Use of Hardness Testing in Determining Processing Conditions and Ductility of Metal Alloys

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Abstract

An experiment was run to measure the hardness of eleven metal samples. The identity of ten samples was known with the eleventh to be determined after the data had been examined. Ultimately it was determined that this sample closely resembled nodular cast iron. After the hardness data was assembled the average hardness of each sample was compared to both the calibration data for the hardness tester and to published hardness values. This comparison led to assumptions being made as to the processing conditions of each of the samples. After the processing conditions were determined the samples were ranked in order of increasing ductility. Finally a metal was chosen from the group for a wear resistant application based on this ranking. The hardest of the eleven samples, gray cast iron, was chosen for this application.

1 Introduction

Hardness testing is a method by which the overall toughness of a material can be determined. There are several different scales that can be employed in hardness testing based on the material under examination. All of the different scales operate in the same manner. They also use the same equipment to obtain results.

Hardness tests are performed on a hardness tester. The tester consists of an anvil that the specimen sits on during testing. An indenter is then pressed into the specimen. The type of indenter used, the weight used and the way the indentation is measured are the three ways that the proper hardness scale is determined. The Rockwell B scale uses a 0.1875 mm (1/16") steel ball as the indenter with a mass of 100 kg. The other unique feature of the Rockwell B scale is the way in which the indentation is measured. A majority of the other hardness scales measure the diameter of the indentation in some manner whereas the Rockwell B scale measures the depth that the indenter penetrates the specimen [1].

The ductility of a specimen can be found based on the results of the hardness tests. Generally the harder a material is the less ductile it will be. Using this reasoning a

set of materials can be ranked by their ductility. Hardness is also a key factor in determining the proper material for a given application. For example, an application that requires good wear resistance would require a hard material. Because hardness is related to the materials ability to resist surface deformations it can be directly associated with toughness.

2   Experimental Procedure

Eleven metal samples were obtained form the instructor for the hardness tests. The type of metal in each sample is given in Table 1. Each sample was tested three separate times using the Rockwell B scale. This scale employs a 0.1875 mm (1/16") steel ball with a load of 100 kg. Care was taken to insure that each test was conducted sufficiently far from indentations left by precious tests.

Once the hardness values were gathered they were analyzed. The results are shown in Table 1. The gathered hardness values were compared to published values. This comparison is shown in Figure 2. The results of the comparison were used to infer their processing conditions and rank them according to their ductility.

3   Results

The results of the statistical analysis are shown in Table 2. The standard deviations of the samples showed quite a bit of variation, as did the range. Some of the samples do approach the data for the calibration in Table 1.

The average hardness for each of the eleven samples were all relatively close to the published values. No statistical analysis was performed on the difference between the average and published hardness values. The published hardness values shown in Table 3 were taken from metals with the same composition with different processing conditions.

Once published values were found for each metal sample the compostion of each was found. The composition of each sample based on the published data is shown in

Table 4. These compositions give the acceptable range of primary alloying elements. They also exclude impurities in the alloys. The probable processing conditions for each of the eleven samples are listed in Table 3.

Under specific processing conditions published values were found that closely resembled those of the samples. From the similarities in hardness and given the consistent composition shown in Table 4 inferences were made based about the processing conditions of the eleven test samples. These inferences are contained in Section 4.

Table 1: Results of Calibration Performed on Hardness Tester, 11 am 6-7-05

Calibration Results, RB
92.5
92.4
92.0
92.0
91.7
92.3
92.0

Standard: 91.2 ± 1.2 RB

Standard Deviation: 0.28115

Mean: 92.1

Range: 0.8

In addition to the inferences made about the processing conditions, an estimate can be made as to the identity of the unknown sample of cast iron. The sample can be identified by comparing the hardness values recorded to published values for cast iron samples.

