Stepwise Transformation of Stress Induced Martensite in Ni-Ti Alloy

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Introduction

Superelasticity of NiTi alloy is connected closely with stress induced phase transformation. Generally, stress-strain ($\sigma - \varepsilon$) curves are used to describe the mechanical behaviour. It is usefull to clearity the nature of the transformation at variant deformation stages corresponding to σ-εcurve.

A perfect superelasticity in 51.6 at% Ni-Ti alloy has been obtained after a special treatment.[1] This present work is to report some results of in situ observations for this alloy on loading and unloading.

Experimental

The alloy used in this investigation was 51.6 at% Ni-Ti alloy, which was produced and treated as that reported in work[1]. A S4-10 SEM with tensile stage was used to measure σ - ε curve and observe synchronously sample surface using second-electron image. The dimensions of the specimen were 0.35 x 6 x 20 (mm).

X-ray diffraction was carried out in a D-6c diffractometer with a loading attachment, using radiation CuK , 35 KV tube voltage and 10mA current. Tensile specimen was 40 by 6 (mm). Measurements were made under a series of selected strains (ε =0 ~10%, once every 2%).

The foils were observed in a tensile holder of a H-700 TEM, operated at 200KV.

Results and Discussion

1. Stress-Strain Curve and Surface Aspects

The σ - ε curve of the alloy (Fig.1) shows a elastic oA section,

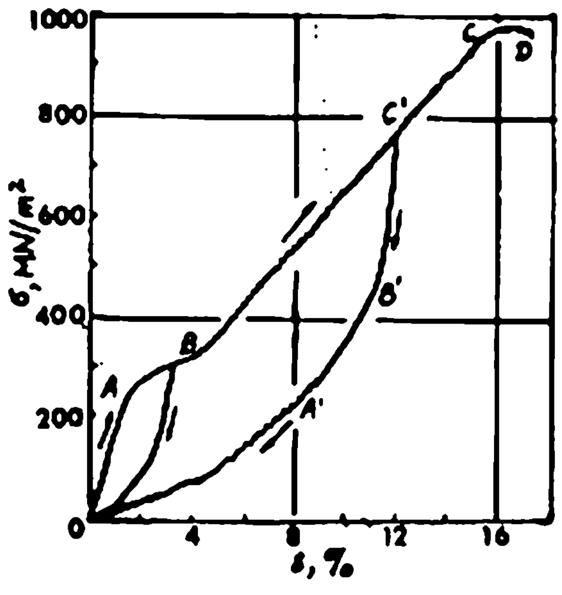

Fig.1. Stress-strain plot of 51.6at.%Ni-Ti alloy

two yield plates (AB and CD sections) and a sawtoothed BC section on loading, and a complete reversion along C'-B'-A'-O on unloading when the stress does not exceed point "C". After point "C", residual strain will exist and fracture will take place soon.
At AB section, a "dim area" on specimen surface appeared, which expended with increasing strain and reversible shrinkaged on unloading. But corresponding the sawtoothed BC section, micro-surface reliefs were observed by SEM[1]. The results suggest that the two transformation stages (AB and BC) have perhaps different nature.

2. Original Microstructure of the Alloy
After water quenching from high temperature (973K-1173K), Ms temperature of the alloy is below 223K and the microstructure at room temperature is β parent phase with CsCl (B2) order lattice[2]. After a proper treatment the alloy is of very good superelasticity and composed of β matrix and a few distorted B19' martensite with a=0.288nm, b=0.414nm, c=0.463nm, $r=97^\circ$ and twin substructure.

3. X-ray diffraction
X-ray diffraction patterns relating to different strains were recorded. Some results within 2θ being 43° - 53°, where the main diffraction lines of β phase and martensite appear, are shown in Fig.2. With increasing strain from 1.5% to 4% (i.e. AB section of deformation in Fig.1) no new martensite appears, but (110) line of β phase widens unsymmetrically, that is generally a distinction for R-phase transformation. After strain exceeds 4%, the diffraction intensities of β phase begin to decline, meanwhile those of martensite increase and new diffraction lines $(020)_M$, $(002)_M$ appear. At ε =10% martensite has become the dominant component in the specimen. This fact indicates that BC section of $\sigma-\varepsilon$ curve corresponds to martensitic transformation. It can be also concluded that the sawtoothed steps on BC section and micro-relief on specimen surface are the characters of stress induced martensitic transformation in the alloy.

