SIGNIFICANCE OF DWT TESTING FOR LINE PIPE SAFETY

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ABSTRACT

The drop-weight tear test (DWTT) is a common test method to determine the fracture appearance and fracture ductility of steel. International standards such as EN 10274 [1] and ASTM E 436 [2] cover drop-weight tear tests on ferritic steels in general, API RP 5L3 "Recommended Practice for Conducting Drop-Weight Tear Tests on Line Pipe" [3] considers the recommended test method to determine the fracture ductility of line pipe in particular as referred in API Specification 5L "Specification for Line Pipe" [4]. The fundamental purpose of DWT tests is to determine the appearance of propagating fractures in pipe steels over the temperature range where the fracture mode changes from brittle to ductile. In order to ensure a safe operation of gas transmission pipelines it is essential to provide line pipe steels with sufficient high fracture toughness. For example, the investigation of long running ductile fractures in gas pipelines is of tremendous importance when considering the integrity and safety of gas transmission pipelines. A typical measure for the toughness of steels is the Charpy energy determined with the Charpy V-notch impact test. The Charpy V-notch test is a small scale test, but in fact only full scale tests on pipes are suitable to yield information on the real fracture behaviour of pipe lines under service conditions. It has been found that the drop-weight tear test is an appropriate measure to predict the ductile to brittle transition temperature.

Therefore, the main objective of this study is to give a general overview on the most important parameters that influence the test result achieved by the drop-weight tear test. Parameters such as test temperature, energy and the type of notch determine the test result on a more test based level, whereas microstructure, grade and size of the tested line pipe material are parameters given by the test material. Both affect the transition temperature from ductile to brittle in a characteristic way.

1 INTRODUCTION

The avoidance of brittle fracture is of importance in most applications of line pipes. The drop weight tear test (DWTT) can be used to determine the fracture appearance of and fracture resistance against propagating fractures over a temperature range covering brittle and ductile fracture mode. Whereas impact tests, primarily related to the behaviour of the material subjected to a single force, can predict the likelihood of brittle fracture in cases where there is sufficient service experience, there are certain draw-backs correlated to specimen size and test method. On the other hand, DWT test as a medium scale test has been found suitable to predict closely the behaviour of the component and is therefore stipulated in standards for linepipes. This study is aimed at outlining important parameters that can influence the result of the DWT test.

2 DEVELOPMENT OF DWT TESTING

The avoidance of brittle fracture in gas transmission pipelines has traditionally been ensured by the DWTT, established in the second half of the sixties based on a research work carried out by Battelle. Before that the studies on the fracture propagation phenomenon were based upon the so called Athens test, a full scale burst test consisting of a test section of about 200m in length pressurised with natural gas [5]. It is evident that this test methodology is rather elaborate, therefore research focussed on a laboratory test that allows evaluation of the transition temperature in a correct and easy way. The results of the West Jefferson test, a burst test carried out on a short pipe length filled to around 90% with liquid and pressurised with gas, emerged as a duplicate of the full scale test results regarding fracture appearance and fracture speed [6]. Moving to an even smaller test type, i.e. a laboratory test, the comparison between West Jefferson test results and the Charpy impact energy test proved not satisfactory. The transition temperature of the Charpy V specimen is shifted towards lower temperatures in comparison to the pipe

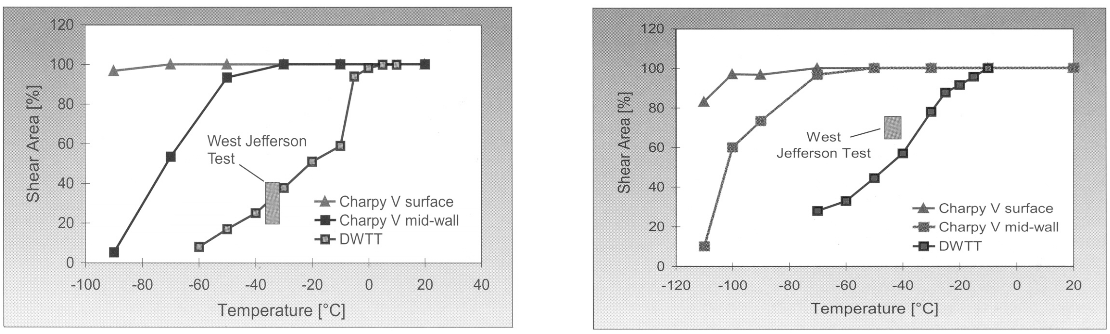

Figure 1: Comparison of transition temperature obtained by Charpy impact test, BDWT test and West Jefferson Test

