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APPLICATION OF A STATISTICAL ANALYSIS TECHNIQUE FOR CHARACTERIZING THE DEFORMATION BEHAVIOR OF THE MATERIAL UNDER DYNAMIC IMPACT LOADING

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Abstract

We used a statistical technique for characterizing the deformation behavior of a material built by selective laser melting (SLM) under dynamic impact loading. An ASTM E23 standard Charpy impact tester was used to break the ASTM A370 standard Charpy specimens. The Charpy tested specimen experiences compression and tensile loading across the specimen surface. The surface morphology changes in the two loading conditions. A 3D digital microscopy captures the fractured surface image of the failed Charpy specimens. We used 300x magnification during surface raw data image development to capture most of the surface features, such as melt pool boundaries, and elongated deformation sites. The microscope develops a 3D surface morphology from depth-from-defocus (DFD) technique. We extract a big volume of surface raw data from the 3D surface morphology developed by the DFD method. We used the normal distribution method for statistically characterizing the deformation behavior of the material.

Introduction

Data mining and statistics cast great attention to the researchers. Recently, numerous amount of works have been published for a wide variety of applications. Both of the disciplines, data mining and statistics are necessary for evaluating the structure in data [1]. We developed large data sets from the fractured surface of a specimen. We used an optical method called depth-from-defocus (DFD) technique, for developing 3d profile data of the fractured surface of the specimen. The sample was produced by selective laser melting (SLM) process. We chose SLM technique for material manufacturing, because the manufacturing method is a new technique and widely used for producing engineering materials for various applications. In the SLM process, the material property changes with building parameters such as layer orientations, building angles, and laser scan speeds. In this work, we proposed a statistical technique for characterizing material deformation.

Sample preparation and testing

In this work, we used an aluminum alloy, $AlSi_{10}Mg$ sample that was produced by selective laser melting process. The built layer orientation was 0^o and the layer thickness was 30 µm. The average powder particle size was 20 µm. The specimen was built with ASTM A370 standard that is 10 mm × 10 mm × 55 mm. The specimen was tested with ASTM E23 standard Charpy impact tester. Figure.1 shows the Charpy V-notch tested specimen and the crack propagation initiates from V-notch end. The hammer of the Charpy impact tester struck on the opposite face to the V-notch by the pendulum and the specimen breaks. The specimen experiences two loading conditions: compression and tension. The V-notched end experiences tension while the opposite end suffers deformation due to the compressive loading of the pendulum strike. Therefore, the deformation of the specimen across the fracture surface has two different characteristics.

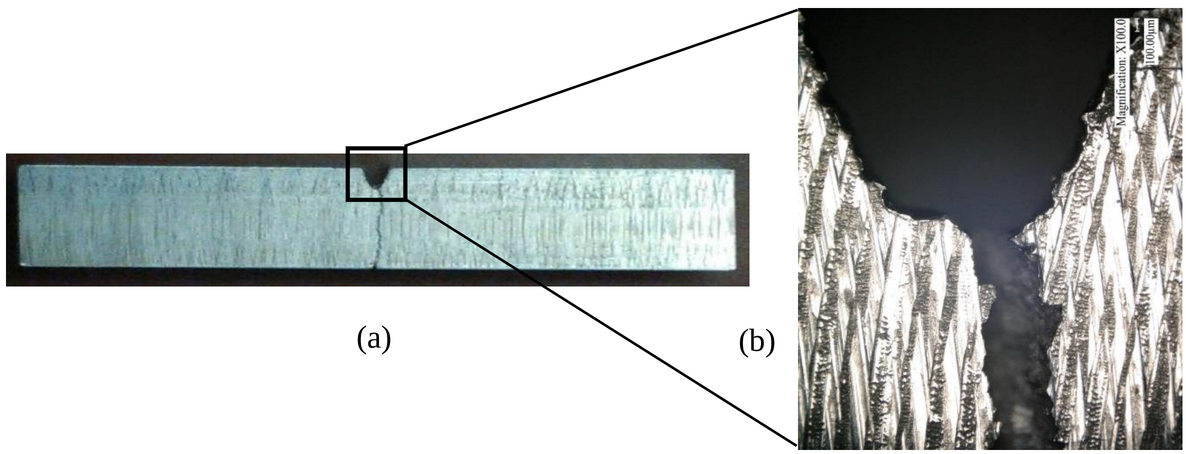

Figure 1. Charpy V-notch specimen: (a) tested specimen, and (b) optical micrograph of V-notch at 100x magnification

