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MORPHOLOGY OF LATH MARTENSITE FORMED FROM DEFORMED AUSTENITE IN 18% Ni MARAGING STEEL

I. Tamura, K. Tsuzaki and T. Maki

Department of Metal Science & Technology, Faculty of Engineering, Kyoto University, Sakyo-ku, Kyoto, 606, Japan

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Abstract.— The change in the morphology of lath martensite with deformation of austenite (ausforming) has been studied by using an 18% Ni maraging steel. Specimens in austenitic state were deformed in tension by several strains (true strain $\epsilon = 0.1 \sim 1.0$) at 773 K (which was above M_d temperature). In the case of conventionally quenched (not-deformed) specimen, an austenite grain contained several packets and each packet was almost completely partitioned by parallel blocks. However, this morphology of packets and blocks was markedly changed when martensite was formed from deformed (work-hardened) austenite. The packet size was increased with an increase in the amount of deformation. On the other hand, block width was decreased with an increase in the amount of deformation (up to about $\epsilon = 0.2$) and blocks became wavy or finely segmented when austenite was heavily deformed ($\epsilon = 0.4 \sim 1.0$). From the observation of the formation process of lath martensite by applying the Greninger-Troiano heat treatment, it was found that laths with the same habit plane (one of four $\{111\}_\gamma$ habit planes) were preferentially formed in an austenite grain when the specimen was deformed before transformation, although four $\{111\}_\gamma$ martensite habit planes were almost evenly observed in an austenite grain in a conventionally quenched specimen. Because of such a restriction of the variant of martensite habit plane, the ausformed lath martensite exhibits the characteristic morphology.

I. Introduction

The lath martensite structure in ferrous alloys is characterized by packets and blocks in a prior austenite grain [1-3]. Since packets or blocks are fundamental microstructural units which control the mechanical properties, especially the toughness of lath martensite structure [4,5], it is important to make clear the various effects on the morphology of lath martensite. The present authors have studied effects of chemical compositions, austenite grain size and cooling rate on the morphology of lath martensite in Fe-C and Fe-Ni alloys [3,6,7]. In the present study the effect of deformation of austenite (ausforming) on the morphology of lath martensite was examined. The ausforming is an attractive thermo-mechanical treatment for improvement of strength and toughness of martensitic steels and thus there have been many studies on ausforming from several points of view [8,9]. However, the detailed studies on the morphology (optical microstructure) of ausformed lath martensite (i.e., the martensite formed from strain-hardened austenite) are surprisingly limited.

The purpose of this paper is to show that the lath martensite morphology is remarkably changed with the deformation of austenite (ausforming) before martensitic transformation. An 18% Ni maraging steel was used for the present study because this steel exhibits the typical lath martensite structure even when the specimen is not cooled so rapidly [3], although the ausforming is not generally applied to the maraging steel since the increase in the strength due to ausforming is very small in this steel [10].

II. Experimental Procedure

The 18% Ni maraging steel whose chemical composition is 18.30% Ni, 8.95% Co, 5.00% Mo, 0.7% Ti and 0.015% C (mass %) was used. M_s and M_f temperatures of this steel were 490 K and 380 K, respectively. Specimens of 130 mm in length (gage section of 20 mm long and 4.5 mm in diameter) were machined from as-received bars.

Heat treatment and deformation condition are shown in Fig. 1. Thermo-mechanical treatment was performed with a Gleeble testing machine. Specimens were austenitized at 1523 K for 120 s in Ar gas atmosphere (an austenite grain size of 200 μm was obtained by this treatment) and cooled to 773 K (above M_d temperature) and deformed in tension to various strains at strain rate of $3 \times 10^{-2}/\text{s}$ and then air cooled to room temperature to produce lath martensite. After this treatment, the specimens were maraged at 773 K for 1.2 ks in order to make it easy to reveal the martensite packets and blocks by etching.

