Part IV : Solid-Solid Phase Transformations I

Module 5. Martensitic transformations

5 Martensitic transformations

5.1 Motivation

What is the transformation involved in the shape memory alloys – alloys that can be deformed, and by heating can be made to regain their original shape?

5.2 Martensitic transformation

Martensitic transformation is the name for any transformation that takes place in a diffusionless and military manner – that is, these transformations take place through atomic movements which are less than one atomic spacing; and in these transformations atoms change their positions in a coordinated manner (unlike thermally activated diffusional, or, so-called, civilian processes). In shape memory alloys such as Ni-Ti (nitinol), it is the martensitic transformation that is responsible for the shape memory effect. In this module, we describe some characteristic features of the martensitic transformations (with specific reference to steels in which, this transformation is responsible for hardening by quenching). This module is very cursory in details and we refer the interested reader to [1] and [2] for details.

Since martensitic transformations are diffusionless, necessarily, the local composition does not change during the transformation. It is only the crystal structure that changes. For example, in Fe-C alloys, the austenite (fcc) transforms into martensite (bct); in Ni-Ti, an ordered bcc (called austenite) transforms to another ordered CsCl type structure (called martensite). Note that since martensitic transformation is diffusionless, if the austenitic phase is ordered, the martensitic phase is also ordered.

Martensites are typically found in lath and plate morphologies: see the schematic in Fig. 38. The lens shaped martensites are coherent with the surrounding austenite as shown in the schematic Fig. 39. As is clear from this schematic, after transformation, lines drawn on a prepolished surface show tilts.

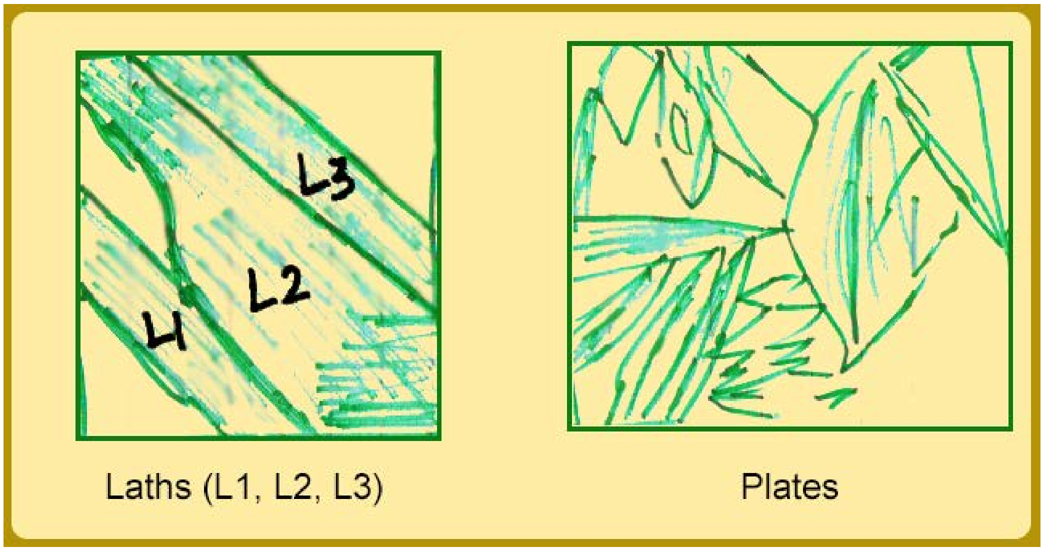

Figure 38: Laths and plates of martensites.

