MEEN 160

MATERIALS SELECTION IN MECHANICAL DESIGN

EXPERIMENT #3

THE DUCTILE TO BRITTLE TRANSITION AND THE SELECTION OF STEEL FOR LOW TEMPERATURE SERVICE

by

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Introduction:

The purpose of this laboratory was to use a series of Charpy impact tests to determine the dependence of the fracture resistance on temperature of an annealed ferritic medium carbon steel and an age hardened aluminum alloy. At room temperature and above, steels are extremely ductile and resistant to brittle fracture and fail by dimple rupture. However, at lower temperatures they become brittle and are fracture by cleavage whenever they contain notches and are subject to impact loads. Aluminum alloys do not exhibit a ductile to brittle transition but instead exhibit a gradual decrease in impact energy with decreasing temperature and fracture by ductile dimple fracture at all temperatures. For this laboratory Charpy impact testing and Rockwell B hardness testing were used to demonstrate the ductile to brittle transition in AISI/SAE 1045 steel and the absence of it in 6061-T6 aluminum alloy.

Experimental Procedure:

For this laboratory two tests were performed to demonstrate the ductile to brittle transition in steel at different temperatures and the absence of it in aluminum alloys. To achieve different temperatures for the specimens, they were first immersed in different temperature baths which included liquid nitrogen (-196°C), dry ice in methanol (-75°C), a cooling unit (-40°C), ice water (0°C), air at room temperature (25°C), an antifreeze unit (60°C), boiling water (100°C) and oil (150°C and 200°C). Then the specimens were fractured using the impact machine. One of the halves of the fractured specimen was then again immersed in one of the temperature baths and the Rockwell B hardness test was performed. After the testing was performed, the specimens were looked at with a low powered microscope to determine the percent ductile (shear) fracture.

Results:

A. Data

Table 1. Nominal Chemical Composition of AISI/SAE 1045 Steel and 6061-T6 Aluminum Alloy

Alloy Type	**Alloy Element**							
	Fe	**Al**	**C**	**Mn**	**Si**	**Cr**	**Mg**	**Cu**
AISI/SAE 1045 Steel	Bal.	---	0.46	0.75	---	---	---	---
6061-T6 Aluminum	---	Bal.	---	---	0.6	0.23	1	0.27

Table 2. Charpy Impact Energy, Percent Ductile Fracture and Rockwell B Hardness Values for Annealed 1045 Steel

Specimen Number	Heating/Cooling Medium	Test Temp. (C)	Hardness (R_B)	Impact Energy (ft. lb.)	% Ductile Fracture
S1	Liquid Nitrogen	-196	97.6	2.4	0
S2	Liquid Nitrogen	-196	92.0	1.5	0
S3	Liquid Nitrogen	-196	91.9	0.9	5
S4	Dry Ice/Methanol	-75	92.7	4.8	0
S5	Dry Ice/Methanol	-75	91.5	6.5	10
S6	Dry Ice/Methanol	-75	92.1	4.0	10
S7	Cooling Unit	-40	87.8	13.6	20
S8	Cooling Unit	-40	91.8	5.5	10
S9	Cooling Unit	-40	85.0	10.9	10
S10	Ice Water	0	89.0	22.7	40
S11	Ice Water	0	86.4	12.2	20
S12	Ice Water	0	88.7	15.1	20
S13	Room Temp.	25	98.8	26.3	40
S14	Room Temp.	25	95.6	19.4	15
S15	Room Temp.	25	94.6	16.6	40
S16	Antifreeze Unit	60	88.2	23.9	60
S17	Antifreeze Unit	60	89.1	21.3	50
S18	Antifreeze Unit	60	94.8	19.0	70
S19	Boiling Water	100	87.2	56.4	85
S20	Boiling Water	100	87.3	58.9	60
S21	Boiling Water	100	85.8	60.9	85
S22	Oil	150	88.1	52.3	100
S23	Oil	150	87.8	57.4	100
S24	Oil	150	80.5	59.4	100
S25	Oil	200	85.2	60.0	100
S26	Oil	200	85.7	63.6	100
S27	Oil	200	85.6	55.9	100

