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Failure pressure of medium and high strength pipelines with scratched dent defects

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ABSTRACT

It is very important in engineering design and integrity assessment of pipeline to accurately predict its failure pressure, especially for the pipeline with mechanical damages. This paper numerically investigates the failure pressure of medium and high strength pipelines with scratched dent which is on the outer surface of the pipe. Pipe materials of two different grades are chosen in the analysis which represent medium and high strength steel, respectively. Failure pressure of an intact pipeline with fixed ends is derived analytically. On the basis of the maximum plastic strain failure criterion put forward by previous scholars, failure pressure of finite element models containing dent and scratch defects is determined. Parametric studies are carried out to obtain the influencing rule of the dimensions of dent and scratch. The effects of scratch length and depth on failure pressure with various dent depths are obtained. Finally, a formula is fitted for predicting the failure pressure of pipelines with scratched dents on the basis of finite element results. Compared to burst test data from literature, the proposed formula is proved to be reasonable.

1. Introduction

Pipelines are one of the primary means for transporting oil and gas in petrochemical industry. Pipeline system has been widely used because of its advantageous efficiency and safety [1]. As the demand of oil and gas is on the increase, the capacity of transmission pipeline should be improved. The general trend of pipeline is high grade, large diameter, and high-pressure operation [2]. There is a great risk of corrosion and mechanical damage for these pipelines during their service life. For example, the knocking and scraping action of the excavating equipment always leads to dent and scratch on the outer surface of the pipe [3,4]. Such defects have been major concerns in maintaining pipeline integrity [5]. There are several relevant authoritative standards in practice to evaluate the residual strength of corroded pipelines, such as ASME B31 G [6] and DNV-RP-F101 [7] codes, both of which consider that the failure of corroded pipeline is controlled by defect size as well as the flow stress of the material. However, as for dented pipelines, there are no existing codes concerning its remaining strength. Most of the standards are with respect to whether the dent is allowable in the pipe. In addition, all the standards are based on dent depth [8–11] except for ASME B31.8 [12] which gives a procedure for strain-based evaluation. According to appendix R of ASME B31.8, hoop bending strain, axial bending strain and axial membrane strain are calculated, respectively. Then the total strains for both inner and outer surface of the pipe are obtained. By comparing the total strains with the allowable value, whether the pipe is in safe condition can be determined. Dent

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Nomenclature

D, D'	The instant and original outside diameters, respectively
t, t'	The instant and original wall thicknesses, respectively
a	Scratch depth
c	Scratch length
h_0	Dent depth without spring back/displacement-controlled load
h	Dent depth after spring back
E	Elastic modulus
σ_1, σ_2, σ_3	Principle stresses
ε_1, ε_2, ε_3	Principle strains
σ_a, σ_h, σ_r	Axial, hoop, radial stresses, respectively
ε_a, ε_h, ε_r	Axial, hoop, radial strains, respectively
σ_M, ε_M	Von Mises equivalent stress and equivalent strain, respectively
K	The strain hardening coefficient
n	The strain hardening exponent
σ_s	Engineering yield strength
σ_b	Engineering tensile strength
σ	True stress
ε	True strain
P_f	Failure pressure of a pipe with scratched dent
P_0	Failure pressure of an intact pipe
P_t	Failure pressure of test data

profile is generally acquired by internal inspection tools. However, whether the calculation of the strains is accurate and whether dent profile is close to the real one are highly dependent on the number of the sensor channels of the tool.

Researchers from all over the world have carried out large amounts of experiments and numerical simulations on dented pipelines, laying a foundation for its engineering evaluation. I.B.·Iflefel et al. carried out a series of researches on dented pipelines with and without gouges [13–15]. Although internal pressure is taken into consideration, the main objective is to study the collapse behavior of the pipe under the interaction of internal pressure and bending moment. Besides, the size of the specimen selected in the tests is Φ84.1 × 2.1 mm which is too small compared to pipeline steel. M. Allouti and C.·Schmitt conducted two sets of experiments on A37 steel pipe [16,17]. One is with smooth dent; the other is with dent and gouge defects. It is concluded that whether the dent contains a gouge or not, there is no significant effect on burst strength of the pipe compared to the defect-free one. Yet the material they chose is a kind of alloy steel, unlike what is commonly used in long-distance pipeline. Therefore, the conclusion is not applicable to the latter. Ying Wu and Jiewen Xiao applied the research of metal forming limit to dented pipelines [18]. They used an integral value to represent cumulative damage of the material. When it reached one, failure happened. With this method, damage degree of the pipe during deformation can be well predicted. However, two material constants in the expression of the integral should be determined by at least two tensile tests, thus making the problem more difficult. W. Hanif and S. Kenny used finite element analysis (FEA) to establish a model matrix to account for a range of influential parameters including pipe/indenter geometry and pressure factors [19]. Multivariate nonlinear regression analysis was developed to obtain the expressions of the maximum equivalent plastic strain (PEEQMAX), both for zero pressure indentation and for pressurized indentation. Then coupled effect of dent and artificial corrosion showed the distribution curves of the equivalent stress and PEEQMAX, where inflection point was found around the boundary of corrosion zone. No depth studies were carried out on burst pressure based on these results. Hossein Ghaednia and Sreekanta Das did several burst tests as well as FEA on X65 and X70 grade pipelines with dent-crack defects [20–22]. According to their studies, dent depth and operating pressure have little influence on burst strength of the pipe unless the crack depth reaches a certain value, beyond which dent depth can significantly affect burst strength. Being focused on dent and crack, they put forward a failure criterion in FEA which can be used in the following analysis. However, they lack enough finite element calculations and the conclusions are limited to the pipe specimens in their studies. Other research priorities of dented pipelines are related to fatigue life [23,24].

Table 1
Material properties and dimensions of the models.

Steel grade	External diameter D/mm	Wall thickness t/mm	Elastic modulus E/GPa	Yield strength σ_s/MPa	Tensile strength σ_b/MPa
X65	762	8.5	200	540	620
X70	1016	14.6	200	570	640

Note: The properties of X65 are from Ref. [26]; the properties of X70 are from Ref. [21].