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Densification and Deformation Behavior of Sintered P/M Zinc-Zinc Oxide Composite during Cold Upsetting

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Abstract

Studies were carried out to evaluate the initially preformed density and initial aspect ratio on the densification behavior of sintered Zinc and Zinc Oxide composite. The preform possessed 0.85 is the initial density. Aspect ratio for three different oxidizing temperatures (at 150°C, 200°C and 250°C) varied from 0.4 to 0.85. Properties of Zinc-Zinc Oxide composites with respect to linear strain, lateral strain and true stress were evaluated and plotted. Studies revealed that higher stress and higher strain values are obtained in composite when compared to the Zinc dust. The composite of Zinc-Zinc Oxide obtained at 150°C possessed the highest stress and strain when compared to the composites obtained at others two temperatures (200°C and 250°C).

Keywords: Densification; Metal Matrix Composite; Zinc Oxide; Powder Metallurgy; Aspect Ratio; Sintering; Cold Upsetting; Preforms

1. Introduction

The term “composite” broadly refers to a material system which is composed of discrete constituents (the reinforcement) distributed in a continuous phase (the matrix). It derives its distinguishing characteristics from the properties of its constituents, from the geometry and architecture, and also from the properties of the boundaries (interfaces) of its different constituents. Composite materials are usually classified on the basis of physical or chemical nature of their matrix phase, like polymer matrix, metal-matrix and ceramic composites etc. Among the materials that are developed to an increasing extent metal matrix composites.

The space industry was the first sector interested in the usage of these materials. Another sector of even greater economic importance for the development of new metal matrix composites (MMC’s) is the automotive industry [1]. The flexibility associated

with MMC’s in tailoring their physical and mechanical properties as required by the users have made them suitable candidates for a spectrum of applications related to automobile and aeronautical sectors [2]. The introduction of fine dispersed particles into the metal matrix has significant reinforcing effects when maintained at elevated temperatures [3-7].

Many composites that are used today are at the leading edge of material technology, with performance and costs appropriate to ultra demanding applications such as spacecraft. But heterogeneous materials combining the best aspects of dissimilar constituents are available in nature and are being used as such for millions of years. Powder forging technique is accepted as the most economical and efficient technique leading to pore elimination and superior mechanical strength. Although several processes are available for producing MMC’s, the powder metallurgy technique was found to be the most suitable because it yields better mechanical properties. Zinc Oxide is an amorphous white powder used as a pigment in plastics, paints and primers etc. It is also reported to be the best ultraviolet light absorber of all commercially available pigments.

Research on dispersion strengthened materials points out the significance of the properties of the starting metallic powders and also the importance of the starting structure in preserving the structure of the final product [8]. A very important aspect of dispersion strengthening is the even distribution of oxide particles, their fine dispersion, especially in nanometer scale, and the introduction of a possible amount of dispersed particles into the volume of the base metal.

The powder metallurgy sintered parts possesses 10-30% porosity which can be advantageously used, but the mechanical properties of the component are adversely effected by the presence of porosity [9, 10]. Therefore, the parts intended for dynamic applications, the final compaction should be close (up to about 1-2%) to that of fully dense material. Forging of the sintered preforms result in a precision component with the reduction or elimination of porosity. The reduction in porosity during forging, results in a decrease in preform volume. The yielding of porous materials, thus, does not follow the laws of volume constancy. Further, the ‘material parameters’ (such as, modulus of elasticity and modulus of rigidity) are functions of density of the deforming body and as such the ‘material parameters’ also undergo a variation along with a change in porosity (density).

Initially, there had been some experimental, semi-experimental or analytical approaches using slab method for obtaining the density of porous formed metal parts [11-

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16]. Thereafter, several researchers studied the forging of porous materials and billet by using finite element method taking material to be rigidly plastic. An attempt to use numerical method for the analysis of powder metal forging operation has also been studied by various researchers using a rigid plastic approach [17]. Rigid plastic approach could be acceptable for large deformation by excluding the effect of elastic behaviour of the material. Subsequently, there have been some attempts to develop elastic-plastic approach to study the deformation of porous materials [18, 19].

