13TH INTERNATIONAL CONFERENCE ON SHOT PEENING

MONTREAL, CANADA
SEPT 18TH TO 21ST 2017

Simulations and experiments to investigate surface modification induced by shot peening

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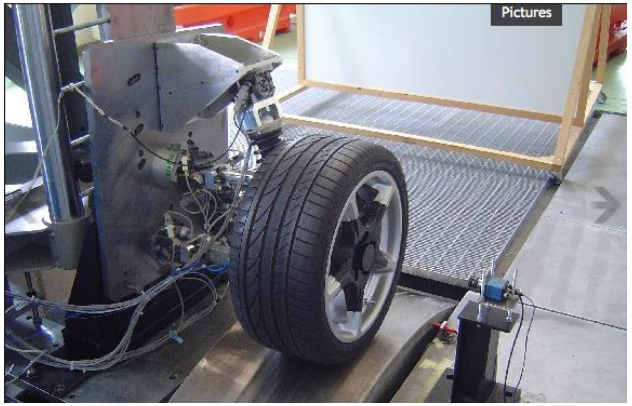
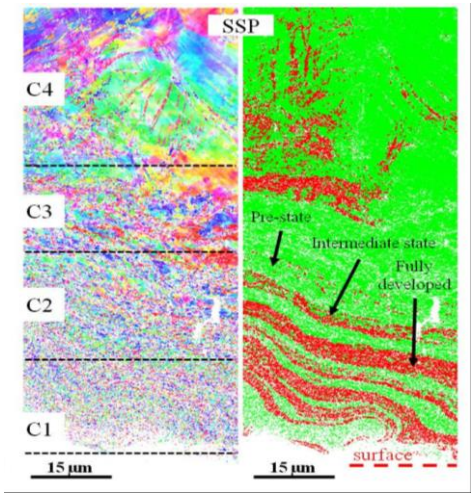




Outline

Introduction

Simulating shot peening

- ✓ Evolution of the models
- ✓ Residual stresses
- ✓ Almen intensity and coverage

Comments

One step beyond

- ✓ Roughness and topography
- ✓ Microstructure
- ✓ Grain refinement

Conclusions

Introduction

- Shot peening has been seen for many years more as an art than as a science.
- This is due to the complexity of the physics underlying this technological process.
- Shot peening.....
  - ✓ Induces geometrical non linearity due to the not-conformal contact condition.
  - ✓ Induces plastic deformation (another non linear effect).
  - ✓ Induces high-strain rates and non linear dynamic conditions

A model able to simulate the final state of the treared surface is not and easy issue.

INTRODUCTION

Y. F. Al-Obaid
Dean, Faculty of Technological Studies, Paaet, Kuwait

A Rudimentary Analysis of Improving Fatigue Life of Metals by Shot-Peening

In this paper, a rudimentary analysis of improving fatigue life of metals is presented. The process is viewed as one of repeated impact of a stream of hard shots on to a target. The model considers first a single shot impinging upon a target and, on bouncing, it leaves a residual stress below the surface of the target. The problem is then generalized to consider the effect of a stream of shots by assuming their effect to be uniformly distributed over the entire surface. The analysis is highly simplified and it mainly aims at understanding the mechanics of this complicated process. Although rudimentary, the theoretical analysis is seen to be in reasonable agreement with experimental results performed with shots on targets of various materials.

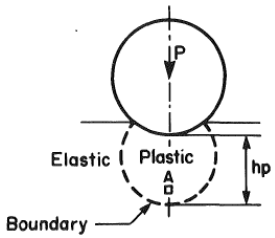
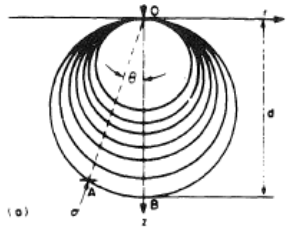


Fig. 2 Elastic-plastic boundary below contact zone



Journal of Applied Mechanics (1990), Vol. 57

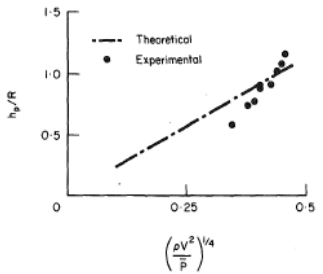


Fig. 5 Variation of depth of plastic zone with (damage number)

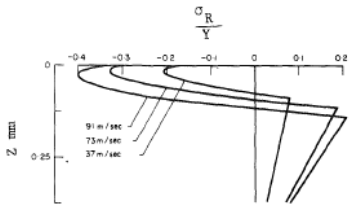


Fig. 7 Theoretically predicted residual stress distribution for different shot velocity

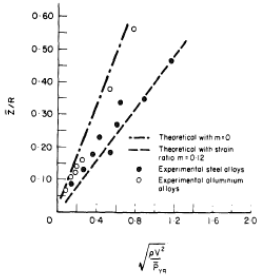


Fig. 6 Variation of indentation with the square root of the damage number

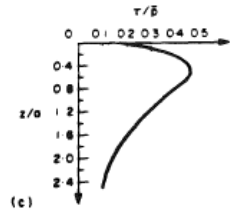


Fig. 4(a) Boussinesq solution for concentrated load p, (b) lines of constant τ/p, and (c) $\tau/\bar{p}$ versus z/a for vertical center line

Al-Obaid developed one of the first theoretical/approximate models, evidencing the main factors to consider in a shot peening model.

SIMULATING SHOT PEENING

ELSEVIER

Journal of Materials Processing Technology 110 (2001) 277–286

Journal of Materials Processing Technology

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Relating Almen intensity to residual stresses induced by shot peening: a numerical approach

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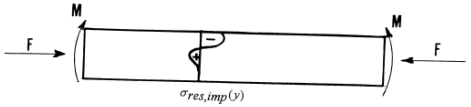
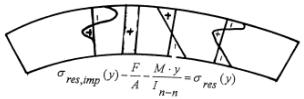
Received 27 October 1999; received in revised form 31 July 2000; accepted 24 November 2000

This paper considers some of the most influent factors in finite element modelling:

- 3D dynamic explicit analysis
- Multiple impacts
- Kinematic hardening rule
- Hourglass control
- Elastic waves rebound (damping)





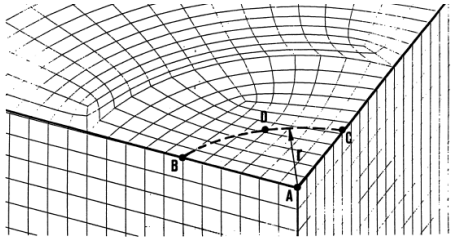
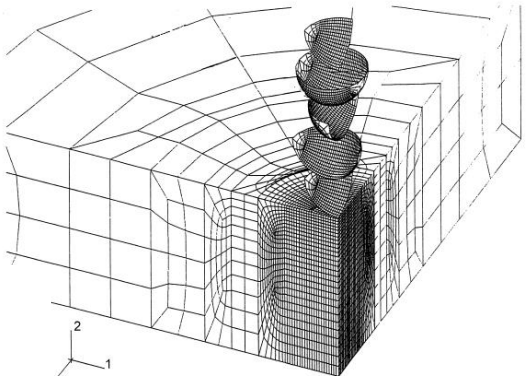
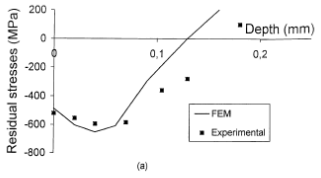
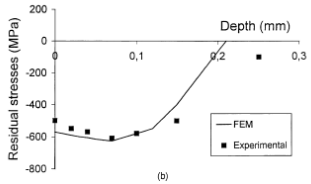
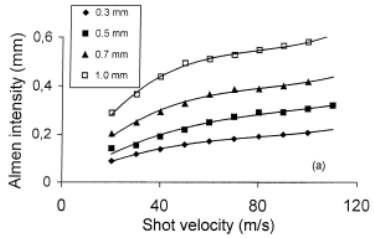


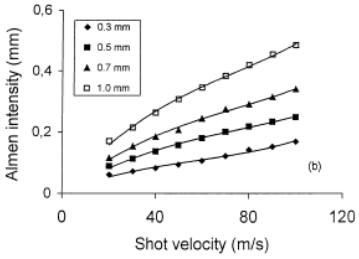
Fig. 2. Scheme of the position of the centrelines of the impacts (r = radius of the impact dimples; its value depends on the diameter of the shot and on its velocity).





