Formability Characteristics Of Aluminium Based Composites-A Review

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***Abstract*-In this review, the formability characteristics of Aluminium based composites using FEM and statistical tool are discussed. Formability characteristics of Metal Matrix Composites (MMCs) have been influenced by many factors viz., temperature, pressure, volume fraction of reinforcement, size and shape of particles. Investigation on wall friction, friction between particles and matrix powder are also presented. Detailed review has been carried out on the workability studies on upsetting of MMCs and forming limit diagrams. The state of the art has been discussed with the help of literatures.**

***Index Terms*—Upsetting, Deformation, Formability, MMCs, Powder Metallurgy, FEM**

I. Introduction

Metal Matrix Composites (MMCs) exhibit the ability to withstand high compressive stresses by transfer and distribution of applied load from the matrix to the reinforcement phase[1]. However, the compositions and relative amounts of the two phases are limited to narrow range, controlled by equilibrium conditions. These MMCs are fabricated by the addition of a reinforcement phase to the matrix by use of several techniques such as Powder metallurgy, Liquid metallurgy and squeezing-casting[2],[3].

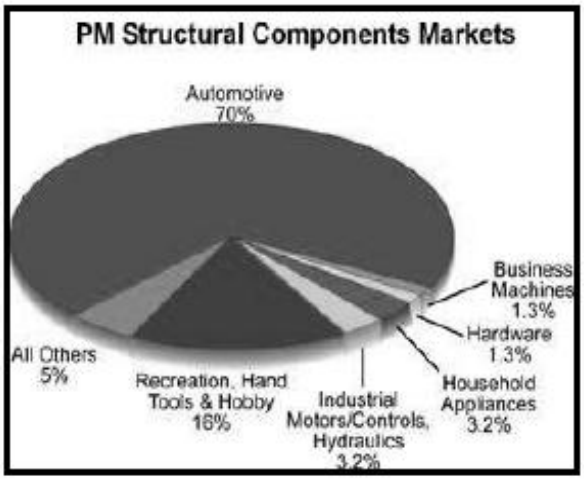

Figure.1 PM Products Market Distribution

The reinforcement phase is generally one of the following constituent: continuous boron, or graphite fibers or hard particles such as SiC and Al_2O_3 in the form of discontinuous particulate[4],[5]. The volume fraction of reinforced particles or whiskers is generally added within the range 10-30%[6]. A comprehensive review of the current and potential application incorporated with FEM for cast aluminium matrix composites on its formability characteristics in the automotive industry, manufacturing industry etc., have been provided through collection of literatures.

II. Fabrication of Metal Matrix Composites

Fabrication, a mixing process, is a critical step for homogeneous distribution through powder metallurgy[7]. Selection of particle size and shape influence consolidation. Some of the consolidation techniques are sintering, hot pressing, hot-isostatic pressing, plastic deformation and hot extrusion.

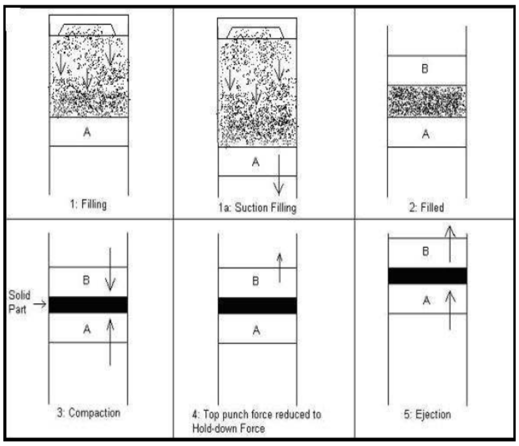

Figure.2 Production Process

A. Compaction

Compaction is widely used in metal forming industries. This technique usually involves relatively simple steps of blending powder and subsequent compression of mixture to produce compacts with stability [8].The simplicity and economic advantage of compression technique have attracted the attention of researchers. However data on simulation of powder compaction is scarce.

