

STRESS INDUCED MARTENSITE MORPHOLOGY IN STAINLESS SHAPE MEMORY ALLOYS

Bueno, J. C.^{1,*}; Nascimento, F. C.^{1,2}; Mei, P. R.¹; Otubo, J.³

Universidade Estadual de Campinas, Dep. de Engenharia de Materiais, 13083-970
Campinas, SP, Brasil e-mail: jubueno@fem.unicamp.br

¹ Universidade Estadual de Campinas, FEM

² Universidade Estadual de Campinas, IFGW

³ Instituto Tecnológico de Aeronáutica

Shape memory alloys (SMA) present the capacity to recover their original form, after plastic deformation, by heating above A_F (final temperature of martensite in austenite transformation) [1]. The shape memory effect (SME) in the Fe-Mn-Si alloys is related to the transformation of the fcc structure austenite (γ), to the hcp structure martensite (ϵ), and the posterior reversion of this process. The ϵ (hcp) \rightarrow γ (fcc) reversion occurs by heating and results in recovering the memorized shape [2-4]. The identification of the phases in the microstructure is the first step for a more complete study of the $\gamma \rightarrow \epsilon$ transformation on SMAs. Martensite morphology depends on factors as chemical composition, number of training cycles and microstructure refinement that is very important because they influence strongly the shape recovery properties [2, 5]. Further, with the analysis of different phases, others factors can be explored, such as: mechanical properties and SME.

The investigated alloy was melted in a vacuum induction furnace. The chemical composition of the alloy is showed in Tab. (1). A previous study [2], determined this alloy passed for a thermomechanical treatment (annealing to 1050°C in different times) resulting samples with grain size (GS) values differentiated. Afterwards, the samples were submitted to the training cycles. Each complete cycle corresponds to 4% of deformation by compression followed by heating at 600°C for 30 minutes, and then until room temperature. For some cycles, a half of the specimen was kept in the deformed state and the others were recovered. The samples final characteristics are showed in Tab. (2).

The samples were tested to optimize the specific reagent $K_2S_2O_5 + NH_4HF_2$. According Bergeon et al [6], this reagent reveals the martensitic phase with a specific color (color etching). The tests with the reagent were performed varying and time of attack and the concentration in distilled water. The images were acquired using the optical microscope NEOPHOT. This equipment allows to identify the existing phases in the material through distinct colors.

The martensite plates were distributed inside the austenitic grain, being that this characteristic is independent of the GS and/or the training. The Fig. (1) presents this characteristic of the morphology of the ϵ -martensite for different conditions. In the Fig. (2) we can also observe accommodation of variants of ϵ -martensite which occurred with larger frequency in samples with smaller GS. New ϵ -martensite orientations with crossing of plates occurs in samples with larger GS as showed in Fig. (3). In this regions occurs precipitation of α' -martensite of body centered cubic structure as can be seen in the Fig. (3). The α' -phase is characterized by particle shape or rod shape inside the ϵ -phase. The length of these short particles is about 9 μ m, value near to the obtained by J. Otubo [3] which was approximately 10 μ m.

The main results obtained in this work by metallography and optic microscopy are:

- (1) In the samples with larger grain size (129 μ m), appear α' -martensite that is characterized by rod shape inside the ϵ -phase with length about 9 μ m;
- (2) Crossing plates and new orientations of ϵ -martensite occurs more times in samples with larger GS;
- (3) The martensite plates were distributed inside the austenitic grain and this characteristic is independent of the microstructure refinement and the training.

References:

- [1] H. Funakubo, Shape Memory Alloys, Ed. Hiroyasu Funakubo, University of Tokyo, (1987) Capítulo 1
- [2] F.C. Nascimento, Efeito do Tamanho de Grão nas Propriedades Mecânicas e na Recuperação de Forma de Ligas Inoxidáveis com Efeito de Memória de Forma, Tese de Doutorado (2002) DEMA/FEM/UNICAMP, Campinas, SP.
- [3] J. Otubo, Desenvolvimento de ligas inoxidáveis com efeito de memória de forma: elaboração e caracterização, Tese de Doutorado (1996) DEMA/FEM/UNICAMP, Campinas, SP.
- [5] D. Z. Liu, S. Kajiwara, T. Kikuchi, N. Shinya, Philosophical Magazine Letters, Vol. 80, Nº 12 (2000) 745-753
- [6] Q. Meng, Y. Rong, S. Chen, T.Y. Hsu, X. Zuyao, Materials Letters 50 (2001) 328-332
- [7] N. Bergeon, G. Guenin, C. Esnouf, Materials Science and Engineering A238 (1997) 309-316

Table 1 – Chemical composition (wt %)

C	Si	Mn	P	S	Co	Cr	Ni	Mo	Cu	O,*	N,*
0,009	5,25	8,26	0,002	0,006	11,84	12,81	5,81	0,001	0,16	50	52