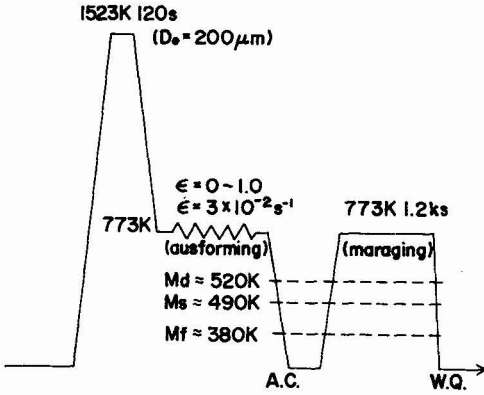


Fig. 1 Conditions of heat treatment and deformation of austenite.

at the most deformed part of specimen. Specimens were electrolytically etched with CrO_3 10 g + H_2O 90 ml for revealing the packet boundaries, and were chemically etched with FeCl_3 10 g + HCl 30 ml + H_2O 90 ml for revealing the block structure of lath martensite. The strain indicated in the present paper is the true strain (ϵ) calculated from the reduction of area of the deformed specimen, i.e., $\epsilon = \ln(A_0/A)$, where A_0 and A are areas of cross section of specimen before and after deformation, respectively. Sizes of austenite grain, packet and block were measured by the linear intercept method.

The optical microstructure of the lath martensite was observed on the longitudinal section of specimens. When specimens were heavily deformed at 773 K, the necking of the specimen occurred to some extent. In this case, the microstructure was observed

III. Results and Discussion

(1) Morphology of lath martensite formed from non-deformed austenite

Fig. 2(a) shows the optical microstructure of lath martensite formed from non-deformed austenite (hereafter referred to as non-austenite). Fig. 2(b) is

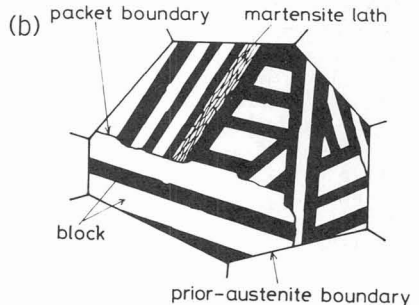
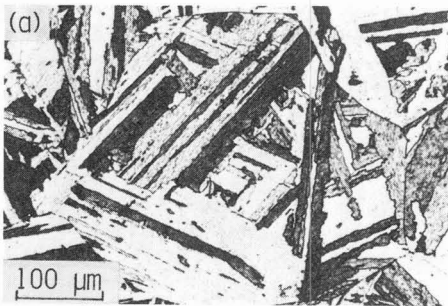
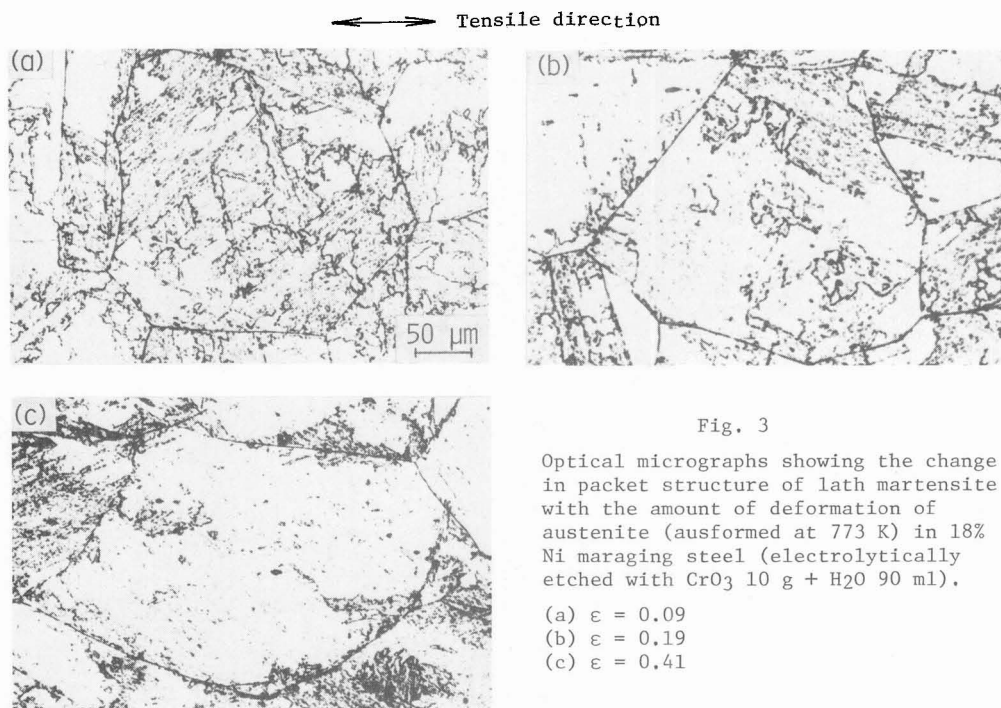