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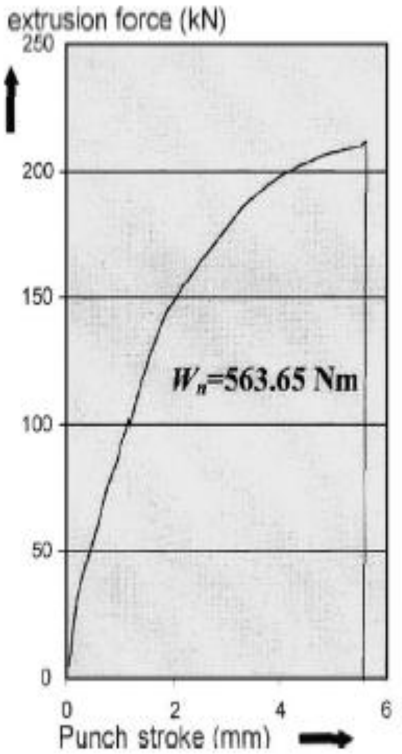

Figure 3.Load-Stroke Diagram

The significance of studying the movement of powder during simulation is to visualize the compaction process and to determine the development of internal cracks which is due to insufficient material flow [8]. Mathematical expressions for powder movement act as a base for compaction process which can be incorporated to modern computational tools. A method of analysis is to be employed in order to keep the number of factors that influence the powder movement to minimum. Uniaxial die compaction is commonly employed to promote the cohesion and densification of powder particles at low cost with high productivity. It also has advantage of fabricating billet with full densification. Fabrication can be done by mechanically alloying or Ultrasonic consolidation. Knowledge on relationship between the powder morphology, shapes and powder characteristics are vital to manufacture higher performance products by mechanical alloying process. Ultrasonic Consolidation process could be applied for the fabrication of MMC where fusion technique is not feasible and cold process is necessary [1].

B. Modeling of Mechanical Behavior of Powder During Compaction.

The mechanical behavior of powder during compaction can be analyzed using Numerical Methods in which the powder is modeled as an elastic-plastic continuum material [9]-[11].

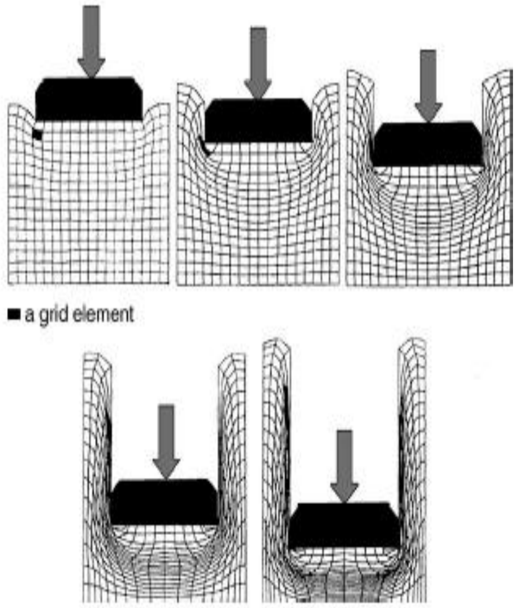

Figure 4.A Grid Pattern and Grid Element Moving

Drucker–Prager Cap (DPC) model was chosen as yield surface of medium which represents the failure and yield behavior by DPC model. The relationship between relative density of powder bed and applied pressure is also obtained. Further more, close examination of evolution of stress distribution during unloading reveals that there is a narrow band exists from the top edge towards the bottom centre of billet. Due to presence of band, potential failure occurs that leads to introduction of cracks [12]

III. Workability Studies

Workability is a technological concept that depends up on ductility of the material and the nature of the process parameters.

A. Workability Studies on Cold Upsetting of Al-Al2O3 Composite Material

Experimental research work has been performed for understanding of working behavior of Aluminum based composites under various stress state conditions namely uniaxial, plane and triaxial stress states [14],[15]. The working behavior of powder compacts at various state conditions were analysed.From the analysis, it is concluded that flow stress increases with increase in initial preform density whereas it decreases for smaller aspect ratio. It is also observed that preforms with higher aspect ratio and initial density experiences crack at higher strains.

B. Forming Limit Diagram

It is an effective tool to determine the formability of metals in varying strain conditions. Forming limit diagram are utilized to solve sheet metal forming problem in general, subjected to various combination of strain in particular. Necking during sheet forming sets the limit to maximum extent the sheet metal can be formed [16],[17]. The information on formability of aluminium sheets is vital for the manufacturers and researchers as well. Investigations on formability of different sheet thickness of aluminium alloys have been studied and further choosing the exact forming applications has been reported. It is believed that strain distribution profiles, obtained from forming experiment, yields good agreement with formability parameters.