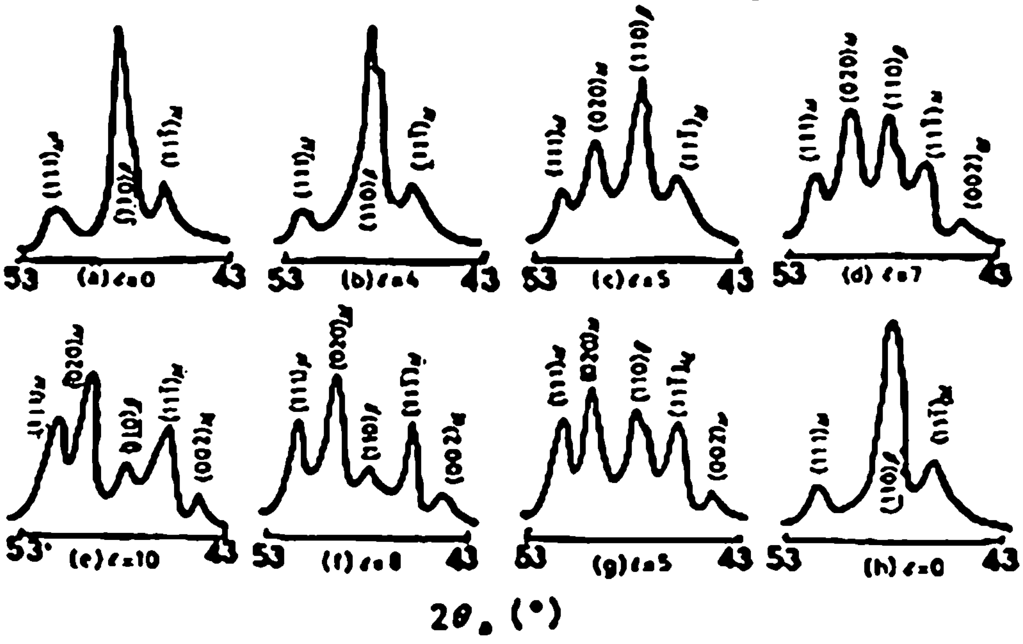

Fig.2. Variation of X-ray diffraction patterns with ε
a-e: loading; e-h: unloading

The relative peak's intensities change also with strain. The intensity of (020)$_M$ is getting stronger and stronger, and finally instead of (111)$_M$ becomes the strongest one in diffraction pattern It is due to the preferred orientation effect of the stress induced martensite.[3]
The variations of diffraction patterns are completly reversible on loading and unloading as shown in Fig.2.

4. TEM Observation

Fig.3 is a series of TEM images and SAD patterns taken at different temperatures, showing ordering parent phase (Fig.3a), R-phase transformation characterized by extra diffraction spots at 1/3 positions of the B_2 (β-parent) reciprocal lattice (Fig.3b) and temperature induced martensite (Fig.3c). As a comparision, Fig.4 give some photos taken on loading. It is worth to mention the extra spots at 1/3 positions, but only along {011} direction of the reciprocal lattice as ε =1.5%~4% (Fig.4b). This is also an evidence for stress induced R-phase transformation and perhaps the preferred orientation of the R-phase. The reversible growth

