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Comparison of workability strain and stress parameters of powder metallurgy steels AISI 9840 and AISI 9845 during cold upsetting

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ABSTRACT

A complete experimental investigation on the workability behaviour of nickel–chromium–molybdenum steel grades namely AISI 9840 and AISI 9845 of powder metallurgy preforms was performed. Cold upsetting of aforesaid composites with different aspect ratios namely 0.42, 0.63 and 0.93 was carried out with graphite lubricant and the formability behaviour of the preforms under triaxial stress-state condition was determined. A new formability strain parameter was proposed, evaluated and compared with formability stress parameter for all the above said preforms. The characteristics of various stress and strain ratio parameters with respect to relative density were also analyzed and presented for comparison.

1. Introduction

Ferrous powder metallurgy (P/M) processing is a net or near net-shaped production technology, which in many instances eliminates the need for secondary machining operations. Ferrous P/M offers a wide range of engineered materials for structural applications and satisfies close dimensional tolerance requirements for parts with complex geometries [1]. The vast application of ferrous powder materials such as automotive applications, household appliances, hardware, industrial motors/controls and hydraulics, recreation and tools, stipulates the increase of interest to analysis of powder metals behaviour under the forming processes. Powder preform forging involves the fabrication of a preform by the conventional P/M processing technique, followed by the conventional forging of the preform to its final shape with substantial densification [2].

Workability is a term used to assess the ability of a material to hold up the induced internal stresses of forming prior to the splitting of material occurs. It is a complicated technological concept that depends not only on the material but also the various process parameters such as stress, strain rate, temperature and friction. Workability criterion of P/M compacts was discussed by Abdel-Rahman and El-Sheikh [3]. They investigated the effect of relative density on the forming limit 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 and the effect of relative density was discussed. Wifi et al. [4] 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. The fracture of cylindrical specimen with longitudinal surface notch compression test was experimentally studied by Petruska and Janicek [5] and it evaluates the ability of various ductile fracture criteria of different geometry and end conditions to predict the failure initiation.

An experimental and theoretical research work was carried out by Gouveia et al. [6] with test samples of various geometry for the determination of critical damage at fracture under several loading conditions. The reduction in porosity during forging results in the decrease of preform volume. The yielding of porous materials thus does not follow the laws of volume constancy and the material parameters undergo a variation along with a change in porosity. Narayanasamy and Ponalagusamy [7] developed a mathematical theory of plasticity for compressible powder metallurgy materials. Sljapic et al. [8] investigated the appearance of fracture in the cold forming of brass during axisymmetric and non-axisymmetric conditions. Bao [9] established a relationship between the stress triaxiality and equivalent strain to crack formation. Further, it was observed that the equivalent strain and the stress triaxiality were the important parameters which governed the crack formation. The secondary effects are induced primarily by the stress and strain ratio parameters.

In the present work, a complete experimental investigation on the workability behaviour of nickel–chromium–molybdenum steel grades of AISI 9840 and AISI 9845 powder metallurgy preforms was performed. Preforms with different aspect ratios namely

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Nomenclature

F	force applied on the cylindrical preform for deformation	σ_m	hydrostatic stress
h_0	initial height of the cylindrical preform	σ	true stress
h_f	height of the barreled cylinder after deformation	ε	true strain
D_0	initial diameter of the preform	ε_z	true strain in the axial direction
D_B	bulged diameter of the preform after deformation	ε_θ	true strain in the hoop direction
D_{TC}	top contact diameter of the preform after deformation	ε_r	true strain in the radial direction
D_{BC}	bottom contact diameter of the preform after deformation	ε_{eff}	effective strain
α	Poisson's ratio	β	formability stress index
σ_z	true stress in the axial direction	ρ_0	initial preform density of the preform
σ_θ	true stress in the hoop direction	ρ_f	density of the preform after deformation
σ_r	true stress in the radial direction	ρ_{th}	theoretical density of the fully dense material
σ_{eff}	effective stress	R (or) $\frac{\rho_f}{\rho_{th}}$	relative density

0.42, 0.63 and 0.93 were subjected to cold deformation with graphite lubricant and their formability behaviour under triaxial stress state condition was determined. The variation of a newly proposed formability strain parameter with respect to relative density was evaluated. The formability strain parameter was compared with the formability stress parameter for the two different powder metallurgy steel grade preforms of AISI 9840 and AISI 9845. Also the characteristics of various stress and strain ratio parameters such as σ_z/σ_{eff}, $\sigma_\theta/\sigma_{eff}$, σ_θ/σ_z, σ_z/σ_m, σ_θ/σ_m, $\varepsilon_z/\varepsilon_{eff}$, $\varepsilon_\theta/\varepsilon_{eff}$, $\varepsilon_\theta/\varepsilon_z$, $\varepsilon_z/\varepsilon_m$, $\varepsilon_\theta/\varepsilon_m$ with respect to relative density were analyzed and presented.

