Apparent Morphologies of Coarse Plate Martensite

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The apparent morphologies of coarse martensite plates were researched in detail in this paper. It was found that coarse plate martensite may appear as parallel to each other, or packet, or 60° angular, or equilateral triangular, or equilateral hexagonal morphologies. Moreover, traditional ideal believing the orientation of martensite to be a chaotic and random distribution was analyzed, and showing that any martensite will combine regularly together along the habit plane pursuant to a definite pattern, hence the regular distribution of martensitic plates in space should be a spontaneous tendency. Other viewpoints concerning plate martensite were also discussed.

KEY WORDS: coarse plate martensite; plate martensite regular distribution; shape altering factor.

1. Introduction

It is universally accepted that the distribution of martensitic plates is random and cannot be parallel to each other1–3) or not shows packet structure3–5) while lath martensite can merely exhibit packet-like, or equilateral triangular, or equilateral hexagonal structure.6–9) Therefore, the widely prevailing criterion identifying the type of martensite under optical microscope is that the packet or equilateral triangular martensite is lath martensite.1–9) Recently, the authors10–13) have studied in depth on the apparent morphologies of fine plate martensite in medium and high carbon steels, and found that when austenitizing temperature is higher, the chemical composition is homogenized, grains are coarsened and crystal defects are diminished, which in turn reduces the obstruction to directional nucleation and growth of martensite, fine plate martensite will become a regular arrangement, appearing as packet-like or equilateral triangular morphologies. Such martensites in medium and high carbon steels were named as Fibre Martensite10,11) or Packet Plate Martensite by the authors.12,13,23)

If it is verified that martensite coarse plate can also combine regularly together along the habit plane in compliance with a certain geometric figure, traditional idea considering the distribution of plate martensite to be chaotic and random will be completely negated, this will therefore possess an important significance for the veritable realization of martensite microstructure feature as well as the investigation of martensite transformation theory and heat treatment technologies.

An attempt in this paper is made to conclude that coarse plate martensite is also a regular arrangement in space, in terms of many optical and scanning electron micrographs.

2. Experimental Materials

The chemical compositions of the tested steels are shown in Table 1. The specimen dimensions of all steels were of φ10×5 mm. Most of specimens with φ3 mm center hole were carbonized in solid carburizer at 1 200°C for 5–20 h and cooling in furnace, then homogenizing annealing at 1 200°C for 10 h. The hardening medium was oil. Finally, carbon content of specimens was analyzed again. 160CrMnTi steel represents a mean carbon content of 1.60%.

3. Results and Analyses

3.1. Parallel Coarse Plate Martensite

Optical microstructures of three steels quenched from high temperatures are shown in Fig. 1, and many martensite coarse plates appear as parallel to one another in four mi-

Table 1. Chemical compositions of steel tested (wt%).

| Steel  | C     | Mn   | Si   | Cr   | Ni   | W   | Ti   |
|--------|-------|------|------|------|------|-----|------|
| 45     | 0.46  | 0.64 | 0.26 | -    | -    | -   | -    |
| T9     | 0.86  | 0.47 | 0.19 | -    | -    | -   | -    |
| T11    | 1.12  | 0.25 | 0.18 | -    | -    | -   | -    |
| 18CrMnTi | 0.23 | 1.03 | 0.32 | 1.20 | -    | -   | 0.095|
| 20CrNi | 0.20  | 0.42 | 0.19 | 1.68 | 2.70 | -   | -    |
| 30CrMnSi | 0.32 | 1.00 | 1.06 | 0.90 | -    | -   | -    |
| CrWMn  | 1.03  | 1.04 | 0.27 | 1.13 | -    | 1.48| -    |

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crographs. On the basis of reference 3), the as-quenched microstructures are \{225\} plate martensite when carbon content is 0.5–1.4%, and they are \{259\} plate martensite when carbon content is 1.5–2.0%. Thus, the habit plane of martensite is \{225\} \(\alpha\) for steel 90Cr2Ni4 and 110CrMnTi, and it is \{259\} \(\alpha\) for steel 160CrMnTi. Whichever habit plane is, martensite will nucleate and grow on the habit planes parallel to each other, forming parallel coarse plates. Some adjacent plates will combine into one plate, which is shown in Figs. 1(a) and 1(b). The conditions of forming martensite plate parallel to one another are: homogeneous chemical composition of austenite, perfect crystal lattice and few crystal fault.

