Temple University, College of Engineering

MEE-3305 Materials Laboratory

Time: 1:00pm Section: Wed Group: D

Lab title: Charpy Impact Testing

Each of the following members has made significant contribution to this lab report and we agree to receive a grade as a group:

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Date: 02/13/2024

Grading Rubric

Lab objectives	Methods and materials	Experimental results and data analysis	Discussion of the results	Conclusions	Writing
2 points	5 points	40 points	40 points	3 points	10 points

Lab Objectives

In this lab experiment, we were introduced to the Charpy impact test, which is used to find the relative toughness of a material. The Charpy impact test consists of a 27kg hammer having maximum potential energy mgh, releasing at 1.5m into a 55mm length by 10x10mm variety of notched metal bars at different temperatures, at maximum kinetic velocity 5.5m/s. After impact, the Charpy impact machine displayed the energy loss on a screen in joules (j). Using the data from the Charpy impact machine, we were asked to find the effect different temperatures had on the impact toughness along with how carbon content affected the impact toughness.

Methods and Materials

The Charpy Impact testing machine used is the Tinius-Olson Model# 148725 in conjunction with the T.O. Model Impact 104 data acquisition module. This configuration allows for a pendulum energy capacity of 406 Jules, stored in a 27 kg weight at 1.5 m in height. Repeatability testing done by ASTM E23-23a returns a standard deviation of ± 0.5J. Testing samples are machined according to ASTM to dimensions 55mm in length by a 10x10mm cross section and a 45° V-notch with a nominal radius of 0.25mm. Three steels of different carbon content including, 1018, 1045, and 4140 steel, are tested for their toughness. Each of the three sample materials are tested at various temperatures to determine differences in stored energy. These testing temperatures are 100°C, 24.8°C, 0°C, and -78°C, achieved by placing each of the materials in either a hot water kettle, room temperature, ice, and dry ice respectively. Dimension values were measured after each material was sufficiently adjusted to its testing temperature.

The experiment carried out by the Charpy Impact test determines the fracture toughness or amount of internal energy before fracture. This includes both elastic and plastic deformation of a material. The Tinius-Olson Model# 148725 calculates the energy absorbed by observing the energy difference of the pendulum apparatus before and after the impact. Energy of the pendulum can be calculated by the difference in the vertical height of the mass described as:

$$E = mg(h_o - h_f)$$

where h_f is the final height, the pendulum can achieve after the impact.

All participants must stand behind the safety barrier whenever the pendulum is in motion and crossing only when certain the pendulum has the safety latch engaged. To carry through with the simple beam impact test, raise the pendulum into its top position by continuously adding momentum to its oscillation. Once the pendulum has successfully latched to the top of the apparatus, immediately close the safety latch to prevent the accidental release of the pendulum via the latch handle. Place the Charpy sample onto the anvil with the V-notch facing away from side to be impacted by the hammer. Ensure all people and objects are cleared from the testing perimeter before continuing. Unlatch the safety and pull the release lever. Press the electronic brake button to stop the pendulum from swinging. The resulting difference in energy will be displayed on the data acquisition module.

Within this experiment, we tested 3 different steel alloy bars as described above. For 1018 steel the carbon content is known to be 0.18%. Along with this carbon content, this steel has a BCC atomic structure, which makes it more ductile. When discussing ductile materials, the material that is being studied shears, meaning the cross section is deformed before breaking. If the material is brittle, the cross section will appear flat, with small bumps, this means it has fractured. This steel can transform into FCC, however, but it takes a tremendous amount of heat 710°C. Since we only heated the steel bar to 100°C, it is still BCC. With this steel having a relatively low carbon content, we expect a ductile break at room temperature, along with at 100°C. When executing the Charpy Impact test on temperature 0°C and -78°C, the expected outcome would become a mixture of a fracture and shearing.

