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# An experimental investigation of propagation the semi-elliptical surface cracks in an austenitic steel

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ABSTRACT

This paper presents the results of experimental studies of propagation of the semi-elliptical cracks in 1.4541 austenitic steel commonly used for the construction of the industrial pipelines. The work includes the results of studies of the structure and mechanical properties of 1.4541 steel used to build new pipeline sections and steel after many years of service. Fatigue crack growth analysis was performed by using the method of electrical potential drop (EPD). In order to confirm correctness of the electrical potential drop measurement method a two other experimental methods were used in comparative studies, staining of fatigue fracture and using a strain propagation gauge. Elaborated EPD measurement methodology enables a continuous recording of the dimensions of propagating semi-elliptical cracks, both under variable tension and under constant bending, which was confirmed during the tests.


## 1. Introduction

Pipelines are one of the most important infrastructure components in the distribution of gases and liquids. The most importance is due to its high efficiency of fluid transport, low costs and safety. Therefore pipelines are commonly used as a mean of transportation for chemical agents and widely incorporated in chemical and petrochemical industry. Industrial pipes are made of various materials, but steel is the most widespread structural material in mentioned branches [1], especially stainless/austenitic steel. Predominance of these grades of steel results from their beneficial combination of very good mechanical properties and excellent corrosion properties, such as a high resistance to pitting and stress-corrosion cracking [2–4]. Moreover, austenitic steels are used even for installations that are utilized in nuclear plants [5,6].

Industrial pipes are predominantly exposed to a variable loads resulting from the changes in pressure, temperature or strain, induced by transported fluid. The conditions of usage are often deteriorated by a caustic environment decreasing the lifetime of structure [e.g. 7–9]. This character of loading has direct influence on the fatigue nature of failure.

An experimental analysis of fatigue properties and crack propagation has composed one of the most interesting subjects of the research works concerning various structural materials, particularly the steels. The most often defined purpose of these studies is determination of the fatigue crack growth rate or the crack propagation nature in relationship with the number of load cycles and their type. In order to measure the fatigue crack propagation various experimental methods are used. An optical method is the most willingly applied technique due to its simplicity and satisfactory measuring accuracy. Except the mentioned way, standards [10] recommend usage: the single specimen compliance unloading method, the ultrasonic method, the acoustic emission method, the resistance method or the potential drop method. All aforementioned methods are applicable mainly in tests conducted on compact specimens and specimens with central throughout hollow [11–16]. In order to determine the growth of semi-elliptical crack propagation two optical methods are mainly used, namely the staining method and the method of short-lived load amplitude decreases or increases. They enable to capture the shape of crack front at particular stages of crack growth [17,18]. But in these procedures a post failure investigation of the crack surface can be conducted. For this reason the optical methods cannot be used in assessment of the fatigue life of industrial pipelines, but during crack propagation scientific researches or in comparative studies ordering the estimation of the new measuring methods of propagating crack. This problem can be solved by applying one of other methods, for example the direct current electrical potential drop (EPD) technique. This method is quite widely practiced in the crack propagation measurements in materials that are the electrical

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conductors and have measurable electrical resistance. The determination of crack length is based on the changes of electric resistance in a specimen with a propagating crack. The electric field parameters are dependent on the sample geometry and the size of crack. If a direct current is applied to the specimen, the electrical potential on the specimen between calibration points increases together with the crack growth [19]. The above effect is a consequence of the electric field change, resulting from disturbances of the current flow lines. A two-dimensional electric field is obtained by application of direct current, which is constant throughout the whole thickness of a specimen.

In this paper, an experimental analysis of semi-elliptical crack propagation using modified electrical potential drop technique is conducted. This purpose was selected as a result of as-of-yet existing imperfect procedures for the fatigue life determination of industrial pipelines and based on the fatigue crack propagation. Nowadays, the methods taking into account the surface/internal cracks propagation (semi-elliptical or elliptical) are used for this purpose [20,21]. The above mentioned calculation methodologies of pipeline wall thickness are performed assuming existence of critical or admissible crack depth. The pipeline fatigue life can be computed on the basis of various modified equations originating from the linear or non-linear fracture mechanics [22]. This attitude requires the knowledge of a crack length, both initial and final, and crack propagation rate.

