

## High Resolution Microscopy Analysis of a New Precipitate Phase in the High-Temperature Shape Memory Alloy $\text{Ni}_{30}\text{Pt}_{20}\text{Ti}_{50}$

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Shape memory alloys constitute a group of materials that have the ability to recover deformation through heat induced phase transformation. The most prevalent NiTi alloys have found a wide use in a variety of dental, surgical and engineering applications. New types of alloys based on the NiPtTi system are promising for high temperature actuation of up to 300°C [1]. Their implementation in aeronautics could significantly improve the efficiency of devices on new generation turbine engines.

A previously unidentified precipitate phase in the  $\text{Ni}_{30}\text{Pt}_{20}\text{Ti}_{50}$  alloy has been analyzed using electron diffraction and STEM HAADF imaging. The observations were performed on FEI Tecnai TF20 operated at 200kV and FEI Titan 80-300 with  $c_s$ -correction on the electron probe, and operated at 300kV. The HAADF method is especially valuable for structural analysis at the atomic level in the present NiPtTi alloy. Given the atomic number of the elements in the alloy:  $Z(\text{Ni})=28$ ,  $Z(\text{Pt})=78$ ,  $Z(\text{Ti})=22$ , it is expected that atomic columns enriched in Pt are possible to identify due to the nature of imaging process.

A lower magnification view of the microstructure is shown in Fig.1(a). The microstructure consists of the precipitate phase and B19 martensite. The precipitates have a diameter of approximately ~200-400 nm and are commonly seen to contain number of internal faults. The crystallographic nature of the precipitates was analyzed on several zone axes as plotted on the stereographic projection in Fig.1(b). The diffraction pattern analysis reveals that the precipitates have a close structural connection with B2 austenitic phase; the main subset of the diffraction spots in each pattern has the required symmetry and the spacing of B2 phase. Moreover, the corresponding zones axes have the correct angular relationship. An example of the highest symmetry zone (D1), which contain a subset of diffraction spots that are fully consistent with the  $(110)_{\text{B2}}$  reflections from  $[111]_{\text{B2}}$  is shown in Fig.1(c). An example of HAADF observation from several other zone axes is shown in Fig.1(d,e,f). Images such as those from D2 and D3 zones reveal that symmetry and the periodicity of the visualized columns is fully consistent with Ni sub-lattice of B2 austenite. The additional intensity variation within these columns is detected, which suggests Pt partitioning on the Ni sublattice. Observations from zones that are perpendicular to the D1 axis reveal more details about the partitioning of Pt on the Ni sub-lattice. For example, the observation from D6 zone reveals that Pt is present in two closely spaced columns, shown in Fig.1(f). The columns appear as dumbbell motifs that can be fully mapped onto B2 lattice in the  $[110]$  projection. The other Ti and Ni sublattice sites are not clearly detected in the HAADF images due to their much weaker scattering strength.

The crystallography of the new precipitates will be discussed in light of the experimental observations. It will be shown that the observations can be fully explained with Pt ordering on B2 lattice and that the precipitates internal faults represent different crystallographic variants, as shown in Fig.2. The possible role of the ordered phase in promoting desirable high temperature shape memory properties will also be described. This work was supported by NASA Glenn Research Center [2].

[1] Noebe, R., T. Biles, and S.P. II, NiTi-Based High-Temperature Shape-Memory Alloys: Properties, Prospects, and Potential Applications, in *Advanced structural materials: properties, design optimization, and applications*, T.S.S. Winston O. Soboyejo, Editor. 2007, CRC Press: Boca Raton, FL.

