Observation of Stacking Fault Tetrahedral in TWIP Steel

G. Dini [1*] , S. Vercammen [2]

[1] *Department of Nanotechnology Engineering, Faculty of Advanced Sciences and Technologies, University of Isfahan, Isfahan 81746-73441, Iran*

[2] *K. U. Leuven, Department of Metallurgy and Materials Engineering, Kasteelpark Arenberg 44, B-3001 Leuven, Belgium*

Abstract

Low stacking fault energy face centered cubic (FCC) materials contain characteristic defect structures. Stacking fault tetrahedral are one of those rare structures that occur under special experimental conditions. For the first time, stacking fault tetrahedral were observed in Fe-30Mn-3Al-3Si twinning induced plasticity (TWIP) steel. Their presence resulted from a quenching heat treatment.

Keywords: TWIP steel; Stacking fault tetrahedral; Quenching; Low SFE.

1. Introduction

Stacking fault tetrahedra (SFT) are the major vacancy extended clustered defects in some metals such as copper and gold [1)]. SFT are rarely observed in low stacking fault energy (SFE) FCC metals and alloys. They can be formed by different treatments such as (i) high energy irradiation, (ii) heavy plastic deformation, and (iii) quenching from elevated temperatures [2, 3)]. For the first time, in this study SFT were observed in high manganese low SFE twinning induced plasticity (TWIP) steel.

TWIP steels are a promising new type of steel grade with respect to structural applications [4)]. They combine both strength and ductility [5)]. The occurrence of deformation twins, as a result of the low SFE, during straining causes a profitable strain hardening behavior [5, 6)].

2. Experimental Procedures

A plate of TWIP steel 20mm in thickness and the chemical composition of Fe-30Mn-3Al-3Si (wt. %) was homogenized in an air furnace at 1200 ºC for 1h and then water quenched. The sample preparation methods and experimental procedures included TEM observations, as presented in the Ref. 4.

* *Corresponding author*
Tel.: +98 313 793 2900; Fax: +98 313 793 2901
Email: g.dini@sci.ui.ac.ir
Address: Department of Nanotechnology Engineering, Faculty of Advanced Sciences and Technologies, University of Isfahan, Isfahan 81746- 73441, Iran
1. Assistant Professor
2. Assistant Professor

3. Results and Discussion

Based on the chemical composition of TWIP steel, the SFE was estimated by thermodynamic calculations. According to the model developed by Grässel et al. [7)], the SFE of the current TWIP steel was about 40 mJ/m^2. Coherent annealing twins (Fig. 1a) as well as stacking faults (Fig. 1b), as the characteristics of low SFE materials, appeared after the homogenizing treatment.

The subsequent quenching gave rise to the formation of SFT as shown in Fig. 1c. They look similar to the ones observed in gold by R.M.J. Cotterill [1)] (Fig. 3a). Compared to the previous one, the observed SFT in the current work were rather large (>100 nm), as shown in Fig. 1c.

The triangular shape stemmed from the projection of a regular tetrahedron with equilateral triangles on {111} planes and edges parallel to <110> directions. This tetrahedron was identical in shape to that in Thompson's reference (Fig. 2a).

As can be seen in Fig. 2b, the ABD plane was parallel to the electron beam with $\gamma B = 1/6[\bar{1}12]$ being the zone axis. This plane could only show up as the edge of the triangle, but as the shear on this plane was perpendicular to the diffraction vector g, no contrast was detected. The planes ABC and ACD, BCD and ACD would give rise to fringes parallel to their line of intersection, AC and DC, respectively. Those fringes could be seen in Fig. 3.

In this figure, the bright field, the dark field and the weak beam dark field diffraction conditions have been utilized to study the nature of SFT by analyzing the diffraction contrast properties of a given stacking fault tetrahedron under known diffraction conditions (e.g., g= $[1\bar{1}1]$).

