Shot Velocity Measurement

Linnemann W*, Kopp R*, Kittel S** and Wüstefeld F**

Institute for Metal Forming, RWTH Aachen*, Shot Peen Center Aachen**

ABSTRACT

In the past, a number of models and measuring systems have been developed at the Institute for Metal Forming to change the shape of large structural components, in particular those in use in the aerospace industry, with which the degree of coverage of the shot and the shot distribution on the surface of the peened component during the forming process could be determined. The latest development, a system for on-line measurements of the velocity of shot particles with diameters between 0.3 mm and 10 mm, enables a complete documentation of the peening process during both shot peen forming and hardening. Such a control of the most important peening parameters allows shot peening to very narrow tolerances and is of decisive importance for quality assurance.

This contribution will primarily explain the principle of the velocity measurement. The experimental part of this report will describe the relationships between the shot velocity and the peening parameters of acceleration pressure and shot flow. Furthermore, a measurement of the shot rebound velocity during shot peen forming wil be presented. The dependence of the Almen intensity on the pre-set shot velocity in a further application of the process wil be investigated.

KEYWORDS

Shot velocity, shot rebound velocity, Almen intensity, degree of coverage, controlled shot peening

INTRODUCTION

Shot peen forming is a partially effective forming process derived from shot peen surface hardening (1) in which the desired overall forming of the component is achieved through a large number of statistically distributed shot impacts. The cross-section of the peened component is partially or completely plastified depending on the velocity and mass of the incident balls to generate both convex and concave curvatures of the component.

This mechanism is used with a corresponding process control to produce a defined curvature in one or more axes on large structural components, in particular those in use in the aerospace industry (2,3,4). Components of this kind are already being used for the outer skin of the Airbus A310 and as a structural tank for the ARIANE 4 rocket. More recent developments concern multicurvature geometries, e.g. tank domes for the future ARIANE 5 European rocket.

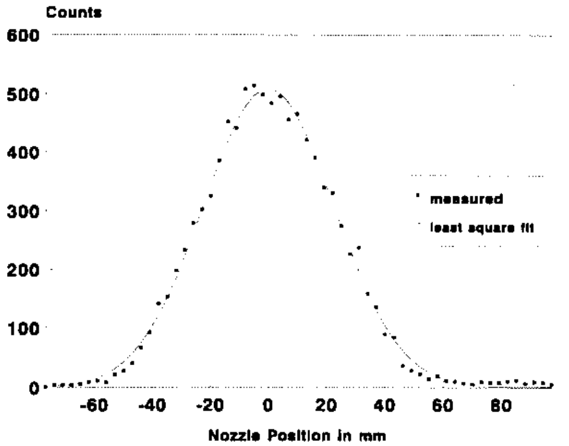
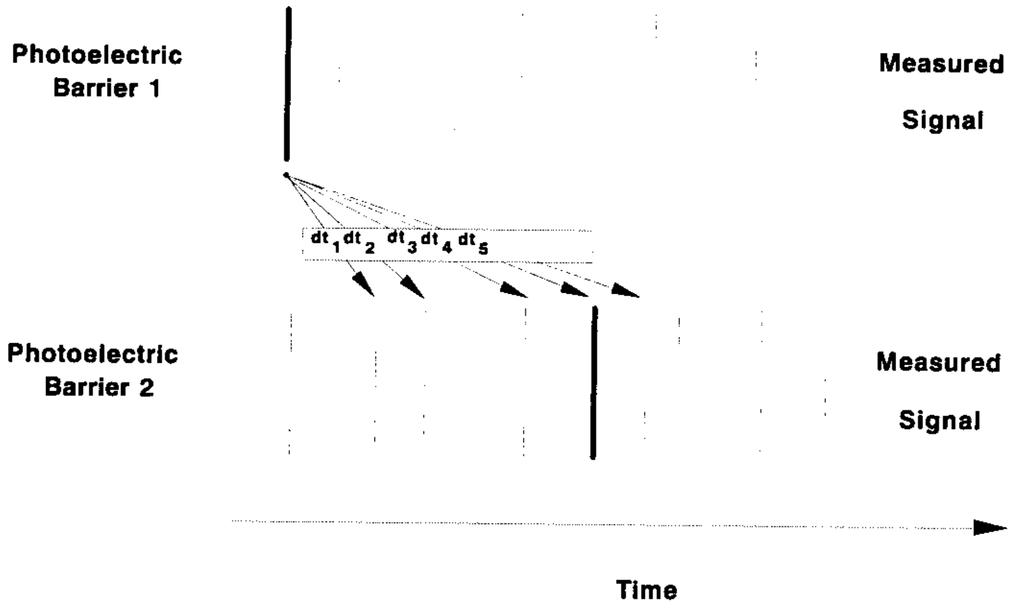


