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The analysis of damage degree of oil and gas pipeline with type II plain dent

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ABSTRACT

Dent is a common type of defect in oil and gas pipelines and the assessment on dented pipelines is carried out with major international standards and specifications based on dent depth as the evaluation criteria. However, such evaluation criteria based on depth does not account for the impact of various parameters (e.g. parameters of dent, parameters of pipeline and the internal pressure of pipeline) on the evaluation result, as a result, many dented pipelines lose their efficacy, even though they meet the depth-based standards. The influence of parameters changes on the damage degree of II-type dented pipelines is investigated on the basis of Oyane's ductile fracture criterion and by the method adopting finite element numerical calculations. Finally, the non-linear regression analysis is conducted and based on the outputs, a specific expression of dent depth and pipeline damage degree is also acquired within a certain scope of application.

1. Introduction

Dent is one of the most common mechanical damage forms in oil and gas pipeline, which can be caused by the following factors: the incorrect excavation of construction machinery, the impact from falling rock above the pipeline and from protrusion below it, or other accidents [1,2,3]. Pipeline dent is a serious threat to the safe operation of the pipeline, some dents will cause pipeline failure immediately under the action of internal pressure, while others will provide an opportunity for the appearance of cracks instead of leading to cracks immediately. Along with the runtime increasing, those cracks are emerging and developing, thus decreasing residual strength and fatigue life of the pipeline and increasing the potential harms of pipeline safe operation [4,5].

At present, a series of researches have been conducted on integrity assessment for dented pipeline, such as Canadian pipeline design standards CSAZ662-03 [6]and its auxiliary manual CSA Z662.1-03 [7], British Standard BS7910-2005 [8], Australia national Standard AS 2885.3-2001 [9], the American Petroleum Institute API 579-1-2007 [10], American Society of Mechanical Engineers ASME B31.4 — 2006 and B31.8 — 2003 and other standards, all allowing that the dent depth reaching to <6% of the pipeline diameter is acceptable [11,12,13]. However, some pipelines of which dent depth over 10% of the pipeline diameter can also work during norm operation, while other pipelines can leak in spite of dent depth lower than 3% pipeline diameter [14]. It shows that even though the dent depth not exceed acceptable threshold, pipeline accidents can still happen. Therefore, the evaluation method simply based on dent depth cannot meet the demands of oil and gas industry, it is necessary to account for more parameters when evaluating the dented pipeline.

Takuda applies Oyane's criterion into the cylindrical component deep drawing and hole-flanging forming technology of sheet metals, widely study composite boards which are constituted by mild steel, aluminium, its aluminium alloy, magnesium alloy and zinc alloy or by the aluminium alloy and the mild steel, and also utilize this criterion to predict the forming limit on the basis of

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Nomenclature

Letters

I	integral value
C_1, C_2	material constants
F,G,H,L,M,N	anisotropy parameter
r	Lanckford coefficient
n	Poisson ratio
E	elastic modulus
x	x-direction
y	y-direction
z	z-direction
a	the minor axis lengths of ellipsoidal
b	the major axis lengths of ellipsoidal
t	wall thickness
D	outer pipe diameter
t/D	radio of wall thickness to diameter
L	major axial length of pipeline model
d	dent depth

Greek letters

$\overline{\varepsilon}_f$	equivalent fracture strain
$\overline{\varepsilon}$	equivalent fracture strain
$\overline{\sigma}$	equivalent stress
σ_m	hydrostatic pressure
$\sigma_{0,1,2}$	maximum, intermediate and minimum principal stress components
ε_1	strain value at which the starting point of the plastic deformation
ε_2	allowable tensile strain
σ_b	materials fracture stress

finite element numerical simulation. Finally, it turns out that a good consistency exists between their findings and the test results [15]. Allouti et al. hold that the formation process of dent is similar to that of sheet metal. They applied dents to pipeline with a circular head and investigated the influence of dent depth on the critical pressure of pipeline and the damage degree of the pipeline by the method based Oyane ductile fracture criterion and combined with finite element numerical analysis. The final analysis conclusions and the testing result have a good consistency [16].

Plain dent is defined as a smooth dent that contains no wall thickness reductions (such as a gouge or a crack) or other defects or imperfections (such as a girth or seam weld) [5].In order to classify and analyze plain dents on the pipeline easily, plain dents are divided into two categories (type I and type II) according to the size of the angle between macro-axis of ellipsoidal indenter and pipeline axis, among them, we choose type II as the study object of this thesis. By assuming that type-II pain dent is formed by pressing the pipeline with ellipsoidal indenter whose macro-axis parallel to pipeline axis. Under a circumstance of the same dent depths, the dent length will increase with the increasing of the macro-axis of ellipsoidal indenter, and so does the dent width. The diagrams of type II plain dent are shown in Fig. 1.

Against deficiencies of depth-based assessments, we used the method based on damage mechanics to assess the damage degree of pipeline with type II plain dent in this thesis. First, the finite element software ANSYS was used to establish the pipeline model and various outputs were obtained with different parameters as inputs. Second, Oyane ductile fracture criterion based on damage mechanics was used to process the results of finite element and the damage degree of pipeline was represented by damage variable. Finally, we obtained a specific expression of dent depth and the damage degree of pipeline as well as the influence law of parameters changes on the damage degree of pipeline.

2. Oyane ductile fracture criterion based on damage mechanics

Damage mechanics is a discipline which is mainly used to study macro-mechanical effects caused by the generation and development of micro-defects inside materials as well as the final processes and laws leading to material damage. In order to better predict the materials' deformation, damage, working life and so on, an internal variable named the “damage variable” is brought in describing the mechanical effect of materials containing micro-defects, also called the mechanical behavior of damaged materials [17]. The so-called damage means that during material processing or smelting, macro- or micro-structures are changed under the influence of factors such as temperature and load, etc. which can cause the micro-defect into embryo, inoculation, expansion and confluence, then it lead to the degradation of macro-mechanical performance of materials, eventually forming