To: Paul Lynch

From: Group D

Subject: Tensile Testing, Hardness, Green Sand Molds

Dear Paul:

The objective of this lab was to introduce the basics of green sand molding as well as the methods of conducting the Brinell Hardness test, the Rockwell test, and the Tensile test.

For green sand molds, the first task was to fill each side(cope and drag) of the flask with sand. The sand must be packed very tightly or the mold will not be strong and crack. This can be done manually by a wedge and flat ram, or pneumatically with the jolt squeeze. Once the cope and drag are each filled, a sprue was used to create a hole in which molten metal will be poured in. The hole must be carefully measured to line up with the well on the pattern. After this was completed, the flask and pattern were separated and a jacket was placed overtop to eliminate any shifting. Finally, via ladle, the liquid metal from the induction furnace was poured into the mold, and puppies were created.

The second half of the lab involved performing the tensile test the Brinell Hardness test and the Rockwell test on various metals. For the each test, three different metals (6061 Aluminum, Hot Rolled Steel, and Copper) were observed. For the tensile test, the metal was placed into the machine which applied stress to the metal until it failed. The computer program showed a live stress-strain curve, so that the different stages could be observed graphically as they appeared in the metal being tested. This process was done twice for each metal and average was taken to insure a stable result. The Rockwell Hardness Test was done on the Hot Rolled Steel. This test involved placing a sample of metal into the machine and the diamond bit indent the sample with 60 kgf. The Rockwell Hardness number was then converted to the Brinell Hardness number using a scale provided in the shop. The Brinell Hardness Test was the final test performed on the copper and Aluminum piece. The Brinell Test worked similar to the Rockwell Test, however it used a 10mm steel or tungsten carbide ball to make indentations. The indentations were then measured with the BOSS software which gave the Brinell Hardness number based on the size of the circular indent made.

<u>Important terminology that need to be fully understood to conduct this lab are:</u>
Green Sand: “The Black Stuff.” Made of Silica Sand, Bentonite Clay, and water.
Flask: Contains the mold and where the sand is dumped.
Pattern: It sits on the match plate, compared to the “bucket used to make the sandcastle.”
Parting Line: Midpoint of the match plate, and mid point of top and bottom half of the mold.
Parting Compound: Chalky dust which is used to separate the sand mold from match plate.

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Muller: Mixes the sand, clay, and water. Creates the green sand.
Jolt Squeeze: It is a pneumatic device that compacts the green sand into the mold.
Cope: Top half of the sand mold.
Drag: Bottom (Bigger) half of the sand mold.
Riser: Extra pool of molten metal that FEEDS in to compensate from the liquid to solid shrinkage.
Gate: Connects the runner system to the casting(mold cavity)
Sprue: Hole cutter, creates a passage which the metal from the ladle is poured to the well.
Core: Resin bonded sand piece inserted into a mold to produce a hollow cavity.
Induction Furnace: Electrically melts the molten metal.
Ladle: Takes the molten metal from the furnace into the sand mold.
Jacket: Holds the top and bottom halves of the sand mold in place to transport the mold.

Tensile Strength is the force required to pull an object till the point that the object fractures. Yield Strength is the maximum stress that has been applied to the work piece before it reaches its plastic deformation state. The tensile strength is measured in (lbs) and the tensile strength the following materials H.R. Steel, 6061 Al and Copper are 7822, 5363 and 5057(table 1). The amount of stress applied to the H.R. Steel before it breaks was 45.85% higher than the amount of stress required to break the 6061 Al and 54.67% higher than it would have required breaking the Copper workpiece. Since Strength is directly proportional to hardness of a material it can be stated that H.R. steel is the hardest of all the material provided followed by 6061 Al and then Copper.

The elastic modulus measures how stiff an object is compared to the other. It is the slope of the stress V/S strain curve before the object reaches permanent deformation passing yield strength mark of the graph. The smaller the modulus of elasticity of an object, the more the object is prone to deformation. The moduli for the same materials as stated above are as follows 43,805,080psi for H.R. Steel, 29,734,220 psi for 6061 Al and 26,933,670psi for the copper (table 1). The modulus of Copper is the least amongst the 3 materials, which means it is easier for the copper to deform than the others. Copper is 10.4% less stiffer than 6061 Al and 62.6% less stiffer that H.R. Steel.

Hardness of a material is its resistance to permanently change shape when a force is applied. The materials used for the hardness testing are Copper, Aluminum and H.R. Steel and the data received from the hardness test are 75.8, 105.7 and 135 (table 2 and table 3). These data have been received through the brinell hardness- 500 kgf (10mm ball). H.R. Steel is the hardest materials out of the other 3. The force required to permanently change shape for the H.R. Steel is 21.7% more than is would be for Aluminum and 44% more than it would require for Copper.

Hardness is directly proportional to the tensile strength of the material which means that H.R. Steel is 21.7% more stronger than Aluminum and 44% more than Copper.