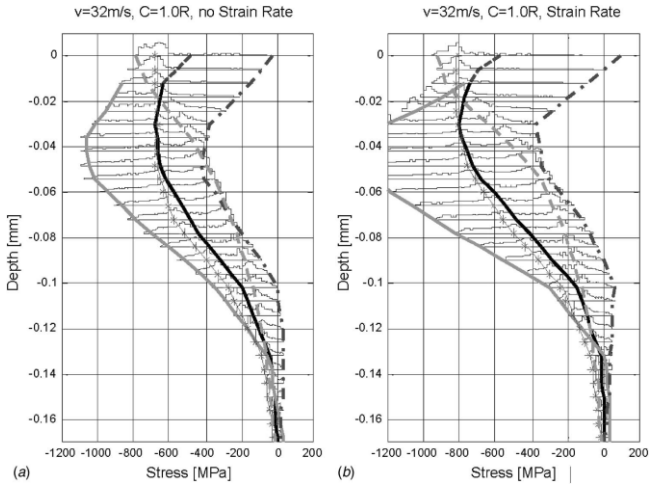


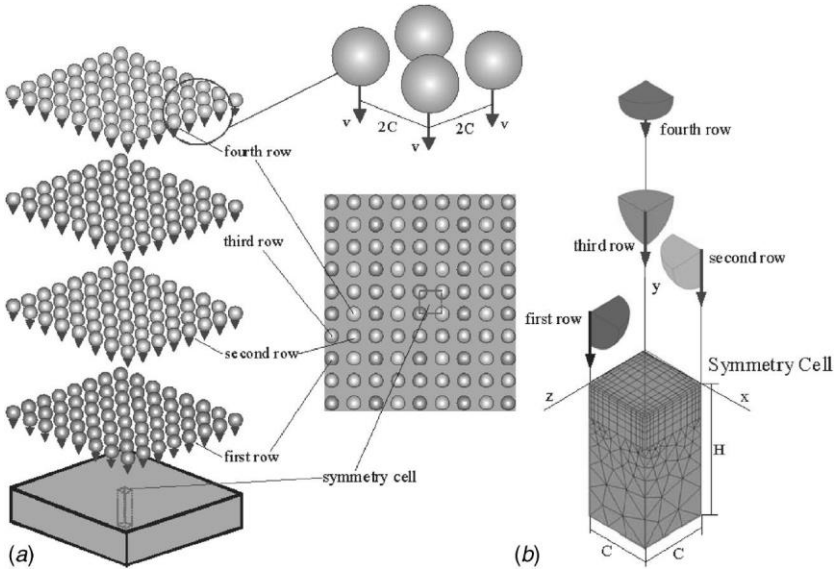




Simulating shot peening

Meguid developed multiple shots models aimed at assessing the influence of the distance of multiple impacts and of the strain rate.
The residual stresses were validated with experimental measurements performed by using the hole-drilling technique (material: Ti-6Al-4V)

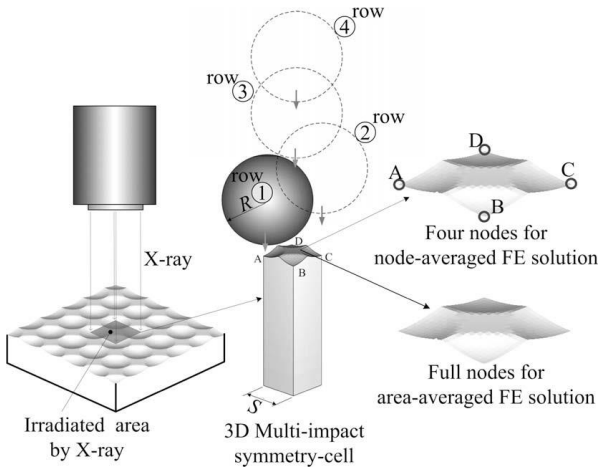


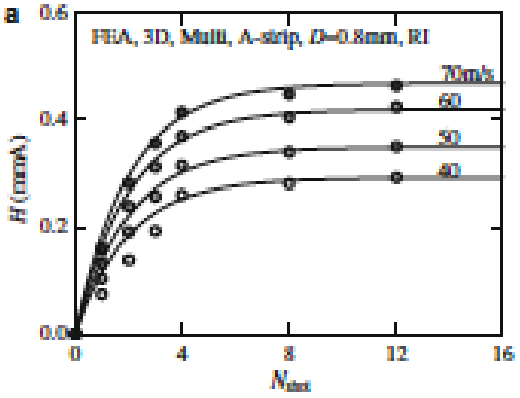


S.A. Meguid, G. Shagal, J.C. Stranaty (2007) Development and Validation of Novel FE Models for 3D Analysis of Peening of Strain-Rate Sensitive Materials, Journal of Engng Mat.Tech (ASME Trans), ***129, 271-283.***

SIMULATING SHOT PEENING

Taehyung Kim, Jin Haeng Lee, Hyungyil Lee, Seong-kyun Cheong (2010)
*An area-average approach to peening residual stress under multi-impacts using a three-dimensional symmetry-cell finite element model with plastic shots, Materials and Design, **31**, 50-59.*





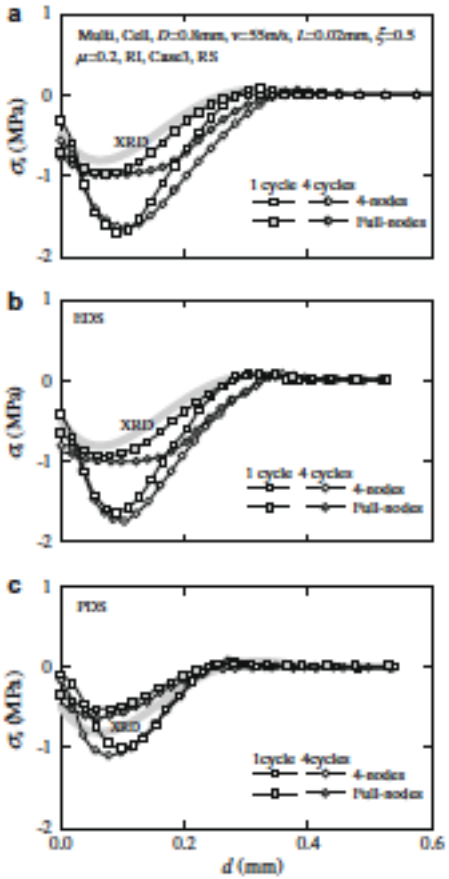


Fig. 3. Comparison of full-nodes averaged residual stress with four-node-averaged residual stress in (a) RS, (b) EDS and (c) PDS.

Simulating shot peening - Coverage

The determination of coverage by using FE simulations needs to define a model to relate a limited number of impacts to the real process, characterized by much more impacts.

Key points:

Definition of a representative volume

Random sequence of impacts

Definition of a relation to relate the FE results to a real coverage value.

Simulating shot peening - Coverage

Applied Surface Science 259 (2012) 186–194

Contents lists available at SciVerse ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

On the shot peening surface coverage and its assessment by means of finite element simulation: A critical review and some original developments

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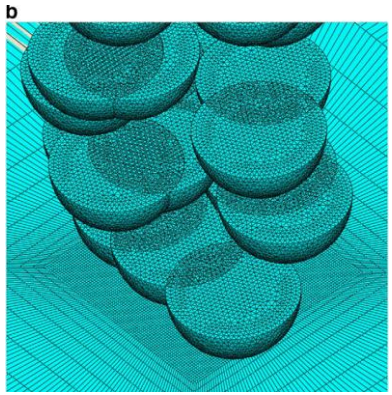
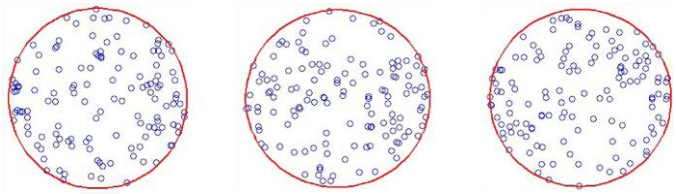
Politecnico di Milano, Department of Mechanical Engineering, Via La Masa, 1, 20156 Milano, Italy

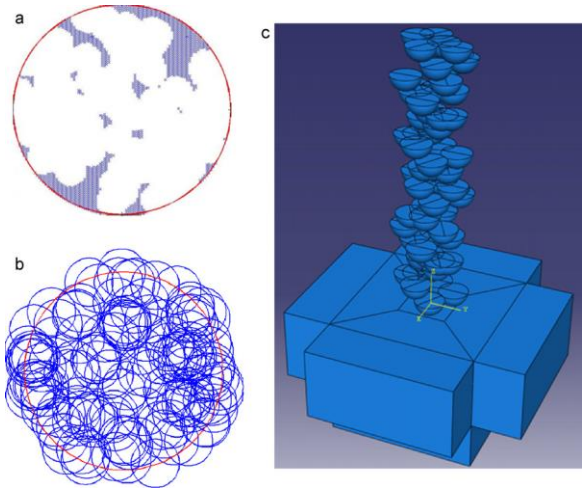


Definition of a representative volume

Pseudo-random sequence of impacts

Avrami's equation is used to relate the FE plastic coverage to a real coverage value.



