Materials Science & Engineering A 595 (2014) 1–9

Contents lists available at ScienceDirect

Materials Science & Engineering A

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

Constitutive analysis for hot deformation behaviour of novel bimetal consisting of pearlitic steel and low carbon steel

X.J. Gao [a,b], Z.Y. Jiang [a,*], D.B. Wei [a,c], H.J. Li [a], S.H. Jiao [d], J. Xu [e,**], X.M. Zhang [e], J.T. Han [f], D.F Chen [b]

[a] School of Mechanical, Materials and Mechatronic Engineering, University of Wollongong, Wollongong, NSW 2522, Australia
[b] College of Materials Science and Engineering, Chongqing University, Chongqing 400044, China
[c] School of Electrical, Mechanical and Mechatronic Systems, University of Technology, Sydney, NSW 2007, Australia
[d] Baosteel Research Institute, Baoshan Iron & Steel Co. Ltd., Shanghai 200941, China
[e] State Key Laboratory of Rolling and Automation, Northeastern University, Shenyang 110004, China
[f] School of Materials Science and Engineering, University of Science & Technology Beijing, Beijing 100083, China

ARTICLE INFO

Article history:
Received 30 August 2013
Received in revised form
28 October 2013
Accepted 30 October 2013
Available online 20 November 2013

Keywords:
Constitutive equation
Pearlitic steel
Bimetal
Prediction of flow stress

ABSTRACT

To understand the high temperature flow behaviour of a novel pearlitic steel (PS) and low carbon steel (LCS) bimetal, hot compression tests in a wide range of temperature and strain rate were conducted on a Gleeble 3500 thermo mechanical simulator, and the constitutive model was developed based on the experimental data. The measured true stress–strain curves exhibited three types of variation patterns, which are (i) a plateau type, (ii) single peak type and (iii) multi peaks type. These patterns well displayed the effects of the deformation temperature, strain rate and plastic strain on the flow behaviour of the bimetal. By incorporating the Zener–Hollomon parameter and material parameter functions of $\alpha(\varepsilon)$, $n(\varepsilon)$, $Q(\varepsilon)$ and $A(\varepsilon)$ into Arrhenius-type constitutive equation, the flow stress values predicted by the proposed model show a good agreement with experimental results by the evidence of reproducing true stress–strain curves accurately, high value of correlation coefficient ($R=0.9873$) and low value of average absolute relative error ($AARE=4.81\%$). The proposed constitutive equation can be used to realise numerical simulation and determine processing parameters during hot-working of the PS/LCS bimetal.

1. Introduction

Hypo eutectoid steels with high volume fraction of pearlitic structure and a small quantity of ferrite have been widely used in applications where reasonable strength and wear resistance are demanded. However, poor ductility and toughness as well as inferior weld ability are always keeping a lid on their further utilisations [1–4]. Recently, a novel bimetal consisting of hypo eutectoid pearlitic steel (PS) and low carbon steel (LCS) was developed to overcome those shortcomings by absorbing the advantages (i.e. excellent ductility and superior weld ability) of the latter component [5]. In order to improve the mechanical properties of the bimetal, various thermo mechanical treatments such as hot rolling and forging processes are generally proceeded on the bimetallic billet. However, the coexistence of harder PS and softer LCS in a layered structure of the bimetal makes the hot deformation behaviour different from that of the constituent components. Bonding of dissimilar steels into a single bimetal inevitably creates the interface and results in macro-heterogeneity of plastic deformation due to the discrepant hot-working responses. Therefore, it is of vital importance to study the high temperature flow behaviour of this novel bimetal.

Increasing recognition has been given to the constitutive equation as an effective method for predicting the material's flow behaviour based on a limited number of experimental data [6–20]. This mathematical representation is successfully used in the finite element code to simulate the deformation of the material under specified loading conditions. Over the past years, some efforts have been done on the development of constitutive equations for metal matrix composites (MMCs) by means of torsion or isothermal compression tests in a wide range of temperatures and strain rates [15–17]. Spigarelli et al. [15] studied the hot-working response of an Al-6061/20% Al_2O_3 composite using torsion tests and presented a consistent constitutive equation for both creep and hot deformation. Shao et al. [16] proposed the modified Arrhenius-type constitutive equation for 20 vol% SiC_p/2024 Al composite by analysing the experimental data derived from hot compression tests. Wang et al. [17] performed the hot compression tests on $Al_{18}B_4O_{33w}$/AZ91D composite and a modified Arrhenius-type constitutive equation

* Corresponding author. Tel.: +61 2 4221 4545; fax: +61 2 42215474.
** Corresponding author. Tel.: +86 24 83687220; fax: +86 24 23906472.
E-mail addresses: jiang@uow.edu.au (Z.Y. Jiang), xujz@ral.neu.edu.au (J. Xu).

0921-5093/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.msea.2013.10.096

was obtained. Despite an increase of attention is invested into the MMCs for clarifying their hot deformation behaviours, few investigations have been carried out to model the constitutive flow pattern of layer-structural bimetal, which is one of the metal matrix laminated composites.

