel. It is essential that the applied tensile stress during pre-stress shot peening is within the elastic range of the material being processed. It is emphasized that a permanent change in shape will only occur when the part is shot peened, and that if the part were to be removed from the pre-stressing fixture without being shot peened it will spring back to its original shape.

When shot peen forming is combined with a super imposed bending stress, the part is elastically pre-stressed in the desired direction of curvature. As reported by R.K. Kopp and H.W. Ball, the plasticized zone is greater than that of non pre-stressed components subjected to the same peening intensity (Fig. 6b).

6. SHOT PEENING WITH ELASTIC STRETCHING PRE-STRESSES

In components which are to be multiaxially curved, the material must flow from the thickness into the length during stretching-assisted shot peen forming. Part of the component is pre-stressed (eg. strip pre-stressing) and the pre-stressed region shot peened.

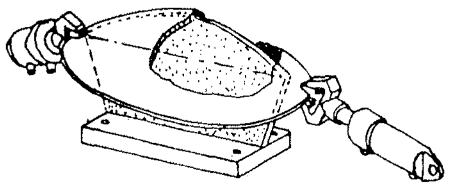

Fig. 7. The working principles of a quasi-stretching pre-stressing device

The working principles of a quasi-stretching pre-stressing device is shown in Fig.7. The pre-stressing forces are so low that the pre-stresses remain in the elastic range. A simple milled plate can save as the contouring tool.

Fig. 6c. shows the pre-stress resulting from stretching and the superimposed stress Pc induced by the shot peening impact. The plasticized zone is deeper than in the cases discussed above. Given the suitable choice of forming parameter, full plasticization of the work piece without excessive surface roughness is achievable, allowing material to flow longitudinally.

7. RECENT DEVELOPMENT OF THE PEEN FORMING PROCESS

The mathematical model given by R. Kopp and H. W. Ball as KSU model a simple micro computer model, which currently enables shot peen forming parameters for uniaxially curved components to be predetermined and relationships to be displayed graphically /8/. One example is shown in the form of nomogram/work sheet (Fig. 8). It gives the procedure for calculating the forming parameters.

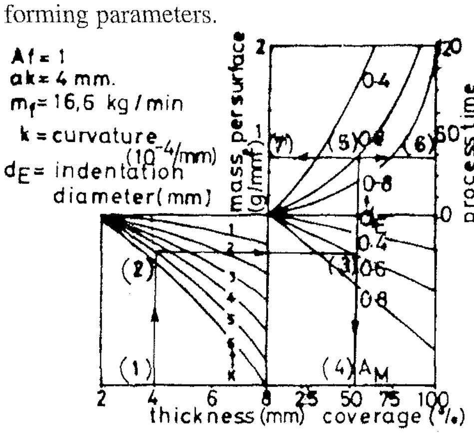

Fig. 8. Nomogram for pre-determination of shot peen forming parameters

Example:
Taking ball diameter dR = 4 mm
Adjusting factor Af = 1
Shot flow mf = 16.6 Kg/min.
Sheet thickness 4 mm.(l) as in Fig. 8
Final curvature R = 5 x 10^{-4} mm (2)

The coverage required to produce the component curvature with a selected indentation diameter of dE = 0.6 mm (3) is calculated as Am = 54% (4). In the upper half of the figure, the peening time for a component area of 1m2 of roughly tgm = 45 m in (6) is read off at point (5). The mass per surface required to determine the machine set points is derived from (7) as mf = 0.7 mm^2. Using the same procedure, it can be seen from the nomogram that, for example, the required curvature cannot be produced given a selected indentation diameter of dE = 0.4.

By altering the input variables, a cost effectiveness analysis and an estimation of such component characteristics as coverage, surface topography and curvature can be performed, as can an analysis of process feasibility in terms of plant capabilities.

Calculation of the forming parameters with the aid of the KSU model is currently restricted to unixially curved components where components of uneven thickness are to be formed, a partial calculation is carried out for the uniform thickness section of the component.

8. APPLICATION AND ECONOMY OF SHOT PEEN FORMING

Shot peen forming is nowadays generally used where the number of work pieces in batch are too small to justify investment in mass production processes such as stretching or die bending, or where, for example, three point bending cannot be used for uni-axially curved or integrated components. In principle, however, shot peen forming is also suitable for large curvatures.

