(U) Shrink Porosity Analysis by Segmentation and Thresholding

Walter Rose

US Army DEVCOM
Armaments Center

Picatinny Arsenal, NJ 07806

(U) Abstract: Accurately quantifying shrink porosity from digital radiographs can be challenging. Traditionally, radiographers will rely on extensive training and experience to determine if a certain amount of shrink porosity is acceptable or exceeds the limits dictated by radiographic specifications. In this paper, a program was devised that can quantify the amount of shrink porosity present in an item.

(U) Research Innovation and Objective(s): Quantifying shrink porosity by use of computer vision is a challenging task. Although the method described herein is not fully automated it can be deployed in a research and development (R&D) environment to accurately quantify the amount of shrink porosity in an item.

(U) Impacts on Warfighter Mission: Ensuring that the warfighter has the best materials requires state of the art non-destructive testing techniques. Evolving from a subjective to an objective approach allows for a consensus to be achieved regarding the quality of the manufacturing process across governmental entities and contractors.

(U) Keywords: porosity, radiography, computer vision, non-destructive testing

1. (U) Introduction

(U) In this paper we discuss the application of computer vision techniques to quantify the amount of shrink porosity in a radiograph. Shrink porosity appears during the material solidification phase. Shrink porosity manifests during periods of material shrinkage. The metal injected inside a mold starts its cooling phase when it makes contact with a wall. Thermal conduction causes metal solidification from the external surface to the core. During this phase the volume of metal decreases causing a convective gradient toward the external surface. [1]

(U) Although the method described herein relies on precise thresholding, once the threshold is determined by the radiographer, the computer can then easily calculate the corresponding area for pixels that exceed the threshold. When a radiographer reviews images, typically he/she must rely on judgement as to if the sum of the areas that exhibit porosity exceed requirements dictated by military specifications. Military specifications dictate the maximum sum of the projected areas that is allowable depending on which segment of the artillery shell is being examined. In addition to that, there are different permissible areas depending upon on energetic composition. It is the determination of which pixels to consider in conjunction with the operation of summing areas that leads to a greater amount of subjectivity than is usually desired. Using a computer program partially removes aspects of this subjective process and allows for an accurate area to be calculated expeditiously.

(U) In order to appreciate the complexity of the problem, consider the following artillery shell shown in figure 1. The red box shown is 5/8 square inches. It is the task of the radiographer to conceptualize the total shrink porosity present and assess if this exceeds the area of the red box in which case the shell would be deemed rejectable.

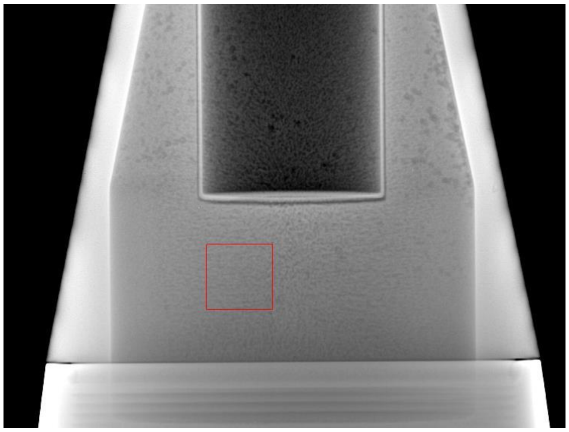

Figure 1. Radiograph of an artillery shell with red box of an area of 5/8 square inches

(U) To demonstrate shrink porosity consider figure 2 below. There are a few things to point out concerning the shrink porosity displayed in figure 2. First, it is apparent there is nonuniform illumination. That is, the radiograph is brighter towards the center and the bottom of this radiograph than towards the top and the sides. This presents a challenge when it comes to automating this process even in a single radiograph. If we set a threshold that will differentiate an acceptable pixel value from an unacceptable pixel value, it will only be valid locally. An additional threshold will have to be defined when moving to another region.

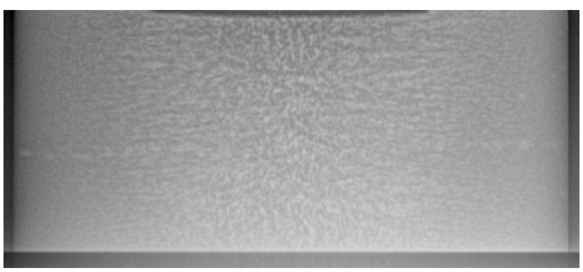

Figure 2. Radiograph with propietary ADE filter [2]

The second thing to point out concerning figure 2 is to emphasize that the phenomenon of shrink is fundamentally a lack of material. Therefore, in a positive image shrink will apear as lighter spots.

