SAND2016-6683C

Flowforming of Austenitic Stainless Steel

Background: Flowforming involves deforming a material between spinning rollers and a spinning mandrel and workpiece. The rollers advance axially along the length of the mandrel while spinning. The tube wall thickness decreases and the tube length increases during processing; the mandrel sets the internal diameter. Deformation is mainly in the axial direction but also circumferentially (and radially) resulting in a slight spiral pattern. Very high strength can be achieved from cold deformation with highly elongated grains.

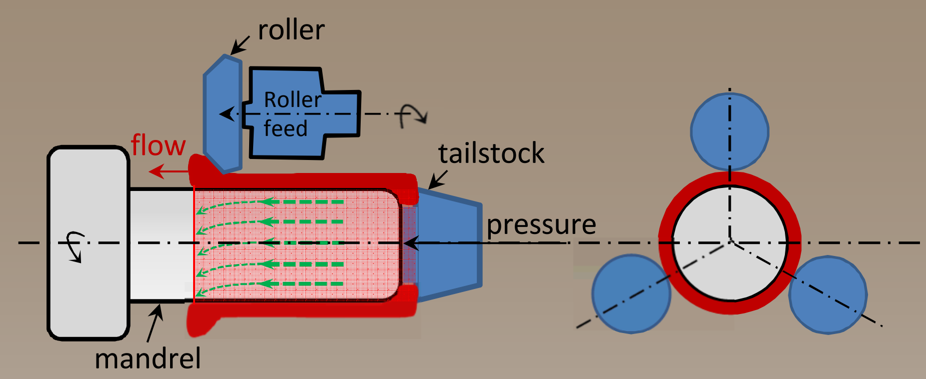


Figure 1. Forward flowforming. Green lines ~ material flow.[1]

Etchant, all micrographs: 60% Nitric/40% H_20 electrolytic

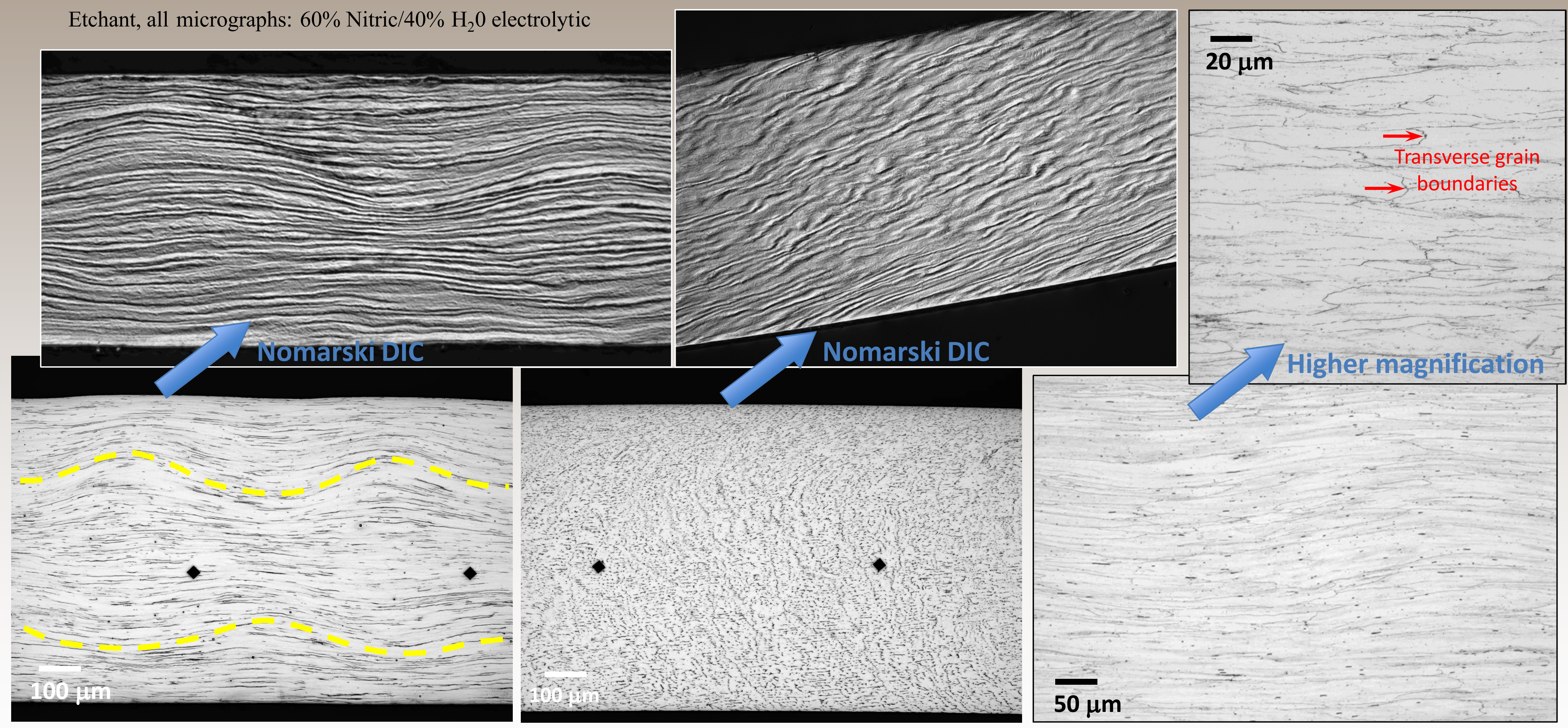


Figure 1. Flowformed 304L tube microstructure. Vickers indents indicate high hardness

