Progress in Materials Science 88 (2017) 412–466

Contents lists available at ScienceDirect

Progress in Materials Science

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

Welding and Joining of NiTi Shape Memory Alloys: A Review

J.P. Oliveira [a,b,*], R.M. Miranda [c], F.M. Braz Fernandes [a]

[a] *CENIMAT/I3N, Departamento de Ciências dos Materiais, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal*
[b] *Department of Materials Science and Engineering, The Ohio State University, 1248 Arthur E. Adams Drive, Columbus, OH 43221, USA*
[c] *UNIDEMI, Departamento de Engenharia Mecânica e Industrial, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal*

ARTICLE INFO

Article history:
Received 15 March 2017
Accepted 6 April 2017
Available online 19 April 2017

Keywords:
NiTi shape memory alloys
Welding
Joining
Dissimilar joints
Superelasticity
Shape memory effect

ABSTRACT

NiTi is an increasingly applied material in industrial applications. However, the difficulties faced when welding and joining is required, limits its broader use in the production of complex shaped components. The main weldability problems associated with NiTi are: strength reduction, formation of intermetallic compounds, modification of phase transformation and transformation temperatures, as well as, changes in both superelastic and shape memory effects. Additionally, NiTi is envisaged to be joined to other materials, in dissimilar joints with more complex problems depending on the other base material. Thus, intensive research in welding and its effects on the joints performance has been conducted since the early stages of NiTi. This paper presents a detailed review of welding and joining processes applied to NiTi, in similar and dissimilar combinations considering both fusion and solid-state processes. Since laser is the most studied and applied welding process, a special section is devoted to this technique.

Contents

Abbreviations: A, austenite; BM, base material; EDS, energy dispersive spectroscopy; FIB, focused ion beam; FSW, friction stir welding; FZ, fusion zone; GTAW, gas tungsten arc welding; HAZ, heat affected zone; HI, heat input; M, martensite; MIG, metal inert gas; MAG, metal active gas; MRW, micro-resistance welding; Nd:YAG, neodymium-doped yttrium aluminium garnet; R, crystal growth rate; T, temperature gradient; SEM, scanning electron microscopy; SMAs, shape memory alloys; TEM, transmission electron microscopy; TIG, tungsten inert gas; UTS, ultimate tensile strength.

* Corresponding author at: Department of Materials Science and Engineering, The Ohio State University, 1248 Arthur E. Adams Drive, Columbus, OH 43221, USA.

E-mail addresses: jp.oliveira@campus.fct.unl.pt, desousaoliveira.1@osu.edu (J.P. Oliveira).

http://dx.doi.org/10.1016/j.pmatsci.2017.04.008
0079-6425/

1. Introduction

The demand for shape memory alloys (SMAs) has increased in recent years due to their functional properties, namely shape memory effect and superelasticity, present unique solutions for state-of-the-art applications. As a consequence of intensive research activity, shape memory alloys have been used in a wide variety of fields, mainly biomedical, automotive and aeronautical, taking advantage of their smart functionalities and a good actuation force-to-weight ratio [1].

Shape memory alloys are functional materials that present two very distinct properties: superelasticity and shape memory effect. Among these alloys, NiTi is the most important one, not only because of its functional properties, but also because it presents high strength and ductility [2].

The functional properties exhibited by these alloys are due to a reversible martensitic transformation. SMAs have two phases: a low temperature one, known as martensite (M), and a high temperature one, known as austenite (A) or parent phase.

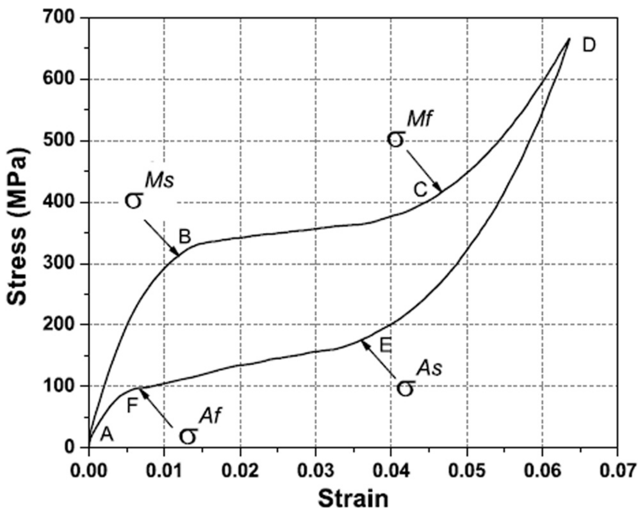

Fig. 1. Typical superelastic behaviour of a shape memory alloy [6].