Now, consider the following cropped positive radiograph. A section of figure 2 has been isolated and displayed in figure 3 below.

Figure 3. Cropped Version of original radiograph displayed in figure 2.

The objective is to isolate the lighter portions of this image. Recalling that an image is nothing but a matrix of numbers, it will be an easy task for the computer to count how many entries of this matrix exceed a predetermined threshold. The mean greyvalue of figure 3 is 16,230 and the standard deviation is 628. For this test, lets set the threshold to 17,346 and produce the same radiograph with the shrink being white. Figure 3 shows the result of this thresholding procedure. As we will explain later, we did not binarize the image, althought it might appear that way.

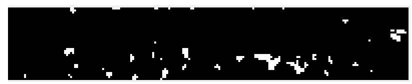

Figure 4. Thresholding procedure applied to Figure 3 with a threshold of 17,346.

Comparing figure 4 and figure 3, it appears as if some of the shrink has been captured but not all of it. Lets attempt to repeat the same procedure on figure 3 but with a different threshold. As can be seen below, when the threshold is reduced, more pixels will be categorized as shrink. Figure 5 seems to more accurately capture all of the shrink porosity present when compared to our original radiograph displayed in figure 3.

Figure 5. Thresholding procedure with a threshold of 16,500.

The objective of this work is to repeat this procedure for the entirety of figure 2 which will allow the computer to accurately quantify the shrink given a prescribed agreed upon set of thresholds.

2. (U) Method

(U) In order to accuriately capture enough shrink porosity, it was determined that 18 different regions were needed. These regions are displayed in figure 6. Therefore, 18 different thresholds were needed in order to properly quantify the amount of shrink porosity in this region of the artilery shell. Table 1 of the appendix shows the mean, standard deviation and the threshold assigned to each respective region.

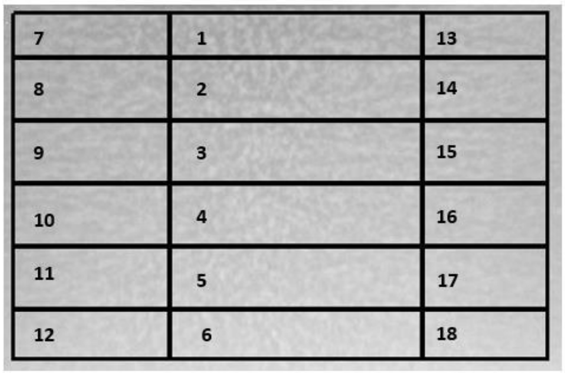

Figure 6. Numbered Regions for assigment of thresholds

Recall that these thresholds are arbitrary and need to be chosen by the radiographer. What is advantageous about this method is that any number of radiographers can assign threshold values. Once those threshold values are determined the computer program then calculates the projected area in a defined manner. Therefore, both conservative and liberal estimates for thresholds can be chosen so that an objective decision can be made as to if the artillery shell is in compliance to military specification.

Lastly, I would like to describe the basic subroutine that is applied a total of eighteen times so that local thresholding can be applied. First, a region of interest is determined. The goal of this first step is to get an area of uniform illumination which can be determined subjectively but also objectively with the aid of a histogram. Second, a matrix of zeros and ones is created whereby a zero represents a pixel value that is less than the threshold and one indicates a pixel value greater than the threshold. Using this matrix as a "mask", we have identified the locations in our original region of interest where the pixel value exceds the threshold. Therefore, the last step is to simply set all values that weren't identified in the "mask" to zero, so that only the pixels that exceed the threshold remain. It is then a simple routine to calculate the number of non zero entries in the remaining matrix. This number represents the number of pixels that have exceeded the threshold and are identified as contributing to the shrink porosity.

3. (U) Conclusion & Future Work

(U) The creation of this program allows for a degree of versatility. Since the program presented here is both computationally fast and accurate, both liberal and conservative threshold estimates can be taken into account when making critical judgement calls on the integrity of artillery.