The second steel tested was 1045 steel. For this steel, there is a BCC atomic structure present. For this steel, since it does have a higher carbon content, which is 0.45%, does make it significantly more brittle. With it being more brittle at room temperature we were able to hypothesis the Charpy Impact test would show most brittleness properties, showing the brittleness of the material at the core, and little ductile around the edges. When introduced to the higher temperature, the steel should still show brittleness due to the high carbon content. When introduced to the colder temperatures, steel reacts by becoming more brittle, meaning the already brittle steel will become more so, causing the Charpy Impact machine to show a very low force at both 0°C and -78°C.

The third steel that was tested at the four different temperatures was 4140. The carbon content of this steel is 0.40%. Like the 1045 steel, this steel also has a high carbon content. We expected the cross section to be a mix of shear, and fracture at 20°C, and more ductile at 100°C. for the colder temperatures, the steel bar should show to be very brittle, however we shouldn’t obtain as low of values as the 1045 steel.

Experimental Results and Data Analysis

Steel	Carbon Content	HRA	Energy Loss			
			100	22	0	-78
1018	0.18%	88.78	158.69	76.602	14.161	2.9401
4140	0.40%	21.86	74.488	57.117	59.244	8.7329
1045	0.45%	78.42	74.488	13.494	33.486	2.3767

Steel	Carbon Content	Lateral Expansion (mm)			
		100	22	0	-78
1018	0.18%	0.68	0.32	0.14	0.11
Percent Difference		6.81%	3.26%	1.42%	1.12%
4140	0.40%	0.97	0.21	0.05	-0.27
Percent Difference		9.73%	2.12%	0.50%	-2.64%
1045	0.45%	0.08	0.76	0.21	0.20
Percent Difference		0.81%	7.68%	2.12%	1.99%

Table 2: Data Collection of Energy Loss, Lateral Expansion, and Rockwell

Table 1: Data Collection of Energy Loss, Lateral Expansion, and Rockwell

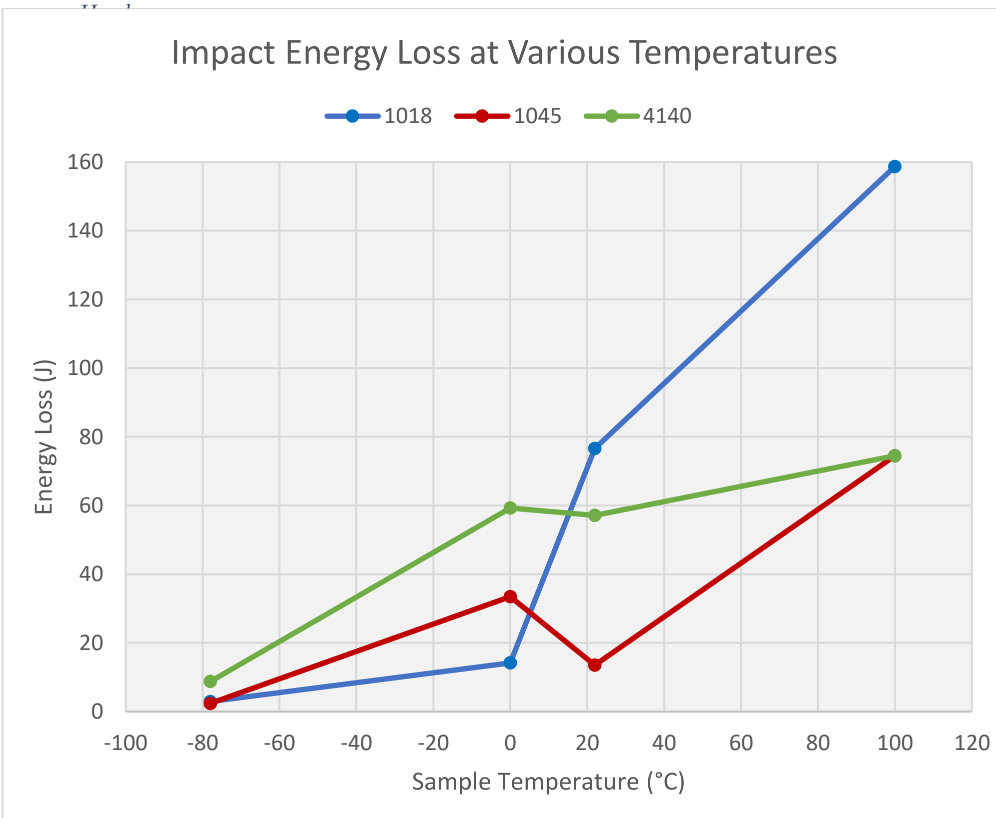


Figure 1: Impact Energy Dependent on Temperature for Constant Carbon Content of Steel