Figure 1: Shot distribution as determined in the experiments

The latest development in the field of shot peen forming of spherically curved large structural components relates to a quarter tank bulkhead for the ARIANE 5 rocket. This development work has been carried out in co-operation between Shot Peen Center Aachen GmbH, Daimler-Benz Aerospace AG and the Institute for Metal Forming of Aachen Technical University (5). The consistent use of the methods developed for a controlled shot peen forming (6) has proven that a quarter segment of the ARIANE 5 tank bottom can be manufactured within a very short space of time.

Apart from the models to determine the degree of shot coverage and shot distribution on the surface of the component, the process developed in Aachen can also be used for an on-line measurement of the shot velocity. This measurement of the shot velocity allows the peening process to be performed with the accuracy necessary for industrial-scale operation.

The physical parameters of the peening process, in particular the shot velocity and mean shot mass, are important factors in shot peen hardening too. Peening tests with different sizes of shot were carried out during the course of our work (7). The shot velocity was hereby chosen so that the Almen intensity remained constant during peening with the different sizes of shot used. Subsequent examinations of the residual stresses induced in the workpiece resulted in different depth curves.



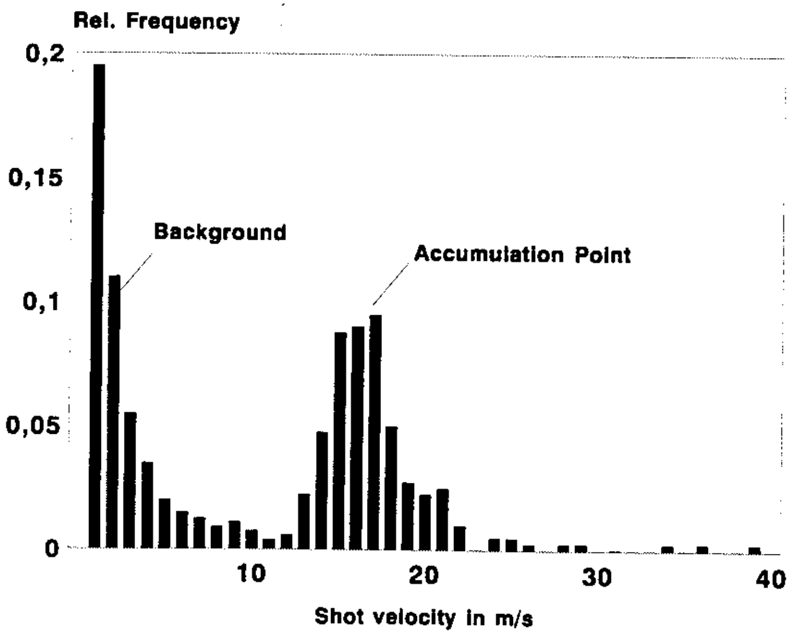


Figure 2: Principle of velocity measurement

These considerations show that a knowledge of the physical parameters during the forming process is important for both shot peen forming and shot peen hardening. This is why the principle of velocity measurement which was successful in the field of shot peen forming was transferred to shot peen hardening. The first prototype permits the measurement of the shot velocity between 5 and 100 m/s, whereby the shot should at present have a minimum diameter of 0.3 mm. The measuring equipment can be installed directly below the acceleration nozzle to enable a measurement of the shot velocity during the forming process.