Table 3. Charpy Impact Energy, Percent Ductile Fracture and Rockwell B Hardness Values for 6061-T6 Aluminum

Specimen Number	Heating/Cooling Medium	Test Temp. (C)	Hardness (R_B)	Impact Energy (ft. lb.)	% Ductile Fracture
A1	Liquid Nitrogen	-196	60.8	21.5	100
A2	Liquid Nitrogen	-196	51.7	14.7	100
A3	Liquid Nitrogen	-196	56.1	18.3	100
A4	Dry Ice/Methanol	-75	52.5	14.0	100
A5	Dry Ice/Methanol	-75	58.3	16.3	100
A6	Dry Ice/Methanol	-75	53.9	21.5	100
A7	Cooling Unit	-40	53.6	20.6	100
A8	Cooling Unit	-40	54.9	15.7	100
A9	Cooling Unit	-40	33.3	12.3	100
A10	Ice Water	0	54.7	11.5	100
A11	Ice Water	0	51.6	16.8	100
A12	Ice Water	0	54.9	18.6	100
A13	Room Temp	25	51.9	22.0	100
A14	Room Temp	25	55.3	15.3	100
A15	Room Temp	25	55.1	16.7	100
A16	Antifreeze Bath	60	48.5	18.8	100
A17	Antifreeze Bath	60	41.0	16.0	100
A18	Antifreeze Bath	60	49.9	24.6	100
A19	Boiling Water	100	47.6	20.0	100
A20	Boiling Water	100	45.0	14.9	100
A21	Boiling Water	100	44.2	12.7	100
A22	Oil	150	47.1	19.9	100
A23	Oil	150	51.9	13.6	100
A24	Oil	150	48.0	13.4	100
A25	Oil	200	31.2	12.1	100
A26	Oil	200	35.9	12.5	100
A27	Oil	200	40.4	12.4	100