The extremely flexible shot peen forming process enables difficult uniaxially or multi-axially curved sheet metal geometries, which would require high machine effort and energy consumption if processed by conventional methods to be produced with elastic pre-stressing similar to that for bending or stretching.

9. ECONOMY SHOT PEEN FORMING VS. CONVENTIONAL FORMING

Shot peen forming can be applied to virtually any size of part which will exclude conventional presses, pinch rollers or stretch presses.

Varying material thickness is readily accommodated by shot peen forming unlike press or stretch forming. Packing pieces or post machining operations are eliminated.

Shot peen forming works well on compound shapes where radii of curvature, are with in elastic range of the material at that thickness. Design changes can be accommodated quickly and economically with changes to peening parameters and alterations to check fixtures.

Shot peen forming is dieless process and so on die proving work is necessary.

No need for metal to the left on parts as a forming aid as, for example, for the gripping jaws when stretch forming, considerable savings, therefore to the manufacturer who has a reduced amount of material of post forming machining or trimming operations.

Press or stretch forming require greater ductility than is required for shot peen forming and so very often expensive post forming heat treatment is necessary. The heat treatment can cause distortion which may be counted by careful use of expensive fixture to hold the parts shape during heat treatment. As shot peen forming can be applied to the fully machines, fully heat treated part all the problems can expenses are eliminated as the raw material can be purchased in fully heat treated-condition.

Fatigue and stress corrosion: when post forming processes are required to induce either fatigue life improvement or stress corrosion cracking resistance in parts, the additional operations will add to the manufacturing costs — if the part is formed by techniques other than shot peening. Material handling is a cost factor in any process and it is eliminated by the shot peen forming process as the parts are saturation shot peened on the same machines as do the shot peen peened on the same machines as do the shot peen forming. Saving in the order of 20 to 30% can be made by combining shot peen forming with shot peening for fatigue enhancement.

Fatigue life improvements have been reported by several aircraft companies comparing press forming followed by shot peening and with shot peen forming. In all cases the shot peen formed parts showed the best fatigue life.

10. EXPERIMENTAL WORK

Pneumatic shot peening equipment with the syphon induction method of shot aspiration was designed and developed for laboratory peening purposes (Barett and Todd 1984). The equipment without driving unit and airsource is show in Fig. 9a. It shows symphonic action nozzle, shot hopper and forming fixture only (Fig. 9b).

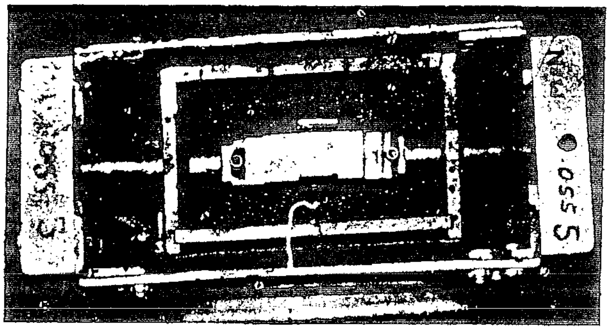

Fig. 9a. Fixture clamped on the shaft

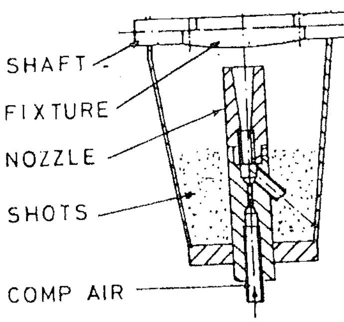

Fig. 9b. Equipment used for peen forming

Peen forming fixtures used for this investigation were designed and fabricated as show in Fig. 10. These were made separately for forming two different radius of curvatures 96 mm and 175 mm. Each fixture was clamped on the shift which was mounted in front of the nozzle as shown in Fig. 9b. The work piece was located width wise in between two center screws placed on the vertical line as shown in the plan of Fig. 10.