* percentage in pfm

Table 2 – Samples characteristics

Grain Size (μm)	Annealing 1050°C (min.)	Number of training cycles	Status
75 +/-13	10	2	DEFORMED
		4	
		5	
106 +/-17	60	4	
		5	
129 +/-18	480	2	

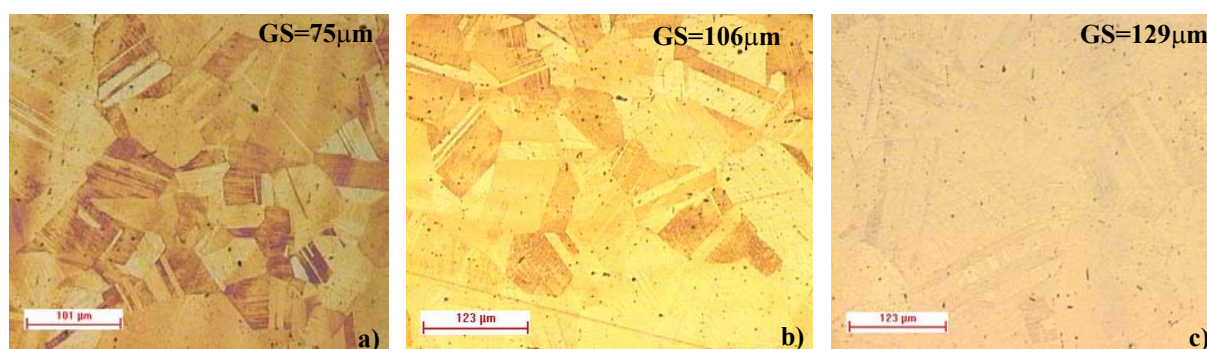


Figure 1 – Optic microscopy showing the morphology of the ϵ -martensite inside the austenitic grain. a) Etching: 2,0g K₂S₂O₅:0,5gNH₄HF₂:50mlH₂O, t = 18 min; b)Etching:2,0gK₂S₂O₅:0,5gNH₄HF₂:50mlH₂O; t = 12 min. c)Etching: 2,0g K₂S₂O₅:0,5g NH₄HF₂:100ml H₂O, t = 8 min;

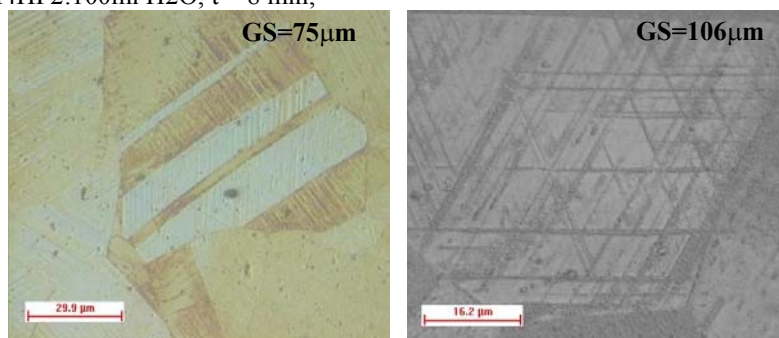


Figure 2 – Optic microscopy showing crossing of ϵ -martensite plates and the orientation change of the ϵ -martensite; Etching: 2,0gK₂S₂O₅:0,5gNH₄HF₂:50mlH₂O, t = 18 min.

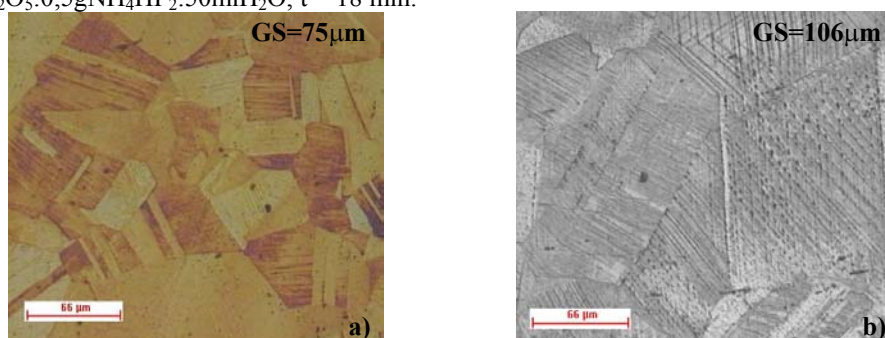


Figure 3 – Optic microscopy showing the α' -martensite inside the ϵ -martensite plates in the samples of larger GS; a) Etching: 2,0gK₂S₂O₅:0,5gNH₄HF₂:50mlH₂O, t = 18 min; b) Etching: 4,0gK₂S₂O₅:1,0gNH₄HF₂:50mlH₂O, t = 6 min.