# Hardness Measurement using Image Analysis in Matlab

K.Suganeswaran
*Assistant Professor*
*Department of Mechatronics Engineering*
*Kongu Engineering College, Erode, Tamilnadu, India*

N.Nithyavathy
*Assistant Professor (Senior grade),*
*Department of Mechatronics Engineering*
*Kongu Engineering College, Erode, Tamilnadu, India*

Dr.R.Parameshwaran
*HOD & Associate Professor,*
*Department of Mechatronics Engineering*
*Kongu Engineering College, Erode, Tamilnadu, India*

G.Raja
*UG scholar,*
*Department of Mechatronics Engineering*
*Kongu Engineering College, Erode, Tamilnadu, India*

M.Arun Prakash
*UG scholar,*
*Department of Mechatronics Engineering*
*Kongu Engineering College, Erode, Tamilnadu, India*

**Abstract-** Today Brinell hardness tests are followed in the industry to measure the hardness of the material. Hardness is the property of a material that resists bending, scratching, cutting and plastic deformation. In this method, a specific force is applied on the surface of a component. Thus, it results in the formation of an indentation. The depth of the impression formed onsurface of the component depicts the hardness of the component. The value of depth measured is the value of hardness. In the present investigation, hardness of a material is measured from the diameter of the indent formed. The depth and the diameter of indentation are directly proportional to each other. In the present study, images of the component were taken for analysis. Image analysis using MATLAB software is employed to measure the diameter of the indentation from the obtained images. Thus, from the measured value of diameter, the appropriate hardness value of the component is calculated. By digitizing the process of hardness measurement a stable result is obtained irrespective of variation in time.

Keywords – Bending, Scratching, Plastic deformation, Brinell hardness test method, Indentation, Digitizing

## I. INTRODUCTION

Hardness is the property of a material that enables it to resist plastic deformations, usually by penetration. It may also refer to resistance to bending, scratching, abrasion or cutting. Hardness is not an intrinsic material property dictated by precise definitions in terms of fundamental units of mass, length and time. A hardness property value is the result of a defined measurement procedure. The usual method to achieve a hardness value is to measure the depth or area of an indentation left by an indenter of a specific shape, with a specific force applied for a specific time. The diameter of the circle formed by the indentation is proportional to the depth of the indentation. There are three principal standard test methods for expressing the relationship between hardness and the size of the impression, these being Brinell, Vickers, and Rockwell. For practical and calibration reasons, each of these methods is divided into a range of scales, defined by a combination of

applied load and indenter geometry. Among the methods of hardness measurement the one that is used in the industry is Brinell hardness testing method.

*Brinell Test Method*

All Brinell tests use a carbide ball indenter. The test procedure is as follows:

The machine used in the industry for performing the Brinell hardness Test is shown in the Figure 1i). The indenter is pressed into the sample by an accurately controlled test force as shown in the Figure 1ii). The force is maintained for a specific dwell time, normally 10 - 15 seconds. After the dwell time is complete, the indenter is removed leaving a round indent in the sample. The size of the indent is determined optically by measuring two diagonals of the round indent using either a portable microscope or one that is integrated with the load application device. The Brinell hardness number (BHN) is a function of the test force divided by the curved surface area of the indent. The indentation is considered to be spherical with a radius equal to half the diameter of the ball. The average of the two diagonals is used in the formula as shown in the Figure 2 i) to calculate the Brinell hardness number.
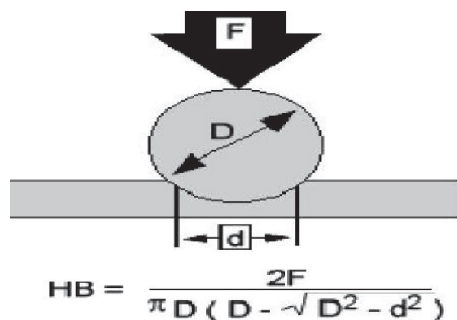
The Brinell number, which normally ranges from HB 50 to HB 750 for metals, will increase as the sample gets harder. Tables are available to make the calculation simple. A typical Brinell hardness is specified as 356 HBW. Where 356 is the calculated hardness and the W indicates that a carbide ball was used. Previous standards allowed a steel ball and had an S designation. Steel balls are no longer allowed. The depth of the impression on the component for the applied amount of load as shown in the Figure 2 ii) is proportional to the hardness of the component. Instead of measuring the depth, the diameter of the circle formed by indentation is measured manually, because the depth and the diameter of indentation are directly proportional to each other. The diameter of the indentation is measured manually by using microscope. From a look up table (comprises of hardness value of a component for a particular diameter of indentation) the hardness value of a component for a particular diameter is noted down manually.



