Hardness Test Analysis

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Abstract: The purpose of this lab is to perform the hardness test and evaluate the results, determine the effect of heat treatment and composition on the hardness of plain carbon steel, and compare the hardness of some technologically important alloys among as-received brass, as-received copper, HEA, and nickel superalloy. For harder materials, the indenter should be Rockwell C; while for softer materials, the indenter should be Brinell. As a result, the harder material will show less elastic deformation than ductile material.

INTRODUCTION

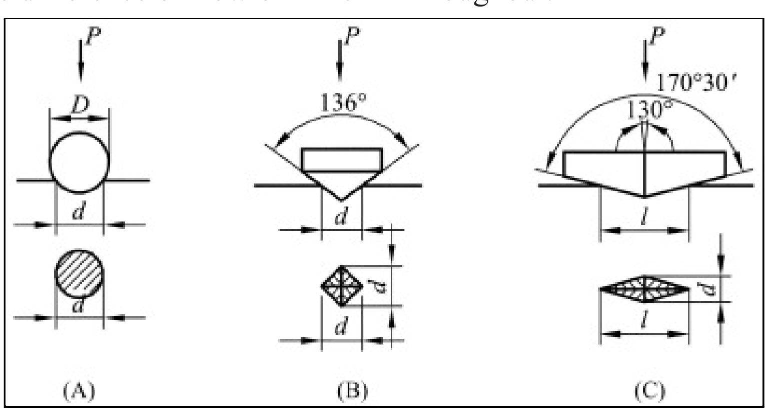
A hardness test is performed in order to find out the resistance to localized deformation among materials. In order to gain usable results, choosing the right type of indenter is very important. For hard material, a sharp indenter should be used, such as Rockwell C. For soft material, a dull indenter should be used, such as Brinell, otherwise, the indenter will penetrate the soft specimen and make the material's hardness unable to be tested.

In order to find out the effect of heat treatment on material hardness, 1018 and 1045 steel with different cooling rates will compare with their own kind. In order to find out the effect of composition, 1018, and 1045 steel with the same heat treatment, which is only differed in carbon concentration, and copper and brass, which are differed in zinc concentration, will compare with each other.

BACKGROUND THEORY

The hardness tests are not a result of physical properties but rather a characteristic of the material. This means that the process in which the tests are conducted bare no value to the physical system but rather pertain to the description of how the material behaves under these conditions. With this in mind, one has to remember that the type of material that is undergoing testing matters because it depends on what test is being applied for proper results. Further, the dimensions, size, and thickness of the sample can also affect which test should be run as well as the overall 3D shape the sample holds.

For each hardness test, there are certain qualifications the material must have to achieve useful results. First, if the material is soft or hard is used to determine what test will be applied as well as what indenter is best [1]. For each test, there are certain indenters that can indent deeper into the sample than others, and if the sample is too brittle a deep indentation will only cause cracking making the measurement inaccurate. Also, the overall sample size that is undergoing the test matters because of how much load is applied during the process. Smaller samples or thin samples require smaller loads for more precise readings. The size of the sample not only accounts for the area of indentation but the volumetric shape as well. If the sample has curves due to being cylindrical or round this affects how the test is done by using correction factors accounting for the difference of flow of material throughout.



[1]

THEORETICAL ANALYSIS

In this experiment, a total of 4 sets of experiments were established to determine the effect of heat treatment history and the composition of the material itself on the hardness of the material.

The first group is the difference in the history of heat treatment: Quenching and air cooling. For 1045 steel and 1018 steel, the samples that cool faster will have a higher hardness because they have more dislocations and residual stress in the crystal. For quenched samples, this phenomenon is more pronounced because they are in the martensite phase.

The last three groups are comparative analyses of materials with different compositions: 1045 steel and 1018 steel. The higher the carbon content, the higher the hardness of the steel. Because excess carbon content usually leads to more lattice deformation and defects, thus resisting sliding, which is the driving force of plastic deformation. This can be proved in the experiment. For brass and copper: Brass is an alloy of copper and zinc. The substitution of impurity Zn is the cause of the accumulation of defects and planar defects in brass. Through this control group, the effect of Zn on the hardness of the material can be obtained.

Inconel vs HEA: The hardness range of HEA with different compositions is very wide.

