CONTROLING SURFACE ROUGHNESS THROUGH SHOT MEDIA SIZE DISTRIBUTION

David Bahr[1] and Siavash Ghanbari[1]

1 Center for Surface Engineering and Enhancement, School of Materials Engineering, Purdue University, West Lafayette IN USA

Abstract
A simulation has been developed to predict the surface roughness profile and residual stresses as a function of media size distribution and shot velocity on steel samples. The simulation was validated by direct comparison to Almen strip tests. The simulation probed shot peening tests with different shot sizes and peening conditions such as individual impacts, sequential impacts, and mixed (i.e. concurrent) impacts. The simulation results are compared with experimental outcome measured by optical profilometer and x-ray diffraction in published experimental tests. Using a mixed size distribution of shot, rather than sequentially peening with larger and then smaller shot, appears to provide a smaller surface roughness than peening with larger shot alone, while providing a surface roughness similar to that with a finer peening size.

Keywords Roughness, hardness, shot size.

Introduction

Dual shot peening [1], where larger shot is first used to impart larger or deeper residual stresses and finer shot is used to minimize surface roughness or variations, is known to have an impact on the uniformity of residual stress [2] as well as the microstructural refinement on the surface layer [3]. Compressive residual stresses are developed by plastically deforming the metallic substrate and elastic deformation will be recovered by unloading of the impacting shot. Wohlfahrt showed two types of residual stresses that developed during the shot peening process, first a direct plastic elongation of the primary layer of the peened surface due to multiple shot dents and the second one is the elastic-plastic deformation that creates compressive residual stresses with a maximum intensity within the substrate [4]. This cold working process and residual stresses help to prolong the fatigue life, but too much peening may lead to surface flaws that are potential sites for fatigue crack initiation.

The purpose of this study was to develop a computational process to predict roughness and residual stress profiles for nominal coverages of 100% peening with the ability to vary the shot size. Previously published work by Bagherifard and co-workers [5] was used as the benchmark for model validity.

Computational Methods

The complete description of the processes used to simulate the peening process is provided in a recent publication by the authors [6]. In summary, we used conventional 1070 steel Almen strips for calibrating the model to ensure our stress and coverage matched experimentally measurable bulk peening conditions. The finite element simulation of the peening process was carried out in Abaqus/ Explicit 6-14. Shot particles were modeled as rigid balls with diameters between 0.3 and 0.60 mm, impacting the test piece at random locations until 100% of the surface had experienced plastic deformation. To obtain reasonable computational time the sample mesh was chosen as approximately 1/12th of the expected dimple diameter [7]. To determine coverage conditions, we simulated peening

Almen strips and calculated the Almen height as a function of number of impacts, and then converting those to coverage (shown in figure 1 for 0.5 mm shot at different velocities).

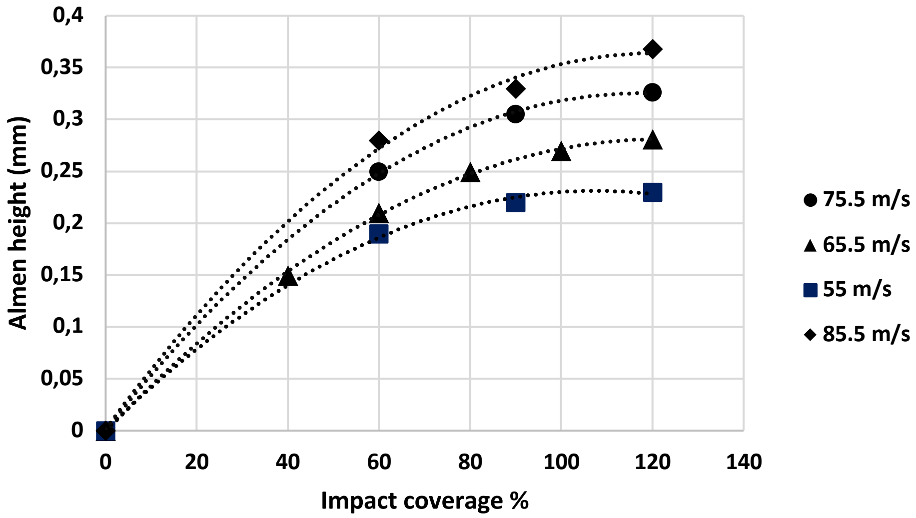

Figure 1. Almen height as a function of coverage for varying shot velocity using 0.5 mm shot to calibrate model conditions.