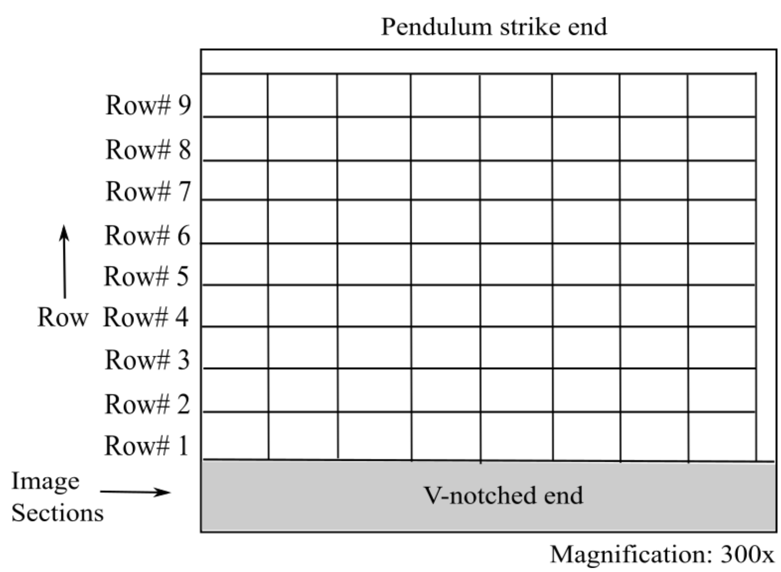

Figure 2. Data collection process of Charpy V-notch specimen. There were 9 rows and 8 image sections at 300x magnification.

