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Experimental study of weld fatigue strength reduction for a stainless steel piping component

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Abstract

An experimental mean curve and a design fatigue curve corresponding to 95% survival probability were derived from realistic fatigue experiments on a non-welded water pressurized piping component with primarily focus on high cycle fatigue. The components were subjected to a synthetic variable amplitude bending deformation. Comparison with the results obtained for a similar piping component with a circumferential butt weld allowed the determination of an experimental fatigue strength reduction factor. Comparison with the fatigue procedure and design curve in ASME BPVC Section III allowed to quantify its conservatism with regards to accounting for the presence of a weldment and more generally transferability.

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Keywords: austenitic stainless steel; welded pipe; experimental strain analysis; spectrum loading; high cycle fatigue.

1. Introduction

Weldments are considered critical for the fatigue strength of structures or components. Fatigue cracks do namely tend to occur in the vicinity of welding joints rather than in the smooth base material. Welds represent indeed a local structural discontinuity or stress concentration which results in a general fatigue strength reduction, i.e. the load level

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Nomenclature

A	factor in Langer fatigue model
B	exponent in Langer fatigue model
C	cut-off limit in Langer fatigue model
i	dummy index
k	scaling factor
K_f	fatigue strength reduction factor
K_t	notch or concentration factor
n	number of cycles in a load spectrum with strain amplitudes exceeding the cut-off limit
N	number of cycles or predicted fatigue life
q	notch sensitivity factor
ε_a	axial strain amplitude
$\|\|\bullet\|\|_{BC}$	BC-norm or equivalent measure

inducing a given fatigue life will typically be lower for the component or structure including a welding joint. The stress concentration introduced by the weld can be related to geometrical notches in for instance weld toes or different local material properties resulting from the welding process. In design, the fatigue strength reduction factor (FSRF), here denoted K_f, quantifies this detrimental effect of a stress concentration. This quantity is also designated as the fatigue notch factor or fatigue effective stress concentration factor. In the case of a welding joint, it is defined for a given number of cycles as the ratio of the fatigue strengths of the smooth or plain component and the welded component. It is often approximated conservatively by the stress concentration or notch factor denoted K_t. Different formula relating both factors have been proposed in the literature [1], but a classic approach introduces the notch sensitivity factor [2], q, defined in Eq. (1):

$$q = \frac{K_f - 1}{K_t - 1} \tag{1}$$

It varies in the range 0 to 1. For q approaching 0, the material is considered notch insensitive as microstructural plastic deformation effectively relieves the stress concentration. Consequently the presence of a notch or discontinuity does then hardly affect the components fatigue strength. However for q=1, a limited amount of microstructural plastic deformation does not reduce the stress concentration yielding $K_f = K_t$. Accurate measures of the FSRF for a given weld are however best determined experimentally, due to the significant number of parameters affecting its value.

ASME Boiler and Pressure Vessel Code Section III [3] covers design and construction rules for nuclear facility components. For design against fatigue, the code includes material specific design curves (Wöhler diagrams) and accounts for the reduction in fatigue strength of welded components using FSRFs [4]. Lifetime extension of nuclear power plants requires amongst others revised assessments of components to determine remaining fatigue life. Good understanding and increased knowledge about the inherent conservatism in the ASME III code is therefore crucial to avoid unnecessary over-conservatism, which may result in costly inspection programs or replacements.

The ASME fatigue design curve is constructed from a mean curve using adjustments factors [5]. These factors are supposed to account for the fundamental issue of transferability. The design curve is namely intended to be applicable for realistic components subjected to realistic loading conditions, whereas the original mean curve is generally obtained from experimental data for small, smooth test specimens subjected to constant amplitude loading. In an earlier investigation, the margins of the fatigue design curve for austenitic stainless steel in ASME III were investigated for a realistic piping component with a circumferential butt weld, see [6]. A water pressurized welded piping component with nominal wall thickness of 3 mm was subjected to variable amplitude, reversed bending deformation, see experimental set-up in Fig. 1(a). The welding joint was in as-welded condition, see Fig. 1(b). The weld capping was not removed which induced geometrical irregularities. This previous investigation highlighted