B. Graphs

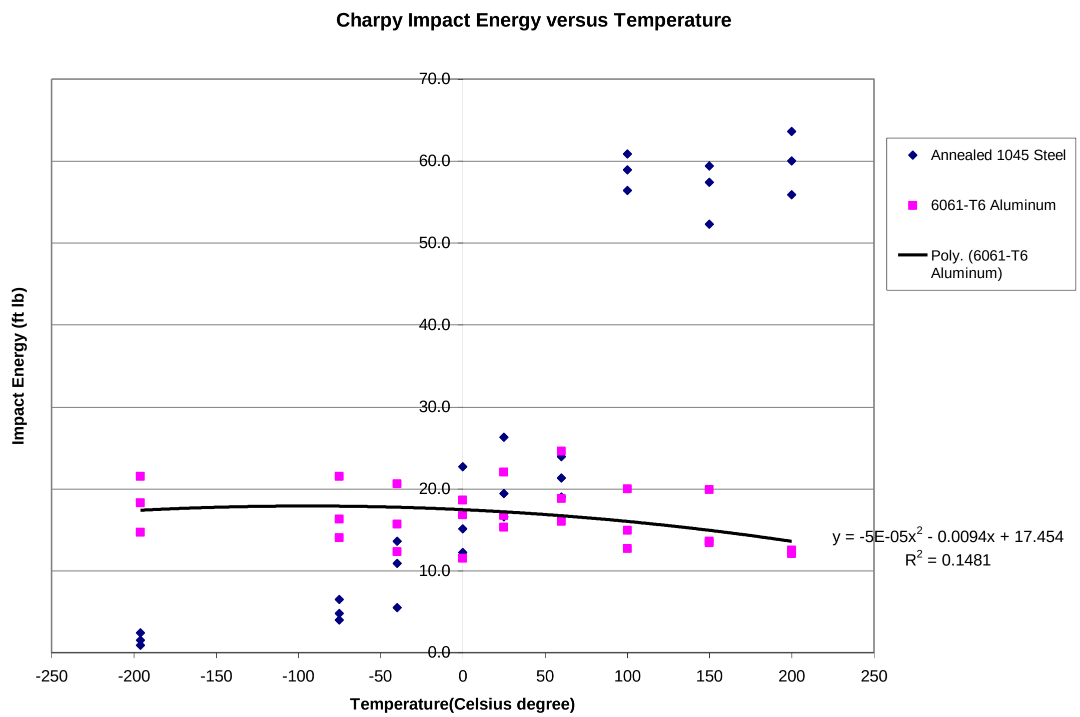

Figure 1. Charpy impact energy vs. Temperature

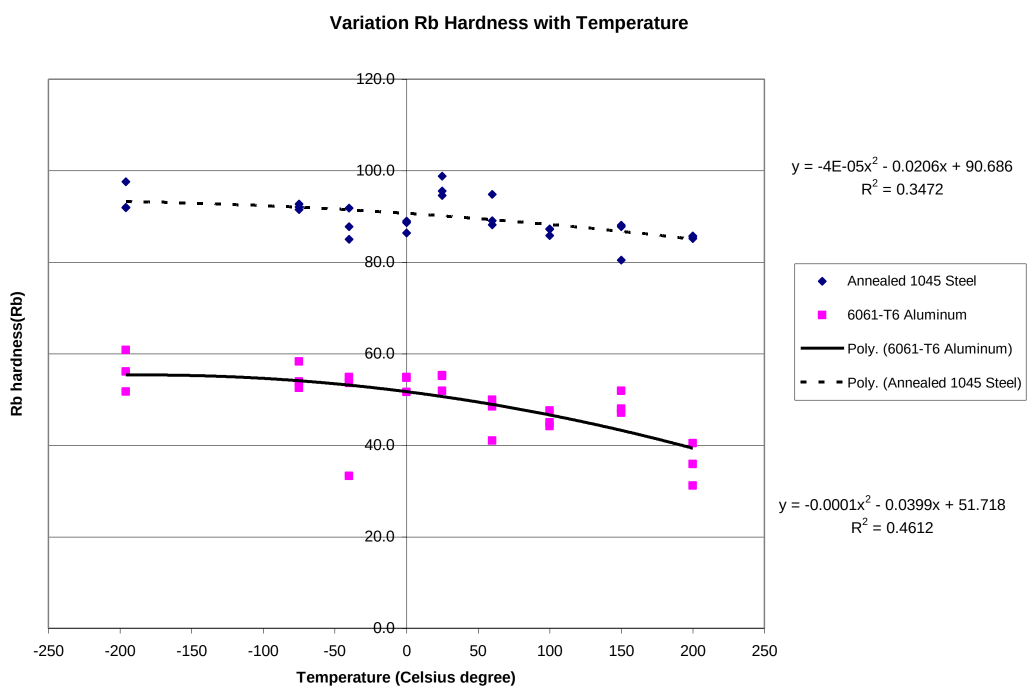

Figure 2. Variation Rb Hardness with temperature

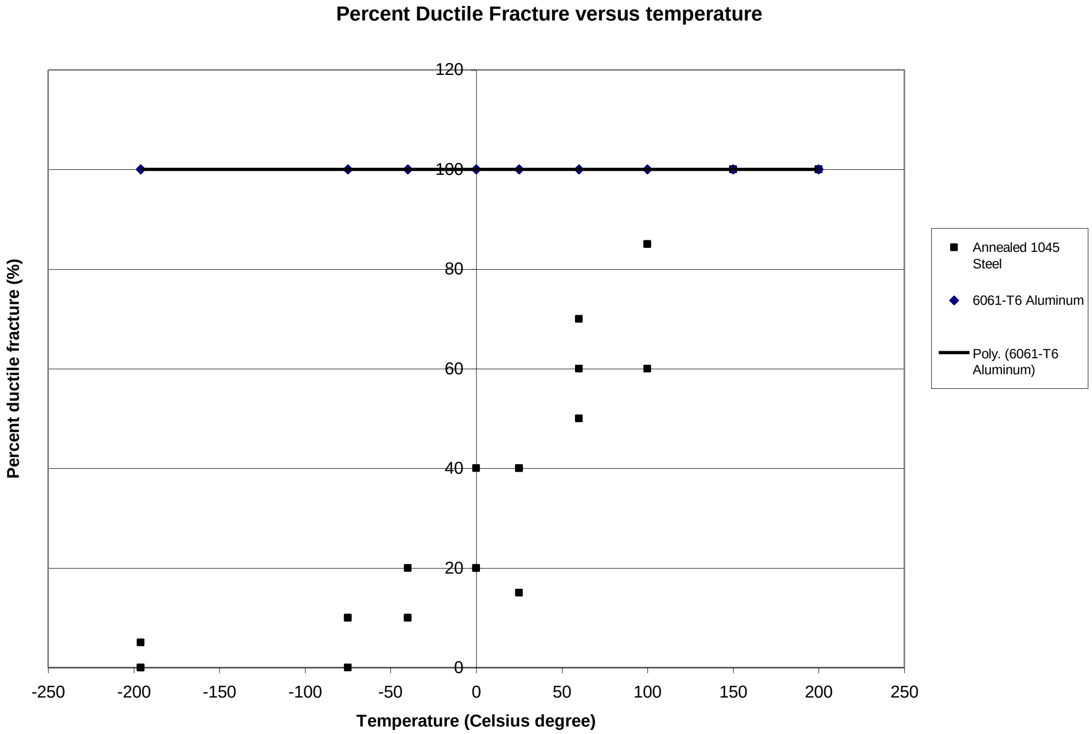

Figure 3. Percent Ductile Fracture versus Temperature

	Ductile to Brittle Transition Temperature (Tc) [Celsius Degrees]
Annealed 1045 Steel	25

Table 4. Ductile to brittle transition temperature through the ductile to brittle transition temperature for the annealed AISI/SAE 1045 Steel at 30 lb ft

	50% ductile fracture temperature [Celsius Degrees]
Annealed 1045 Steel	44

Table 5. 50% ductile fracture temperature through the percent ductile fracture versus temperature graph for the annealed AISI/SAE 1045 Steel at 50% ductile percent

(a) at the liquid nitrogen boiling point

(b) at a temperature midway through the ductile to brittle transitition

(c) above the "upper shelf" temperature

Figure 4. Schematic diagrams of the macroscopic appearance of the fracture surfaces of Charpy impact specimens of the AISI/SAE 1045 steel.

Discussion:

Based on the results of this experiment, hardness testing can be used to predict brittle fracture in steels. Because annealed steel 1045 and aluminum, which have different percent of ductile fracture and Charpy impact energy with various temperature, show similar trend for hardness with various temperature.