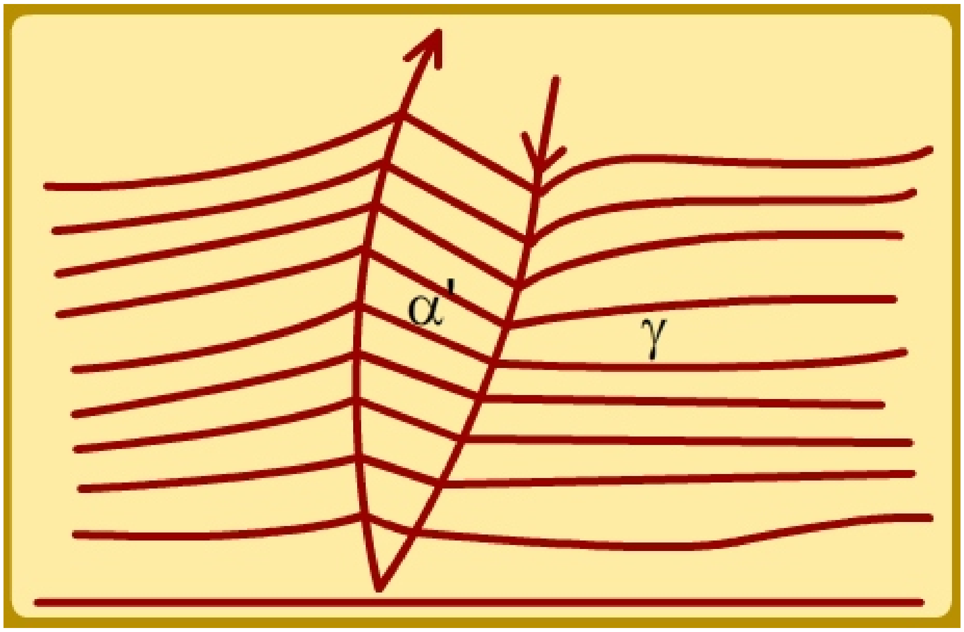

Figure 39: Martensite plate coherency with austenite.

The martensites grow (almost) at the speed of sound in the material and hence need no thermal activation. The martensites start forming on reaching the so-called martensite start (M_s) temperature and their formation stops after reaching the martensite finish temperature (M_f). The driving force for martensites to form is shown in Fig. 40.

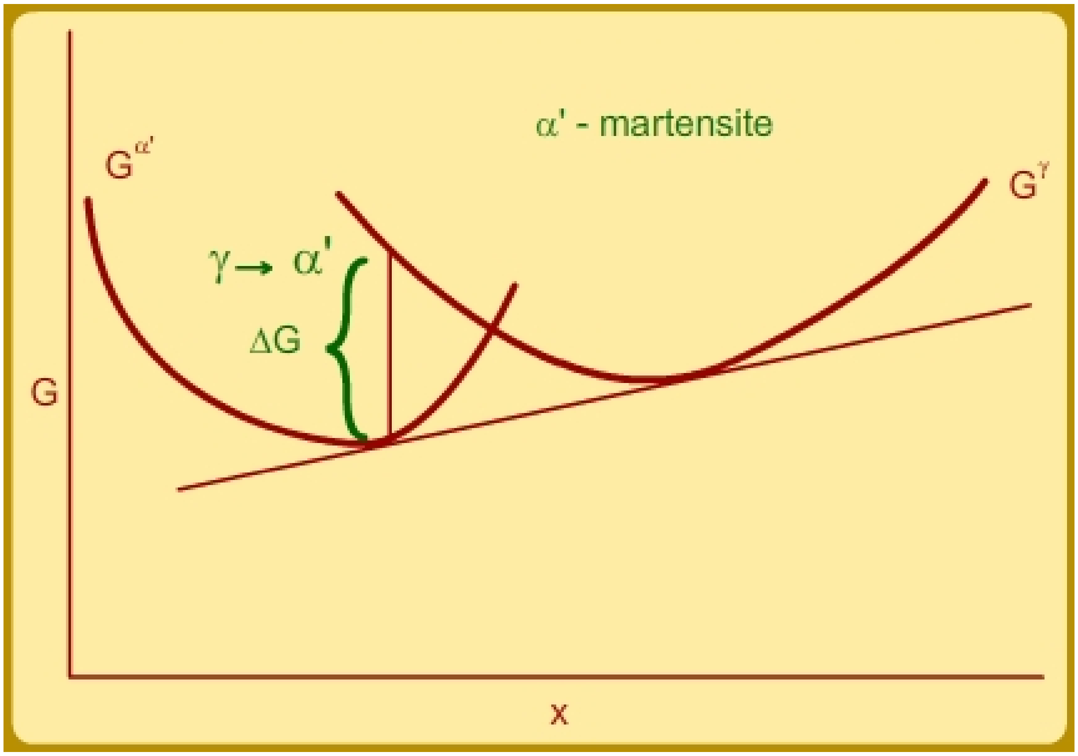

Figure 40: Driving force for formation of martensite.