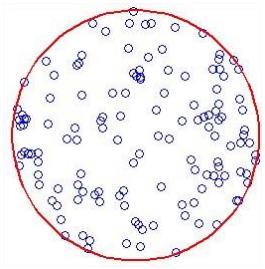
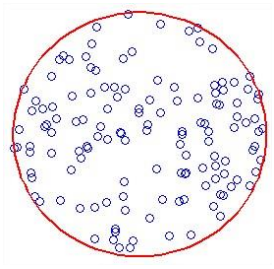
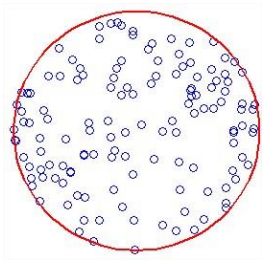
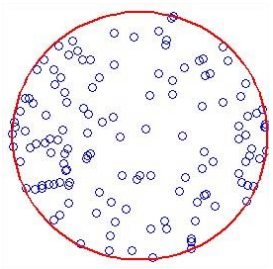
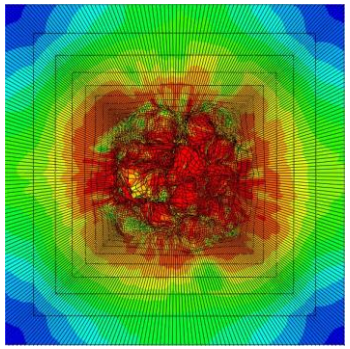
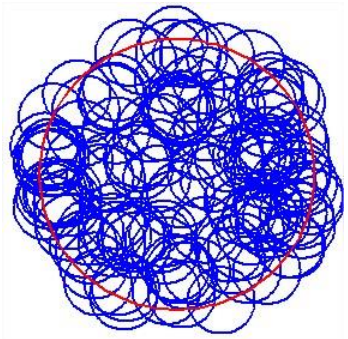


Simulating shot peening - Coverage

Relation between coverage (C) and the ratio of total indent area to the target area (A_r)

100% Coverage: 67 impacts

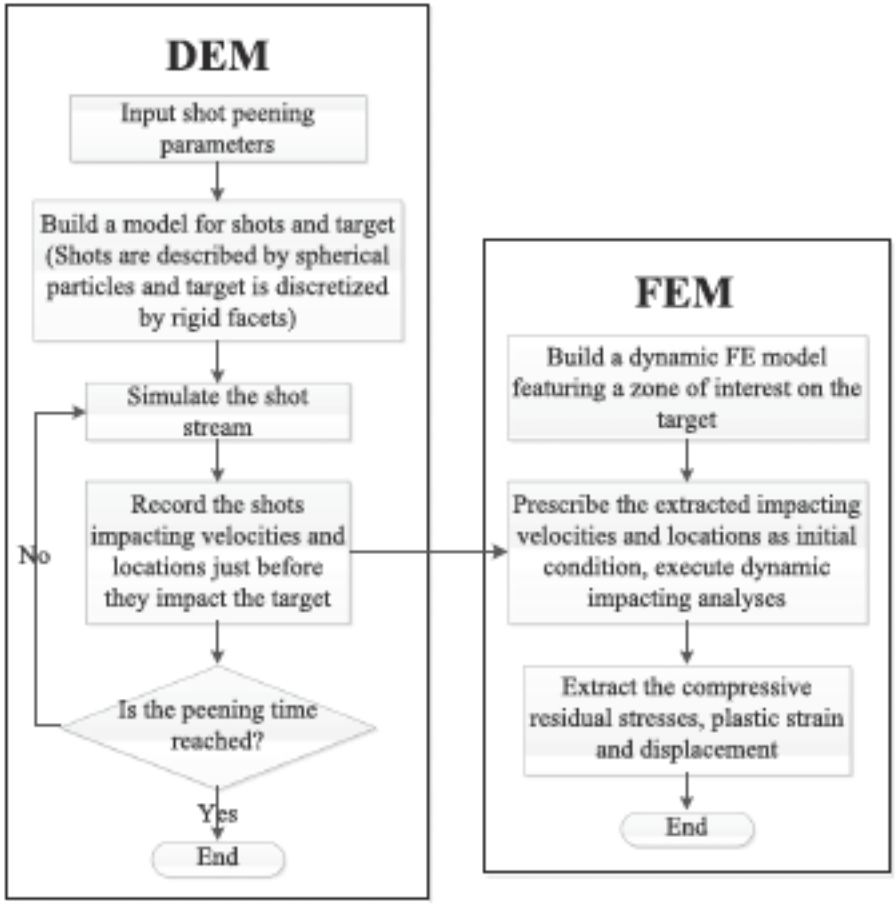
200% Coverage: 134 impacts

Simulating shot peening - Coverage

F. Tu, D. Delberguea, H.Y. Miao, T. Klotz, M. Brochu, P. Bocher, M. Levesque
A sequential DEM-FEM coupling method for shot peening simulation
Surface & Coatings Technology 319 (2017) 200–212

A sequentially coupled Discrete Element Model (DEM) - Finite Element Model (FEM) to predict the process' effects in terms of residual stresses and roughness is developed and experimentally validated mainly in terms of residual stresses.



Comments

- The evolution of the shot peening models have moved toward a more and more realistic representation of the process.

- However, it is important to pay attention to the definition of the correct material parameters, that are a critical point to achieve reliable results. This means that a series of experimental tests must precede the model.

- The numerical model are generally verified considering the residual stress field as key-factor for the final assessment: but, is this the only thing we need?

One step beyond

…The determination of residual stresses does not complete the knowledge of the surface state after shot peening.

There are two other effects that should be considered and evaluated by using simulations:

- **Surface topography and roughness**
- **Microstructural modifications, especially for high intensity coverage values.**

The investigation of these effects needs also fine experimental tests and observations.

Surface, topography and roughness, why?

Surface topography is an important factor of the surface state in many present and possible applications:

Fatigue

Wear

Osseointegration

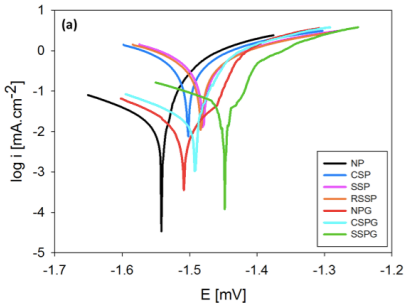
Bacterial adhesion

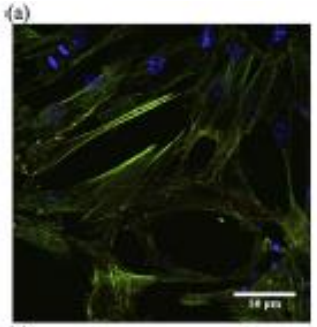
Hydrophobicity

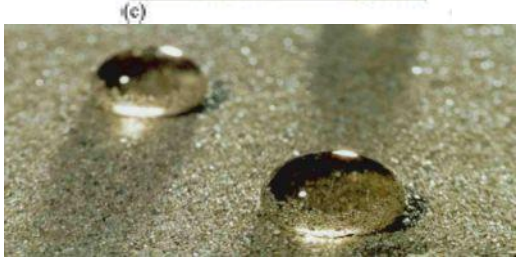
Corrosion

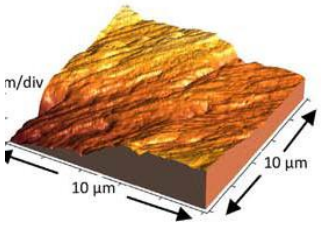
.....

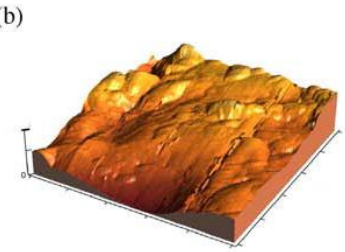
.....

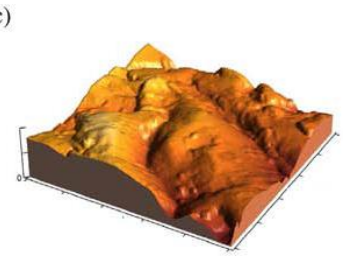












Surface topography and Roughness, why?

Contents lists available at ScienceDirect

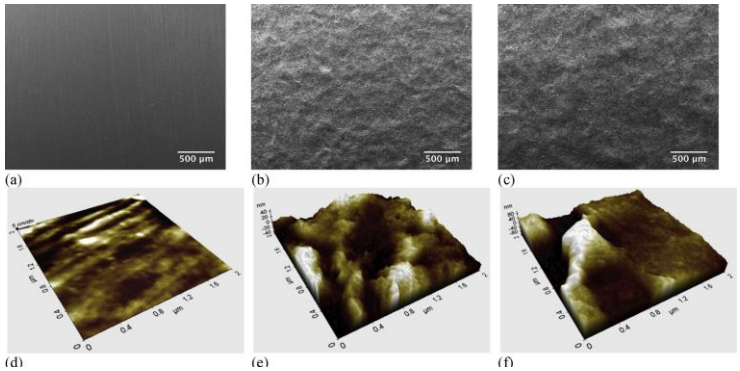
Biomaterials

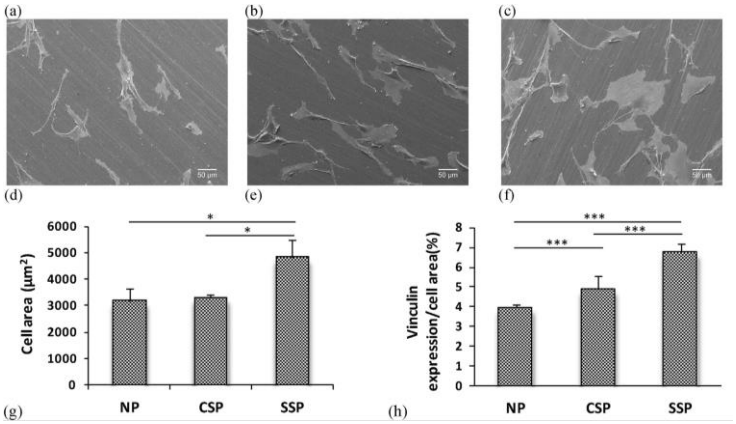
journal homepage: www.elsevier.com/locate/biomaterials