The aim of the present work is to study the mechanics of cold forging of powder metal preforms taking into account its plastic strains as the work material which undergoes deformation. The model developed was applied to study the forging of an axis symmetric short solid cylindrical part under simple upsetting. The analysis was carried out for the press forging with slow rates of deformation where inertia and temperature effects were negligible. The computed results predicted the densification pattern of the work material and the loads required to produce the desired deformation.

2. Problem Formulation

Present investigation focused on the densification behavior of sintered Zinc-Zinc Oxide powders when taken in varying quantities. Frictionless compression tests are used to find out the fundamental plastic flow characteristics of porous metals. Studies reveal that the deformation was uniform with barreling of cylindrical surfaces. The proposed study also carries out to evaluate the initial preformed density and initial aspect ratio on the densification behavior of sintered Zinc-Zinc Oxide composites. The preform possessed 0.85 as initial density and the aspect ratio for three different oxidizing temperatures (150°C, 200°C and 250°C) varied from 0.4 to 0.85. Four performs, each of different aspect ratio were taken for each temperature.

A critical literature survey reveals that several attempts has been made in producing components through powder metallurgy route, which may contain one or the other type of impurifier. These perhaps could not be verified during the course of several investigations as the fine dispersion of self oxidized material in the component perhaps induced improved properties. A wide variety of research in the area of elemental powder and its own oxide composite has been carried out. But earlier investigations have shown that extruding the sintered preform containing the self oxidized dispersions in different proportions on extrusion may induce improved mechanical properties.

It is well established that in the metal forming operations the deformation is never strictly homogeneous and therefore pores present on the surface of the component can never be closed either due to the predominance of tensile forces or due to hydrostatic forces present in the dead metal zones. Therefore, it is more likely that the particulate structure will be prevalent at the surface of the component irrespective of preform design for any upsetting test.

For studying the behavior of Zinc-Zinc Oxide composite during cold upsetting, mechanical properties should be given priority. In most of the methods adapted for studying the strengthening of the composite, strengthening metal must have higher melting point than matrix metal. In this method, we have developed Zinc Oxide as a strengthening component, but it possesses higher melting temperature than Zinc (matrix metal). The basic advantage of dispersion strengthened materials is that it does not improve yield strength at ambient temperature or work hardening rate. The present investigation on composite carried out at three different oxidizing temperatures (150^{o}C, 200^{o}C, and 250^{o}C). Duration of treatment was three hours and a single preform density was taken for four different aspect ratios in cold compression test.

3. Experimental Procedure

3.1. Materials Required:

The materials required for this investigation are: Zinc dust for composite preparation, graphite/molebdenum-di-sulphide for using as lubricant, high carbon-high chromium die steel punch and die, two flat plates heat treated to Rc 52 to 55 and tempered to Rc 45 to 48, a stainless steel tray, and an electric muffle furnace.

3.2. Preparation of Zinc-Zinc Oxide Composite:

For obtaining self oxidizing Zinc-Zinc Oxide powder, the Zinc powder was taken in a steel tray, which was placed in an electric furnace maintained at 150^{o}C for three hours. Thereafter on cooling, the oxidized powder was removed from the furnace and stored carefully. Similarly, the same procedure was followed for making composites at 200^{o}C and 250^{o}C. During this process some portion of the Zinc powder normally gets partially oxidized.

3.3. Grinding of Oxidized Powder:

In oxidized zinc powder, some parts of the Zinc normally contains Zinc Oxide. Generally, the oxide layer possesses an irregular surface; which needs to be changed to regular surface. To shape this irregular layer of oxide, the composite was taken in a clean ceramic bowl and grounded continuously for six hours.

3.4. Compaction of Zinc-Zinc Oxide Powder :

Cold compacts of Zinc-Zinc Oxide are prepared by using high carbon-high chromium steel dies. To avoid sticking of the metal powder to the surface and also to reduce co-efficient of friction due to its high density, graphite was used as lubricant. A known amount of metal powder was poured into the die and the punch was introduced into the die from the top. Thereafter, the whole setup was transferred to 0.60 MN capacities universal testing machine (UTM) for compaction. A load of 18 ton, 20 ton, and 22 ton was gradually applied to get the compacts, thereafter, the compacts were ejected out by removing the butt.