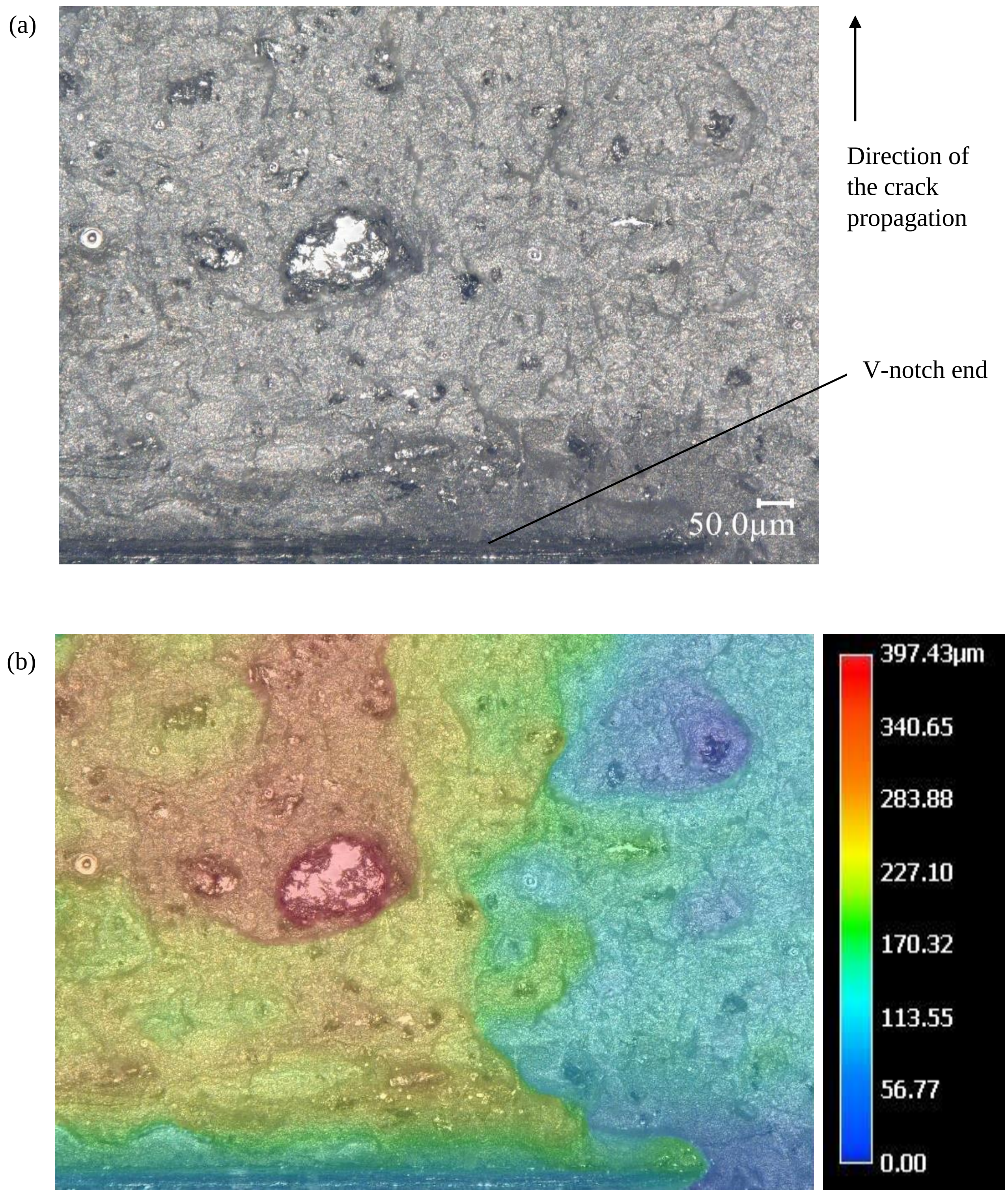

Figure 3. Fractured surface of the Charpy V-notch tested specimen: (a) 2d surface morphology, and (b) 3d surface texture with the height profile.

We applied 3d-digital microscopy for studying the fractured surface of the specimen. The image data measurement process was shown in Figure 2. We collected the raw data by using depth-from-defocus (DFD) technique. DFD is a passive autofocusing method that uses a relationship between the depths, camera parameters, and recovers the depth information by computing the degree of blur [2]. Figure. 3 (a), shows a 2d fractured surface image was developed by using the DFD method. The magnification of the image was 300x. Figure 3 (b) shows the corresponding height profile and the maximum height was 397.43 µm.

Data collection technique

We collected the image raw data with 300x magnification all over the surface by using the DFD technique. At 300x magnification, the pixel size was 0.638 µm, and the field of view was horizontally 1.02 mm and vertically 0.76 mm. The surface size of the Charpy specimen was about 8 mm × 10 mm, because 2 mm was off due to the notch. Therefore, it took around 72 raw images all over the surface. We ignored the edge part of the surface of the specimen, because

