Empirical Determination of the Ductile to Brittle Transition Temperature of Steel Samples

Abstract

Material science is field of engineering focusing on the causes of variation in the properties of substances to allow considered decisions about fabrication of products to be justified. The material property under consideration here is the mechanism of fracture, either ductile or brittle. Impact testing has been performed on a steel samples using a Charpy Machine.

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Introduction

Products designed by engineers require materials to be selected from which they are manufactured. How a material fails is critical information for deciding from what to fabricate products that have to withstand potential impacts. Failure of a material occurs through the propagation of a crack until fracture. Fractures are categorized as either ductile or brittle depending on the propagation of a crack. The process of modelling crack propagation is complex, requiring empirically derived material properties and geometric information about the body and the crack [1]. It is further complicated by the type of fracture by which a material will fail varying with temperature. It is therefore difficult to derive from analysis alone if a material will fail with a brittle or ductile fracture. When working with new or proprietary materials for which existing data about performance under impact is not available, it is often more straightforward to determine material properties by empirical testing.

Samples of material can be exposed to an impact sufficient to cause failure, for example hitting with a hammer and the resulting fracture can be qualified as either brittle or ductile. The drawbacks with this approach are the ability to replicate conditions when performing repeatable tests and the lack of quantified numerical data about the material performance. A Charpy machine [Siewert 1999] overcomes these drawbacks by using a pendulum, swung from a known height, to fracture a material. The height reached by the pendulum after impact allows the energy absorbed by the impact to be quantified and multiple samples can be exposed to identical impacts from the same pendulum started from the same position.

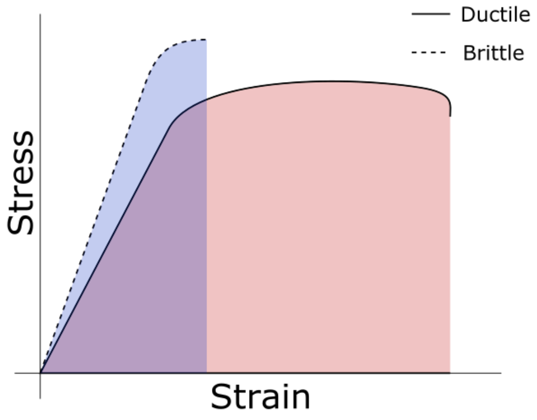
The work presented here discusses the use of a Charpy machine to investigate the fracture mode, either brittle or ductile, of a steel under consideration for manufacturing a product which will operate at extremes of temperature. Multiple tests will be performed at various temperatures to determine the ductile to brittle transition temperature (DBTT). Previous Charpy impact tests on varying grades of cold rolled steel have been performed by Takahashi et al [3] and the results will be used for comparison.

Aim

Determine the impact toughness of a specimen of the material under consideration at a variety of temperatures and compare the ductile and brittle transition temperature to previously published values.

Theory

A material under a tension load will experience an extension. The relationship between stress and strain for a ductile and a brittle material, is shown in figure below.



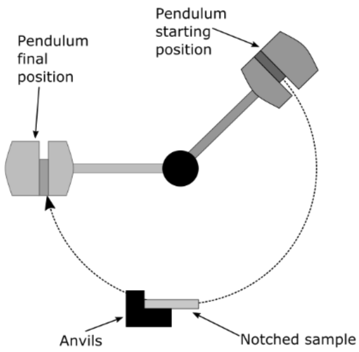
As loading increases from zero, both materials extend linearly under "elastic" deformation. When a material reaches the limit of elastic deformation, and the relationship between stress and strain deviates from linearity and plastic deformation begins. A brittle material will fracture following a small increase of additional stress beyond the elastic limit. Conversely, a ductile material will continue to deform to significantly greater extensions before failing.

The area under a stress strain curve is representative of the energy absorbed by the fracturing. Therefore ductile fractures typically absorb greater amounts of energy to fracture from impact.

Method

This experiment involves breaking six samples at varying temperatures using a Charpy machine, as shown in the figure below, and measuring the energy absorbed by the sample during impact. We conducted the experiments at sample temperatures of:

Test Number	Sample Temperature	Environment used
1	-196	Liquid nitrogen
2	-80	Dry ice
3	0	Iced water
4	20	Room temperature
5	100	Oven
6	200	Oven



The availability of equipment and materials capable of maintaining these temperatures and into which the sample can be immersed was their reason for selection. To fabricate the six samples required for testing in the Charpy machine, 3 mm steel was cut in a vertically milling machine to a rectangular section of 25 mm by 10 mm. A V-shaped notch, measuring 2 mm by 1 mm, is ground into the 25 mm length of the specimen. To allow later identification, we labelled each sample.

Two thermostatically controlled ovens were preheated to 100^{o}C and 200^{o}C. Using heat resistant gloves and tongs, we placed one sample in each oven and left it for sufficient time to reach equilibrium temperature. We immersed a further two sample in iced water (0^{o}C) and dry ice (-80^{o}C) using the tongs. Room temperature was determined using an alcohol thermometer located in the laboratory.

Before conducting the first experiment, we checked the operation of the Charpy machine and interlockers on the protective doors. A sample at room temperature was loaded between the anvils of the Charpy machine, with the notch facing away from the pendulum. The precise location of the sample was adjusted using the locating prong and the protective doors were closed. Instrumentation built into the Charpy machine was zeroed and the pendulum released, breaking the sample. The impact energy was recorded from the digital display. In order to later examine the fracture surface, we allowed the broken sample to return to room temperature, to avoid the risk of burning, carefully removed from the machine and stored.

For safety reasons, heat resistant gloves and tongs were used to remove the sample from the oven at 200^{o}C, and it was placed into the Charpy machine. We minimized the time taken to move the sample from the hot and cold environments to reduce the heat loss from the sample during transit, which would reduce the temperature of the sample from its known value. The impact test on the Charpy machine was conducted following the same procedure adopted for the room temperature sample. We then repeated this for the sample from the 100^{o}C oven, the sample immersed in the iced water and the sample immersed in the dry ice.

To perform the final test, heat resistant gloves and a face mask were used to ensure protection from the risk of burns. The remaining sample was lowered, using tongs, into a dewar of liquid nitrogen until the production of white vapour ceased. This indicated the sample had reached a temperature of -196^{o}C. The sample was then placed into the Chapy and tested using the same method as the other samples. We examined and recorded the fracture surface of all six samples.

Results

The experiment captured both qualitative impact energy data and qualitative fracture surface appearance.