Computational Materials Science 47 (2009) 46–59

Contents lists available at ScienceDirect

Computational Materials Science

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

Analysis of workability behavior of Al–SiC P/M composites using backpropagation neural network model and statistical technique

S. Sivasankaran [a], R. Narayanasamy [a,*], T. Ramesh [b], M. Prabhakar [b]

[a] Department of Production Engineering, National Institute of Technology, Thiruchirappalli 620 015, India
[b] Department of Mechanical Engineering, National Institute of Technology, Tiruchirappalli 620 012, India

ARTICLE INFO

Article history:
Received 28 April 2009
Received in revised form 5 June 2009
Accepted 17 June 2009
Available online 14 July 2009

Keywords:
Metal matrix composites
Powder metallurgy
Artificial neural network
Analysis of variance

ABSTRACT

This paper presents an artificial neural network (ANN) model for predicting and analyzing the workability behavior during cold upsetting of sintered Al–SiC powder metallurgy (P/M) metal matrix composites (MMCs) under triaxial stress state condition which is the multifaceted technological concept, depending upon the ductility of the material and the process parameters. The input parameters of the ANN model are the preform density, the particle size, the percentage of reinforcement and the applied load. The output parameters of the model are the axial stress, the hoop stress, the axial strain, the hoop strain, the instantaneous strain hardening index, and the instantaneous strength coefficient. This model is a feed forward backpropagation neural network and is trained and tested with pairs of input/output data. A very good performance of the neural network, in terms of good agreement with the experimental data has been achieved. As a secondary objective, quantitative and statistical analyses were performed in order to evaluate the effect of the process parameters on the workability and the plastic deformation behavior of the composites.

1. Introduction

Extensive research work in the material science has been directed on the road to the development of new light weight engineering materials possessing improved specific strength, stiffness, creep, fatigue, and wear resistance even at elevated temperatures. These properties are not achievable with light weight monolithic titanium, aluminium, and magnesium alloys. In contrast, metal matrix composites have established their potential for providing a major jump in concert [1]. Advance automotive and aerospace technology requires these materials to improve performance in which SiC reinforced Al-matrix composites have been investigated elaborately for automobile applications such as diesel engine pistons, piston rings, connecting rods, drive shafts, brake discs, cylinder liners etc. owing to their excellent mechanical properties and light weight [2].

Manufacture of precision engineering components from powdered material today has become an established mass production technology. The growth of the P/M industry is based primarily on its ability to produce intricate shapes and close tolerances with maximum material utilization [3]. In the development of new aerospace alloys based on aluminium, titanium and super alloys, P/M technique plays a predominant role [4]. P/M products are widely used from the automotive industry through to aerospace, ordnance, power tool, electronics, business machines, household appliances, garden equipment and much more. Moreover, P/M route has become widely recognized as a superior way of producing high-quality parts for a variety of important applications. This success is due to the advantages of the process which offers over other metal forming technologies such as forging and extrusion; advantages in material utilization, shape complexity and near-net shape dimensional control among others. These, in turn, yield benefits in lower costs and greater versatility [5].

Workability is concerned with the extent to which a material can be deformed in a specific metalworking process without the initiation of cracks. The ductile fracture of the component is the most common mode of failure in any metalworking process. Workability is the complex technological concept that depends upon the ductility of the material and the details of the process parameters. It is the term used to the shaping of materials on various bulk deformation processes like forging, extrusion and rolling, to evaluate the capacity of a material to withstand the induced internal stresses of forming before the splitting of material occurs [6]. Therefore, a complete description of the workability of a material is specified by its flow stress which depends on processing variables such as strain, strain rate, preheat temperature, die temperature, its failure behavior and the metallurgical transformation that characterize the alloy system to which it belongs. Abdel-

* Corresponding author. Tel.: +91 431 2500812 (Res.), +91 431 2503504 (Off.); fax: +91 431 250 0133.
E-mail addresses: sivasankarangs1979@gmail.com (S. Sivasankaran), narayan@nitt.edu (R. Narayanasamy), tramesh@nitt.edu (T. Ramesh), mprabha2000@rediffmail.com (M. Prabhakar).