After calibration with experimental Almen strips, we then simulated a hardened steel system [5] using random shot impact with steel shot of 0.6, 0.43, and 0.35 mm. Shot velocity was fixed at 80m/s, and we used the simulation conditions in Table 1 were used to determine surface roughness and the subsequent residual stress profile.

Table 1. Simulation conditions for shot size and order processing.

FEM modeling	D (mm)	Distribution of Shots % (0.6 mm, 0.43 mm, 0.35 mm)	Sequence	Rz, μm
Shot peening model-1	0.6	100%, 0%, 0%	n/a	14
Shot peening model-2	0.43	100%, 0%, 0%	n/a	25
Shot peening model-3	0.35	100%, 0%, 0%	n/a	43
Shot peening model-4	0.6, 0.43, 0.35	33%, 33%, 33%	Mixed simultaneous	26
Shot peening model-5	0.6, 0.43, 0.35	33%, 33%, 33%	Sequential impact (0.6 mm→0.43 mm→ 0.35 mm)	25
Shot peening model-6	0.6, 0.43, 0.35	20%, 40%, 40%	Mixed simultaneous	24

Results
First, the effect of shot size distribution on the Almen height as a function of the number of impacts was determined. Two shot distributions were used, the wide distribution had 60% 0.6 mm, 20% 0.5 mm, 10% 0.4 mm., and 10% 0.3 mm shot, while the narrow distribution was 85% 0.6 mm, 10% 0.5 mm, and 5% 0.4 mm. The resulting mass of shot is shown in Table 1, and the resulting arc height of the Almen strip is shown in Figure 2.

Table 2. Mass of shot used in range simulation as a function of impacts

Number of shots	Mass of shots, wide range (g)	Mass of shots, narrow range (g)
12,000	3.9	4.76
28,000	9.11	11.09
40,000	13.02	15.83
52,000	16.93	20.69
68,000	22.13	26.95