2. Experimental details

2.1. Specimen preparation

Atomized iron powder of $-150\ \mu m$ was procured and analyzed for its purity. The same was found to be 99.7% and 0.3% insoluble impurities. Powder mix corresponding to Fe–0.4% C–0.8% Mn–0.3% Si–1.0% Ni–0.8% Cr–0.25% Mo designated as AISI 9840, Fe–0.45% C–0.8% Mn–0.3% Si–1.0% Ni–0.8% Cr–0.25% Mo designated as AISI 9845 were blended on a pot mill to obtain a homogeneous powder blend. The characterization of iron powder and the powder blend corresponding to AISI 9840 and AISI 9845 steel composition was studied by determining the flow rate, the apparent density, the tap density and the particle size distribution. Fig. 1 shows the SEM photograph of iron powder. A sieve analysis is made to determine the particle size as stated in Table 1. Green compacts of the powder blend with initial preform density of 84% of the theoretical density are prepared on a 1.0 MN capacity hydraulic press using suitable punch and die setup. Table 2 shows the characteristics of AISI 9840 and AISI 9845 powder compacts. An indigenously developed ceramic coating [10] was applied on the free surfaces of the compacts and dried under room-temperature conditions for a period of 9 h. A second coating was applied at a direction of 90° to the direction of first coating and allowed to dry for a further period of 9 h under the same conditions as stated above. The ceramic-coated compacts were sintered in an electric muffle furnace in the temperature range of 1120 ± 10 °C for a period of 100 min and ultimately cooled to room temperature in the furnace itself. The ceramic coatings are machined off and further machining is carried out to such dimensions, so that to obtain preforms with initial aspect ratios 0.42, 0.63 and 0.93.

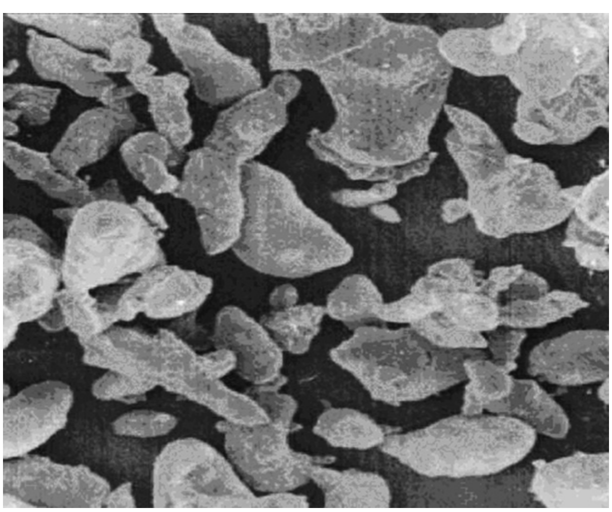
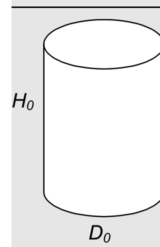


Fig. 1. The SEM photograph of iron powder.

2.2. Deformation test

Initial dimensions of the specimen such as initial diameter (D_0), initial height (h_0) and the initial preform relative density (ρ_0) were measured and recorded. The deformation of the preform was carried out between two flat, mirror finished open dies on a hydraulic press of 1.0 MN capacity. Each compact was subjected to the incremental compressive loads of 0.05 MN and the upsetting was carried

Table 2
Characteristics of AISI 9840 and AISI 9845 powder compacts



Material	Aspect ratio	Height (H_0) (mm)	Diameter (D_0) (mm)	Initial preform density (%)
AISI 9840	0.42	10.12	24.09	84
	0.63	15.13	24.02	
	0.93	21.90	23.55	
	0.42	10.02	23.85	84
	0.63	15.16	24.07	
	0.93	22.34	24.02	

Table 1
Characterization of iron powder

Characteristics										Iron
Apparent density (g/cc)										3.26
Flow rate (s) per 50 g										24.5
Compressibility (g/cc) at a pressure of 400 ± 10 MPa										6.20
Sieve analysis										
Sieve size (μm)	150	+125	+106	+ 90	+ 75	+ 63	+ 53	+ 45	+ 37	− 37
Percent distribution (weight)	3.88	20.21	9.10	3.40	20.80	17.92	4.60	1.91	3.72	13.20