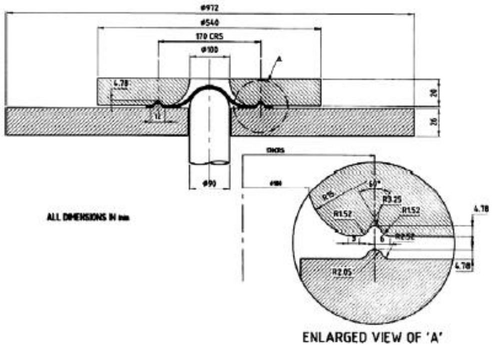

Figure 5. Froming Limit Diagram[16]

C. Processing of Al-SiCp Composite by Powder Metallurgy

Aluminum and its alloys, discontinuously reinforced with silicon carbide particulate, have been developed for various applications as silicon carbide in aluminium matrix results in increased strength and modulus. While processing Al-SiC_p composite, powder metallurgy and conventional ingot metallurgy are two methods employed to fabricate MMC.Among the two, powder metallurgy has been employed widely to fabricate MMCs because the properties are homogeneous and hence yields products with superior mechanical and metallurgical properties. From the earlier work [18], it is concluded that faster cooling rate and increase in volume fraction of SiCp leads to substantial improvement in strength. Moreover ductility increases with increase in temperature which enhances the flowability during processing.

IV. Mathematical Theory of Plasticity for Composite Material

A mathematical equation for calculation of flow stress in case of simple upsetting test is proposed for powder metallurgy preforms [19]. Numerical integration is carried out to compute yield stress, hydrostatic stress. It is also found that derived plasticity equations are adequate for describing the deformation behavior of sintered porous metals [20].

A. Yield Behavior of Cold Compacts:

The yield surface which arises from hydrostatic stress in the closed-die compaction, is strongly dependent upon deformation path. Hydrostatic compaction produces a yield surface which is approximately elliptical in mean stress whereas closed-die compaction generates yield surface which is elongated along loading direction [21]. The presence of inclusions strengthens the powder compact and thereby enlarges the yield surface; on the contrary, it does not change the shape of yield surface for both iso-static and closed-die compaction along straining paths.

B. Formulation, Validation and Numerical Procedure

Models of non-linear elasticity based on logarithmic description was first proposed by Hecky have gained much popularity. Constitutive equations are in two folds1) General lagragian and 2) isotropic Eulerian forms. Experimental data such as deformation, tension, torsion loadings with inclusion are employed for validation. Constitutive model investigated have revealed that Jacobi Iteration method presents a very good alternative to analytical solution of tensors [22].

C. Investigation of Yield Surface

Macroscopic yield surface of monolithic or composite powder depends on relative density of powder, particle arrangement and inter particle of cohesive strength as well. Powder compacts with no cohesive strength show nearly zero yield strength without confining pressure. With increasing cohesion, the yield surface expands and at full cohesion the yield surface is about twice the size of surface when compared in the absence of cohesion. Moreover, the Yield function as proposed by Xin et al[23] gives satisfactory description of the obtained yield surface.

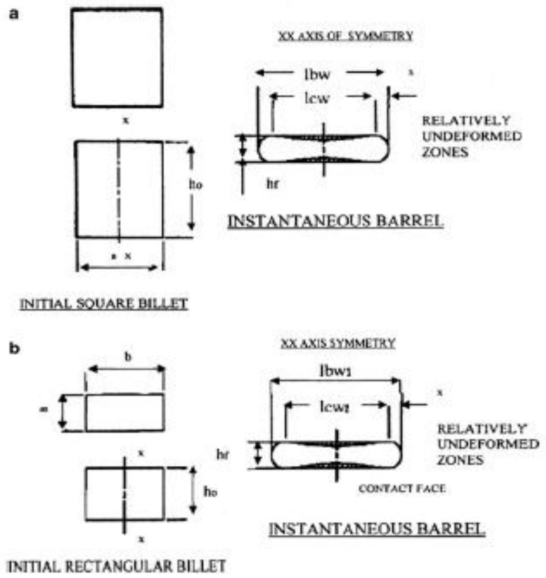

Figure 6.Schematic view of barreling[24]

V. Studies on Barreling During Upsetting

When a solid cylinder is compressed axially between a top and bottom plates, the work piece material in contact with their surfaces undergoes heterogeneous deformation resulting in barreling of cylinder [24]. The shape of barreling in simple upsetting was proposed as an arc of circle or circular curvarture and parabolic form.Narayanasamy et al[12] showed theoretically that barell radius could be expressed as function of axial strain by proposing a power law and verified through experimental results.

