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Fatigue behaviour of an autofrettaged high-pressure vessel for the food industry

J.M. Alegre *, P. Bravo, M. Preciado

Department of Civil Engineering, EPS, University of Burgos, c/Villadiego s/n 09001 Burgos, Spain

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Abstract

The autofrettage technique is commonly used to produce compressive tangential residual stresses near the bore of high-pressure vessels. These compression stresses improve the fatigue life of the vessel during the loading–unloading high-pressure cycles. The present paper presents the fatigue design of an autofrettaged thick-walled vessel for the food industry, working at an internal pressure of 500 MPa. A finite element analysis has been performed in order to obtain the residual stresses after the autofrettage at an internal pressure of 925 MPa. The material of the vessel was a 15-5PH stainless steel hardened by precipitation, which shows a strong Bauschinger effect. For FE simulations, the material has been modelled considering an elastic–perfectly plastic behaviour for the loading phase and a Ramberg–Osgood behaviour for the unloading phase, with its coefficients depending on the previous equivalent plastic strain reached during the loading process. The simulation procedure is explained in detail. Finally, the fatigue life of the vessel was obtained using the residual stresses obtained in the previous simulations stage.

Keywords: High pressure processing; Autofrettage; Bauschinger effect; Plastic behaviour

1. Introduction

In the last decade, non-thermal inactivation techniques have been a major research issue, as a consequence of an increased consumer demand for nutritious qualities, fresh like food products with a high organoleptical quality and an acceptable shelf life. The investigated inactivation technologies are, for example, high pressure processing (HPP), pulsed electrical fields, UV decontamination, high power ultrasound, and oscillating magnetic fields. An extensive review of these methods can be found in [1]. The high pressure processing is the technology by which a product is treated to a high level of hydrostatic pressure (>200 MPa) during a specific period of time. The number of foods suitable to undergo high pressure processing is very large, including a wide variety of meat products (boiled ham, cured ham…), fish, ready-to-serve meals, as well as the majority of fruit, vegetables and juices.

To carry out the high pressure processing, it is necessary to design high-pressure equipment that has a sufficient capacity to work cyclically on a production line. Nowadays, this processing is achieved by subjecting

* Corresponding author. Tel.: +34 947 259 420; fax: +34 947 259 485.
E-mail addresses: jalegre@ubu.es (J.M. Alegre), pmbravo@ubu.es (P. Bravo), mpreciado@ubu.es (M. Preciado).

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the product to high pressures inside huge vessels capable of pasteurising large volumes of product. Water is the medium that transmits the pressure, which means that, before being processed, the products must be packaged in a flexible container capable of resisting the small variations of volume that take place during the operation.

To reach the processing pressure, $p_w = 500$ MPa in the present vessel, and achieve a life span of the high-pressure machine that makes it cost-effective, more than 100,000 work cycles must be carried out. For this, the vessel and some of the machine parts can be designed using the autofrettage technique. This autofrettage technique consists of subjecting the vessel to an over-pressure which locks plastic strain in an internal core, so that when the vessel is unloaded some residual compression stresses are generated in the previously plastic core. This way, when the vessel is subjected to its interior work pressure, the mean tangential stresses in the inside decrease considerably and, as a consequence, the fatigue resistance of the vessel is significantly improved.

In recent years, many studies have been carried out in order to determine the state of stress that appears after the autofrettage process [2–4]. In plasticity, most of the steels undergo a phenomenon known as the Bauschinger effect [5–8], which consists of a reduction of the yield stress in compression as a result of a previous tension yielding. This effect reduces the theoretical residual compression stresses that are generated during the autofrettage process and it must therefore be taken into account during the fatigue design of the vessel.

The present article presents the steps that have been taken for the design of a high pressure vessel which was developed using the autofrettage technique and manufactured using a precipitation hardening stainless steel 15-5PH that shows a high Bauschinger effect. The procedure used to obtain the residual stresses is explained in detail.

2. Description of the high pressure equipment

The high-pressure vessel described in the present paper consists of a hollow cylinder with an external diameter of $d_e = 800$ mm, an internal diameter of $d_i = 300$ mm, and a length of $L = 4500$ mm. It contains an internal 20 mm thick jacket, which guarantees the detection of a leak before the vessel breaks and which has been introduced after the autofrettage of the vessel.

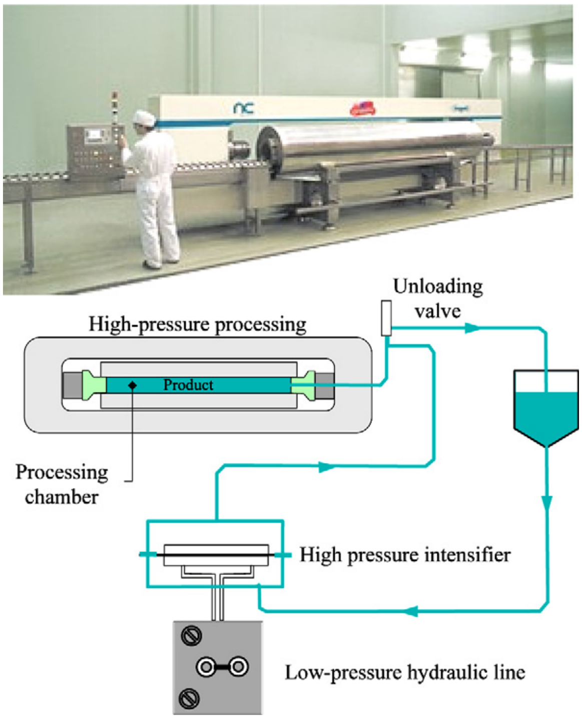

Fig. 1. Diagram of the high-pressure processing machine.