i) Brinell hardness Testing Machine          ii) Indentation Formation
Figure 1 Photographic view of Brinell hardness Testing Machine and Indentation Formation



$$HB = \frac{2F}{\pi D ( D - \sqrt{D^2 - d^2} )}$$

i) BHN Equation Formation          ii) Model image of impression formed
Figure 2 BHN Equation Formation and Model image of impression

*Demerits of the Existing System*

The present method of hardness measurement invokes lot of manual operations for measuring the diameter of indentation and in finalizing the hardness value which requires a lot of consciousness from the workers side.

Practically it is too difficult for a human being to be more conscious throughout a couple of hours in such process of measurement using microscope.It is not certain that the manual process of measurement using microscope will yield a versatile output. For each worker the way of measuring i.e. their working style will be different, it leads to different outputs. Hence at the end of time the accuracy in measurement gets reduced to a large extend. In this manual measurement process we can't assure a versatile output [4]. And also for worker to worker the way of measurement i.e. their working style will be different, it leads to different outputs. The rest of the paper is organized as follows. Proposed methodology and process flow are explained in section II. Experimental results are presented in section III. Concluding remarks are given in section IV.

## II. Proposed methodology

### A. Proposed Methodology

Our project "Hardness Measurement Using Image Analysis in MATLAB" incorporates following set of operations which are depicted as flow diagram in the Figure 2(i).
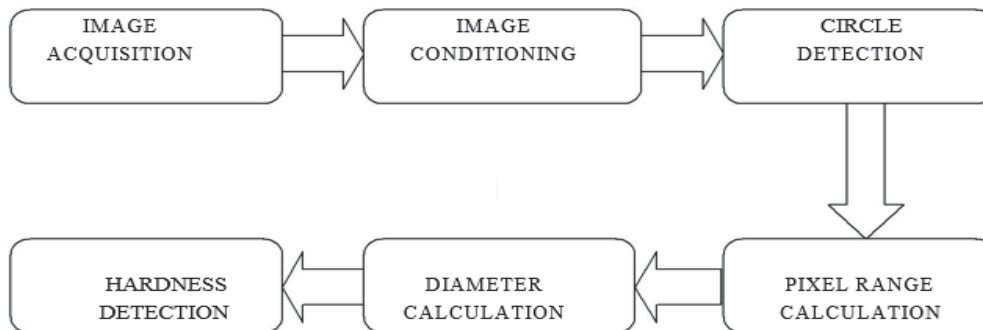


Figure 3 Flow Diagram of Proposed Methodology

### B. Various Processes Involved

#### Reading the Image

In this process of reading the component's surface where the spherical impression is formed is acquired as image using a camera with calculated specifications. The characteristics of the acquired image, plays a major role in the precision of the measurement. In the method of image processing, a large amount of data is obtained from the image. For acquiring such data, more number of operations is done over the image. These operations will yield efficient results only if the image supports such processes. Hence it is necessary to capture the images with higher quality. Then the acquired image as shown in the Figure 3 is fed into the MATLAB coding for the further processes.
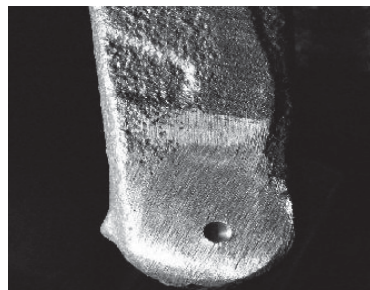


