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A new method to quantify the heterogeneity of a shot stream – coverage and indent distribution

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1. Introduction

Mechanical surface treatments, such as conventional shot peening (CSP), are commonly used in the industry to enhance the mechanical properties [1], [2], the fatigue life span [3]–[6] and the resistance to stress corrosion cracking [7]–[9] of metallic components. From the component point of view, the surface receives thousands of shot impacts with different impact speeds and angles. CSP being stochastic process, means of controlling their repeatability and homogeneity have to be developed, such as the measurement of Almen intensity [10], [11] and surface coverage. The latter is defined as the ratio of the area of impacted surface over the area of total surface to be treated. It is generally evaluated visually, as recommended by the SAE J2277 standard [12], by an operator with a magnification from x1 to x30. In the industry, "full coverage" is usually defined as 98%, while it is common to specify coverages higher than 100%, for instance 200 %.

In the field of shot peening, industrial tools have been developed along the years to try helping operator to better determine the surface coverage, such as special dies [13], [14], topography analysis [15]–[18], or image analysis [19]–[22] of the peened surface. It is worth noting that so far, these approaches only focus on the mean surface coverage, but fail to conduct more detailed analysis of the indented surface, from which precious information about the shot stream can be gathered. As an example, taking into account heterogeneities in the shot stream is essential to guarantee a homogeneous treatment, especially when shot peening is applied to large and complex surfaces.

2. Objectives

Therefore, the present work provides a quantitative method suited for measuring surface coverage, as well as shot stream properties, such as the effective stream spot size, indent size distributions and impact densities. The method presented hereafter applies to coverage lower or equal to 100%.

3. Methodology

This new method for quantifying the shot peening heterogeneity relies on an experimental protocol developed for the specimen preparation and shot peening operations, and combined with an image acquisition procedure using an optical digital microscope. The obtained images are then analyzed with specific image processing algorithms. The latter have been implemented in ImageJ[1], an open source image processing software. The combination of the experimental protocol and developed image processing algorithms allow quantifying heterogeneities in the shot stream, by analyzing both the surface coverage and the indent sizes and density distributions.

3.1. Specimen preparation and shot peening

[1] ImageJ website <http://imagej.net/Welcome>, visited on March 30th 2016.

316L stainless steel specimens are used. The surface to be peened is polished using 80/320/800/1200 grits, then diamond paste down to 1µm. The aim is to obtain reflecting surfaces with no scratches or defects.

For the shot peening operation, the specimen is held in place with four bolts, as illustrated in Figure 1. Peening parameters are set, such as air pressure, media type, mass flow, working distance, peening angle and nozzle velocity. During peening, the nozzle moves back and forth across the specimen width along an axis centered with respect to the specimen center (Figure 1). A peening cycle is defined as one back and forth movement of the nozzle. The change of direction of the nozzle occurs far for the specimen. For measuring coverage evolution, several specimens can be peened for different number of peening cycles or only one can be use by alternating peening cycles and image acquisition. For measurement of indent characteristics, only one peening pass (half a cycle) is applied to the specimen.

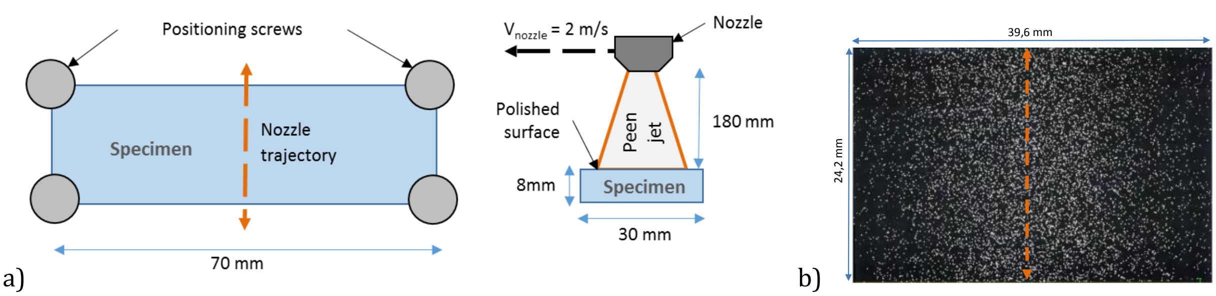


Figure 1: Illustration of specimen positioning and nozzle trajectories (a); example of indented surface after a step of image acquisition (b).

