California State University, Long Beach

Department of Mechanical and Aerospace Engineering

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Lab Report

By

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Experiment Number: 1

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Title: Metallographic Observation and Analysis and Hardness Testing

Course Number: MAE 361

Section Number: 3

Class Number: 5859

Instructor: Dr. Shamim Mirza

Objective:

To determine the suitability of a material meaning its hardness distribution in grains, shape and size measuring a steel like material under the United Hardness Tester apparatus. In this experiment carbon steel AISI/SAE 1018 is used to determine the hardness using the “hardness testing electric system”.

Apparatus:

Equipment	Brand	Model	Image
5-Station Hand Grinder	Pace Technologies	Penta 5000	
Tru-Blue Hardness Testing System - “A” Scale (Diamond Indenter)	United	Tru-Blue II	

Table 1. Apparatuses Used

Samples:

Sample (Material)	Image
Carbon Steel AISI/SAE 1018	

Table 2. Sample Material

Procedure:

We have given carbon steel AISI/SAE 1018 for the material being measured in the experiment. Prior to the hardness testing we must have a smooth surface. There were two different sanding methods of achieving this; however our lab group utilized the Pace Technologies hand grinder. We started with a lower grit number which means a harder surface which removes more material to save time. The starting point was 360 grit sandpaper and then moved up to 600 then 800 then finally 1200. We ensured to keep the direction of the sanding consistent over each stroke and between different grits. We only polished one side of the sample to get the data points in this lab which was different from the lab manual.

After establishing a smooth surface, the Tru-Blue Hardness Testing System is set up to the “A” scale with a diamond indenter. This scale applies a load of 60kg to the specimen. The steel specimen is placed below the indenter with the approximate space of a hair. The button to apply the load is pressed, with the testing system automatically applying the load and presenting data on its screen. We insured to include three separate load tests of the carbon steel in different locations to minimize error.