CONTROLLED SHOT PEEN FORMING

A two-dimensional distribution, which can be described by a Gaussian distribution, usually occurs beneath the acceleration nozzle of a pressure or injector-gravitation shot peening unit. The shot velocity beneath the acceleration unit can easily be measured with a photoelectric barrier. The nozzle is hereby moved vertical to the photoelectric barrier and the detected signals per unit of time are simultaneously recorded depending on the nozzle position (8,9) (Fig. 1).

As already explained in (6), almost any distribution of the shot quantity per area can be set in the preliminary stages of the peening process, assuming a normal, through distribution the choice of suitable shot line intervals and mass flows along a line.

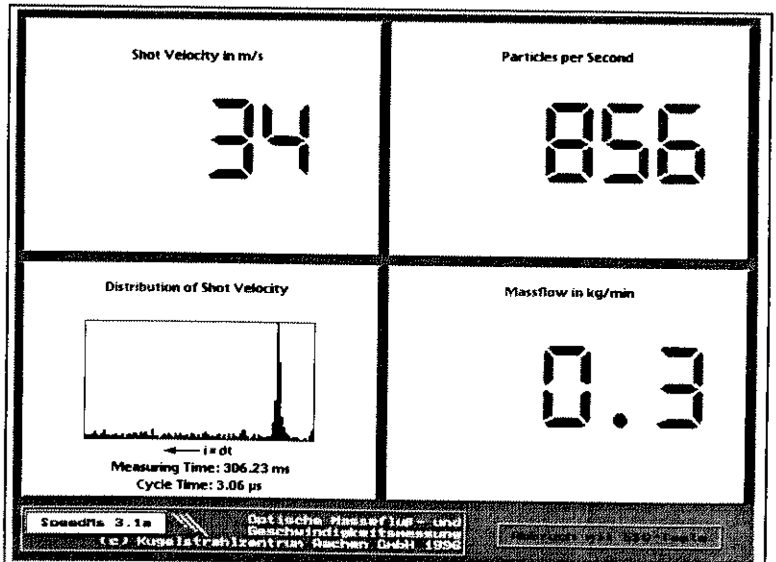


Figure 3: Snapshot of on-line mass flow and velocity measurement

The on-line measurement of the peening parameter relative velocity of the nozzle over the component, mass flow and a knowledge of the shot distribution already allow a local documentation of the shot distribution and degree of shot coverage on the surface of the component. The additional on-line measurement of the shot velocity for the first time allows a documentation of the complete shot peen forming process, which is of decisive importance for quality assurance. This development also allows the observance of strict manufacturing tolerances since it allows a direct reaction to possible fluctuations in the forming process.

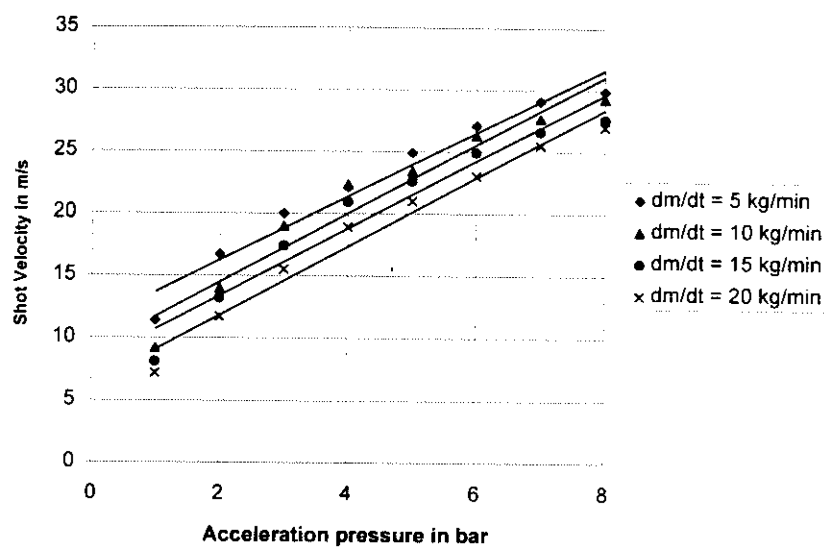


Figure 4: Shot velocity of 6.35 mm balls accelerated with an injector-gravitation nozzle as a function of the jet pressure. The shot flow was varied in the individual series of measurements.