3.5. Aluminium Coating of Samples and Sintering of Coated Samples:

During sintering operation, the sample surface gets changed to oxide. To avoid getting it changed to oxide before sintering aluminium paint was used as an anti-corrosive agent. A total of three consecutive coats applied each, after drying for minimum 12 hours at room temperature. Sintering was carried out at 390^{o}C for ninety minutes and compacts were allowed to cool in the furnace itself.

3.6. Cold Deformation on Sintered Zinc-Zinc Oxide Composite:

Initial height (H) and diameter (D) of all the composite samples were taken. From initial dimension, H/D ratios were calculated. In UTM, 50 kgf least count was set. Before the deformations were done, graphite was applied as lubricant on both the flat plates as well as on the sample contact surfaces to reduce friction. Samples were deformed starting with 250 kgf and then at subsequent intervals of 250 kgf till cracks on the surface appears. The compressive loads at which fine cracks appeared at the free surfaces of the preforms were recorded. The application of compressive load continued till the cracks became predominant at the top, bottom, bulge and height. Dimensional changes on the compacts due to deformation were measured by means of digital vernier caliper.

4. Results and Discussions

The sintered P/M Zinc-Zinc Oxide composite was made under three different oxidizing temperatures (150^{o}C, 200^{o}C, and 250^{o}C). Cylindrical preforms of four different aspect ratios for each temperature was employed in the compression tests.

Plots were drawn for pure zinc between the hoop strain and the axial strain to compare with composite (Figure 1) and zinc-zinc oxide composite (Figures 2, 3, and 4).The rate of change of hoop strain with respect to axial strain was not the same for all aspect ratios. This indicates that each aspect ratio had different slope and the hoop strain increased with axial strain. Among the three different oxidizing temperatures, sintered preforms oxidized at 150^{o}C had more strain values. Similarly, the aspect ratio of 0.55 also had high strain values when compared with others. From the plots it was also evident that the strain increased with higher aspect ratios. The deformation of the composites is less. Due to the low value of hoop and axial strain, composites have the low ductile property .This composite is more suitable for the compressive load applications.

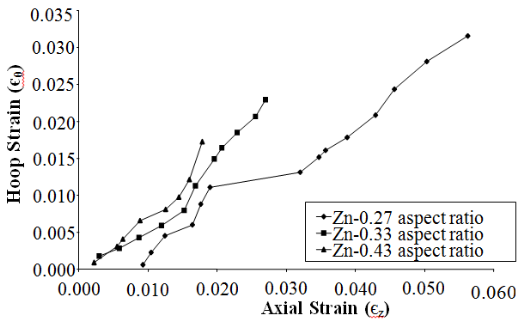

Figure 1: Axial Strain (ϵz) Versus Hoop Strain (ϵθ) for Zinc.

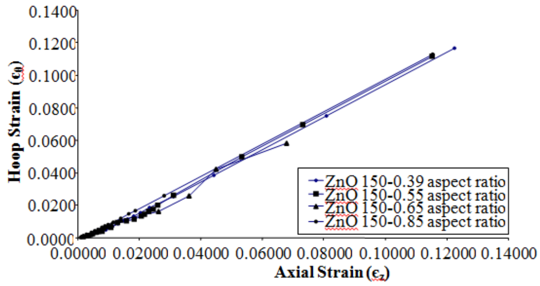

Figure 2: Axial Strain (ϵz) Versus Hoop Strain (ϵθ) for 150^{o}C.

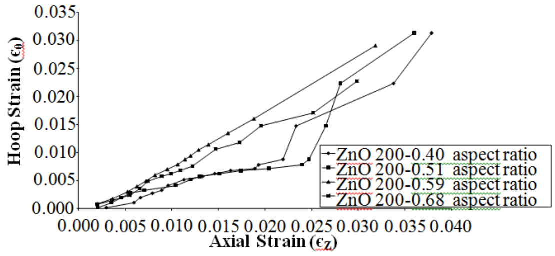

Figure 3: Axial Strain (ϵz) Versus Hoop Strain (ϵθ) for 200^{o}C.

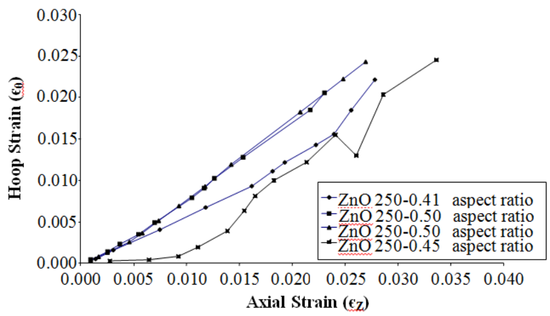

Figure 4: Axial Strain (ϵz) Versus Hoop Strain (ϵθ) for 250^{o}C.

