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Hot working behavior of Fe–29Ni–17Co analyzed by mechanical testing and processing map

Seyed Mehdi Abbasi [a], Amir Momeni [b,*]

[a] KNT University of Technology, Tehran, Iran
[b] Materials Science and Engineering Department, Hamedan University of Technology, Hamedan, Iran

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ABSTRACT

The hot workability of Fe–29Ni–17Co was analyzed using hot compression tests over temperature range of 900–1200 °C and at strain rates of $0.001\,s^{-1}$ to $10\,s^{-1}$. In order to analyze the hot ductility behavior of the material, hot tensile tests were performed at the same temperature range and strain rate of $0.1\,s^{-1}$. The flow curves at temperatures higher than 1000 °C were typical of dynamic recrystallization, while at lower temperatures work hardening was more dominant. The strain rate sensitivity parameter increased considerably with increasing temperature and the corresponding influence of strain rate was found negligible. The power dissipation and the instability maps of the studied material were developed based on the dynamic material model. From the developed processing map of the material, better workability at temperatures beyond 1000 °C was elicited. Hot tensile tests reported a hot ductility trough over the range of 1100–1150 °C. It contributed to a slight decrease in the reduction in area and strain to fracture. Despite the influence of hot ductility trough, mechanical testing and microstructural observations emphasized the better workability of the studied material at temperature range of 1000–1200 °C and the studied strain rates.

1. Introduction

Hot deformation is an essential step during the processing course of many industrial alloys. To achieve the desired properties in either finished or semi-finished products needs the accurate design of the hot working step as well as the in-dept knowledge about the behavior of the alloy that is being hot deformed. For many years processing maps have been increasingly used to design the appropriate regimes of hot working for different industrial alloys. A processing map, originally proposed by Raj [1], is defined as a representation of microstructural mechanisms of a given material and entails a superimposition of power dissipation and instability map which are depicted on the basis of dynamic materials model (DMM) [2]. DMM is a continuum model in which an instability criterion based on the principles of irreversible thermodynamic as applied to large plastic flow is utilized to mark flow instability regimes [3]. Considering the power-law constitutive equation between flow stress and strain rate, the efficiency of power dissipation and the instability parameter are calculated as follows [4,5]:

$$\eta = \frac{2m}{m+1} \tag{1}$$

$$\xi(\dot{\varepsilon}) = \frac{\partial\ \ln(m/(m+1))}{\partial\ \ln\ \dot{\varepsilon}} + m \tag{2}$$

where η and $\xi(\dot{\varepsilon})$ respectively denote the efficiency of power dissipation and the instability parameter and m is the strain rate sensitivity parameter.

Fe–29Ni–17Co alloy is a low expansion alloy which is widely used for glass-to-metal sealing purposes [6–8]. According to the past researches, structure and physical characteristics of this alloy such as the thermal expansion coefficient are strongly affected by hot working. Besides the importance of physical properties, the mechanical attributes of the alloy are highly sensitive to the microstructure and therefore to the hot deformation regime. It is known that the lower the grain size, the best combination of mechanical characteristics and thermal expansion will be achieved [9]. Therefore, two aims that should be considered for a better design of the hot deformation processing of this alloy are grain refinement and the assurance of stable flow. Many previous investigations have declared that both aforementioned purposes are satisfied if dynamic recrystallization (DRX) comes into operation as the dominant microstructural phenomenon.

It has been well documented that in low and medium SFE materials, DRX is the most important microstructural phenomena and often leads to a considerable grain refinement [10,11]. However, at low strain rate and high temperature regimes, usually known as the creep, DRX may be associated with grain coarsening [12].

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* Corresponding author. Tel.: +98 9123349007; fax: +98 811 8380520.
E-mail address: ammomeni@aut.ac.ir (A. Momeni).

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Besides this perceivable influence, the steady state flow established by the occurrence of DRX often prevents the formation of plastic instabilities and ensures the stable flow that is another goal [13]. This in turn highlights the importance of DRX in the hot deformation of this alloy and accentuates the development of an applicable processing map showing the regions of safe and unsafe deformation. Hence, the current investigation is devoted to develop the processing map of Fe–29Ni–17Co and further analysis of hot ductility using hot tensile tests in order to study and optimize the hot workability under actual industrial hot working processes.

2. Experimental procedures

The material used in this investigation was Fe–29Ni–17Co whose chemical composition is given in Table 1. The ingot of this alloy was sand cast and refined by electro-slag remelting (ESR) process. After homogenization heat treatment at 1100 °C for 3 h, the ingot was hot rolled by 3 passes up to total reduction of 55 percent. The hot rolled strip having the final thickness of 24 mm was used to prepare hot compression samples. The initial microstructure of the hot rolled strip is illustrated in Fig. 1. Cylindrical compression samples with the height of 13.5 mm and the diameter of 9 mm were prepared according to the ASTM E209 standard with the axis along the rolling direction of the strip. Graphite powder was used to reduce the friction coefficient and minimize the sample barreling. An INSTRON 8502 testing machine equipped with a fully digital and computerized control furnace was employed to perform hot compression tests at strain rates ranging from $10^{-3}\,s^{-1}$ to $10\,s^{-1}$ and at temperatures of 900–1200 °C. In order to soak the temperature before testing, the specimens were held 10 min at the deformation temperature. After hot compression test, the specimens were cooled down within 3 s and then were cut along their longitudinal axes and prepared by the standard metallographic techniques to characterize the microstructures. In order to analyze the hot ductility of the material, hot tensile tests were carried out in range of 900–1200 °C and at constant strain rate of $0.1\,s^{-1}$. The specimens for tensile testing were prepared according to ASTM E8M standard. The tests were continued till fracture and the corresponding reduction in area and elongation to fracture were recorded.