Table 2: Statistical Analysis of Eleven Metal Samples

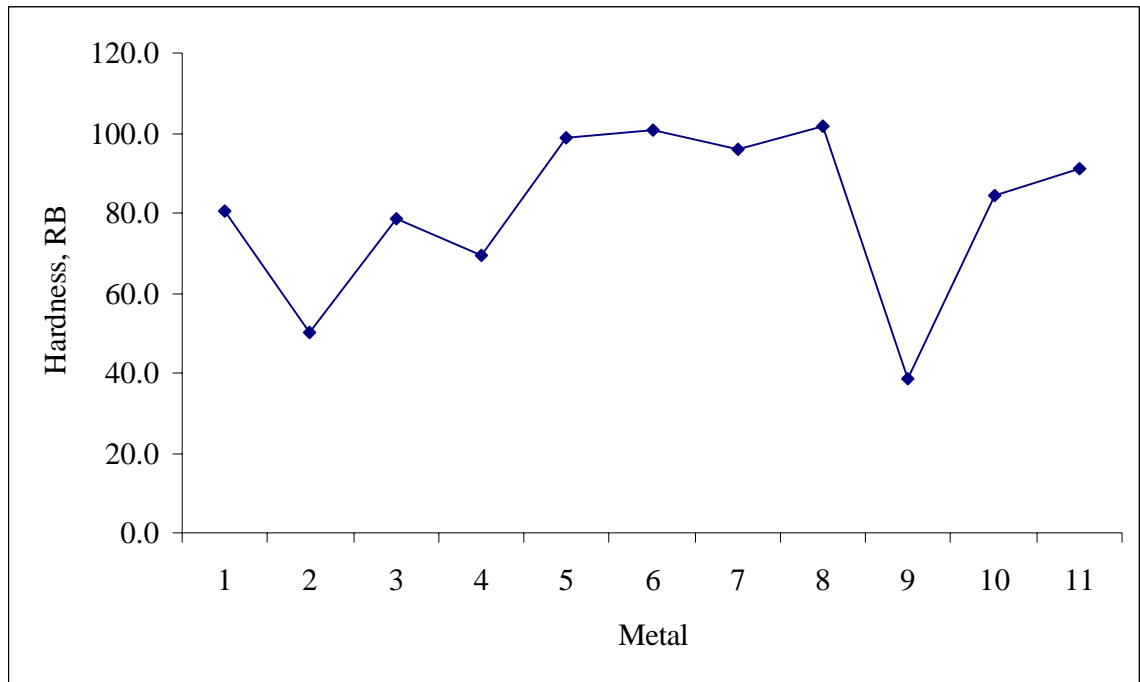| Metal	Hardness, RB					
	1	2	3	μ	R	σ
AA2024	80.5	80.7	80.4	80.5	0.3	0.2
AA6061	51.2	49.9	49.1	50.1	2.1	1.1
Phosphor Bronze	76.9	79.4	79.9	78.7	3.0	1.6
Brass	65.8	69.8	72.5	69.4	6.7	3.4
C1018	98.2	100.5	97.3	98.7	3.2	1.7
? Cast Iron	101.1	101.1	100.1	100.8	1.0	0.6
Ductile Cast Iron	95.5	96.0	95.9	95.8	0.5	0.3
Gray Cast Iron	101.7	102.5	101.0	101.7	1.5	0.8
Cu	38.6	37.0	40.7	38.8	3.7	1.9
Ti	82.6	85.5	84.9	84.3	2.9	1.5
Stainless Steel	88.2	95.3	89.6	91.0	7.1	3.8

Figure 1: Average Hardness Across 11 Metal Samples, Ordered as in Table 1

Table 3: Average Hardness Values For Eleven Metal Samples with Published
Hardness Values and Processing Conditions