The most important aspect of martensitic transformation is the crystallography of the martensite; it is closely related to two things, namely, the presence of invariant plane in the austenitic phase (which is indicated by the tilt of lines drawn on a prepolished surface before the transformation) and the presence of a habit plane with specific (Kurdjumov-Sachs) orientation relationship. As shown in Fig. 41, it is possible to obtain a bct crystal from the fcc one; however, such a bct unit cell has to be contracted by 20% in the c direction and expanded by about 12% in the a and b directions to account for the measured lattice parameters of the fcc and martensitic phases (see Fig. 42). This strain (-20% along c and +12% along a and b) is known as Bain strain. Further, the observed orientation relationships between the austenite and martensitic phases can be explained using such a (so called Bain) transformation of the fcc to bct phase. However, Bain strain alone is not sufficient to explain the presence of an invariant plane. Hence, theories of martensite crystallography typically involve Bain strain coupled with certain shears and lattice rotations to explain the observed invariant planes. However, these are outside the scope of these notes. The interested reader is referred to [2] for details.

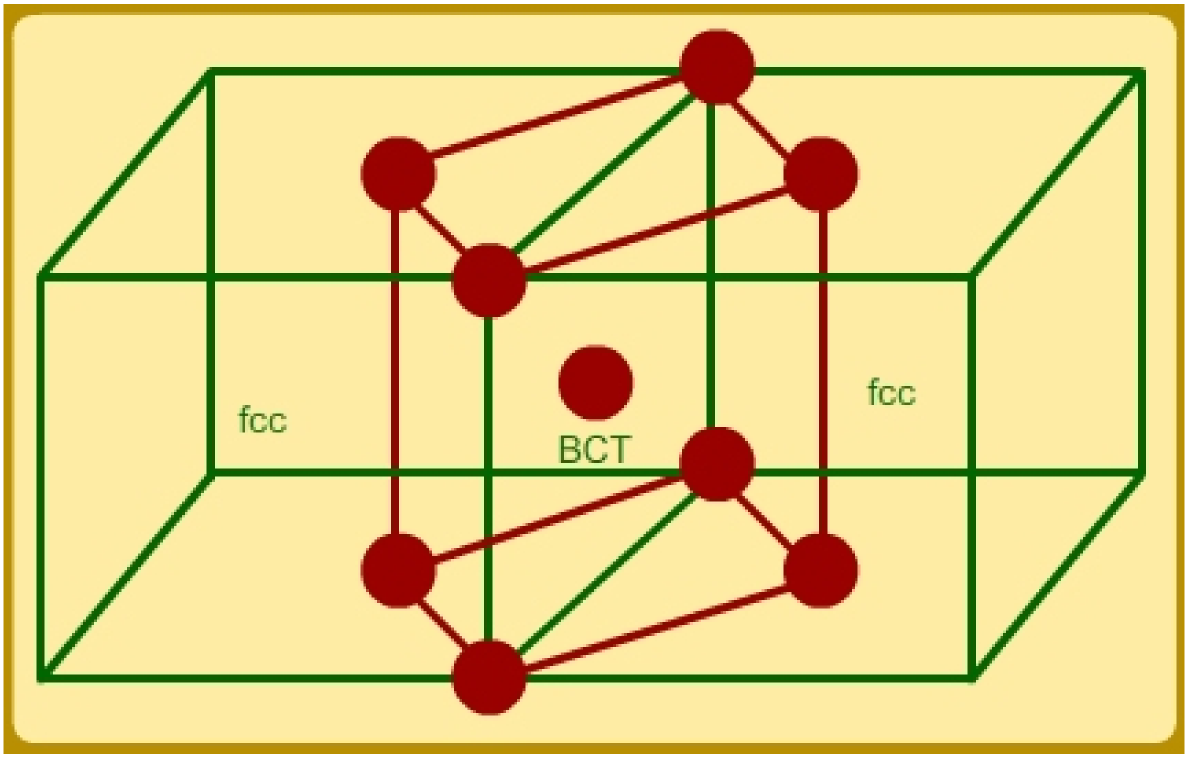

Figure 41: FCC versus BCT crystal structures.