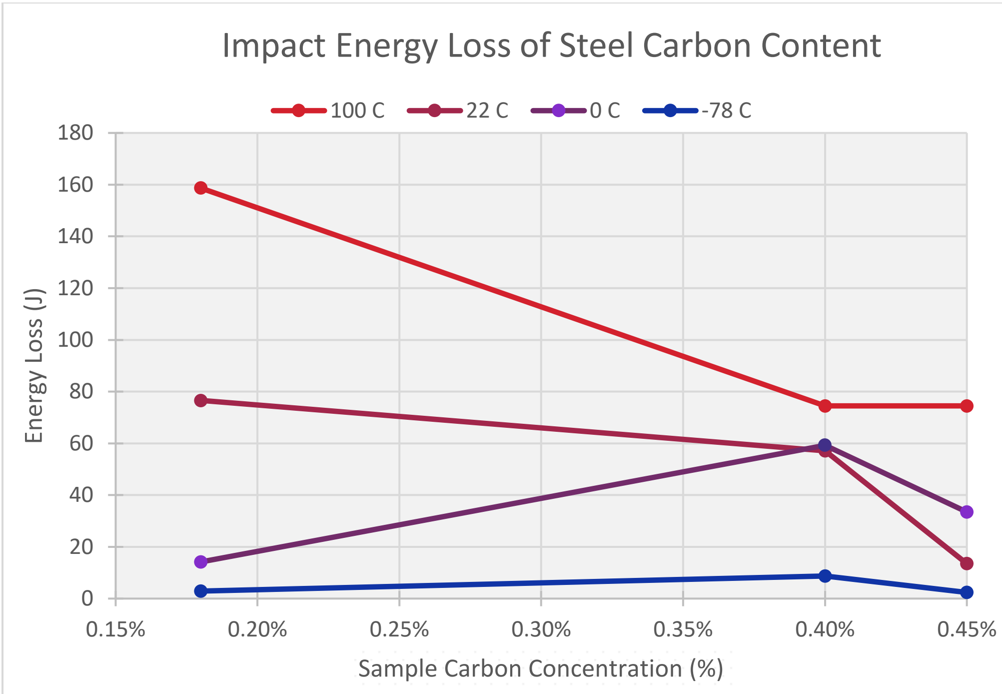


Figure 2: Impact Energy Dependent on Carbon Content of Steel for Constant Temperatures