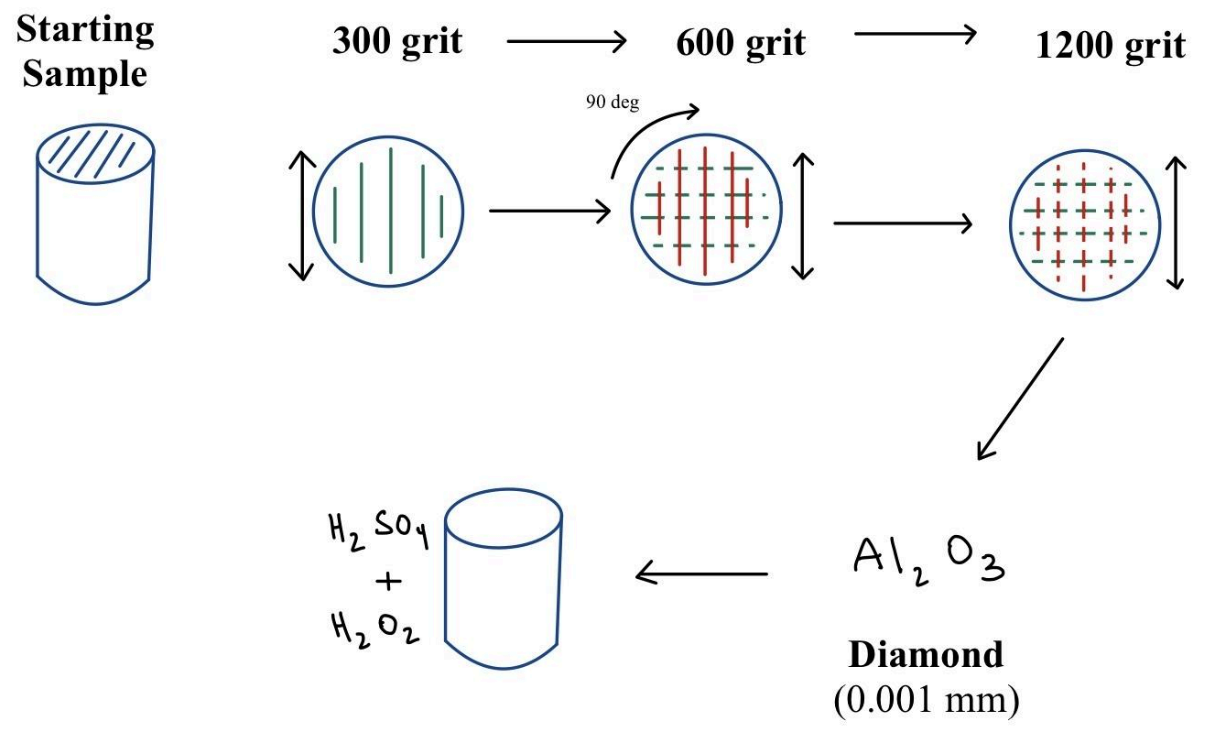

Figure 1. Procedure Visualization

Test Results:

Hardness Scale Equipped:

Scale Symbol	Indenter	Major Load (Kg)
A	Diamond	60

Table 3. Hardness Scale Specifications

Hardness Testing Loads on Specimens:

Trail Number	Hardness (N/mm^2)	Average Hardness for each specimen (Kg) & % Error
1*	57.33	
2*	56.82	Specimen 1:Trail 1-3: **57.25*** % Error: **28.65%**
3*	57.59	
4	55.53	
5	58.17	Specimen 2:Trail 4-7: **57.25** % Error: **28.65%**
6	58.05	
7	51.89	
8	57.91	Specimen 3: Trail 7-9: **55.88** % Error: **25.57%**
9	57.85	
10	54.20	
11	57.70	Specimen 4:Trail 10-12: **56.59** % Error: **27.17%**
12	57.86	

Table 4. Class Data for Hardness Testing Loads on Specimens

*Test results acquired by this group

Calculations:

Trial No.	Hardness (N/mm^2)	$(x-\overline{X})$	$(x-\overline{X})^2$
1*	57.33	0.59	0.3481
2*	56.82	0.08	0.0064
3*	57.59	0.85	0.7225
4	55.53	-1.21	1.4641
5	58.17	1.43	2.0449
6	58.05	1.31	1.7161
7	51.89	-4.85	23.5225
8	57.91	1.17	1.3689
9	57.85	1.11	1.2321
10	54.20	-2.54	6.4516
11	57.70	0.96	0.9216
12	57.86	1.12	1.2544
Σ	680.9	17.22 ($\sum_{i=1}^{12} \lvert x - \overline{X} \rvert$)	41.0532

Table 5. Data for Calculations for Standard Deviation/Mean/Average Deviation

Grain Size

A) **Intercept**

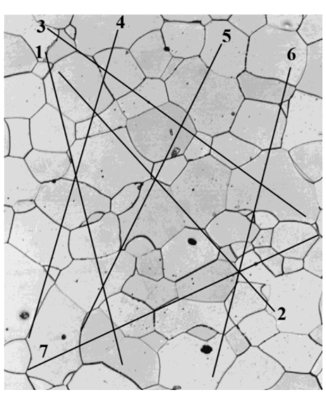

Figure 2.

Number of lines	Number of grains
1	11
2	10
3	9
4	8.5
5	7
6	10
7	8
(7x60mm)=420mm	Sum=63.5

Table 6. Line and Grain Numbers

Grain Size: $\frac{420\ mm}{63.5}$= 6.614mm

Actual Grain Size: $\frac{420\ mm}{63.5 \times 100} = .06614$ mm = d

B) ASTM

(b) Estimate the ASTM grain size number for this material (Figure is100X).

