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The Influence of the Velocity of a Peening Medium on the Almen Intensities and Residual Stress States of Shot Peened Specimens

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1 Introduction

Up to now, the properties of shot peened components and the reproducibility of the peening process have been assessed by the aid of the Almen test. The bending height of the Almen strip is a measure of the peening intensity, taking all peening parameters into account in an integral way. The Almen test, however, can only be applied offline and it is not unambiguously correlated with the resulting properties like, e. g. residual stress. Therefore, a system for direct measurement of peening medium velocity was used to determine the correlation between peening parameters including the mean shot velocity and the Almen intensity. For that purpose, specimens, made of the German steel grade 42CrMo4 were shot peened under different conditions and velocity distributions as well as resulting residual stress distributions were analyzed.

2 Description of the Measuring Procedures

2.1 Principle of Shot Velocity Measurement

A system of measuring the velocity of shot particles in the particle flow was developed by /1/. Moving particles set off a signal at each of two light barriers in a time interval dt. Theoretically, the shot velocity can be calculated directly from the path it has taken ds and the time measured dt. In the real peening process a large number of shot particles are found simultaneously between the two measuring points, so that series of signals are registered at both light barriers. Evaluating them statistically provides us with an accumulation point at the time interval corresponding to the actual mean velocity of the shot particles. This principle of velocity measurement allows us to make statements also about the quantitative fluctuations around this mean value. The algorithm used in the measuring program subdivides each measuring cycle into a sequence of equidistant time windows. The absolute number of particles registered for each measuring cycle is then inserted in the corresponding time windows. This enables us to match the signals in the individual time windows with individual velocities, which allows us to make statements regarding the distributions of velocities.

2.2 Measuring of the Residual Stress Depth Distributions

Specimens made of 42CrMo4 of the dimension 50 mm × 50 mm × 10 mm in a normalized as well as a quenched and tempered state were shot peened. The quenched and tempered specimens were heat treated in such a way, that they exhibited the same hardness of 500 – 520 HV as Almen strips. Residual stresses were measured always in the center of the specimens using standard X-ray diffraction methods. Crkα-radiation was used to measure lattice strain distributions at {211}-lattice planes of ferrite or martensite respectively. The area irradiated by the X-ray beam was collimated to a diameter of 1 mm. For the calculation of residual stress values from the measured lattice strain distributions, the elastic constants E=210000 MPa and ν=0.285 were used. Depth distributions of residual stresses were determined by successive electrochemical layer removal.

For the shot peening tests a conventional NC-controlled air pressure peening machine was used and for the process the following parameters were varied:

Table 1: Parameters for shot peening tests

materials state:	normalised and quenched and tempered
shot diameter:	S110 and S170
nozzle diameter:	10 mm and 15 mm
nozzle distance:	100 mm and 150 mm
mean shot velocity:	(20), 25, 30, 35, 40, 45 m/sec.
mass flow:	200, 600 g/min. (S110) and 2000, 4000 g/min. (S170)

3 The Influence of the Peening Parameters on the Mean Shot Velocity and the Velocity Distribution

In order to investigate the effect of various peening parameters on shot velocity and the distribution of velocity, we used rounded off wire shot of two different sizes (S110 with ∅ 0,3 mm and S170 with ∅ 0,4 mm). For each Almen saturation curve we employed 8 to 10 Almen strips of type A (thickness 1,295 mm). Furthermore, the mass flow dm/dt and the velocity of the peening medium v_B were varied, and two different nozzle geometries (internal jet diameter 10 mm in the case of Nozzle A and 15 mm in the case of Nozzle B) were used. The influence of the height of the nozzles was also examined in selected series of measurements (h_N = 100 or 150 mm).

3.1 Influence of the Peening Parameters on the Mean Shot Velocity

Figure 1 shows the mean shot velocities related to the peening pressures for the shot media S110 (left) and S170 (right)

It becomes clear that the shot velocity does not increase linearly relative to the peening pressure, but rather the relation is described by a degressive curve. A greater mass flow at the same pressure brings about a decrease in velocity.

The highest velocities were attained with the narrower peening nozzle. Overall the velocities attained for S170 are lower than those for the finer S110.

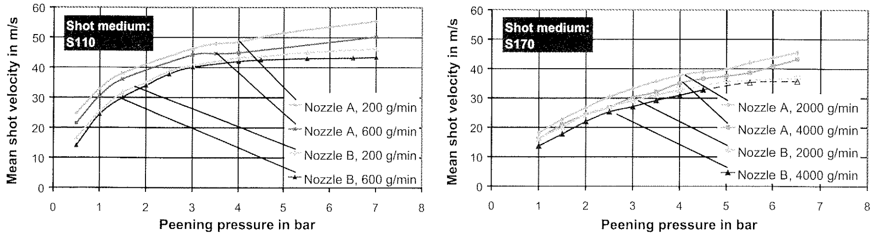
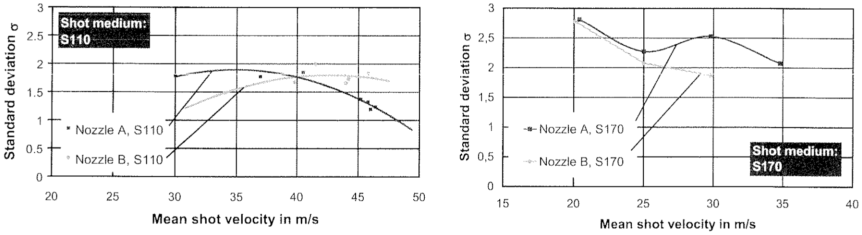


