On fracture analysis of exploded pressure vessels and pipes

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ABSTRACT

The main scope of this paper is the analysis of the specifications of deflagration-induced and detonation-induced deformation and fracture behaviors of cylindrical tubes. The main characteristics of deformation and fracture behaviors were studied through experimentations on steel pipes and failure analysis of a compressed natural gas (CNG) cylinder. The paper also reports the results of transient-dynamic elasto-plastic finite element (FE) analyses of the combustion-induced deformation and fracture behaviors of the pipe and the CNG cylinder. The FE models were composed of 3D brick elements equipped with interface cohesive elements for crack growth analysis. Very good agreement was found between the simulation results and the observed deformation and fracture patterns. It was shown that, because of different loading conditions, specific deformation and fracture features can develop during the explosion process.

1. Introduction

Deflagration and detonation are two major events that may cause catastrophic failure of pressure vessels and pipes. Deflagration is a rapid combustion process that occurs in a confined space, while detonation is a self-sustained shock wave that propagates through the explosive material.

Deflagration is characterized by a rapid, self-sustained chemical reaction that occurs inside a confined space. The pressure and temperature inside the vessel rapidly increase, leading to a high structural stress that may cause failure. Detonation, on the other hand, is a much faster and more intense event that results in a much higher pressure and temperature, leading to an even more severe failure.

Understanding the behavior of pressure vessels and pipes under these events is crucial for safety and design purposes. The analysis and prediction of such events require a thorough understanding of the materials, the geometry of the vessel or pipe, and the loading conditions. Numerical simulations using finite element analysis (FEA) are commonly used to predict the behavior of these structures under deflagration and detonation.

The main scope of this paper is the analysis of the specifications of deflagration-induced and detonation-induced deformation and fracture behaviors of cylindrical tubes. The main characteristics of deformation and fracture behaviors were studied through experimentations on steel pipes and failure analysis of a compressed natural gas (CNG) cylinder. The paper also reports the results of transient-dynamic elasto-plastic finite element (FE) analyses of the combustion-induced deformation and fracture behaviors of the pipe and the CNG cylinder. The FE models were composed of 3D brick elements equipped with interface cohesive elements for crack growth analysis. Very good agreement was found between the simulation results and the observed deformation and fracture patterns. It was shown that, because of different loading conditions, specific deformation and fracture features can develop during the explosion process.


References

[1] Detonation

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1- تجزیه و تحلیل تغییر فرم و شکست ناشی از دندان‌شیب یک لوله در این بخش بررسی تغییر فرم و شکست ناشی از تراک داخلی یک لوله فولادی گرزش شده است.

2- روش تحقیق
نمونه‌های تجربی، قطره‌های کوچک از لوله‌های فولادی (S55k، کد سرد شده) و با اعمال و خواص مولکول در جدول 1.1 آورده شده‌اند. قطره‌های کوچک از لوله‌های فولادی (S55k، کد سرد شده) و با اعمال و خواص مولکول در جدول 1.1 آورده شده‌اند.

3- تجزیه و تحلیل نتایج
در این بخش بررسی تغییر فرم و شکست ناشی از تراک داخلی یک لوله فولادی گرزش شده است.

4- منابع تحقیق
عکس‌های مبلمان و جدول 2.1 نشان می‌دهد که لوله‌های فولادی به صورت گنزه‌ای دندان‌شیب یک لوله در این بخش بررسی تغییر فرم و شکست ناشی از تراک داخلی یک لوله فولادی گرزش شده است.

5- جدول 1

<table>
<thead>
<tr>
<th>Table 1 Dimensions and Material properties of the steel tube</th>
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<td>مقدار</td>
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<td>500</td>
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<tr>
<td>8780</td>
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<td>350</td>
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</tbody>
</table>

6- Fig. 1 Schematics of pressure loadings for two different types of internal combustions in cylindrical tubes. The amplitudes of deformations and structural waves are exaggerated for clarity.

7- شکل 1 شماتیک برخوردهای فشار برای دو نوع مختلف احراز داخلی در لوله‌های استفاده‌اند. دامنه تغییر فرم و امواج سیال به منظور وضوح افزایش آنی بررسی شده‌اند.
Table 2 Johnson-Cook parameters for St52-3 cold-drawn steel with standard strain-rate form.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>A</td>
<td>750 MPa</td>
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<tr>
<td>B</td>
<td>150 MPa</td>
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<tr>
<td>C</td>
<td>2.6</td>
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<tr>
<td>N</td>
<td>1</td>
</tr>
</tbody>
</table>

Fig. 3 The snapshots of simulated crack growth caused by a supersonic pressure wave at different time intervals (ms) for two similar FE models with different pre-crack locations.

Fig. 2 Right: the fractured tube (direction of the moving pressure is shown by the arrow). Left: the crack initiation (thumbnail crack) and the subsequent incremental growth at both directions.
The snapshots show the initiation and growth of the main crack, the parallel cracks, and the multiple cracks caused by traveling of a sonic pressure wave from the neck towards the bottom of the cylinder [24].

Fig. 4 FE simulation of deformation and fracture of a CNG cylinder. The snapshots show the initiation and growth of the main crack, the parallel cracks, and the multiple cracks caused by traveling of a sonic pressure wave from the neck towards the bottom of the cylinder [24].


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