Engineering Failure Analysis 49 (2015) 67–78

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Fracture mechanics based approach to fatigue analysis of welded joints

Andrea Carpinteri, Camilla Ronchei, Daniela Scorza, Sabrina Vantadori *

Department of Civil-Environmental Engineering & Architecture, University of Parma, Parco Area delle Scienze 181/A, 43124 Parma, Italy

ARTICLE INFO

Article history:
Received 3 November 2014
Received in revised form 30 December 2014
Accepted 31 December 2014
Available online 12 January 2015

Keywords:
T-joint
Cyclic bending
Surface crack
Stress-intensity factor
Francis turbine runner

ABSTRACT

Decades of operating experience related to welded T-joint connections in metallic structures have shown that fatigue cracks generally develop at welding due to both material heterogeneity (mismatch) and stress concentration. In the present paper, the fatigue behaviour of a metallic welded T-joint subjected to cyclic bending is analysed. A semi-elliptical surface crack is assumed to exist at the welding. The crack propagation is numerically examined by using the stress-intensity factor (SIF) values obtained from finite element analyses, and extensively presented in a recent work. Geometry and sizes of the welded T-joint are chosen in order to compare numerical results with experimental data available in literature, related to an actual welded joint of a common Francis turbine runner.

1. Introduction

As is well known, material heterogeneity such as that represented by a mismatched welded T-joint in metallic structural components may have an important role on fracture behaviour of such components [1]. Mismatch means that base metal and weld metal have different mechanical properties in terms of yield stress, elastic modulus, Poisson's ratio and hardening properties [2,3]. Cracks generally nucleate at welding, that is, in a zone characterised by both material heterogeneity and high stress gradients due to the welding geometry. Several criteria are available in the literature for fracture assessment of welded joints [4–6]. In presence of cyclic loading, such cracks can grow up to failure of the structural components [7,8].

Unexpected failure of turbine blades in hydroeletric plants [9] can occur either very early in service life or after twenty years of operation [10,11]. Such a difference in terms of turbine life is due to the fact that the integrity of the turbines is strongly dependent on design, manufacture and material properties [12,13].

The aforementioned turbine failure is produced by cyclic service load [14,15], represented by either start-up and shut-down operations or transverse blade vibrations, the latter caused by the interaction of the guide vane wakes with the runner blades.

In the present paper, the fatigue crack growth simulation for a metallic welded T-joint is carried out by employing a model [16] based on the Paris law [17]. The geometry, sizes and loading here analysed are chosen in order to numerically simulate some experimental fatigue tests available in the literature [10], related to a common Francis hydraulic turbine runner welded joints with hot-formed steel blades welded to both band and crown (Fig. 1).

* Corresponding author. Tel.: +39 0521 905962.
E-mail address: sabrina.vantadori@unipr.it (S. Vantadori).

http://dx.doi.org/10.1016/j.engfailanal.2014.12.021
1350-6307/

Nomenclature

a, b	semi-axes of the ellipse
$B^*_{m(bn)}$	polynomial coefficients of the power series expansion for stress distribution σ^*_{bn}
D	blade width
F	trasversal force acting on the blade
I_ξ	error index on the predicted value of ξ
I_α	error index on the predicted value of α
$K_{I(bn)}, K^*_{I(bn)}$	SIF and dimensionless SIF, respectively, for stress distribution σ_{bn}
$K_{I(m)}, K^*_{I(m)}$	SIF and dimensionless SIF, respectively, for elementary stress distribution $\sigma_{I(m)}$
$K_{t(b)}$	stress concentration factor for bending
l_F	arm of the force F, with respect to the XY plate
N_f	fatigue life
N_0	number of loading cycles to crack initiation
R	stress ratio
t	blade thickness
t_1	band/crown thickness
XYZ	global coordinate system
w	local coordinate axis, with its origin A at the most internal point on the crack front
α	crack aspect ratio
ΔN	number of cycles of each bending loading block producing crack propagation during experimental beach marking procedure
$\eta = w/a$	normalised coordinate, with its origin at the most internal point on the crack front
$\sigma_{bn}, \sigma^*_{bn}$	Mode I stress distribution and dimensionless Mode I stress distribution, respectively, at the location of the highest stress concentration for the uncracked T-joint
$\sigma_{I(m)}$	m-th elementary stress distribution
$\sigma_{ref(b)}$	nominal surface stress under bending
$\sigma_{ref(b),\,max}$	maximum nominal surface stress under cyclic bending
$\sigma_{ref(m)}$	reference stress for the m-th elementary stress distribution $\sigma_{I(m)}$
ρ	radius of the transition arc between blade and band (or crown)
ξ	relative crack depth

The specimens consisted of T-joint samples (Fig. 2(a)) made according to the standard manufacturing process for commercial turbines runners. For each specimen, the vertical plate represented the blade, and the horizontal one the band (or crown). Such plates were joined by a double fillet weld. The weld geometry at the T-joint transition is represented by a circular arc, and described by the radius, ρ (Fig. 2(a)).

The specimens were subjected to cyclic bending. Load levels were chosen in a way that the fatigue life of the specimens ranged between 10^4 and $2(10)^5$ loading cycles. Therefore, HCF loading was taken into account, according to the definition by Schijve [18].

In such a contest, a linear elastic fracture mechanics approach is suitable for the numerical simulation of the aforementioned experimental campaign. A semi-elliptical surface crack is assumed to exist in the welded zone of the T-joint (Fig. 2(a)). Such a crack shape was that generally observed during the above campaign, and commonly occurs during welding [19,20].

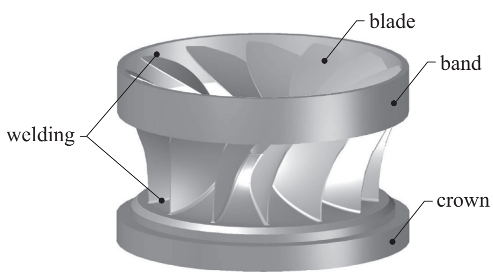

Fig. 1. Francis hydraulic turbine runner.