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Fracture Toughness Testing for Improving the Safety of Gas Pipelines

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Abstract: For standard fracture mechanical tests flat specimens (principally CT or SENB) are required. This brings problems for investigating fracture mechanical properties of thin-walled pipes because it is necessary to straighten the pipe bands [1]. However, this operation causes internal stresses to be induced not only in the semi-product subjected to straightening but also in finished specimens. A question therefore arises to what extent are then the magnitudes of the fracture toughness determined representative for the actual cylindrical wall. To solve this problem fracture mechanics tests were carried out on flat (straightened) CT specimens as well as on curved CT specimens with the natural curvature. The R – curves as well as the resulting parameters of the fracture toughness, obtained for both types of CT specimens, were compared and it was concluded that the fracture toughness of the pipe material determined on straightened CT specimens was practically the same as that obtained on curved CT specimens.

Experimental

Curved CT specimens simulate, to some extent, stress conditions in the pipeline wall loaded by internal pressure. In order to ensure the application of the load in the hoop direction, it was necessary to design and manufacture a fixture that would enable to convert the straight force, generated by the loading machine, to the tangential one, i.e. a force which would act along a circle of the identical diameter to that of the pipe. Such a fixture was designed and manufactured on the basis of the work of Evans, Kotsikos and Robey [2].

In collaboration with RCP Prague we have developed a force converter for tangential loading of curved CT specimens. Its 3D schematic picture is shown on Fig. 1. The straight force, applied at the jaws of the testing machine, is transferred by a pin to the upper and bottom arm of the force converter. Motion of the arms of the force converter around the connecting hinge provides a tangential action of the force at the holes of a curved CT specimen relative to the circumscribed circle around the connecting hinge that goes by central cylindrical area of the specimen.

It is apparent that the force converter is bound only to certain specific cross section dimensions of the pipe. For experimental research of the effect of pipe band straightening on fracture toughness values a gas linepipe DN 250 (Ø 266/8) made from low-C steel ČSN 411353 was chosen. The reason for this was a high curvature of the cylindrical surface of the pipe so that the eventual effect of straightening of the pipe band could be very apparent. Fracture toughness characteristics were determined on the basis of R-curves following the standard [3].

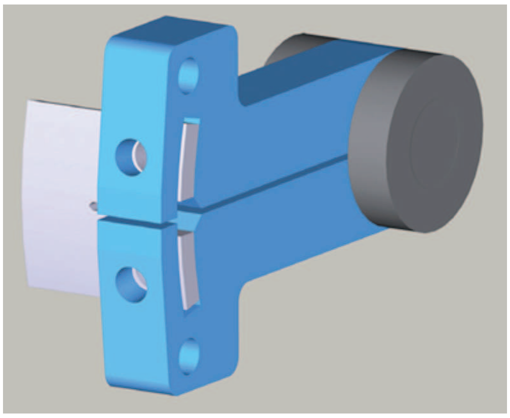

Fig. 1. A force converter

Results

It was found that the R curve obtained on curved CT specimens exhibited a lower gradient than that determined on flat (straightened) specimens. This is very likely to be associated with strain hardening of the semiproduct during straightening. However, the lower position of the R curve determined on curved specimens does not mean any significantly lower values of fracture toughness characteristics. For example, the J_m value is lower by 1.1 %, the $J_{0.2}$ value is lower by less than 3 %, and the J_{in} value is even higher than that obtained on flat (straightened) CT specimens. In terms of absolute values these differences are 2.9 N/mm for J_m, 4.6 N/mm for $J_{0.2}$, and 29.7 N/mm for J_{in} in favour of curved CT specimens. Considering a scatter of the results in the form of $(J - \Delta a)$ points given by both the natural process of the subcritical crack growth and inaccuracies in determination of the J integral, especially crack extension during monotonic loading of specimens, it can be stated with a high reliability that the fracture toughness of the pipe material determined on straightened CT specimens is practically the same as that obtained on curved CT specimens.

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