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Failure criterion of buried pipelines with dent and scratch defects

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ABSTRACT

The excavation of buried pipelines shows that combined dent and scratch defects exist at the bottom of the pipe due to the extrusion and scraping action of rocks, which is likely to decrease its pressure bearing capacity. This paper experimentally investigates the tensile strength of CT80 steel plates with dent and scratch defects. Results show that the tensile strength is affected to varying degrees by dent depth, scratch depth and the indenter diameter. Finite element analysis (FEA) is then carried out to propose the failure criterion by comparing with experimental results. It is thought that failure happens when the equivalent stress of the intermediate node in the direction of the remaining thickness of the defect center of the model reaches the true tensile strength of the material. With this criterion, large numbers of finite element calculations can be developed to study the failure pressure of buried pipelines with combined dent and scratch defects.

1. Introduction

Buried oil and gas transmission pipelines have been widely used and have become significant networks for transmitting large quantities of energy over long distances from production sites to consumption areas [1,2]. Causes of pipeline accidents have been identified and are summarized in Table 1. From the percentage of the occurrence, it is seen that mechanical damage is the main cause of pipe failure. This type of damage can be divided into dent, scratch and the combined dent and scratch. The study of mechanical damage is still in an immature stage, especially for the research of failure pressure of pipelines with dent and scratch defects.

A series of evaluation criteria were set by authority organizations, such as ASME B31.4 [4], API 1160 [5], CSA Z662 [6], 49 CFR 195 [7] and 49 CFR 192 [8]. Depth-based assessment method is mostly used in these criteria. 6% of the outside diameter is always thought to be a critical depth of the dent beyond which the dent should be repaired. Besides, dents with scratches or gouges are recommended to be repaired immediately. It has been verified by several experiments that plain dents with a depth of 24%D do not significantly reduce the burst strength of a pipe [9]. The degree of the strain in the pipe cannot be measured with depth-based method. Therefore, it is likely to underestimate deep but smooth dents and overestimate shallow but sharp dents in the evaluation process [10]. A strain-based assessment method is proposed by ASME B 31.8 [11], in which the calculation of hoop bending strain, axial bending strain and axial membrane strain is given. Thereby, the equivalent strains for internal and external pipe wall can be obtained and compare them to the allowable value to determine whether the dent is acceptable. However, Dauro Braga Noronha Jr. and Ming Gao et al. [12,13] argued that the dent region is in a plastic strain state. Hence, those equations for the calculations of the strains based on the assumption of plane strain state are false.

The key to study the ultimate internal pressure of dented pipelines is how to determine pipe failure. Samer Adeeb and David Horsley [14] defined 20% as the critical strain in the study of the safe working pressure during excavation of a pipeline in a rock ditch. They think that pipe fails when the maximum principle strain reaches 20%. Nevertheless, the evidence for the provision of 20% was not stated in their study and they did not take material property into consideration. Hossein Ghaednia et al. [15] carried out numerical studies on burst

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Nomenclature

D	outside diameter of the pipeline (mm)
t	thickness of the plate (mm)
E	elastic modulus (GPa)
σ_s	yield strength (MPa)
σ_u	nominal tensile strength (MPa)
$\sigma_u^{'}$	true tensile strength (MPa)
$\varepsilon_f^{'}$	true fracture strain
a	scratch depth (mm)
d	indenter diameter (mm)
F	applied load to the indenter (kN)
T_p	tensile strength of an intact specimen (kN)

strength of dent-crack pipelines. It is assumed that failure occurs when the J-integral at any integration point around crack tip reaches $1.15J_{1C}$ (J_{1C} is the critical integral). Yet the formation mechanism of scratch is different from that of crack, thus it cannot be treated as crack. Sreekanta Das and Roger Cheng [16] considered the equivalent plastic strain in their study of fatigue fracture of pipelines, where they argue that when the equivalent plastic strain reaches the rupture plastic strain of the material in uniaxial tensile test, failure happens. The proposal of this failure criterion is under fatigue loading condition, which is unlike that of monotonic loading. A denting failure criterion was put forward by Jong-Hyum Baek and Yonng-pyo Kim et al. in their study of load bearing capacity of pipelines where they defined failure by the points of force drop, fracture stress and fracture strain [17]. However, the failure mode of the pipe at the action of internal pressure differs from its collapse behavior which is the focus of their study, so that the criterion does not apply to the former.

Research of the ultimate strength of pipelines with combined dent and scratch defects should be based on an appropriate strength criterion. There is a lack of certain rationality and general applicability of the existing assessment criteria for dented pipelines. For this reason, together with the consideration of the cost of full-size tests, this paper is completed to investigate the tensile strength of CT80 steel plate with dent and scratch defects. This work was developed using the combination of experimental study and finite element method. A strength criterion with respect to the material property was put forward by analyzing and summarizing the comparison results.

2. Experimental procedure

Buried pipelines are thinned-wall structures with large diameter. This feature decides that the pipe is in a plane stress state, as seen in Fig. 1. Therefore, we can use a plate to study small curvature problems. Adib, H and Jallouf, S et al. have studied curved specimen in order to take into account the curvature of the pipe [18]. However, this study is about a strength problem which is irrelevant to stress intensity factor. Consequently, there is no need to consider the curvature of the pipe.

2.1. Manufacture of the defects

A steel with nominal yield strength of 80 ksi, named CT80 is used as the material of the specimen, for it has the similar property with API X80 steel which is commonly used in buried pipelines. The length, width and thickness of the specimens are 190 mm, 120 mm and 3.18 mm, respectively. Material properties obtained from tensile tests are listed in Table 2.

Table 1
Causes and percentage of pipeline accidents [3].

External interference	Construction defect	Corrosion	Ground movement	Hot-tap mad by error	Other and unknown
49.6%	16.5%	15.3%	7.3%	4.6%	6.7%

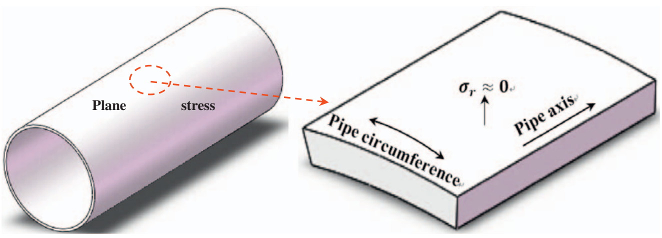

Fig. 1. The pipe in plane stress state.

Table 2
Material properties.

Elastic modulus E/GPa	Yield strength σ_s/MPa	Nominal tensile strength σ_u/MPa	True tensile strength $\sigma_u^{'}$/MPa	True fracture strain $\varepsilon_f^{'}$
186	580	715	787	0.1867