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Engineering Failure Analysis 12 (2005) 453–464
ENGINEERING FAILURE ANALYSIS
www.elsevier.com/locate/engfailanal

Experimental investigation of the limit load of the ANSI B16.9 tees with and without cracks under internal pressure

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Received 4 January 2004; accepted 12 January 2004
Available online 25 January 2005

Abstract

The experimental results of plastic limit load of 14 Chinese ANSI B16.9 tees, under internal pressure, were reported in this work. Among the selected specimens, two were made of stainless steel and the others were made of plain carbon–manganese steel; eight junctions were defect free and six had outside, non-through wall cracks at the flank or the crotch corner. Results of dimensional surveys of Chinese ANSI B16.9 tees were presented first, and then the collapse behaviour and the significant bulging of the side flanks of junctions with and without cracks were depicted. The relationship of plastic limit load with structural dimensions and crack size were then summarized on the basis of experimental results. The existing estimation formulae were evaluated by using the experimental results.

Keywords: Bulging failures; Plastic deformation; Limit load; Pipeline failures; Tee joints

1. Introduction

ANSI B16.9 tee is a common configuration used in pipeline installations of power generation, chemical processing plants and petroleum refineries. To reduce the risk of component failure, engineering flaw assessment methods, e.g. the R6 routine [1], API 579 [2] and the Engineering Treatment Model (ETM) [3] are often adopted. Applying these methods, the limit load is a crucial input parameter and the accuracy of the final result often strongly depends on the accuracy of limit load calculation. Although work concerning the limit load calculation of this kind of component was reported recently [4–8], most of these earlier researches concentrated on the limit load evaluation by using finite element method (FEM) and theoretical

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1350-6307/$ - see front matter
doi:10.1016/j.engfailanal.2004.01.007

Nomenclature

a	depth of crack
c	half length of crack
D	mean diameter of run pipe
D_0	outside diameter of run pipe
d	mean diameter of branch pipe
P	internal pressure
P_{L}	limit pressure of tee without crack
$P_{\mathrm{L}}^{\mathrm{c}}$	limit pressure of cracked tee
$P_{\mathrm{L}}^{\mathrm{exp}}$	measured limit pressure of tees from test using twice-elastic-slope method
$P_{\mathrm{b}}^{\mathrm{exp}}$	measured burst pressure of tees
r	radius of transition between branch and run pipe, as shown in Fig. 1
T	mean wall thickness of run pipe
t	mean wall thickness of branch pipe
T_{m}	average value of actual wall thickness
T_0	normal wall thickness
ΔV	volume increment
σ_{f}	flow stress
σ_{b}	ultimate stress
j_0^P	weakening factor of equal diameter tee under internal pressure

approximation. It is well known the collapse test is essential for limit load analysis of complicated structures. However, for ANSI B16.9 tees there is very little experimental data available up to now.

More recently, a numerical and experimental study on the mechanical behavior of a branch under out-of-plane bending was presented by Chapuliot et al. [6]. However, the geometry of the welded cylinder–cylinder intersection junction is considerably different to ANSI B16.9 tees investigated in this work. The main difference between the ANSI B16.9 tee and welded piping branch junction is that no welding exists around the crotch of the former and thus the stress peak is eliminated in the zone. An earlier limit load test of ANSI B16.9 tees subjected to external moment was performed by Schroeder [9]. The results indicate that the plastic limit moments of ANSI B16.9 tees are approximately equal to 1.5–2.2 times the theoretical limit load solution of straight pipe with the same diameter. For the tees with through-wall cracks in the flank, reported by Yahiaoui et al. [4,10], no obvious reduction of the limit load was observed compared to the defect free tees, and the failure mostly occurs in the vicinity of the welding of the straight pipes. Considering only one specimen was used in Yahiaoui et al's. [4,10] test, the above result was not necessarily suitable for other type tees.

Within this work reported here, pressure tests of 14 ANSI B16.9 tees with and without cracks were conducted and then the relationship of plastic limit load with structural dimensions and crack size were analyzed systemically. The existing estimation formulas for plastic limit pressure of ANSI B16.9 tees were evaluated by using the experimental data.

2. Presentation of specimens

Fourteen ANSI B16.9 tees fabricated by different manufacturers were selected to carry out the experiments for plastic limit loads. Of the 14 components surveyed in this paper, two are made of stainless steel