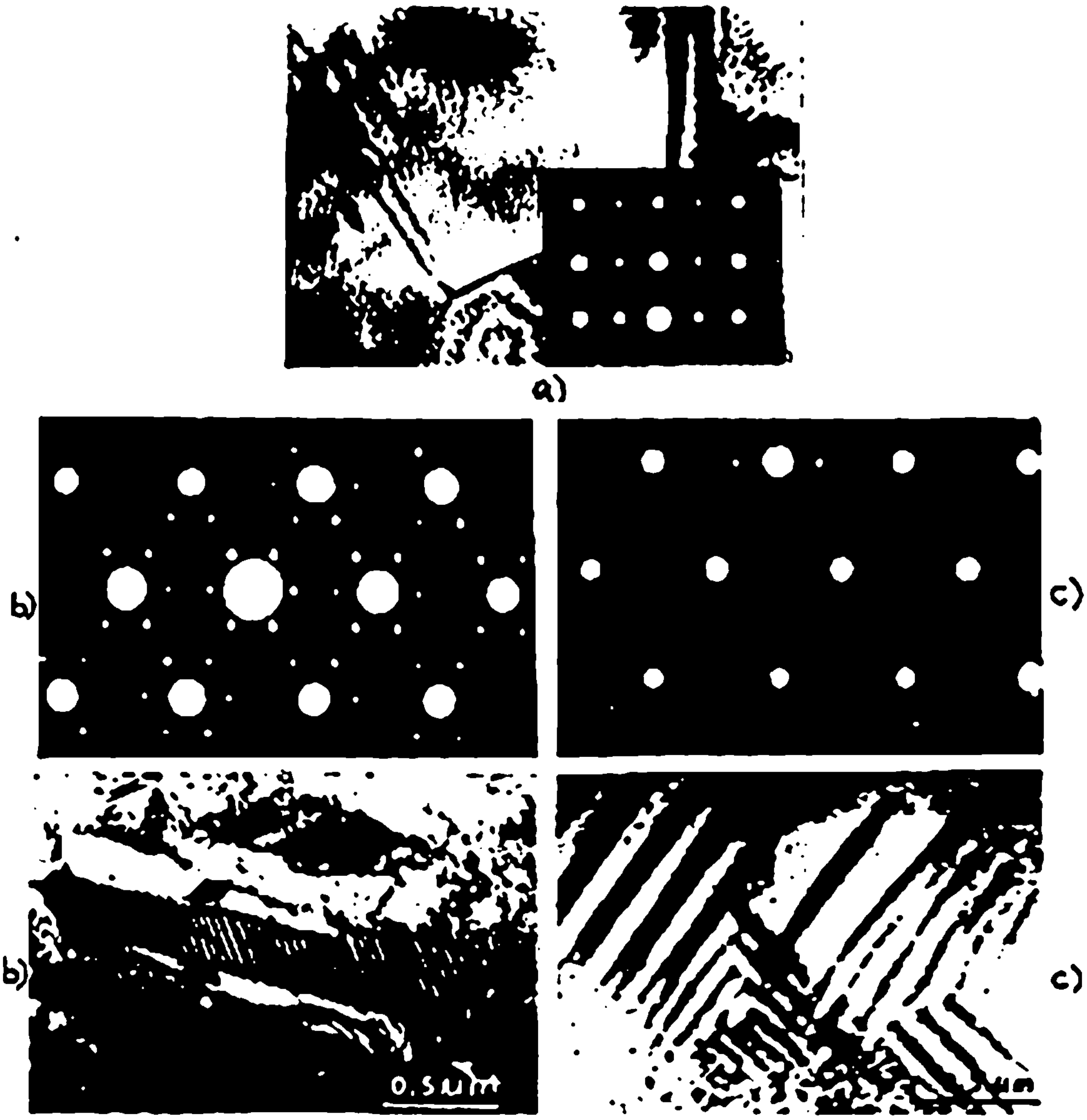

Fig.3. TEM images and SAD patterns of temperature induced transformation

Fig.4. TEM images and SAD patterns of stress induced transformation

and shrinkage of stress induced martensite on loading and unloading at BC section of deformation can be also clearly seen under TEM (Fig.5). It is interesting to note that the martensite growth is not "continuously" but "jumpily". That means, for example, a martensite plate in the field of view grows to 5, 16, 28, 35, 52mm step by step, it stays at every length for a short time and then rapidly grows to next length. It seems that the growth of a stress induced martensite must overcome a series of uncontinuous energy barries. That is maybe the reason for sawtoothed stress-strain curve.

Fig.5. variation of stress induced Martensite during loading (A-D) and unloading (D-F)

Conclusion

1. An excellent superelasticity can be obtained in 51.6 at% Ni-Ti alloy after a suitable treatment
2. Stress induced transformations can be devided into two parts: R-phase transformation and martensitic transformation
3. Stress induced martensite grows jumpily.

References

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