**ME220 – Mechanics of Materials Laboratory**

Charpy Impact Test

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Section 1

Subsection A

**Executive Summary:**

The objective of this lab is to analyze the effect of temperature on toughness under impact conditions using the Charpy impact test. A material that is tough can undergo a large amount of plastic deformation before fracture and as a result is able to absorb large amount of energy before fracture. Toughness is related to the ductility of a specimen. A ductile material such as low-carbon steel is more tough than a brittle material such as cast iron. However, toughness is affected by external conditions. Surface defects, such as a notch, act as stress concentrators in the material. Metals with a BCC crystal structure, such as steel, behave in a brittle manner below a certain temperature called the transition temperature. The rate at which the load is applied also affects the toughness. The Charpy impact test applies a very high load rate to a specimen with a notch in it to measure the fracture energy of the specimen. Since the notched specimens are made as uniformly as possible and the loading rate is constant between tests, the effect of temperature can be observed on different metals. In this lab specimens of a 2024-T4 aluminum alloy, an A36 steel, and a tempered 4140 alloy steel are tested using the Charpy impact test. Specimens of each metal are placed in various types of baths and allowed to sit in the baths for at least 10 minutes. This ensures that the material reaches the same temperature as the bath. The temperature of the bath is recorded and the specimen is removed and quickly placed in the testing apparatus. The test is performed and the resulting fracture energy is recorded. The process is then repeated for each of the baths and each type of specimen. Both the A36 steel (figure 1) and 4140 tempered steel (figure 3) experienced a ductile to brittle transition while the aluminum (figure 2) did not. This is expected since the aluminum’s FCC crystal structure has a large number of slip planes. The 4140 steel experienced some strange behavior where the fracture energy was higher between the 33.3°F sample and 146°F than for the 212°F sample. Due to their behavior, both the A36 steel and 4140 steel are not suitable for applications in extreme cold while the aluminum is still practically viable.

**Results and Calculations:**

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| Figure 1: A-36 Steel Impact Test Results |
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| Figure 2: Aluminum Impact Test Results |

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| Figure 3: 4140 Steel Impact Test Results |

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| Figure 4: Boiling Water Specimens | Figure 5: Liquid Nitrogen Specimens |

**Discussion:**

The fracture energy of both the A-36 Steel and 4140 Steel noticeably decreased with temperature, while the fracture energy for aluminum decreased very slightly but was largely scattered around the same value. The values for the 4140 steel are not what was expected because the values for fracture energy between 3.2°F and 209°F are higher than the fracture energy at 209°F. The result can be seen in the difference between the fracture surfaces of the specimens that were about 212°F (Figure 4) and the specimens that were about -312°F (Figure 5). The hot steel specimens both fractured in a noticeably ductile manner. The surfaces are rough and irregular and the specimens were not broken fully in half. Meanwhile the cold steel specimens both have very flat and square fracture surfaces, which is characteristic of brittle fracture. Both the A36 and 4140 steels had passed their transition temperatures in the liquid nitrogen bath. The aluminum surfaces appear nearly the same for the specimens from both types of bath. Aluminum has an FCC crystal structure so a transition temperature is not to be expected.

When operating at extremely low temperatures the aluminum is going to be most useful. Both types of steel are extremely brittle at very low temperatures. They are both still strong, but their brittleness means that they aren’t tough enough to be practical. They fracture before plastically deforming. At relatively low temperatures (below -32 °F) the A36 steel is no longer useful. However, the 4140 steel has not yet reached its transition temperature and remains ductile. Therefore, both aluminum and the 4140 steel still have practical uses at relatively low temperatures.

Test Description

The specimen is supported by the testing apparatus on both ends. When the hammer comes down it strikes the specimen directly in the center of the notch. The force of the hammer is then counteracted by the force of the apparatus pushing back on both ends. This creates stress in the specimen that is higher than it can handle so it fractures. The shear stress causes an angle at the point where the hammer strikes. The associated angle change causes tension on the far side from the hammer and that side expands.

**Conclusion:**

A36 steel experiences a transition temperature that is significantly higher than the 4140 steel. The 4140 steel does experience a transition temperature, but since that temperature is below -200°F it is suitable for the majority of applications, the main exception being cryogenic applications. Since both types of steel have BCC structures, the presence of a transition temperature is expected. If the temperature gets low enough that the steel does become embrittled it remains strong, but its toughness is significantly decreased. This is an important consideration since fracture can unexpectedly occur if one is unaware of the transition temperature. The aluminum behaved consistently with other FCC materials and did not experience a ductile to brittle transition temperature. The fracture energy values were scattered around a base line with a very small decreasing trend as temperature went down. This makes it a suitable material at a very broad range of temperatures as it remains ductile and therefore it remains tough.