It is worth noticing that the majority of martensite plates formed, whether coarse or fine, are parallel to one another within a narrow twin range of austenite (see Fig. 1(c)), and many parallel fine martensite plates grow up from side of coarse martensite plate (see Fig. 1(d)). The included angle between fine martensite plates grown (i.e. the branched part) and coarse martensite plate is approximately 130–140°, just equals to the 135° included angle which is that between two blades of numerous butterfly martensites.

3.2. Packet Coarse Plate Martensite

What shown in Fig. 2(a) is quite difficult to be found. It indicated that a lot of coarse martensite plates are parallel to each other and built up packet-like structure. There are at least three clusters composed of parallel martensite plates in the figure. Martensite clusters also built up equilateral triangular frame, as illustrated in Fig. 2(b), the best part of dark clusters are consist of numerous parallel martensite narrow fine plate. Figure 3 is a photograph of a dark cluster in Fig. 2, which is examined with scanning electron microscope at higher magnifications, and it can be seen clearly...
that coarser martensite plates with a visible midrib are parallel to one another.

These micrographs demonstrate sufficiently that if only the condition permits, lots of martensite plates will bring out parallel to each other along same habit plane during martensite transformation, and the packet-like structure formed is a nature law while not a specific phenomenon. Thereby, it is a spontaneous tendency in martensite transformation for martensite plates being parallel to one another and making up packet-like structure. The chief reason of resulting in traditional idea that the nucleation of martensite is individual and random is because chemical composition of austenite is cruelly inhomogeneous after carbide solved and a great deal of crystal faults come into being at lower austenitizing temperature.

3.3. As-equilateral Triangle Coarse Plate Martensite

The packet martensite of steels and alloys may combine into equilateral triangular relief, which was observed by many researchers. But the authors have found that coarse martensite plates also may appear as equilateral triangular morphologies, as shown in Fig. 4 and Fig. 2(b).

It can be explained using Fig. 5 why coarse martensite plates can emerge as equilateral triangular relief. The habit plane \(\{225\}\) of martensite bears two same Miller indices, which create favorable conditions for building up an equilateral triangle. Three planes \(\{225\}\), \(\{252\}\) and \(\{522\}\) in the habit plane \(\{225\}\) are shown in Fig. 5, and their three sides are \(de\), \(ad\) and \(ae\) respectively, which compose an equilateral triangle. That is to say, after forming coarse martensite plates or martensite packet on these three habit planes, the transverse sections of these martensite plate in three habit planes will exhibit an equilateral triangle, if only the observed surface of the specimen is parallel to plane \(ade\).

In this way, \(\{225\}\) martensite plates not only may form packet martensite, but also may build up a regular space structure on the grounds of a definite rule, showing equilateral triangular relief.

No martensite wide plates are observed within \(\{111\}\) plane in Fig. 5, since plane \(ade\) is not a habit plane for \(\{225\}\) martensite, the nucleation and growth of martensite plate is impossible on \(\{111\}\) plane, hence the transverse section of parallel martensite plates formed along \(\{225\}\), or \(\{252\}\), or \(\{522\}\) habit plane can only be watched. It is a direct evidence that martensite narrow plates are parallel to a side of the triangle within an equilateral triangle in Fig. 2(b), especially Fig. 4(a).

Because the space included angle of adjacent plane \(\{225\}\) has five kinds: 30°, 45°, 60°, 75°, 90° and 135°, martensite narrow plates of which the included angle is 30° and 45° all display within an equilateral triangle of Fig. 2(b) and Fig. 4.

