Engineering Failure Analysis 59 (2016) 17–27

Contents lists available at ScienceDirect

Engineering Failure Analysis

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

Assessment of undercut defect in a laser welded plate made of Ti–6Al–4V titanium alloy with probabilistic domain failure assessment diagram

S. Jallouf [a,*], K. Casavola [a], C. Pappalettere [a], G. Pluvinage [b]

[a] Politecnico di Bari Bari, Italy
[b] FM. C Silly-sur-Nied, France

ARTICLE INFO

Article history:
Received 22 July 2015
Received in revised form 7 September 2015
Accepted 6 November 2015
Available online 7 November 2015

Keywords:
Failure assessment diagram
Titanium alloy
Probability of failure

ABSTRACT

A domain failure assessment diagram has been used to assess an undercut defect in a laser welded plate made of Ti–6Al–4V titanium alloy and to compute the probability of failure. Evaluations of the safety factor and uncertainty with the assessment angle have been obtained. The low probability of failure indicates that laser welding is a safe process for aeronautical components which need a high level of reliability.

1. Introduction

The early methods for design against the risk of failure were based on the concept of permissible stress design. These methods are usually determined by ensuring that permissible stresses σ_{ad} remain within the limits through the use of a safety factor, and the strength limit is generally the yield stress Re for conservative reasons:

$$\sigma_{ad} = \frac{\text{Re}}{f_s}. \tag{1}$$

The safety factors are defined in a deterministic way by the "state of art" for each field, possibly codified in standards. The design material properties are defined as some percentile of the material resistance distribution. The safety factor is then defined as the ratio of the ultimate strength, which corresponds to the mean value of the strength distribution over the admissible stress. The admissible stress is the failure stress associated with a low and conventional probability of failure P_f^* (10^{-4} or 10^{-6} if there is risk to human life). If the ultimate strength follows the Weibull distribution, the probability of failure is given by the following relationship:

$$P^* f = \exp - \left[\frac{\Gamma(1 + 1/m)}{f_s}\right]^m \tag{2}$$

* Corresponding author.

http://dx.doi.org/10.1016/j.engfailanal.2015.11.018
1350-6307/

where m is the Weibull modulus and the safety factor is:

$$f_s = \Gamma(1 + 1/m) / \left[\mathrm{Ln} \frac{1}{P^*_s} \right]^{1/m} \tag{3}$$

We can see that the safety factor increases considerably when the Weibull's modulus decreases, i.e., the scatter of material strength increases.

In a failure assessment diagram (FAD), any kind of rupture (brittle, elastoplastic or plastic collapse) can be represented by an assessment point with coordinates of non-dimensional applied load L_r and non-dimensional applied crack driving force k_r. The safety factor is defined as the relative distance from the assessment point to the failure curve (see Fig. 1). A probabilistic extension of the safety factor through FAD definition has been proposed by [1] and it is used to define within the safe domain of the FAD the safety domain with maintenance and the security domain without maintenance.

The present work is aimed to assess an undercut defect in a laser welded plate made of Ti–6Al–4V titanium alloy using SINTAP NFAD [2]. Statistical analyses of the validation data are conducted to derive the modelling uncertainty, which is then applied in example calculations to explore the effect on failure probability estimates.

2. Deterministic failure assessment diagram

The failure assessment diagram (FAD) accounts for any kind of failure: plastic collapse as well as brittle fracture and elastic–plastic failure. The FAD exhibits a failure curve as the critical non-dimensional stress intensity factor k_r versus the non-dimensional stress or loading parameter L_r.

The non-dimensional crack driving force k_r and non-dimensional applied stress L_r are primarily defined as the ratio of applied stress intensity factor, K_{app}, to the fracture toughness of the material, K_c^*.

$$k_r = \frac{K_{app}}{K_c^*} \tag{4}$$

The British Standard (BS) firstly improved the FAD diagram by introducing the J integral or crack opening displacement as:

$$k_r = \sqrt{\frac{J_{app}}{J_{mat}}} \ \ or \ \ k_r = \sqrt{\frac{\delta_{app}}{\delta_{mat}}} \tag{5}$$

where J_{app} and δ_{app} are the applied J integral and crack opening displacement and J_{mat} and δ_c are the fracture toughness in terms of the critical value of the J integral or critical crack opening displacement of the material. Non-dimensional stress L_r is described as the ratio of the gross stress σ_g over flow stress (chosen as yield stress σ_Y, ultimate stress σ_{ul}, or classical flow stress $R_c = (\sigma_Y + \sigma_{ul})/2$):

$$L_r = \frac{\sigma_g}{R_c}. \tag{6}$$

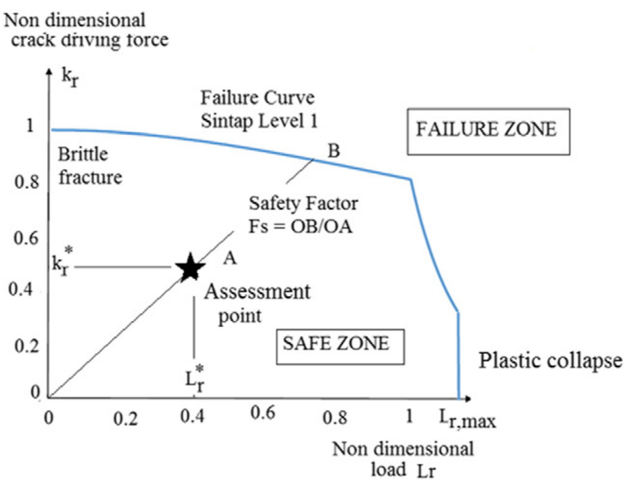

Fig. 1. Typical failure assessment diagram (FAD) indicating safe and failure zones and assessment point and safety factor.