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A b s t r a c t

Title	Phase Transformations and Mechanisms of hardening by annealing in Austenitic Stainless Steels deformed by High Pressure Torsion

(800 words)

Severe plastic deformation (SPD) techniques represent one of the most effective ways of producing ultrafine-grained structures in metallic materials, which showcase a wide range of improved mechanical and physical properties when compared to their polycrystalline counterparts. High pressure torsion (HPT) is a well-known procedure to obtain nano and submicrometer grained microstructures in bulk materials.

To study the effect of large strains and strain rate on the phase transformation of austenitic stainless steel SUS 304 and SUS316L, deformation by high pressure torsion (HPT) was performed. The strain was given up to 10 revolutions (which correspond to equivalent strain of 300 at the edge of disk specimen) at rotation speeds of 0.2 and 5 rpm under a compressive pressure of 5 GPa at room temperature. It was found that the strain induced transformation (SIT) of both forward ($\gamma \rightarrow \alpha'$) and reverse ($\alpha' \rightarrow \gamma$) occur during severe plastic deformation depending on deformation condition. For the low strain rate (0.2 rpm), the volume fraction of γ decreased rapidly in the early stage of HPT and100% of α' formed after 0.5 turns and then almost no change thereafter. Using strain rate (5 rpm), α' volume fraction increased to 80% in the early stages of deformation and decreased as HPT progressed. The decrease in α' volume fraction with strain was attributed to temperature rise during deformation which results in reverse $\alpha' \rightarrow \gamma$ transformation.

This study also investigated annealing behavior of ultra-fine grained austenitic stainless steel containing 100% deformation induced α' and also 100% γ and its effects on mechanical properties. For SUS304, a peak in hardness, electrical resistivity and saturation magnetization was observed when samples were annealed at 400°C. Atom probe tomography showed that on annealing deformed samples containing 100 α' for 1 h, elemental segregation occurred along grain boundaries. The observed segregation was associated with an increase in hardness and electrical resistivity while the increase in saturation magnetization is due to strain relaxation. On annealing for temperatures higher than 500°C, there was a decrease in the 3 properties and this was attributed to reverse $\alpha' \rightarrow \gamma$ transformation. On annealing for 500h the precipitation of G phase, a complex

silicide of general formula $Mn_{15}Ni_{48}Si_{33}Fe_{2}Cr_{2}$, was observed by both HRTEM and atom probe tomography. The composition of the precipitate was observed to vary with annealing time. It is confirmed that the observed early stage hardening on annealing is due to elemental segregation to grain boundaries while the late stage hardening is caused by grain G-phase precipitation. A high deformation level imparted by HPT generates high dislocation density and is an important criterion in G-phase formation in SUS304. This is the first observation of G phase precipitation in the deformation induced martensite of SUS304. The precipitation of g-phase was associated with severe embrittlement of the alloy as observed from tensile tests.

No precipitation was observed on annealing cold worked SUS316L and the degree of hardening by annealing was significantly lower than that observed in SUS304. However for SUS316L, pure nano-crystalline (NC) γ can be obtained by HPT at 5rpm for 10 turns. Hv and Yield Strength (YS, 0.2% offset) increased from 1.4GPa and 280MPa of the coarse grained (CG) sample to 4.9GPa and 1700MPa in the as HPTed state respectively. Post-deformation heat treatment doesn't arouse phase transformation but caused Hv and YS variation. Results show that Hv and YS increases with annealing temperature to reach peak hardness of 5.7GPa and 2230MPa at 500°C for 1hr. Annealing at temperatures higher than 500°C resulted in a continuous decline in Hv and YS values. Although elongation was decreased to a value of 16%, it is still in a useful range for this material. The combination of YS (or UTS) and elongation is the best ever reported in the literature.