THE PRINCIPLE OF SHOT VELOCITY MEASUREMENT

In this contribution the shot velocity is measured by recording the time it takes for a shot particle to cover a defined distance. Photoelectric barriers are installed at a defined distance directly at the outlet of the acceleration nozzle.

During shot peen forming, and in particular shot peen hardening, there is always a large quantity of shot between the two photoelectric barriers, making a clear classification of the shot particles recorded at the first and second photoelectric barriers impossible.

The velocity of the shot can nevertheless be determined with the aid of a statistical interpretation of the signal sequences registered at the two points of measurement.

The necessary preconditions are:

1. The number of shot particles registered in a measuring time interval is always much larger than 1.

2. In a freely selectable measuring interval the majority of the shot particles supply signals to both the first and second point of measurement.

3. The individual shot particles move independently of one another.

These conditions are generally given with the normal dosing of the shot quantities during shot peen forming and above all shot peen hardening.

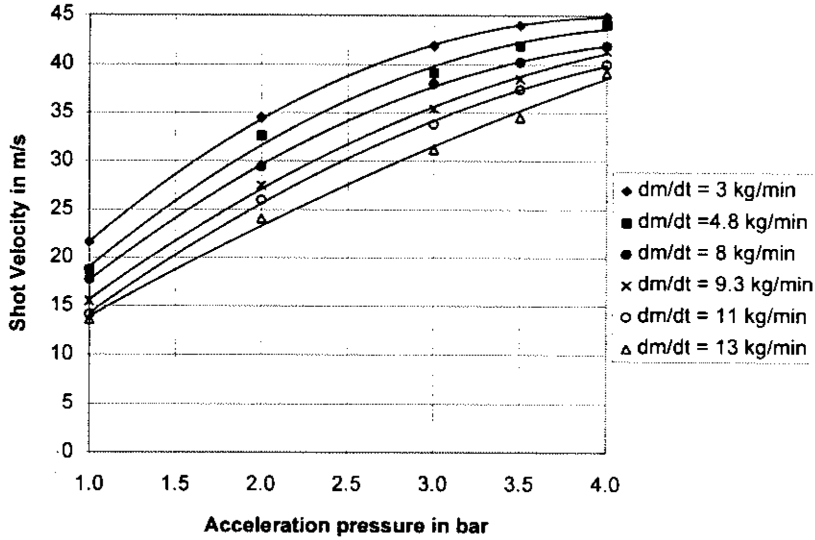


Figure 5: Shot velocity of 1 mm balls accelerated with an pressure nozzle as a function of the jet pressure. The shot flow was varied in the individual series of measurements.

If the time measurement starts when a particle passes the first photoelectric barrier, any of the signals later registered at the lower photoelectric barrier could be generated by this particle. At this point in time of the measurement, all that can be said is that a time interval has been recorded which corresponds to the time actually required by the particle to travel the distance between the photoelectric barriers. If this measurement is repeated, the actual time required is recorded in each measuring cycle whereas the random times will be distributed over a larger time interval. This procedure thus provides an accumulation point at the time interval corresponding to the actual velocity of the individual shot particle (Fig. 2).

Fig. 3 shows the velocity distribution of a shot with a diameter of 1 mm determined using this method. The velocity can be clearly determined in this application case on the basis of the position of the accumulation point. The signal-to-background ratio improves, the more balls recorded during the measuring time, which is why the accuracy of the velocity measurement increases with smaller shot.

The principle for a measurement of shot velocity presented here can also be used to measure the velocity of rebounding balls without changing the set up of the apparatus. The photoelectric barriers are simply installed directly above the surface of the peened workpiece.