Figure 4 Acquired image of component

#### Image Conditioning

Acquired images can't be simply analyzed because the acquired image may not be in a condition to provide the necessary data for the functions used on it. Hence various processes are done over the acquired image to condition them in order to get the required data. Functions that are utilized in the step of conditioning the

image are

      i.     Structuring Element
     ii.     Gray Thresholding

*Structuring Element*

This function creates a flat, disk-shaped structuring element, as shown in Figure 4 where R specifies the radius. R must be a nonnegative integer. N must be 0, 4, 6, or 8. When N is greater than 0, the disk-shaped structuring element is approximated by a sequence of N periodic-line structuring elements. When N equals 0, no approximation is used, and the structuring element members consist of all pixels whose centers are no greater than R away from the origin. If N is not specified, the default value is 4. Morphological operations run much faster when the structuring element uses approximations (N > 0) than when it does not (N = 0). However, structuring elements that do not use approximations (N = 0) are not suitable for computing granulometries. Sometimes it is necessary for structuring element to use two extra line structuring elements in the approximation, in which case the number of decomposed structuring elements used is N + 2.
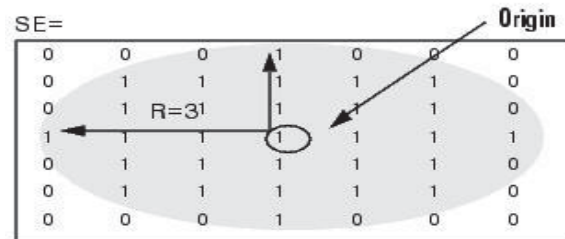


Figure 5 Structuring Element Concept (Source: mathworks.in)

*Gray thresholding*

This function computes a global threshold that can be used to convert an intensity image to a binary image. The level is a normalized intensity value that lies in the range 0-1. The gray thresh function uses Otsu's method which chooses the threshold to minimize the interclass variance of the black and white pixels. Multidimensional arrays are converted automatically to 2-D arrays using reshape. The gray thresh function ignores any nonzero imaginary parts. Level EM = gray thresh (I) returns the effectiveness metric as the second output argument. The effectiveness metric is a value in the range 0-1 that indicates the effectiveness of the thresholding of the input image. The lower bound is attainable only by images having a single gray level, and the upper bound is attainable only by two-valued images. In computer vision and image processing, Otsu's method is used to automatically perform clustering-based image thresholding or the reduction of a gray level image to a binary image. The algorithm assumes that the image to be threshold contains two classes of pixels or bi-modal histogram then calculates the optimum threshold separating those two classes so that their combined spread (intra-class variance) is minimal[7]. The extension of the original method to multi-level thresholding is referred to as the Multi Otsu method. Otsu's method is named after Nobuyuki Otsu.

*Identifying the Circle of Indentation*

Once the image is conditioned to an appropriate level various steps are performed over the image to detect the circle of indentation[3]. Various steps that are performed in the process of detecting the indentation circle are

- Canny Edge detection Method
- Image dilation Process
- Find Circles Function
- Object Polarity

*Canny Edge Detection Function*

BW = edge (I, 'canny') specifies the Canny method. BW = edge (I,'canny', thresh)specifies sensitivity thresholds for the Canny method. Thresh is a two-element vector in which the first element is the low threshold and the second element is the high threshold. If you specify a scalar for thresh, this scalar value is used for the high threshold and 0.4*thresh is used for the low threshold. If you do not specify thresh or if thresh is empty ([ ]) edge chooses low and high values automatically. The value for thresh is relative to the highest value of the gradient magnitude of the image. The canny algorithm runs in 5 separate steps:

- Smoothing: Blurring of the image to remove noise.

