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DISCUSSION

J. LeMay[6]

The authors have presented a clear and useful picture of deformation maps, showing how these may be derived for specific operating conditions in terms of temperature in a simpler manner than the more familiar deformation maps of Ashby [26],[7] which are now finding their way into the reference texts [27]. They have demonstrated the potential value of these maps to the designer, and shown how they can provide assistance to the experimentalist or researcher in deciding under what conditions additional tests should be made in order to define the required constitutive equations more fully for the alloy of interest. Thus, the interactions which are necessary between the physical metallurgist, materials engineer, and designer in order to achieve a better understanding of materials behavior have been clearly shown, this being one of the matters with which the Rensselaer Conference was principally concerned. However, two questions come to mind, and I should be grateful to have the authors' comments on them.

First, it would appear that one might produce a map of the Ashby-type [26] graphically and without the use of a computer, from a series of maps of the type derived by the authors and produced for a series of temperatures. I should be interested to know if the authors have attempted to do this, and to have their comments on whether the labor and computational time involved would be reduced from that required to generate on Ashby-type map directly.

Second, I am interested in the authors' treatment of grain boundary sliding as a sequential process coupled with intragranular deformation. In an earlier paper [28], the authors treated grain boundary sliding as an independent mechanism, and stated that this would overestimate the extent of sliding. However, if one compares the field devoted to sliding in the normalized grain size/stress map for aluminum at $T = 0.5T_m$ where the coupled analysis is employed (Fig. 3 of the present paper), with the equivalent field where sliding is treated independently (Fig. 2 of reference [28]), it is seen that there is a lack of correspondence, and indeed, the area for independent sliding is much smaller. It is certainly important in a practical situation not to underestimate the extent of the conditions for sliding, as these have the greatest potential for the development of intergranular cavities leading to tertiary creep and intergranular failure.

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[7]Numbers 26–28 in brackets designate Additional References at end of discussion.

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Author's Closure

Professor LeMay has raised two excellent points for discussion, and we welcome this opportunity to respond.

First, there is the question of producing maps of the type developed by Ashby [29][8] from our simpler maps developed for conditions of constant temperature. Although we have made no attempt to generate Ashby-type maps, it is, of course, very feasible to do this by using a series of our maps constructed for different temperatures. A simple method of calculating maps of our type for several different temperatures was presented earlier [30]. It would be a relatively simple process to transfer informa-

[8]Numbers in brackets designate Additional References at end of closure.

tion from these maps to give Ashby maps of normalized stress versus homologous temperature.

A word of caution is necessary, however, since our maps, as developed to date, refer specifically to high temperatures ($>0.4\ T_m$), and cover normalized stresses in the range of $\sigma/G \sim 10^{-8} - 2 \times 10^{-3}$. Even higher stresses would be experienced at lower temperatures, and, as in the work of Ashby [29], this requires an inclusion of the theoretical shear strength and an equation for the thermally-activated dislocation glide process.

Second, Professor LeMay points out that the field for grain boundary sliding in the present work (Fig. 3) is larger than the field for sliding presented in an earlier analysis (Fig. 2 of reference [31]). This difference arises because of the method of incorporating sliding as a deformation process. In the earlier work [31], grain boundary sliding was considered as an *independent* mechanism, and the constitutive equation for sliding in aluminum was assumed to be identical to an equation derived earlier for sliding in magnesium [32, 33]. If this equation correctly described the sliding process in Al, then the incorporation of sliding as an independent mechanism would lead to an *upper limit* for the magnitude of sliding. In the present work, it was assumed that sliding and an intragranular accommodation process occurred *sequentially*, and, in addition, the appropriate equations for the sliding and accommodation processes were derived directly from an analysis of the experimental results obtained on Al by McLean and Farmer [34].

Of these two different approaches, the present work is the more satisfactory because it is based in part on experimental data. Clearly, however, it is imperative that more experiments are performed to directly measure the magnitude of grain boundary sliding over a range of testing conditions, since the absence of these data makes it extremely difficult to incorporate sliding on to deformation mechanism maps in a reliable and useful manner.

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