Fig. 2 Optical micrograph (a) and schematic illustration (b) of lath martensite formed from non-deformed austenite in 18% Ni maraging steel (1523 K, 3.6 ks \rightarrow air-cool). Etchant: FeCl_3 10 g + HCl 30 ml + H_2O 120 ml.



the schematic illustration showing the construction of lath martensite structure corresponding to Fig. 2(a). As is evident from Fig. 2, the lath martensite structure in maraging steel is characterized by consisting of packets and blocks. An austenite grain is partitioned into several packets which consist of parallel laths with the same habit plane. Each packet is further partitioned into some parallel blocks which are made up of parallel laths having essentially the same orientation (i.e., the same variant), and blocks are separated by high angle boundaries. It is characteristic in 18% Ni maraging steel that the blocks of non-ausformed lath martensite are well developed and thus the packet is almost completely partitioned by parallel blocks.

(2) Morphology of lath martensite formed from deformed (strain-hardened) austenite

The change in the packet morphology of lath martensite with deformation of austenite at 773 K is shown in Fig. 3. Since the ausforming temperature (773 K) is below the recrystallization temperature of austenite in this steel, the martensite is formed from strain-hardened austenite (hereafter referred to as ausformed martensite). It appears that the number of packets in an austenite grain decreases and hence the packet size becomes large with an increase in the amount of deformation of austenite. When an austenite is deformed more than $\epsilon \approx 0.4$, the austenite grains which contain only few large packets are frequently observed (Fig. 3(c)).

Fig. 4 is a set of histograms showing the distribution of packet size in non-ausformed or ausformed lath martensite. The mean packet size is increased with an increase in the amount of ausforming. It is characteristic that the fraction of large packet size is increased with increasing the amount of ausforming. This indicated that, in the ausformed lath martensite, an austenite grain contains few large packets and some small packets, although the packet size in non-ausformed martensite is fairly uniform,

Fig. 5 shows the change in the block morphology of lath martensite with the deformation of austenite at 773 K. In the specimen ausformed by $\epsilon = 0.09$ (Fig. 5(a)),

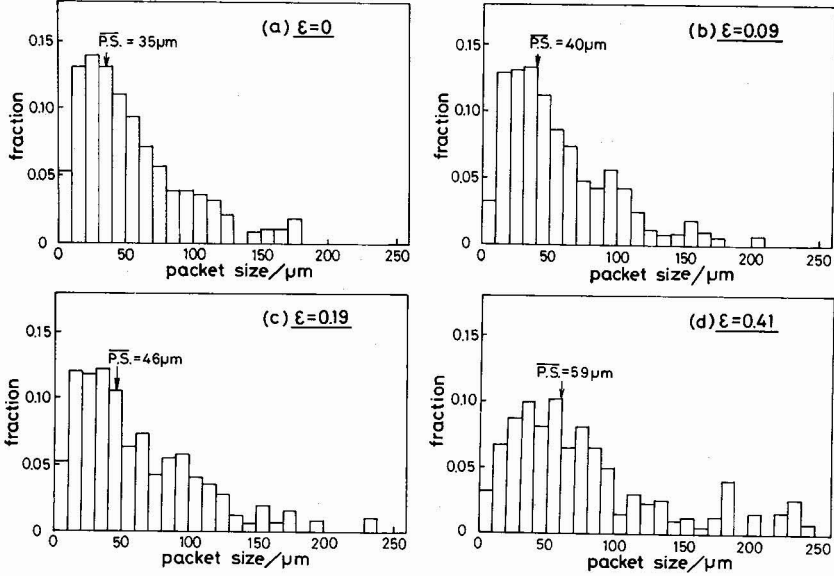


Fig. 4 Histograms showing the distribution of packet size in non-ausformed ($\epsilon = 0$) or ausformed lath martensite in 18% Ni maraging steel. The mean initial austenite grain size was 200 μm .

