Mechanism of Arrowhead Fracture Occurrence in DWTT

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ABSTRACT

Separation is often observed after Charpy V-notch tests or Drop Weight Tear Tests (DWTT). Separation is defined as the fracture morphology whereby many cracks were formed parallel to the rolling plane. On the other hand, an arrowhead fracture is often observed near the surface of DWTT. The morphology of the arrowhead fracture is similar to that of separation. In this study, the relationship between arrowhead fracture and microstructure was investigated as compared with that between separation and microstructure. From this study, it was thought that the mechanism of arrowhead fracture formation was the same as that of separation formation although stress constraint in arrowhead fracture was different from that in separation.

KEYWORDS: Line pipe; fracture; separation; DWTT; Charpy impact test

INTRODUCTION

High strength line pipe steels, with API (American Petroleum Institute) X80 grade yield strength or higher, have been used for many pipeline projects because of the lower costs to transport natural gas. Crack arrestability of brittle and running ductile fractures is one of the required properties for high strength line pipe steels as cracks must be arrested, even if a brittle fracture occurs from welds such as girth welds. Cracks must also be arrested if the line pipe body is subject to ductile fractures.

The DWTT (Drop Weight Tear Test) (Eiber, (1979)) is a primary test method that evaluates the crack arrestability of brittle fractures. This test evaluates whether a ductile crack is transferred from a brittle fracture after a brittle crack is initiated just under the notch. Previous results (Amano, (1986)) indicated that the crack speed fell below 450 m/s and that the crack was subsequently arrested in the full crack burst test, for line pipes with a DWTT shear area of more than 40%. However, a DWTT shear area of 85% or higher is required for such specifications as those of the API because DWTT shear area scattering is taken into account in a circumferential direction.

On the other hand, the required Charpy V-notch energy (Maxey, (1975); Subcommittee Summary report AISI, (1974); Poynton, (1974)) for crack arrestability of running ductile fractures was proposed in comparison with the full crack burst test results and the Charpy V-notch energy of the line pipe body, and the Charpy V-notch energy correlated with that of the full crack burst test results up to API grade X70. However, the required Charpy V-notch energy was multiplied by a safety factor, such as 1.3, 1.4 or 1.7, for high strength steels with an API grade of X80 or higher.

Therefore, improving the DWTT shear area and Charpy impact energy is important to ensure good crack arrestability of brittle and running ductile fractures. Specifically, it is important to understand brittle fracture morphology in order to suppress brittle fractures.

Separation is often observed in DWTT or Charpy V-notch impact tests. Separation is defined as the fracture morphology whereby many cracks were formed parallel to the rolling plane. It is reported that the formation of remarkable separation deteriorated the crack arrestability of running ductile fracture (Fujishiro, (2011)). Therefore, it is very important to clarify the conditions under separation occurs. In recent clean and pure steels, the mechanism of the occurrence of separation was proposed as follows. At first, the mechanism of the occurrence of separation was reported by Matsuda (1982). He detailed the conditions leading to separation in API grade X70 line pipe steels. This report identified the conditions under which separation occurred, mainly involving deformed ferrite microstructures. In this case, {100} and {111} textures were integrated in the deformed ferrite with a brittle fracture occurring from the interface between the {100} and {111} textures because of the difference in plastic anisotropy, while the crack propagated along the {100} texture. Another type of separation was formed for line pipe steels. Secondly, separation also occurred when a ferrite and bainite/martensite composite microstructure was formed. A brittle fracture arose from the interface between the soft and the hard phase, with the crack propagating along the interface between the soft and hard phase, which is parallel to the rolling plane or along the {100} texture parallel to the rolling plane (Hara, (2012)). Finally, separation occurred along the elongated prior austenite boundary when the prior austenite boundary became brittle due to precipitation or the prior austenite boundary weakened (Hara, (2012)).

However, arrowhead fracture, shown in Fig. 1, was often observed near the surface of DWTT and it has a similar morphology to that of separation. In this study, the relationship between arrowhead fracture and microstructure was investigated. The mechanism by which arrowhead fracture was formed was compared to the mechanism of separation occurrence.