Figure 2. Transverse views, as-flowformed

Figure 3. Higher magnification, as-flowformed

As-flowformed:

Flowformed 304L stainless steel tube microstructures are shown in Figs. 1-3. In addition to highly deformed grains in the longitudinal direction, the microstructure exhibits a wave-like pattern, which is accentuated by differential interference contrast (Nomarski DIC) imaging. The wave pattern correlates to roller spin and axial feed; a single wave produced during each revolution. Observed wavelengths varied with initial preform thickness and wall reduction, indicating different parameters used by the vendor. In the transverse view, a complex pattern is observed -- a section through a spiral pattern of material deformed in the axial and circumferential (and radial) directions simultaneously.

Heat Treated: Heat treatments were applied to investigate the range of properties obtainable after the flowform cold-working process. Experiments included 600, 700, 800, and 850˚C for up to 10 hours. At 700°C for 30 minutes, Fig. 4, partial annealing has occurred. Fine-scale (~2 micron grain size) equiaxed recrystallized grains are present and pockets of unrecrystallized grains are found. The material is estimated to be 50% recrystallized. At 800˚C, full recrystallization and some grain growth has taken place, Fig. 5. The only remaining evidence of flowforming is the wave-like pattern of MnS stringers in the longitudinal view at low magnification. Note, this etchant does not show twins.

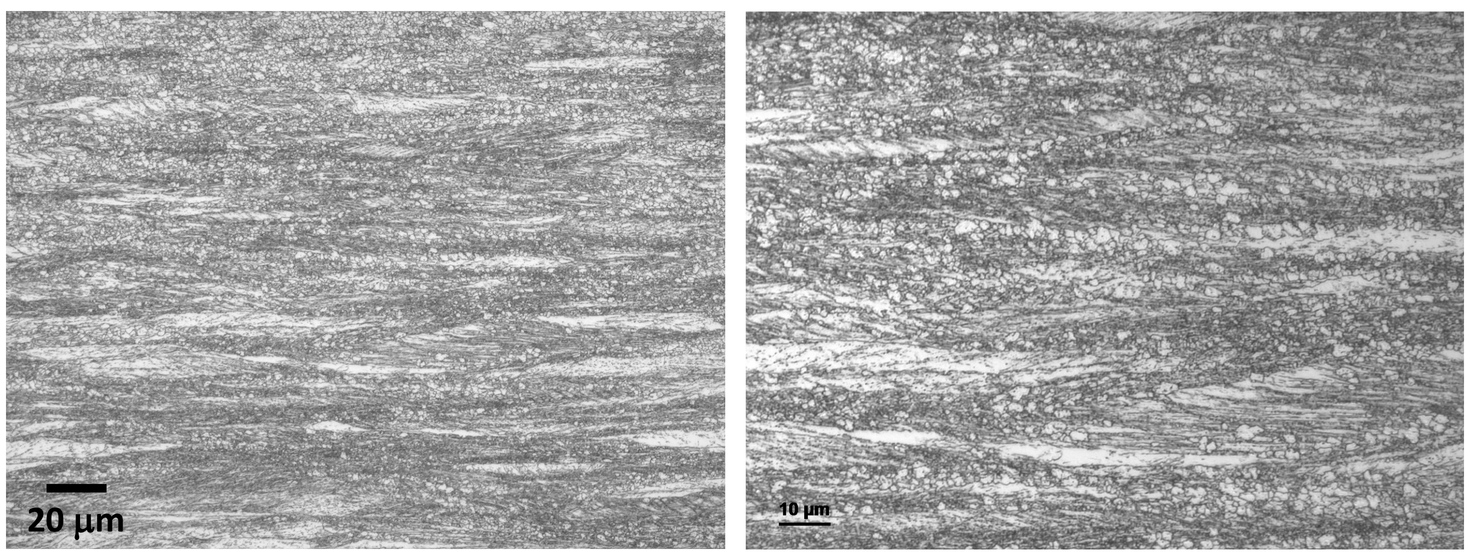


Figure 4. Post-flowform anneal 700˚C/30 min, longituidnal view, ~50% recrystallized

