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FACTORS DETERMINING TWINNING IN MARTENSITES

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In a recent investigation\(^{(1)}\) of substructures and strength of ausformed steels, it was found that the extent of twinning in martensite decreased with increasing amounts of deformation of the metastable austenite prior to transformation to martensite. It was shown that the precipitation of carbides in austenite occurred after a critical amount of deformation. Since the extent of twinning in ausformed martensites was extremely low, twinning was not regarded as a strengthening parameter. The strength of ausformed steels was thus explained on the basis of dislocation density and precipitation. Here the factors influencing the presence or absence of transformation twinning will be considered.

Transmission electron microscopy investigations of the transformation substructure in Fe-C alloys by Kelly and Nutting\(^{(2)}\) and in Fe-Ni alloys by Speich and Swann,\(^{(3)}\) showed that the amount of transformation twinning increased with solute concentration. The change in transformation substructure from dislocations to twinning is not a sharp one. The steels we investigated were based on a composition Fe-28\%Ni-0.3\%C with or without Cr, Mo, V (see Table I) so that in all these alloys, after conventional heat treatment the martensites were twinned.

Table I

<table>
<thead>
<tr>
<th>Heat No.</th>
<th>%C</th>
<th>%Ni</th>
<th>% Alloying Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>1410</td>
<td>0.3</td>
<td>27.94</td>
<td>---</td>
</tr>
<tr>
<td>1398</td>
<td>0.28</td>
<td>24.92</td>
<td>4.50 Mo</td>
</tr>
<tr>
<td>1541</td>
<td>0.32</td>
<td>16.40</td>
<td>4.72 Cr</td>
</tr>
<tr>
<td>1402</td>
<td>0.29</td>
<td>24.73</td>
<td>1.85 V</td>
</tr>
</tbody>
</table>
Two reasons have been proposed for the occurrence of twinned martensite in steels containing C or Ni.

a. $M_s$ Temperature

Since both C and Ni lower the $M_s$ temperature and promote twinning, it has been suggested$^2$ that low $M_s$ temperatures favor twinned martensites (for review see ref. 4). This is in agreement with results on both F.C.C. (Cu for example$^5$) and B.C.C. (iron for example$^6$) metals where plastic deformation takes place by twinning at low temperatures, suggesting that at these temperatures the critical resolved shear stress for twinning is lower than that for slip. On this basis low $M_s$ temperatures would be expected to favor transformation twinning in martensites. Thus all alloying elements which lower $M_s$ temperatures should favor twinning.

b. Stacking Fault Energy

Little is known about the influence of stacking fault energy on transformation substructures, although Kelly and Nutting$^7$ postulated that twinning in martensite is favored by austenites of high stacking fault energy. This result agrees qualitatively with the observation of twinning in Fe-Ni steels by Speich and Swann,$^2$ as Ni is known$^8,9,10$ to raise the stacking fault energy of austenite. This effect of stacking fault energy is opposite to what is found for mechanical twinning in F.C.C. metals, where the lower the stacking fault energy the higher is the tendency for deformation by twinning.$^5,11$ This would suggest that as far as transformation twinning is concerned the effect of solutes on $M_s$ temperatures is more important than their effect on stacking fault energy.

It has been clearly established from our work on ausformed steels$^1$. 
that increasing deformation of metastable austenite favors precipitation and reduces the extent of transformation twinning. The deformation of austenite and the removal of alloying elements from solid solution by the formation of precipitates both raise the $M_s$ temperature of steels. On the other hand the solutes present in the present steels are known to lower the stacking fault energy\(^{(8,9,10,12)}\) and hence their depletion from solid solution as carbide precipitates should raise the stacking fault energy of austenite. According to Kelly and Nutting\(^{(7)}\) this should favor twinning. However, since this is not the case it further suggests that $M_s$ temperature rather than stacking fault energy of austenites is the important factor in determining twinning.

It is also worth noting that transformation twinning occurs in body centered martensites and since the body centered structures in general have high stacking fault energies, the latter parameter cannot be very important in determining twinning in steels which undergo the martensitic transformation. Also, there may be no direct correlation between stacking fault energy of austenite and twinning in martensite. No observations of faulted martensites have been reported for steels, but in Cu-Al alloys of low stacking fault energy, the lattice invariant shear in martensite occurs by faulting.\(^{(13)}\)

These considerations strongly suggest that the $M_s$ temperature determines the occurrence of transformation twinning in martensitic structures, rather than the stacking fault energy of austenites.

\*No data are available on the effect of $V$ on stacking fault energy of austenites, but observations on the effect of other solutes suggest that $V$ also lowers the stacking fault energy.
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REFERENCES

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