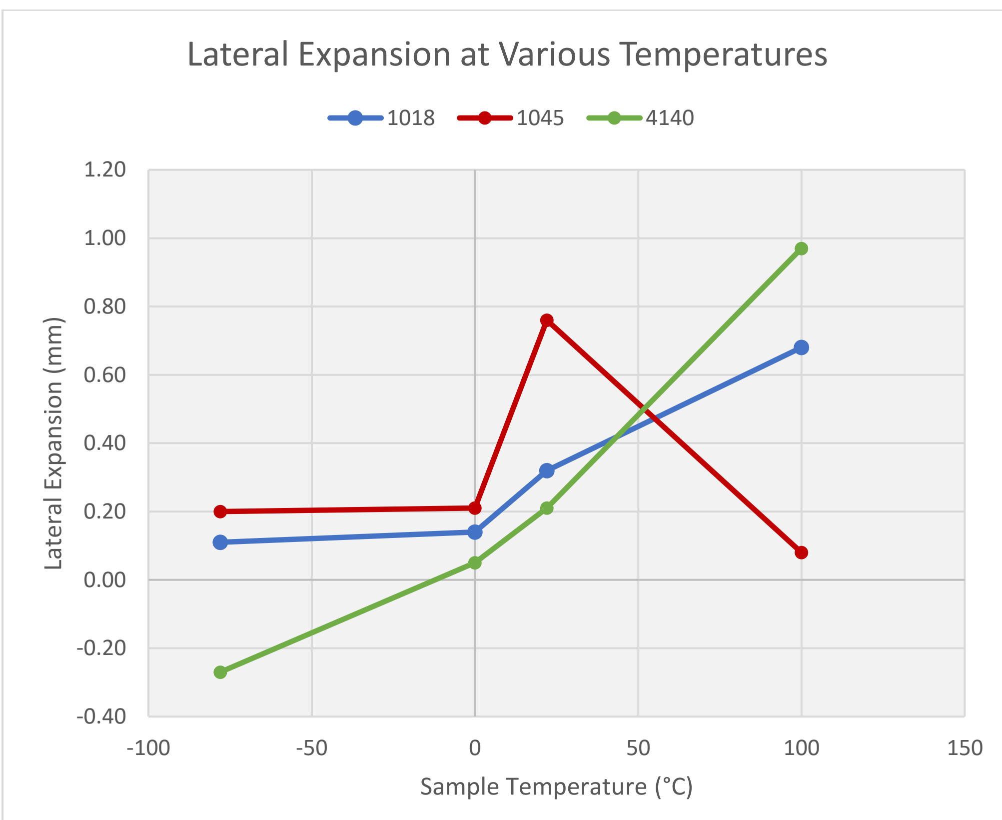


Figure 3: Lateral Expansion Dependent on Temperature for Constant Carbon Content of Steel

2/13/2024

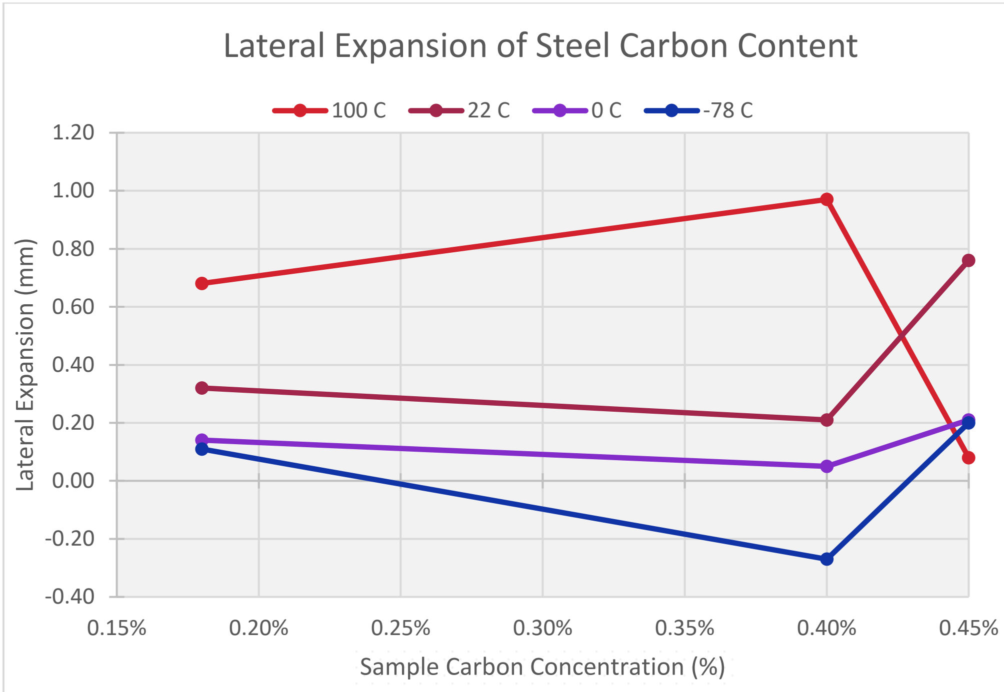
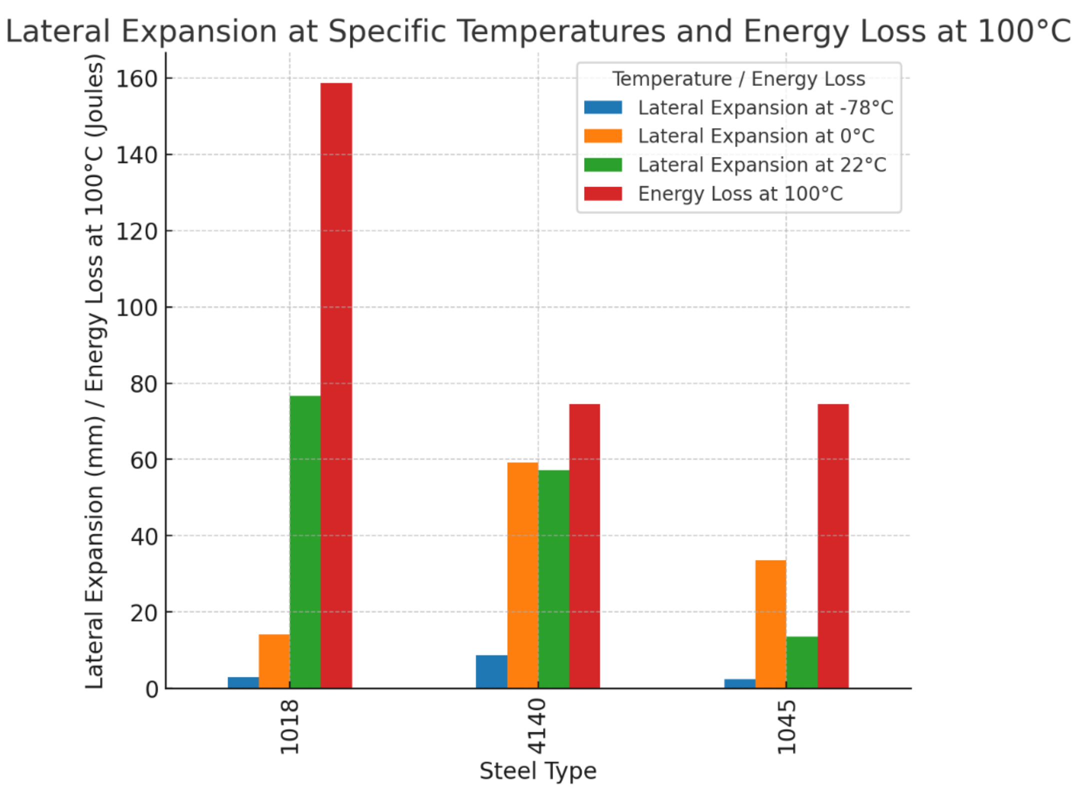