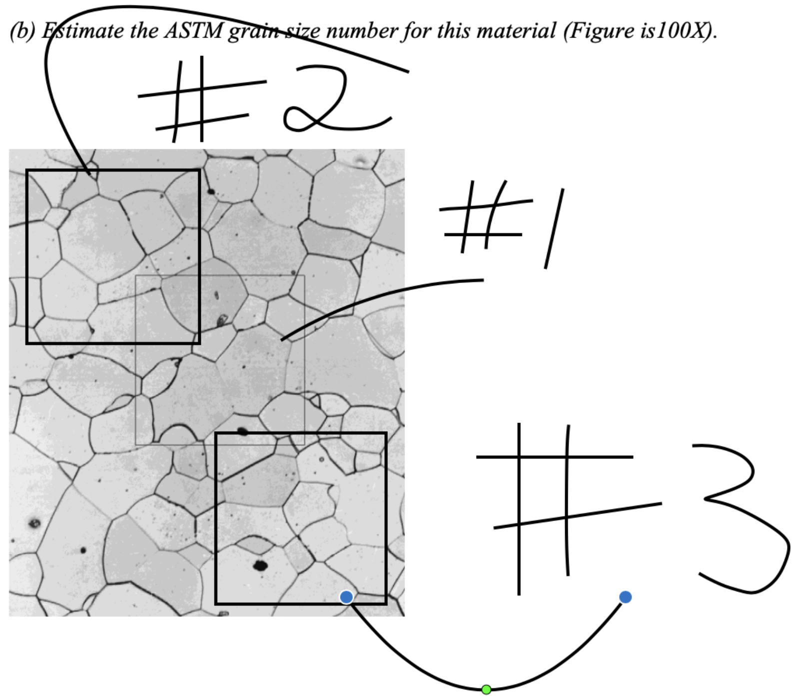

Figure 3.

Box #1:

Number of Grains(N)= $1+1+1+1+1+\frac{3}{4}+\frac{3}{4}+\frac{3}{4}+\frac{1}{2}+\frac{1}{2}+\frac{1}{4}+\frac{1}{4}+\frac{1}{4}+\frac{1}{4}+\frac{1}{8}+\frac{1}{8}+\frac{1}{8}+\frac{1}{8}$= 9.75 grains

(n=Grain size numbers)

$N=2^{n-1} \Rightarrow log\ N = (n-1) * log\ 2 \Rightarrow n-1=\frac{log\ N}{log\ 2} \Rightarrow n = (\frac{log\ N}{log\ 2}) + 1$

$n= \frac{log(9.5)}{log(2)} +1 = 4.2479$

Actual Grain Size: $\frac{0.254}{\sqrt{2^{n-1}}} = \frac{0.254}{\sqrt{2^{4.2479-1}}} = 0.082408$ mm

Box #2:

Number of Grains(N)= $1+1+1+1+1+1+\frac{3}{4}+\frac{3}{4}+\frac{3}{4}+\frac{3}{4}+\frac{3}{4}+\frac{1}{2}+\frac{1}{2}+\frac{1}{2}+\frac{1}{2}+\frac{1}{2}+\frac{1}{4}+\frac{1}{8}+\frac{1}{8}$= 11.75 grains

(n=Grain size numbers)

$N=2^{n-1} \Rightarrow log\ N = (n-1) * log\ 2 \Rightarrow n-1=\frac{log\ N}{log\ 2} \Rightarrow n = (\frac{log\ N}{log\ 2}) + 1$

n= $\frac{log(11.75)}{log(2)}$ +1 = 4.5546

Actual Grain Size: $\frac{0.254}{\sqrt{2^{n-1}}} = \frac{0.254}{\sqrt{2^{4.2479-1}}}$ = 0.074099 mm

Box #3:

Number of Grains(N)= 9(1)+7(¾)+¼+4(⅛)= 15 grains

(n=Grain size numbers)

N=$2^{n-1} \Rightarrow log\ N\ =\ (n\ -\ 1)\ \ *\ log\ 2 \Rightarrow$ n-1=$\frac{log\ N}{log\ 2} \Rightarrow n\ =\ (\frac{log\ N}{log\ 2})\ +\ 1$

n= $\frac{log(15)}{log(2)}$ +1 = 4.9069

Actual Grain Size: $\frac{0.254}{\sqrt{2^{n-1}}} = \frac{0.254}{\sqrt{2^{4.2479-1}}}$ = 0.0655825 mm

Average Actual Grain Size:

Average Actual G.S= $\frac{n_1+n_2+n_3}{3} = \frac{0.082408+0.074099+0.0655825}{3}$ = **0.074029 mm**