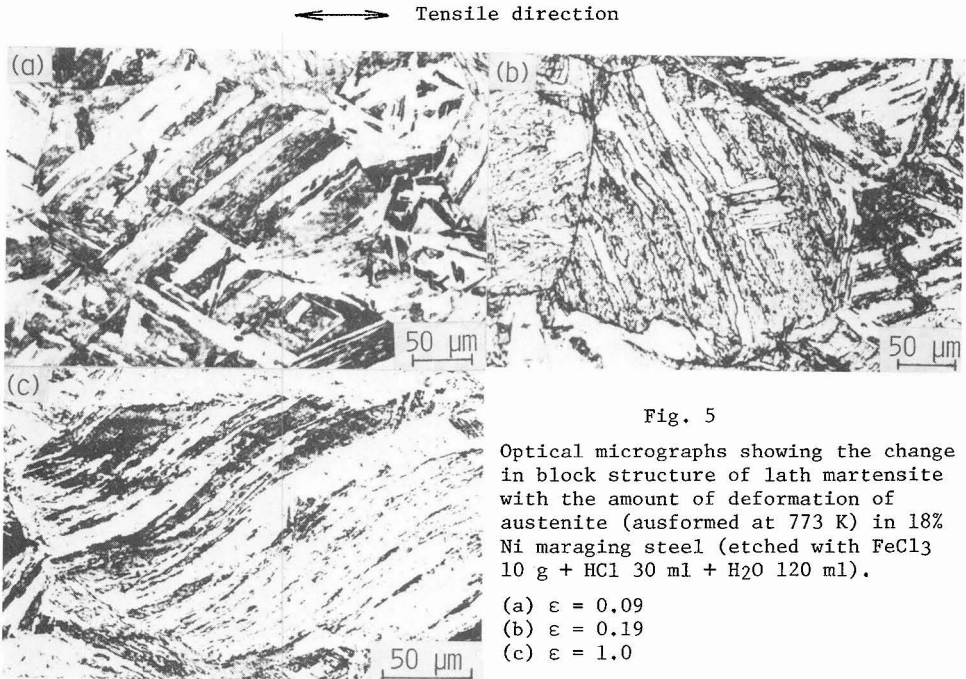


Fig. 5

Optical micrographs showing the change in block structure of lath martensite with the amount of deformation of austenite (ausformed at 773 K) in 18% Ni maraging steel (etched with FeCl_3 10 g + HCl 30 ml + H_2O 120 ml).

- (a) $\epsilon = 0.09$
- (b) $\epsilon = 0.19$
- (c) $\epsilon = 1.0$

blocks are well developed and partition the packet region as with non-ausformed martensite (Fig. 2(a)). However, when specimens are ausformed by $\epsilon = 0.19$, the block boundaries become slightly wavy and their width becomes small as shown in Fig. 5(b). When specimens are heavily ausformed by $\epsilon = 1.0$ (Fig. 5(c)), block boundaries are heavily wavy and blocks are often finely segmented, and their width becomes much smaller. The change in the mean packet size and block width with the amount of ausforming is shown in Fig. 6. With increase in the amount of ausforming, the packet size becomes large but the block width becomes rather small. The block width of ausformed martensite deformed by ϵ more than 0.4 could not be measured because of the fine segmentation of blocks.

Present results indicate that the morphology of ausformed lath martensite is characterized by large packet size and less-developed blocks. The difference of morphology between non-ausformed martensite and ausformed martensite must be connected with the formation process of martensite laths. In the present study, the formation process of martensite laths was observed by applying the Greninger-Troiano heat treatment, in which specimens were cooled at various temperatures T_1 (between M_s and M_f) after austenitizing treatment (for non-ausformed martensite) or after ausforming at 773 K (for ausformed martensite) and heated at 773 K for tempering of martensite

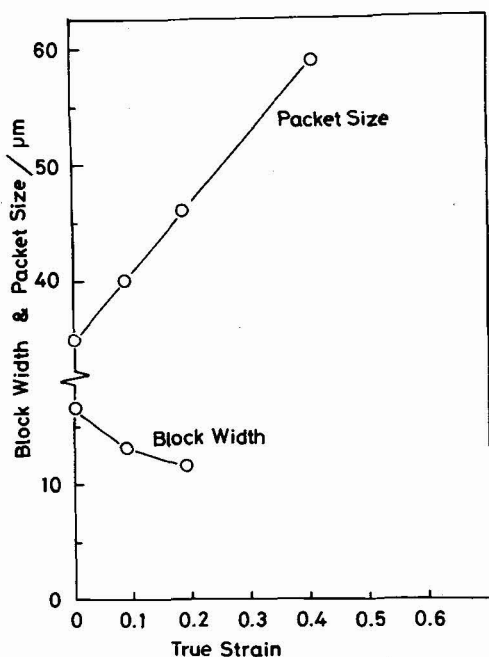


Fig. 6

Changes in the mean packet size and block width of lath martensite with the amount of deformation of austenite (ausformed at 773 K) in 18% Ni maraging steel. The mean initial austenite grain size was 200 μm .