3.2. Image processing of shot peened surfaces

The algorithm developed to measure the coverage from a stitched image S_{ini}, uses existing ImageJ functions combined in a specific order. The core function of the algorithm lies in the enhancing functions used to remove undesired artefacts, such as dust particles and scratches. The first step consists of converting the original image (Figure 2.a) into an 8-bit grayscale image before applying a threshold to obtain a binary image (Figure 2.b). As shown in Figure 2.a, some indent marks do not appear "filled". In order to fill the inside of such indents, without altering their actual contours, a first series of erosions followed by a geodesic reconstruction is applied (Figure 2.c). The resulting image is then inverted. A second series of erosions followed by a geodesic reconstruction is applied, using the same parameters as earlier (Figure 2.d). After these operations, the image can be inverted back, where non-peened areas appear dark again (Figure 2.e). A comparison between the final image and the original image is given in Figure 2.f, where red areas represent the indent marks on the final image. At this point, the image is ready for measuring the coverage, i.e. the fraction of red pixels.

This method can be applied for a single image or a series of images to study the coverage as a function of peening time. It can also be applied to an entire image or a subsection.

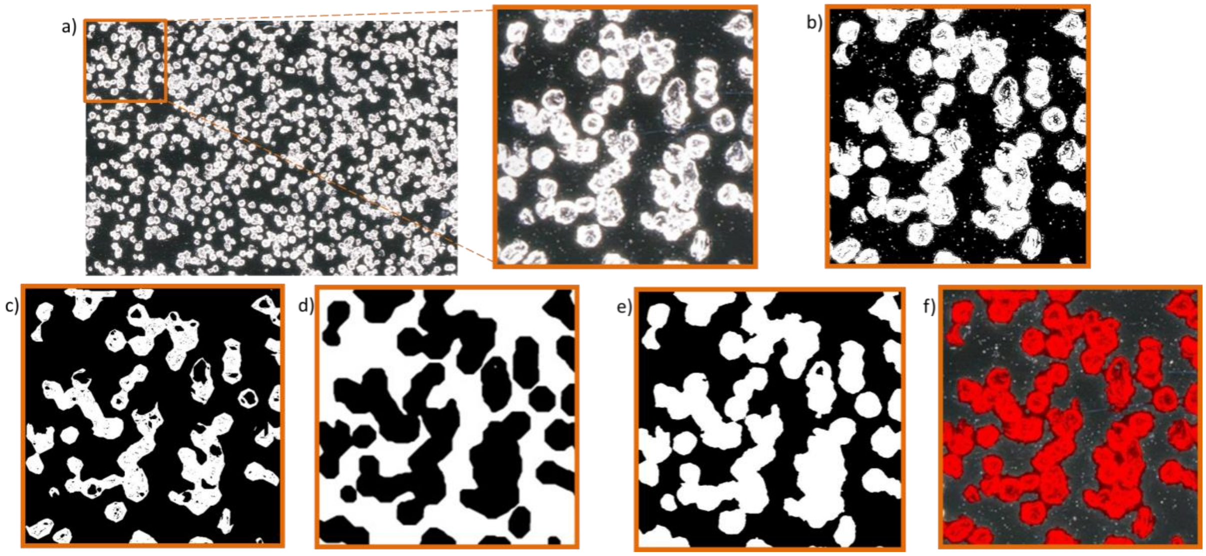


Figure 2: Resulting image for each major step of the I2P method dedicated to coverage measurements; starting with the initial image (a), the threshold step (b), the first series of erosions and geodesic reconstruction (c), after the second series of erosions and geodesic reconstruction (d), the final image (e) and a comparison with the original image (f).

4. Shot peening of 316L steel specimens

The developed method was applied on four specimens, made of AISI 316L steel, and shot peened at IRT M2P with the same conditions (ASH130 media, Almen intensity of 0.12 mmA). The evolution of coverage is studied as a function of the number of shot peening pass, along the trajectory of the nozzle and perpendicularly to it. A similar analysis is also conducted, after one pass of the peening nozzle, to better quantify the physical properties of the shot stream.

In terms of coverage analysis, the results show that the coverage is homogeneous in the direction of the nozzle trajectory and that it evolves similarly with the peening cycles, with little dispersion, for all four specimens (Figure 3.a). Perpendicular to the nozzle trajectory, the coverage follows a bell like shape centered in the middle of the shot stream (Figure 3.b).

