Supplementary Material

Hot working of an Fe-25Al-1.5Ta alloy produced by laser powder bed fusion

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Hot Workability Assessment

In the current study, hot workability is evaluated using the concept of processing maps [1] based on the principles of the dynamic materials model (DMM) and Ziegler flow instability criterion [2].

S1. Strain Rate Sensitivity Map

The relationship between the true stress and the true strain rate in the logarithmic scale can be expressed by a 3-order polynomial fit using the following equation:

$$log\sigma = a + \ blog\dot{\varepsilon} + c(log\dot{\varepsilon})^2 + d(log\dot{\varepsilon})^3 \tag{S1}$$

where a, b, c, and d are material parameters depending on the temperature. By forming partial differentials on both sides of Equation (S1), the strain rate sensitivity, m, can be formulated by:

$$m = \frac{\partial(log\sigma)}{\partial(log\dot{\varepsilon})} = b + 2c\ log\dot{\varepsilon} + 3d\ (\log\dot{\varepsilon})^2 \tag{S2}$$

The 3D variation of m as a function of T and $\dot{\varepsilon}$ is plotted, and the correlation between the variation of m and the microstructure evolution during hot deformation is discussed.

S2. Processing Map

A processing map is built by superimposing a power dissipation map and an instability map. At a given temperature in the hot working regime, the externally applied power is consumed via two major paths: heat generation due to plastic flow and dissipation due to microstructural changes. The instantaneously dissipated total power is determined as follows:

$$P = \int_0^{\dot{\bar{\varepsilon}}} \bar{\sigma}.d\dot{\bar{\varepsilon}} + \int_0^{\bar{\sigma}} \dot{\bar{\varepsilon}}.d\bar{\sigma} = G + J \tag{S3}$$

where $\bar{\sigma}$ and $\dot{\bar{\varepsilon}}$ are the effective stress and the effective strain rate, respectively. The first and second integrals are called G (content) and J (co-content) and represent the power dissipation through plastic deformation and microstructural dissipation, respectively. The relative partitioning of power between the heat generation and microstructural transitions is defined by the strain rate sensitivity (of flow stress), m, as follows:

$$m = \frac{dJ}{dG} = \frac{\dot{\bar{\varepsilon}}\,d\bar{\sigma}}{\bar{\sigma}d\dot{\bar{\varepsilon}}} = \frac{d\ (ln\bar{\sigma})}{d\ (ln\dot{\bar{\varepsilon}})} \tag{S4}$$

The efficiency of power dissipation (η) with respect to a linear dissipator (m = 1) is defined by:

$$\frac{\Delta J/\Delta P}{(\Delta J/\Delta P)linear} = \frac{m/(m+1)}{1/2} = \frac{2m}{m+1} \equiv \eta \tag{S5}$$

A power dissipation map displays the 3D variation of η as a function of temperature and strain rate.

Instability maps are developed based on a continuum instability criterion derived from the extreme value principles of irreversible thermodynamics when applied to the continuum mechanics of a large plastic flow. The instability criterion is given by the dimensionless parameter ξ, as follows:

$$\xi(\dot{\varepsilon}) = \frac{\partial \ln (m/m+1)}{\partial ln\dot{\varepsilon}} + m \leq 0 \tag{S6}$$

A flow instability map represents the variation in the dimensionless instability parameter, ξ, with the deformation temperature and strain rate. The parameter ξ is calculated by substituting Equation (S2) with Equation (S6) as follows:

$$\xi(\dot{\varepsilon}) = \frac{2c+6d\ log\dot{\varepsilon}}{m(m+1)\ ln\dot{\varepsilon}} + m \tag{S7}$$

The temperature and strain rate regime with negative ξ values results in flow instability, which should be avoided during hot deformation operations. In contrast, the temperature and strain rate condition where the efficiency of the power dissipation takes its maximum without causing flow instability is considered the optimum processing window for hot working. Based on the results of microstructure investigations, the deformation mechanisms are characterized and correlated with the optimum region of the processing map.

References

1. Prasad, Y.V.R.K. Processing Maps: A Status Report. *Journal of Materials Engineering and Performance* **2003**, *12*, 638–645, doi:10.1361/105994903322692420.
2. Ziegler, H.; Eidgenössische Technische Hochschule. *Some extremum principles in irreversible thermodynamics, with application to continuum mechanics;* Swiss Federal Institute of Technology: Zürich, 1962.