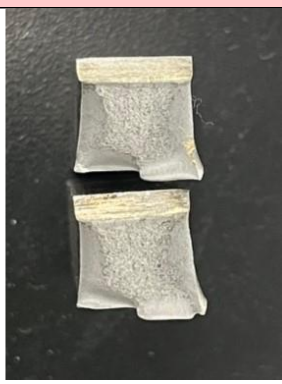
Figure 4: Lateral Expansion Dependent on Carbon Content of Steel for Constant Temperatures



Sample Calculations:

$$E = mg(h_o - h_f)$$

Fracture Samples

100°C	24.8°C	0°C	-78°C
1018			
			
1045			
			
4140			
			

Discussion

During our experiment, we noticed there was a close correlation between the temperatures of the steel bars and the energy loss corresponding with them. When referencing the energy loss/temp graph from above, it shows the 3 different carbon steels, and the 4 states of temperature that they were tested at. Starting with the dry ice, it is shown all four steel bar samples broke very easily with no more than ~10 Joules of energy. Progressing to 0°C, there starts to be a difference in toughness between the 3 samples. At this temperature, some samples broke with as little as ~15 Joules and some with as much as 60 Joules. When moving to the room temperature data, there was a dip in energy loss for 4140 and 1045 steels. Generally speaking, there was still a trend towards more impact energy loss. A hypothesis was drawn that this could be an error resulting from the positioning of the steels on the machine not being perfect, resulting in inconsistent data. By far, the most significant amount of energy needed to break the samples happened at 100°C, where it took from 75 to 160 Joules. It should be noted that 1018 steel absorbed nearly double the impact energy other two samples. This correlates with the carbon content being nearly half of 4140 and 1045. This makes sense when taking into account that as temperature of materials increases, ductility also increases. Likewise, a decrease in carbon content would create a less brittle alloy, which is evident by the experiment results.