PROCEDURE

The hardness test was conducted on ordinary carbon steel samples with two different heat treatments numbered 1045, ordinary carbon steel samples with four different heat treatments numbered 1018, brass and copper samples, nickel superalloys, and high-entropy alloys. The following are the steps:

A 1/16 inch ball indenter was used to measure the hardness of the sample. First, put the sample in the middle of the sample stage, and rotate the sample stage to move the rudder upwards until the screen shows that the settings are complete. Afterward, change the position of the remaining measurements to avoid differences in the edges and special parts of the sample. Continue to repeat the same steps at least 5 times for each sample. To avoid accidental errors

Finally, collect data.

RESULTS

Sample	*Hardness Type*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*Average*
1045 Quenched	HRB	86.1	85.2	90.9	89.4	84.3	93.8	92.8	88.9
1045 Room Cooled	HRB	67.2	71.2	77.4	78.4	79.8	73.7	77.4	75.0
1018 Quenched	HRB	80.7	86.1	84.7	84.5	88.5	89.1	83.3	85.3
1018 Room Cooled	HRB	78.3	77.1	76	76.8	77.3	78.1	79.8	77.6
1018 As Received	HRB	96.1	96.8	95.7	95.8	95.3	-	-	95.9
1018 Furnace Cooled	HRB	68.2	65.3	61.5	68.2	66.2	-	-	65.9
Brass As Received	HRA	37.2	38.1	42.8	40.8	40.3	-	-	39.8
Copper As Received	HRA	28.7	27.8	28.4	29.1	28.3	-	-	28.5
HEA	HRB	51.8	51.9	52.4	51.9	52.3	-	-	52.1
HEA	HRA	26	28	27.9	29.1	28.5	-	-	27.9
Nickel Super Alloy	HRB	97.2	95.8	100	98.5	96.6	-	-	97.6
Nickel Super Alloy	HRA	60.9	59.2	60.4	59.1	59.5	-	-	59.8

Table 1: *The samples listed are specified by which Rockwell test was applied: HRA scale uses a diamond indenter whereas the HRB scale uses a 1/16" Ball. There were 5 rounds of measuring on all samples except for the 1045 & 1018 steel that had 7 measurements total.*

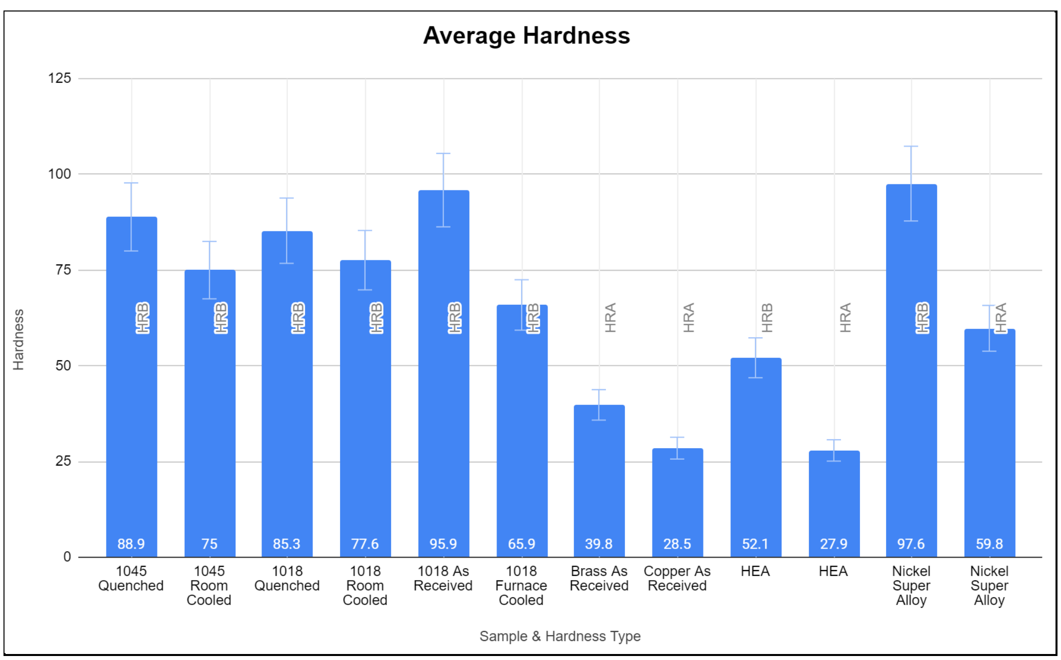


Figure 1: *The average hardness and Rockwell test type of each sample are plotted with error bars of 10%.*