behaviour (Figure 1), therefore resulting in a non-conservative prediction. As ductile fracture mode is ensured by keeping the minimum operating temperature above the ductile to brittle transition temperature of the line pipe steels it is important to have reliable results from the laboratory tests. Different test methods were investigated to solve the problem and the Battelle Drop Weight Tear Test (BDWTT) showed the best correlation to the full scale behaviour [7]. The test specimen is 76 mm in height by 254 mm in length by full wall thickness in width, as can be seen in Figure 2. The original specimen had a pressed notch of 5mm depth that is centred between the supports on the anvil in the testing machine. In the course of the test the specimen is completely broken in one impact by a weight falling on the specimen side opposite the notch. Due to the plastic deformation induced by the impact, certain parts of the fracture surface are neglected when determining the percent shear area in accordance with the relevant test standard. In Figure 2 the area that is to be considered in the evaluation of percent shear area is cross hatched. The test was soon standardised by the American Petroleum Institute [3], other standardisation bodies followed later. Typical wall thicknesses in use at that time were below 13 mm and the yield strength of the steel grades was around 360 MPa with relatively low toughness levels. In the course of time, development of modern steel has led to higher levels of strength coupled with higher toughness of the material. Furthermore, the increase in operating pressure levels of pipelines required for greater wall thicknesses of the line pipes. As the area of application of the DWTT was broadened, it became clear that testing conditions could have a major influence on the result of the DWTT. Finally the energy consumed by the propagating crack was measured with the aim of characterising the resistance of line pipe steels against propagating ductile fracture, a totally different assessment of the test results. In this report the effect of test conditions on the result of the BDWT tests will be described.

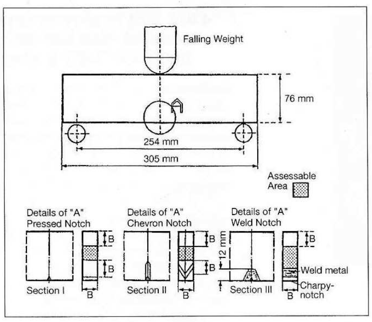

Figure 2: Schematic representation of BDWTT set-up

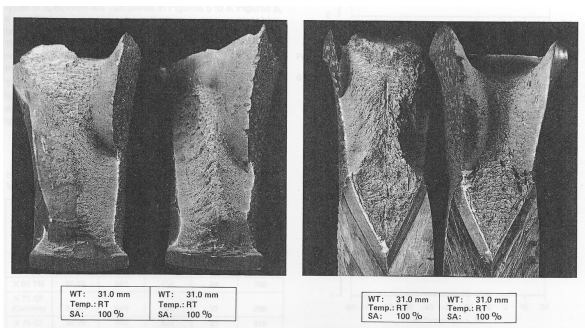

Figure 3: Appearance of fracture surfaces [API notch (a), Chevron notch (b)]

4 INFLUENCE OF SPECIMEN THICKNESS

API standard for DWTT stipulates, as an option for heavy wall thicknesses, that the full wall thickness may be machined down to 19mm. In these cases, the test temperature must be lower than specified temperature by 6°C to 10°C, depending on the original wall thickness. The effect of machining on the transition temperature was investigated [12]. The test results are depicted in Figure 5 in a diagram showing the measured transition temperature versus the specimen thickness that was machined from originally 32mm stepwise down to 15mm. The graph demonstrates that there was no common trend in the test results. Whereas the test on one material did show an influence of the machining on the transition temperature, reducing it by a small amount, the tests on the second material did not show an influence at all. The authors concluded that the general reduction of the test temperature that is stipulated in API 5L3 did not seem justified for all types of steels.

5 INFLUENCE OF AVAILABLE IMPACT ENERGY ON TRANSITION TEMPERATURE

The sensitivity of DWTT results to the available impact energy was shown in publications [13]. Figure 6 shows by means of example results of a comparative study incorporating QT and TM steels. Both materials show a rise in the transition temperature as the impact energy is increased. Whereas the TM material shows a saturation in this trend, i. e. above a certain energy level the transition temperature remains stable, the QT material has a continuously rising transition temperature. This is an important finding because the impact energy is not precisely described in test standards, hence a considerable scatter in results cannot be excluded.