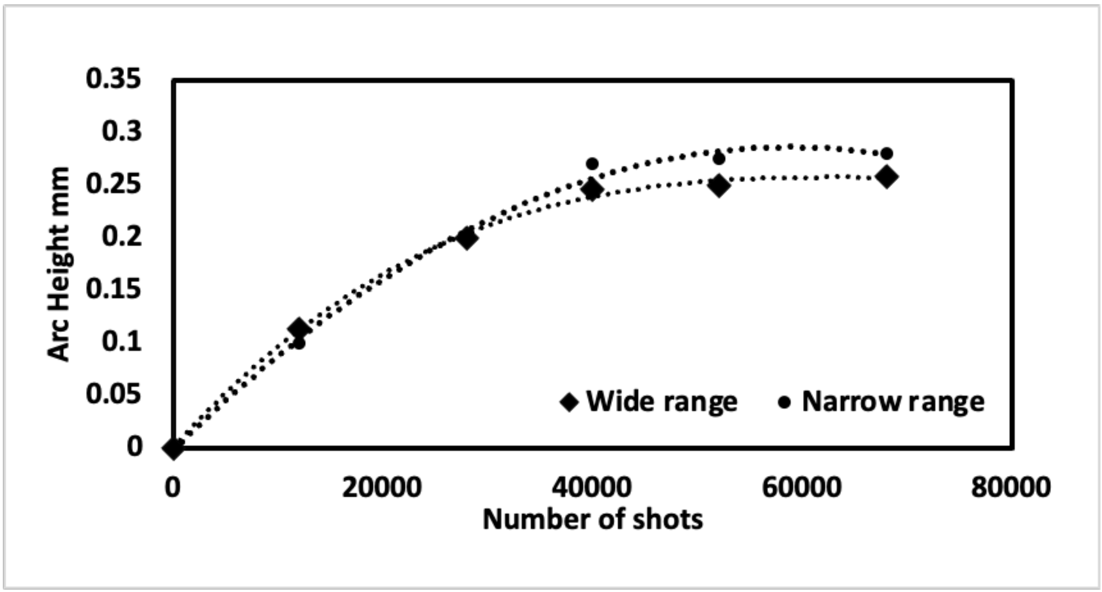

Figure 2. Almen arc height as a function of shot size distribution, showing the narrower (and larger average size) distribution leads to slightly larger arc heights for a similar number of impacts.

Next, the simulations described in Table 1 were carried out, a typical surface topology and stress distribution is shown in Figure 3. While different roughness parameters were determined (RMS, arithmetical of five highest conditions, and the maximum high to low peak) were determined, all scaled similarly. For this paper, we will consider only the Rz, calculated by measuring the vertical distance from the highest peak to the lowest valley within five sampling lengths, which is the largest (worst case) roughness measurement extracted in this study. Similarly, from the simulation we can extract a typical stress profile, shown for several of the conditions in Figure 4. Table 1 shows the Rz surface roughness as a function of the process condition.

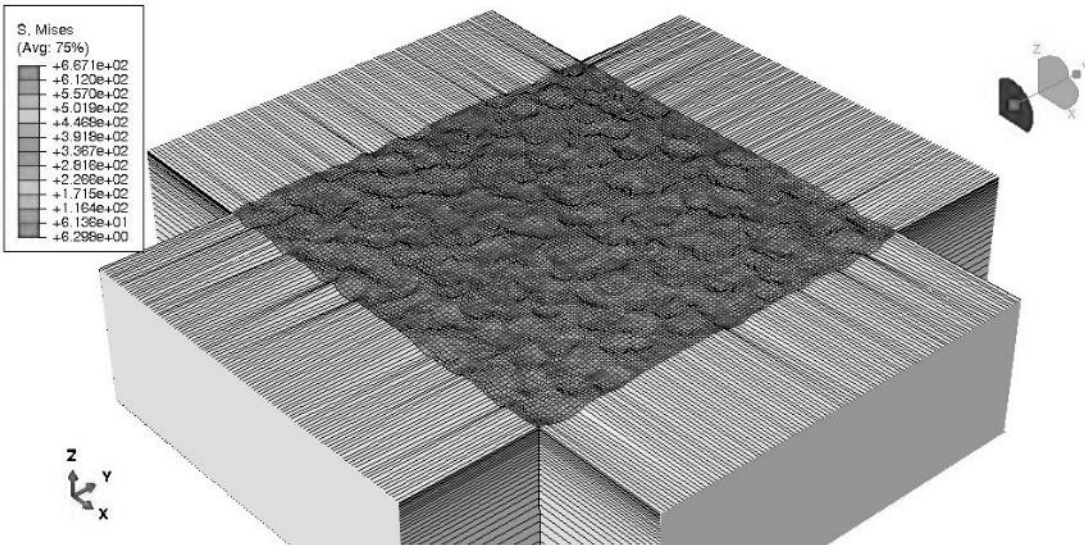

Figure 3. Typical surface profile and von Mises stress of the hardenable steel substrate after peening (here for case 4, mixed shot size distribution).