In this paper, isothermal compression tests of a novel PS/LCS bimetal have been conducted at different temperatures and strain rates to characterise the flow behaviour during hot deformation. On the basis of the experimental results, a phenomenological approach [21] was applied to formulate the Arrhenius-type constitutive equation in which the flow stress was expressed by the hyperbolic laws and the strain compensation [22] was considered. The reliability of the proposed constitutive equation was evaluated against the experimental observations over the entire testing range.

2. Material and experimental procedure

2.1. Material

The chemical compositions of the selected PS and LCS are listed in Table 1. The PS/LCS bimetal was produced by centrifugal composite casting technology with the PS as the inner layer and the LCS as the outer layer. Since the different physical properties of

Table 1
Chemical compositions of PS and LCS (wt%, analysed by atomic emission spectroscopy).

Steel	C	Si	Mn	P	S	Ni	Cr	Cu	Ti	V
PS	0.63	0.60	0.31	0.031	0.0165	0.01	0.011	0.012	0.012	0.0055
LCS	0.122	0.22	0.37	0.023	0.015	0.01	0.011	0.009	< 0.002	< 0.003

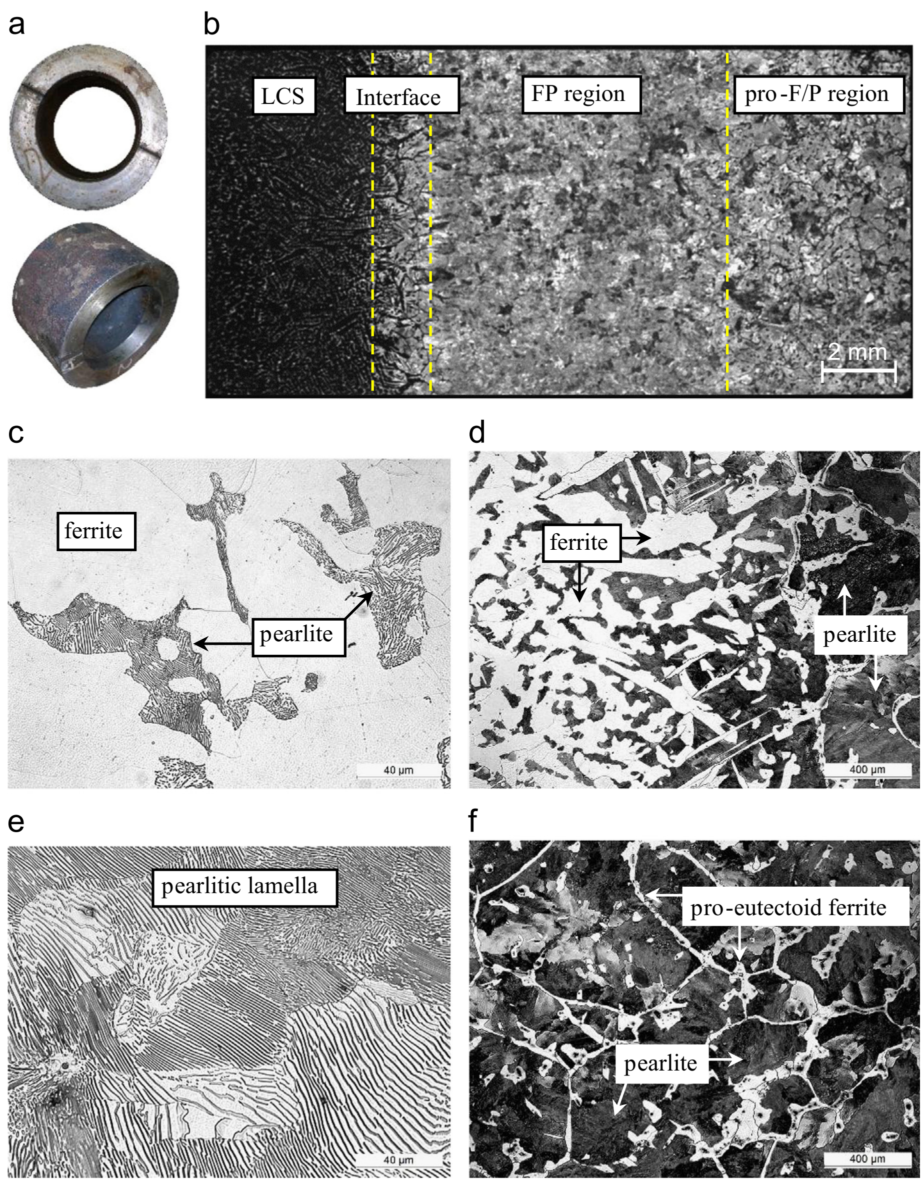

Fig. 1. Photographs and optical micrographs of the cast PS/LCS bimetal: (a) photographs, (b) overall cross section showing four different regions, (c) microstructure of LCS layer, (d) microstructure of interface, (e) microstructure of FP region, and (f) microstructure of pro-F/P region.