The influence of nanostructured features on bacterial adhesion and bone cell functions on severely shot peened 316L stainless steel

Sara Bagherifard [a, b, c, *], Daniel J. Hickey [d], Alba C. de Luca [c], Vera N. Malheiro [c], Athina E. Markaki [c], Mario Guagliano [a], Thomas J. Webster [d, e]

[a] Department of Mechanical Engineering, Politecnico di Milano, Milan, Italy
[b] Harvard-MIT Division of Health Sciences and Technology, Massachusetts Institute of Technology, Cambridge, MA, USA
[c] Department of Engineering, University of Cambridge, Cambridge, UK
[d] Department of Chemical Engineering, Northeastern University, Boston, MA, USA
[e] Center of Excellence for Advanced Materials Research, King Abdulaziz University, Jeddah, Saudi Arabia





It is shown that the cell adhesion is positively affected by severe shot peening mainly because of the different surface topography, while bacterial adhesion in much weaker.

Surface topography and roughness.

Applied Surface Science 258 (2012) 6831–6840

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Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

Numerical and experimental analysis of surface roughness generated by shot peening

Sara Bagherifard, Ramin Ghelichi, Mario Guagliano*

Department of Mechanical Engineering, Politecnico di Milano, Via La Masa, 1, 20156 Milano, Italy

The trend of the surface roughness vs shot coverage and velocity is studied.

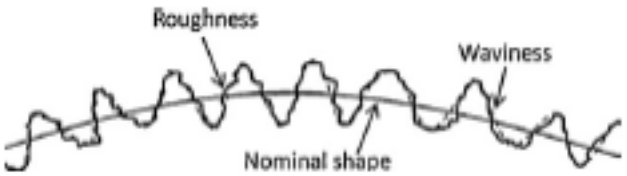
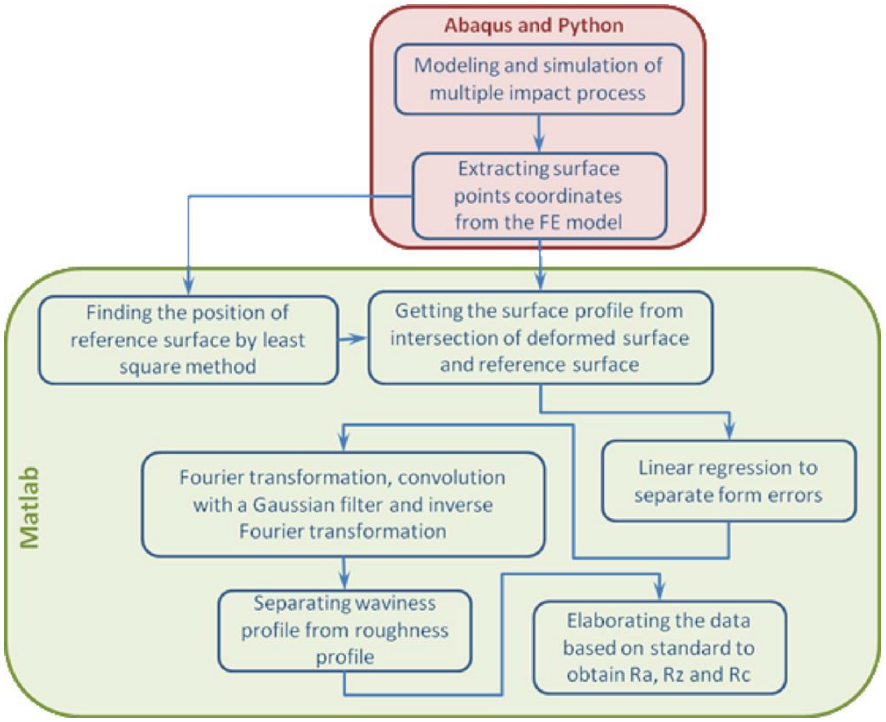


Fig. 6. Roughness and waviness profile.

The surface aspect of the simulated surface depends on the model definition.



Topography and roughness

Applied Surface Science 258 (2012) 6831–6840

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Numerical and experimental analysis of surface roughness generated by shot peening

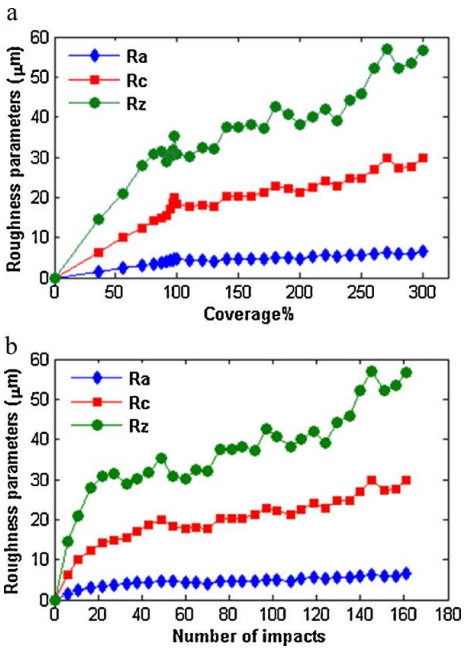
Sara Bagherifard, Ramin Ghelichi, Mario Guagliano*

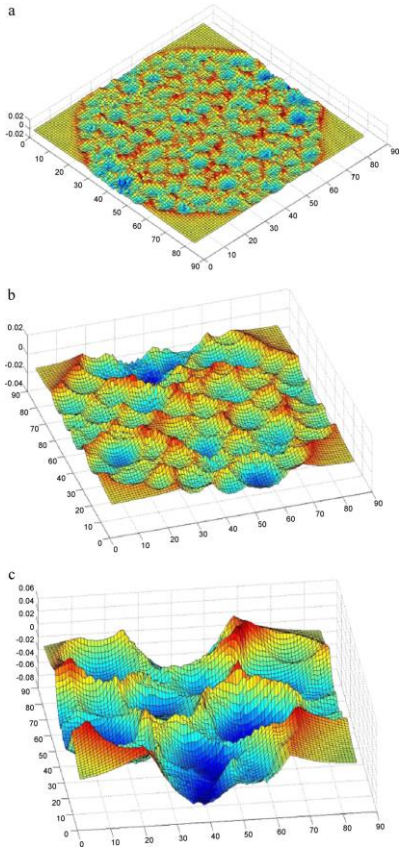
Department of Mechanical Engineering, Politecnico di Milano, Via La Masa, 1, 20156 Milano, Italy

The results were validated with the measurement of the main roughness parameters.

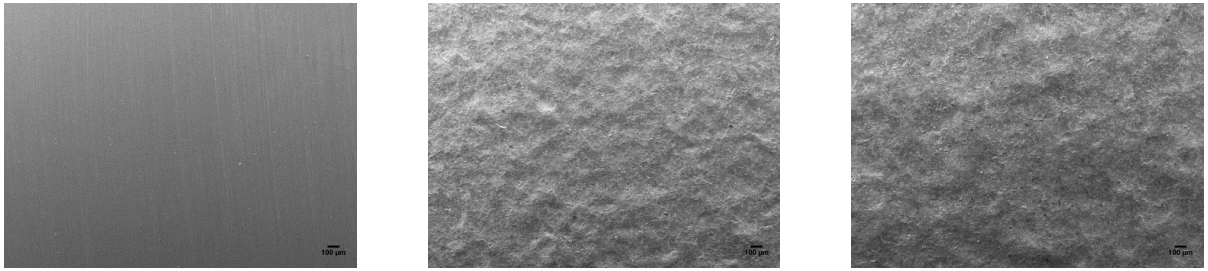
Table 5
Comparison of numerical and experimental surface roughness measurements.