Table 1
Chemical composition of the material used in this investigation.

Element	Ni	Co	Mn	Si	C	S	P	Fe
Composition (wt%)	29.00	17.00	0.50	0.30	0.03	0.02	0.02	Balance

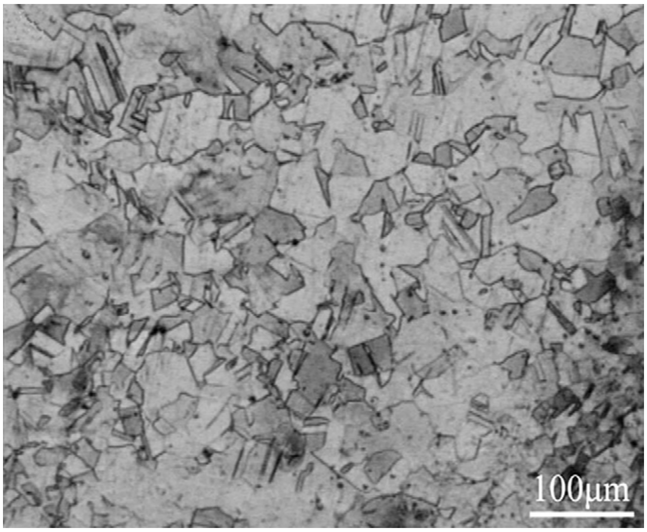

Fig. 1. Starting microstructures of Fe–29N–17Co used in this investigation.

3. Results and discussion

3.1. Flow curve and processing map

Fig. 2 indicates the typical flow curves of the studied material at different deformation conditions. The flow curves obtained especially at high temperatures such as 1100–1200 °C and low strain rates are representing the typical DRX curves with a single peak. The observed single-peak DRX behavior is known as a way to grain refinement. On the other hand, at low temperatures, e.g. 900 °C, and at high strain rates the peak on the flow curve is not clearly observed and the flow stress keeps on a gradual increase over the whole strain of testing. This is signifies that at latter condition the potential of DRX decreases and the corresponding peak is shifted to higher strains. As the DRX is a thermally activated process, increasing strain rate or decreasing temperature declines the tendency for the nucleation and growth of new grains. It seems that DRX in the studied alloy is rather sluggish comparing to the austenitic stainless steels and it is likely owing to the high concentration of Ni in the

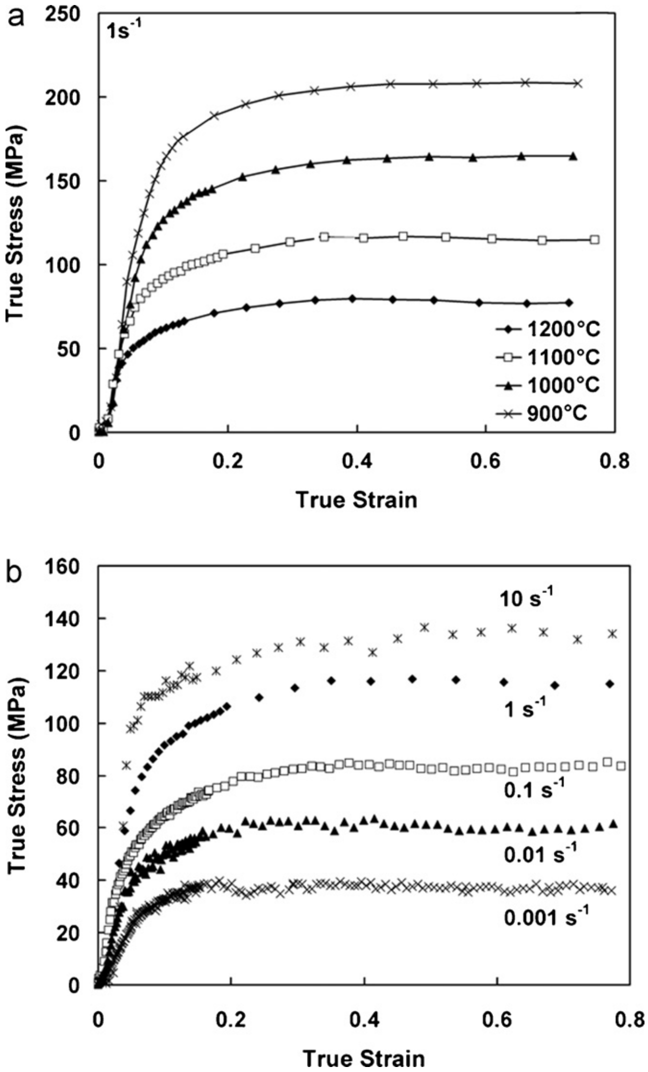

Fig. 2. Representative true stress–strain curves at different deformation regimes, (a) constant strain rate of $1\,s^{-1}$, (b) constant temperature of 1100 °C.