Engineering Fracture Mechanics 179 (2017) 225–239

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

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

A special notched tensile specimen to determine the flow stress-strain curve of hardening materials without applying the Bridgman correction

Shengwen Tu [a], Xiaobo Ren [b], Bård Nyhus [b], Odd Magne Akselsen [b], Jianying He [a], Zhiliang Zhang [a,*]

[a] Department of Structural Engineering, Norwegian University of Science and Technology, Trondheim 7491, Norway
[b] SINTEF Materials and Chemistry, Trondheim 7456, Norway

ARTICLE INFO

Article history:
Received 12 March 2017
Received in revised form 19 April 2017
Accepted 23 April 2017
Available online 25 April 2017

Keywords:
Flow stress-stain curve
Notched tensile specimen
True stress-strain curve
Weldment
Bridgman correction

ABSTRACT

Structural integrity assessment of weldments requires the input of flow stress-strain curve of each individual material zone. To cope with these challenges, a cylindrical cross weld tensile specimen with a notch located either in the weld metal, base metal or possibly heat affected zone has been previously developed by the authors to determine the true stress-strain curve for the material zone of interest. The disadvantage of this notched tensile testing method as well as the standard tensile testing method using a smooth specimen, is that the well-known Bridgman correction still has to be applied in order to obtain material's equivalent or flow stress-strain curves. In this study, tensile specimens with various notch geometries have been scrutinized and a 'magic' specimen with a special notch geometry has been identified. By using this special notched tensile specimen, material's flow stress-strain curve can be directly calculated from the recorded load versus diameter reduction curve and no Bridgman correction is needed. The method is very accurate for power-law hardening materials and becomes less accurate for materials with significant Lüders plateau in the initial yield region.

1. Introduction

Material's flow stress-strain curve governs the plastic behaviour, and structural integrity assessment of weldments using finite element method requires the input of flow stress-strain curve of each individual material zone. Smooth specimens with circular or rectangular cross section are widely used for determining the true stress-strain curves of base material, weld metal or heat affected zone, and materials' flow stress-strain curves can be derived from the true stress-strain curves. For standard smooth tensile specimens, necking happens along with localized deformation on the specimen, accompanied by the occurrence of tri-axial stress state in the localized region. The true stress calculated from the load divided by current area of the minimum cross section would be inaccurate to represent the material's equivalent stress due to the existence of tri-axial stress state in the localized region. Based on a stress state analysis in the localized region, Bridgman [1] proposed a correction method that links to the ratio of a/R, a is the current radius of the minimum cross section and R is the current notch radius. Simple finite element analysis of smooth tensile specimens [2] shows that with the Bridgman correction, the

* Corresponding author.
E-mail address: zhiliang.zhang@ntnu.no (Z. Zhang).

http://dx.doi.org/10.1016/j.engfracmech.2017.04.039
0013-7944/

Nomenclature

a	current minimum cross section radius
a_0	initial minimum cross section radius
$D = 2a_0$	initial minimum cross section diameter
d_0	initial outer diameter of notched tensile specimen
E	Young's modulus
G	notch geometry correction factor
G^m	magic notch correction factor
H	weld zone length in the notched region
L	specimen length
n	material hardening exponent
P	global load
R_0	initial notch radius
R	current notch radius
ν	Poisson's ratio
ε_0	yield strain
ε	average true strain
ε_L	Lüders plateau strain
$\overline{\varepsilon^p}$	equivalent plastic strain
$\Delta\sigma$	absolute stress error
σ_0	yield stress
$\overline{\sigma}$	material's flow stress
$\sigma_{e,notch}$	engineering stress of a notched tensile specimen
σ_{eq}	Mises equivalent stress
σ_T	true stress of a smooth tensile specimen
$\sigma_{T,notch}$	true stress of a notched tensile specimen
σ_T^G	G corrected true stress for notched tensile specimen

Bridgman corrected stress-strain curve differs to material's equivalent stress-strain curve input for the numerical analysis when strain is large. La Rosa and Risitano [2] applied the Bridgman correction to different steels, C40, FE36, AISI304, D98, etc., and found that with the increase of strain the error $\Delta\sigma$ between the material equivalent stress and the Bridgman corrected stress for steel D98 would be as large as 10.6% at the strain $\varepsilon = 1.35$ (Fig. 1). The assumption used in the Bridgman correction method is that the distribution of equivalent strain and equivalent stress is uniform over the minimum cross section [1]. However, previous finite element analyses [3–7] indicate that this may not be true. In practice, the application of the Bridgman correction is also not trivial because one has to measure the current radius of the minimum cross section and the current notch radius simultaneously. Le Roy [8] proposed a function for estimating the a/R without paying attention to the material properties. Correction methods have also been proposed for rectangular cross section specimens [9–12]. Ling [13] proposed a method based on extrapolation of the true stress-strain curve before necking. However, this approximation is not suitable for the case when the strain is large.

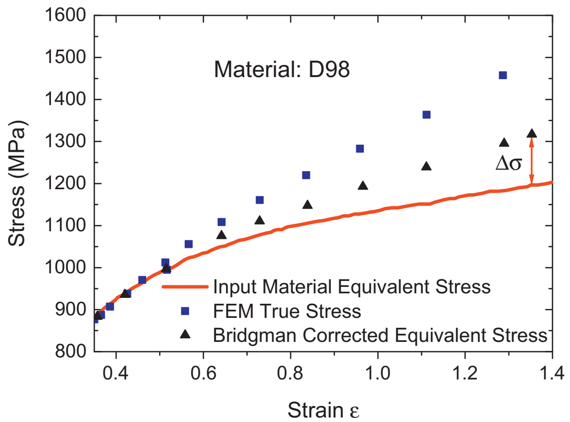

Fig. 1. Comparison between input material equivalent stress and Bridgman corrected true stress [2]. FEM true stress is calculated by dividing load by current minimum cross section area.