Figure 1: Mean shot velocity related to peening pressure

3.2 The Influence of the Peening Parameters on the Shot Velocity Distribution

In what follows we have plotted the velocity distributions resulting for various types of peening medium and for mean shot velocities. Figure 2 shows typical standard deviations for Nozzles A and B, in each case for both peening media.

The values for the standard deviation vary for the S170 much more than they do for the S110. It is not only that their characteristics depend on the geometry of the nozzle, the size of the shot also plays an important role. Their respective behavior was reproduced for varying mass flows. Accordingly, the reasons for these ways of behaving must have to do with the flow conditions specific to each of the nozzles, and the various peening parameters have a great influence on these.



dm/dt = 600 g/min **dm /dt = 2000 g/min**

Figure 2: The effect of the peening medium and the nozzle geometry on the standard deviation of shot velocities

4 Influence of the Shot Velocity on the Shot Peening Results

4.1 Influence of the Mean Shot Velocity and the Velocity Distribution on the Almen Intensity

It is generally supposed that there is a linear relation between the mean shot velocity and the Almen intensity. In the investigations presented here, deviations from the linear progression can also be seen, as is shown in Figure 3 for the peening media S110 and S170. By way of example we have illustrated the correlations at a nozzle height of 100 mm. Qualitatively the result will be similar at a nozzle height of 150 mm.

The highest Almen intensities are attained by Nozzle B, although the kinetic energy of the shot deployed is the same for both nozzles because of the identical mean velocities and mass flows. Accordingly, the Almen intensities depend greatly on the geometry of the nozzle. The intensities are respectively higher if the mass flow is greater. Since quite radically different Almen intensities were ascertained for different mass flows, the reasons for this must have to do with the hit effects of the shot, given that the masses deployed per area m_A remain mathematically speaking the same.

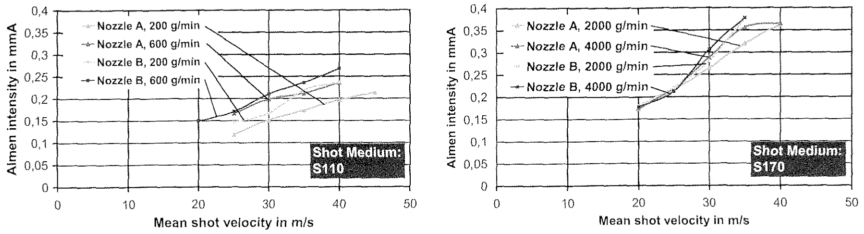


Figure 3: Almen intensities related to the mean velocity for the peening media S110 (left) and S170 (right)

In what follows, oversaturations of 200, 300 and 400 % were induced at the saturation point by means of repeated peening of Almen strips and the arc heights in relation to mean shot velocity were illustrated in Figure 4 by way of example for the peening medium S170, a mass flow of 2000 g/min and a nozzle distance of 100 mm.

Nozzle A displays a somewhat degressive course of the arc heights at higher velocities, Nozzle B a progressive one. We also found this behavior with peening medium S110 as well as at a nozzle distance of 150 mm. The distributions of velocity outlined above cannot be the reason for the higher peening intensities of Nozzle B, since for the peening media S110 and S170 we determined opposite curvatures of the distributions, whereas the nozzle characteristics in relation to the Almen intensity remain the same for both peening media.

Where the geometry of the nozzle has a small internal diameter, the jet of shot will be tightly bundled, and as a result the cone of dispersion will be slight. Consequently, a larger amount of the shot than is the case with other nozzles will strike the Almen strip almost vertically and will then bounce off again vertically, which could constitute a greater hindrance for the shot moving towards the Almen strip, or cause it to deflect or reduce in intensity. This could be substantiated by trials with different impact angles. The resulting arc height differences between the nozzles decreased substantially. Due to the complex flow conditions inside the nozzle the flow of particles will attain a mean shot velocity and a distribution of velocity. Both can be measured at the nozzle outlet online. Along their path to the component or the Almen strip interactions will take place amongst the particles, which will be significantly influenced by the nozzle geometry. On the surface double hits play a role, which are also affected by mass flow and cone of dispersion. Once these influences are known for a certain peening configuration by pre-tests, the shot velocity measurement systems supplies a good possibility of online controlling of the peening intensity.

