Memorandum

DATE: March 12, 2014

TO: MechMate Consulting

FROM: Zane Gavin, Undergraduate Mechanical Engineering Student, Northeastern University.

RE: Recommendations for framing nail and knife blade

CC: Yung Joon Jung, Assistant Professor, and Sanghyun Hong, Teaching Assistant, Northeastern University

In this lab I investigate the mechanical properties of four materials with the use of two testing methods: Rockwell hardness testing and Charpy impact toughness testing. These materials are Brass (Cu-Zn Alloy), Aluminum Alloy, Cold Rolled Steel, and Hot Rolled Steel. When testing the hardness of each material at room temperature, I will use the Rockwell B scale (HRB). I will test the toughness of the materials at three different temperatures, -200 °C, 25 °C and 200 °C, with a notched-bar specimen. See the Recommendations section for candidates for framing nail and knife blade as well as justifications.

Background Information

The specimen used for both tests is a notched-bar which is essentially just a rectangular prism with a notch (see Figure 1). The notch serves as a breakpoint for the specimen, during the impact test, to present an observable surface. Analysis of this surface, after fracture, provides mechanical properties of the material.

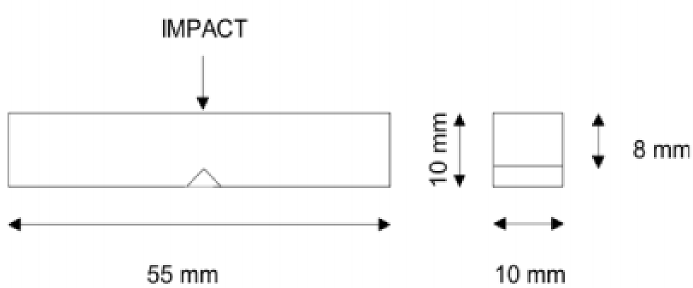

Figure 1: Charpy impact test specimen geometry by ASTM Standard Designation E23-566.

The hardness of a material refers to the force necessary to cause plastic deformation (i.e. permanent deformation) by some other object. Because of the subjective nature of "some other object", scales are used to quantify the hardness of the material used to cause the deformation. In this lab we employ the Rockwell B scale, which utilizes a steel sphere, as an indenter (or striker) at a maximum load of 100 kgF.

The toughness of a material relates to the amount of energy it absorbs before failure. In the Charpy impact test, a pendulum of specified mass swings and fractures a notched-bar specimen. At the point of failure the motion of the friction pointer, an indicator on the Charpy test apparatus, is stopped. From the reading of the friction pointer we can determine how many ft-lbs of energy are required to fracture the specimen. Higher readings indicate more ductile materials (higher toughness). In addition to the friction pointer reading, the surface along which the material breaks yields information. Brittle materials have a relatively flat fracture surface, and ductile materials have a surface that is generally more jagged and one that shows evidence of plastic deformation before fracture.

Hardness Testing Results

You will see from the experimental results of the Rockwell hardness test (see Table 1) that the hardness of each material varied substantially from each other, indicating vastly different mechanical properties.

Table 1: Hardness at Room Temperature (HCB, max. load 100 kgF)

Specimen	Data Point 1	2	3	4	5	6
Brass (Cu-Zn Alloy)	75.4	75.5	75.7	75.6	75.7	75.2
Aluminum Alloy	63.8	62.9	62.9	62.6	63.5	63.2
Cold Rolled Steel	101.9	100.9	101.2	100.7	101	101.2
Hot Rolled Steel	79.6	80.1	80.1	80.3	80.3	80.1

The difference in hardness of the samples is presented in the table (see Table 2) and graph below (see Figure 2). Cold Rolled Steel clearly has the highest relative hardness, followed by Hot Rolled Steel, Brass, and Aluminum Alloy in that order. Note that because the standard deviation is so small, the error bars on Figure 2 are somewhat hidden by the data point symbols.

