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Modelling the effect of particle size and iron content on forming of Al–Fe composite preforms using neural network

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Abstract

Cold upsetting experiments were carried out on sintered Al–Fe composite preforms inorder to model and analyse the formability by simulation using neural network (NN). A model has been developed with a radial basis NN algorithm. The data used were collected by the experimental set up in the laboratory for the sintered Al–Fe composites with the various preform densities, the particle sizes and the aspect ratios. The network is trained to predict the forming characteristics such as the axial stress, the hoop stress, the hydrostatic stress and the Poisson ratio. In addition to that, the value of strain hardening coefficients such as instantaneous strength coefficient (k_i) and instantaneous strain hardening exponent (n_i) is also simulated to find the effect of particle size and the percent of iron content on formability. Regression analysis has confirmed a good agreement between the predicted and the experimental data with least error and hence this approach helps to facilitate a knowledge base in order to generate advice for the designer at the earlier stages of design so that concurrent engineering practices can be made.

Keywords: Neural network; Powder preforms; Al–Fe composite; Upsetting

1. Introduction

Powder metallurgy (P/M) is sometimes the only manufacturing method which can be used for some materials such as composite materials, porous materials, refractory metals and special high duty alloys. The P/M method competes with other methods on the basis of cost which can be lowered for high volume production of complicated components. In most cases such components are manufactured using a classical P/M route which involves deformation of the metal powder followed by sintering. Meanwhile understanding the density distribution of powder compacts during deformation and the compaction behaviour of porous metals during forming is very important in achieving good quality P/M parts.

The product manufactured using P/M technology can lead to significant material and energy savings in many cases. In fact the consideration of P/M often does not occur until the part has been in conventional production for a considerable period of time. Generally a part is identified for the manufacture using P/M process; the selection of material and process parameters requires inputs from a number of experts in the field. Unlike wrought parts, design specifications to determine the process parameters and type of powder to be used in

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Nomenclature

D_0	initial diameter of the preform before deformation
D_b	bulged diameter of the preform after deformation
D_c	contact diameter of the preform after deformation
h_0	initial height of the cylindrical preform before deformation
h_f	height of the preform after deformation
ε_z	true strain in the axial direction
ε_θ	true strain in the hoop direction
σ_z	true stress in the axial direction
σ_θ	true stress in the hoop direction
σ_m	hydrostatic stress
v	Poisson's ratio
k_i	instantaneous strength coefficient
n_i	instantaneous strain hardening exponent

producing a P/M part are to be used. One of the reasons for not designing a part using P/M technique in the first instance is due to the lack of suitable guidelines in the selection of appropriate metal powder grade and process parameters. Hence, knowledge-based systems (KBS) that are currently used in a number of designs and manufacture applications can also be used to support closer integration of P/M design/manufacture functions.

Neural network (NN) models have been studied in recent years, with an objective of achieving human like performance in many fields of knowledge engineering. NN applications are growing rapidly as artificial intelligence tools in the area of speech recognition, pattern recognition and in robotics and communication [1]. Many researchers have attempted to use neural networks for various applications in manufacturing such as, tool wear prediction, TTT diagram prediction, powder packing density optimization, P/M process modeling, turning force prediction and on-line monitoring, etc. [2–5]. Smith [6] 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. The numerical technique of NN modeling may offer the solution.

In cold working a porous P/M material would experience the usual strain hardening characteristics as well as geometrical work hardening. This, in fact, explains why the flow stress increases as the amount of axial strain is increased. However, the rate of increase in the stress value with respect to strain is greater than that would be observed in a fully dense material of the same composition under identical testing conditions, as the continued reduction in the porosity level during upsetting increases the load bearing cross-sectional area. This, in turn, increases the stress required for further deformation, resulting in strain hardening behaviour. Thus the total work-hardening behaviour in a porous material is due to the combined effects of densification and cold working [7,8].

Lee and Altan [9] investigated the influence of flow stress and friction on metal flow in upset forging of ring and cylinders considering the work-hardening of material. The mechanical alloying technique is applied for the production of composite materials characterized by very fine grains [10]. Narayanasamy and Pandey [11] analysed the total work hardening in P/M preforms by conducting experiments. Kuhn and Downey [12] investigated compaction characteristics of iron-sintered compacts (preform) and proposed a plasticity theory to determine the yield criterion. Elwakil [13] and Sutradhar et al. [14] briefed the analytical prediction of flow properties on iron-sintered preforms. The effect of relative density of the preform on the forming limit using upsetting test was investigated [15]. Mamalis et al. [16,17] studied the porosity and micro-defects on plastically deformed porous materials using yield criterion.

Plastic deformation of sintered porous materials under compression is accompanied by an increase in density. The continued increase in bulk density under compression for porous materials causes an increase in flow stress and also the resistance. This resistance increases due to enhancement of density and to work-hardening effects; the work hardening exponent '*n*' is the function of initial compact density for sintered iron preforms. In view of the above, the characteristic hardening effect due to deformation of porous preforms must be taken into account under cold conditions of deformations.

In this investigation, an attempt has been made to simulate the effect of particle size and the iron content by using NN with various combinations of input variables like the compacting load, the aspect ratio, the particle size, the iron content and the fractional density ratio for sintered Al–Fe composites. Once it is predicted, we can justify the effects of these input parameters on formability of cylindrical sintered Al–Fe composite preforms without experimentation.

2. Experimental details

Atomized aluminium and iron powder was thoroughly mixed in a ceramic bowl. The green compacts