Predicting Crack Arrest in Line Pipes

Alexander Völling
Salzgitter Mannesmann Forschung GmbH
Duisburg, Germany

Marion Erdelen-Peppler
Salzgitter Mannesmann Forschung GmbH
Duisburg, Germany

Christoph Kalwa
Europipe GmbH
Mülheim an der Ruhr, Germany

Holger Brauer
Salzgitter Mannesmann Line Pipe GmbH
Hamm, Germany

Brahim Ouaissa
Salzgitter Mannesmann Großrohr GmbH
Salzgitter, Germany

Heike Meuser
Salzgitter Mannesmann Grobblech GmbH
Mülheim an der Ruhr, Duisburg, Germany

ABSTRACT
As predicted ductile fracture arrest in line pipes more and more failed to match with the outcome of full-scale tests within the last decade, the applicability of standard prediction tools to modern pipeline design is put into question. To overcome this shortcoming, research at SZMF is focused on deriving a novel approach to crack-arrest prediction. Two independent routes are being followed. An analytical, energy based criteria shall allow for arrest pressure predictions involving a material toughness value. In a numerical approach by FEM, material damage is covered by an energy based cohesive zone model representing material resistance. The characteristic mechanical material quantities are determined by DWT testing involving pre-fatigued specimens.

KEY WORDS: Toughness; crack-resistance curve; ductile crack growth; DWT testing; J-integral; cohesive zone model; crack arrest.

INTRODUCTION
Responding to market demands, strength and toughness properties of pipeline steels have been continuously increased as outcome of research and development within the steel industry over the last decades. At the same time, well established and more than 35 years old prediction tools for arrest of long-running ductile fracture have lost their reliability with respect to new steel grades for pipeline systems. As result of a first pragmatic solution by applying safety factors on a predicted minimum Charpy value, stringent toughness requirements have been established in terms of high Charpy impact energy. This issue brought up the question about the significance of the Charpy value as indicator for material toughness and input parameter for crack arrest predictions.

Over the last years, researchers all over the globe started to quest for alternative testing methods and different characteristic values to measure toughness of a material. Drop-weight tear (DWT) testing, originally developed only for determination of a transition temperature via fracture surface appearance, came naturally into the focus of ongoing research. Recent developments were mainly dealing with specimen modifications and notching procedures influencing crack initiation, propagation velocity and a toughness parameter as testing result. The latter relates to energy, measured by load-time plot from instrumented DWT testing, and crack-tip opening angle, e.g. determined in high-speed camera observation of specimen failure. Following standard fracture mechanics approaches, work within that scope at Salzgitter Mannesmann Forschung (SZMF) is focused on derivation of energy parameters in DWT testing representing ductile failure behaviour in terms of a dynamic crack-resistance curve $J_e-\Delta a$.

TOUGHNESS BY J-INTEGRAL
In fracture mechanics, the $J$-integral is a well established parameter. It is a measure of material resistance to crack-growth or quantifies the crack-tip loading in terms of a local component stressing. Testing