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SEVERE ELECTROPLASTIC DEFORMATION OF TiNi ALLOY

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Opportunity of electropulse impact application to increase deformability of the hard deformed alloy during severe plastic deformation is examined. For the first time display of electroplastic effect (EPE) in coarse-grained TiNi alloy with shape memory effect is investigated. It is shown that EPD by cold rolling significantly increases total and single strain to failure. The formation of amorphous, nanocrystalline and UFG structures by EPD depends on the pulse current density that is critical parameter of the new method.

Introduction

Increase of deformability for structure materials, especially hard deformed and nanostructured alloys, is the urgent problem. Shape memory effect (SME) TiNi alloys possess a remarkable complex of mechanical and functional properties, especially high in nanostructured (NS) and ultrafine-grained (UFG) states [1]. To obtain NS or UFG states severe plastic deformation (SPD) technique is used, the realization of which for a case of long-size products of thin section (wire, foil, sheet) is not a simple problem as the TiNi alloys are susceptible to strong strengthening and their deformability is limited. The EPE at cold rolling observable for many pure metals and alloys [2] can be considered as alternative of nano- and UFG states formation in TiNi alloys. The aim of the paper is investigation of EPE and its influence on structure and deformability of the TiNi alloy.

Experimental procedures

The experimental material was Ti–50.7 at.% Ni alloy in the quenched state with coarse-grained structure of B2 phase. Samples for electroplastic deformation

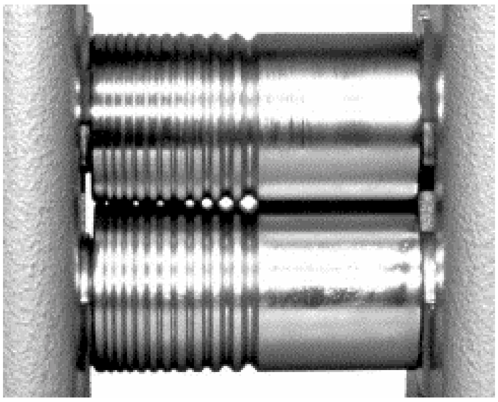


Fig. 1. Rolling mill stand

(EPD) in the form of strips of 2 × 6 × 150 mm were cut mechanically from initial billet, and their surface was processed by an electrochemical method to remove the work-hardened layer. EPD by cold rolling was performed on electromechanical rollers (Fig. 1), equipped with a surge current generator.

Supply and removal of current was via sliding contact (negative pole) to a sample deformation zone and one of the rollers (positive pole), accordingly. Cold rolling was conducted at a room temperature at a rate of 4 m/min in a step-by-step mode at adjustable single thickness reduction (±25 μm), that allowed to define with the minimal error the moment of microcracks occurrence or failure. The unipolar pulse current was supplied from the generator with the pulse frequency of 10^3 Hz, pulse duration of $0.8 \cdot 10^4$ and electrical porosity $Q = 12$. Cold rolling was conducted in two regimes: at constant current density ~ 80 A/mm^2 and at increasing current density up to 240 A/mm^2 during deformation. After each step samples were held in air or cooled in water to avoid influence of possible heating. The temperature on the sample-simulator subjected to electropulse current of the maximal density did not exceed 150°C. True strain e at cold rolling calculated by change of the sample thickness $e = \ln h_s/h_f$, thus the maximal strain corresponding to the occurrence of the first microcracks or failure was determined. Microhardness was measured on PMT-3 device under loading of 100 g. TEM study of thin foils was done in a microscope JEM-100C.

Experimental results

Deformability of the alloy at cold rolling with a current (j = const) is considerably above than that at cold rolling without a current (Table). So, single (total) deformation e before failure makes 0.45(0.86) and 0.8(> 1.42), accordingly, for cold rolling without a current and with a current. At cold rolling with a current at maximal strains the sample does not break into parts as it occurs at cold rolling without a current (Fig. 2,*a*,*b*).

Experiments have shown that removal of edge microcracks during EPD allows to enhance strain to failure. The main reason of the appearance of microcracks during EPD is connected with a stress-strain state that changes from equal three-dimensional mainly to flat biaxial at thickness reduction of the sample.

At increasing current density from 80 up to 240 A/mm^2 during cold rolling to a minimally possible thickness of 100 μm the development of microcracks and sample failure were not observed (Table). All the subsequent experiments were executed at constant current density of 80 A/mm^2.

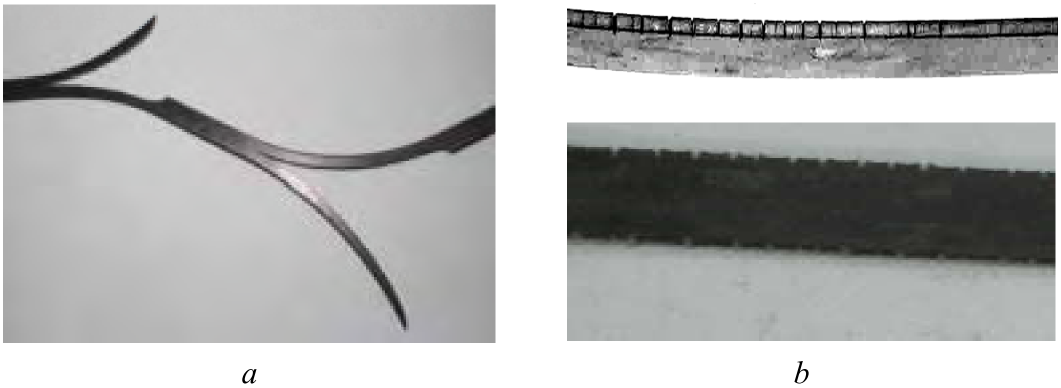


Fig. 2. Sample view after cold rolling without (*a*) and with (*b*) current

Table

True strain to failure and microhardness at cold rolling with and without current