When determining the rebound velocity, it has to be remembered that the rebounding balls first pass the lower photoelectric barrier and then registered by the upper photoelectric barrier after a certain time interval. The velocity distribution which is of interest here results from the distribution of the recorded negative time intervals. In this case, the position of the accumulation point provides the actual rebound velocity of the shot.

The distribution of the rebound velocity is not affected by the incident balls since the signals generated by these balls are randomly distributed in a negative time direction.

RESULTS OF EXPERIMENTS

Fig. 4 shows the shot velocity determined using this measuring method as a function of the acceleration pressure with a variation of the shot flow for various shot sizes. The shot with a diameter of 6.35 mm was accelerated using an injector-gravitation nozzle in the tests, whereas the smaller shot with a diameter of 1 mm was accelerated in a pressure jet system.

Using an injector-gravitation nozzle, the relationship between the shot velocity and acceleration pressure is linear, irrespective of the size of the shot used. It can also be seen that the pre-set shot flow has a significant influence over the shot velocity. The higher the shot flow, the lower the resulting velocity of the shot. If the shot flow is varied between 5 and 20 kg/min, the variation in the relative velocity is between 10% and 20%.

With the pressure jet system, the pre-set system pressure is used simultaneously to convey and accelerate the shot. The energy required to convey the shot is not converted into kinetic shot energy. It is thus to be expected that the pre-set shot flow has a great influence over the shot velocity. This effect is shown in Fig. 5. The actual shot velocity changes by up to 30 % at a constant jet pressure and depending on the pre-set mass flow.

