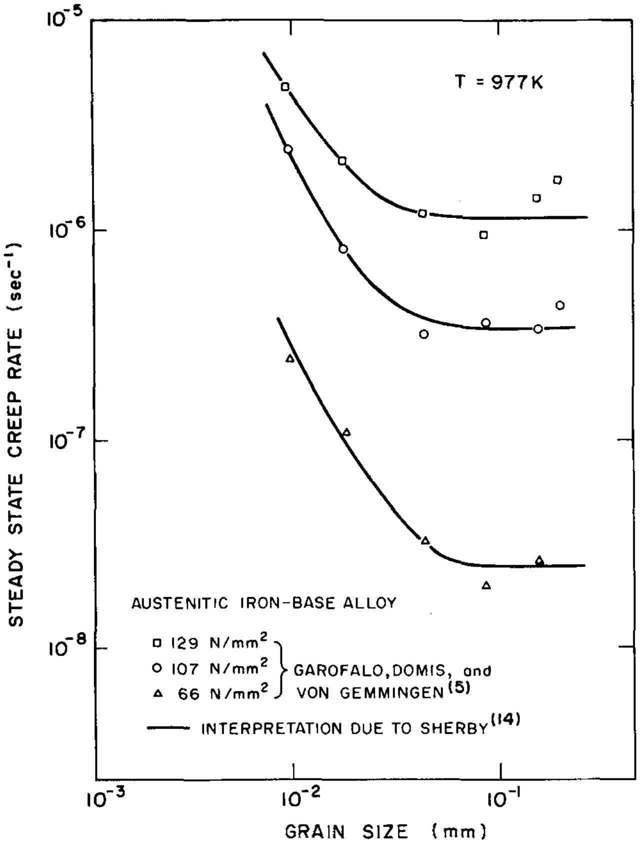


Fig. 3—Grain size dependence of steady state strain rate for an austenitic iron-base alloy tested at 997 K showing the effect of stress on the observed behavior. (Garofalo, Domis, and von Gemmingen[5]).

in grain size for these data as owing to the contributions of Coble creep. However, since the activation energy for creep was independent of grain size and greater than $Q_{gbd}$ and since the stress dependence for creep at the smallest grain size investigated was much greater than 1, the increase in strain rate cannot be due entirely to Coble creep and must be controlled in part by the effects of accommodated grain boundary sliding. It should be noted that it is impossible to compare these data directly to Eq. [7] because there is no independent expression for $\dot{\epsilon}_{gbs}$ in this alloy.

Therefore, it is concluded that the increase in strain rate with decrease in grain size is due mainly to the contributions of accommodated grain boundary sliding to the total strain, with contributions of diffusional creep important only for very small grain sizes. Additionally, it is shown how measurements of the stress dependence and activation energy for creep as a function of grain size can be used to aid in interpretation of the observed grain size dependence of the steady state strain rate. Finally, the temperature at which the investigation of the grain size dependence of the steady state strain rate is performed will control the relative magnitudes of $\dot{\epsilon}_g$ and $\dot{\epsilon}_{gbs}$ and, thus, will control the stress and temperature dependence of a portion of the observed data.

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# Observation of Stacked Layers of Twins and ϵ Martensite in a Deformed Austenitic Stainless Steel

L. REMY AND A. PINEAU

The twinning of fcc austenite and the fcc → hcp martensitic transformation are crystallographically very similar. In austenite, twins and hcp martensite ($\epsilon$) can be formed respectively by the superposition of stacking faults either on every (111) plane or every second (111) plane. Several mechanisms have been proposed for the formation of twins and $\epsilon$ martensite. Among them, the pole mechanism is well known (see Ref. 1 for twinning and Refs. 2 to 4 for the $\epsilon$ phase). In this short communication, we would like to report the results of an observation which does not support the pole mechanism.

The $E_d$ temperature was previously determined in stainless type compositions and Co-Ni-Cr-Mo alloys.[5,6] $E_d$ is defined as the maximum temperature at which the fcc → hcp phase transformation can be induced by plastic deformation in polycrystalline tensile specimens before necking. Just below the $E_d$ temperature, composite bands formed by stacked layers of $\epsilon$ platelets and twins were observed in these alloys.

Fig. 1 shows such a band in a Fe-18 Cr-7 Ni-0, 18 C stainless steel and the accurate determination of the different phases in the band. In this alloy, the temperature $M_s$ at which the spontaneous $\gamma \rightarrow \alpha'$ phase transformation takes place is 190 K; the temperature $E_s$ at which the spontaneous $\gamma \rightarrow \epsilon$ martensite transformation occurs is $\geqslant 300$ K.[7] The temperatures below which the $\gamma \rightarrow \alpha'$ and $\gamma \rightarrow \epsilon$ transformations are induced by plastic deformation are $M_d$ ($\gamma \rightarrow \alpha'$) $\simeq$ 360 K and $E_d$ ($\gamma \rightarrow \epsilon$) $\simeq$ 420 K respectively. This steel was deformed ($\epsilon$ = 20 pct) at 380 K, *i.e.*, between $M_d$ and $E_d$. The transfor-

