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The effect of grain size on the mechanical response of a metastable austenitic stainless steel

C.W. Sinclair[1], D. Marechal[2] and J.D. Mithieux[3]

[1] *Department of Materials Engineering, The University of British Columbia, Vancouver, V6T 1Z4, Canada*
[2] *Département DuMAS de I2M École Nationale Supérieure d'Arts et Métiers, Esplanade des Arts et Métiers, 33405 Talence Cedex, France*
[3] *APERAM, Centre de Recherche, BP. 15, 62330 Isbergues, France*

Abstract. The combination of high environmental resistance and excellent strength, elongation and energy absorption make austenitic stainless steels potentially attractive for transportation applications. In the case of metastable grades that undergo a strain induced martensitic transformation it is possible to significantly change the mechanical properties simply by changing the austenite grain size. Predicting such behaviour using physically based models is, however, extremely challenging. Here, some recent work on the coupling between grain size and mechanical response will be presented for a metastable AISI 301 LN stainless steel. Successes and continuing challenges will be highlighted.

MICROSTRUCTURE OBSERVATION

Stainless steels that undergo a strain induced martensitic transformation offer an impressive combination of mechanical and physical properties compared to carbon steels. Beyond the issue of cost, another weakness of such stainless steels is in the area of formability (Schmitt, 2002). A significant challenge with such materials is to predict accurately the behaviour of these steels using physically-based models. This gap limits the ability of materials engineers to be able to development new solutions to improve formability and alloy to reduce cost.

One simple way of significantly manipulating the mechanical response, and consequently formability, of metastable austenitic stainless steels is through grain size refinement. In a material such as a 301 LN stainless steel it is possible, through controlled thermomechanical processing to achieve fully recrystallized microstructures with a grain size as small as 0.5 μm (Fig. 1).

Upon mechanical testing this alloy is seen to progressively transform from a fully austenitic microstructure to a nearly fully α'-martensite microstructure (Marechal 2011). The sequence and kinetics of this transformation are, however, seen to be grain size dependent. It is seen that the transformation kinetics are non-monotonic with grain size, a grain size of ∼1 μm showing the lowest rate of transformation. Closer inspection shows that in the case of the finest grain sizes the transformation takes place directly from austenite to α'-martensite whereas in the coarse grained material the transformation more commonly proceeds by the route austenite to ε-martensite to α'-martensite (Fig. 2).

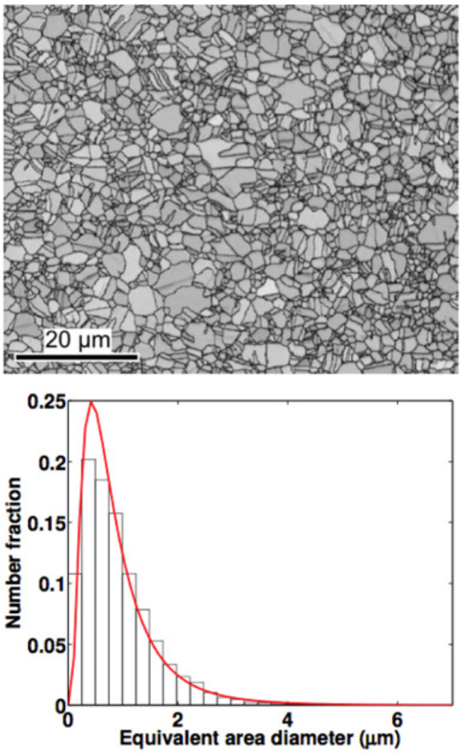
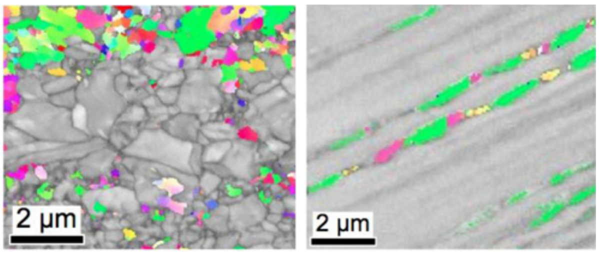


Figure 1. Band contrast EBSD map and corresponding equal area diameter grain size distribution showing a material processed to have a 0.9 μm grain size.

GRAIN SIZE AND TENSILE RESPONSE

Figure 3 (Marechal 2012) illustrates the tensile response of the 301 LN alloy as a function of the initial grain size. Knowing the rate of martensitic transformation, one can develop a simple *dynamic* composite model capable of predicting the overall mechanical response of a material comprised of a certain fraction of austenite and α'-martensite. The important consideration here is that each new nuclei of α'-martensite formed on straining sees a different history and is at a different stage of its work hardening response. A simple averaging procedure can be developed, however, which allows for a closed form prediction of the average response of the α'-martensite



(a) (b)

Figure 2. 301 LN stainless steel after plastic strain showing the presence of α'-martensite (colour) in austenite (grey). a) Austenite grain size of 0.5 μm with nucleation of α'-martensite on austenite grain boundaries and b) austenite grain size of 28 μm showing the formation of α'-martensite in previously formed bands of ε-martensite.

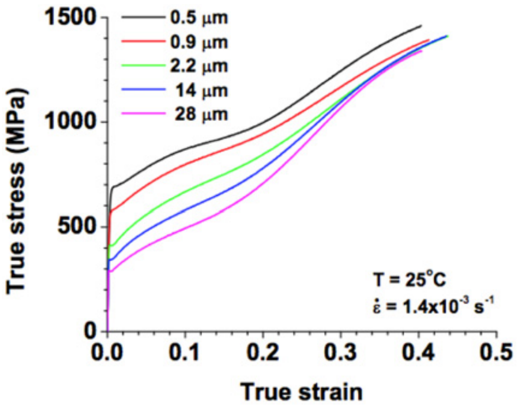
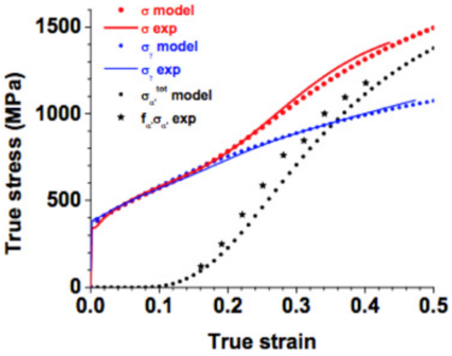


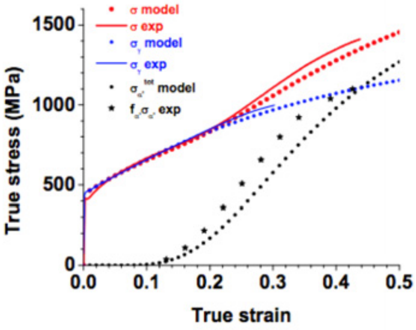
Figure 3. Tensile response of the AISI 301 LN alloy having different grain sizes (shown).

phase assuming that equal strain conditions prevail. Figure 4 illustrates the predicted stress-strain response compared to such a dynamic composite model.

In summary, it is possible to obtain a wide range of mechanical properties in austenitic stainless steels simply by changing austenite grain size. Aside from the typical sources of coupling between grain size and mechanical response, it was seen here that an additional factor, the effect of grain size on transformation kinetics, has to be considered in metastable austenitic stainless steels.



(a) 14 μm



(b) 2.2 μm

Figure 4. Predicted composite tensile response and experimentally measured tensile response for materials having two different grain sizes. Also shown are the predicted and experimentally measured transformation kinetics and the mechanical response of austenite.

References

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