Fig. 3. Light optical micrographs of partially transformed microstructures after 1% sodium disulphite etching. (a) MI thermal cycle interrupted after 45% transformation. (b) HI thermal cycle interrupted after 30% transformation. Bainite in white, martensite in grey. Black lines delineate some of the partially formed bainite packets. Arrows in (a) indicate some parallel "bainite groups" forming a part of the bainite packet.

marked with arrows in Fig. 3(a)). These parallel features, every of them appearing as a single "grain" in the light micrographs, correspond to the "bainite groups" defined from the TEM observations. Interfaces between bainite groups and martensite (i.e., former austenite) are very straight for the medium MI cooling rate, and much more irregular for the slower HI cooling rate. The groups are probably plate-shaped, so that they sometimes appear to be "thick" in light micrographs. Consistently with TEM observations, the growth direction of groups is well defined, at least at the early stages of growth.

By careful examination of light micrographs of fully transformed microstructures (Fig. 4(a) and (b)), the bainite packets still appear as sets of groups separated by second phase particles. The HI microstructure appeared to be more "granular" than the MI microstructure, with thicker, less well defined groups. These "morphological" packets are highly intricate, in particular in the MI microstructure. Most former austenite grain boundaries are clearly visible, allowing the mean austenite grain size to be measured (Table 2). The austenite to bainite phase transformation is not complete, and numerous M–A constituents are found, in particular after the HI cycle (Table 2). Detailed size distributions of austenite grains and of second phases can be found in [9].

3.3. Bainite packet crystallography

3.3.1. Austenite to bainitic ferrite orientation relationships

In the present study, the orientation of the former austenite grains was calculated using the following method, which differs from the one used by Suh and co-workers [20,21]. The $\{001\}_\alpha$ pole figure of bainitic

ferrite within a given former austenite grain can easily be obtained using EBSD as shown in Fig. 5 for the fully transformed MI microstructure. The three Bain zones are clearly visible as indicated by numbers in Fig. 5(a). They are, in fact, centered on the $\{001\}_\gamma$ poles of the former austenite grain. The distribution of the bainite orientation within the Bain zones is not homogeneous (Fig. 5(b)), because a maximum of 24 variants of bainite can form from a given austenite grain due to the particular crystallographic orientation relationship between austenite and bainitic ferrite. The $\{001\}_\gamma$ poles, and thus the orientation of the former austenite grain, could then be readily determined using the following iterative procedure. From a first estimate of the austenite orientation, the experimental $\{001\}_\alpha$ pole figure of the bainite phase was compared with the theoretical pole figure plotted using the 24 KS and the 12 NW variants calculated from the orientation of austenite. The calculation was repeated until both experimental and calculated Bain zones matched exactly. The accuracy of the method is estimated to be around 0.5° for each of the three Euler angles. With this method, there is no need of measuring the austenite phase, and thus of retaining it. Therefore, the proposed method can be used to investigate the austenite to ferrite phase orientation relationship for any steel composition. A reconstructed pole figure is shown in Fig. 5(c). The experimental orientation relationship is well within the Bain zone, but is not necessarily exactly either the KS or NW relationship. This had already been quoted by others for upper bainite using TEM thin foil analysis [18,22–25] and for Widmanstätten kamacite (a body-centred cubic phase in iron–nickel meteorites) using X-ray synchrotron diffraction analysis [26].