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Technical Report

Studies on the formability of powder metallurgical aluminum–copper composite

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ABSTRACT

Formability is concerned with the extent of deformation that the materials undergo before failure; thus its investigation is critical for successful processing of materials during bulk deformation. The present investigation has been undertaken to generate the forming limit diagrams for powder metallurgical aluminium–copper composites for different initial relative densities and copper contents. Sintered aluminium–copper composite compacts of 2%, 4% and 6% copper content with different initial relative densities have been prepared by applying recommended powder compaction pressures. The material properties such as apparent strain hardening exponent and strength coefficient were determined using stage wise compression test to generate the formability limit diagram. Densification curves were plotted to investigate the effect of initial relative density and copper content on the pore closure phenomena during deformation. Theoretical and experimental investigations using standard ring compression test were carried out to determine friction factor between tool and work piece interfaces for different initial relative density and copper content. The critical transition densities vide the forming limit diagram were found to be 84%, 85.3%, 86% and 87.5% for pure sintered aluminium, Al–2%Cu, Al–4%Cu and Al–6%Cu composites respectively. The friction factor between tool and work piece interfaces has showed increasing pattern for all the cases with decrease in the initial relative density and increase in the copper content of the composite.

1. Introduction

Powder metallurgical (PM) components have superior properties than parts made through other manufacturing processes. It is rapid, economical and high volume production method for making parts from powders. This route yields products with higher strength, wear resistance and close dimensional tolerance. It involves various steps: powder mixing or blending, compaction and sintering.

Nowadays, numerous secondary processing techniques have been used to enhance the reduced mechanical properties of PM components due to the presence of residual porosity left after sintering. Precision cold forming can result in higher production of parts with good dimensional control and good surface finish [1]. It is often possible to use cheaper materials with low alloy content because of extensive strain hardening during cold forming. It is also reported [2] that cold working is one of the methods to promote strength in which the strain induced will be the prominent factor for strengthening wrought materials. The same is true for PM materials too; however the additional factor that governs the work hardening behaviour is the pore closure phenomena.

In metal forming operations, formability of a material is crucial technological concept that mainly depends on the ductility of the material and associated process parameters. Several authors [3–7] investigated workability and/or effects of process parameters on the workability of PM aluminum and/or aluminum metal composites. Narayansamy et al. [5] studied the workability of Al–Al_2O_3 PM composite on cold upsetting and observed that the workability of a material purely depends on the amount of ductile fracture present in the material. Raj et al. [8] presented an experimental investigation on the effect of different percentage of carbon and manganese on the workability and strain hardening behaviour of Fe–C–Mn sintered composites during cold upsetting. They observed better workability for a composition of Fe–0.1C–0.5Mn because of higher initial fractional density and pore closure phenomena.

Forming limit diagram (FLD) is a valuable tool for analyzing the deformation mechanics of metal forming. It has been used as a reference to estimate how the material close to failure. Chakravarthy et al. [9] investigated the influence of temperature on the FLD of sintered PM performs through determining the critical transition

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density (CTD) vide the diagram. The CTD separates the safe working zone from the fail zone in further processing of the materials to produce crack free products. The results of previous works [10–12] present that formability of cold extrudates are significantly dependent on the initial relative density of deformed PM materials. Since all the stresses acting during cold extrusion are compressive, the extrudates have better mechanical properties and density nearer to the corresponding wrought materials.

According to Narayanasamy et al. [13], the work hardening behavior of PM preforms comprises of both the effect of geometric hardening and matrix hardening. Thus persistent pore closure phenomena and matrix hardening are considered during the determination of strain hardening exponent and strength coefficient for PM materials. The general Ludwik equation for fully dense materials is given as $\sigma = K\varepsilon^n$, where σ is the true stress, ε is the true strain, K is the strength coefficient and n is strain hardening exponent. Correspondingly, the flow stress equation for the PM preforms can be equivalently given as $\sigma = K_a\varepsilon^{n_a}$, where K_a is the apparent strength coefficient and n_a is the apparent strain hardening exponent. Both the apparent strength coefficient and apparent strain hardening exponent are functions of the relative density of sintered preforms [14].

According to the FLD generated by Chakravarthy et al. [9], the variations of K_a and n_a against initial relative density are used to determine the CTD of the PM preforms which determines the minimum initial relative density to obtain crack free cold extrudates. The CTD value exists at the transition point on the slope of linear plot of K_a and n_a values for different initial relative densities of the preforms. It determines the formability of sintered PM preforms during cod extrusion. Das et al. [15] conducted experimental research on the effect of the reinforcement particles on the forgeability and mechanical properties of aluminum-metal composite and observed that the forgeability of the material is greatly dependent on the weight percentage of the reinforcement particles. Further research was performed by Madhusudan et al. [16] on fabrication and deformation studies on aluminum–copper composite metallic materials and reveled that when the weight percentage of copper reinforcement increases, the composite undergoes early fracture.