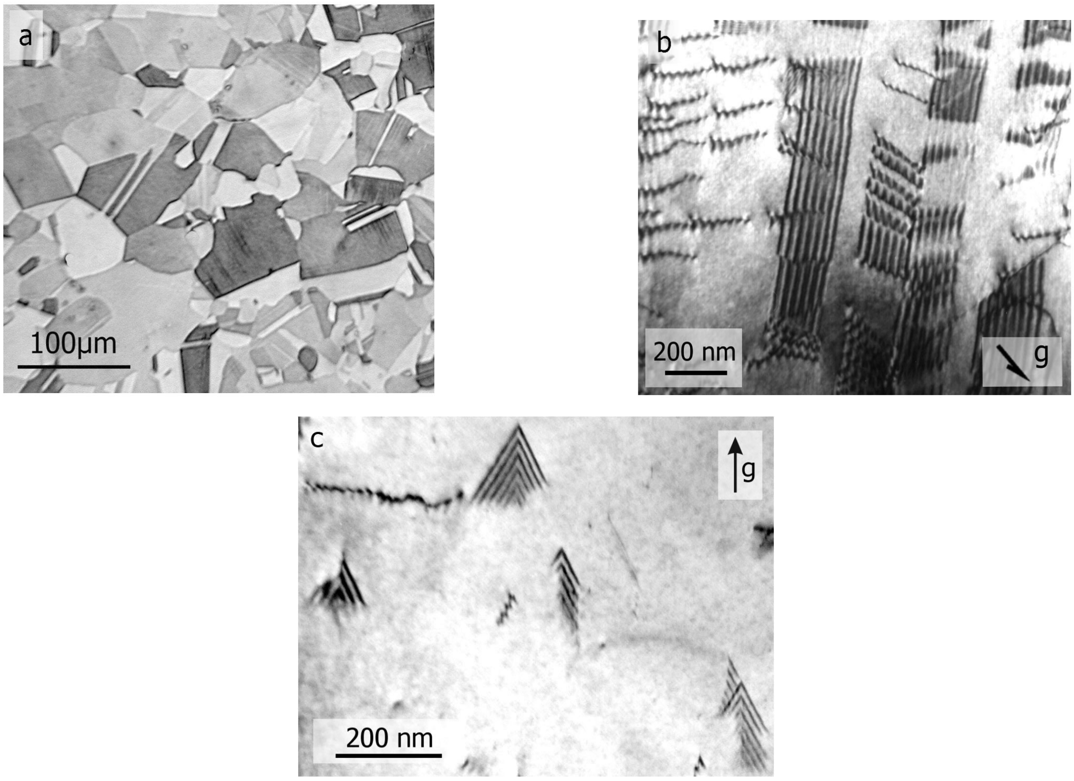

Fig. 1. (a, b) Optical micrograph and bright field image (the zone axis γB=[011] and diffraction vector g=[$\bar{1}1\bar{1}$] of the homogenized TWIP steel, respectively, and (c) bright field image (γB= 1 / 6 [$\bar{1}$12] and g= [1$\bar{1}$1]) of the homogenized and quenched TWIP steel, showing several (parts of) the large SFT.

