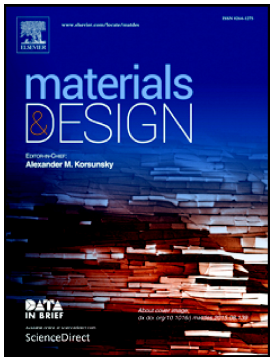

Control of phase transformations and microstructure for optimum realization of one-way and two-way shape memory effects in removable surgical clips

E. Ryklina, A. Korotitskiy, I. Khmelevskaya, S. Prokoshkin, K. Polyakova, A. Kolobova, M. Soutorine, A. Chernov

PII: S0264-1275(17)30865-1
DOI: doi: 10.1016/j.matdes.2017.09.024
Reference: JMADE 3357

To appear in: *Materials & Design*

Received date: 15 May 2017
Revised date: 7 September 2017
Accepted date: 11 September 2017

Please cite this article as: E. Ryklina, A. Korotitskiy, I. Khmelevskaya, S. Prokoshkin, K. Polyakova, A. Kolobova, M. Soutorine, A. Chernov , Control of phase transformations and microstructure for optimum realization of one-way and two-way shape memory effects in removable surgical clips, *Materials & Design* (2017), doi: 10.1016/j.matdes.2017.09.024

CONTROL OF PHASE TRANSFORMATIONS AND MICROSTRUCTURE FOR OPTIMUM REALIZATION OF ONE-WAY AND TWO-WAY SHAPE MEMORY EFFECTS IN REMOVABLE SURGICAL CLIPS

E. Ryklina,[a] A. Korotitskiy,[a] I. Khmelevskaya,[a] S. Prokoshkin,[a*] K. Polyakova,[a] A. Kolobova,[a] M. Soutorine,[b] A. Chernov[b]

[a] National University of Science and Technology "MISIS", 4, Leninskiy prospect, Moscow 119049, Russia; ryklina@tmo.misis.ru; akorotitskiy@gmail.com; khmel@tmo.misis.ru; prokoshkin@tmo.misis.ru; vachiyan@yandex.ru; frau.kolobowa@ya.ru.

[b] Globetek 2000 PTY Ltd, Suite 10/2 St. Andrews Street, Brighton, Victoria, 3186, Australia; msoutorine@yahoo.com.au; an_chernov@mail.ru

ABSTRACT

The functioning of a newly developed "smart" clip for permanent or temporary clipping of the blood vessels is based on one-way and two-way shape memory effects (SME and TWSME, respectively) of Ti-Ni alloy. The clip remains in the ready-to-close position before it is locally heated up to 40–45 °C. Once heated by a specially developed clip-holder device, it closes due to realization of the SME, thus softly clipping the vessel. Upon local cooling, the clip opens due to the TWSME realization and can be easily removed without trauma to the vessel. To solve the problem of realization of SME and TWSME in the required temperature ranges and with the best functional characteristics, a thermomechanical treatment of Ti-50.7 at.%Ni alloy for controlled precipitation of Ti_3Ni_4 phase particles and subsequent martensitic transformations was developed. A special regime of the clip thermomechanical treatment, including hot rolling and post-deformation isothermal annealing (aging), SME training procedures, and special design of the clip, was developed to obtain the best combination of the recovery strain and recovery stress of the clip. The phase transformations and microstructure were studied using differential scanning calorimetry, X-ray diffractometry, and transmission electron microscopy. The functional properties of the clips were determined using a bending method for inducing strain. The bench tests of the clip confirmed the effectiveness of the optimized thermomechanical treatment and training regimes as well as the cross-shaped clip design.

Keywords: titanium nickelide; thermomechanical treatment; phase transformations; microstructure; functional properties; surgical clip.

1. Introduction

Many surgical interventions require temporary closure of tubular structures. For blood vessels, it can be important to restore the blood flow again after completion of the procedure. It is also important to avoid damage to the blood vessel wall during its closure and reopening. A removable clipping device has to be used for these purposes. Traditional clips used in surgical practice are made of steel, titanium, or ductile materials [1,2] and operate under mechanical force via a special applicator [3,4]. Mechanical force is also required to reopen the clip after completion of the intervention [5]. This often leads to over-tightening of