Table 2: Average Hardness and Standard Deviation of Data

Specimen	Average	Standard Deviation	Percent Error
Brass (Cu-Zn Alloy)	75.516	0.194	0.257
Aluminum Alloy	63.15	0.441	0.699
Cold Rolled Steel	101.15	0.413	0.408
Hot Rolled Steel	80.083	0.256	0.319

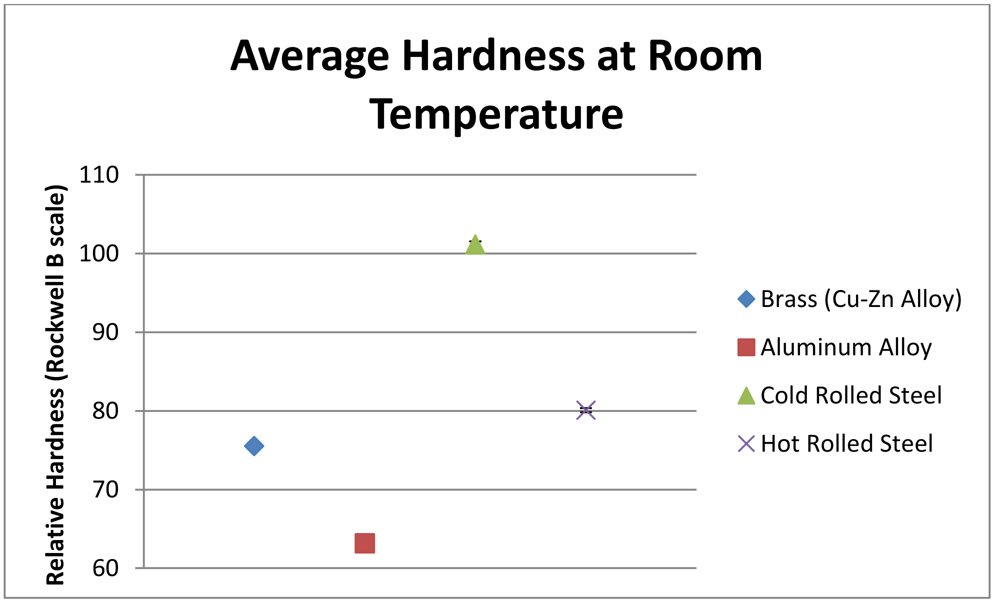

Figure 2: Average Hardness at Room Temperature

Impact Testing Results

The impact test yielded interesting results about the relationship between the toughness of material and temperature (see Table 3). In general, toughness increases with higher temperatures. This holds true for all four materials, according to the data between the two extreme temperatures, -200 °C and 200 °C (see Figure 3). Increased toughness with increased temperature does not, however, hold for Brass and Aluminum Alloy, in the transition from -200 °C to 25 °C, where toughness actually decreases slightly before increasing as a higher temperature is reached. As mentioned above, the "toughness" quality is the amount of energy absorbed by the specimen before failure and in the Charpy impact test, it is measured in ft-lbs.

Table 3: Impact Data at Various Temperatures

Temperature	Brass (Cu-Zn Alloy)	Aluminum Alloy	Cold Rolled Steel	Hot Rolled Steel
-200°C	12 ft-lbs	20 ft-lbs	5 ft-lbs	5 ft-lbs
25°C	8 ft-lbs	15 ft-lbs	22 ft-lbs	86 ft-lbs
200°C	29 ft-lbs	32 ft-lbs	48 ft-lbs	91 ft-lbs