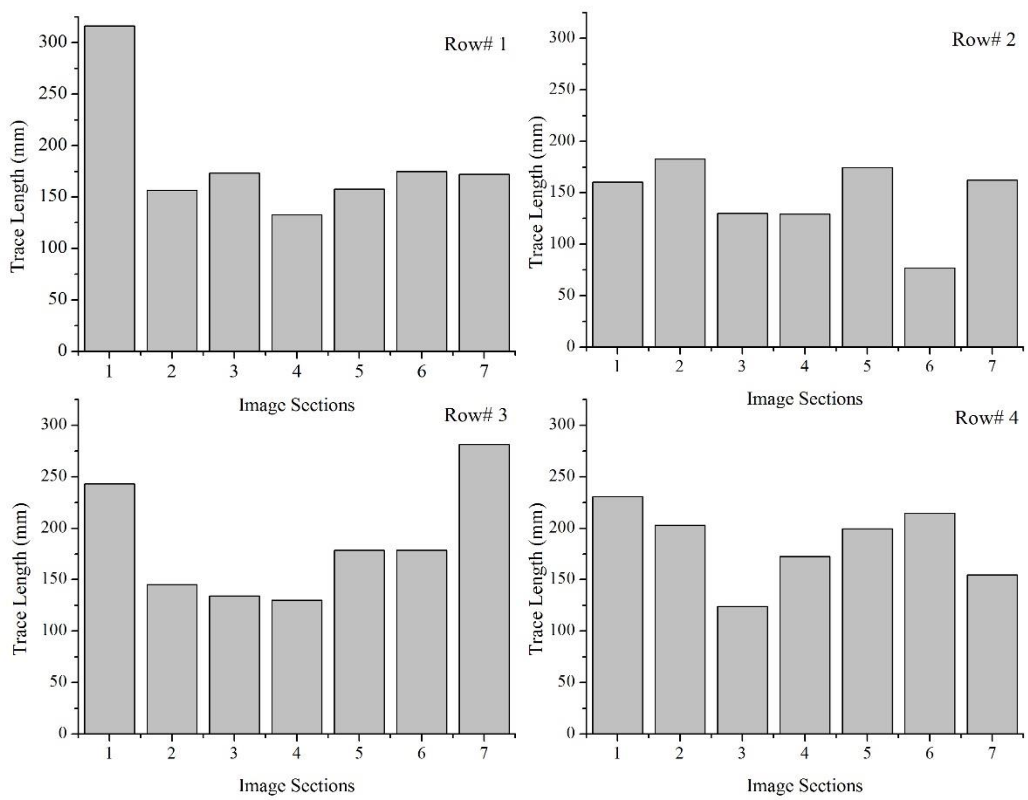

Figure 4. Tensile part of the Charpy V-notch specimen. The specimen experienced tension due to crack initiation point at V-notch. When compression occurred at the opposite end, the crack started to develop and propagated through the specimen.

that was deformed due to the ductile nature of the specimen. We collected images from the V-notch part to the opposite end of the specimens. It took around 9 rows and each row had 8 images. The images were manually taken. We tracked the movement of the camera by using a vertical and horizontal bar on the surface and the camera was moved by a joystick available on the console unit of the microscope.

We extracted the digitalized raw data of the images of the surface and found about 138.24 million data points were developed all over the surface.

Statistical analysis technique

We used a concept of a statistical technique for analyzing large data sets, called principal components analysis. It is a technique for extracting information from available data and finding the trends. In our case, we developed a matrix for each image data points and found the trace of the matrix of each image. We used MATLAB® (R2018a) for finding the values of the trace length for each matrix of an image. The trace length for each image showed general