Treatment	Single strain to failure *e*	Total strain *e*	HV	Notice
Initial state	0	0	275	–
Cold rolling without current	0.45	0.43	400	No cracks
		0.54	525	Cracks
		0.86	590	Failure
Cold rolling with current (j = const)	0.8	0.54	420	No cracks
		0.84	581	No cracks
		1.42	590	Cracks
Cold rolling with current ($j \neq$ const)	Not specified	1.75	505	No cracks

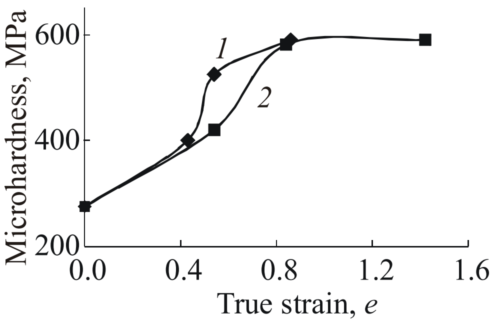
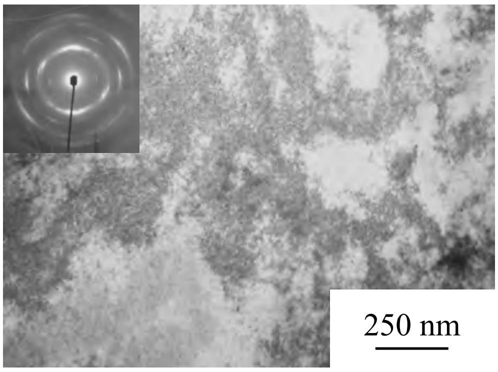


Fig. 3. Microhardness dependence on true strain at cold rolling (*1*) and EPD (*2*)

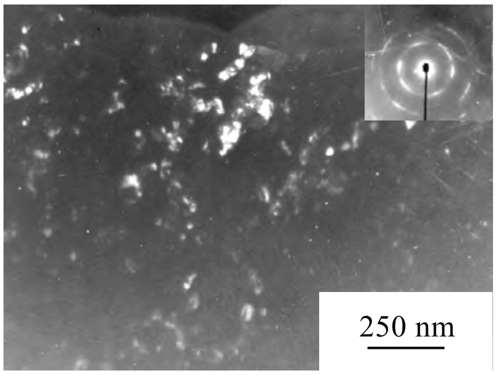
Microhardness evolution with cold rolling allows to estimate the strengthening features of TiNi and to compare them for different cold rolling modes (Fig. 3). It is seen that at identical maximal microhardness value of the alloy (HV = 590) strain hardening degree in an interval e = 0.4–0.6 for EPD is lower than for usual cold rolling. Indirectly it can testify to features of the mechanism of EPD that provides a stress relaxation and the increase of deformability at EPD.

Microstructure studies of samples after EPD (j = const, e = 0.8) have revealed the amorphous and nanocrystalline areas with the grain size of 5–10 nm (Fig. 4,*a*).

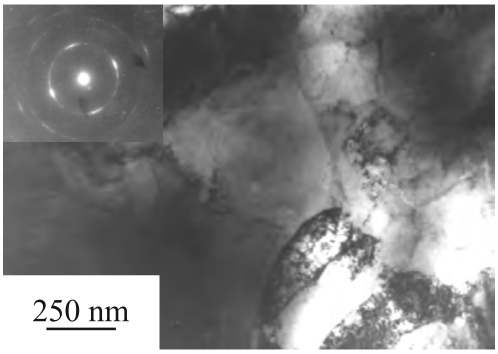
Annealing of the deformed alloy at a temperature of 400°C during 1 h leads to nanocrystallization of amorphous areas and to grain growth till the average size of 25 nm defined on dark-field image of structure in a reflex of high-temperature phase B2 (Fig. 4,*b*).



a



b



c

Fig. 4. TEM pictures of TiNi after EPD: *a* – j = const, e = 0.8; *b* – j = const, e = 0.8, T_{ann} = 400°C, 1 h, dark field; *c* – $j \neq$ const, e = 1.75

EPD to higher strain and with increasing current density (e =1.75, $j \neq$ const) forms nonuniform UFG structure with the grain size more than 500 nm (Fig. 4,*c*).

Conclusions

EPD is a powerful tool for the formation of amorphous, nanocrystalline and UFG structure in TiNi alloy. The structure type is defined by EPD conditions among which the pulse current density is a critical parameter of EPD technology. EPD considerably increases deformability without use of intermediate annealings that raises technological plasticity and commercial potential of the method.

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