DEVELOPING CORRELATIONS AMONG THE DIFFERENT HARDNESS NUMBERS FOR ALUMINIUM

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Abstract— We use the concept of hardness almost every day. Hardness is used to measure a variety of resistances including scratching cutting and indenting.A procedure is described for performing different hardness tests based upon indentation on various metals and its alloys. Different hardness numbers are available for different materials and under application of different loads as per ASTM standards. In the present day situations, there may be some cases where performing all the hardness tests may not be possible. In that type of situations, the correlations among different hardness numbers will be of great use. Using these correlations we can calculate any hardness number knowing the other one.

To develop the correlations, Data analysis was accomplished using experimental data and the graphs were plotted and various trends were noted. Origin lab Pro V8.0 software was used to generate plots and to show the correlation between different hardness numbers. Out of all trends plotted by Origin Lab, the trend which has the root mean square value nearer to 1 is taken as best fit.

Index Terms— Brinell Hardness number, Hardness, Hardness numbers, Relation among hardness numbers, Rockwell Hardness number Vickers Hardness number.

1 INTRODUCTION:

Hardness is one of the most basic mechanical properties of engineering materials. Hardness test is practical and provide a quick assessment and the result can be used as a good indicator for material selections. This for example, the selection of materials suitable for metal forming dies and cutting tools. Hardness test is also employed for quality assurance in parts which require high wear resistance such as gears.

The nomenclature of hardness comes in various terms depending on the techniques used for hardness testing and also depends on the hardness level of various types of materials. Among all the hardness tests, indentations tests are most commonly used in engineering applications. Therefore, indentation hardness measurement is conveniently used for metallic materials. A deeper or wider indentation indicates a less resistance to plastic deformation of the material being tested, resulting in a lower hardness value.

The indentation techniques involve Brinell, Rockwell, Vickers and Knoop. Different types of indenters are applied for each type. The standard test methods according to American Society Testing Materials (ASTM) are available are, for instance, ASTM E10-07 (Standard test method for Brinell hardness of metallic materials), ASTM E18-08 (Standard test method for Rockwell hardness of metallic materials) and ASTM E92-41 (Standard test method for Vickers hardness of metallic materials). These hardness testing techniques are selected in relation to specimen dimensions, type of material and the required hardness information.

2. Proposed Work:

To develop the correlations among the different hardness numbers.

2.1 HARDNESS:

Hardness is the measure of a material's resistance to localized plastic deformation i.e., the degree of resistance offered by a material to indentation or scratching, abrasion and wear.

2.2 SIGNIFICANCE OF HARDNESS:

The selection of a material plays an important role in designing any machinery or automobiles. In order to withstand the load without attaining any wear and tear, the hardness of the material should be high.

2.3 TYPES OF HARDNESS TESTS:

This includes maily three type's tests to determine Hardness. 1. Scratch Tests, 2. Dynamic Hardness test 3. Static indentation test

2.4 INDENTATION PRINCIPLE

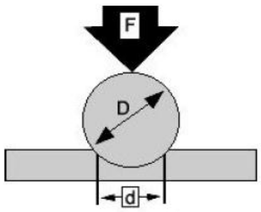
When indenter is pressed into surface under a static load, a large amount of plastic deformation takes place. The material thus deformed flows out in all directions. Lesser the indentation greater is the hardness number and vice versa.

2.5 TYPES OF HARDNESS TESTS BASED ON INDENTATON:

1.Briness Hardness Number
2.RockWell Hardness Number
3.Vickers Hardness Number.

3. BRINELL HARDNESS TEST

In Brinell hardness test, a spherical ball (steel or carbide) indenter with a diameter D is forced into the material with a force (F) within the range of 500-3000kgf.Brinellhardness number is represented by HB which is calculated from the equationwhere'd' is the indentation diameter.