0927-0256/$ - see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.commatsci.2009.06.013

Nomenclature

F	upsetting or forging load on the cylindrical preform for deformation (KN)	α	Poisson's ratio
h_0	initial preform height (mm)	σ_z	true axial stress (MPa)
h_f	deformed height of the preform after deformation (mm)	σ_θ	true hoop stress (MPa)
D_0	initial diameter of the preform (mm)	σ_m	mean or hydrostatic stress (MPa)
D_B	bulged diameter of the preform after deformation (mm)	σ_{eff}	effective stress (MPa)
D_{TC}	top contact diameter of the preform after deformation (mm)	ε_z	true axial strain
D_{BC}	bottom contact diameter of the preform after deformation (mm)	β_σ	formability stress index
		R	relative density
		n_i	instantaneous strain hardening index
		k_i	strength coefficient

Rahman and El-Sheikh [7] discussed the workability criterion of powder metallurgy compacts and they investigated the effect of the relative density on the forming of P/M compacts in upsetting. They also proposed a workability factor (β) for describing the effect of the mean stress and the effective stress with the help of two theories. An experimental and theoretical research work with test samples of various geometry for the determination of critical damage at fracture under several loading conditions was carried out by Gouveia et al. [8]. Bao [9] established a relationship between the stress triaxiality and equivalent strain to crack formation. He has stated that the equivalent strain and the stress triaxiality were the important parameters which governed the crack formation and the stress and the strain ratio parameters induced the secondary effects. The fracture of cylindrical specimen with longitudinal surface notch compression test was experimentally studied by Petruska and Janicek [10] and it evaluates the ability of various ductile fracture criteria of different geometry and end conditions to predict the failure initiation. Investigation on the appearance of fracture in cold forming of brass during axisymmetric and non-axi-symmetric conditions was done by Sljapic et al. [11]. Previously, numerous research works by Narayanasamy et al. [12–15] have been carried out on the workability behavior of various composites under uniaxial, plane, and triaxial stress state conditions. Their results have shown that the workability behavior of metals/alloys/composites of P/M components depends on the aspect ratio, the preform geometry, the particle size and the percentage of reinforcement for the composites, the die geometry, the lubricants, and the compacting load. The results have shown that the high strain hardening index value, high strength coefficient, lower aspect ratio, and high initial preform relative density increases the densification behavior as a result of which workability improves.

The accomplishment of design for manufacturing methods in P/M industry requires systems that can store material and process related information in an easily usable form. This information can then be used at the design stage to select material, verify the properties attainable through the process before part designs are finalized [16]. Hence, modeling is necessary for the understanding and control of any process.

In recent years, artificial neural network is one of the most powerful computing modeling facilities, based on statistical approach, currently being used in many fields of engineering for modeling complex relationships which are difficult to describe with physical models. ANN applications are growing rapidly as artificial intelligence tools in the arenas of speech recognition, pattern recognition, robotics, tool wear prediction, powder packing density optimization, online monitoring, P/M processing and communication [17–21]. Smith et al. [22] applied the modeling techniques to various aspects of P/M technology manufacturing situations that are too complex for standard statistical methods, because of the numerous variables involved and the non-linearity of the relationships. Ko et al. [23] proposed a methodology for the preform design considering workability by ANNs and Taguchi method and also using the numerous approximate solution tools called Finite Elemental Simulation for the prediction of ductile failure. Wifi et al. [24] developed a computer aided workability evaluation system and coupled to an elasto–plastic large strain finite element package to check for ductile fracture in bulk formed work pieces using different workability criteria. Selvakumar et al. [16] investigated the effect of the particle size and the iron content on forming of Al–Fe composite using radial basis neural network with various combinations of input variables like the load, the aspect ratio, the particle size, the iron content and the fractional density ratio. An attempt on workability had not been reported by these authors. Poshal and Ganesan [25] studied the formability behavior of sintered aluminium preforms (data developed by Narayanasamy et al.) during cold upsetting under triaxial stress state condition using radial based neural network approach and concluded that a lower aspect ratio and higher initial fractional density preform exhibits improved formability index values compared to that of higher aspect ratio preforms. However, it is found in the Ref. [25] that the formability stress index and other stress ratio values determined are not correct due to the wrong interpretation of the theory proposed in the Ref. [26].

Therefore, the present work is carried out in order to satisfy the researchers in this area. Further, the literature reveals that there is little effort reported on the use of ANNs in workability behavior of P/M components under triaxial stress state condition. Hence, in this paper it has been attempted and presented that an artificial neural network approach to develop a well correlated model which predict the workability behavior of Al–SiC composites under triaxial stress state condition by considering the particle size, the percentage of reinforcement, the fractional density ratio or relative density, and the upsetting load as input neurons for ANN model. The experimental results of the axial stress, the hoop stress, the effective stress, the formability stress index, the instantaneous strain hardening index, and the instantaneous strength coefficient are set as output neurons in the model.

The previous work carried out by Narayanasamy et al. [27] investigated the effect of particle size of SiC in aluminium matrix on workability and strain hardening behavior, but the effect of very large size of SiC (i.e. 180 μm), the quantitative and statistical analyses considering the effect of the particle sizes and percentage of SiC have not been reported. Hence the same has been attempted and presented.

2. Collecting the experimental data and the mathematical analysis

Narayanasamy et al. [27] have carried out the experimental work of Al–SiC P/M composites and the experimental readings