Specimen series	Roughness parameter	Numerical result [μm]	Experimental result [μm]	Difference (%)
NP	R_a	–	0.59	–
	R_c	–	3.20	–
	R_z	–	4.10	–
SP1	R_a	1.82	1.77	−2.7
	R_c	9.76	7.71	−21
	R_z	12.40	10.51	−15.2
SP2	R_a	4.11	4.59	+11.7
	R_c	18.15	18.68	+2.9
	R_z	28.81	29.70	+3.1

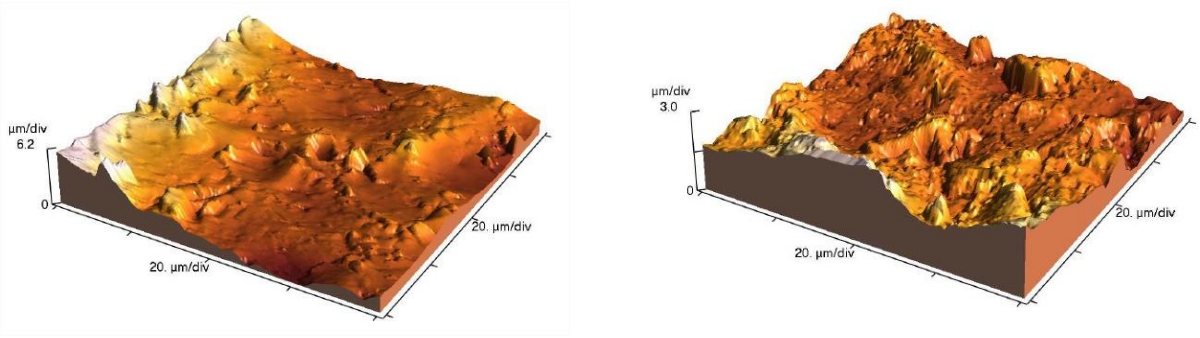




The next step, a smaller scale



Scanning electron micrographs of 316L samples' surfaces (a)NP (b)CSP (c)SSP



Atomic force microscope topographical images of 316L samples' (a)CSP (b)SSP

- The next achievement is expected to be the ability to get by simulation the aspect of surface topography at different scale levels.
- This means also the need to use more advanced experiments for validation.

Grain refinement, why?

Grain refinement lead to superior properties and open new possible applications of shot peening and shot-peening derived treatments.

Contents lists available at SciVerse ScienceDirect

Materials and Design

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Technical Report

Fatigue behavior of notched steel specimens with nanocrystallized surface obtained by severe shot peening

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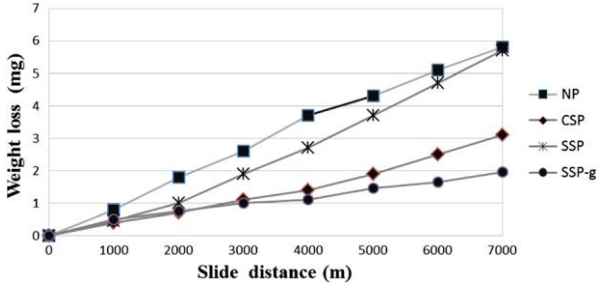
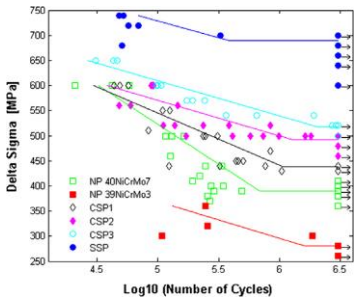
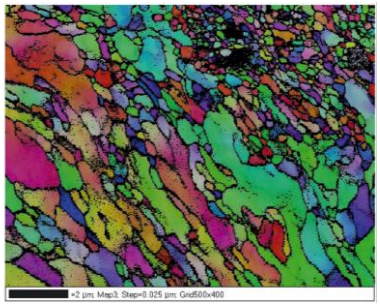
[b] University of Oviedo, Department of Material Science and Metallurgical Engineering, Gijón, Spain







FFEMS Fatigue & Fracture of Engineering Materials & Structures

doi: 10.1111/ffe.12210

Influence of severe shot peening on wear behaviour of an aluminium alloy

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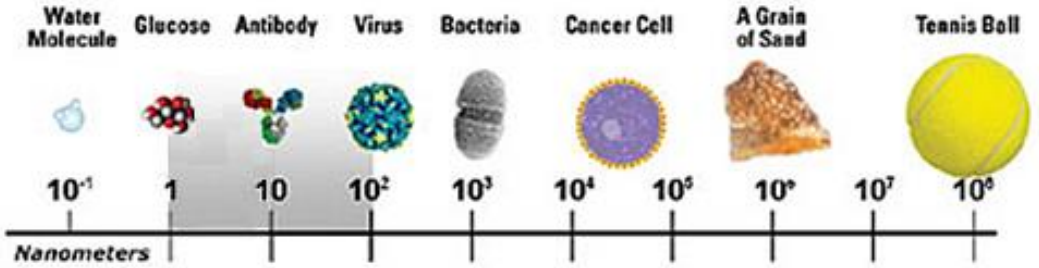
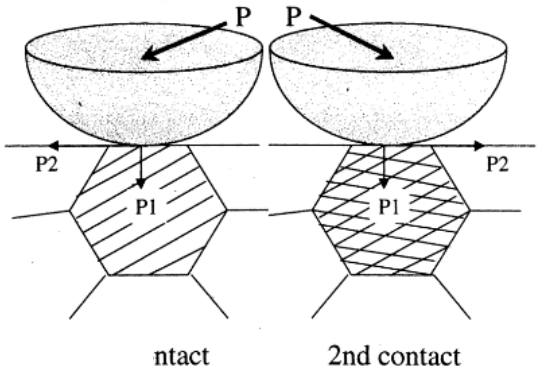
Grain refinement, why?

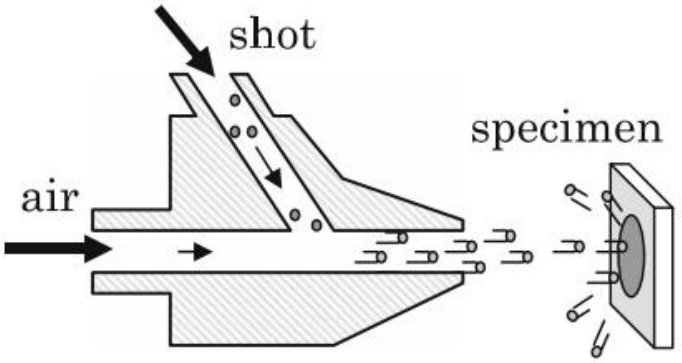


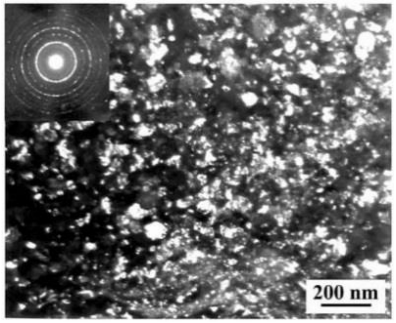
Coarse-grained structure



Nano-structured surface

Coarse-grained structure

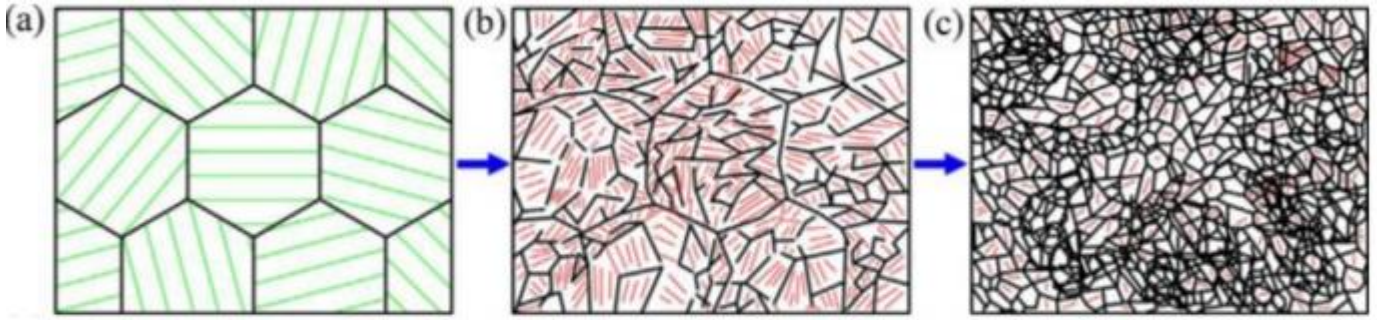




By using intensity and coverage values higher than usual it is possible to get a nanostructured layer of material with superior properties.

Grain refinement, why?

The key factors to obtain surface nanocrystallization are the accumulated plastic strain (>6-8) and the strain rate.



Schematic model of microstructural evolution for grain refinement (a) annealed coarse-grains with different crystal orientations (green lines represent slip planes); (b) the formation of the LAGBs (red lines) and HAGBs (black lines); (c) balance between the LAGBs and the HAGBs

It is necessary to determine the right shot peening parameters (intensity and coverage) to obtain the grain refinement (without damaging the surface and with reasonable cost and time). It is assumed that grain refinement start when the accumulated palstic strain in at least 6-8.