DISCUSSION

The hardest material tested was a nickel superalloy achieving a very high hardness reading of 97.6. These same alloys can also reach a moderate hardness reading of 59.8. This shows the capability of alloys to be processed and altered concentration to achieve incredible levels of hardness. Alloys can also be manufactured to achieve extremely low levels of hardness; this can be seen through the hardness results of the tested high entropy alloys. In table one, HEAs are seen to be able to possess both moderate hardness values and very low hardness readings of 27.9. This value is lower than copper, a material known for its ductility.

Copper is a very soft material that becomes slightly harder when combined with zinc to form brass. Due to the low hardness of these materials, their applications are limited to those with low impacts and not supporting any substantial loads.

No significant difference was observed between the 1045 and 1018 samples. This finding can be interpreted as meaning that carbon composition does not have a large impact on hardness. The heat treatment underwent and the resulting microstructure has a larger influence over the material hardness.

The hardness values of steels follow a predictable trend: from softest to hardest, furnace cooled, room cooled, quenched, and as received. The faster the metal is cooled after heat treatment, the harder the resulting material will be. The as-received steel must have undergone some combination of heat treatment and cold working to achieve a hardness reading of 95.9.

DISCUSSION QUESTIONS

1) Is hardness related to other properties of the material?

Hardness measures the resistance of deformation created from friction and abrasion. Although hardness is not a fundamental physical property it can relate to the tensile strength, proportional limit, ductility, work-hardening properties, shear strength, and modulus of elasticity. Depending on how the material reacts the samples can exhibit elastic, plastic deformation, or even fracture.

2) Why do you think we observe different hardness for different samples?

Different hardnesses are observed on different samples because of the material they are. The properties of the material are heavily dependent on the bonding and microstructure which affects the surface harness. The various hardness tests also account for the level of hardness expected such that Rockwell and Brinell are macro hardness tests whereas Vickers and Knoop are microhardness tests. The methods of using macro hardness imply that the intermolecular bonds are strong and can withstand a higher load of surface indentation.

3) What are the applications of the materials that we tested today?

The applications of the materials that were tested in the lab are as follows:

1045 Steel	The most known use is for axles, bolts, forged connecting rods, crankshafts, torsion bars, light gears, and guide rods
1018 Steel	The most known use is for forged motor shafts, hydraulic shafts, and pump shafts and machinery parts (in a surface hardened condition)
Brass	The most known use is for locks, gears, bearings, valves, braces, brackets, and base plates.
Copper	The most known use is in the forms of copper plates, pipes, and heat sinks where quick heat transfer is needed.
HEA	High entropy alloys are a result of mixing large quantities of elements and therefore their applications can have a large range. The most common creations result in altering mechanical and electrical and magnetic properties to achieve optimized results such as high yield strengths at very high temperatures or exhibiting superparamagnetism and high magnetic coercivity.
Nickel Super Alloy	The most common use is in regards to corrosive and elevated temperature oxidation environments like turbine blades, high-speed airframe parts, fossil fuel, and nuclear power plant components.

4) What hardness test would you use for a 10-micrometer coating? Why?

The various hardness tests can be split into two categories of hardness type: Rockwell and Brinell are used for macro hardness whereas Vickers and Knoop are used for microhardness. If the sample being tested had a 10 μm coating, the scale of work is considerably small and therefore would use the Vickers or Knoop test. Assuming that the coating is just one layer and not multiple thin layers, the Vickers test is more applicable due to its diamond indenter allowing for further indentation than Knoop.

CONCLUSION

In conclusion, carbon concentration does not show a significant impact on the material's hardness through the comparison between 1018 and 1045 steels. However, when compared with their own kind, a trend is discovered that the faster the metal is cooled after heat treatment, the harder the resulting material will be. The composition of zinc makes brass harder than copper, thus, able to apply in fields that need high strength.

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