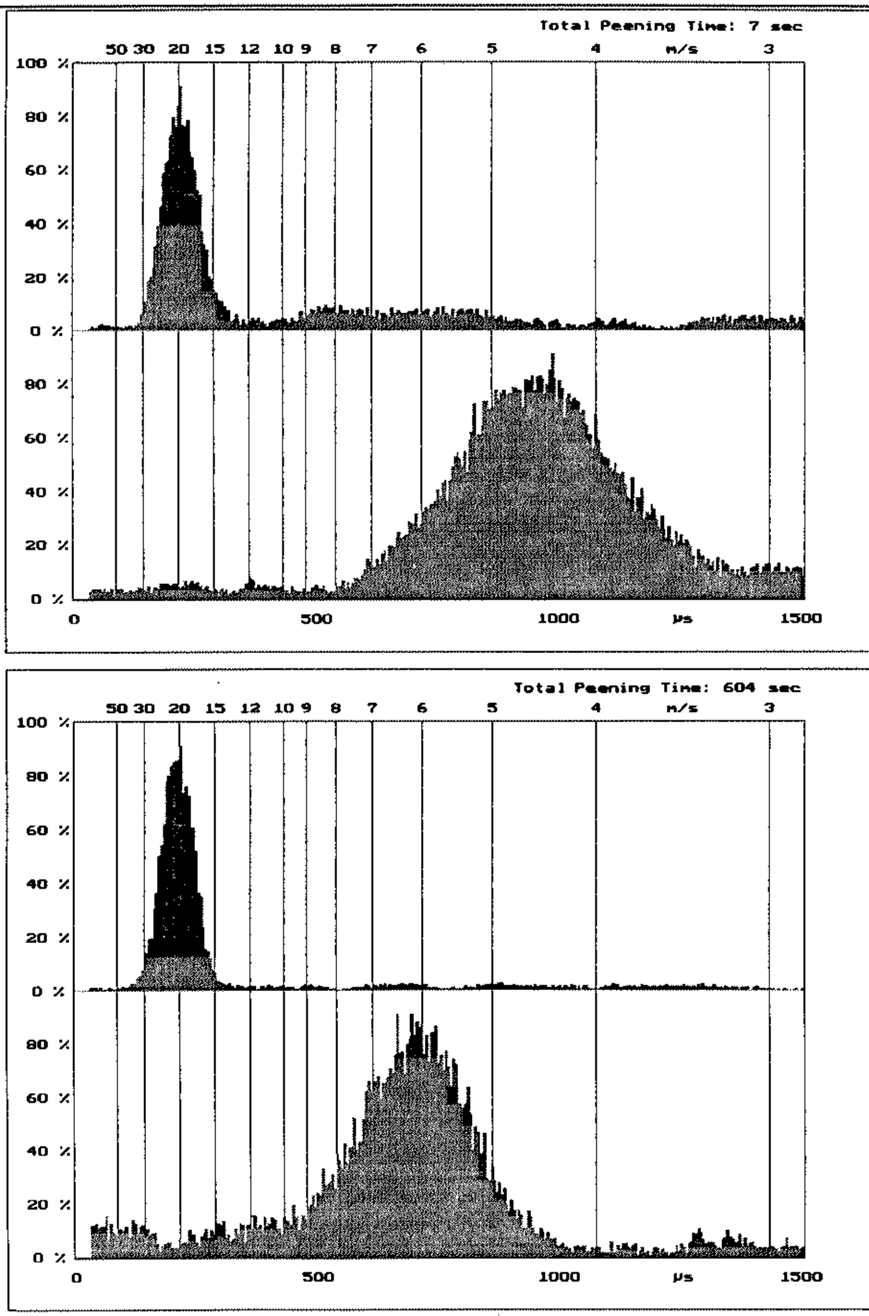


Figure 6: Snapshot of the velocity distribution of incident and rebounding balls after 7 s peening time (upper illustration) and 640 s peening time (lower illustration)

On the whole, these complex relationships between the shot velocity, acceleration pressure and shot flow show that the measurement of the shot velocity is indispensable for a defined shot peen process.

The results of a further application for the new process are shown in Fig. 6. This shows the velocity distribution of the incident and rebounding balls after 7 s peening time and after 604 s peening time. It can be seen that the velocity of the incident balls is independent of the peening time whereas the velocity of the rebounding balls changes with the peening time. Fig. 7 shows the velocity of the rebounding balls as a function of the expected hits on an infinitesimally small area on the surface of the component (material AlMg3; thickness 10 mm). It can clearly be seen that the rebound velocity of the balls (steel balls with a diameter of 6.35 mm) increases with an increasing number of hits per unit area and asymptomatically converges on one value. The material at that point becomes harder with each hit. The change in form brought about by the balls is reduced