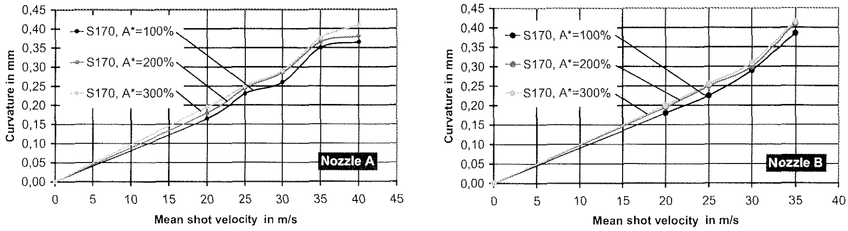


Figure 4:. Arc heights in cases of oversaturation

4.2 The Influence of the Mean Shot Velocity and the Velocity Distribution on the Residual Stress Depth Distribution

As an example for the influence of the mean shot velocity on the residual stress depth distribution Figure 5 shows results for the quenched and tempered state, the S110 shot and for the nozzle parameters diameter 15 mm and distance 100 mm as well as the mass flow of 200 and 600 g/min.

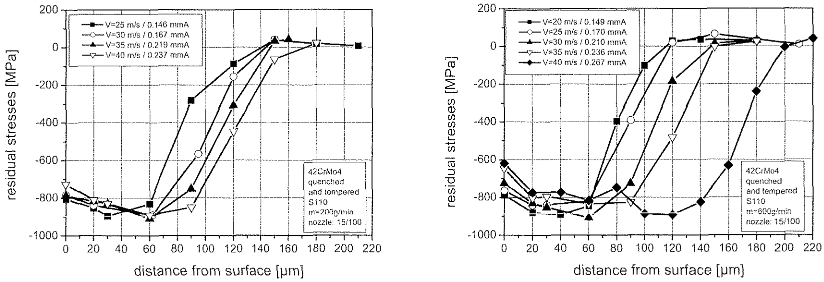


Figure 5:. Residual stress depth distribution with shot S110; nozzle diameter 15 mm; distance 100 mm; mass flow 200 g/min. (left) and 600 g/min. (right)

As can be seen, the thickness of the layer with compressive residual stress is considerably influenced and increases with increasing shot velocity, whereas the surface value and the amount of maximum residual stress below the surface do not depend on the mean shot velocity. To compare quantitatively the influence of different process parameters on the resulting residual stress depth distributions, the surface distance, where a compressive residual stress value of –200 MPa for the normalized and –400 MPa for the quenched and tempered specimens respectively was reached, was used as a measure. These stress values correspond roughly with 50 % of the maximum compressive residual stress amount.

In Figure 6, the correlation between these depths and the applied mean shot velocities is plotted. Except for the low mass flow (200 g/min) and a nozzle diameter of 10 mm in all cases a more or less linear trend with a scatter band of up to 50 µm at a given velocity can be seen. A wider spread of particles, caused by a larger nozzle distance or a larger nozzle diameter, tends to result in a deeper position of the defined stress value.

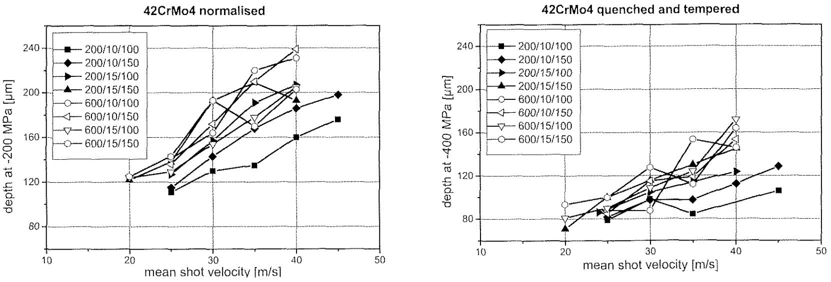


Figure 6: Residual stress depth distribution with S110 shot; nozzle diameter 15 mm; distance 100 mm; mass flow 200 g/min. (left) and 600 g/min. (right)

5 Conclusion

In this study peening medium velocities have been measured online and have been correlated with the results of Almen tests. In practice, the influence of shot velocity on Almen intensity has hitherto not been taken into consideration. Moreover, peening pressure was used as a process parameter. The resulting Almen intensities are substantially affected by the geometry of the nozzle. The greater the scattering range of the nozzle, the higher will be the Almen intensities measured. The reasons for this are to be found in the interactions taking place in the particle flow and in the probability of multiple hits.

Different mean shot velocities do not affect the surface value and the amount of maximum residual stress below the surface but have a significant influence on the thickness of the affected surface layer.

By means of online-measurement of peening medium velocity it is possible to measure and adjust the stationary state present at the nozzle outlet. More influence factors are to be located in the particle flow as well as in the type and number of strikes. As long as their influence can be ascertained through prior experiments, measuring shot velocity can be employed as an online control of the peening process. This verification of the Almen intensities resulting for various shot velocities is valid for the respective configuration of apparatus and nozzles. Cyclical interruption of production so that Almen tests can be carried out to control the process can be greatly reduced or dispensed with altogether in this case.

6 Acknowledgements

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7 References

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