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Effect of rolling conditions on the structure and shape memory properties in Fe-Mn-Si alloys

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Abstract – Lattice defects play an important role in controlling the $\gamma \rightarrow \varepsilon$ martensitic transformation in shape memory ferrous alloys. This work focuses on the relation between various rolling and annealing processes, the resulting microstructure, and strain recovery of two Fe-Mn-Si alloys with different stacking fault energy. Rolling experiments carried out at temperatures in the 20ºC to 1000ºC range, give rise to quite different microstructures varying from a high dislocation density to a structure containing only a few isolated dislocations. In addition, annealing temperature has a very important influence not only on the dislocation arrays but also on the stacking faults remaining in the austenite, whose density depends on the SFE value for the alloy. In the frame of the processing parameters selected for this work (i.e. roll speed and degree of deformation values) rolling at intermediate temperatures and annealing at temperatures of 600ºC seems to be the most appropriate method to obtain a microstructure favorable for a nearly full degree of shape recovery.

After an initial rolling stage at 1000ºC to a thickness of 1,7 mm, a group of Fe-30Mn-4Si (30Mn) sheets were further rolled to 1 mm at different temperatures, and then annealed between 600ºC and 1000ºC. TEM observations of samples with a different thermomechanical history showed marked microstructural differences. Among the observed defects, stacking faults, nuclei of ε martensite, and dislocations arrays, which affect the movement of partials dislocations and the yield stress of the austenite, appear to be quite determinant on the shape memory properties. The presence of twining and some martensite plates in the matrix, as well as the shape and final size of the grains are also affected by the thermomechanical process. The figures below display microstructural features for the different conditions studied. Subsequent tensile and bending tests demonstrate that sheets rolled at 600ºC and annealed at 650ºC reach the higher degree of shape recovery, although it was only of about 55% for the 30Mn alloy. On the other hand, in similar experiments performed with sheets of a more complex alloy, Fe-15Mn-5Si-9Cr-5Ni (15Mn), a larger density of stacking faults is introduced in the austenite matrix. The stacking fault energy is in fact lower for this composition, so that, perfect dislocations can easily split into partials when annealing is carried out at the recovery temperature. The simple unidirectional rolling route leads to optimum results: the 15Mn sheets processed in this way at 800ºC and annealed at 600ºC show a 100% strain recovery after bending deformation and heating above the austenite full formed temperature A_f.

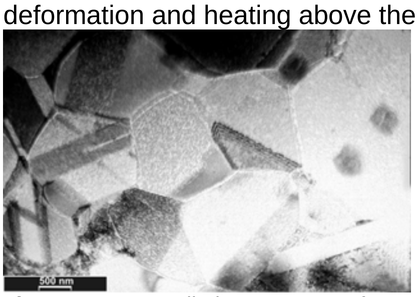

Figure 1: 30Mn rolled at 20ºC transforms completely to martensite; annealed at 650ºC retransforms to austenite with a grain size of about 2 μm. Some dislocation arrays are observed, and stacking faults in many directions are stopped by grain boundaries.

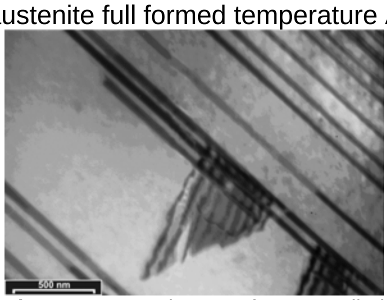

Figure 2: TEM image of 30Mn rolled at 20ºC and annealed at 1000ºC: dislocations are removed. Some martensite plates and stacking faults are observed in broad grains.

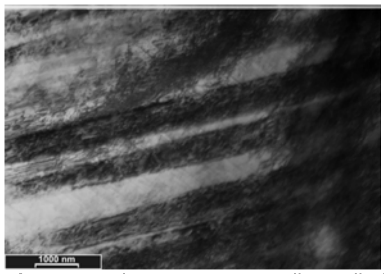

Figure 3: The same 30Mn alloy rolled at 600ºC and annealed at 650ºC shows dislocation bands and low dense dislocation arrays between the bands.

Figure 4: 30Mn alloy rolled at 1000ºC shows a large density of martensite plates which form on cooling to low temperatures. These plates play a negative role on the shape recovery.

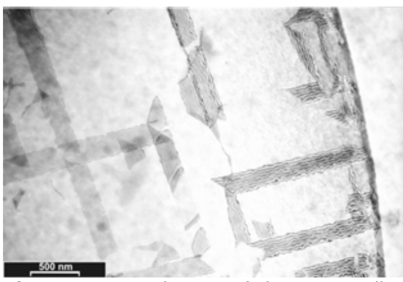

Figure 5: TEM image of the 15Mn alloy, unidirectionally rolled at 800ºC and annealed at 600ºC. It shows stacking faults aligned in two directions.

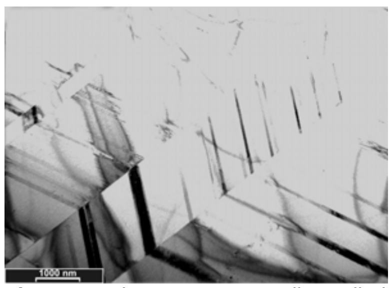

Figure 6: The same 15Mn alloy rolled at 20ºC and annealed at 1000ºC. Complete recrystalization leads to dislocations annihilation in austenite grains. Stacking faults aligned in different directions ends at grain and twin boundaries.