6 INSTRUMENTED DWT TESTING

In accordance with existing procedures for the performance of instrumented impact testing, an instrumented DWTT was developed. The objective here is to measure the energy consumed by the specimen in the different phases of crack development, to distinguish between crack initiation and crack propagation behaviour and to compare these values with full scale test behaviour. The basic instrumentation consists of a load sensor and a data logger. The load is commonly monitored by strain gorc Ip [illegible]

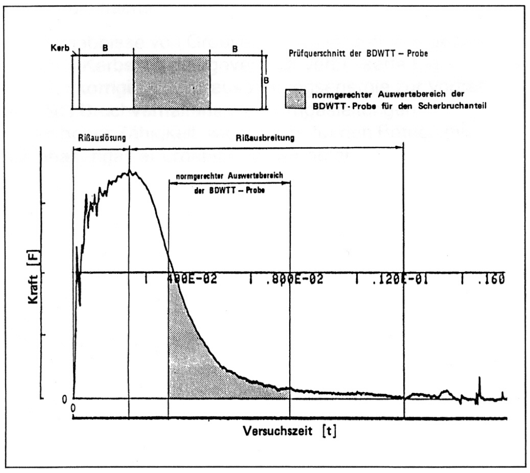

Figure 7: Assessable part of fracture surface and force versus time graph

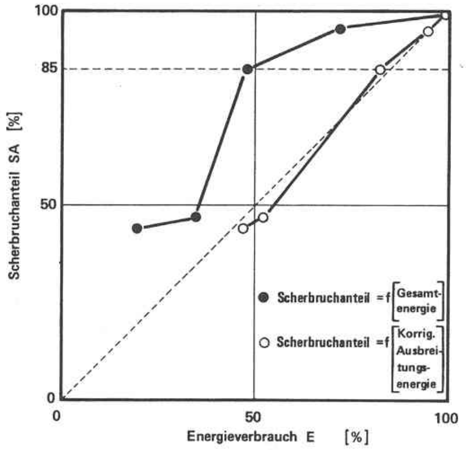

Figure 8: Correlation between shear area and absorbed energy of BDWTT specimens (full symbols :total energy, open symbols: corrected propagation energy term)

effects of testing conditions on the results of instrumented DWTT were carried out [14]. It was shown that there is a correlation between the impact energy and the crack speed. The maximum crack speed was measured as about 60 m/s, corresponding to around half the speed that occurs in a full scale test. Differences in speed were also observed for steels with varying toughness levels, where an enhancement of the toughness led to lower crack speeds when testing in the same conditions. The information about the crack speed can be utilised to compare the assessable parts of the fracture surface with the corresponding energy consumed by the propagating crack. The procedure is outlined in Figure 7 where the assessable parts of the fracture surface as well as the corresponding parts of the energy versus time graph are marked. It can be seen that the propagation energy has to be reduced by a certain amount to correspond to the assessed area. It can be expected that the energy consumed in the early parts of the propagation phase are influenced by the plastic deformation introduced in the specimen, the same holds true for the end of the propagating phase. This is especially important when correlating the energy and the shear area on the fracture surface. Figure 8 shows clearly that the two properties correlate only if the propagation energy term is corrected.

7 Current developments

Up to now design against propagating ductile fracture for gas transmission pipelines is carried out on basis of Charpy impact test results. The most widely used approach is the Battelle simplified formulae that uses Charpy values to characterise the toughness of the material [15]. Being a semi-empirical approach, it worked well at the time it was developed with the commonly used materials. Soon it became clear that above a certain material grade that is associated with a higher toughness level correction factors are needed to predict the result of full scale tests. Early research showed that the Charpy impact values above 150 J are no longer representative for ductile fracture resistance as a larger portion of the energy consumed is required for the crack initiation [16]. In an extreme case, no fracture initiation takes place at all and the test turns from an impact test to a bend test. Correspondingly the comparison between impact energy values and DWTT energy values do not show a satisfying correlation for these high toughness materials. The drawback in utilising DWTT energy for the assessment of propagating ductile fracture phenomenon, although it is seen as a promising alternative to Charpy impact energy, must be seen in the lack of an applicable methodology. At the same time, modified DWT tests are being used to measure the CTOA which is seen as the most appropriate material property for the characterisation of the resistance against ductile propagating fractures [17]. This is another example for current research activities.

8 Conclusions

The DWT test that was developed in the 1970’s still plays a major role in the characterisation of line pipe safety. The requirements for test results, which are included in most line pipe standards, depend on the application of the pipes and can vary between 50% shear area to guarantee safety against brittle fracture and 85% shear area as a condition ensuring the fracture propagation mode to be ductile. The actual assessment in then carried out employing Charpy impact test results, yet current research results indicate that the use of DWTT results may be beneficial for this purpose, too. Because of the advantages of the DWTT in comparison to other toughness test methods, current standards should be critically reviewed with focus the effect the test conditions themselves can have on the test results.

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