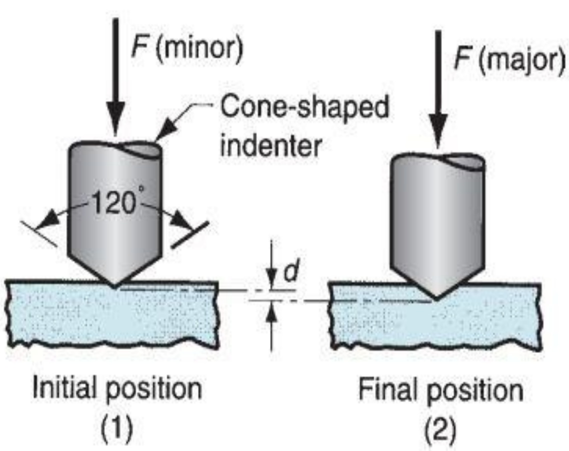
$$HB = \frac{2F}{\pi D\left(D - \sqrt{D^2 - d^2}\right)}$$

75 HB 10/500/30 INDICATES A BRINELL HARDNESS OF 75 MEASURED WITH A BALL OF 10 MM DIAMETER AND A LOAD OF 500 KG APPLIED FOR 30S.

4. ROCKWELL HARDNESS TEST

The Rockwell hardness test method consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load of 10 kgf. After attaining the equilibrium position major load is applied which increases the depth of penetration? After attaining the equilibrium the major load is removed to obtain the permanent penetration. In this test, the hardness number is calculated based on the depth of indentation. There are different Rockwell scales Rockwell A-V.

40 HRC indicates Rockwell hardness number of 40 and 'C' represents the scale.



4.1 Test Procedure for Rockwell Hardness Test

1. The indenter moves down into position on the part surface
2. A minor load is applied and a zero reference position is established
3. The major load is applied for a specified time period (dwell time) beyond zero
4. The major load is released leaving the minor load applied

The resulting Rockwell number represents the difference in depth from the zero reference position as a result of the appli-

Rockwell Hardness Test Scales		
Scale Symbol	**Penetrator**	**Load kg**
A	Brale	60
B	1/16-in. Ball	100
C	Brale	150
D	Brale	100
E	1/8-in. Ball	100
F	1/16-in. Ball	60
G	1/16-in. Ball	150
H	1/8-in. Ball	60
K	1/8-in. Ball	150
L	1/4-in. Ball	60
M	1/4-in. Ball	100
P	1/4-in. Ball	150
R	1/2-in. Ball	60
S	1/2-in. Ball	100
V	1/2-in. Ball	150
Superficial Tester Scales		
15N, 30N, 45N	N Brale	15, 30, 45
15T, 30T, 45T	1/16-in. Ball	15, 30, 45
15W, 30W, 45W	1/8-in. Ball	15, 30, 45
15X, 30X, 45X	1/4-in. Ball	15, 30, 45
15Y, 30Y, 45Y	1/2-in. Ball	15, 30, 45

cation of the major load

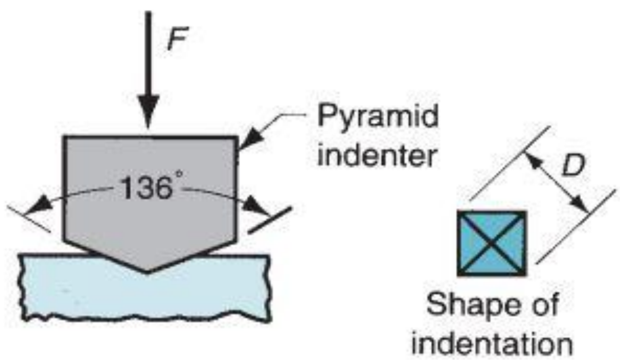
5 VICKERS HARDNESS TEST

This test is similar to Brinell hardness test, where it replaces ball indenter with pyramid type diamond indenter. It is based on the principle that impressions made by this indenter are geometrically similar regardless of load (F).The Vickers hardness number (HV) can be determined by the formula.

$HV=1.854F/D^2$

Where D= Diagonal of the impression made by the indenter.