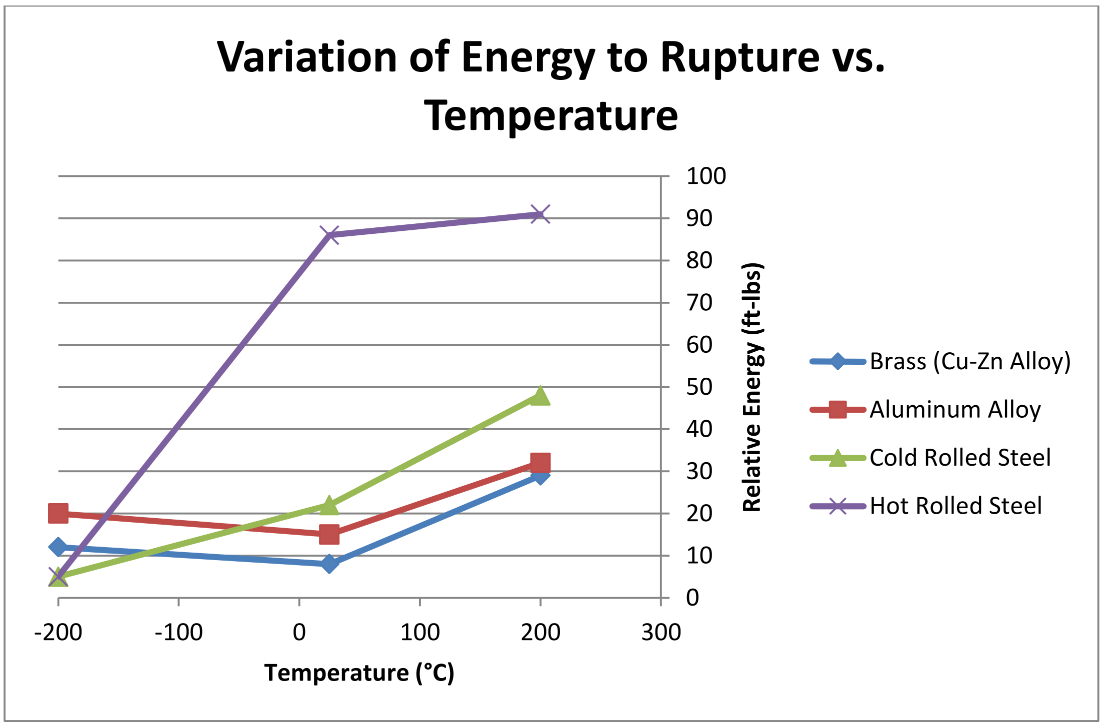

Figure 3: Variation of Energy to Rupture vs. Temperature

The Charpy impact test also revealed interesting qualitative results. You will notice in Figures 4 through 7 that the fracture surfaces are relatively distinct. For example, the Charpy impact tests on Brass all resulted in a flat surface, indicating brittle behavior (see Figure 4). Aluminum Alloy had a jagged surface, at each tested temperature, indicating a more ductile behavior (see Figure 5). The specimen of Cold Rolled Steel, tested at -200 °C , and Hot Rolled Steel, tested at 25 °C, did not break at all, indicating even more ductility than Aluminum Alloy or Brass (see Figures 6a) and 7b), respectively). Full qualitative results can be viewed in Table 4.

Figure 4: Notched-bar specimen of Brass after impact test at a) -200 °C b) 25 °C and c) 200 °C