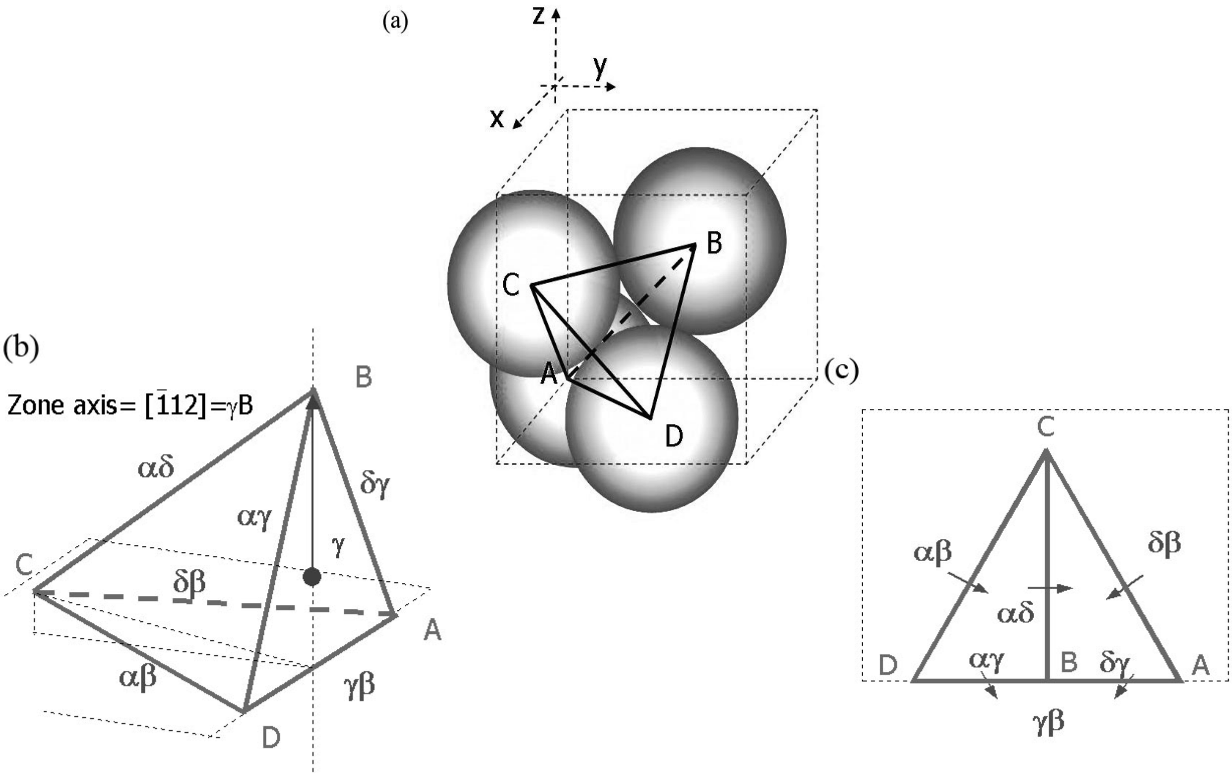

Fig. 2. (a) The Thompson tetrahedron ABCD, in 3D, representing 1 / 8 of the FCC unit cell with the origin of the coordinate system, and (b, c) 3D and 2D views of the tetrahedron oriented along γB= 1 / 6 [$\bar{1}$12]. In (c), the orientation of the stair rod dislocations on each edge is indicated.

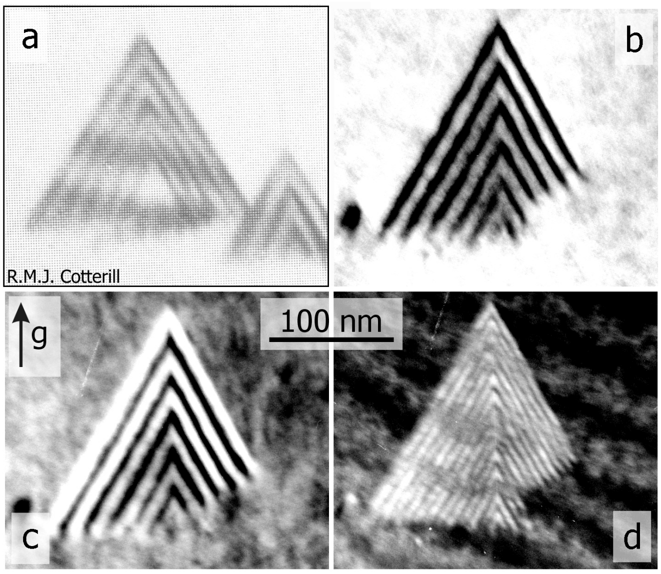

Fig. 3. (a) SFT observed by R.M.J. Cotterill [2], (b) Bright field, (c) dark field and (d) weak beam dark field (kinematical diffraction condition) images of a stacking fault tetrahedron with g= $[1\bar{1}1]$.