The extension questions that needed to be researched are as follows:

1. Strain hardening also known as work hardening is a term used where the metal used for testing becomes stronger and harder by plastic deformation. While the tensile test is taking place, stress is being applied to the metal and the number of dislocations increases which makes it stronger and harder. Smaller the grain size the metal stains harder than compared to larger grain size.(1)

2. Engineering stress at any load, is the load divided by the initial cross-sectional area. At any load, the true stress is the load divided by the cross-sectional area at that exact instant. (2)

3. Fracture toughness is performed to measure the resistance of a material to applied stress with the presence of a crack. Impact toughness measures the energy absorbed by the metal before it reaches fracture. Fracture toughness testing uses the flaw size and its features to evaluate the ability of the metal containing the flaw to resist fracture. During impact toughness the energy absorbed by the metal is measured by considering the difference in the height when the hammer was released and the final height the hammer reaches after it has hit the metal piece.(3)

4. 4340 steel has a Yield Strength of 1240 MPa, an Ultimate Tensile Strength of 1550 MPa, and Fracture Toughness of 100 $MNm^{-3/2}$. Titanium in comparison has a Yield Strength of 910 MPa, an Ultimate Tensile Strength of 950 MPa, and a Fracture Toughness of 85 $MNm^{-3/2}$. Steel clearly is the stronger of materials based on these numbers, but it has a much higher density of 7.8 Mg/m^3 compared to titanium's 4.5 Mg/m^3. When comparing prices, 4340 Steel was $0.25/kg while Titanium was $16.25/kg. Titanium was 65 times more expensive. (4)

5. Ductile Casting Iron is considered the upgraded version of Grey Casting Iron. Both Grey Iron and Ductile Iron are prepared by adding carbon in the hot beds where they are liquefied but in the case of Ductile Iron, magnesium is also added. After researching in the differences between Grey and Ductile Casting Iron, two notable differences are the tensile strength and the ductility. The approximate tensile strength of Grey Casting Iron is 20,000psi whereas the minimum tensile strength of Ductile Iron is 60,000psi. Ductility is a solid material's ability to deform under tensile stress. The spherical shaped molecules of graphite in Ductile Iron gives it a high ductility. The A395 is the most Ductile of the Ductile Irons and has a Ductility of 18 to 30 percent elongation. Grey Iron does not have any recognizable elongation. (5)

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6. A wrought alloy is hot and/or cold worked mechanically, or thermo-mechanically, to form its' desired shape. It can be worked multiple ways, some of which are rolling, extrusion, forming, or forging. A cast alloy is heated up and poured into a mold to solidify into its final shape, usually more complex shapes. These methods include sand-casting, and die or pressure die casting. (6)

7. The current market price of copper is $0.19/oz and its main industry uses are building construction, electric and electronic products, and transportation equipment. For silver, the market price is $19.49/oz. Silver is present in nearly every industry, everything from non-corroding electrical switches, to chemical-producing catalysts. The current market price for nickel is $0.55. Nickel is frequent in everyday lives, including in food preparation equipment, mobile phones, medical equipment, transport, buildings, and power generation. (7)

8. Steel is considered stainless when there is a high percentage, between 16 and 36%, of chromium (Cr) present, making it corrosion resistant. The presence of chromium forms a tightly-adhering oxide layer, mostly CrO, which stops further corrosion. Nickel is used as an alloying element for the formation of austenitic structure and gives 300 series stainless steel grades their strength, ductility, and toughness, even at very low temperatures. The influence of nickel results in significant improvement in acidic resistance. (8)

9. Austenitic stainless steels display a single-phase, the face-centered cubic (fcc) structure. This structure is composed of a balance of alloying additions, predominantly nickel. Austenitic stainless steels have very high toughness and can be strengthened by work hardening.

Ferritic stainless steels have the body-centered cubic (bcc) structure known as ferrite. These steels contain from 10.5 to 30 weight percent chromium, as well as other alloying elements. Ferritic mechanical properties include stress-corrosion cracking (SCC) resistance, good resistance to pitting, but poor toughness.

Martensitic stainless steels hold a body-centered cubic (bcc) or body-centered tetragonal (bct) structure. These steels are composed of alloys of chromium and carbon. Higher carbon contents make these steels have a greater strength and hardness, therefore a very poor ductility.

Duplex stainless steels are two phase alloys based on the iron-chromium-nickel system. These steels are usually composed of equal proportions of the bcc ferrite and fcc austenite in their microstructure. Mechanical property advantages of duplex stainless steels are strength and hardness, chloride SCC resistance, and pitting corrosion resistance. (9)

10. Hardenability is the ability of a steel to form martensite. The hardenability of steel is a function of the carbon content and other alloying elements and the grain size of the austenite.(10)

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Appendix

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IE311 LAB#1 DATA SHEET

Please Paste the following tables into the Results Section of Lab Report #1

Table 1: Tensile Testing Data

Material	Yield (lbs)	Yield (kpsi)	Tensile (lbs)	Tensile (kpsi)	Tot. % Elong.	Modulus (psi)
H.R. Steel	7822	65.2	7961	66.3	13.1	43,805,080
6061 Al.	5363	43.6	5373	43.7	6.5	29,734,220
Copper	5057	40.5	5077	40.6	12.5	26,933,670

Table 2: Brinell Hardness Data

BRINELL HARDNESS – HB (500 kgf, 10mm ball)				
Material	Measure 1	Measure 2	Measure 3	Average
Copper	77.4	75.6	74.6	75.8
Aluminum	103	106	108	105.7

Table 3: Rockwell Hardness Data

	ROCKWELL A – 60 kgf Diamond				
Material	Measure 1	Measure 2	Measure 3	Measure 4	Average
H.R. Steel	53.2	49.3	50.9	49.2	50.7
BRINELL HARDENSS-HB (3000 kgf, 10mm C ball) Equivalent:					135

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