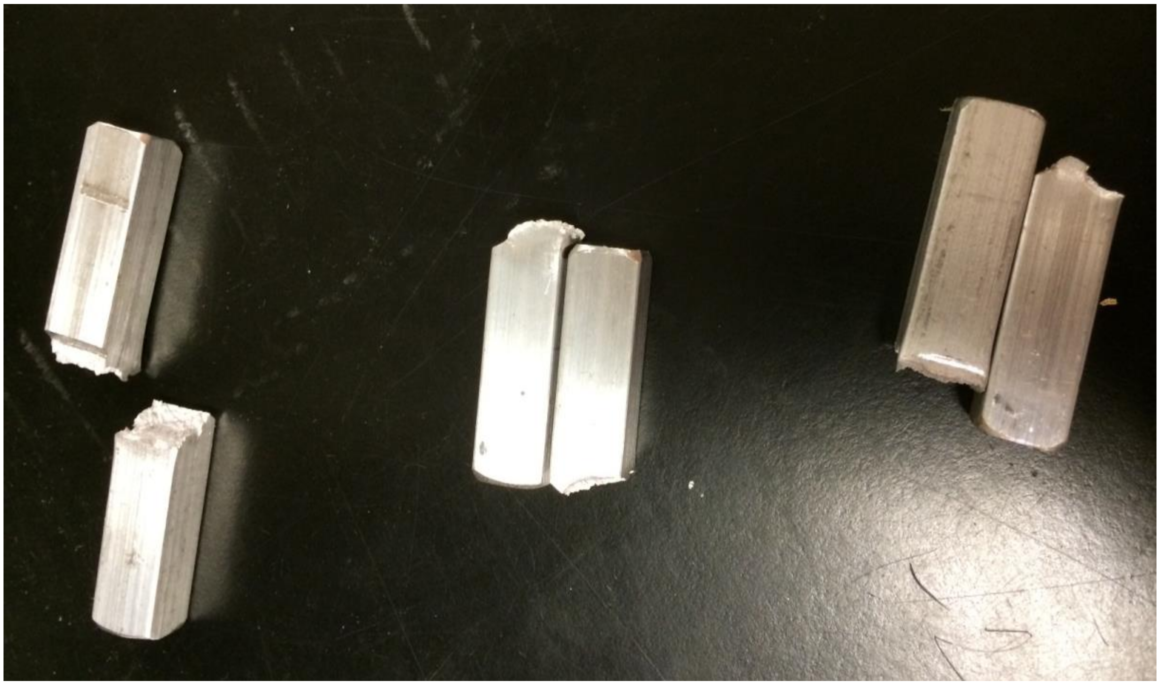

Figure 5: Notched-bar specimen of Aluminum Alloy after impact test at a) -200 °C b) 25 °C and c) 200 °C

Figure 6: Notched-bar specimen of Cold Rolled Steel after impact test at a) -200 °C b) 25 °C and c) 200 °C

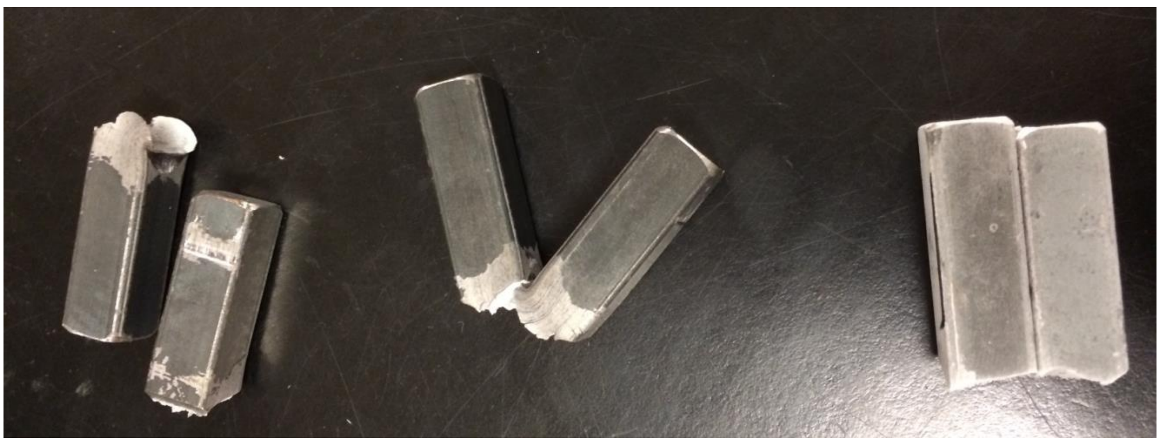

Figure 7: Notched-bar specimen of Hot Rolled Steel after impact test at a) -200 °C b) 25 °C and c) 200 °C