As shown in Fig. 3, the stair rod dislocation situated on the CB edge (αγ) was invisible under this diffraction condition (the phase factor 2πg.δr being zero when δr is , where a is the lattice parameter). If g is changed to $[\bar{2}\,\bar{2}\,0]$ or $[\bar{3}\,\bar{1}\,\bar{1}]$, the stair rod dislocation shows contrast as shown in Fig. 4.

SFT are probably built by the mechanism proposed by Silcox and Hirsch in [8]. They proposed the following mechanism for SFT formation. A vacancy disc is nucleated on a {111} plane and collapsed to form a loop bounded by Frank partial dislocations a/3<111>. Each of the Frank partial is dissociated to form a low energy stair-rod partial a/6<110> and a Shockley partial dislocation a/6<112> . A stacking fault tetrahedron is then formed by the Shockley partials gliding toward the apex of the tetrahedron formed by the three intersecting {111} planes and the original loop {111} plane. The reaction of Shockley partials at each intersection of {111} planes produces stair rod partial dislocations. The formed stacking fault tetrahedron has four triangular {111} planes bounded by six stair rod partial dislocations.

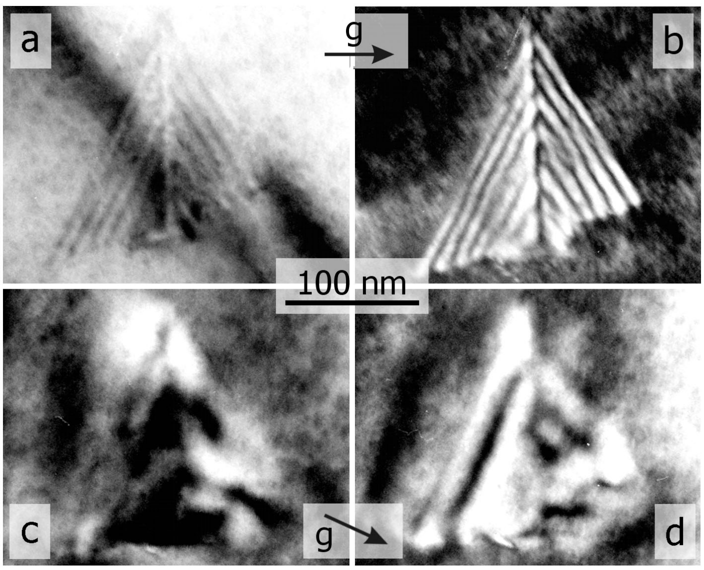

Fig. 4. Bright field and dark field images of the same stacking fault tetrahedron, as shown in Fig. 3, for different diffraction conditions: (a, b) g= $[\bar{2}\,\bar{2}\,0]$ *, and (c, d) g=* $[\bar{3}\,\bar{1}\,\bar{1}]$.

4. Conclusion

To conclude, in this study, for the first time, SFT were observed in TWIP steel. They resulted from a quenching treatment and appeared in TEM as large, 100 nm wide, triangles. The low SFE of TWIP steel supported their presence as well as the large amount of wide stacking faults.

References

[1] R.M.J. Cotterill: Philos Mag, 6(1961), 1351.
[2] D. Hull and D.J. Bacon: Introduction to Dislocations, Pergamon Press, Oxford, (1984), 98.
[3] J.P. Hirth and J. Lothe: Theory of Dislocations, Wiley, New York, (1982), 154.
[4] S. Vercammen, B. Blanpain, B.C. De Cooman and P. Wollants: Acta Mater, 52(2004), 2005.
[5] G. Dini, A. Najafizadeh, R. Ueji and S.M. Monir-Vaghefi: Mater Des, 31(2010), 3395.
[6] G. Dini, R. Ueji, A. Najafizadeh and S.M. Monir-Vaghefi: Mater Sci Eng A, 527(2010), 2759.
[7] O. Grassel, G. Frommeyer, C. Derder and H.Hofmann: J Phys IV France, 7(1997), 383.
[8] J. Silcox and P.B. Hirsch: Philos Mag, 4(1959), 72.