- Finding gradients: The edges should be marked where the gradients of the image has large magnitudes.
- Non-maximum suppression: Only local maxima should be marked as edges.
- Double thresholding: Potential edges are determined by thresholding.
- Edge tracking by hysteresis: Final edges are determined by suppressing all edges that are not connected to a very certain (strong) edge.

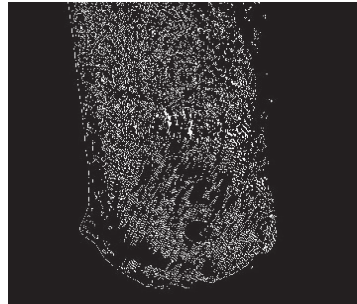The resultant image of the Edge Canny method is shown in the Figure 6:



Figure 6 Result obtained from Edge Cannny method

*Image dilation Process*

This function dilates the grayscale, binary or packed binary image IM returning the dilated image, IM2. The argument SE is a structuring element object, or array of structuring element objects, returned by the structuring element function. If IM is logical and the structuring element is flat, image dilate performs binary dilation. Otherwise it performs grayscale dilation[6]. If SE is an array of structuring element objects, image dilation performs multiple dilations of the input image, using each structuring element in SE in succession. The resultant image after performing dilation process is shown in the Figure 7.



Figure 7 Result of Dilation Process

*Find Circles Function*

It finds circles with radii in the range specified by radius range. The additional output argument, radii, contains the estimated radii corresponding to each circle center in centers.

*Object Polarity Function*

Object polarity indicates whether the circular objects are brighter or darker than the background, specified as the comma-separated pair consisting of 'Object Polarity' and either of the text strings in the following table 1.

**Table 1 Object Polarity Table**

| Colour | Appearance |
|---|---|
| 'bright' | The circular objects are brighter than background. |
| 'dark' | The circular objects are darker than background. |

For example 'ObjectPolarity','bright' specifies bright circular objects on a dark background.

*Calculation of Pixel Range*

From the detected circle the number of pixels that are occupied in the line of diameter of the circle is calculated by using Hough Transform.The Hough transform can be used to determine the parameters of a circle when a number of points that fall on the perimeter are known[5]. A circle with radius R and center (a, b) can be described with the parametric equations 1 & 2.

$$x = a + R \cos ( \ ) \qquad\qquad ( 1 )$$

$$y = b + R \sin ( \ ) \qquad\qquad ( 2 )$$

When the angle sweeps through the full 360 degree range the points (x, y) trace the perimeter of a circle. If an image contains many points, some of which fall on perimeters of circles, then the job of the search program is to find parameter triplets (a, b, R) to describe each circle. The fact that the parameter space is 3D makes a direct implementation of the Hough technique more expensive in computer memory and time.

Quantifying a circle in an image involves 3 parameters, namely, the center position (xc, yc) and the radius r. The main steps of the proposed Hough technique approach for the extraction of circles in ultrasound images were:

A region of interest was selected in each image .The output of the canny edge detection method produced binary images having 1's at the edge locations. The Hough technique algorithm was then applied to compute all the circles in the binary image. The algorithm used a three dimensional accumulator array P (xc, yc, r) where (xc, yc) corresponded to the coordinates of the center and r was the radius of the circle. For any candidate binary edge image pixel and    for any radius rmin<=r <=rmax, the coordinates (xc,yc) were calculated and the corresponding elements of the accumulator array were increased by one.

The limits of the radii were set after experimental testing and were based on the knowledge that the desired circles radii vary between these values during systole and diastole of the vessel. The elements of the accumulator matrix having a final value larger than a certain threshold denoted the circles that were present in the binary image. The result of the Hough technique is an image that contains a large number of candidate circles. However, the final step of the algorithm reaches the optimum based on the criterion of the difference in brightness between areas around circular features. Then the number of pixels that are occupied in the line of diameter of the circle of indentation is obtained as result. The set of pixel values for each diameter of the indentation are tabulated in table 2.