Many parallel branches or burr growing out from a side of martensite coarse plate may be yet illustrated using Fig. 5. After forming a coarse martensite plate along the habit plane \(\{522\}\) (plane \(abe\) in Fig. 5), a branch of martensite plate with \(\{225\}\), habit plane may grow out from intersecting line \(ce\) where plane \(\{225\}\) intersects with \(\{522\}\), then a blade with \(\{225\}\) habit plane will appear. The included angle \(\angle acd\) between the blade and the trunk is 135°. This is the reason why many parallel branched blades frequently grow out from a side of martensite coarse plate. The included angle between this blade and its parent usually is that of butterfly martensite (approximately 135°), and sometimes it will be other angles.

The authors have presented that the nature of butterfly martensite is a sort of plate martensite.

3.4. Equilateral Hexagonal Coarse Plate Martensite

It is extremely difficult to obtain Fig. 6(a) in which coarse martensite plates emerge an equilateral hexagonal relief. Beside coarser martensite plate parallel to a side of triangle or forming in zigzagged arrays with an included angle of 60°, the rest is martensite coarse plates appeared as equilateral triangle up which equilateral hexagonal shape is built, the dark contrast area is packet plate martensite.

The geometric analysis for equilateral hexagonal morphologies is shown in Fig. 6(b). The equilateral hexagonal relief is made up of planes \(\{111\}\) appearing as equilateral
triangle in six cubic cells, and it is the dashed line in figure.

3.5. Other Morphologies of Coarse Plate Martensite

The common morphologies of \{259\} martensite is in zigzagged arrays, as indicated in Fig. 7(a), and the included angle between adjacent martensite plates is generally 45° and bearing a midrib, showing up internal twins within some martensite plates, and exhibiting a transverse crack within numerous martensite plates.

In contingent case, the authors have observed a morphology shown in Fig. 7(b), \{259\} martensite appears as a dendritic shape and adjacent dendrites are parallel to each other. It may be concluded from this that the regular distribution of martensitic plates in space should be a natural character.

The included angle between the habit planes \{259\} possesses three kinds: 45°, 90° and 135°. The included angle of coarse martensite plate displayed zigzagged arrays in Fig. 7(a) is 45°, and the included angle between branch and trunk of coarse martensite plate appeared as dendritic relief in Fig. 7(b) is 90°. Figure 7(c) is the space position of plane \{259\} and \{952\}, and Fig. 7(d) is the transverse section of these habit plans on plane xoy, representing that the included angle between two categories of habit plane is 90°. Numerous branches with the habit plane \{259\} grow parallel to one another from the habit plane \{952\} of a trunk.

In as much as the carbon content of \{259\} martensite is very high, more than about 1.5%, its tetragonality and specific volume are so large that the work of nucleation is significantly larger than the work of growth, the formation of martensitic nucleus is thus very difficult. When the degree of super-cooling is smaller, many parallel branched blades usually grow out from one (see Fig. 1(d)) or two (see Fig. 7(b)) sides of martensite coarse plate (trunk), forming a dendritic shape.

\{259\} martensite can not display equilateral triangular and hexagonal morphologies in whole observation. This is mainly discrimination between the apparent morphologies...
of \{225\} and \{259\} martensites. This is due to the results that three Miller indices of \{259\} habit plane are all different. Hereby their habit planes cannot comprise equilateral triangle and hexagonal relief.

It is now generally agreed that all \{259\} martensites bear midribs, while not \{225\} martensite emerges midribs.\(^8,18\) This conclusion cannot be established in the present investigation. Figure 3 and Fig. 8 indicate that some martensite plates of 45 steel (see right part in Fig. 8(a)), T9 steel (see upper part in Fig. 8(b)) and CrWMn steel (Fig. 8(c)) all display midribs. The amount of martensite plate with a midrib increases with an increase in the carbon content, but some \{259\} martensites do not show midribs, as illustrated in Fig. 7(b). Hence, the midrib is not the characteristic of \{259\} martensite.

4. Discussion

1. Above discussion of space distribution of coarse plate martensite is based on ideal condition, namely, homogeneous chemical composition of austenite, perfect crystal lattice, the absence of second phase, etc. In practical case, regular space arrangement of plate martensite will be suppressed or harmed due to the following reasons. Such reasons are termed Shape Altering Factors by the authors.

   (1) Chemical composition: effecting on Ms temperature, the strength of austenite and martensite, austenitic stacking fault energy, the critical resolved shear stress for twinning and slipping, etc.