GRAIN REFINEMENT

Contents lists available at ScienceDirect

Surface & Coatings Technology

journal homepage: www.elsevier.com/locate/surfcoat

A numerical model of severe shot peening (SSP) to predict the generation of a nanostructured surface layer of material

S. Bagherifard, R. Ghelichi, M. Guagliano *

Politecnico di Milano, Department of Mechanical Engineering, Via La Masa, 34 20156 Milano, Italy

The goal is to estimate

- **favorable peening parameters for generation of nanocrystals**
- **residual stresses**
- **surface work-hardening**

Considered issues

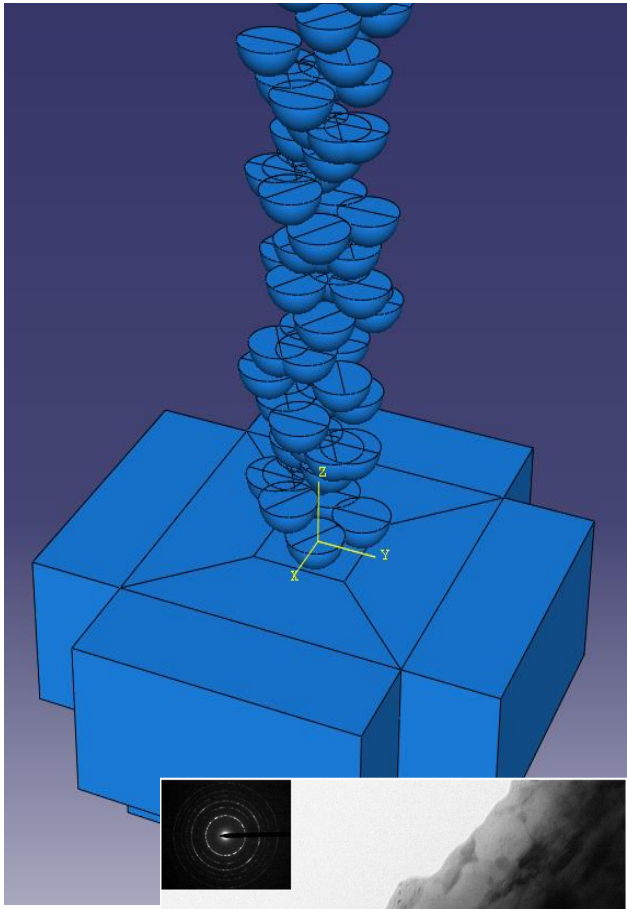
- **Material model**
- **Mesh convergence**
- **Surface Coverage assessment**
- **Randomness of impact position and sequence**

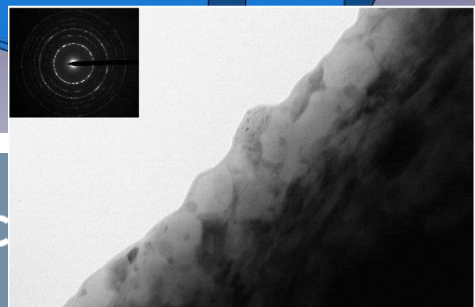
Target model:

3D rectangular body, half infinite elements on side faces.

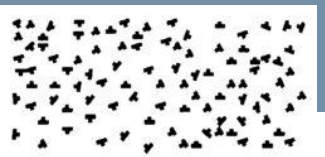
Shot model:

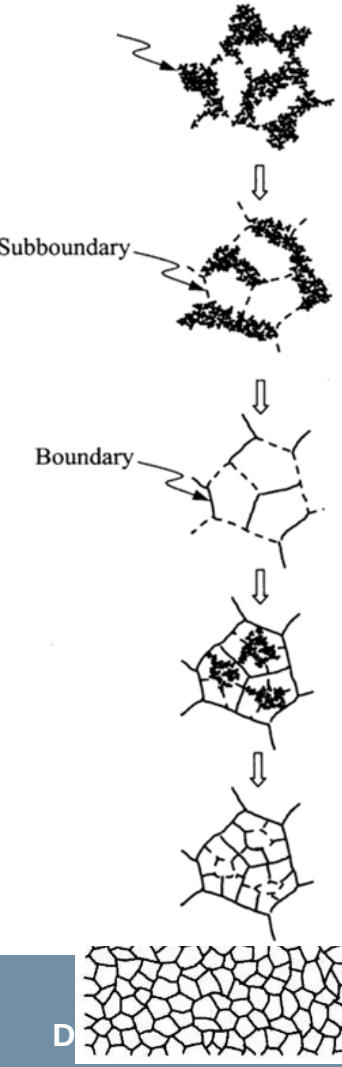
Half spherical bodies, isotropic elastic behaviour, velocity in the z-direction regarding an impact angle=90º.





Simulating grain refinement





Contents lists available at ScienceDirect
Acta Materialia
journal homepage: www.elsevier.com/locate/actamat

Experimental assessment and simulation of surface nanocrystallization by severe shot peening

S.M. Hassani-Gangaraj [a,b,*], K.S. Cho [a,c], H.-J.L. Voigt [a], M. Guagliano [b], C.A. Schuh [a]
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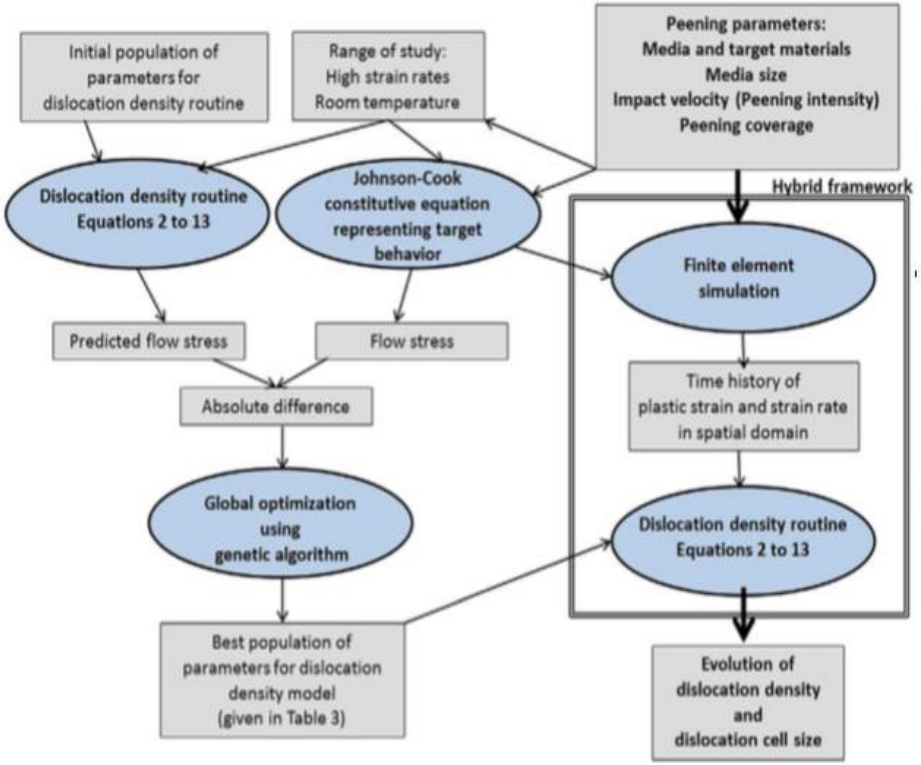
[c] Center for Advanced Materials Technology (CAMT), Kookmin University, Seoul 136-702, Republic of Korea

A model to post process the finite element results based on the dislocation density growth theory (Mughrabi (1983),

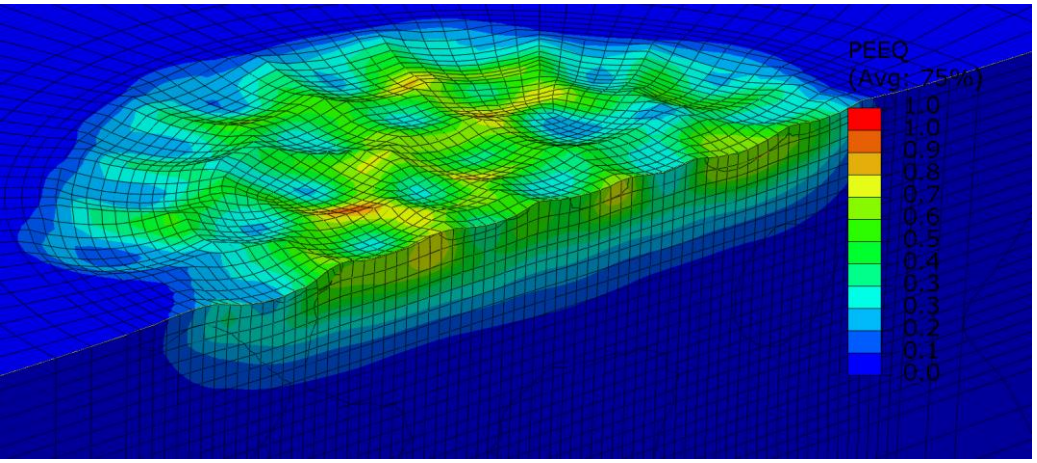
Prinz&Argon(1984),

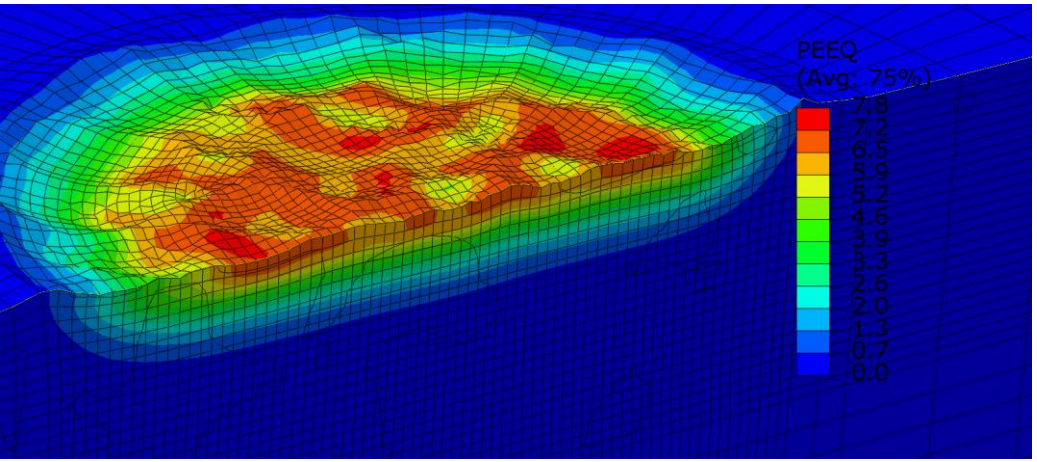
Nix et al.(1985),

Estrin (1998)) has been developed and implemented.