Corrosion-resistant austenitic steels type 18/8 (containing about 18% Cr and 8% Ni) are commonly used for the structures of chemical pipelines. It is important that particular attention should be given to the method of structure dimensioning which is determined by the present material's fatigue properties. Therefore, the present technical condition of pipelines has to be conducted by an assessment of mechanical properties of the pipe material. It becomes crucial if the cracks, material defects or deviations from original pipeline geometry were revealed or assumed service life is expected to exceed. For this reason, it is essential to investigate the fatigue strength of austenitic steels with different assumptions.

**Table 1**
Composition of examined steels.

| Steel 1.4541 | Chemical composition Wt [%] | | | | | | |
|---|---|---|---|---|---|---|---|
| | C | Si | Ti | Cr | Mn | Fe | Ni |
| A (I) | 0.05 | 0.81 | 0.38 | 17.80 | 1.74 | 70.21 | 9.02 |
| A (II) | 0.04 | 0.66 | 0.59 | 18.67 | 1.59 | 69.36 | 9.14 |
| B | 0.07 | 0.64 | 0.66 | 18.08 | 1.19 | 69.54 | 9.81 |

## 2. Subject of the research

The study was conducted on the pipe segments of overhead industrial pipeline made of the 1.4541 stainless steel (marked also as AISI 321 or X6CrNiTi18-10). Three materials states are being considered. The first material (signed "A(I)") was received from the segment of new pipeline, the second (signed "B") was excised from an old ex-service pipeline operated for thirty years and the last one (signed "A(II)") was excised from a section of the old pipeline that has not seen service and retained until present moment. In order to confirm if any differences in composition or strength properties between all considered materials exists the appropriate investigations were conducted.

All specimens have been made from the pipeline sections with the outside diameter of Ø600 mm and wall thickness of 5 mm. Investigated material "B" was excised from a section of two-pressure acid installation (KDC II) being operated in one of the chemical plants. The installation is used for transportation of 10.5-percent nitric oxide with temperature of 436 K.

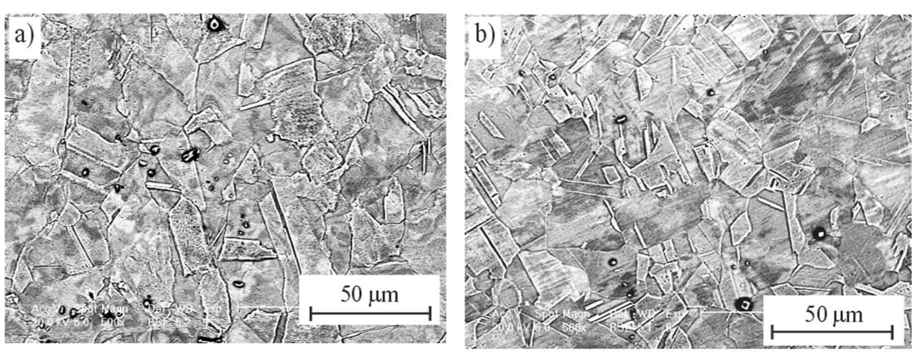


**Fig. 1.** The structure of material A(I) in transverse (a) and longitudinal (b) micro-section.

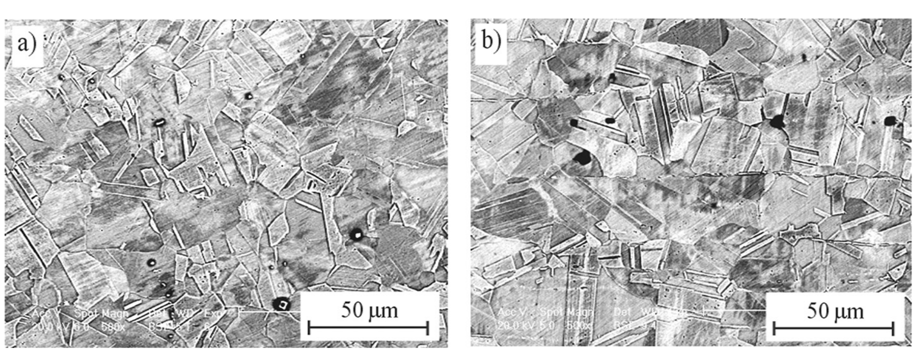


**Fig. 2.** The structure of material A(II) in transverse (a) and longitudinal (b) micro-section.