   (2) The homogeneity of chemical composition: its effect is same as (1) above. In addition, it may vary the type of habit plane, maximal dimension and shape of individual platelet and the combination of plate etc. in micro-regions.

   (3) The tetragonality and specific volume of martensite: altering the type and combinational morphology of martensite, including the angle included between two adjacent plates of martensite.

   (4) Crystal fault: its effect is same as (1) above, beside, also changing the maximal dimension and shape of individual platelet and the combination of martensite.

   (5) Second phase and austenitic twinned plane: modifying the maximal dimension and shape of individual platelet and the combination of martensite.

During conventional heat treatment, because of lower austenitizing temperature, the effect of Shape Altering Factors mentioned above is strengthened, then the distribution of martensite plates on the random observed surface plane of specimen appears as a chaotic morphology. But the space structure of martensite plate is still of a regular arrangement, merely the space scope of regular arrangement of martensite becomes smaller, and the perfect extent of regular arrangement of martensite becomes weaker, so the regular space structure of martensite cannot exhibit on the general observed surface plane of specimen. Certainly, it is also one of the reasons that the optical resolution is lower.

2. The orientation of crystal is examined by X-ray diffraction analysis, electron diffraction analysis and optical interferometer etc., but the results obtained occur frequently inconformity. For example, it is now commonly considered that the habit plane of lath martensite is \{111\}_r\(^8,19\) but later some data determined are \{557\}_r,\(^20\) \{345\}_r\(^21\) and \{213\}_r\(^21\). The authors have specified the concrete habit plane using the identifying procedure of optical microstructure.\(^22\)

The packet martensite containing 0.4–0.9% C is built up of many martensite plates, big and small, parallel to habit plane.\(^10,11,23\) When the observed surface of specimen is parallel to its habit plane \{111\}_r, beside appearing as equilateral triangle as Fig. 2(b), martensite wide plate may be observed within these equilateral triangles, as indicated in Fig. 8(a), and martensite packet is composed of many parallel narrow plates (see right upper corner). If the observed surface of specimen is completely parallel to \{111\}_r, many more martensite wide plates will emerge.\(^23\)

The author in researches have acquired that when the total amount of alloying element is less than 5%, martensitic habit plane is directly related to the carbon content; during C\<0.2%, the habit plan is \{557\}_r; during 0.4–0.9%, that is \{111\}_r; during C=1.0–1.4%, that is \{225\}_r; during C\>1.5%, that is \{259\}_r.\(^22\)

In order to further test and verify that when the total amount of alloying element is less than 5%, whether martensitic habit plane will be vary with the kind and amount of alloying element, seven steels were thus adopted in the present investigation. All the present and other\(^22\) experimental results show that the effect of alloy element on the habit plane is very weak when the total amount of alloying element is less than 5%.
5. Conclusions

(1) Traditional idea considering the orientation of martensite to be a chaotic and random distribution is unilateral. Any martensites will combine regularly together along the habit plane in accordance with a definite geometric figure.

(2) Shape Altering Factors affecting the apparent morphology of martensite are: Chemical composition and its homogeneity, tetragonality and specific volume of martensite, crystal fault, second phase and twinned plane within austenite grains, etc. Such factors can only change the space scope and extent of regular arrangement, but cannot remove the nature of regular arrangement of martensite.

(3) \{225\} and \{259\} martensitic coarse plates all may be parallel to each other, and appear as packet and as the included angle of 45°, 90° and 135°. \{225\} martensite coarse plates may yet display equilateral triangular and equilateral hexagonal relief. Thus the widely prevailing point of regarding the packet or equilateral triangular martensite found under optical microscope as lath martensite is unreasonable.

(4) When observation under scanning electron microscope, packet-like \{225\} martensite may bear a visible midrib, and some \{259\} martensite may has not a midrib. Thereby it is unsuitable to regard martensite with a midrib as \{259\} martensite.

(5) Based on theoretical analyses and practical observation, \{225\} martensite may exhibit equilateral triangular and hexagonal morphologies, while \{259\} martensite cannot emerge such morphologies. Hence, this may become a new criterion identifying these two plate martensites under optical microscope.

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