800 HV/10 indicates Vickers hardness of 800 and 10 indicates load applied in kgf.

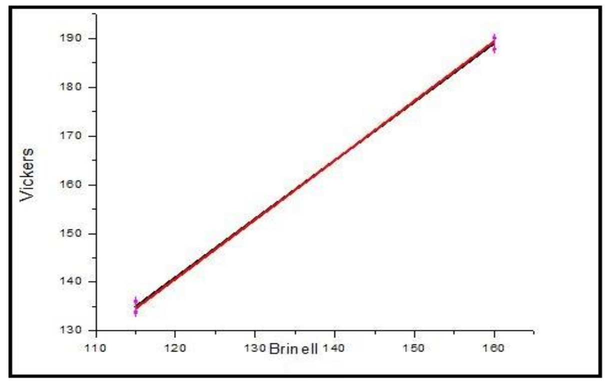


6. DIFFERENT HARDNESS NUMBERS ALUMINIUM MATERIALS

Brinell Vs. Vickers

BRINELL HARDNESS NUMBER	VICKERS HARDNESS NUMBER
160	189
155	183
150	177
145	171
140	165
135	159
130	153
125	147
120	141
115	135

PLOT BETWEEN BRINELL HARDNESS NUMBERS AND

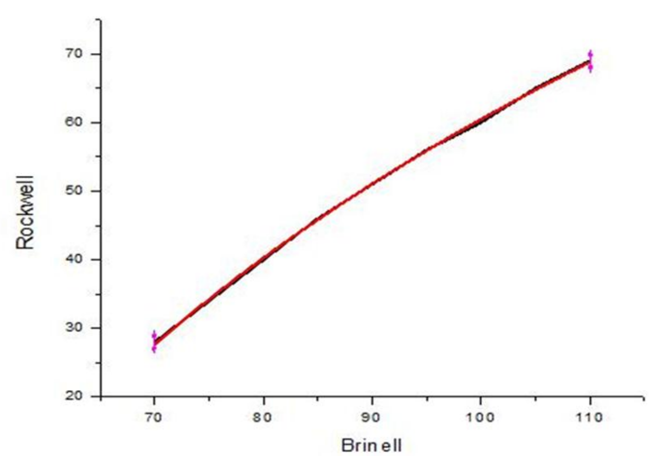


VICKERS HARDNESS NUMBERS

Brinell Vs. Rockwell(B)

BRINELL HARDNESS	ROCKWELL HARDNESS(B)
70	28
75	34
80	40
85	46
90	51
95	56
100	60
105	65
110	69

PLOT BETWEEN BRINELL HARDNESS NUMBERS AND ROCKWELL HARDNESS NUMBERS



EQUATIONS USING ORIGIN SOFTWARE

BRINELL Vs. VICKERS for ALUMINIUM		
Series	**Equation**	**RMS (R^2)**
Exponential	$Y=57.768e^{0.0075X}$	0.9978
Logarithmic	Y=802.77746ln(0.24885 ln(X))	0.9965
Polynomial	Y=-3+1.2X	0.9997
Power	$Y=X^{1.03323}$	0.9998

BRINELL AND VICKERS HARDNESS VALUES CORRESPONDING TO DIFFERENT FITS

S.No	BRINELL	VICKERS	EXPONENTIAL	LOGARITHMIC	POLYNOMIAL	POWER
1	105	**123**	126.96	117.85	124	**122.56**
2	100	**117**	122.29	109.39	118	**116.53**
3	95	**111**	117.78	100.40	112	**110.52**
4	90	**105**	113.45	90.81	105	**104.51**
5	85	**98**	109.28	80.55	99	**98.52**
6	80	**92**	105.26	69.52	93	**92.54**
7	75	**86**	101.36	57.61	87	**86.57**

FITTING DIFFERENT FITS INTO THE EQUATION USING ORIGIN LAB

BRINELL Vs. ROCKWELL for WROUGHT ALUMINIUM PRODUCTS		
Series	**Equation**	**RMS (R^2)**
Exponential	$Y=133.320-249.886e^{-0.0123X}$	0.99862
Logarithmic	Y=407.10017ln(0.25192ln(X))	0.99958
Polynomial	Y=-42.21111+1.023333X	0.99416
Power	$Y=X^{0.87385}$	0.72448

S.No	BRINELL	ROCKWELL	EXPONENTIAL	LOGARITHMIC	POLYNOMIAL	POWER
1	150	**89**	94.01	**94.82**	111.28	79.72
2	145	**87**	91.50	**92.05**	106.17	77.39
3	140	**86**	88.85	**89.17**	101.05	75.05
4	135	**84**	86.02	**86.16**	95.93	72.70
5	130	**81**	83.01	**83.02**	90.82	70.35
6	125	**79**	79.81	**79.73**	85.70	67.98
7	120	**76**	76.41	**76.27**	80.58	65.59