We also observed a significant relationship between the temperature conditions of the steel samples and both their energy absorption and lateral expansion characteristics. The analysis on the data gathered for the three carbon steels at the four different temperatures revealed differences in their mechanical behavior under impact in the test.

The samples submerged in dry ice showed a uniform response across all steel types; each fractured with negligible energy absorption, 2.94, 8.73 and 2.37 Joules, pointing out their brittle nature at low temperature. As we changed the temperature to 0°C, the deviation in mechanical strength between the steel samples became evident, showing material-specific responses to thermal conditions.

Upon reaching room temperature, an unexpected reduction in energy absorption was noted for the 4140 and 1045 steel varieties. Examining deeper into the lateral expansion measurements provided further insights. These data points indicated the material ductility and were aligned with the energy absorption data at each temperature. This correlation allows us to understand the impact of thermal conditions on the steels' capacity to experience plastic deformation before failure.

The lateral expansion data obtained from the experiment shows the transition in material behavior with temperature variations. At sub-zero temperatures, the steels presented minimal lateral deformation, aligning with the low energy absorption and the brittle fracture observed. As temperatures ascended to 0°C and further to ambient conditions, the disparities in lateral expansion among the steel types became more pronounced, reflecting a gradual shift towards ductile fracture mechanisms, especially in steels with lower carbon content.

Conclusions

In this lab we were introduced to the toughness testing of steels by using a machine called Charpy Impact testing. Using the machine, we received energy loss numbers in joules (j), and used the numbers, along with the temperatures at 4 different states, created various graphs to help illustrate and prove our hypothesis. There were some odd data points we had such as in the energy loss vs temperature graph, but the graph over all shows all carbon steels becoming more ductile as the temperature rises. Overall, it was a successful experiment with expected results from the hypothesis.

Appendix

Steel 1018	+100 ^{0}C	+22 ^{0}C	0 ^{0}C	-78 ^{0}C
Before A,mm:	9.99	9.83	9.83	9.82
After A, mm:	10.67	10.15	9.97	9.93
Lateral Expansion (Δl)	0.68	0.32	0.14	0.11
Energy Loss	158.69	76.602	14.161	2.9401
HRA - B scale	88.78	88.78	88.78	88.78

Steel 1045	+100 ^{0}C	+22 ^{0}C	0 ^{0}C	-78 ^{0}C
Before A,mm:	9.97	9.92	9.94	10.21
After A, mm:	10.94	10.13	9.99	9.94
Lateral Expansion (Δl)	0.97	0.21	0.05	-0.27
Energy Loss	74.488	13.49	33.486	2.38
HRA - B scale	78.42	78.42	78.42	78.42

Steel 4140	+100 ^{0}C	+22 ^{0}C	0 ^{0}C	-78 ^{0}C
Before A,mm:	9.92	9.9	9.92	10.07
After A, mm:	10.00	10.66	10.13	10.27
Lateral Expansion (Δl)	0.08	0.76	0.21	0.20
Energy Loss	74.49	57.117	59.24	8.7329
HRA - B scale	21.86	21.86	21.86	21.86

		Trial	HRC	
HRA Calibration - C scale		1018 - B scale - 1/16 ball		
1	63.3	1	88.8	**Mean**
2	64.2	2	88.7	88.78
3	64.3	3	87.8	**Std Dev**
4	64.4	4	88.8	0.7085
5	64.5	5	89.8	
		1045 - B scale - 1/16 ball		
		1	77.8	**Mean**
		2	80.3	78.42
		3	78.1	**Std Dev**
		4	78	1.0569
		5	77.9	
		4140 - C scale - diam tip		
		1	22.5	**Mean**
		2	23.4	21.86
		3	20	**Std Dev**
		4	22.2	1.3031
		5	21.2	