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Proposal of new Pipe-Ring specimen for fracture mechanics

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Abstract

Thin - walled pipes are not suitable for measuring fracture toughness parameters which are of vital importance in pipes because the crack failure is the most common in pipes. They are not suitable because it is impossible to make standard specimens for measuring the fracture toughness like SENB or CT specimens from the thin wall of the pipe. Lot of researches noticed this problem, but only few are found the good and cheap alternative solution for measuring the fracture toughness. Gubeljak and Matvienko proposed so - called Pipe - Ring specimen (PRS) or Pipe - Ring Notched Bend specimen (PRNB) as alternative solution to the SENB specimen. Until now, only the idealized geometry of PRS specimen is analysed, so specimen which is not cut out from the real pipe but made from plate. On this way, the residual stresses are neglected. The aim of this work is to estimate the hoop residual stresses in the real pipes used in boiler industry, produced by hot - rolling technique, so seamless pipes. These kinds of pipes are delivered only normalized, but not stress relieved too. Therefore, there are surly residual stresses present in pipes which are result of manufacturing technique, but also of uneven cooling after the production process. Within this work, hoop stress as the most relevant for pipes is estimated by two methods: incremental hole drilling method and splitting method. Although residual stresses are cause of collapse of many constructions, still in most cases of analysis and design of individual parts, structures and plants residual stresses are not taken into consideration. Residual stresses surly have some effect on the fatigue behaviour of materials as well as on the fracture toughness of material, therefore it is recommended to take them into account while calculating the lifetime of component or structure.
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Keywords: residual stress; pipe; hoop stress; incremental hole drilling method; splitting method; tensile test; *F* - CMOD; PRS; PRNB; SENB

1. Introduction

Within this work, residual stresses are estimated in PRS specimens who are cut out from the real pipe, and the basic idea is that one PRS specimen loaded with double force in relation to the SENB specimen has very similar behavior, Figure 1. This kind of specimen is proposed by Matvienko and Gubeljak as replacement for standard Single Edge Notched Bend specimens (SENB) for measuring the fracture toughness of material [1], [2], [3], [4], [5]. Since in most cases of thin walled pipes it is impossible to produce the standard SENB specimen from pipe wall, PRS specimen is the simplest and the cheapest alternative solution. On example of pipes considered in this researches, seamless pipes produced according to the EN 10216-2, there are 951 different pipe dimension available, but only from 251 pipes it is possible to produce standard SENB specimen, and from 700 pipes it is not possible due to thin wall of the pipe or due to the small outside diameter.

In [6] Likeb was analyzed PRS specimens in relation to the SENB and Compact Tension (CT) specimens, but in order to avoid the residual stresses, PRS specimens are made from steel plate. So it is necessary to estimate residual stresses in pipes in order to assess their impact to the fracture toughness. Of course, residual stresses firstly depends on the production process of pipes, so besides of hot rolled pipes analyzed in this paper, it is necessary to estimate residual stresses also on other pipe types.

Since the residual stress are depend also on the dimensions of pipes, within this paper, residual stresses are measured on four different pipe dimensions varying the outside diameter and wall thickness as follows: D = 114,3 mm, B = 12,5 mm; D = 219,1

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mm, B = 22,2 mm; D = 168,3 mm, B = 8 mm and D = 193,7 mm, B = 7,1 mm. All considered pipes are made from standard boiler steel 16Mo3 according to the standard EN 10216-2.

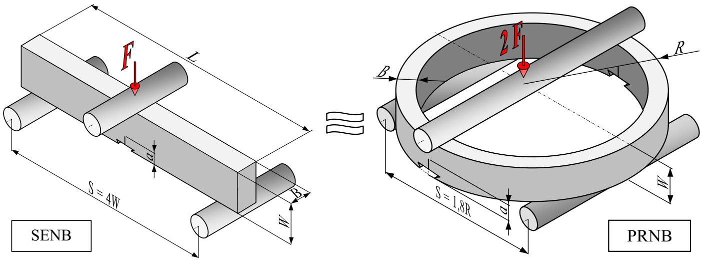

Fig.1 Similarity of SENB and PRS specimen

2. Experimental procedure

Since it is quite hard to simulate all the production process numerically, the residual stresses are estimated experimentally using two methods: incremental hole drilling method according to ASTM E 837-08 [7] and splitting method according to ASTM E 1928-99 [8].

For implementation of both methods, material properties are obtained from the tensile tests. Tensile specimens are made from all four considered pipe dimensions taking into account two states: as delivered state and stress relieved state in order to minimize the residual stresses.

Also in the previous researches about the PRS specimens, the imperfections of the pipes are neglected. According to the EN 10216-2 [9], tolerance for outside diameter of pipe is ± 1% or ± 0,5 mm (larger values is relevant) and tolerance for wall thickness is ± 12,5% or ± 0,4 mm (larger values is relevant). By performed dimensional analysis of considered specimens it is concluded that there are even larger deviations for wall thickness in some specimens, even for 9 % larger than allowable by standard. Since the dimensions of specimens can vary significantly, it is expected some deviation in the values of residual stresses as well.

2.1. Tensile test

The actual characteristics of the material in means of E and ν are required for both: incremental hole drilling method and splitting method. So tensile tests are performed for specimens made from all four analyzed pipes in both states: as delivered and stress relieved state. Tensile specimens are made according to the DIN 50125:2004-01 [10] from the blank piece cut out in the longitudinal direction of pipe. From pipes with B = 12,5 mm and B = 22,2 mm tensile specimens with diameter d = 5 mm are made and from pipes with B = 7,1 mm and B = 8 mm tensile specimens with diameter d = 4 mm are made. 24 tensile specimens in total are made, 3 from every pipe in both mentioned states. Tensile tests are performed on the tensile testing machine Instron 1255-8500 Plus at the Fakulteta za Strojništvo in Maribor, Figure 2. E is obtained based on tensile tests, and ν is taken into account with value 0,3.

a) b) c)

Fig.2 Tensile test: a) tensile testing machine, b) tensile specimen with extensometer before testing, c) tensile specimen after testing

2.2. Incremental hole drilling method

Incremental hole drilling method (IHDM) is categorized as semi - destructive method since it implies drilling the small diameter hole (d = 1,8 mm) into the material and measuring the deformation around the hole using the special developed strain

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