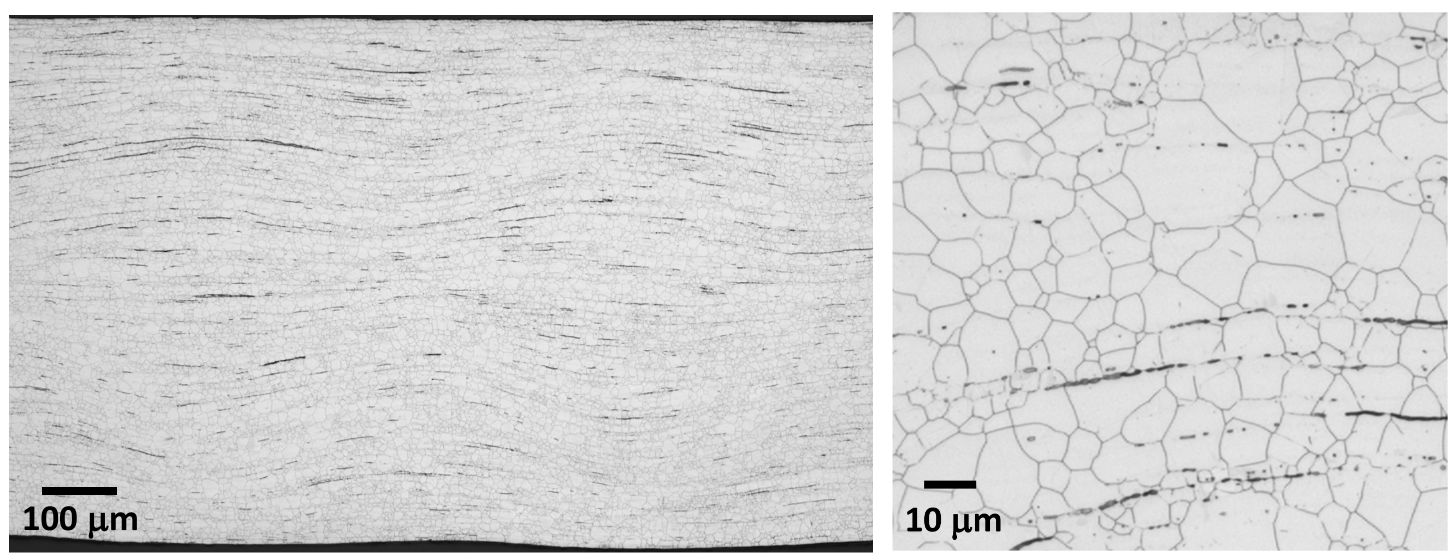
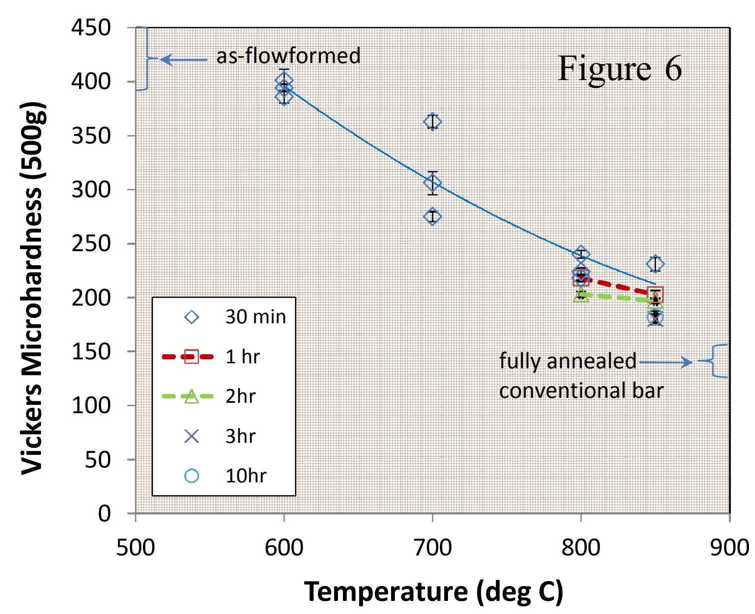


Figure 5. Post-flowform anneal 800˚C/2hr, longitudinal view

Microhardness: Microhardness measurements were used to determine the effects of flowforming and post-flowform heat treatment on the mechanical properties of 304L SS, Fig.6. At 600°C, almost no change in hardness is observed compared to the as-flowformed condition. At 700°C, the hardness decreases and more sample-to-sample scatter is evident due to partial recrystallization (mixed microstructure). More significant reductions in hardness are obtained at 800 and 850°C, although full annealing comparable to conventional tube material is not yet achieved at these temperatures. The results show that a broad range of strength and ductility can be obtained with post-flowform annealing.



[Ref. 1] M. Sivanandini et al., Int. J. Scientific & Engineering Research, Vol. 3, No. 5, 2012, pp 1-11.