**Table 2 Pixel Range Table**

| DIAMETER OF THE CIRCLE | NUMBER OF PIXELS |
|---|---|
| 4.00 | 19.9 |
| 4.10 | 22.7 |
| 4.20 | 25.6 |
| 4.30 | 28.3 |
| 4.40 | 31.1 |
| 4.50 | 34.0 |
| 4.60 | 36.7 |
| 4.70 | 39.5 |
| 4.80 | 42.4 |
| 4.90 | 45.1 |
| 5.00 | 47.9 |

*Detection Of Diameter*

The diameter of the circle is obtained in terms of pixel range in the previous step. By manual calculations a set of formulae has been framed with the considerations of Height of the camera, Focal Length of the

camera, Boundaries of the component and Reference value[1]. Using the acquired pixel range in this formulae diameter of the circle is calculated in mm.

*Hardness Detection*

From the lookup table where the hardness value of the component for a specific diameter of the indentation is framed, the hardness value for the particular component is obtained for the diameter obtained in the previous step.Following Table 3 is the look up table which comprises of various possible diameters of indentation with their corresponding hardness values which are all calculated from the previously committed experiments.

**Table 3 Hardness Value Lookup Table**

| DIAMETER OF INDENTATION (in mm) | HARDNESS VALUE (in BHN) |
|---|---|
| 3.50 | 302 |
| 3.55 | 293 |
| 3.60 | 285 |
| 3.65 | 277 |
| 3.70 | 269 |
| 3.75 | 262 |
| 3.80 | 255 |
| 3.85 | 248 |
| 3.90 | 241 |
| 3.95 | 235 |
| 4.00 | 229 |
| 4.05 | 223 |
| 4.10 | 217 |
| 4.15 | 212 |
| 4.20 | 207 |
| 4.25 | 201 |
| 4.30 | 197 |
| 4.35 | 192 |
| 4.40 | 187 |
| 4.45 | 183 |
| 4.50 | 178 |
| 4.55 | 174 |
| 4.60 | 170 |
| 4.65 | 167 |
| 4.70 | 163 |
| 4.75 | 159 |
| 4.80 | 155 |
| 4.85 | 152 |
| 4.90 | 148 |
| 4.95 | 146 |
| 5.00 | 143 |

### III.RESULT AND DISCUSSION

After performing the above mentioned series of operations over the acquired image it will be in a condition to provide necessary data for the operations going to be performed on it for extracting the data. It is found that the hardness value decreases with the increase in diameter of the indentation MATLAB result for the circle detection coding [2] is shown below in the Figure 8 to Figure 12
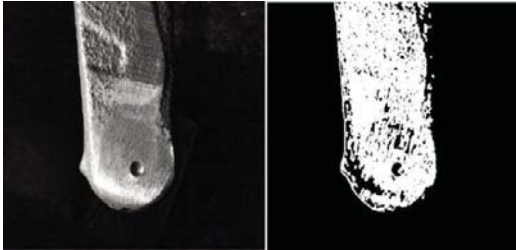


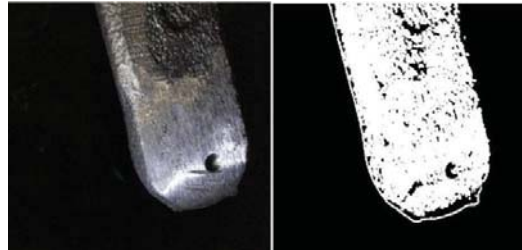Figure 8 Circle of 4.70mm Diameter



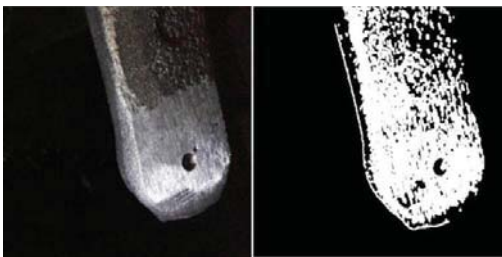Figure 9 Circle of 4.40mm Diameter
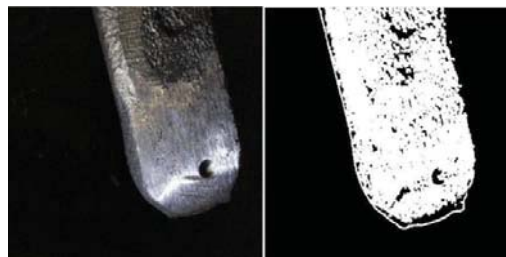