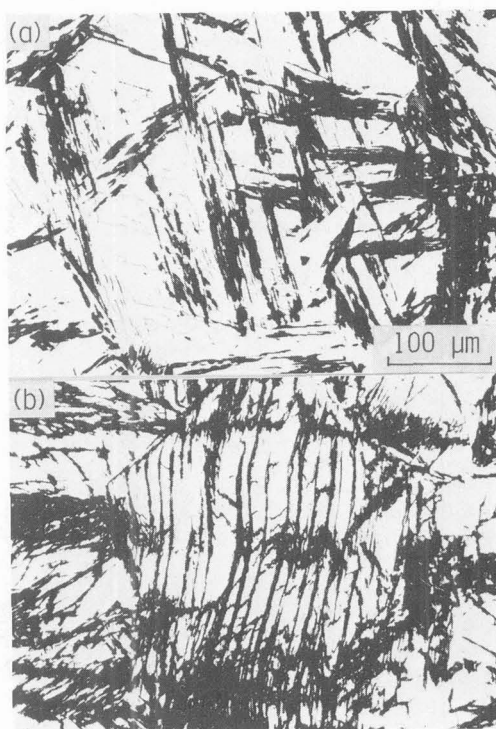


Fig. 7

Optical micrographs showing partially transformed lath martensite in non-ausformed specimen (a) and ausformed specimen (b). Etchant: 20% nital.
 (a) 1473K, 3.6ks \Rightarrow 440K, 10s \Rightarrow 773K, 1.2ks \Rightarrow R.T.
 (b) 1523K, 120s \Rightarrow ausformed at 773K by $\epsilon = 0.20 \Rightarrow$ 458K, 100s \Rightarrow 773K, 1.2ks \Rightarrow R.T.

and then cooled to room temperature. By this treatment, only martensites formed at or above T_1 were darkened by the proper etching and thus these martensites can be easily distinguished. Fig. 7 shows examples of partially transformed martensite structure. In the case of non-ausformed martensite (Fig. 7(a)), parallel laths are formed in cluster and make a banded structure (this may correspond to the block). Parallel banded structures are formed at a certain region of the austenite grain. The regions which consist of parallel banded structures become the packets when the transformation is completed. It is to be noted that four kinds of $\{111\}_\gamma$ habit plane of lath martensite are evenly observed in an austenite grain. On the other hand, when the austenite is deformed before transformation, it is characteristic that one of the four $\{111\}_\gamma$ habit planes is predominantly formed in an austenite grain and thus parallel banded structures extend almost completely inside the austenite grain without any partitioning effect as shown in Fig. 7(b). This restriction of the variants of martensite habit plane might be closely related with the preferential martensite formation on the most active slip plane (one of four $\{111\}_\gamma$ planes) in the deformed austenite. Such a preferential formation of martensite laths with the same habit plane results in the large packet size in an austenite grain. When specimens are heavily deformed, banded structures (and thus the blocks) become wavy because of the bending of slip plane of austenite [11]. The reason why the block width becomes small in ausformed lath martensite is not clear at present. However, it may be considered that the nucleation sites of lath martensite are increased by plastic deformation of austenite and thus many banded structures which consist of clustered laths are finely formed.

IV. Conclusion

The change in the morphology of lath martensite with deformation of austenite (ausforming) has been studied. The main results obtained are as follows.

(1) In the case of conventionally quenched (not-deformed) specimen, an austenite grain contained several packets and each packet was almost completely partitioned by parallel blocks.

(2) The morphology of packets and blocks was markedly changed when martensite was formed from deformed (work-hardened) austenite. The packet size was increased with an increase in the amount of deformation. The block width was decreased with an increase in the amount of deformation (up to true strain $\epsilon \approx 0.2$) and blocks became wavy or finely segmented when austenite was heavily deformed ($\epsilon = 0.4 \sim 1.0$).

(3) It was found that laths with the same habit plane (one of four $\{111\}_\gamma$ habit planes) were preferentially formed in an austenite grain in a deformed specimen, although four $\{111\}_\gamma$ martensite habit planes were almost evenly observed in a conventionally quenched specimen. This restriction of the variants of martensite habit plane in the deformation specimen, which might be closely related with the preferential martensite formation on the most active slip plane (one of four $\{111\}_\gamma$ planes), resulted in the large packet size of lath martensite.

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