Charpy V Notch Behavior of ToughMet® 3

CVN tests for various tempers of ToughMet3 were done at room temperature (0°F, -107°F,-144°F and -320°F (-18 °C, -77 °C, -98 °C and -196 °C). Unlike some steel, ToughMet3 does not exhibit a ductile-to-brittle transition, but CVN results do not correlate with low temperature tensile test results. In general, the CVN energy does not vary much with temperature for the lower ductility tempers, including ToughMet3 AT110 and TS160U. The high toughness temper of ToughMet3 TS95, shows a gradual, linear decrease in the CVN energy from room temperature down to -320 °F (-196 °C).

Introduction

Using ultimate tensile strength and elongation to calculate the energy absorbed during the tensile test may be an indication of a material's toughness, but it is an unreliable indicator of its tendency to fail catastrophically. This is because these parameters only represent the ability of a material to deform in the unconstrained tension of a tensile test. In practice, materials see many different stress states. As a result there have been various methods developed to determine fracture properties at specific conditions both to predict failure and determine material suitability. The Charpy V-notch (CVN) and plane strain fracture toughness testing are two tests widely used.

The Charpy Test

The introduction of alloyed steel in the 1800's led to vast improvements in design and manufacturing. The combination of steel's high tensile strength and ductility resulted in a tough material suitable for use in both structural components, such as bridges and buildings and mechanical components like pressure vessels and moving parts. As their use continued to increase, steel alloys failed unexpectedly in applications designed based on ductility and strength. As the study of failure modes expanded, designers became increasingly interested in impact loads. What started as a drop test on a finished part in the mid 1800's evolved to use of a notched material coupon struck by a pendulum, known as the Charpy V Notch (CVN) test (**Figure 1**).

Materion tests the CVN impact strength of its materials in accordance with ASTM E-23 with a Type A specimen. The notch is cut so the test is done in the LC (longitudinal circumferential) orientation when the sample is taken from the mid radius (**Figure 2**).

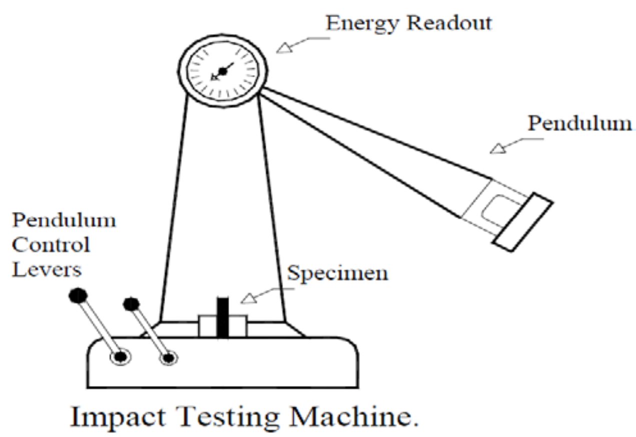

Figure 1: Charpy Impact Tester

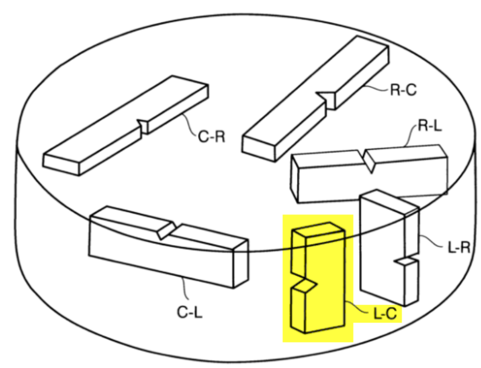

Figure 2: Diagram showing different sample/notch orientations. LC is highlighted

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ToughMet® 3 CVN Results

ToughMet3 has a face center cubic structure which precludes failure due to cleavage and a ductile-to-brittle transition. However, it can fail in a brittle manner in the macro scale. The difference between cleavage and ductile fractures are shown in **Figure3**.

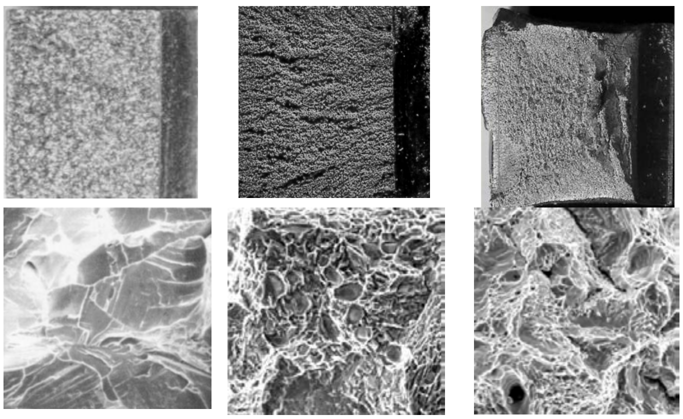

Figure 3: Fracture surfaces of broken coupons from CVN tests. From left to right: Cleavage fracture of low carbon steel, brittle fracture of T3 AT 110 , ductile fracture of T3 TS95. The top row is the entire surface and the bottom row is a 2000+ magnification on an SEM.

