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# Micro-tension behaviour of lath martensite structures of carbon steel

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ABSTRACT

A micro-tension testing technique was used to investigate the deformation behaviour of lath martensite structures with several types of boundaries in carbon steel. The martensite structures exhibited sufficient necking strains and ductile fractures, whereas the uniform strain was limited owing to a lack of strain-hardening ability despite the increased flow stress. The yield stress of the lath martensite structures strongly depended on the in-lath-plane orientation. The critical resolved shear stress of the in-lath-plane slip systems was considerably lower than that of the out-of-lath-plane slip systems. This finding suggests that the block boundaries are an effective grain boundary for impeding dislocation gliding. Plastic deformation transfer was restricted by the packet boundaries, which greatly rotated the crystallographic orientation of the in-lath-plane slip systems between neighbouring martensite variants.



## 1. Introduction

The mechanical properties of steels can be greatly adjusted by controlling the microstructure through alloying, heat treatment, and mechanical processing. The lath martensite microstructure is the most important constituent in high-strength steels for automobile, construction, and civil engineering structures. Strengthening is often achieved through a combination of several mechanisms; in particular, lath martensitic steels are strengthened because of the mutual interaction of dislocations, solid solution of carbon atoms, and grain refinement effect. The presence of such varied effects complicates understanding of the strengthening mechanism. Advances in nanometre-scale sensing techniques have enabled the contribution of each mechanism to the strengthening of lath martensite structures to be clarified [1,2]. Ohmura et al. [1] and Hirukawa et al. [2] reported that the grain size has a significant effect on the macro-strength of Fe–C martensite and low-alloy martensitic steels, respectively. Lath martensite has a hierarchical structure comprising prior austenite grains, packets, blocks, sub-blocks, and laths, as schematically shown in Fig. 1 [3]. Twenty-four variants of martensite laths can be formed from a single austenite grain with the Kurdjumov–Sachs (K–S) orientation relationship. The packet contains parallel blocks that have a common habit plane in the prior austenite. In other words, there are six variants of laths available in each packet. The block consists of a pair of sub-blocks that are specific K–S variants with a misorientation of approximately 10° between them. There has been controversy over which boundary is the effective grain boundary that hinders the dislocation movement [4,5].

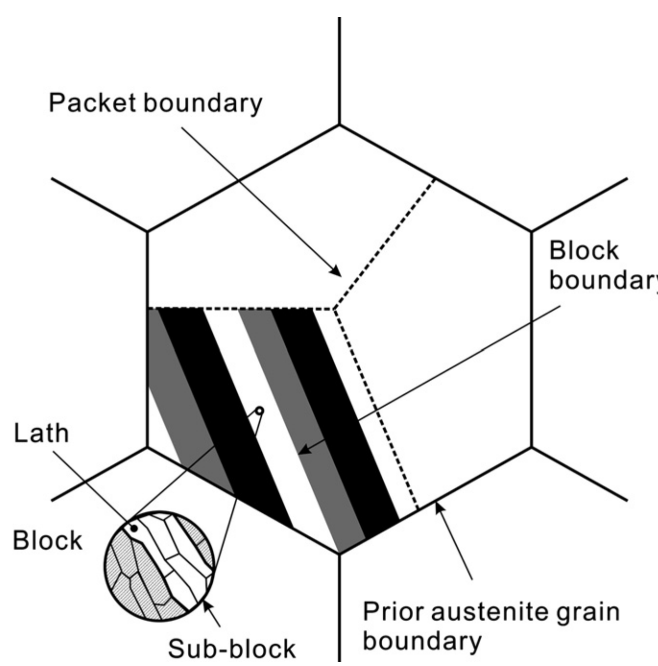


**Fig. 1.** Schematic illustration showing hierarchical structure of lath martensite (after Morito et al. [3]).

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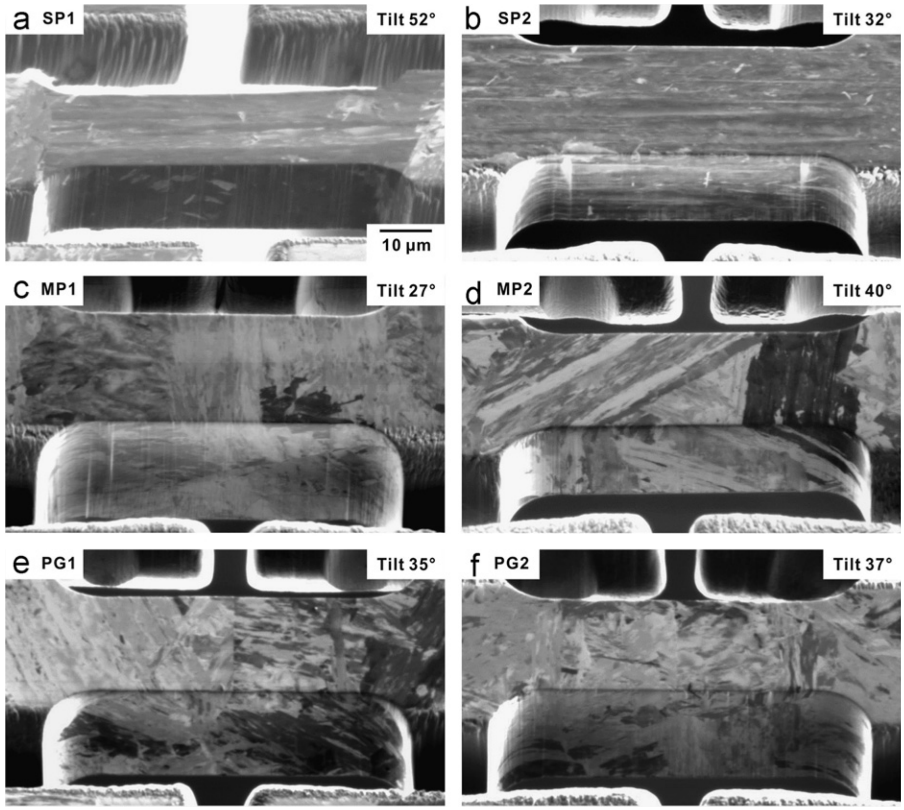