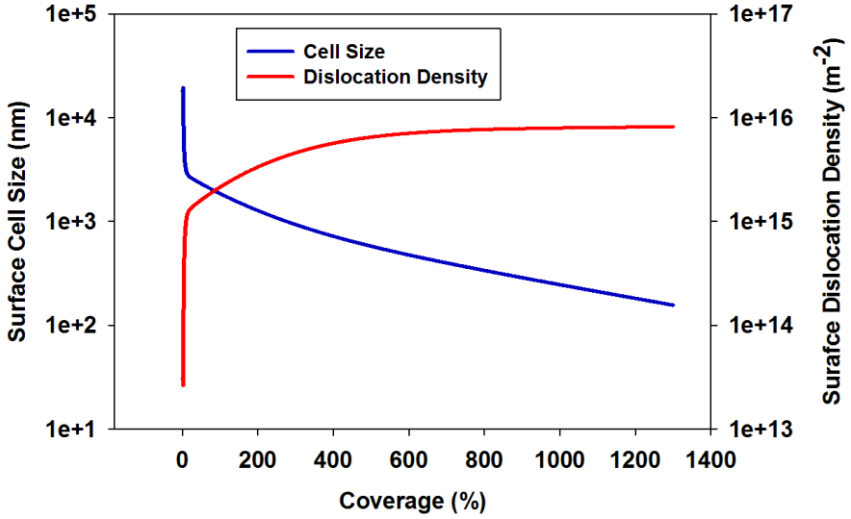


Simulating Grain refinement



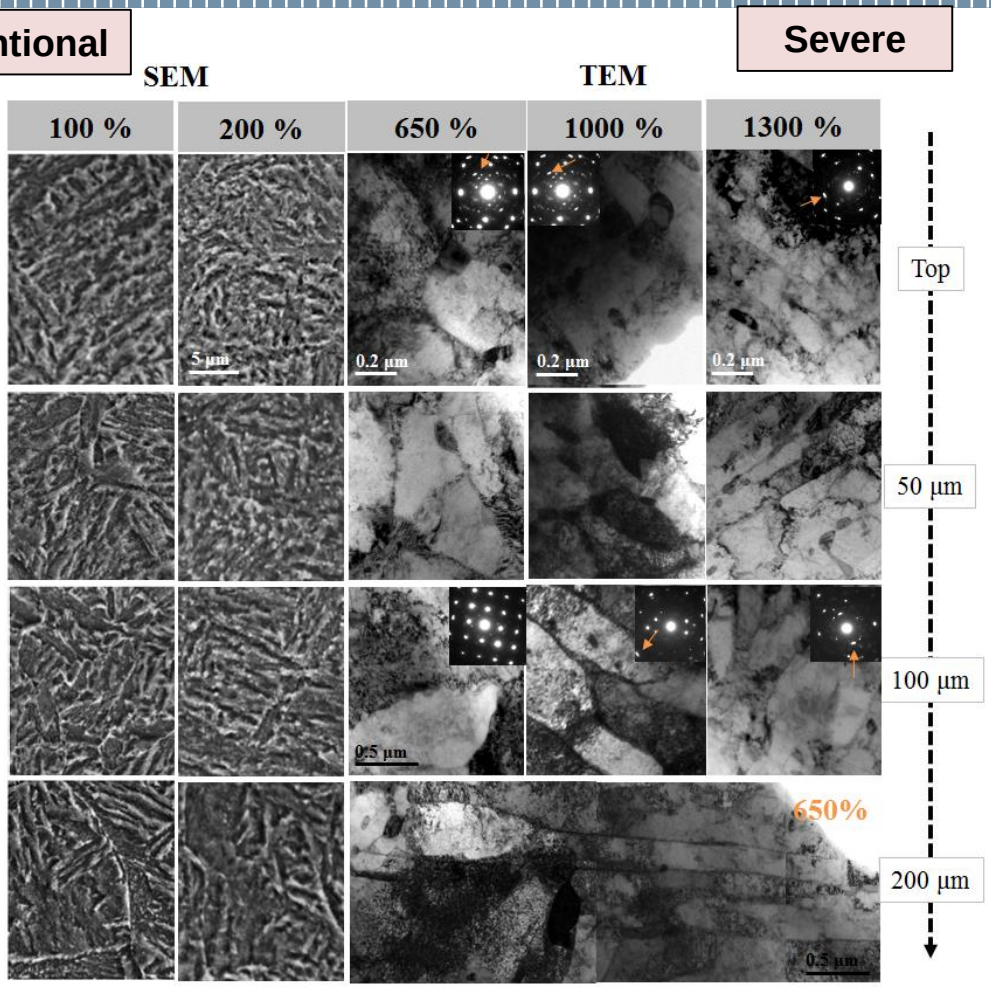


Colour maps of the post-processed results (coverage 100% and 1000%).

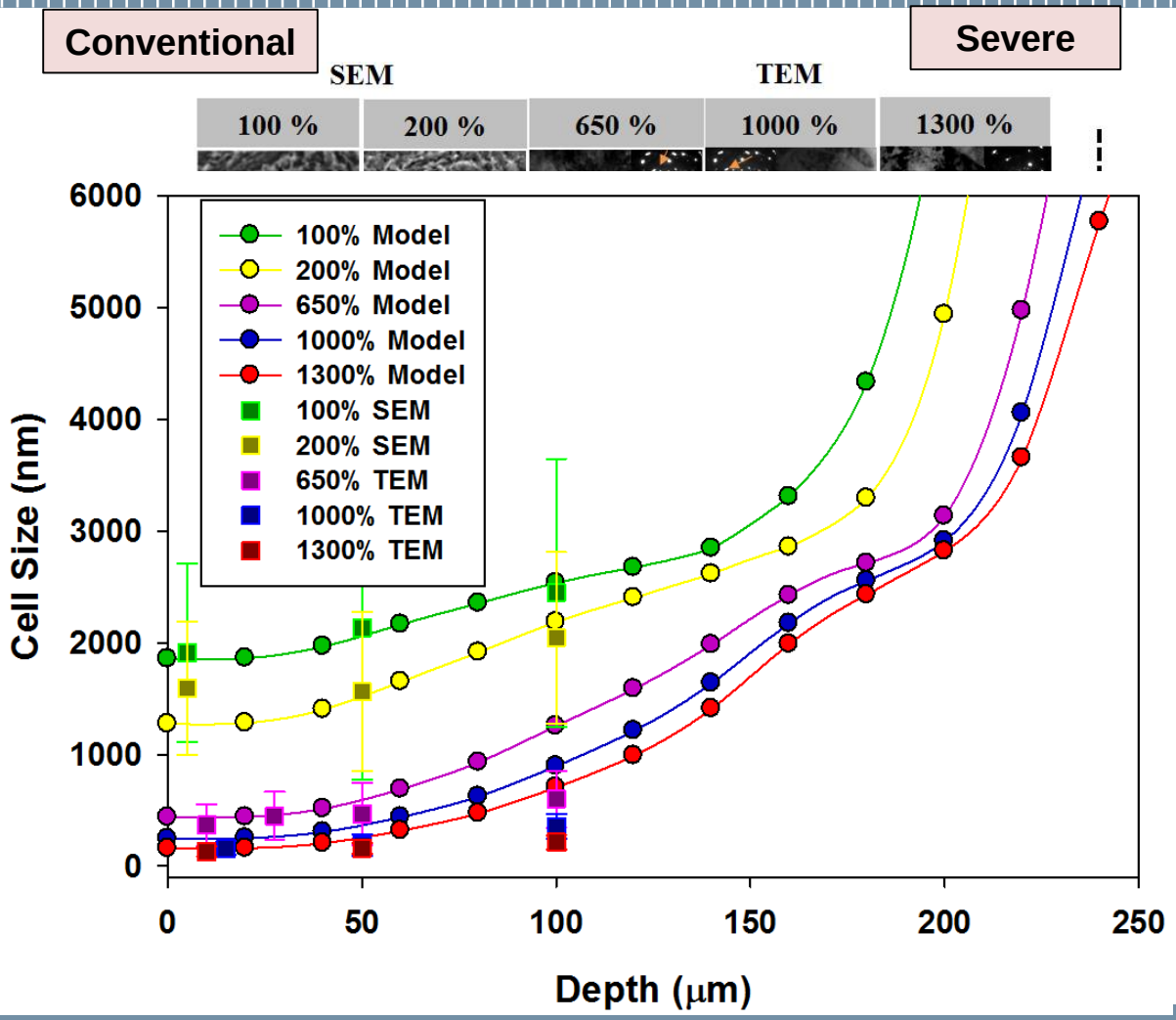


Grain refinement

The results were validated with TEM observations and measurements.