Ductile to brittle transition is between dimple rapture and brittle feature. Bcc metals have high yield strength sensitivity to temperature so the fluctuation exhibits a ductile to brittle transition grain size and strain rate. However, Charpy impact test does not depend on grain size. Therefore, the force at impact creates a moment on the specimen that is largest at the outer edge of the cross-section and zero in the center with a linear decrease from outer radius to center. Ductile failure only occurs where the moment is large enough to negate the shear force created by the impact. At room temperature and above typical low and medium carbon steels, which are all ferritic, are usually extremely ductile and resistant to brittle fracture and fail by dimple rupture. However, at lower temperatures they become brittle and are easily fractured by cleavage whenever they contain notches and are subject to impact loads.

This test does not provide property data for design purposes for material sections containing cracks or flaws. Data of this type are obtained from the discipline of fracture mechanics, in which theoretical and experimental analyses are made of the fracture of structural materials containing preexisting cracks or flaws. The energy values obtained from directly in mechanical design due to the nature of the Charpy impact test. When designing something with a requirement to withstand a certain maximum force. The energy can be used to obtain the force and stress that the member can resist before it fails.

Reference:

Smith, W. F. and Hashemi, J., 2005, Foundations of Material Science and Engineering, 4th Ed, McGraw-Hill, New York.

Metals Handbook, 9th Ed., Vol 11, Failure Analysis and Prevention, 1975, Amer. Soc. Metals, Metals Park, Ohio.