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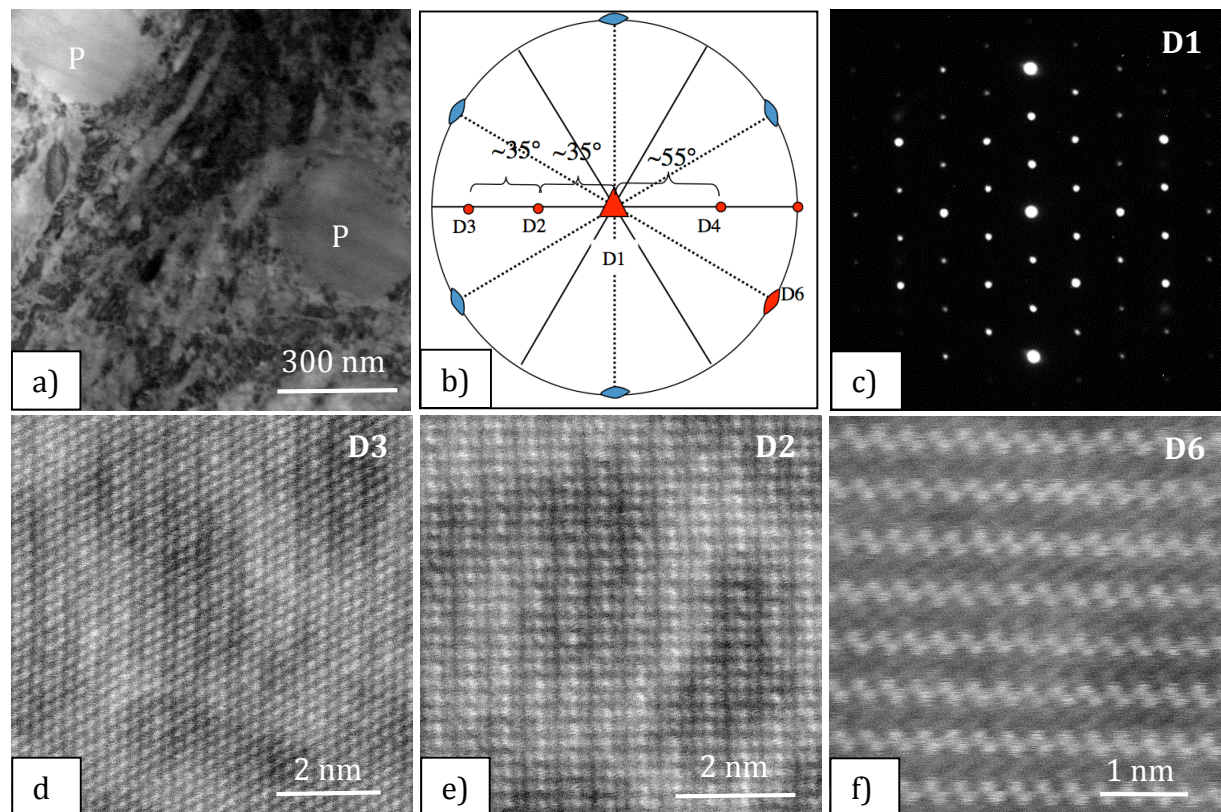


Fig.1. TEM microstructural observation of the aged sample. (b) The angular relationship between the analyzed zone axes.(c) selected area diffraction pattern from D1 zone axis. (d,e,f) HAADF images of the precipitate along several zone axis directions.

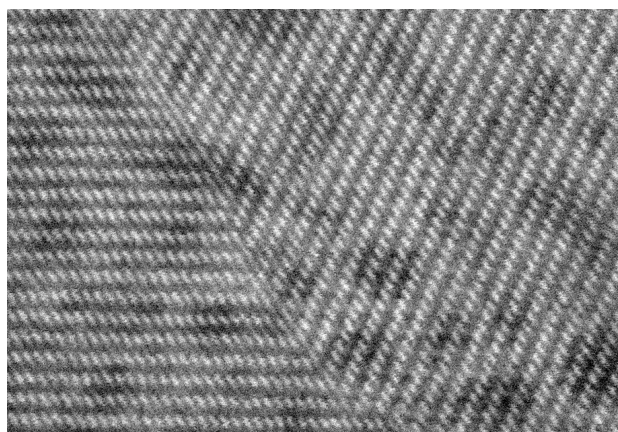


Fig.2. HAADF image of the internal fault within the precipitates.