Plots between the true stress and true strain are shown in Figures 5 to 8. The stress value of preform increased with true strain. The true stress value improved in the sintered preform compared with pure Zinc. It indicates that lower oxidizing temperature may be suitable for getting Zinc-Zinc Oxide composite with higher performance. However, in Zinc-Zinc Oxide composite oxidized at 150^{o}C, the slope of the curve was found to be the highest among the three different oxidizing temperatures (150^{o}C, 200^{o}C, and 250^{o}C) which decreased with increase in oxidizing temperatures. Studies have further indicated that the true stress value was doubled in sintered preform when compared with pure Zinc.

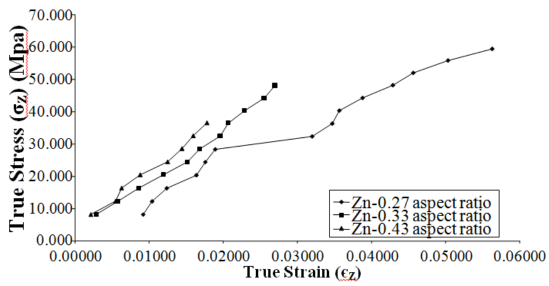

Figure 5: True Stress (σZ) Versus True Strain (ϵZ) for Zinc.

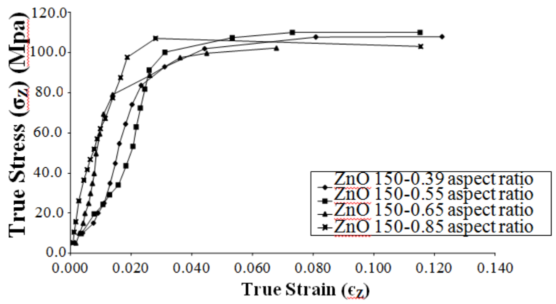

Figure 6: True Stress (σZ) Versus True Strain (єZ) for 150ºC.

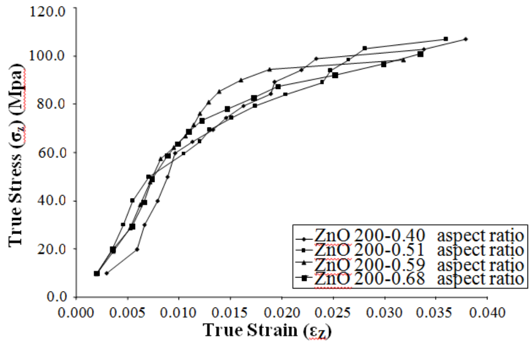

Figure 7: True Stress (σZ) Versus True Strain (єZ) for 200ºC.

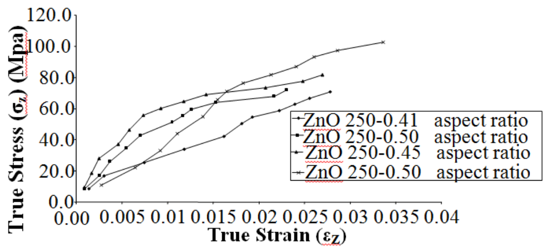

Figure 8: True Stress (σz) Versus True Strain (εZ) for 200ºC.

5. Conclusion

The major findings of the present investigations are:

- The rate of change of hoop strain with respect to the axial strain indicated high values for higher aspect ratios at low oxidizing temperature.
- The rate of change of true stress with respect to true strain was different for different aspect ratios.
- Higher aspect ratio had the maximum value of both true stress and true strain than lower aspect ratio in all sintered composites.
- Oxidized composite obtained at 150^{o}C had the highest stress rate as well as strain rate compared with other two temperatures (viz., 200^{o}C and 250^{o}C).

These investigations have indicated that even though we have obtained Zinc-Zinc Oxide composite using low temperature, we did not obtain the composite of a very high strength. This indicates that we may have to conduct further studies to obtain Zinc-Zinc Oxide composite of sufficiently high strength to make it suitable for industrial applications.

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