A comparison of the effect of temperature on the impact strength for ToughMet3 TS95 and a structural steel is shown in **Figure 4**.

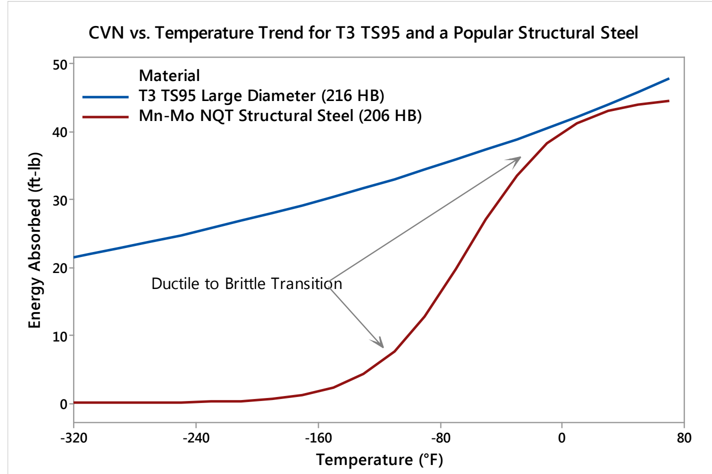

Figure4: Graph showing the temperature relationship between large diameters T3 in the TS 95 temper compared a structural steel with similar room temperature hardness.

The toughness of ToughMet 3 is highly dependent on the processing of the material. In general the cold worked tempers show higher CVN results than material of similar strength without cold work. Charpy V-Notch tests for the several tempers were done at room temperature and colder to demonstrate the lack of a ductile-brittle transition. **Table 1** show results at -107°F and -320°F compared to the room temperature results. Results at 72°F , 0°F, -107°F, -144°F, and -320°F are plotted as fitted line graphs in **Figure 5**. Plotting the tensile fracture energy (the ultimate tensile strength multiplied by the strain at fracture) on the same graphs reveals the lack of correlation with CNV energy.

Table1: CVN Results at -107°F ad -320°F compared to room temperature results

	Room Temperature	-105 F		-320F	
	Test Result	Test Result	Percent of RT	Test Result	Percent of RT
ToughMet 3 AT 110	**5.0 ft-lb**	**4.8 ft-lb**	**95%**	**4.3 ft-lb**	**85%**
ToughMet 3 TS 160U	**5.5 ft-lb**	**5.0 ft-lb**	**91%**	**5.5 ft-lb**	**100%**
ToughMet 3 TS 120U	**13.8 ft-lb**	**11.0 ft-lb**	**80%**	**9.8 ft-lb**	**71%**
ToughMet 3 TS 95	**46.0 ft-lb**	**32.8 ft-lb**	**71%**	**22.3 ft-lb**	**48%**

