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# Experimental and numerical investigation of ductile damage effect on load bearing capacity of a dented API XB pipe subjected to internal pressure

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ABSTRACT

In this paper, the effect of ductile damage on the behavior of a dented steel pipe subjected to internal pressure is investigated by experimental and numerical methods. In the numerical investigation the plastic behavior of pipes under indentation is studied using continuum damage mechanics theory and the elastic–plastic finite element analysis. Finite element calculations are carried out using the damage plasticity model proposed by Xue and Wierzbicki (X-W). The proposed damage plasticity model incorporates effects of four parameters that play important role in predicting the fracture initiation, namely the damage rule, the softening effect, the hydrostatic pressure and the Lode angle. The target dent depth is considered as an indication of the load bearing capacity of the pipe under indentation process by a rigid spherical indenter. To validate numerical calculations, a series of experimental tests are conducted on the pipe with atmospheric pressure. After verification, numerical calculations for different ranges of internal pressures with and without damage effect are carried out and results are compared. It is shown that damage plays an important role on the load bearing capacity of an indented pipe. Results of the present study confirm the credibility of the proposed model in predicting the ductile fracture under multi-axial state of stress loadings.



## 1. Introduction

One of the most challenging parts in transmission systems of gases and liquids from production sites to end users are pipelines. Damages caused by impact of heavy objects and reduction of thickness due to exposure to corrosive environments can significantly affect the performance of pipelines. Therefore, investigation of the behavior of pipelines under various loading conditions is quite necessary in order to minimize damage effects that can be achieved by appropriate design process, material selection and operating practices [1]. The most common causes of damage and failures in onshore and offshore, oil and gas transmission pipelines in Western Europe and North America are external interference (mechanical damage) and corrosion [2]. According to statistics compiled by the U.S. Office of Pipeline Safety, mechanical damage is one of the primary causes of pipeline failures in the United States. [3] The mechanical damage in a pipe is usually classified into two categories: dents and gouges. Gouges, the severely deformed places where cracks can be initiated, are not the subject of the

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**Nomenclature**

*Letters*

| | |
|---|---|
| $A$ | stress asymmetry in Wilkins et al. model |
| $d$ | indenter diameter |
| $D$ | ductile damage |
| $D_{cr}$ | material constant |
| $D_o$ | outer diameter of pipe |
| $L$ | length of pipe |
| $m$ | damage exponent in Xue-Wierzbicki model |
| $n$ | strain hardening exponent |
| $P$ | internal pressure of pipe |
| $p_{cut\text{-}off}$ | cut-off pressure in Xue-Wierzbicki model |
| $p_{\lim}$ | limiting pressure in Xue-Wierzbicki model |
| $q$ | exponent in pressure dependence function in Xue-Wierzbicki model |
| $R$ | mean radius |
| $S_{1,2,3}$ | maximum, intermediate and minimum principal deviatoric stress components |
| $t$ | wall thickness of pipe |
| $x$ | radial coordinate |
| $z$ | axial coordinate |

*Greek letters*

| | |
|---|---|
| $\beta$ | exponent in weakening function in Xue-Wierzbicki model |
| $\gamma$ | ratio of fracture strains at $\chi = 0.5$ and at $\chi = 0$ in Xue-Wierzbicki model |
| $\delta$ | dent depth |
| $\delta_{target}$ | target dent depth |
| $\theta_L$ | lode angle parameter |
| $\phi$ | circumferential coordinate |
| $\mu_p(p)$ | pressure dependence function in Xue-Wierzbicki model |
| $\mu_\theta(\theta)$ | lode angle dependence function in Xue-Wierzbicki model |
| $\varepsilon$ | equivalent strain in Oyane's criterion |
| $\varepsilon_c$ | critical strain to failure (up limit of integral) |
| $\varepsilon_{eq}^p$ | accumulated equivalent plastic strain |
| $\varepsilon_f$ | equivalent fracture strain |
| $\varepsilon_{f0}$ | reference equivalent fracture strain in Xue-Wierzbicki model |
| $\sigma_{eq}$ | von Mises equivalent stress |
| $\sigma_h$ | hydrostatic pressure |
| $\sigma_m$ | mean stress |
| $\sigma_M$ | matrix strength |
| $\sigma_{1,2,3}$ | maximum, intermediate and minimum principal stress components |
| $\mathcal{X}$ | relative ratio of the principal stress deviators in Xue-Wierzbicki model |

present research [4]. In dented area, a permanent plastic deformation occurs in the cross-section of the pipe that causes a local stress and strain concentration and a reduction in the pipe diameter as shown in Fig. 1 [2]. Dents in pipelines are divided into different types based on the degrees of impact on wall dimensions and geometry of indenters [5,6]. The major types of dents defined in the literature are Smooth, Kinked, Plain, Unconstrained and Constrained dents [2,6]. The dents in the present paper are considered both plain and unconstraint, namely plain unconstrained dent. Dent is plain, because contains no wall thickness reduction and is unconstraint, because is free to rebound elastically when the indenter is removed.

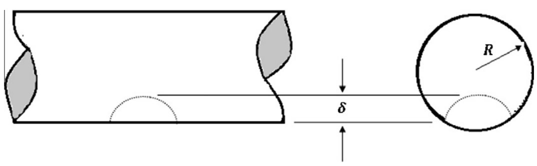


**Fig. 1.** Dimensions of a dented pipe.