Polymer Testing 57 (2017) 245–259

Contents lists available at ScienceDirect

Polymer Testing

journal homepage: www.elsevier.com/locate/polytest

Property Modelling

Constitutive model and failure locus of a polypropylene grade used in offshore intake pipes

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ARTICLE INFO

Article history:
Received 17 September 2016
Accepted 22 November 2016
Available online 25 November 2016

Keywords:
Polypropylene
Polymer
Elastic
Visco-plastic
Failure locus
Weld
Pipe
Finite element analysis

ABSTRACT

BorECO®™ BA212E is a polypropylene block co-polymer which has become a common material in the manufacturing of large diameter non-pressurized gravity offshore intake pipelines. These lines are used for transportation of sea water for cooling of petrochemical process plants. The pipe sections are joined by butt heat fusion welding to create the pipeline. Recently a few premature failures of such pipelines have been reported in the field. Hence, there is a need to characterize the constitutive behavior of the pipe and weld material in order to properly design these pipes. The aim of this work is to determine the material constitutive behaviors of the pipe material and the welded joint material. Uniaxial tensile tests of both the pipe and weld joint material are conducted at various strain rates. Both the pipe and weld material show a rather high strain rate dependency, with the weld material having about half the yield strength than that of the pipe material. An analytical constitutive material model is developed for both the pipe and weld material, incorporating the effect of strain rate. The failure locus, expressed in terms of the equivalent plastic strain at failure vs. the stress triaxiality, for both materials is also determined as part of the constitutive model using notched dumbbell specimens. The constitutive model and failure loci for the pipe and weld material are implemented in a finite element model (FEM) and are validated by conducting a series of independent four-point bend experiments on both material types. The validation is carried out by comparing the FEM results of the four-point bend model with the experimental results, which show a rather good agreement.

1. Introduction

Seawater intake and outfall subsea pipelines are vital components in process plants in the petrochemical industry for providing cooling water during the operation of the plant. Such pipes can measure up to several meters in diameter and are commonly made of glass reinforced polymers (GRP). However, GRP pipes have been the subject of many damages during installation and operation, primarily due to their low impact and damage tolerance. To alleviate this, recently a block copolymer polypropylene (PP) BorECO® BA212E has found a widespread application in non-pressurized gravity pipes used for seawater intake lines in the petrochemical industry. These pipes are usually designed in accordance with international standards [1–3] and a common requirement for subsea pipelines [4] is the resistance to the impact by foreign objects during installation and operation. However, the constitutive behavior of the polypropylene material itself at various loading rates is less understood and not addressed in design standards. In order to assess the impact damage tolerance of the pipe, it is important to characterize the full constitutive and failure behavior of the material grade. Moreover, these polypropylene pipelines are made of pipe sections which are joined by butt heat fusion welding. It is crucial to also address the constitutive and failure behavior of the formed joints, which are commonly the weakest link in the pipeline. When the full constitutive and failure behavior of both the pipe and weld material are determined, a finite element analysis (FEA) can be conducted in order to assess the damage tolerance of the subsea polypropylene pipes based on common industrial practice [4]. Hence, for this purpose the objective of the current study is to determine the constitutive and failure behavior of the BorECO® BA212E polypropylene material and its strain rate dependence.

Constitutive material models of polymers are commonly characterized by visco-elastic [5,6], elastic-plastic [7] or visco-plastic

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http://dx.doi.org/10.1016/j.polymertesting.2016.11.031

[8–15] models, where the elastic-plastic rate-independent model is the simplest approach. A multiplicative modeling approach of the flow stress of the polymer able to predict the stress with strain-rate and temperature dependency was introduced by Inouye [16] and was further enhanced by Tate [17] for polypropylene. For semi-crystalline polymers, the elastic behavior has also been