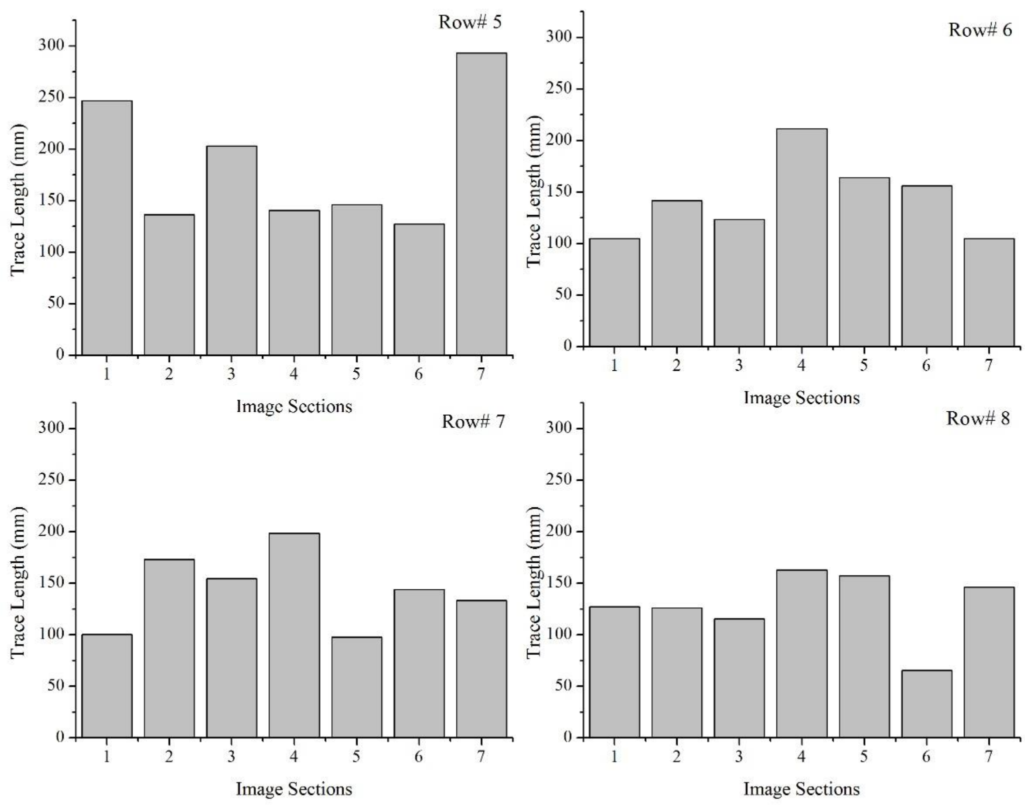

Figure 5. Compression part of the Charpy V-notch specimens

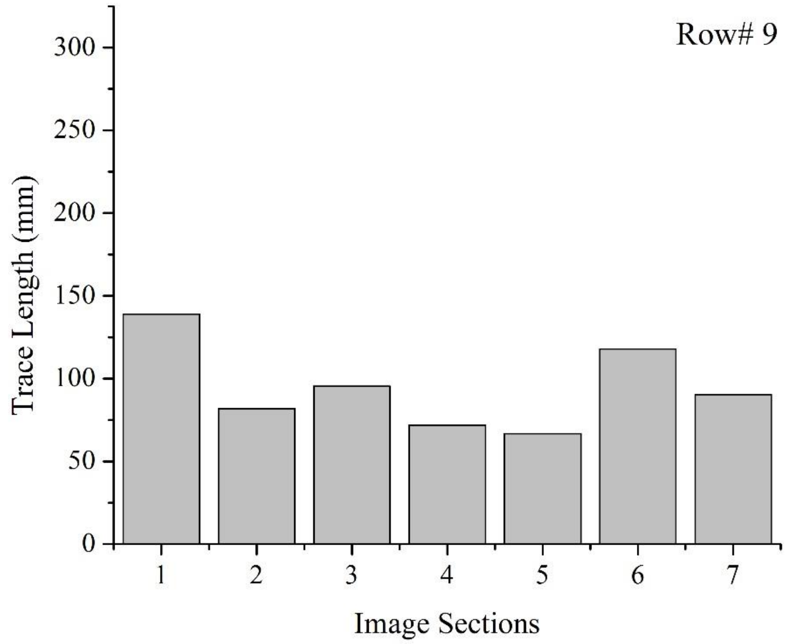

Figure 6. Row# 9 is the closest to the failure end. This part experienced most of the compression due to the pendulum strike.

characteristics of the material deformation, because the area at 300x magnification was small. We got eight image sections for each row. However, we ignored the first image section, because that was an image section of the edge of the specimen which was distorted due to the ductile property of the specimen. The deformation of the material was almost the same near the notched end which was row# 1 (Figure 4 (a).). For the remaining rows, the deformation of the material showed the possible routes of the crack propagation, because those were minimum energy path. Due to the compressive behavior, the trace lengths started to decrease that was shown in Figure 5. The trace length was very low close to the pendulum strike end that was shown in Figure 6. We developed a normal distribution curve for analyzing the trace length data for each row. For this purpose, we used MATLAB® (R2018a) and the data were presented in Table 1. The normal distribution data showed the underlying trend of the material deformation and a possible crack propagation pattern was determined (Figure 7.). In the crack propagation, there were two sections: a tensile part and a compressive part. In both sections, region I and II were marked in two boxes, respectively. Those regions might appear from the material inclusions and an area of further investigation. The failure region with the dashed line (Figure 7.) showed the part that we ignored for the closet to the edge of the sample.