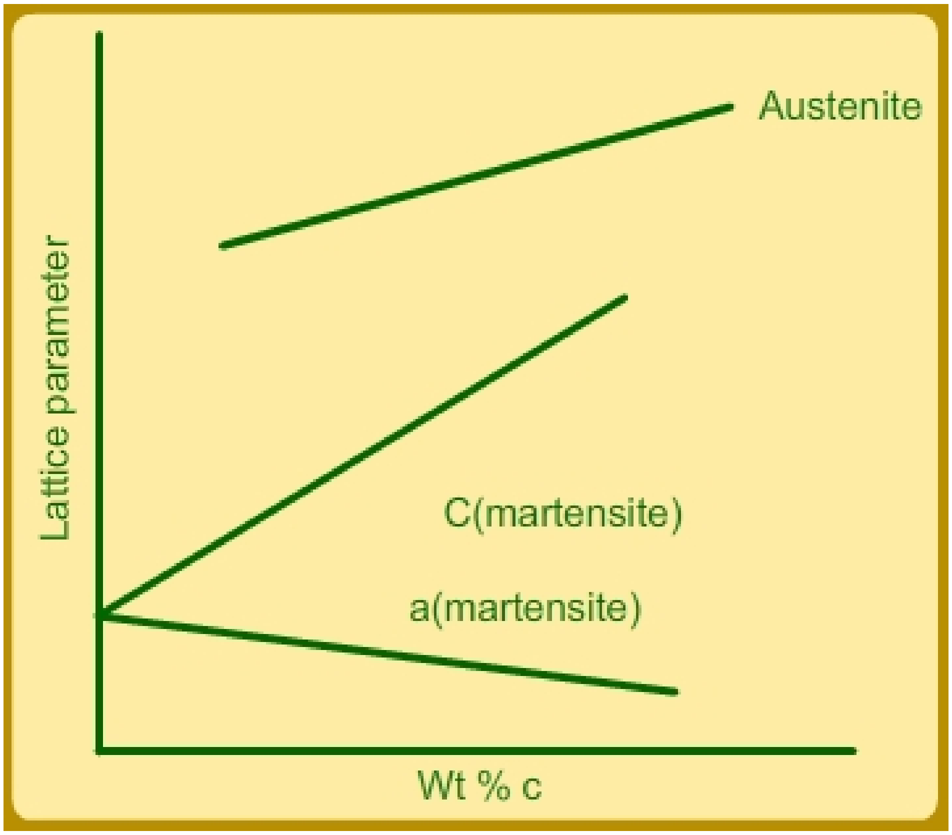

Figure 42: Variation of lattice parameters in the austenite and martensite phases as a function of carbon composition.

Finally, the large strains associated with the formation of martensitic phases and the fast growth rates observed indicate that both the nucleation and growth of martensites are to be explained by invoking mechanisms which deal with dislocations. Again, the details of such theories of martensite nucleation and growth are outside the scope of these modules. We refer the interested reader to [1].

5.3 Tutorial problems and questions

- The changes in lattice parameters (in Å) with carbon concentration (x) for the austenite phase is $a_0 = 3.548 + 0.044x$ and for the martensitic phase is $c = 2.861 + 0.116x$ and $a = 2.861 - 0.013x$. Calculate the change in volume associated with the martensitic transformation for a 1% carbon steel.

5.4 Solutions to the tutorial

- The austenite lattice paramter is 3.592 Å; and that of the martensite are 2.848 and 2.977 Å. In tetragonal form, the volume of the austenite unit cell is 23.15 Å^3 ($a_0 \frac{a_0}{\sqrt{2}} \frac{a_0}{\sqrt{2}}$). The volume of the martensitic unit cell is 24.14 Å^3 (caa). Hence the volume change is 4.3% ($\frac{24.14-23.15}{24.14}$). See [5] for more details.

5.5 Supplementary information

Martensitic transformation is the transformation associated with shape memory alloys. For example, in NiTi alloys, the reversible shear induced diffusionless transformtion from one ordered phase to another is what leads to the shape memory effect. Readers interested in further information on martensitic trasfomations are referred to the textbook by Honeycombe and Bhadeshia [6].

References

[1] David A. Porter, Kenneth E. Easterling, and Mohamed Y. Sherif, Phase transformations in metals and alloys, CRC press, Third edition, 2009.

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[3] K F Kelton and A L Greer, Nucleation in condensed matter: applications in materials and biology, Vol. 15, Pergamon Materials Series, Pergamon, First edition, 2010.

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