The work piece was pre-stressed statically in the direction of curvature to be formed with the help of two set screws, placed perpendicular to the curvature at the two ends of the work piece (Fig. 10 Elevation). Amount of pre-stress was controlled by screwing these two set screws to a suitable position over rectangular washers, which in turn were clamping the two ends of the work piece. After pre-stressing and before peening, it was fully

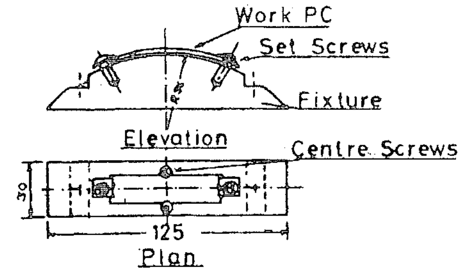

Fig. 10. Peen forming fixture

ensured that there was no permanent deformation over the work piece and pre-stressing was strictly within elastic limit only. Dimensions of the work piece (strip) were 76mm length 20.1mm width and 0.7 mm thickness, and the composition was 0. 8% carbon steel (En 42). Work pieces were hardened and tempered to different temperatures to obtain five different hardness values HRC 10. These work pieces were peened under two different stress conditions on two different fixtures to form radius of curvatures of R = 175 mm and R = 96 mm. Peen forming time was found out for pre-stress and free state peening conditions. Peen formed curvatures were checked after peening by matching the formed piece with the curvature of forming fixture contour under visual observation.

Following peen forming parameters were used to peen form the work piece of different hardness values to a curvature of R = 96 mm under elastic pre-stress and free state conditions:
Shot size = S - 390 (OSS - 5)
Air pressure = 0.6 MPa
Nozzle bore = 5.0 mm
Stand off = 25 mm
Peening was done over the length of the work piece

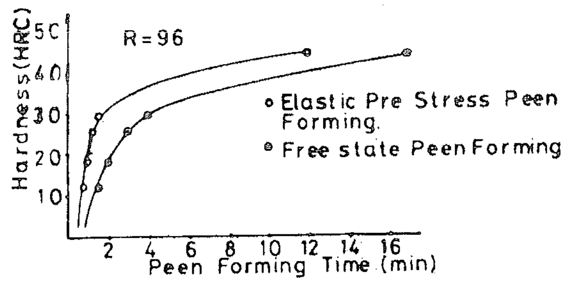

Fig. 11. Effect of elastic pre-stressing on peen forming to a given curvature R = 96 mm of different hardness strips

Peen forming time was obtained under above two stress states for various hardness of strips and plotted as shown in Fig.11. This showed that for a given peening condition, with increase in hardness of work piece, peen forming time increases gradually up to HRO 30 and beyond this value, increase was faster. It was also clear that pre-stress forming required lesser time than that of free state forming under similar peening conditions.

Under same peening conditions work pieces of different hardness values were peened to form a curvature of larger radii (R = 175 mm) under pre-stress and free state conditions. Peen forming time under these two stress conditions were plotted as shown in Fig. 12. Nature of these curves were also similar as that of for smaller radius of curvature. The only difference observed was that for larger curvature, forming time for a given hardness value work piece was lesser.

Experiments were repeated for smaller size shots S-330 keeping all other peening parameters same as mentioned above,

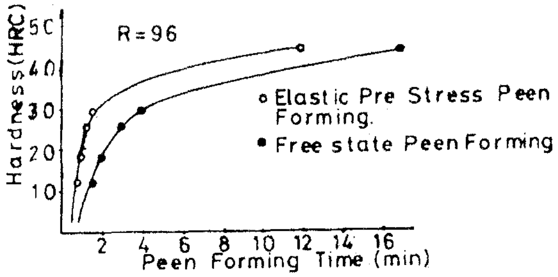

Fig. 12. Effect of elastic pre-stressing on peen forming to a given curvature R = 175 mm of different hardness strips

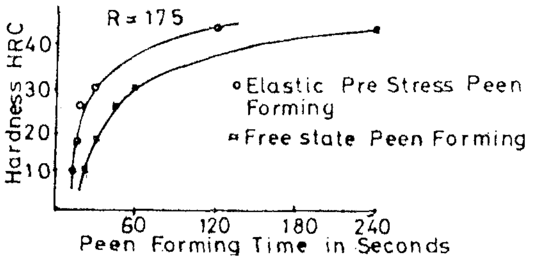

Fig. 13. Effect of work piece hardness on peen forming time to a radius of curvature of 175 mm under elastic pre-stress and free state condition

results for both shots S-330 and 5-390 were plotted in Fig. 13, which showed that peen forming time with smaller shots had increased considerably.

