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Implicit gradient approach for numerical analysis of laser welded joints

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Abstract

This paper analyzes the fatigue strength of laser welded steel joints by applying the implied gradient method. This method is adopted using the same procedure proposed for studying arc welded joints. The fatigue scatter band of laser joints, obtained from numerical analysis of experimental data taken from the literature, is different from the relative curve of arc welded joints. However, at high cycles fatigue the two bands maintain exactly the same average values and the same scatter. The fatigue strength of lap joints with different weld patterns confirms the use of the proposed generalized fatigue scatter band for laser joints.

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Keywords: laser weld; fatigue; welded joints; implicit gradient

1. Introduction

The idealization of a weld considers an open notch with a linear flank and a null notch tip radius [Lazzarin and Tovo (1997), Livieri and Lazzarin (2005)]. Therefore, the stress field in the neighborhood of the notch tip has to be considered as singular [Williams (1952] and the assessment of the fatigue strength of complex welded structures can be carried out by using the numerical design methods classified in scientific literature as local methods. The basic idea of these approaches is to consider the value of an effective physical quantity related to the stress field around the area where the fatigue crack will nucleate [Radaj and Sonsino (1998), Lazzarin and Zambardi (2001), Berto and Lazzarin (2009), Meneghetti (2008), Susmel and Taylor (2011)].

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The propagation phase, at least in welded specimens used for fatigue testing, is usually negligible when compared to the time required for propagating the crack up to a few millimeters [Sørensen et al. 2006].

The idea that material damage is mainly due to the fatigue behavior of a zone around the notch tip is also considered in the implicit gradient method. This approach has been proposed as a design method for welded arc structures or spot welds without making any difference to the procedure in terms of sheet thickness, joint shape or loading type [Tovo and Livieri (2011)]. Many experimental series, very different in terms of sheet thickness and geometry (for example thickness ranging from 3 mm to 100 mm), were analyzed by means of the implicit gradient approach and obtained a master Woehler curve suitable for the evaluation of the fatigue strength of joints under tensile or bending nominal stress. The procedure offers the advantage of representing welded joints in their three-dimensional form without necessarily performing exemplifications in the shape.

The laser procedure is an alternative choice for connecting thin plates usually employed in the automotive industry [Sonsino et al. (2006)]. Furthermore, laser welded joints are also employed in many industrial sectors using thin plates [Cho et al. (2004)] or plates up to 12 mm [see Frank et al. (2011)]. The standard local approaches used for thick joints are not usually suitable for the assessments of laser welded joints. For instance, the approach of fictitious enlargements of notch tip radios proposed by Raday (1996) for assessing welded joints connecting thin sheets with the notch stress approach, a reference radius of 0.05 mm is usually chosen. [Karakas et al. (2008), Bruder et al. (2012), Baumgartner et al. (2015), Marulo et al. (2017)].

This paper, by means of the implicit gradient method, will examine the fatigue behavior of laser welded steel joints taken from the literature. For lap joints, the thicknesses analyzed are typical of the plates used in the automotive field. The fatigue strength of lap joints with different weld patterns is also analyzed: longitudinal-line segment group pattern (LLSG), ladder pattern, sawtooth pattern and double arc pattern (DCA).

Nomenclature

σ_{eff}	effective stress
σ_{eq}	equivalent stress
σ_{av}	average stress
$\sigma_{eff,max}$	maximum effective stress
Δ	range
∇^2	Laplace operator
2α	opening angle
c	characteristic length
g	gap between the two plates
FE	finite element
w	width
w_d	length of weld bead
R	nominal load ratio
s	minimum dimension of the mesh elements
t	thickness
d	weld width
N	fatigue life, cycles to failure
V	volume

2. Basic equation

The implicit gradient method defines an effective stress σ_{eff} related to the local stress fields generated from a stress raiser such as a sharp V notch or a weld [Lazzarin and Tovo (1998)]. It is assumed that fatigue damage is due to the