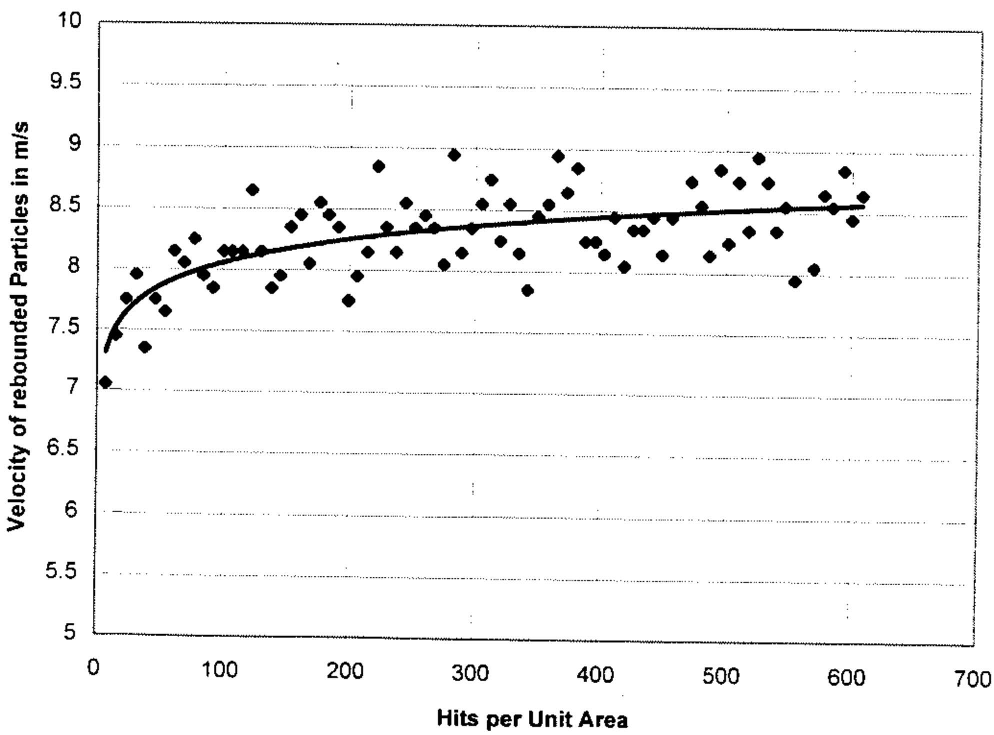


Figure 7: The rebound velocity of the balls

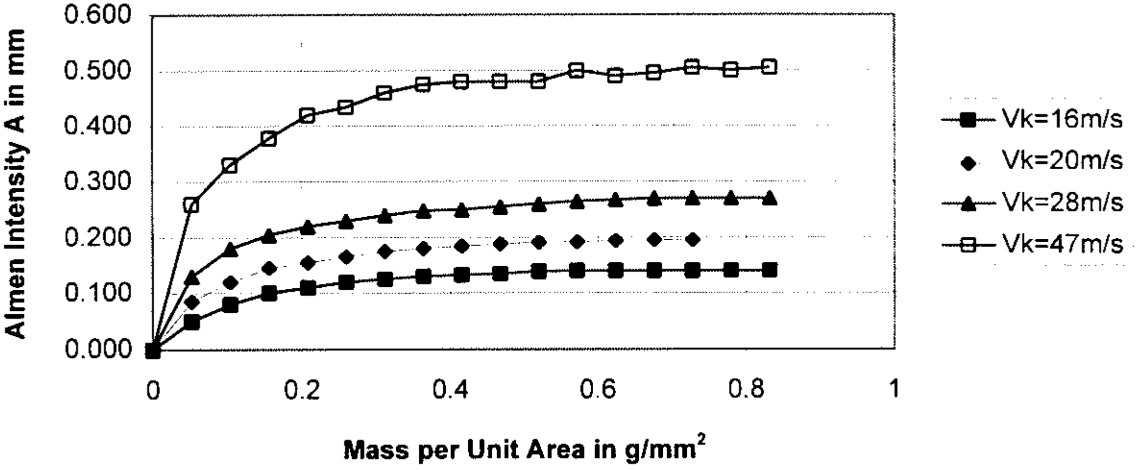


Figure 8: The Almen intensity curves for various shot velocities

correspondingly, leading to a higher rebound velocity.

The relationship between the Almen intensity and shot velocity was investigated using the measuring system presented here for the field of shot peen hardening. During the series of tests performed, shot with a grit of 0.5 mm was used. The quantity of shot per unit of area required to achieve an Almen intensity of between 0.1 mm A and 0.6 mm A is approx. 0.3 g/mm². The quantity of shot per unit area is, to a large extent, independent of the shot velocity, as the Almen intensity curves recorded show (Fig. 8).

Fig. 9 shows the Almen intensity determined in the tests as a function of the velocity of the incident balls. There is a simple linear relationship between the Almen intensity and the shot velocity.

On the basis of these results, and using the models and methods to calculate the shot distribution on the surface of the component already presented, the actual pre-set Almen intensity can be specified through an additional measurement of the shot velocity during the preening process.