Table 4: Qualitative Results, Ductility

Specimen	**Fracture Surface, -200 °C**	**Behavior**	**25 °C**	**Behavior**	**200 °C**	**Behavior**
Brass (Cu-Zn Alloy)	Flat	Brittle	Flat	Brittle	Flat	Brittle
Aluminum Alloy	Jagged	Moderately Ductile	Jagged	Moderately Ductile	Jagged	Moderately Ductile
Cold Rolled Steel	Unbroken	Very Ductile	Very Jagged	Ductile	Jagged	Moderately Ductile
Hot Rolled Steel	Very Jagged	Ductile	Unbroken	Very Ductile	Jagged	Moderately Ductile

Discussion of Mechanical Properties and Overall Results

Because of the repeated Rockwell hardness tests, it was possible to obtain data with an average and standard deviation (see Table 2). Using this standard deviation I was also able to calculate the percent error of the data, indicating the level of data precision. Due to the mechanization and automation of the testing I obtained extremely small percent errors, the error from: Brass was 0.26 %, Aluminum Alloy was 0.70%, Cold Rolled Steel was 0.41%, and Hot Rolled Steel was 0.32%. In the Charpy impact tests, there was only one trial conducted for each specimen, so there can be no measurement of precision.

The results for both tests also lose some value because these tests use relative scales and are not standardized. If they were standardized it would be possible to compare the characteristics of more materials more easily.

The brass specimen had a relatively moderate hardness, a little lower than the midpoint between the hardest and least hard specimens (see Figure 2). It also had a relatively moderate toughness at the lowest temperature -200 °C (see Figure 3). However, it was the least tough specimen at 25 °C and 200 °C. It also exhibited a very brittle property at all tested temperatures.

The aluminum specimen was the least hard, out of all the tested materials (see Figure 2). It was also the toughest at -200 °C, and had a lower than average toughness at 25 °C and 200 °C (see Figure 3). It exhibited moderate ductility at all temperatures.

Cold Rolled Steel registered highest on the Rockwell hardness test, well above the other tested materials (see Figure 2). At -200 °C it was the least tough, at 25 °C and 200 °C it was the second toughest material, however, still substantially less tough than the toughest material (see Figure 3). Cold Rolled Steel did not break at all at -200 °C, indicating extreme ductility. At 25 °C and 200 °C Cold Rolled Steel exhibited moderate ductility.

Hot Rolled Steel had average hardness, about midway between the hardest and least hard material (see Figure 2). At -200 °C it was the least tough, however, this property radically changes at 25 °C and 200 °C – where it has much more toughness than any of the other tested materials (see Figure 3). At both -200 °C and 200 °C, Hot Rolled Steel exhibits moderate ductility and at 25 °C it does not fracture at all demonstrating extreme ductility.

Recommendations

I will now list the most desirable traits for both the knife blade and the framing nail, from there I will suggest a material, of those tested, that best meets the desirable criteria.

Ideally a knife blade is:

- hard, because it is by definition used to cut things
- relatively tough, so that it does not break under a minimal stress and withstands wear

Considering this, Cold Rolled Steel is the ideal candidate; Cold Rolled Steel exhibits hardness well above the other materials and has the second highest toughness, at room temperature (25 °C) – the temperature at which it will be used.

Ideally a framing nail is:

- ductile, so that it does not experience sudden failure (wear is evident upon failure)
- tough, so that it absorbs substantial wear before failure

Considering this, Hot Rolled Steel is the ideal candidate; Hot Rolled Steel exhibits the highest toughness, at room temperature (25 °C), and the highest ductility at room temperature.

Should you have any questions about the hardness testing, impact testing, discussion of mechanical properties and overall results, or the recommendations, please feel free to contact me: Zane Gavin at gavin.z@husky.neu.edu

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