A. Phenomenon of Barrelling in Aluminium Solid Cylinder During Cold Upsetting

Upsetting experiments were carried out on annealed aluminium [24].The curvature of barreled aluminium billets were made on the assumption that it follows the geometry of circular arc. It is found that the barrel radius can follow the powder law equation.

$R=CS^m$; $R= C\ [(\sigma_m/\sigma)\ (h_0-h_f)]^{-m1}$ R-→Radius of curvature; σ_m-→ Hydrostatic stress; σ-→representative stress; h_0-→initial height h_f---→ final height; S-→ new geometrical shape factor, m,C,m1 empirically determined constants

B. Investigation of Barrelling Profile and Effect of Aspect Ratio on Material Flow

Series of experiments have been carried outby varying diameter and height of the billet. It is shown that convenient parts can be produced to its final dimensions by injection upsetting. Billets with large diameter and length offer sound metal flow. It requires high forming load, compared to smaller billet diameter [25]

C. Influence of Geometric Conditions of Die and Workpiece on Barrelling Formation.

The material flow characteristics of solid cylinder during upsetting when it is subjected to different geometric conditions such as taper angle and dimension of surface with in the top die and height to diameter ratio of billet were investigated[25].Between two platens, the top die with conical aperture is moved towards the bottom die with certain velocity. It is reported that the total friction constraint at the top interface becomes greater than bottom one which leads to extrusion of workpiece along upward direction [26].

D. Effect of Friction on Barrelling in Square and Rectangular Billets of Aluminium

Relationships were established between the experimentally derived values of friction factors for different lubricants from standard compression tests. It is observed that molybdenum disulphide exhibits efficient lubricant properties comparing with other lubricants tested [27].The bulge radius increased with increasing friction factor. Hence bulging effect is minimum for molybdenum disulphide. Power law relationship between friction factor and new geometrical shape factor(S) is expressed as

M=C1lnS+C2
M-→friction factor, C_1, C_2→experimentally determined constants

V. Application of Fem in Upsetting

FEM is one of the most powerful available tool to the mechanical engineers in general, manufacturers in particular[28]-[34].FEM codes are used to solve range of problems in various fields viz., civil engg,fluid dynamics etc.These codes can be incorporated in the deformation of MMCs at both macro or micro scale. Modeling task involves sketching the cross section of billet and developing a parametric modeling using package such as PRO/E, CATIA, UNIGRAPHIX etc followed by analysis package. In analysis the model can be remeshed to attain required accuracy of results by generating nodes. Better understanding on the processing conditions affect the final microstructure of billet is visualized through FEM.

A. Inelastic Behaviour of MMC Reinforced With Fibres of Silicon Carbide, Alumina Using FEA

The thermo-mechanical behavior of an aluminium alloy reinforced by different types of fibers is computed by FEM. computations of various monotonic and cyclic loadings show the strong effect of fiber material and the volume fraction of reinforcement on deformation behavior of matrix [28].

B. An Upper-Bound Analysis of Metal Forming Process by Nodal Velocity Fields Using Shape Function.

A new method of constructing a velocity field is proposed to solve metal forming problems by upper-bound elemental technique (UBET)[35].The velocity fields can be composed of nodal points using shape function. Specimen (a)Deformed (b)Undeformed[35]

The velocity fields are applied to analyze the axisymmetric cylinder-upsetting problem. Even if the velocity fields by shape function do not satisfy the volume constancy condition by themselves, they can be made to satisfy it by adding a constrained condition during optimization procedure.