C) Hall Petch

$\sigma_y = \sigma_0\ +\ K_y \cdot d^{-1/2}$

σ_0 = 70 MPa

K_y = 0.74 M*Pa*$m^{1/2}$

$\sigma_y =\ \ 70\ MPa\ +\ \ 0.74\ M\ *\ Pa\ *\ m^{1/2}\ \ \cdot\ (6.614\ *\ 10^{-5} m)^{-1/2}$

$=\ 70MPa\ +.74MPa\ *\ m^{1/2}\ *\ 122.959\ m^{(-1/2)}$

=$70MPa\ +\ 90.99MPa\ =\ 160.99MPa$

σ_y **= 160.99 MPa**

Mean (n=12):

$\overline{X} = \frac{1}{n}\Sigma x_i$

$\overline{X} = \frac{1}{12}(57.33 + 56.82 + 57.59 + 55.53 + 58.17 + 58.05 + 51.89 + 57.91$ + 57.85 + 54.20 + 57.70 + 57.86)

$\overline{X} = \frac{1}{12}(680.9)$

$\overline{X} =$ **56.74**

Average Deviation for all specimens:

$\frac{1}{n}\sum_{i=1}^{n} |x - \overline{X}|=$

From data table $\sum_{i=1}^{n} |x - \overline{X}|$=17.22

$\frac{1}{12}$ (17.22) = **1.435**

Total standard deviation for all specimens:

$s^2 = \frac{\Sigma(x-\overline{X})^2}{n-1}$

$s^2 = ((57.33 - 56.74)^2 + \dots + (57.86 - 56.74)^2)/11$

$s = \sqrt{3.732}$

s = 1.9319

Average Deviation for each group:

Group 1*: Trial 1-3:

$\frac{1}{n}\sum_{i=1}^{n} |x - \overline{X}| = \frac{1}{3}(|(57.33 - 57.25) + (56.82 - 57.25) + (57.59 - 57.25)|$

=**0.283**

Group 2: Trial 4-6:

$\frac{1}{n}\sum_{i=1}^{n} |x - \overline{X}| = \frac{1}{3}(|(55.53 - 57.25) + (58.17 - 57.25) + (58.05 - 57.25)|$

=**1.147**

Group 3: Trial 7-9:

$\frac{1}{n}\sum_{i=1}^{n} |x - \overline{X}| = \frac{1}{3}(|(51.89 - 55.88) + (57.91 - 55.88) + (57.85 - 55.88)|$

=**2.663**

Group 4: Trial 10-12:

$\frac{1}{n}\sum_{i=1}^{n} |x - \overline{X}| = \frac{1}{3}(|(54.20 - 56.59) + (57.70 - 56.59) + (57.86 - 56.59)|$

=**1.59**

Standard deviation for each group:

Group 1*: Trial 1-3: $s^2 = \frac{\Sigma(x-\overline{X})^2}{n-1}$

$s^2 = \frac{1}{3-1}((57.33 - 57.25)^2 + (56.82 - 57.25)^2 + (57.59 - 57.25)^2)$

$s = \sqrt{.15345}$

s = 0.392*

Group 2: Trial 4-6: $s^2 = \frac{\Sigma(x-\overline{X})^2}{n-1}$

$s^2 = \frac{1}{3-1}((55.53 - 57.25)^2 + (58.17 - 57.25)^2 + (58.05 - 57.25)^2)$

$s = \sqrt{2.222}$

s = 1.491

Group 3: Trial 7-9: $s^2 = \frac{\Sigma(x-\overline{X})^2}{n-1}$

$s^2 = \frac{1}{3-1}((51.89 - 55.88)^2 + (57.91 - 55.88)^2 + (57.85 - 55.88)^2)$

$s = \sqrt{11.96}$

s = 3.458

Group 4: Trial 10-12: $s^2 = \frac{\Sigma(x-\overline{X})^2}{n-1}$

$$s^2 = \frac{1}{3-1}((54.20 - 56.59)^2 + (57.70 - 56.59)^2 + (57.86 - 56.59)^2)$$

$$s = \sqrt{4.2785}$$

s = 2.068

Percent Error:

The standard value for the hardness of 1018 carbon steel was found to be at a value of 44.5 MRA. This was found by using the known (theoretical) value of 126 on the brinell scale by the American Iron and Steel Institute. Using the conversion chart this 126 value corresponds to approximately 44.5 on the HRA scale. Our experimental value of hardness using the class average was determined to be 56.74.