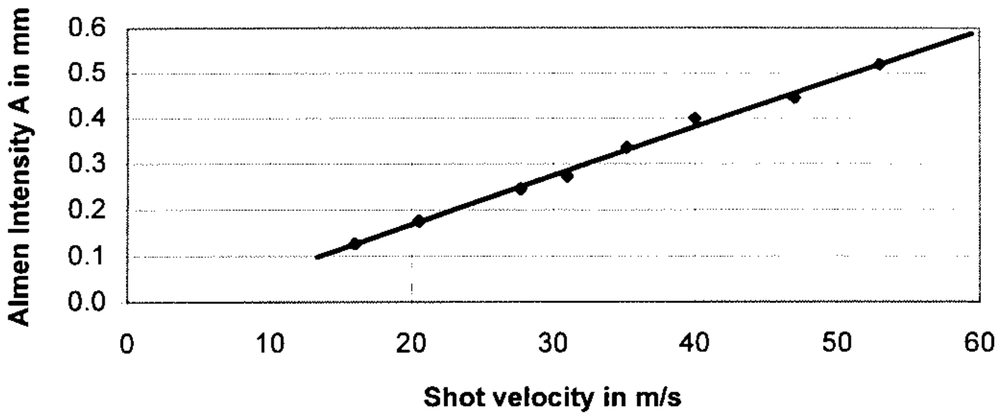


Figure 9: The Almen intensity as a function of the velocity of incident steel balls with a diameter of 0.5 mm

SUMMARY

The Institute for Metal Forming of the RWTH Aachen has been involved in shot peen forming since the beginning of the seventies. Over this period, various components, in particular for the aerospace industry, have been developed to the series production stage on the institute plant. Shot peening has hereby proven to be a very flexible forming process since the same tools (balls) can be used for various components.

The physical parameters recorded in the tests, namely the shot velocity and degree of shot coverage, which are of central importance in shot peen forming, allow a controlled production process to very strict manufacturing tolerances.

The measuring system can also be used to characterise the shot peen process for shot peen hardening, as the relationship between the Almen intensity and shot velocity described here has shown. Using this measuring system, it will in future be possible to specify the desired workpiece characteristic values in terms of the coverage and shot velocity. The peening process could be documented within strict limits analogous to the shot peen forming process with a corresponding on-line control of the shot parameters.

The forming process has been implemented on an industrial scale by the Shot Peen Center Aachen GmbH, a subsidiary of the Beteiligungsgesellschaft Aachener

Region mbH. The Shot Peen Center produces components by shot peening for various application cases according to customer specifications.

A special word of thanks to the Deutsche Forschungsgemeinschaft (DFG), who supported the basic research into shot peen forming, and the Ministerium für Wirtschaft, Mittelstand und Technologie of North Rhine-Westphalia who sponsored the peening plant.

REFERENCES

1. DIN 8200 Strahlverfahrenstechnik: Deutsches Institut für Normung e.V.; Berlin, October, 1982

2. Sauerwein, H.-P.; Kühnle, E.: *Erste Großbauteile von Dornier für Ariane 5 fertiggestellt*; Dornier Post 4/89-1/90

3. Hornauer, K.-P.: *Untersuchungen zur Umformung von Bauteilen durch Kugelstrahlen*; doctoral thesis, RWTH Aachen, 1982

4. Wüstefeld, F.: *Modelle zur quantitativen Abschätzung der Strahlmittelwirkung beim Kugelstrahlumformen*; doctoral thesis, RWTH Aachen 1992

5. Wüstefeld, F. et al.: *¼ Segment Tank Bottom for the European Ariane 5*, ICSP 6, San Francisco, September 1996

6. Kopp, R.; Wüstefeld, F.; Linnemann, W.: *High Precision Shot Peen Forming*; 5th International Shot Peening Conference (ICSP5), Oxford, September 14-17, 1993

7. Herzog, R.; Zinn, W.; Scholtes, B.; Wohlfahrt, H.: *The Significance of Almen Intensity for the Generation of Shot Peening Residual Stresses*, ICSP 6, San Francisco, September 1996

8. Linnemann, W.; Wüstefeld, F.; Kopp, R.: *Reproduzierbares Kugelstrahlumformen*; 10th Aachen Steel Colloquium, Aachen, March 23-24, 1995

9. Kopp, R.; Linnemann, W.; Wüstefeld, F.: *Controlled Shot Peen Forming - On Line Measurement of Coverage and Shot Velocity*, Recueil de Conférences Shot Peening, Strasbourg, September 22, 1994, Deutsche Gesellschaft für Materialkunde (DGM) and Centre Technique des Industries Mechaniques (CETIM)