

“Evaluation of Fracture Speed on Ductile Fracture Resistance”

by

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ABSTRACT

The effect of fracture speed on the ductile fracture resistance of line-pipe steels can have an important effect in the basic understanding of the toughness requirements for crack arrest. Over the last few decades, it has become recognized that the drop-weight tear test (DWTT) better represents the ductile fracture resistance than the Charpy test since it utilizes a specimen that has the full thickness of the pipe and has a fracture path long enough to reach steady-state fracture resistance. The fracture speed in the DWTT is typically 50 to 60 feet per second (15.2 to 18.3 m/s), whereas the fracture speed in the full-scale pipe test is 300 to 1,000 fps (91.4 to 305 m/s). This paper extends the DWTT work to assess if the specimen can be modified to obtain higher fracture speeds and what effect it has on the fracture resistance.

INTRODUCTION

Historically the Charpy test has been used to quantify the ductile fracture resistance of line-pipe steels. It has been used in semi-empirical models to determine the minimum toughness for crack arrest of an axial crack once it reached the critical size to start an unstable fracture [1]. More recently, the drop-weight tear test (DWTT) energy has been used to characterize the ductile fracture resistance better than the Charpy test. The Charpy test is limited by the fact that there is a blunt notch in the specimen, the specimen is not the full thickness of the pipe, and perhaps more importantly, the fracture path of the specimen is not long enough to develop a steady-state fracture. The DWTT specimen overcomes these shortcomings [2].

More detailed analyses of the steady-state fracture region in the DWTT specimen were performed by carefully instrumenting the specimen and measuring the loads, load-point displacements, crack growth and the crack-tip-opening angle (CTOA) while the crack was propagating in DWTT impact tests [3,4].

SUMMARY

In a prior study, a very limited amount of data was developed to determine the effects of modifying the DWTT specimen. The modifications involved changes to the initial notch type as well as using different depth of backslots. The initial notch types investigated were the standard API pressed notch,

a chevron notch, and starting with the standard pressed-notch specimen and quasi-statically loading it to just past maximum load to start a ductile tear (a static-precracked notch). The static-precracking procedure consumes the energy needed to initiate the ductile fracture prior to the impact testing. Figure 1 compared some of the test records.

The backslotting of the DWTT specimen is shown in Figure 2, where the slot is filled with a high strength shim of steel so the compressive loads are transferred but the fracture does not go through the backslotted region. The backslot accomplishes several goals. First, the last ~1/3 of the initial ligament in the DWTT specimen does not contribute to the steady-state fracture process, other than transferring the compressive loads at the start of the test. Hence, one could use a static-precracked DWTT specimen with the shallow backslot and the impact energy obtained from that specimen would represent the energy required for steady-state fracture.

A second observation made in changing the backslot depth was that as the backslot became deeper, then the fracture speed increased dramatically [5]. The high-speed digital video equipment used at that time was limited to 4,000 frames per second and with the deep backslotted specimens the fracture speed was so fast that in a few of the tests only one frame of the crack propagation could be captured. The fracture speed was estimated to be ~300 feet per second (91.4 m/s).

On-going efforts are exploring a different modification to the DWTT test. One aspect is to increase the width of DWTT samples from the standard 3-inch (76.2 mm) to 5-inch (127 mm). This is to increase the ligament length in a deep backslotted specimen to capture more steady-state data. Secondly, there is newer high-speed digital video equipment that can capture full resolution frames at 8,000 frames per second, or reduced resolution frames at 210,000 frames per second. This combined specimen modification and improved instrumentation will make this study viable.

These test efforts are on-going and results will be included in the final paper. Additionally, a new DWTT impact machine is being built at Emc² that has much higher capacity than the one used for past testing. The servohydraulic actuator used in the test system has about 500,000 lb (2,224 kN) capacity under static condition, and dynamically the speeds will be comparable to DWTT impact machines, i.e., the actuator velocity will approach 20 feet per second (6.1 m/s) after about 0.5 inch (12.7 mm) of displacement¹ with a total stroke capacity of 18 inches (0.457 m). As can be seen in Figure 1, the important part of the data is during the first 1.5 inches of displacement, so there is more than enough stroke capacity, load capacity, and speed. The equivalent impact energy capacity of this new test machine is in excess of 75,000 ft-lb (101,700 J). The objectives of the on-going effort is to assess how the fracture speed changes the toughness in different grades of steel, and to assess that effect in a similar manner as was done in Reference [6].

REFERENCES

- [1] Maxey, W. A. "Fracture Propagation" in 5th Symposium on Line Pipe Research, American Gas Association Catalogue No. L30174, Nov. 1974.
- [2] Wilkowski, G. M., "Fracture Propagation Toughness Measurements," Paper K in 6th Symposium on Line Pipe Research, American Gas Association, Catalog No. L30175, November 1979.
- [3] G. M. Wilkowski, D. L. Rudland, Y.-Y. Wang, D. Horsley, A. Glover, and B. Rothwell, "Determination Of The Region Of Steady-State Crack Growth From Impact Tests," in Proceedings of IPC-2002 Conference, October 2002, Calgary, Alberta, Canada.
- [4] D. L. Rudland, G. M. Wilkowski, and Y.-Y. Wang, D. Horsley, B. Rothwell, and A. Glover, "Investigation Into the Use of a Single Specimen For The Determination Of Dynamic Steady State Propagation Resistance In High Toughness Line-Pipe Steels," in Proceedings of IPC-2002 Conference, October 2002, Calgary, Alberta, Canada.
- [5] D. L. Rudland, G. M. Wilkowski, and Z. Feng, Y.-Y. Wang, D. Horsley, and A. Glover, "Experimental Investigation of CTOA in Linepipe Steels," in Engineering Fracture Mechanics, 70, pp 567-577, 2003.
- [6] G. Wilkowski, D. Rudland, H. Xu, and N. Sanderson, "Effect of Grade on Ductile Fracture Arrest Criteria for Gas Pipelines," paper number IPC2006-10350, 2006 International Pipeline Conference.