Table 1. The probability density function (PDF) data of the distribution for the trace length data all over the surface

Number of Rows	Mean (mm)	Variance (mm^2)
Row# 1	183.329	3651.73
Row# 2	145.1	1318.32
Row# 3	184.447	3313.25
Row# 4	185.521	1377.38
Row# 5	184.834	4194.69
Row# 6	143.804	1427.86
Row# 7	143.066	1347.99
Row# 8	128.741	1075.11
Row# 9	94.651	662.96

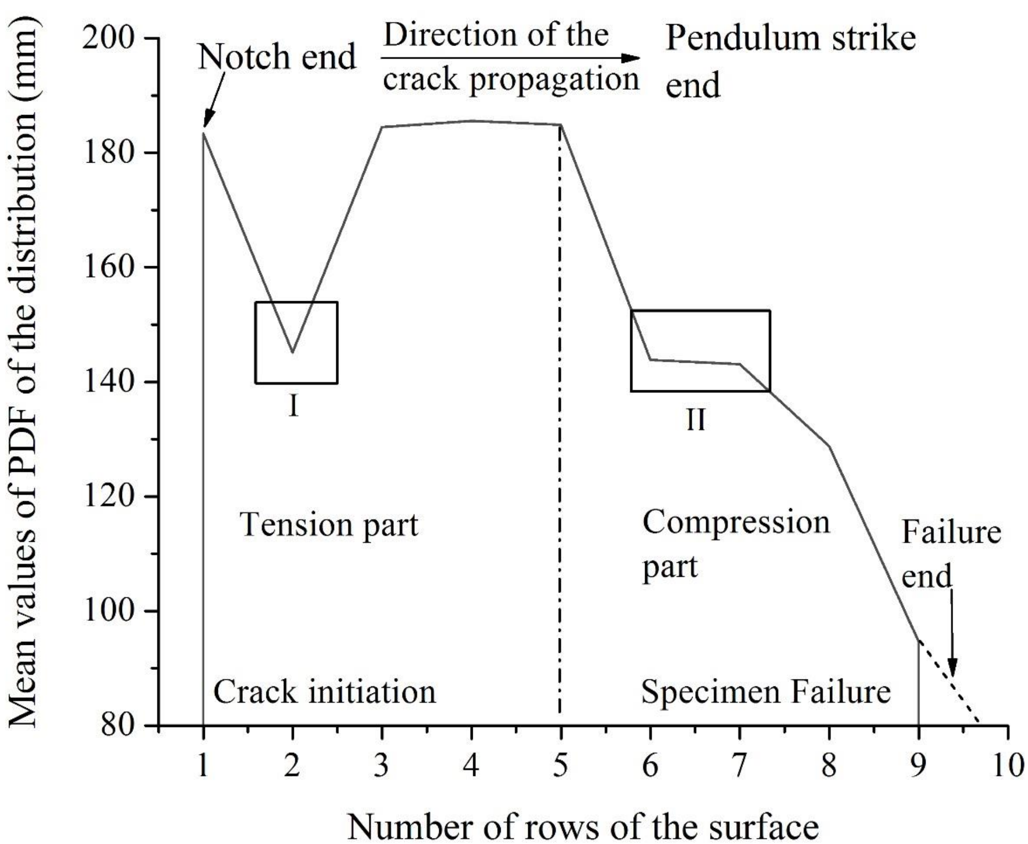

Figure 7. The direction of the crack propagation from the V-notch end to the opposite end of the specimen. The location of the crack propagation path can be approximated from Figure 4-6.

Conclusion

We applied a normal distribution technique for determining the material deformation behavior of SLM built specimen. The sample had a layer orientation of 0^o. For further analysis and characterization, research can be performed with different layer orientations and thickness. We selected the Charpy specimen for the statistical technique, because the Charpy impact testing is a standard laboratory testing method that applies to measure the fracture toughness of the materials and to characterize the brittle-ductile transition [3,4]. The Charpy testing method has been widely accepted and used since the 1940s [5]. We collected the data at 300x magnification with a 3d digital microscope. At higher magnification, the pixel size decreases that increases the data of the surface. In our data, the graphical development showed the minimum energy path of crack propagation. In total, the method provides an insight into the material deformation of the sample.

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