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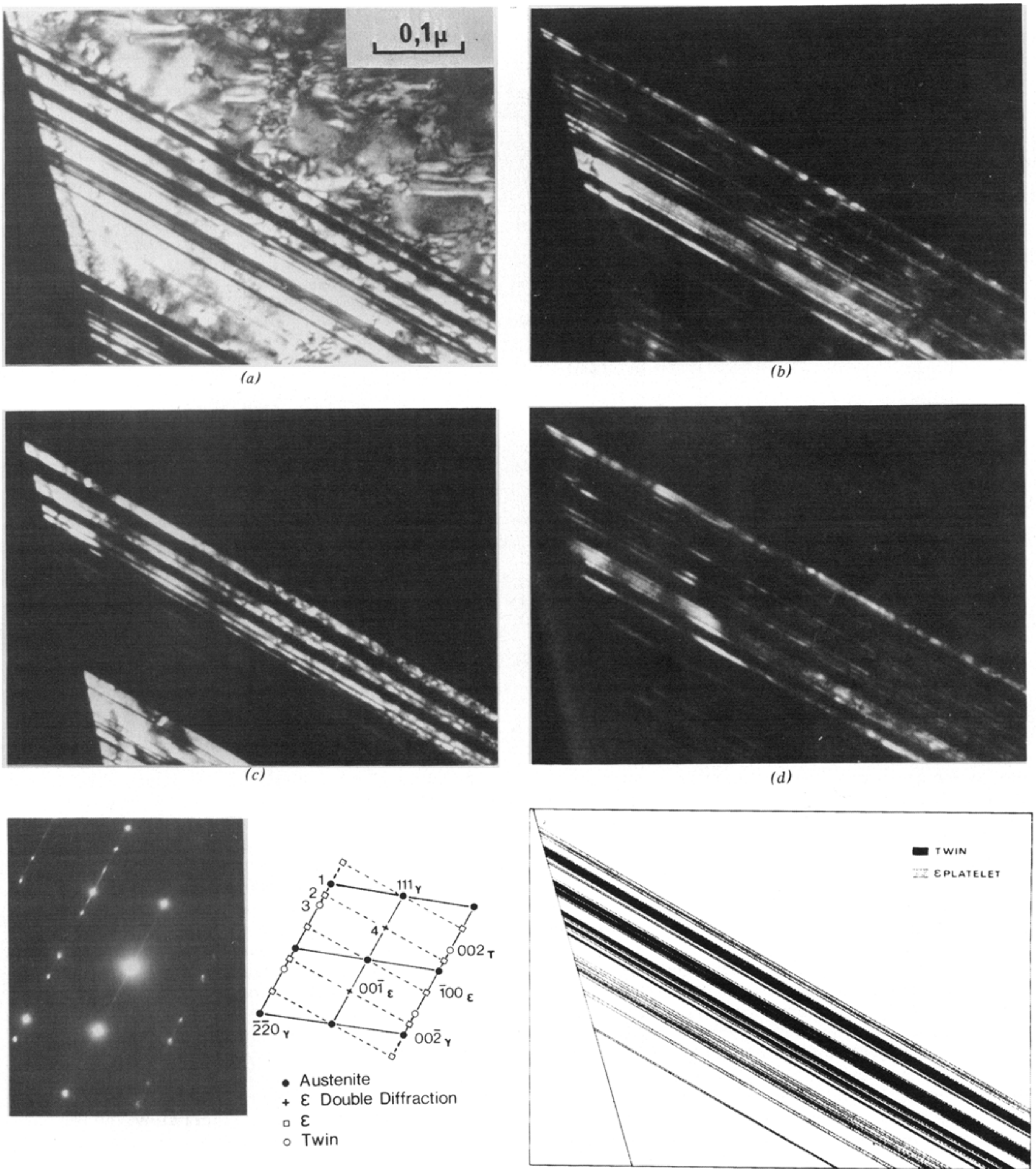


Fig. 1—Electron microscope analysis of a band of twins and ε-platelets: a), b), c), d) dark field images with diffraction spots 1, 2, 3, 4; e) diffraction pattern (electron beam parallel to $[1\bar{1}0]_{\gamma}$); f) schematic drawing of the fine structure of the band.

mation band and its diffraction pattern are shown in Fig. 1(*a*) (dark field image of the matrix) and Fig. 1(*e*). In Fig. 1(*e*), the diffraction patterns of the austenite, the twins and ε martensite are identified. Dark field images obtained from diffraction spots 2, 3 and 4 are shown respectively in Fig. 1(*b*), (*c*), and (*d*). They differentiate between twins and ε platelets. Fig. 1(*f*) is a schematic drawing of the different phases and shows unambiguously that the band observed in Fig. 1(*a*) is formed by the stacking of platelets of matrix, twins and ε martensite, with intermediate regions of alternate twins and ε platelets.