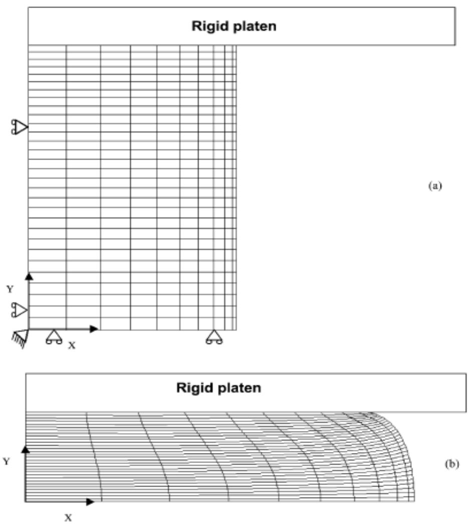

Figure.7 FE Simulation of upsetting of cylinderical[35]

In contrast to upsetting of homogeneous materials, in the case of graded material there is difference in material flow across specimen height due to variation in yield strength. This method combines the advantage of stream function. A Variation Upper Bound Method (VUB) is a method that determines an upper-bound solution using variation calculus.VUB method is attributed to be applicable for the problem of upset forging of ring and it presents an improvement on Upper Bound (UB) Method. From the results obtained, it is clearly indicated that the natural boundary condition, which constraint plastic flow of upsetting ring on contact interface, significantly affects the upper-bound solution not only in predicting bulge profile, but also in calculating the total forming energy rate [35].

C. Determination of Flow Stress by FEM

A common method used for the determination of material flow stress is the application of compression test. At a low strain rate and deformation, the precise flow stress can be obtained. However, at large deformation, the friction in interface between the die and specimen leads to bulging of sample that leads to inhomogeneous stress and strain. As a result, the flow stress precision is affected which can be reduced by (C-FEM)[36].The law of effect of bulging on precision is derived using C-FEM. A modified two-specimen method has been derived from an objective function according to inverse method. Its principle is that flow stress for a given material is a specimen geometry-independent, while flow resistance depends on it. This method not only can evaluate the validity of selected mathematical model, but also it can estimate the on-line coefficient of friction and flow stress[32].The flow stress and coefficient of friction obtained from the method have been examined by FEM and ring compression tests as well.

VI. Analysis of Workability Using Statistical Tool

In recent years, there has been a revival of interest to design the experiment among developed nations[37]-[42]. Because by and large, industries believe that their competitors have been using designed experiments for many years and this has been an important factor in their competitive success.

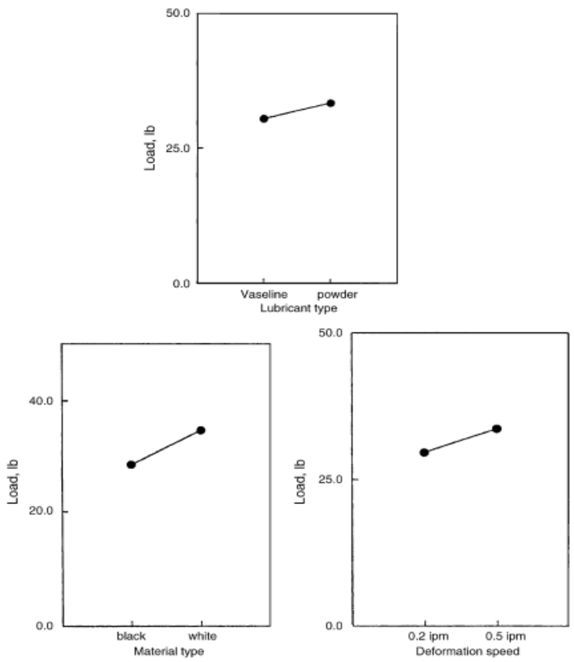

Figure.8 The main factor effect obtained from Statistical analysis[38]

The objective of modeling the process parameters is to determine the variables which are most influential during metal forming. Hence it results in products that are easier to manufacture, lower product cost and shorter product design and development time to use the statistical approach in designing and analyzing an experiment. While deforming copper preforms, Senthil velan et al[48] found that among the various parameters such as strain, strain rate, temperature and density, the effect of forming temperature is vital where as the influence of preform density is only lesser extent.

VII. Conclusions

The aim of this paper is to highlight the current research focus on formability characteristics of aluminium based composites containing SiC_p as reinforcement. However, only few of the investigations were based on systematic approach. Little information regarding particle size and volume fraction related to formability characteristics of aluminum composites is available. The Data collected by researcher through experimental investigation found in good agreement with FEM result. Hence Finite Element Methods and Design of Experiments techniques could be utilized for optimizing the manufacturing process due to its cost effectiveness and time saving.

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