The following table shows mechanical properties of cold drawn AISI 1018 carbon steel.

Properties	Metric	Imperial
Tensile strength	440 MPa	63800 psi
Yield strength	370 MPa	53700 psi
Modulus of elasticity	205 GPa	29700 ksi
Shear modulus (typical for steel)	80 GPa	11600 ksi
Poisson’s ratio	0.29	0.29
Elongation at break (in 50 mm)	15%	15%
Hardness, Brinell	126	126
Hardness, Knoop (converted from Brinell hardness)	145	145
Hardness, Rockwell B (converted from Brinell hardness)	71	71
Hardness, Vickers (converted from Brinell hardness)	131	131
Machinability (based on AISI 1212 steel. as 100 machinability)	70	70

Rockwell						Rockwell Superficial				Brinell		Vickers	Shore
HRA	HRB	HRC	HRD	HRE	HRF	15-N	30-N	45-N	30-T	3000 kg	500 kg		
61	98	21	40.9	---	---	69.9	42.3	20.7	81	228	189	243	35
60.5	97	20	40.1	---	---	69.4	41.5	19.6	80.5	222	184	238	34
59	96	18	---	---	---	---	---	---	80	216	179	230	33
58	95	16	---	---	---	---	---	---	79	210	175	222	32
57.5	94	15	---	---	---	---	---	---	78.5	205	171	213	31
57	93	13	---	---	---	---	---	---	78	200	167	208	30
56.5	92	12	---	---	---	---	---	---	77.5	195	163	204	29
56	91	10	---	---	---	---	---	---	77	190	160	196	28
55.5	90	9	---	---	---	---	---	---	76	185	157	192	27
55	89	8	---	---	---	---	---	---	75.5	180	154	188	26
54	88	7	---	---	---	---	---	---	75	176	151	184	26
53.5	87	6	---	---	---	---	---	---	74.5	172	148	180	26
53	86	5	---	---	---	---	---	---	74	169	145	176	25
52.5	85	4	---	---	---	---	---	---	73.5	165	142	173	25
52	84	3	---	---	---	---	---	---	73	162	140	170	25
51	83	2	---	---	---	---	---	---	72	159	137	166	24
50.5	82	1	---	---	---	---	---	---	71.5	156	135	163	24
50	81	0	---	---	---	---	---	---	71	153	133	160	24
49.5	80	---	---	---	---	---	---	---	70	150	130	---	---
49	79	---	---	---	---	---	---	---	69.5	147	128	---	---
48.5	78	---	---	---	---	---	---	---	69	144	126	---	---
48	77	---	---	---	---	---	---	---	68	141	124	---	---
47	76	---	---	---	---	---	---	---	67.5	139	122	---	---
46.5	75	---	---	---	99.5	---	---	---	67	137	120	---	---
46	74	---	---	---	99	---	---	---	66	135	118	---	---
45.5	73	---	---	---	98.5	---	---	---	65.5	132	116	---	---
45	72	---	---	---	98	---	---	---	65	130	114	---	---
44.5	71	---	---	100	97.5	---	---	---	64.2	127	112	---	---

$$\frac{H_{st.} - H_{exp.}}{H_{st}} x100\%$$

$\frac{44.5-56.74}{44.5} x100\%$ = **27.506% for the class average**

Figure:

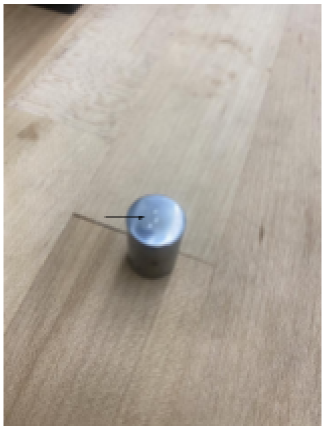

Figure 4. Image of The Material After Three Indentations On Its Surface

Results and Discussion:

Based on our testing, we determined the hardness of SAE 1018 to be 56.74 based on all of the recorded data sets, which is significantly higher than the published value of 44.5 on the HRA scale.. This could be due to insufficient polishing of the specimen. If the specimen was not properly polished, this could result in high and low points on the material's surface, altering the hardness reading during testing. Another potential issue is indentations that are too close together. If the indentations on the surface of the material were too close together, this could create a weak point as the material is pushed to fill in the gap of the previous hole, resulting in a material that appears to be less hard. Our group data had the lowest standard deviation and average deviation among its values. When compared to the rest of the data, this demonstrates that our group produced precise end results. Through different methods such as Intercept method, and ASTM, we calculated the grain size to be 0.06614mm and 0.074029mm respectively.

According to https://waldunsteel.com/products/aisi-1018-carbon-steel/ the grain size should be around 0.05-0.08mm. This concluded the intercept method and ASTM were effective in calculating the theoretical grain size. Finally, the percent error calculated from the theoretical value of 56.5 and the experimental mean value of 56.74 was 27.506%. Overall, the lab experiment for determining the hardness of carbon steel 1018 was a success.

Answers to Questions:

1. What is the hardness and how is it measured?

   Hardness is specified as the durability and a material's resistance to localized plastic deformation meaning its strength which can be identified through various testing procedures and different hardness measurements. Measured though applied stress in a specific point and its amount, specifically a Tru Blue Hardness tester pushing and pointing to the material being used allocating the amount of indentation happening.

2. Why are some of the reasons that will cause inaccurate hardness measurement? Name three.

   An inaccurate hardness measurement may be caused from failure to correctly smooth the surface, improperly placing the indeter above the specimen, and from creating indentations too close to each other.

3. Why are different hardness tests and scales required?

   Different tests and scales are required to suit various types of materials. Determining factors for which test to use include the: material, approximate hardness, shape, heat treatment, and production requirements.

Conclusions:

To determine the suitability of a material, its hardness distribution in grains, shape, and size are measured using the United Hardness Tester apparatus on a steel-like material. The "hardness testing electric system" is used in this experiment to determine the hardness of carbon steel AISI/SAE 1018. It is concluded that a material's hardness is tested using a variety of measurements and determines the amount of strength properties, grain distribution, and overall suitability. This experiment involves polishing the Carbon Steel AISI/SAE 1018 on both sides in the 5-Station Hand Grinder and then placing the specimen in the Tru-Blue Hardness Testing System to calculate the hardness of the material at a specific point. Three indentations are then seen on the material's surface, indicating a relatively high hardness measurement, as described in Table 4. The measured hardness values are 57.33 N/mm2, 56.82 N/mm2, and 57.59 N/mm2, with an average hardness of 57.25 N/mm2. To account for differences in the carbon steel material and determine the relative hardness of its properties, standard and average deviations of 0.392 and 0.283 are calculated. Given the provided grain size images, it was calculated using the Hell-Petch method that the yield strength totals to 160.99 MPa**.** Placing the 1018 sample under a major load of 60 kilograms while using a diamond indenter on the material results in small but sufficient indentations. It can be stated that carbon steel, the material under consideration, has a higher HRA (Hardness), a carbon-like substance that allows the material to be stronger. It has been discovered that such materials, as opposed to other materials, may be extremely difficult to change and alter. Hardness precision can be improved by allocating and pinpointing the exact and good location for the load to be applied, but polishing the material can also help. The 5-Station Hand Grinder or electric orbital sander can be used for polishing. The hand grinder is the primary tool used, but if an orbital electric grinder is used, there may be less error because it is much easier to keep in one direction. By polishing the specimen to a finite surface, the hardness ratio from the apparatus to the material's surface would be clear and exact.

References:

1. Materials Science and Engineering, Introduction, William D. Callister Jr. and David G. Rethwisch. 9th edition, Wiley 2014.

Appendices:

1) Add all original experimental graphs: N/A