It is doubtful that such a composite band could result from pole mechanisms. Different pole dislocations would be necessary for the formation of twins and $\epsilon$ martensite. The density of these different poles in a thin band such as observed would have to be high. Moreover, the arrangement of these poles would have to be such that the twins and $\epsilon$ platelets could be stacked upon each other. The authors feel that these composite structures could be more easily explained by intersection or cross-slip mechanisms such as those proposed by Cohen and Weertman for twinning[8] and Fujita and Ueda for $\epsilon$ martensite.[9]

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# A Geometrical Construction Method of Determining Orientation of Grain Surfaces from {111} Traces

H. S. FONG

{111} traces occur frequently on surfaces of metal grains of cubic lattice structure as twin boundaries, slip lines, Widmanstatten structure, and so forth, and serve as a ready means of identifying the crystallographic orientation of the grain surfaces. This may be done by calculation (preferably with computers as the mathematical equations are complex) derived from the treatment of Drazin and Otte[1] or of Fong;[2] or reference may be made to previously prepared charts or tables such as those of Takeuchi, Honma, and Ikeda[3] and Drazin and Otte.[4] If computers, charts, and tables are not available, one may adopt the manual graphic techniques described by Barrett[5] and Reed-Hill and Baldwin.[6] Both these techniques involve a trial and error procedure and will not generally be regarded to be easy. In each step of the trial and error process, which consists of a rotation of poles about a Wulff net axis, attention has to be paid to the dissimilar movements of four poles along generally different latitude lines of the Wulff net. Judgment has subsequently to be made as to whether each of these poles has moved to certain correct locations. The purpose of this paper is to present a geometrical construction method which will be found less taxing to apply than the methods described by Barrett and Reed-Hill and Baldwin. This procedure demands in each step, again of a trial and error process, only the readily made judgment of whether a certain easily identified length $BA_0$ is equal to a certain length $c$ or not.

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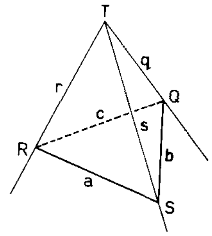


Fig. 1—The grain surface $QRS$ with traces $QR$, $RS$, and $SQ$ produced by {111} planes $RQT$, $SRT$, and $QST$.

Three {111} traces of different directions on a grain surface may be imagined to form a triangle $QRS$ of sides $a$, $b$, and $c$ in length as shown in Fig. 1. This figure also shows the {111} planes $QST$, $SRT$, and $RQT$ which have produced these traces. The orientation of the grain surface $QRS$ will be given by the lengths $q$, $s$, and $r$ of $QT$, $ST$, and $RT$.

There are four arrangements of the {111} planes which form the pyramid $QRST$ in Fig. 1 which we shall refer to as:

Arrangement I: $\angle QTS$, $\angle STR$, and $\angle RTQ$ are all 60°
Arrangement II: $\angle QTS = 60°$; $\angle STR = \angle RTQ = 120°$
Arrangement III: $\angle RTQ = 60°$; $\angle QTS = \angle STR = 120°$
Arrangement IV: $\angle STR = 60°$; $\angle QTS = \angle RTQ = 120°$

The geometrical construction method consists firstly of constructing two circles of radii $a$ and $b$ with common center $C$ and line $XX'$ through $C$ as illustrated in Fig. 2($a$) where $a$ has been taken to be greater than $b$. Consider now a line $YY'$ at 60° to $XX'$ and intersecting $XX'$, the smaller circle, and the larger circle at $P$, $A$, and $B$ respectively. Consider also a point $A_0$ on $XX'$ such that $\angle A_0AP = 60°$ so that $A_0P = AP$. Clearly the triangles $ACP$, and $CBP$, and $BA_0P$ will form a pyramid $A_0BCP$ if side $CP$ of the triangle $ACP$ is joined to side $CP$ of triangle $CBP$, side $BP$ of triangle $CBP$ is joined to side $BP$ of triangle $BA_0P$, and side $A_0P$ of triangle $BA_0P$ is joined to side $AP$ of triangle $ACP$. This pyramid will be like $QRST$ in Fig. 1 for Arrangement I of {111} planes (with corners $A_0$, $B$, $C$, and $P$ corresponding to $Q$, $R$, $S$, and $T$ respectively) except that the trace triangle $A_0BC$ in this case will have side lengths $a$, $b$, and $BA_0$ (instead of $c$). The length $BA_0$ will depend on the location of $A$ on the smaller circle. By locating $A$ at $M$ initially and then letting $A$ progress gradually towards $L$ ($L$ is given by $\angle XCL = 60°$) $BA_0$ will assume all possible lengths consistent with the trace triangle $A_0BC$ having two other sides of lengths $a$ and $b$. If a point is found for $A$ on the smaller circle for which $BA_0 = c$ then the associated lengths $A_0P$, $CP$, and $BP$ should give $q$, $s$, and $r$ in Fig. 1.

Thus having constructed the circles of radii $a$ and $b$ one proceeds to obtain orientations under Arrangement I by finding the location or locations of the line $YY'$ for which $BA_0 = c$. This can be done quickly in simple ways using for example a 60° triangle and a ruler to help determine the successive positions of $P$, $A$, $B$, and $A_0$ and a divider to check whether $BA_0 = c$. A very satisfactory method is to construct the circles on tracing paper and then to superimpose this on another paper on which have been ruled two sets of parallel lines 60° to each other. One set of lines serves to help the visual location of