(U) It has been asked with the increasing number of available commercial off the shelf tools for computed tomography analysis like, Volume Graphics (Hexagon AB) and Dragonfly (ORS), why can't we use these tools or a slight modification thereof to analyze two dimensional radiographs. The reason for this lies in the procedure of computed tomography. The most common execution of computed tomography involves the filtered back projection algorithm. Computed tomography and the associated filtered back projection comprises an intrinsic averaging of the data. This averaging operation is not available in the analysis of two-dimensional radiographs. Therefore, nonuniform illumination is a greater problem in the two dimensional case.

(U) The issue of nonuniform illumination presents unique challenges not just for this work, but for work involving other computer vision tasks such as using object character recognition (OCR). In an another paper I derive a precise mathematical function that characterizes the intensity profile from a point source projected on a screen. This result is an important theoretical result but may be of little practical use. First, very few radiographic sources can be accurately modelled as point sources. Second, fixturing and precise source to detector geometry is required for the mathematical ideal case to apply. Despite the difficulties of applying this formula in production, the formula should be able to be exploited in a research and development context.

Acknowledgements

A special thanks to Jeffrey Williams, NAS 410 Level 3 radiographer for many fruitful discussions and encouragement in pursuit of this work.

References

1. Shrinkage porosity: causes and remedies, Fagnani *https://www.bruschitech.com/blog/shrinkage-porosity-causes-and-remedies*

2. *Vi3 Viewing Software. VJ Technologies*

Appendix

Table 1

Region	Mean	Standard Deviation	Threshold
1	1.62	6.28	16500
2	1.68	6.12	17200
3	1.74	5.03	17500
4	1.79	4.86	18100
5	1.85	4.54	18700
6	1.91	4.07	19400
7	1.58	5.05	16200
8	1.63	5.09	16600
9	1.67	5.05	17000
10	1.72	5.04	17700
11	1.78	5.41	18200
12	1.84	4.68	18700
13	1.67	4.25	16800
14	1.7	4.67	17300
15	1.72	4.25	17700
16	1.76	3.83	18000
17	1.81	4.40	18700
18	1.88	3.8	19300