¹ DWTT testing standards require impact velocities greater than 15 feet per second (4.57 m/s).

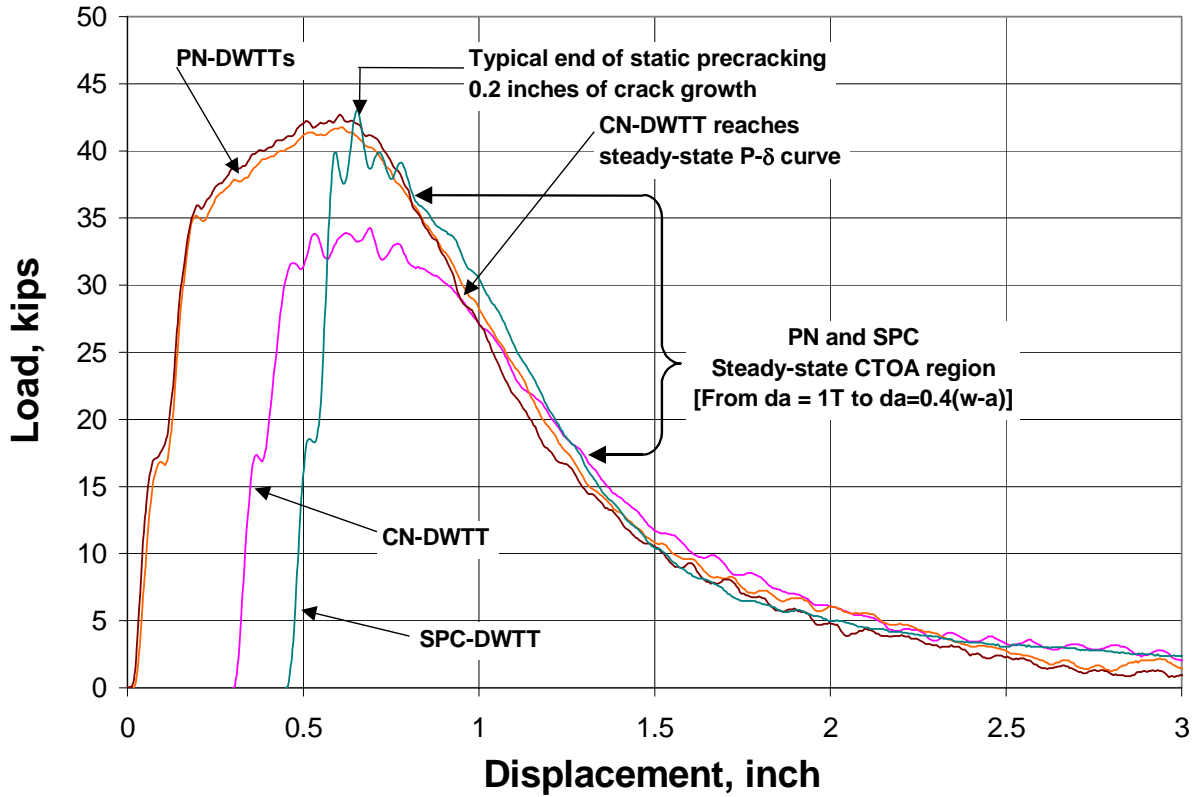


Figure 1 Comparison of dynamic load-displacement curves from standard PN-DWTT, chevron-notched (CN) DWTT, and static-precracked notch (SPC) DWTT specimens
 (Initial displacements of CN-DWTT and SPC-DWTT offset to match the crack growth from the PN-DWTT specimen data.)

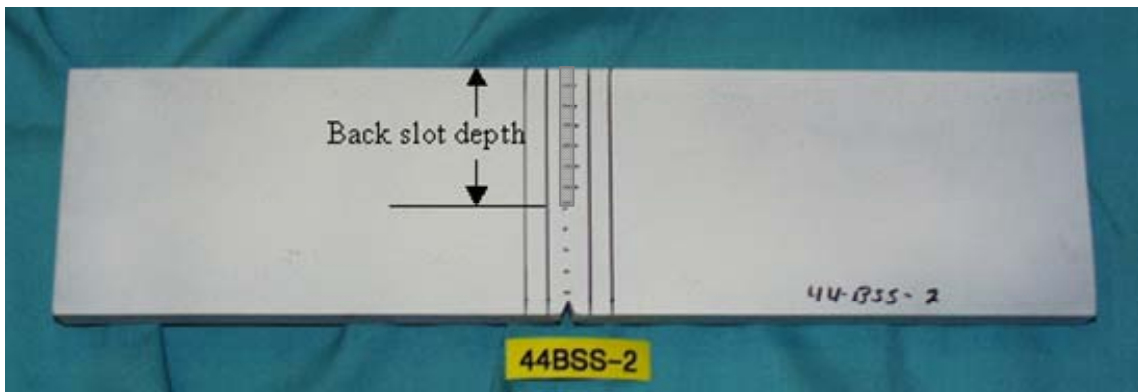


Figure 2 Photograph of back-slotted DWTT specimen