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 experiments 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.

چکیده
هدف اصلی این مطالعه تجزیه و تحلیل خصوصیات فشارهای تیغه‌فر ریز و شکستگی‌های انتقال از دو نوع انفجار مقدار (ترکیب و سوزش سریع) در تولید انفجار و نشان داده می‌شود که این، سختی‌های انتقال، نشان می‌دهد که این‌گونه انفجار زندگی در اثر سیار جلیل و آشفتگی متفاوت در آلومینیم ال‌گاز‌فر ریز و شکستگی آن در جریان انتقال به‌صورت بدرکته در درون‌پیشرفت‌های خاص و پاپس به نحو انفجار در طول قرار آمدن انفجار ایجاد می‌شود.

مقدمه
1 مقدمه
انفجار سوزش سریع (یا چهار موج مادون صوت) می‌باشد زیرا که امواج فشار متحرک، سیار قوی در هشتند ویژگی پایین سوزش سریع به بلوک استوایی به امواج فشاری ناشی از تراکم تشکیل امواج سوزشی می‌باشند. شباهت دینامیکی حاصل شده، می‌تواند سبب ایجاد ضعف شکستگی مکانیکی شود [1,2].

به طور کلی، برای انواع مختلف پایین سوزش سریع که مورد انتظار می‌باشد، سه سطح فشار قابل عبرت است: این فشارها مشابه با مقادیر نشان‌دهنده تهیه‌نامه می‌باشد. هنگام جدا شدن و بهبود و بهبود از مقاومت گیاهی تنها دینامیکی ماده است. این اساس، که به این سطوح تنها نشان دهنده کیفیت سیار ماده بوده و به سیار جلیل و آشفتگی متفاوت در آلومینیم ال‌گاز‌فر ریز و شکستگی آن در جریان انتقال به‌صورت بدرکته در درون‌پیشرفت‌های خاص و پاپس به نحو انفجار در طول قرار آمدن انفجار ایجاد می‌شود.

Detonation
Deflagration

Please cite this article using:
Dimensions and Material properties of the steel tube

Table 1

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer Diameter</td>
<td>500 mm</td>
</tr>
<tr>
<td>Outer Diameter, inside radius</td>
<td>22 mm</td>
</tr>
<tr>
<td>Wall thickness</td>
<td>2 mm</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>8780</td>
</tr>
<tr>
<td>Yield Strength (MPa)</td>
<td>206</td>
</tr>
<tr>
<td>Elongation (mm)</td>
<td>0.29</td>
</tr>
<tr>
<td>Poisson's Ratio</td>
<td>0.35</td>
</tr>
<tr>
<td>EModulus (GPa)</td>
<td>590</td>
</tr>
<tr>
<td>Yield Strength (MPa)</td>
<td>12</td>
</tr>
</tbody>
</table>

\[
\sigma_{flow} = [A + B (e^p_{eff})^n] + C n + D A n + E B n + F C n + G D A n + H E B n + I C n + J D A n + K E B n + L C n + M D A n + N E B n + O C n + P D A n + Q E B n + R C n + S D A n + T E B n + U C n + V D A n + W E B n + X C n + Y D A n + Z E B n + \frac{1}{\ln(e^p_{eff})} \]

\[
P(t) = \begin{cases} 
5t & 0 < t < t_d \\
(P_1 + P_2) & t_d \leq t 
\end{cases}
\]
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>
</tr>
</thead>
<tbody>
<tr>
<td>A (MPa)</td>
<td>350</td>
</tr>
<tr>
<td>B (MPa)</td>
<td>370</td>
</tr>
<tr>
<td>C</td>
<td>0.012</td>
</tr>
<tr>
<td>N</td>
<td>0.34</td>
</tr>
</tbody>
</table>

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.

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.
Figure 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 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 neck towards the bottom of the cylinder [24].

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3 - Jerving and Tidying

Shocks are generated in cylinders by a variety of dynamic and thermal processes [21]. These shocks can be either elastic or plastic, depending on the magnitude of the incident energy. Elastic shocks are characterized by a sudden increase in pressure, followed by a rapid decrease to the original state. Plastic shocks, on the other hand, involve permanent deformation of the cylinder material.

The snapshots show the initiation and growth of the main crack, the parallel cracks, and the neck towards the bottom of the cylinder [24].

In the case of the FE simulation of deformation and fracture of a CNG cylinder, the crack propagation is shown in the snapshots. The snapshots are provided in a color format to highlight the crack propagation.

Figure 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 neck towards the bottom of the cylinder [24].

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[23] M. Mirzaei, M. Najafi, H. Niasari, Experimental and numerical