Computer Code

```
clear all
clc
clf

X = dicomread('GROUP 4-view0001-
ADE.dcm');

W = ROI(X, 700, 1025, 375, 1100);
Z1a = ROI(W, 15, 50, 300, 500);
%Beginning of Center Strip
Z1b = ROI(W, 15, 50, 300, 500);
mask1 = Z1b >= 16500;
Z1b(~mask1) = 0; % shrink is white
N1 = nnz(Z1b);
M1a = mean2(Z1a);
S1a = std2(Z1a);
Z2a = ROI(W, 51, 100, 300, 500);
Z2b = ROI(W, 51, 100, 300, 500);
mask2 = Z2b >= 18712;
Z2b(~mask2) = 0;
N2 = nnz(Z2b);
M2a = mean2(Z2a);
S2a = std2(Z2a);
Z3a = ROI(W, 101, 150, 300, 500);
Z3b = ROI(W, 101, 150, 300, 500);
mask3 = Z3b >= 18629;
Z3b(~mask3) = 0;
N3 = nnz(Z3b);
M3a = mean2(Z3a);
S3a = std2(Z3a);
Z4a = ROI(W, 151, 200, 300, 500);
Z4b = ROI(W, 151, 200, 300, 500);
mask4 = Z4b >= 19023;
Z4b(~mask4) = 0;
N4 = nnz(Z4b);
M4a = mean2(Z4a);
S4a = std2(Z4a);

Z5a = ROI(W, 201, 250, 300, 500);
Z5b = ROI(W, 201, 250, 300, 500);
mask5 = Z5b >= 20626;
Z5b(~mask5) = 0;
N5 = nnz(Z5b);
M5a = mean2(Z5a);
S5a = std2(Z5a);

Z6a = ROI(W, 251, 290, 300, 500);
Z6b = ROI(W, 251, 290, 300, 500);
mask6 = Z6b >= 20351;
Z6b(~mask6) = 0;
N6 = nnz(Z6b);
M6a = mean2(Z6a);
S6a = std2(Z6a);

%End of Center Strip

Z7a = ROI(W, 15, 50, 175, 299);
%Beginning of Left Strip
Z7b = ROI(W, 15, 50, 175, 299);
mask1 = Z7b >= 16200;
Z7b(~mask1) = 0;
N7 = nnz(Z7b);
M7a = mean2(Z7a);
```

```
S7a = std2(Z7a);

Z8a = ROI(W, 51, 100, 175, 299);
Z8b = ROI(W, 51, 100, 175, 299);
mask1 = Z8b >= 16600;
Z8b(~mask1) = 0;
N8 = nnz(Z8b);
M8a = mean2(Z8a);
S8a = std2(Z8a);

Z9a = ROI(W, 101, 150, 175, 299);
Z9b = ROI(W, 101, 150, 175, 299);
mask1 = Z9b >= 17000;
Z9b(~mask1) = 0;
N9 = nnz(Z9b);
M9a = mean2(Z9a);
S9a = std2(Z9a);

Z10a = ROI(W, 151, 200, 175, 299);
Z10b = ROI(W, 151, 200, 175, 299);
mask1 = Z10b >= 17700;
Z10b(~mask1) = 0;
N10 = nnz(Z10b);
M10a = mean2(Z10a);
S10a = std2(Z10a);

Z11a = ROI(W, 201, 250, 175, 299);
Z11b = ROI(W, 201, 250, 175, 299);
mask1 = Z11b >= 18200;
Z11b(~mask1) = 0;
N11 = nnz(Z11b);
M11a = mean2(Z11a);
S11a = std2(Z11a);

Z12a = ROI(W, 251, 290, 175, 299);
Z12b = ROI(W, 251, 290, 175, 299);
mask1 = Z12b >= 18700;
Z12b(~mask1) = 0;
N12 = nnz(Z12b);
M12a = mean2(Z12a);
S12a = std2(Z12a);

Z13a = ROI(W, 15, 50, 501, 600);
%Beginning of Right Strip
Z13b = ROI(W, 15, 50, 501, 600);
mask1 = Z13b >= 16800;
Z13b(~mask1) = 0;
N13 = nnz(Z13b);
M13a = mean2(Z13a);
S13a = std2(Z13a);

Z14a = ROI(W, 51, 100, 501, 600);
Z14b = ROI(W, 51, 100, 501, 600);
mask1 = Z14b >= 17300;
Z14b(~mask1) = 0;
N14 = nnz(Z14b);
M14a = mean2(Z14a);
S14a = std2(Z14a);

Z15a = ROI(W, 101, 150, 501, 600);
Z15b = ROI(W, 101, 150, 501, 600);
mask1 = Z15b >= 17700;
Z15b(~mask1) = 0;
N15 = nnz(Z15b);
M15a = mean2(Z15a);
S15a = std2(Z15a);

Z16a = ROI(W, 151, 200, 501, 600);
Z16b = ROI(W, 151, 200, 501, 600);
mask1 = Z16b >= 18000;
Z16b(~mask1) = 0;
N16 = nnz(Z16b);
M16a = mean2(Z16a);
S16a = std2(Z16a);

Z17a = ROI(W, 201, 250, 501, 600);
Z17b = ROI(W, 201, 250, 501, 600);
mask1 = Z17b >= 18700;
Z17b(~mask1) = 0;
N17 = nnz(Z17b);
M17a = mean2(Z17a);
S17a = std2(Z17a);

Z18a = ROI(W, 251, 290, 501, 600);
Z18b = ROI(W, 251, 290, 501, 600);
mask6 = Z18b >= 19300;
Z18b(~mask6) = 0;
N18 = nnz(Z18b);
M18a = mean2(Z18a);
S18a = std2(Z18a);

W2 = cat(1,Z1a,Z2a,Z3a,Z4a,Z5a,Z6a);
W3 = cat(1,Z1b,Z2b,Z3b,Z4b,Z5b,Z6b);

W4 = cat(1,Z7a,Z8a,Z9a,Z10a,Z11a,Z12a);
W5 = cat(1,Z7b,Z8b,Z9b,Z10b,Z11b,Z12b);

W6 =
cat(1,Z13a,Z14a,Z15a,Z16a,Z17a,Z18a);
W7 =
cat(1,Z13b,Z14b,Z15b,Z16b,Z17b,Z18b);

S1 = N1+N2+N3+N4+N5+N6;
S2 = N7+N8+N9+N10+N11+N12;
S3 = N13+N14+N15+N16+N17+N18;

Sum = S1 + S2 + S3;
Threshold = 25281;
```