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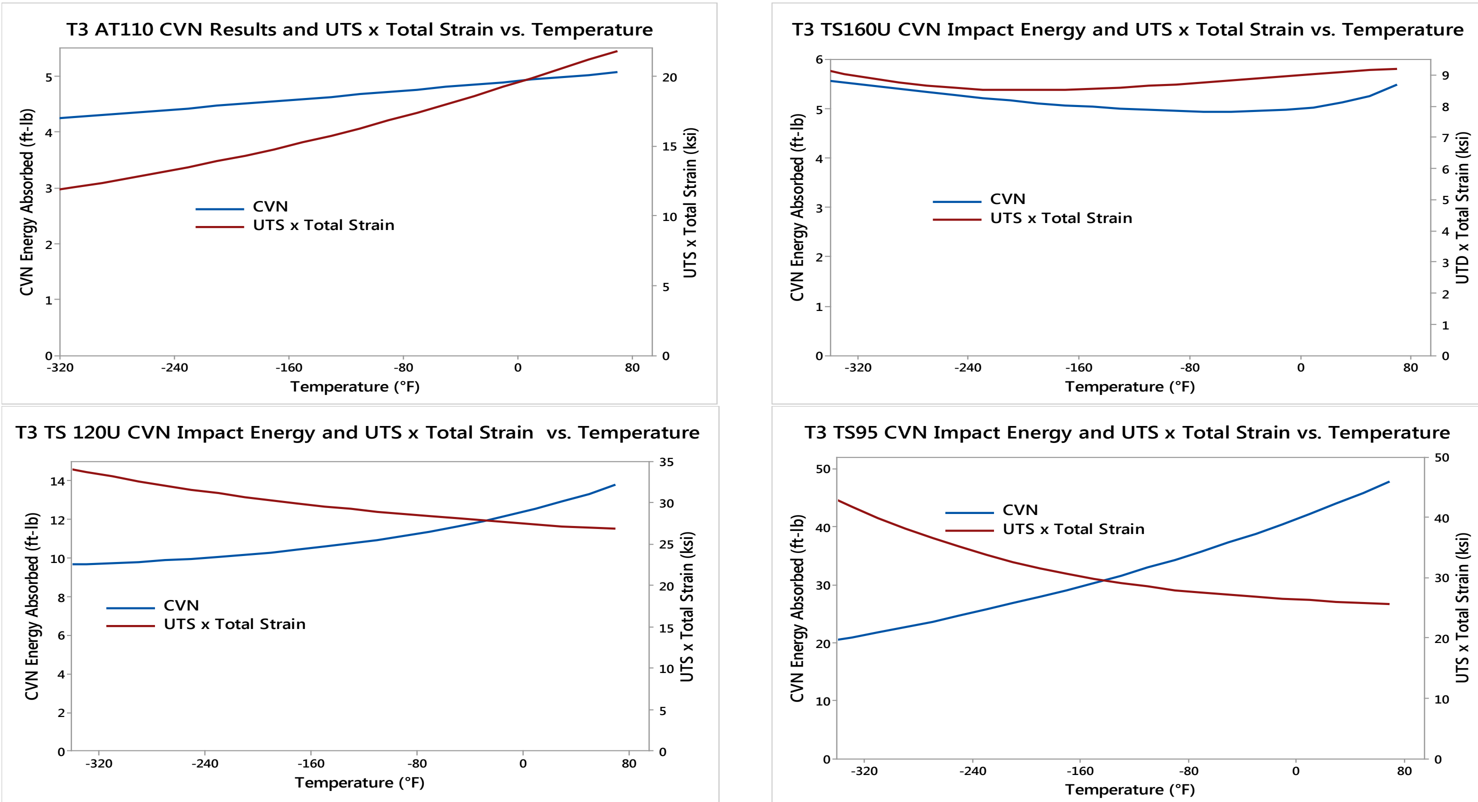

Figure 5: CVN results and tensile fracture energy plotted against temperature for 4 tempers of ToughMet3

Correlation of CVN and Plane Strain Fracture Toughness

The fracture mechanism of a Charpy test is complicated. In most case the fracture starts in plane strain then moves to plane stress as the final shear lip is created. In some cases there are multiple crack fronts. It is impossible to distinguish the energy used in the different fracture mechanisms and crack fronts. Therefore the Charpy value cannot be generalized and used for specific designs. However, measuring magnitude of the applied stress at which a crack of defined length freely propagates when subjected to plain strain provides a more meaningful parameter. This parameter, referred to as the critical intensity or K_{IC}, where I represents the mode of fracture as being normal to the stress being applied. This test, ASTM-E399, is much more complicated than a Charpy test, making CVN testing the more common method of determining fracture toughness. Also it should be noted that ductile materials may require a prohibitively large test pieces to get a valid K_{IC} result. Empirical relations have been developed between plane strain fracture toughness and CVN data. **Figure 6** plots the relation of some steels along with some of Materion's alloys.

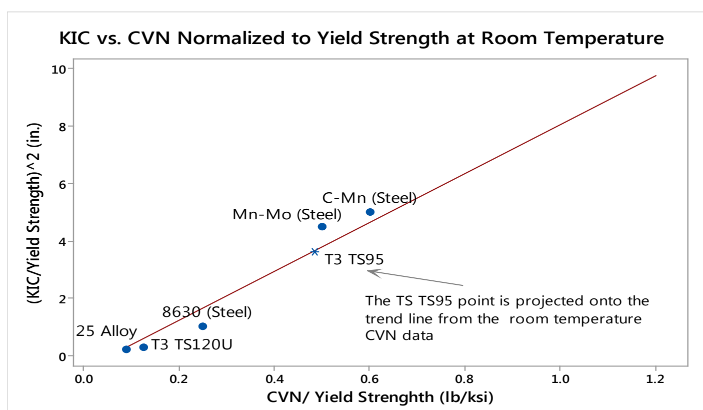

Figure 6: KIC values compared to Charpy values of some popular steels normalized to yield strength and plotted with Materion's alloys.

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