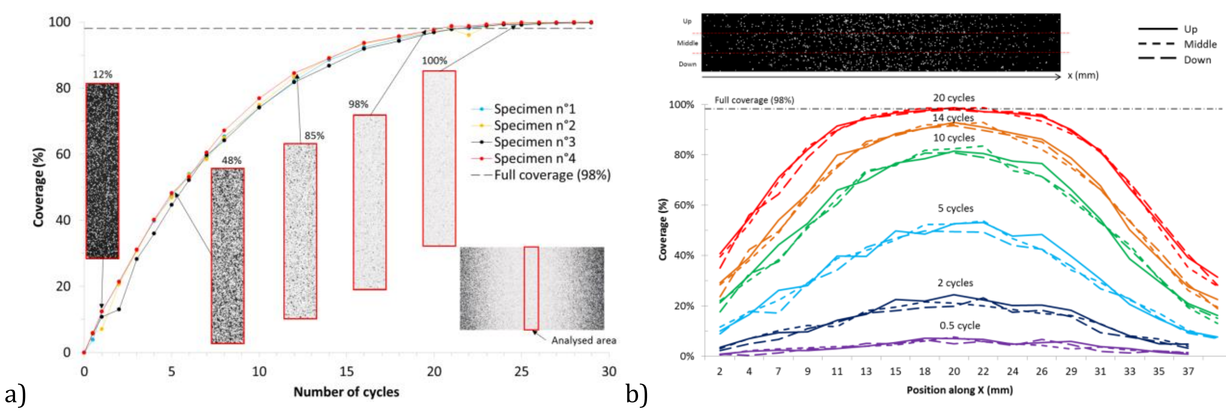
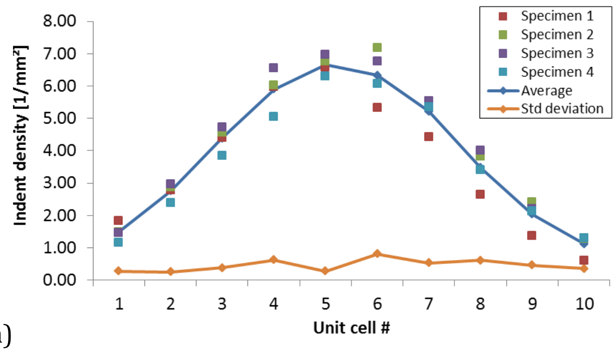
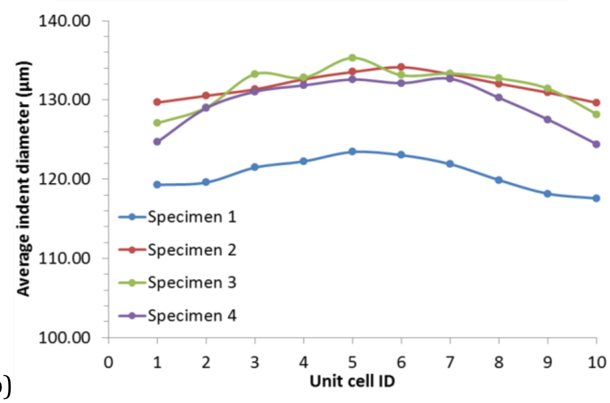


Figure 3: Evolution of surface coverage with the number of peening cycles along the trajectory of the nozzle (a) and perpendicularly (b).

As for the shot stream properties, the analysis of the peened surfaces after one pass of the peening nozzle shows that impact densities follow a bell like function (Figure 4.a), along the length of the specimens, similarly to the results obtained for the surface coverage (Figure 3.b). The measurements of indent sizes plotted in Figure 4.b also exhibit a small variation across the specimens' length. In both cases, the values are maximal at the center of the shot stream and tend to decrease when moving towards the edges. This clearly indicates that the spatial distribution of media is not uniform within the stream. As for the evolution of indent diameters, it is still not yet clear whether the observed variation arise from a heterogeneity in impact speeds within the jet, or from the natural size distribution of the media itself, or from both. Further investigations are required.



a)



b)

Figure 4: Distribution of the indent densities (a) and indent diameter (b) as a function of the specimen length, after one pass of the peening nozzle.

5. Conclusions

In the present paper a new image processing method is presented for accurate indent surface measurement. In particular, the method provides a quantitative and accurate tool for measuring peening coverage in the range of 0 to 100%, but also shot stream properties. The method is implemented using ImageJ, an open source image processing software.

The method is then used on four shot peened AISI 316L stainless steel specimens. Firstly, the coverage analysis conducted shows that coverage is constant along the path of the peening nozzle. In the direction perpendicular to the nozzle path, a bell like distribution is obtained for coverage, with high values at the center of the shot stream and lower values further away. As a function of time, this distribution seems to flatten out in the middle of the specimen and allows to precisely determining the effective spot size and shape of the shot stream.

In a second time, a more detailed analysis of the indents is conducted and shows that the indent densities follow a similar bell like distribution when plotted along the length of the specimens, *i.e.* perpendicular to the shot stream path. The measured indent sizes, for the second population of indents, has an average value of 125 µm for specimen 1 and 145 µm for specimens 2 to 4. The observed results could indicate an increase in impact velocities between specimen 1 and the specimens 2 to 4; which might mean that the peen flow did not yet reach a steady state when peening specimen 1.

Over all, the method seems also capable of identifying repeatability problems and quantifying fluctuations in peening flow.

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