Materials and Design 32 (2011) 716–722

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Characterization of deformation instability in modified 9Cr–1Mo steel during thermo-mechanical processing

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ARTICLE INFO

Article history:
Received 5 May 2010
Accepted 30 July 2010
Available online 4 August 2010

Keywords:
A. Ferrous metals and alloys
C. Forging
F. Microstructure

ABSTRACT

In this study, various existing instability criteria were employed to delineate the unstable flow regions in modified 9Cr–1Mo steel during hot deformation. Experimental stress–strain data obtained from isothermal hot compression tests, in a wide range of temperatures (1123–1373 K) and strain rates (10^{-3}–$10\ s^{-1}$), were employed to develop instability maps. The domains of these instability maps were validated through detailed microstructural study. It has been observed that Hart's stability criterion, Jonas's criterion and Semiatin's criterion under-predicts the instability regions in the studied temperatures and strain rates regime. Gegel's and Alexander's criteria as well as Murty's metallurgical instability criterion, on the other hand, found to over-predict the instability domains. The instability map developed based on Dynamic Materials Model criterion has been found to precisely predict the instability domains. This instability map revealed four major unstable domains. Microscopic examination in these domains revealed that the instability is manifested in the specimens either as localized deformation band primarily along one of the diagonal or inhomogeneous distribution of martensite lath in the prior austenite grains.

1. Introduction

In Liquid Metal Fast Breeder reactor (LMFBR) power plant, the steam generator is considered as one of the critical components as the structural material is exposed to both liquid sodium and water. The failure of the structural material may lead to steam water reaction. In addition to this, the efficiency of the power plant largely depends on the thermal efficiency of the steam generator. Therefore, special attention needs to be paid towards selection of the material for steam generator in LMFBR. Modified 9Cr–1Mo steel which shows properties like good thermal conductivity, high temperature creep resistance, fracture toughness and corrosion resistance [1–3] has been chosen as the candidate material for the structural material of steam generator in Indian fast breeder reactors. This material is also being investigated worldwide for its potential application as in-core structural material in the next generation fast breeder reactors [4–6].

Once the material is selected, the performance of the component depends on the final microstructural condition which is controlled by the adopted thermo-mechanical processes [7,8]. Hence attention has to be paid towards design of the thermo-mechanical processes by optimizing the process variables like temperature and strain rate. For this purpose, process modelling has been considered as a powerful tool. One of the prerequisites for the process modelling is the knowledge of the flow behaviour of the material [9]. Depending on the flow behaviour of materials, various regions in temperature and strain rate window could be broadly classified into two categories; stable and unstable domain. The regimes of temperature and strain rate where deformation is inhomogeneous and produce microstructural defects are termed as "unstable" or "unsafe" domains. The inhomogeneous deformation is unfavourable to the mechanical properties of the product, in particular ductility, fracture toughness [10]. In unstable domain, material may exhibit several kinds of instabilities depending on its processing conditions. At high temperature and low strain rates, material may exhibit superplastic deformation that may generate micro-porosity when it undergoes higher strain under tensile state-of-stress [11]. If deformation is carried out at low strain rate and high temperature regime, material may develop inter-crystalline or wedge cracks [12]. Given a favourable condition during service, this crack may propagate and cause catastrophic failure of the component. Similarly, when the material is deformed at higher strain rates, there is a possibility of local flow softening due to adiabatic temperature rise which usually causes localized slip. The intense flow localization may result in adiabatic shear bands. These bands are undesirable in the components as it may cause failure in the direction of shear bands. Therefore, it is important to distinguish the processing domains where the materials may exhibit unstable behaviour in order to avoid manufacturing of components with undesirable microstructure.

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doi:10.1016/j.matdes.2010.07.038