**Fig. 2.** Scanning ion microscopy images of micro-tension specimens: (a and b) single packet specimens, (c and d) multi-packet specimens, and (e and f) specimens including prior $\gamma$ grain boundaries.

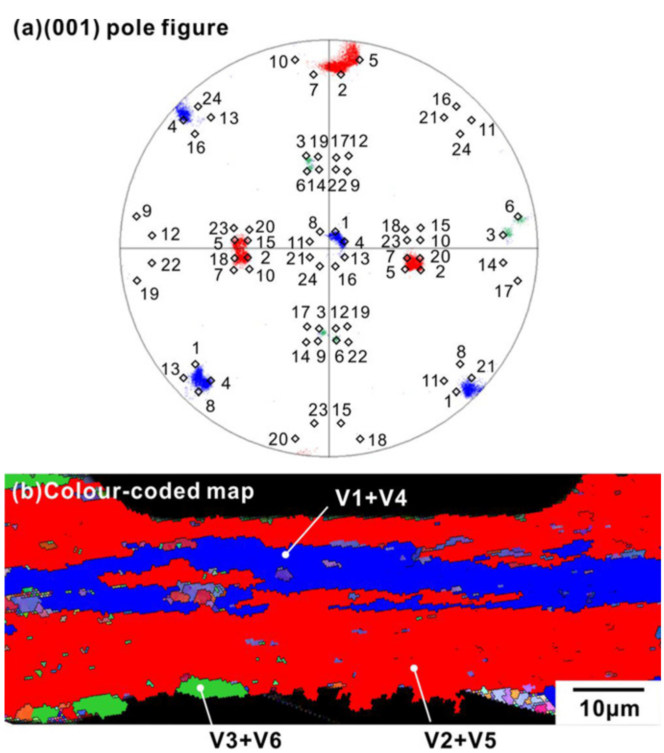


**Fig. 3.** (001) pole figure with six variants V1–V6 and corresponding colour-coded map in SP2 specimen.

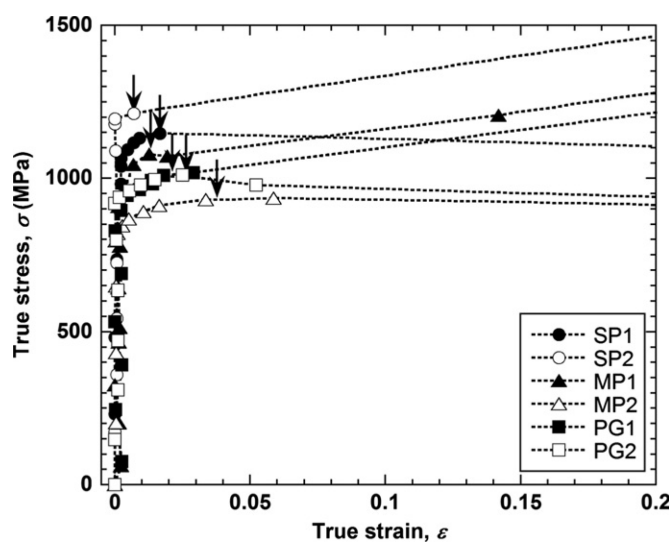


**Fig. 4.** True-stress–true-strain behaviours obtained using micro-tension specimens.

There is usually a trade-off between strength and ductility. Thus, a major challenge in the field of materials science has been to improve the balance between strength and ductility. Inoue et al. [6]and Nambu et al. [7] found that a multi-layered steel of lath martensitic steel and austenitic stainless steel exhibited more than 50% elongation through increased work hardening by dislocation multiplication during tensile straining. Hence, lath martensitic steels do not lose ductility in a broad sense. In addition, characterising the roles of grain boundaries to the plasticity is necessary to provide essential information for the mechanistic understanding of delayed fracture related to hydrogen embrittlement and the fatigue crack problem of lath martensitic steels.

Micro-mechanical testing techniques have developed rapidly along with MEMS technology. Shibata et al. have investigated the