Figure 10 Circle of 4.60mm Diameter
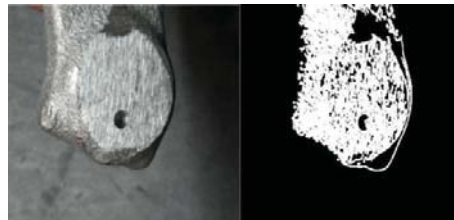


Figure 11 Circle of 4.50mm Diameter



Figure 12 Circle of 4.30mm Diameter

From the result of circle detection coding, in which the circle of indentation is located, the number of pixels that are occupied in the line of diameter of the circle is calculated by using Hough Transform and is shown in the table 4.

Table 4 Pixel Range Result

| DIAMETER OF THE CIRCLE | NUMBER OF PIXELS |
| --- | --- |
| 4.10 | 22.7 |
| 4.20 | 25.6 |
| 4.30 | 28.3 |
| 4.40 | 31.1 |
| 4.50 | 34.0 |
| 4.60 | 36.7 |
| 4.70 | 39.5 |
| 4.80 | 42.4 |
| 4.90 | 45.1 |
| 5.00 | 47.9 |

## V .SUPPLEMNTARY

*Circle Detection Coding*

```
tic;
tstart=tic;
I1=imread('D:\g.jpg');
I=rgb2gray(I1);
se=strel('disk',5);
grey=graythresh(I);
A=edge(I,'canny',grey-0.1);
A1=imdilate(A,se);
A2=imcomplement(A1);
imshow(A2)
[c,r]=imfindcircles(A1,[20 40],'ObjectPolarity','dark'); r=r/8;
telapsed=toc(tstart);
fprintf('total time %f\n \n Radius = %f  pixels\n',telapsed, r);
```

*Alternate Coding For Circle Detection*
```
I=imread('d:\a.jpg');
background=imopen(I,strel('disk',15));
diff=I-background;
I1=rgb2gray(diff);
I1=imadjust(I1);
level=graythresh(I1);
bw=im2bw(I1,level);
bw1=bwareaopen(bw,1); sre=strel('disk',3); bw1=imclose(bw1,sre); bw1=imfill(bw1,'holes');
[bw2,n]=bwlabel(bw1,8); [ma, tc]=bwlabel(bw2,4); ma=im2double(ma); data=regionprops(ma,'all');
un=unique(ma); numel(un); maxi=0;
for
i=2:numel(un)roundness=((4*pi*data(un(i)).Area)/(data(un(i)).Perimeter.
^2)) if roundness>0.85
roundness
end
maxi=max(maxi,roundness)
ele=un(i)
end
radius=(data(ele).EquivDiameter)/2
```

## V.CONCLUSION

Thus this process provides specific solution for the measurement of the diameter of the indentation produced, while measuring hardness using Brinell hardness measurement method. In addition, this process eliminates the human labor that is being utilized in measuring the diameter of indentation during hardness measurement. It also provides the value of hardness straight away, instead of just providing the diameter of the indentation. It also reduces the lead time that is required to manually measure the diameter of the indentation. This process utilizes only half the time that is required to measure the diameter of the indentation manually. Finally, while using a different camera or different lighting, the threshold values for dilation and edge detection should be adjusted in accordance with the new acquired image. Once the necessary threshold values are loaded to the program, theprocess of measurement of hardness is carried out without any human interference.

## VI.ACKNOWLEDGEMENT

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