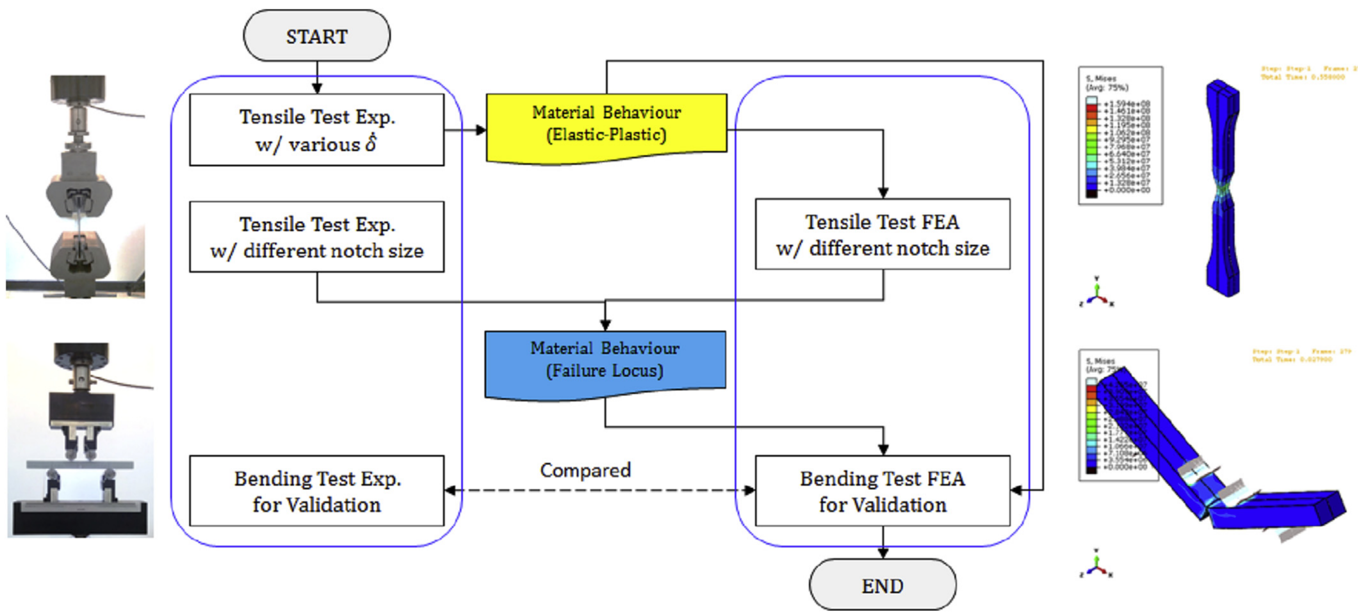

Fig. 1. General ouline of the study.

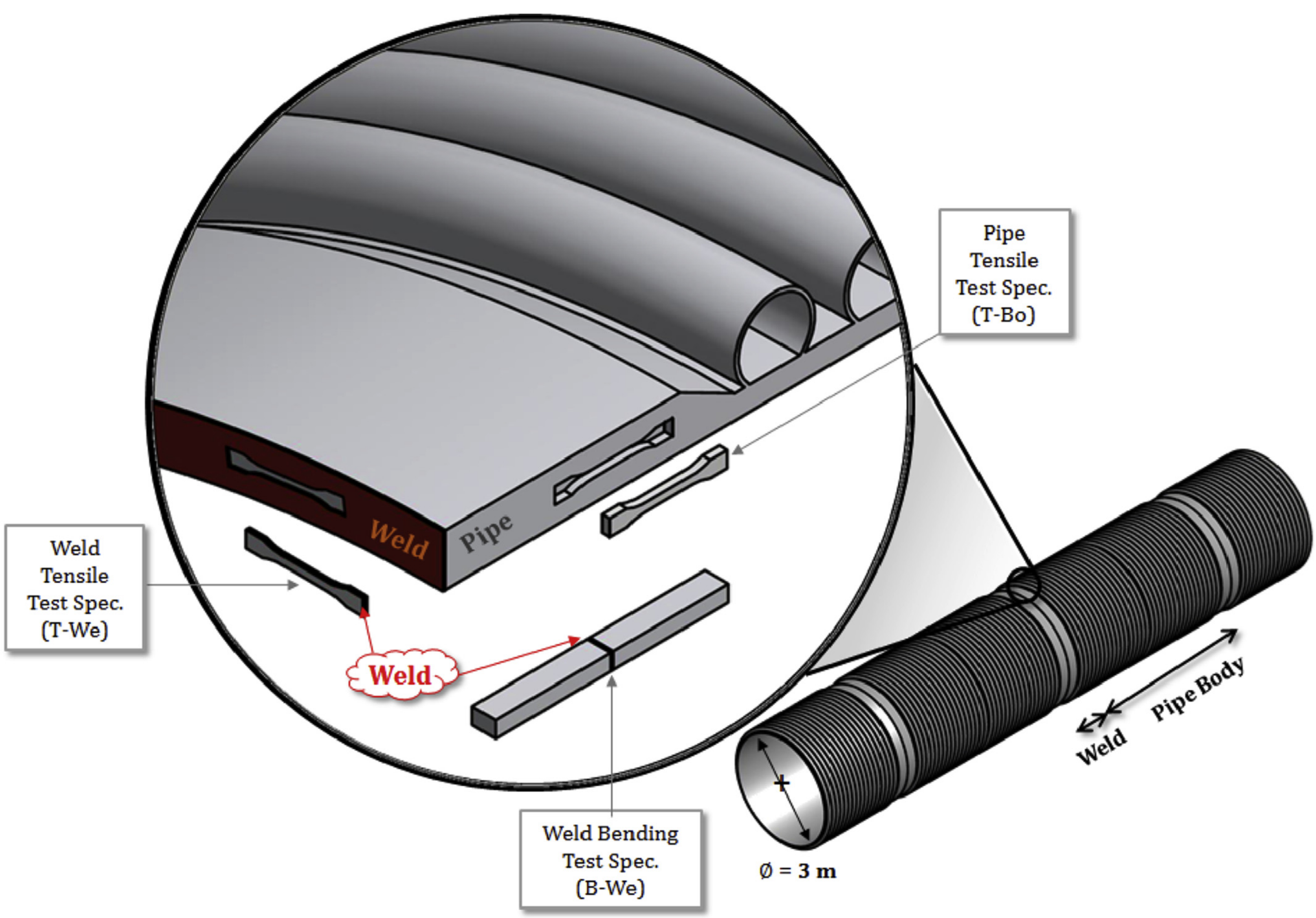

Fig. 2. Pipe and weld specimens taken from a polypropylene pipe.