Residual stresses induced after peen-forming in pre-stress and free state conditions with shots S-390 and S-330 were measured with X-ray diffraction technique. Due to curvature of formed work piece residual stresses were measured in the direction perpendicular to the curvature at the center of the work piece on convex side only. Results were plotted in Fig. 14. It showed that magnitude of residual stresses were more in pre-stress peening than in free state peening conditions. Also higher size shots induced larger amount of residual stress. It was also clear from this figure that as hardness of work pieces were increased the magnitude of residual compressive stressed induced after peen-forming were also increased. The variation of residual stress with respect to work piece hardness was obvious as peen forming time required for harder work piece was also increased almost in similar manner.

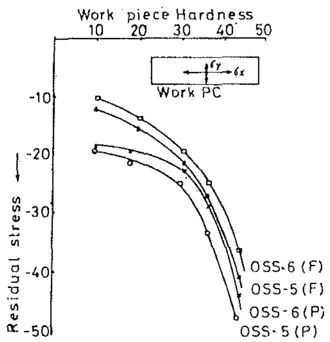

Fig. 14. Residual stress (σy) induced during pre-stress and free state peening with S 390 and S 330 shots

11. RESULTS AND DISCUSSION

Results showed that under free state peening, the variation of forming time with respect to work piece hardness was approximately parabolic. While for pre-stress peening to radius of curvature R = 96 mm (Fig. 11), first the variation of peen forming time with respect to work piece hardness was linear and then it became non-linear. Similar nature of curves were obtained for radius of curvature R = 175 mm. Variation was seen in slope of the straight line portions of the curves. It was clear that shots S-390 under pre-stress condition gave maximum slop and straight line behavior was found up to work piece hardness of HRC 30 only. Therefore shots S-390 was recommended under these conditions for work piece material having hardness value maximum of HRC 30. Coverage in peen formed samples was found to vary from 30 to 40% only.

12. CONCLUSION

It was observed that shot peening could be used to form curvatures with even hard thin sheets without rebound and compound contour more efficiently under elastic pre-stress peening conditions than in free state peening.

Larger the shots, forming time would be reduced and the coverage too, would be less. For higher coverage requirements final peening with similar shots is recommended. For radius of curvature 175 mm shots S-390 could be used efficiently for work piece having hardness value of HRC 30 under pre-stress condition, while shots 5-330 under similar conditions, are recommended for work piece having hardness HRC 15 only.

13. REFERENCES

Tatton, R.J.D. 1986. Shot Peen Forming Impact Surface Treatment, Proc. of Second Int. Conf. on Impact Treatment Processes, UK: 137.

Kopp, R. and Ball, H.W. 1987. Recent Development in Shot Peen Forming. Shot Peening Science Technology Application, Proc. of Third Int. Conf. on Shot Peening W.G.: 300.

Tatton, R.J.D. 1987. Shot peen forming - An Economical Solution, Shot Peening Science Technology Application Proc. of Third Int. Conf. on Shot Peening W.G.: 309.

Hornauer, K.P. Untersuchungen zur Umformung von Bauteilen durch Kugelstrahlen Ph.D. Disertation.

Kopp, R. and Hornauer, K.P. 1982. Kugelstrahlumformen, ein Flexibiles Umformverfahren. First Int. Conf. on Shot Peening, Paris, 1981, Pergamon Press, Oxford, New York, Toronto, Sydney, Paris, Frankfurt: 541 - 554.

Kopp, R., Hornauer, K.P. and Ball, H.W. 1984. Kugelstrahlum Formen, Neuere Technologische und Theoretische Entwicklungen. Second Int. Conf. on Shot Peening Chicago, USA.

Martin, P. Beitrag zur Ermittlung der Einflubgrobenbeim Kugelstrahlen durch Einzelkornversuche. Doctoral thesis, Hamburg.

Kopp, R. and Ball, H.W. 1987. KSU/FSU - Anwenderhandbuch, lnstitit fur Bildsame Formgebung der RWTH Aachen.

Barett, C.F. and Todd, R. "Investigation of the Effect of Elastic Pre-Stressing Technique on Magnitude of Compressive Residual Stress Induced by Shot Peen Forming of Thick Aluminum Plates", Proc. of I.C.S.P - 2 Paramus, New Jersey: 15.