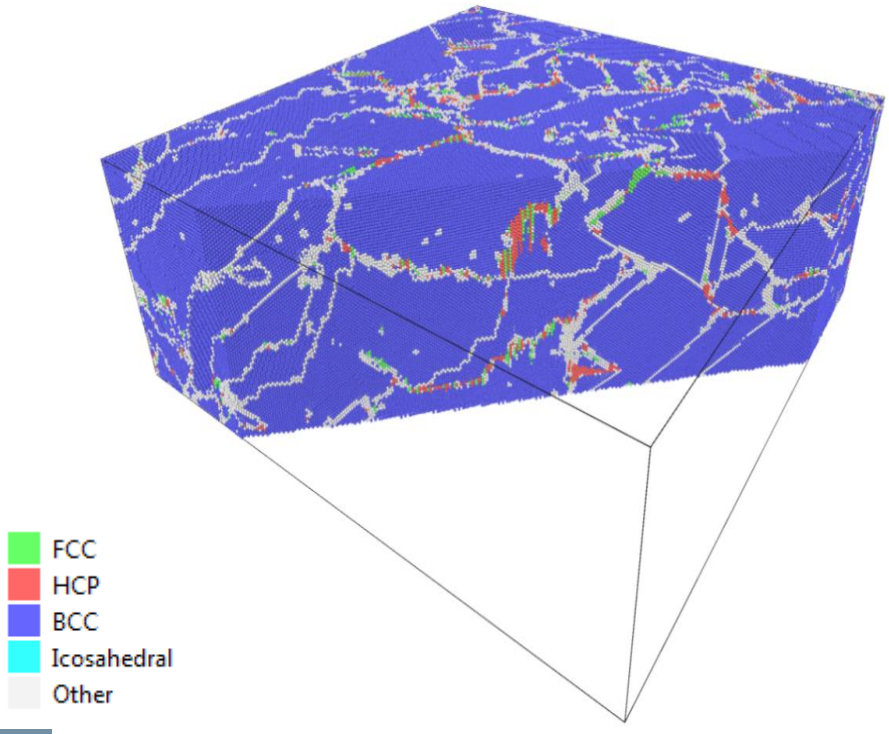


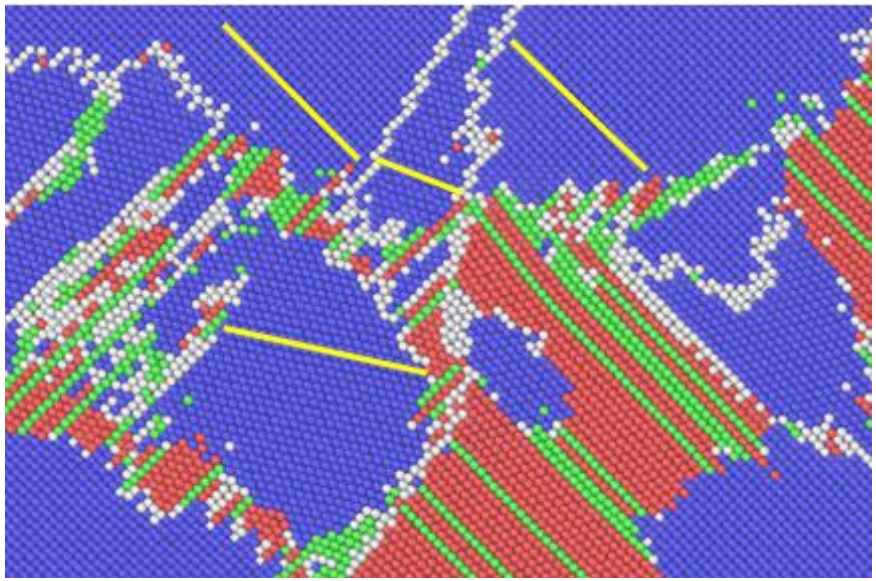
Grain refinement



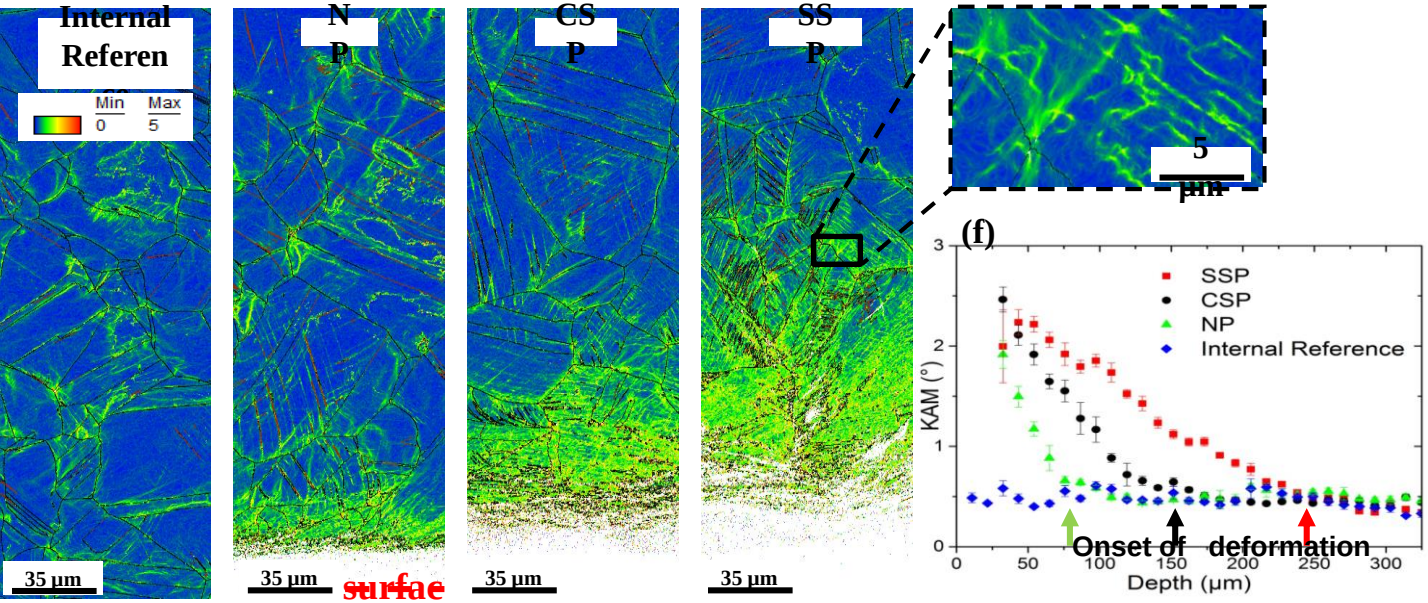
A DIFFERENT APPROACH

- Multiscale approaches starting from FEM solutions and using atomistic simulations is a promising approach for a deeper understanding of microstructural changing induced by shot peening.
- At present very powerful computers are needed.





GRAIN REFINEMENT



- Electron back-scatter diffraction analysis (EBSD) gives important information about the surface state and should be considered for the assessment of the numerical simulations.


Materials and Design 102 (2016) 68–77

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Nanoscale surface modification of AISI 316L stainless steel by severe shot peening

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Conclusions

- **Simulation of shot peening has greatly evolved in the last two decades.**
- **Finite element method is the most suitable tool for numerical modelling of shot peening.**
- **The present models are able to represent the treatment in a very realistic way. However, most of the effort about the effects induced by shot peening were devoted mainly to residual stresses.**

Conclusions

- **Shot peening simulation is still an attractive and challenging subject.**
- **Present and future developments should look not only at residual stresses but also at the other aspects of the surface state (topography and microstructure). This could also open new fields of application for shot peening.**
- **A great effort is required both in terms of multiscale approaches and as regards the experimental methods required to validate the results and to achieve a deeper understanding of the process, getting further advantage by its application.**

My Group, thanks!

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Lebbal Habib, Centre Universitaire de Ain Témouchent, Algeria
Roman Stepanek, Technical University of Brno, Czech Republic
Asghar Heydari, Tarbiat Modarres University, Iran
Victor Llaneza Menéndez, Univeristy of Oviedo, Spain.
Yu Liu, Jilin University, China

Michele Bandini, PhD

THANK YOU!

Questions are welcome but…..

....please, don't shoot me!