Literatures related to the formability study of sintered aluminum–copper composite is limited though the material has got popularity in major industrial applications as air-craft structures, rivets, hardware, truck wheels and screw-machine products as described by Mondolfo et al. [17]. It is relevant to determine the formability of the material through generating the FLD. The present research makes an attempt to generate the FLD for sintered aluminium–copper composite of various initial relative densities and content of copper in the composite. Thus the effect of initial relative density and content of copper on the CTD which demarcates the safe and fail zone for cold forming of sintered aluminum–copper composites are explored. Since friction affects the formability, deformation load, product surface quality and dies wear characteristics, evaluation of the effect of initial relative density and the content of copper on the friction factor is other vital part of the current research. The author expects shift in the values of CTDs and change in the friction factor (m) values due to change in processing conditions throughout the investigation.

2. Experimental details

2.1. Specimen preparation

To investigate the deformation mechanisms in the present work, the porous specimens were prepared from atomized aluminum and copper powders of each −325 μm mesh size. Aluminum powder has 99% pure and a maximum of 0.53% insoluble impurity limit whereas copper powder has minimum of 99% pure and maximum limit of impurities are 0.5% and 0.03% of iron (Fe) and heavy metals (Pb) respectively. The scanning electron microscope (SEM) photographs of aluminum and copper powder are shown in Figs. 1a and 1b respectively.

The PM preforms were prepared from pure aluminum powder and aluminium–copper mix with addition of 2%, 4% and 6% (by weight) copper in the composite to obtain dimensions of 12.5 mm in height and 15 mm in diameter. A pot mill was used

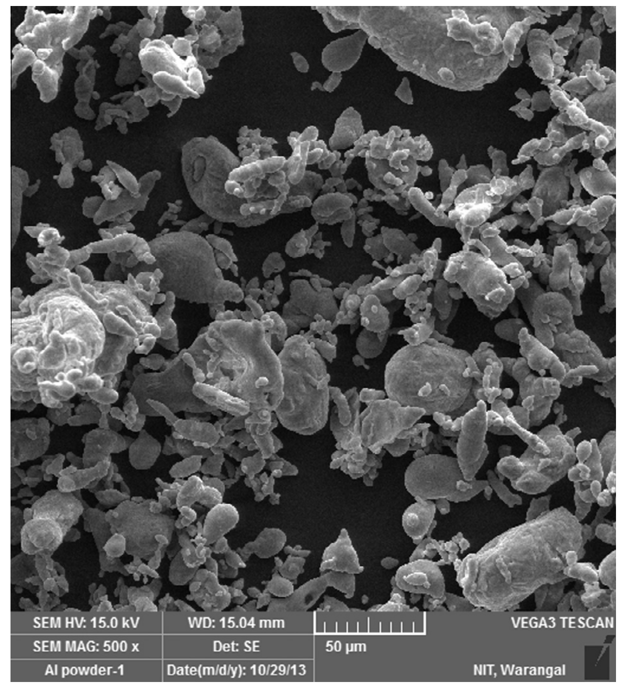

Fig. 1a. The SEM photograph of aluminium powder.

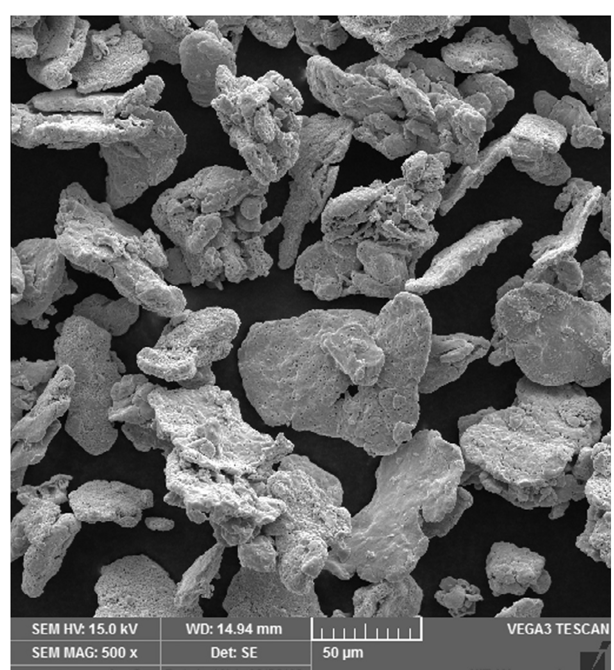

Fig. 1b. The SEM photograph of copper powder.