BRINELL AND ROCKWELL HARDNESS VALUES CORRESPONDING TO DIFFERENT FITS

EXPERIMENTAL RESULTS FOR ALUMINIUM
BRINELL TEST

Load: 500kgf Indenter diameter: 10mm Duration: 30sec

S.NO	INDENTED DIAMETER		
	d_1	d_2	d_{avg}
1	2.5	2.5	2.5
2	2.6	2.6	2.6
3	2.4	2.4	2.4
4	2.5	2.5	2.5
5	2.6	2.6	2.6

CALCULATIONS:

$$BHN = 2P/(3.14D[D-(D^2-d^2)^{1/2}])$$

BHN = 97.637

ROCKWELL TEST

Minor load: 60kgf
Major load: 100kgf
Indenter: 1/16
inch ball diameter

S.NO	ROCKWELL HARDNESS NUMBER
1	59
2	55
3	56
4	57
5	57
6	57
7	56
8	54
9	58
10	55

Average Rockwell Hardness Number=56.4

CORRELATING EXPERIMENTAL RESULTS WITH THEORETICAL DATA:

Experimentally calculating the Brinell hardness number we got BHN=97.6

Experimentally Rockwell Hardness Number=56.4

Using logarithmic series to convert from BHN to Rockwell Hardness Number

$$Y = 407.10017 \ln(0.25192 \ln(X))$$

Where X is the Brinell hardness number and Y is the Rockwell Hardness Number

Substituting the above BHN into the equation

$$Y = 407.10017 \ln(0.25192 \ln(97.6))$$

Y= 58.34

Rockwell Hardness Number = 58.34

$$\therefore \text{Error } \% = \frac{56.4 - 58.349}{56.4}$$

$$= -3.45\%$$

VICKERS TEST

S.NO	DIAGONAL OF THE IMPRESSION		
	d_1	d_2	d_{avg}
1	0.4	0.5	0.4
2	0.5	0.6	0.55
3	0.6	0.4	0.5
4	0.5	0.4	0.45
5	0.6	0.5	0.55

Average value of the diagonal is 0.49

Vickers Hardness Number = $1.854\ P/D^2$

= 115.82

CORRELATING THE EXPERIMENTAL RESULTS WITH THEORETICAL DATA

Experimentally calculating the Brinell hardness number we got BHN=97.6

Experimentally Vickers Hardness Number=115.82

Using power series to convert from BHN to Vickers Hardness Number

$$Y = X^{0.87385}$$

Where X is the Brinell hardness number and Y is the Vickers Hardness Number

Substituting the above BHN into the equation we get

$$Y = (97.6)^{1.03323}$$

= 113.6

$$\therefore \text{Error } \% = \frac{115.82 - 113.6}{115.82} = 1.9\%$$

From the above observations we can say that the following equations give the correlation among hardness numbers of aluminum alloys.

$$Y = X^{1.03323}$$

Where Y=Vickers Hardness Number,
X= Brinell hardness number,
And

$$Z = 407.10017 \ln(0.25192 \ln(X))$$

Where
Z=Rockwell Hardness Number
X=BrinellHardness Number

These are valid only under the following constraints

CONCLUSIONS:

By comparing all the series for Brinellvs Vickers, Power series is giving nearest values for aluminium. These relations can be related by $\mathbf{Y=X^{1.03323}}$

When Y is Vickers Hardness number and X is Brinell hardness number

By comparing all the series for Brinellvs Rockwell, Logarithmic series is giving nearest values for aluminium.These relations can be related by equations $\mathbf{Y=407.10017\ln(0.25192\ln(X))}$

Where Y is Rockwell Hardness Number and X is Brinell Hardness number.

Constraints	Brinell Hardness Number	Rockwell Hardness Number	Vickers Hardness Number
Load applied	500kgf	60-100kgf	15kgf
Indentation specification	10mm diameter ball	1/16 inch ball diameter	Pyramid indenter

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