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Determination of the crack-initiation and propagation conditions in a styrene-acrylonitrile water-filter housing with external ribs based on destructive pressure tests

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ABSTRACT

Fatigue cracks were initiated during the operation of a water-filter housing made from styrene-acrylonitrile (SAN). Using a destructive pressure test, it was confirmed that the sharp transition between the wall and the vertical external ribs of the filter housing at the point of the increased external diameter is the critical area of the water-filter housing. This is a consequence of the stress concentration due to the combined action of the sharp edges of the vertical external ribs and the increased stiffness due to the thicker wall and the mounting of the upper part of the housing onto the filter head. During the destructive pressure tests a crack was initiated on the external surface in the same place and spread in the same direction as the fatigue crack during the operation of the water filter. At the critical point the actual loads due to the stress concentrator are approximately 3.2 times higher than that expected based on the water pressure in the pipeline. The tensile strength of the styrene-acrylonitrile from the water-filter housing was comparable with the literature data. The fracture toughness of styrene-acrylonitrile is low and comparable to the fracture toughness of polymethylmethacrylate. The critical crack depth for the occurrence of an uncontrolled rupture for a continuously increasing load is approximately 100 μm, while the plane-strain condition occurs at a thickness of about 1 mm. A rapidly growing crack in the wall tends to grow in a layer of plane-strain conditions, and from the internal- to the external-wall surface. The possibility of determining the fracture toughness with a destructive pressure test of the housing or a pressure vessel with an external surface stress concentrator was achieved.

1. Introduction

There have been reports in Slovenia of leakages from water-filter housings made of styrene-acrylonitrile. These leaks occurred in the base or along the external vertical ribs of the water-filter housing's wall. A manufacturing defect was present in the leaking base of the housings (a local roughened external surface, below which the crack was present), while in the leaking wall, along the external vertical ribs, the housing was without any defects. According to the latest information, some housings were leaking at the same time along the vertical rib and partially in the area of the internal threads, which are to allow the filter head to be screwed to the housing. In some already used, but still watertight, housings, fatigue cracks were identified in the wall along the external vertical ribs in the area where the external diameter of the filter housing is changed. The lines of the cracks were consistent with the line of a sharp

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transition between the ribs and the wall of the housing [1].

Since the cracks always occur in the areas of maximum stress, or at the site of a local strength excess in the material, it is clear that the sharp transition between the external ribs and the wall of the housing is a strong geometrical stress concentrator. Depending on the type of load, the theoretical elastic stress-concentration factor K_t and the fatigue stress-concentration factor K_f [2,3,4,5,6] are determined. K_t is used for static loads in the range of Hooke's law, while K_f is used for alternating loads. The factor K_f is lower than K_t, but it approaches K_t for a material with greater strength and brittleness and for larger dimensions of the object under investigation.

The primary purpose of the investigation based on a destructive pressure test was to determine and analyze the critical fracture area of the filter housing (i.e., a housing without manufacturing defects) and to answer the question as to why the fatigue cracks initiate in the wall at the external vertical ribs in the area of the changing external diameter of the housing. By analyzing the cracks and their fractured surfaces, together with applying the equations of fracture mechanics, the fracture characteristics of the styrene-acrylonitrile and the characteristics of the initiation and growth of cracks in a catastrophic collapse of the water-filter housing were identified.

2. Experimental

2.1. Methods

A visual inspection was made of the delivered, unused, water-filter housings (with the naked eye and with a 5 × magnifying glass). The typical dimensions and the geometrical characteristics of the housing were measured with a calliper Garant absolute and a Mitutoyo PJ-3000 profile projector with a magnification of 10 × (both measuring instruments have a calibration certificate). The destructive pressure test was carried out with water (a calibrated water manometer with a pressure range p = 0–50 bar was used). The cracks and the fractures were examined with the naked eye, with a 5 × magnifying glass and with a scanning electron microscope (SEM JEOL JSM-5610). Before the SEM analysis the samples were coated with gold. The stress-concentration factor K_t, the mechanical properties of styrene-acrylonitrile and the conditions for the initiation and rapid growth of cracks in the wall of the filter housing due to the pressure overload were theoretically evaluated.

2.2. Samples

The transparent and blue-coloured filter housings are made of amorphous styrene-acrylonitrile, the fracture surface of which always has a brittle character [7]. The geometrical characteristics of the housing with all the relevant dimensions – wall thickness t_w, the average external and internal diameters D_{ext} and D_{int}, the radius of the transition between the larger and smaller diameter r_1, the radius of transition between the vertical ribs and the wall of the hosing r_2 – are shown in Fig. 1. The filter housing has a cylindrical shape with eight vertical external ribs. The upper clamping part has a larger external diameter and it has an internal thread with which the housing is screwed to the filter head. The lower, functional part without threading has a smaller diameter, which is slightly reduced towards the base of the housing (the housing has the shape of a drinking glass). The wall thickness varies, while the average thickness of the wall is t_w = 4.7 mm. The average width of the ribs is w_r = 6.5 mm, while the thickness is t_r = 2.1 mm. The average distance between the ribs (from edge to edge) is l = 20 mm. The radius of the transition between the vertical ribs and the wall is very sharp (r_2 = 0.2 mm) and is even smaller than the notch-tip radius for measuring the impact strength with a sharp notch ISO-V (r = 0.25 mm).

3. Results and discussion

3.1. Visual inspection of the water-filter housings

Before the destructive pressure test all the water-filter housings were visually inspected. Different in-homogeneities that could affect the destructive pressure or the site of crack initiation were searched for. The checked housings have more-or-less expressed thin surface lines on the base and/or in the threaded area. The inspection of the leaking housings that were removed from operation showed that the thin lines are unrelated to the leaks in the housings [1]. The cracks did not initiate at these sites, moreover, the thin lines were not in the same positions as the identified leaks. For the destructive pressure test three housings with the minimum number and the fewest expressed thin lines were selected.

3.2. Destructive pressure test

The manufacturer of the water filters guarantees the collapse of the housing with vertical ribs at a pressure $p_d \geq 32$ bar. The destructive pressure test was carried out with a hand-operated water pump (this was connected to the filter head with a tube) while recording the pressure change with a camera. After filling the system with water and an initial stabilization period for the pressure, the fracture of the housings occurred after one to three actions of the crank at the pressures p_d = 34 bar (1 ×) and 35 bar (2 ×). The measured destructive pressures were greater than the minimum destructive pressure determined by the manufacturer of the water filters. This means that the static strength of the water-filter housings was adequate.