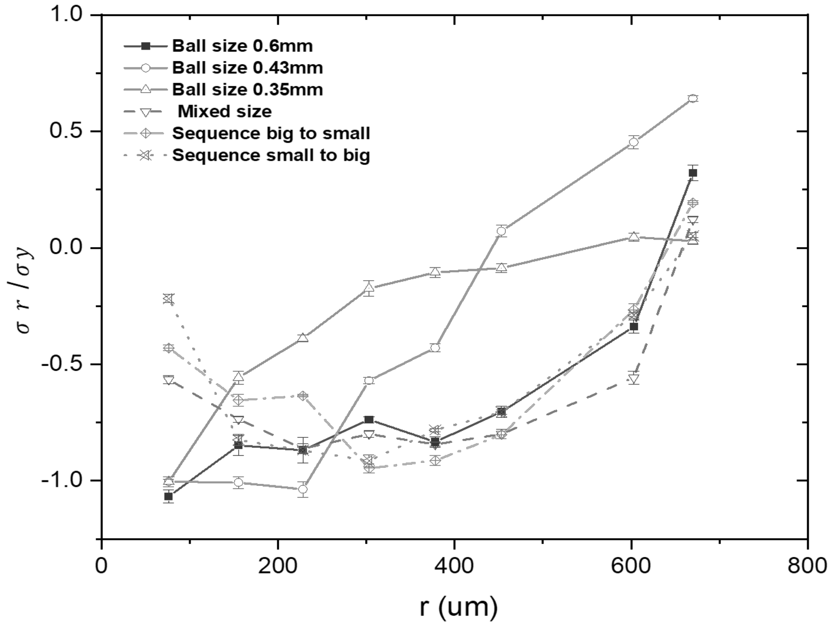

Figure 4. Typical stress profiles, normalized by initial yield strength for multiple size peening conditions. No “0” height is shown because of the variation in surface roughness, but an average height was determined for “0” by selecting the plane at which the integral of the mesh above and below that plane were equal.

Discussion and Conclusions

Sequential peening (three sizes, but not peening to 100% coverage in any given pass) decreased surface roughness over peening with the maximum size shot, as might be expected. The more interesting observation was that using a controlled distribution of shot sizes it appears to be possible to create a surface as smooth as the sequential peening in a single pass. Furthermore, mixed shot peening showed increased the depth of the total compressive residual stresses over sequential impacts (though the maximum value of that stress is slightly lower than the sequential peening or single large diameter peening condition). This suggests that controlling shot size distribution (beyond standard graded shot) can improve surface roughness and residual stresses simultaneously while reducing the risk of the over-peening during sequential impacts.

References

[1] D. Breuer, *Dual* Peening, The Shot Peener, Summer (2013), pp. 18-19.

[2] K. Zhan, C.H. Jiang, V. Ji, *Uniformity of residual stress distribution on the surface of S30432 austenitic stainless steel by different shot peening processes,* Materials Letters, Vol. 99 (2013), pp. 61-64.

[3] O. Unal, R. Varol, *Surface severe plastic deformation of AISI 304 via conventional shot peening, severe shot peening, and repeening,* Applied Surface Science, Vol 351 (2015), pp. 289-295.

[4] H. Wohlfahrt, "*The influence of peening conditions on the resulting distribution of residual stress,*" Proceedings of the 2nd International Conference on Shot Peening*,(1984)* p. 316-331.

[5] S. Bagherifard, R. Ghelichi and M. Guagliano, *A numerical model of severe shot peening (SSP) to predict the generation of a nanostructured surface layer of material*, Surface & Coatings Technology, vol. 204 (2010) pp. 4081-4090.

[6] S. Ghanbari and D.F. Bahr, *Predictoins of decreased surface roughness after shot peening using controlled media dimensions,* Journal of Materials Science and Technology, Vol. 58 (2020) pp. 120-129.

[7] J. Schwarzer, V. Schulze and O. Vohringer, *Evaluation of the Influence of Shot Peening Parameters on Residual Stress Profiles using Finite Element Simulation*, Materials Science Forum, Vol. 462 (2003) pp. 3951-3956.