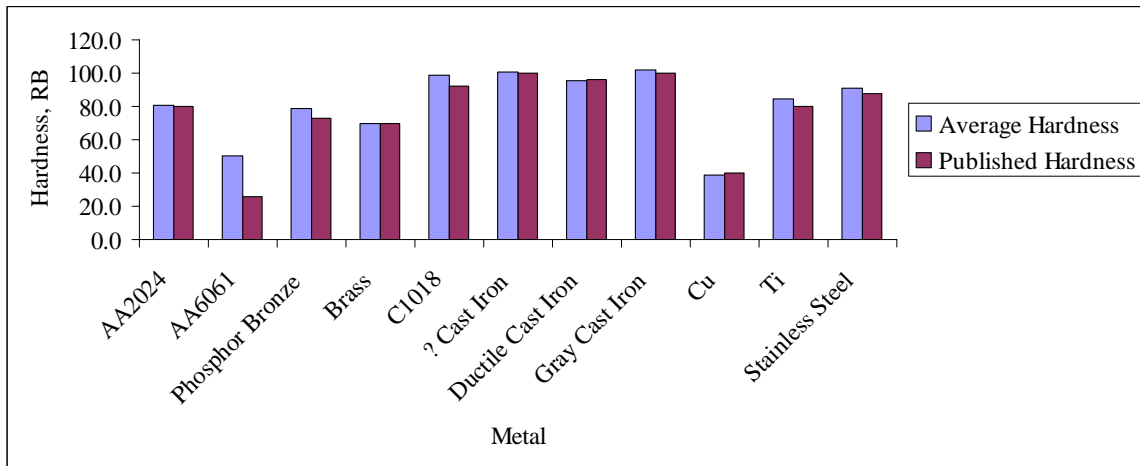| Metals	μ, RB	Published		
		Hardness, RB	Condition	Source
AA2024	80.5	80	T361	[2]
AA6061	50.1	26	T451	[2]
Phosphor Bronze	78.7	73	C50500-H06	[2]
Brass	69.4	70	C27000-H02	[2]
C1018	98.7	92	Carburized	[2]
? Cast Iron	100.8	100	Nodular	[2]
Ductile Cast Iron	95.8	96	80-55-06	[2]
Gray Cast Iron	101.7	100	Class 50	[2]
Cu	38.8	40	C10100-H02	[2]
Ti	84.3	80	Grade 4	[3]
Stainless Steel	91.0	88	18 CR-CB	[2]

Figure 2: Comparison of Average Hardness Values to Published HardnessValues

Table 4: Presence of Alloying Elements in Metal Samples

Metal	Alloying element	Wt. % in Sample
AA2024	Cu	3.8-4.9
	Mg	1.2-1.8
	Mn	0.3-0.9
AA6061	Cr	0.04-0.35
	Cu	0.15-0.4
	Mg	0.8-1.2
	Si	0.4-0.8
Phosphor Bronze	Cu	98.75
	Sn	1-1.7
Yellow Brass	Cu	63-68.5
	Zn	31.3-37
C1018	C	0.14-0.2
	Mn	0.6-0.9
Ductile Cast Iron	C	3.6-3.8
	Ce	0.005-0.2
	Cr	0.03-0.07
	Cu	0.15-1
	Fe	90.738-94.175
	Mg	0.03-0.06
	Mn	0.15-1
	Mo	0.01-0.1
	Ni	0.05-0.2
	Si	1.8-2.8

Table 4: Presence of Alloying Elements in Metal Samples (Cont.)

Gray Cast Iron	C	3.25-3.5
	Cr	0.05-0.45
	Cu	0.15-0.4
	Mn	0.5-0.9
	Mo	0.05-0.1
	Ni	0.05-0.2
	Si	1.8-2.3
Cu	Cu	99.99 min.
Ti	C	0.08
	Fe	0.5
	N	0.05
	O	0.4
	H	0.015
Stainless Steel	C	0.02
	Cr	18
	Fe	80.43
	Mn	0.3
	Nb	0.55
	Si	0.45
	Ti	0.25

4   Discussion

The data obtained from the eleven samples is consistent with the calibration of the hardness tester. The calibration was carried out by performing the tests on metal plates of known hardness. The overall trends in the calibration data appear to be the same as

shown in the data from the samples. The calibration data had a very slight variation that can likely be attributed to the heterogeneous behavior of the calibration plate. The test samples, for the most part, exhibited very small standard deviations.

