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Original Research Article

Fatigue and failure of steel of offshore gas pipeline after the laying operation

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ABSTRACT

The presented paper is mainly aimed at estimating the residual lifetime of metal used for the offshore gas pipeline under a low amplitude cyclic load applying S- and J-methods for pipelaying. Taking into account the preliminary effect of deformation on the welded joint and the base material of the pipe, the tests on fatigue have been carried out and physical and mechanical regularities in fatigue failure in offshore gas pipeline materials have been established.

The obtained results show that the plasticity and embrittlement of the pipe wall employing S- and J-methods for pipelaying do not practically affect the residual lifetime of metal under low amplitude cyclic loading, but rather exert a significant influence within a high amplitude range under the preliminary deformation process that activates the accumulation of fatigue defects and strain aging.

1. Introduction

Worldwide practice mostly accepts two methods for offshore pipelaying: the S-method has been used for pipelaying at small depths, whereas the J-method – for such operations at large depths [1,2]. The pipes are laid from special pipelaying vessels [3,4].

Ukraine is planning the extraction of natural gas at the Black Sea shelf and preparing for the development of pipelaying transport offshore. The peculiarities of operating offshore gas pipelines include external hydrostatic water pressure. No intermediate gas compressor stations can be observed in the pipeline at the continental shelf. Considering that sufficient gas pressure should be ensured at the outlet of the pipeline, the total pressure in the system has been

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increased. Sea water can be characterized by aggressiveness, which results in damage done to the metal structures of the pipeline [5–9].

The stress–strain state of the pipe wall, under the analyzed modes, is calculated prior to laying it. The result of estimation is a technological map of laying pipes, and the norms of allowable defectiveness for field circumferential joints of the pipe. However, the effect of damage caused to the pipe within the laying process on its cyclic life remains unattended by engineers and needs further investigation. Only a few scientific papers concerning the above presented problems are known; however, in general, they require further study [10,11].

The paper focuses on investigating micro-mechanisms for fatigue failure in offshore pipeline steel after deformation, which simulates different pipelaying methods.

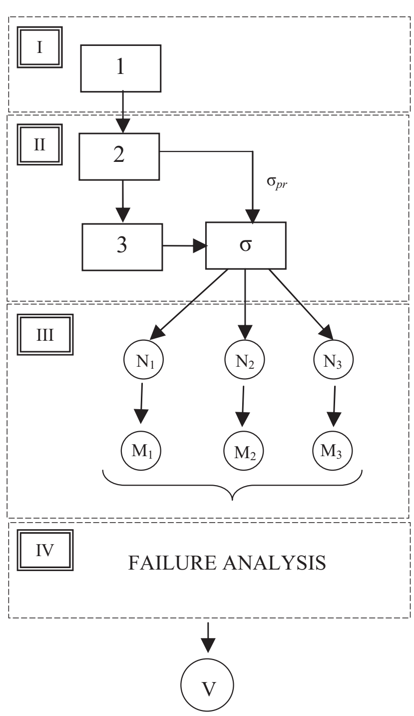
2. Graded nature of investigation into the effect of pipelaying techniques on the cyclic life of pipes

The issue of the degradation and life prediction of the main gas pipelines is known to be extremely complex. To solve this problem, the authors have proposed an algorithm for research, which is based on the previous experience [12], Fig. 1. The conducted investigation refers to the life-expectancy analysis of offshore gas pipelines and allows selecting schemes and methods for testing laboratory specimens. The mechanisms for the effect of pipelaying defined with the help of S- and J-methods have been compared with the identical parameters of cyclic loading, which assists in finding the advantages and disadvantages of each of them. Fractographic analysis determines micro-mechanisms for a material fracture and moves to the examination of generalized failure in order to make conclusions about the life of pipeline steel under various modes of loading.

3. Deformation processes during pipelaying and a method for fatigue testing

3.1. *Short description of S- and J-methods for pipelaying and deformations occurring in the course of these processes*

The S-method for pipelaying has been implemented from a special pipelaying vessel equipped with a specific appliance – stringer, i.e. a truss structure pinned to the fanner, which allows changing the angle of convergence and the curvature radius of the pipeline (Fig. 2a). Moreover, stresses and strains within the pipe are sensitive to the position of the vessel and tensioning the pipeline [3,4]. Rollers are installed on the stinger to guide the pipe. In the overbend section, pipe bends from horizontal to an almost vertical departure angle where the pipe leaves the stinger. Large bending induced by stinger and axial tension force resulting from submerged pipe weight causes plastic deformation in the pipe. The pipelaying vessel motion under actions of environmental loads induces cyclic plastic deformation. The large plastic stress and cyclic behavior need to be minimized and controlled



I – analysis of life problems of the main offshore gas pipelines;
II – relationship between techniques for laying offshore gas pipelines and laboratory techniques for investigating specimens;
III – macro- and micro-mechanisms for the fracture;
IV – generalization of the effect of force factors and the type of pipelaying techniques on the cyclic strength of gas pipeline steel;
V – conclusions;
σ_{pr} – preliminary stress.

Fig. 1 – Algorithm for analyzing the pipelaying technique for the cyclic life of pipes: 1 – reasons for pipe degradation; 2 – methods (S and J) for offshore pipelaying; 3 – laboratory methods for testing specimens; σ_{pr} – stress during pipelaying; σ – parameters of cyclic stress in the gas pipeline; N – cyclic life of steel and the welded joint; M – micro-mechanisms for the fracture.