Given the similarities of the measured hardness values and the published hardness values the processing conditions of the samples can be inferred. The probable treatment conditions are listed in Table 3. The AA2024 sample had a hardness close to that of the 2024 alloy under T361 conditions. This suggests that the sample had been heat treated and water quenched [4]. The AA6061 sample had hardness close to T451 which suggests that it has been heat aged at around 160°C for approximately 18 hours [2]. The phosphor bronze sample had a hardness relatively close to that of C50500-H06 suggesting that the sample had been annealed at approximately 550°C [2]. The yellow brass sample had hardness close to that of C27000-H02 brass, which would suggest that it had been annealed, hot-worked and then allowed to re-crystallize [2]. The C1018 steel sample had hardness close to carburized steel suggesting it had been carburized at 925°C, allowed to box cool, reheated to 775°C, quenched and then tempered at 175°C [2]. The hardness of the ductile cast iron suggests an 80-55-06 alloy. These numbers are the metal's tensile strength, yield strength and % elongation respectively [2]. This relatively high tensile strength suggests that the iron had been heat treated [5]. The hardness of the gray cast iron sample nearly matches that of class 50 gray cast iron. This type of gray cast iron is used as cast [2]. The relatively low hardness of the Copper sample is consistent with pure copper with H02 treatment, which is an annealing process [2]. The titanium sample appears to be grade 4 titanium. This titanium is regarded as an unalloyed material with no additional initial processing carried out [6]. The hardness of the stainless steel sample suggests 18 CR-CB. This alloy is typically annealed to give it excellent creep resistance [2].

The identity of the unknown sample can be assumed based on the hardness measurement. The hardness of the unknown sample appeared to be close to nodular cast iron. This type of cast iron is produced by introducing alloying elements that aid in the formation of graphite spheres in the iron. The nodular cast iron sample in this experiment did not seem to have any post-casting processing carried out on it.

Based on the hardness values given in Table 2 the metal samples can be arranged according to their ductility. Hardness relates to ductility on that the harder the material, the less ductile it should be. The metal samples, ranked from least to most ductile, are gray cast iron, nodular cast iron, C1018 steel, ductile cast iron, stainless steel, titanium, aluminum alloy 2024, phosphor bronze, brass, aluminum alloy 6061 and copper.

The above ductility ranking can in turn be used to determine which of the metals tested would be best suited for a high wear application. The ranking is based on ductility, which is essentially the opposite of hardness. Therefore the least ductile of the samples would be best suited for a wear resistance application. In this case, the gray cast iron had the highest hardness of the metal samples. This is the metal that would have the highest wear resistance property.

The error in this experiment is two-fold. The major source of error would be the location of the hardness test. Each time a sample is hardness tested is becomes slightly harder around the test location because of the deformation. If the indenter were located too close to a previous test site in running this experiment the results would be slightly off. The other error would be in the limitations of the Rockwell B scale. Rockwell be is considered valid in the range of 40 R_B to 100 R_B [1]. There were several samples that had measurements close to the upper extreme of this range and a few went beyond. The metals AA6061 and Copper were at the extreme bottom of the range. Because of this the actual hardness of the sample may vary considerably from what was measured.

5   Conclusions

1)   The variability in the hardness tester suggests that the material is not homogeneous in nature.

2)   The variability in the test samples was closely related to that of the calibration plate.

3) Treatment conditions seem to have a great effect on individual alloys in the same family of alloys.

4) The test materials seem to have been measured correctly as they closely correlate to published hardness values.

5) The rankings of the test samples in order of increasing ductility is gray cast iron, nodular cast iron, C1018 steel, ductile cast iron, stainless steel, titanium, aluminum alloy 2024, phosphor bronze, brass, aluminum alloy 6061 and copper.

6) Gray cast iron would appear to be the most appropriate material in a wear resistance application.

6   References

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