Optimum Design of Metal Composites for Closed Die Forging

S. Sulaiman and M. Jolgaf

***Abstract*—In this paper, the application of commercial finite element software - ANSYS - has been used to model cold closed die forging process. The model has been developed using ANSYS Parametric Design Language (APDL) to simulate a single stage axi-symmetry closed die forging process for H cross sectional shape. The material used is AlMgSi matrix with 15% SiC particles, and its flow curve and fractural strain are obtained from the literature. Ansys Optimizer is used to obtain the maximum height that the material can flow in the rib by changing the *design variables* (DV) and the *state variables* (SV). Normally Design variables are geometrical parameters such as; rib height to width ratio, web height to rib height ratio, fillet radii, draft angle and billet radius. Optimization method called "Sub-Problem Approximation Method" was used to find out the optimal design set. The technique used in this paper can be used for newly developed materials to investigate its forgeability for much complicated shapes in closed die forging process.**

***Index Terms*—Closed die forging, forgebility, metal matrix composite, metal forming.**

I. Introduction

As Oil prices are going high, a strong pressure for weight reduction in car and aircraft fabrication urges the optimization of the design of products employing low weight materials [1]. Aluminum based metal matrix composites [Al-MMCs] are replacing the conventional materials because they exhibit lighter weight and sufficient stiffness and strength, which make them very good candidates for automotive applications [2], [3]. Closed die forging is the main metal forming process for the mass-production of middle-size or small forging parts [4].

Finite element methods and optimization techniques of closed die forging process is still of considerable interest. There are many objectives for these techniques, for example, material flow behavior, fold-over, improper die filling, tool wear and excessive forging loads, especially with a new materials emerging every day with very attractive properties to automobile and aerospace engineering. It is very important to study the flow behavior of these materials to produce defect less closed die forging products. A circular H shape part as shown in Fig. 1 was selected to conduct the finite element simulation and process optimization

Manuscript received October 2, 2012; revised November 20, 2012.

S. Sulaiman is with Department of Mechanical and Manufacturing Engineering, Universiti putra Malaysia (correcponding author, Phone: +6016-2206215; Fax: +603-86567122 (e-mail : suddin@eng.upm.edu.my).

M. Jolgaf was PhD candidate of Department of Mechanical and Manufacturing Engineering, Universiti Putra.

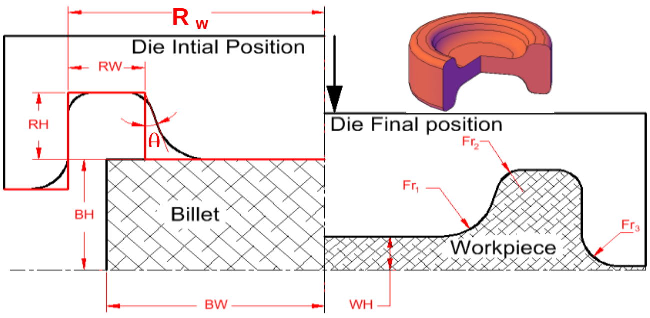

Fig. 1. Configuration of billet and die before and after forging

II. Metal Matrix Composites

Metal-matrix composites, in general, consist of at-least two components, one is the metal matrix and the second component is the reinforcement. The matrix is a metal in all cases, but a pure metal is rarely used as the matrix, it is generally an alloy. In the production of the composite, the matrix and the reinforcement are mixed together.

Aluminum is the most attractive non-ferrous matrix material used particularly in the aerospace and automotive industry where weight of structural components is crucial. Three types of reinforcement are used in MMC; particulate, short fibers and long fibers as shown in Fig. 2. The MMC material used in the simulation is AlMgSi matrix with 15% SiC particles which has a reasonable ductility (limit strain $\varepsilon = 1.05$) [5].

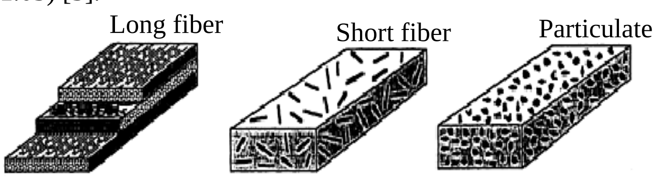

Fig. 2. Types of reinforcement in MMCs [6]

Forging MMCs cause particle and fiber breakage, and normally result in cracks at the outer surface of the billet [7, 8]. To avoid fibers and particles breakage which lead to cracks, the effective strain of the material must be kept lower than the fractural strain obtained from the literature which is $\varepsilon = 1.05$ [5]. The fractural strain is used in the optimization process as a state variable maximum limit.

III. Finite Element Model

The die cavity shape is represented with straight lines with an initial rib height/width ratio (RH/RW) then initial draft angle (θ) and fillet radii (Fr1, Fr2, Fr3), are added to get the

DOI: 10.7763/IJIMT.2013.V4.380

die profile, which is going to be modified until the optimal die shape is obtained for the selected material. The billet is represented with initial radius and then the height is calculated based on the volume of the die cavity, because the die cavity is changing during the optimization loops due to changing the **design variables**. The initial billet is represented with geometrical model consisting of assemblage of finite element. Equations relating the distribution of forces and displacements of the metal are established and the boundary condition and die movement are imposed.

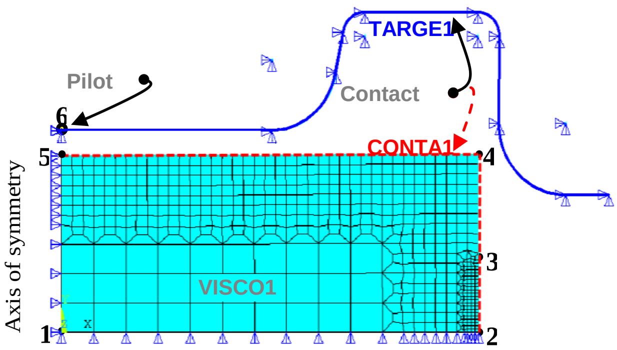

Fig. 3. The discretised model showing boundary condition

The components of the model are shown in Fig. 3. The cylindrical billet is made of AlMgSi reinforced with 15% SiC particles (AlMgSi + 15% SiC) and has an initial radius of 16 mm, just a quarter of the billet and the die being considered for the analysis to reduce the computational time and cost. Three types of elements are used in the model. The billet is built up of two dimensional 4-node viscoplastic solid elements (ANSYS type **VISCO106**). A rigid to flexible contact pair with a pilot node (Node no. 6) is used to represents die/billet contact. A two dimensional 2-node surface-to-surface contact is used to represent friction and sliding contact for the deformable surface of billet (ANSYS type **CONTA171**) and a two dimensional target element is used to model the rigid surface of the die (ANSYS type **TARGE169**), the boundary condition of the die surface follow the boundary condition imposed on the pilot node.

The axis of symmetry (line1-5) of the model is fixed in X direction including the pilot node (node6). The bottom line of the billet (line1-2) is fixed in Y direction. A displacement load is applied on the pilot node ($node_6$) in negative Y direction. The target elements (TARGE169) will be subjected to the same load and boundary condition of the pilot node associated to these elements by default.

Since forging process is associated with large strain, deformation and shape changing, it is hard to obtain a stress distribution, which equilibrates a given set of external load. As a result the total load is applied in a number of increments. During each increment a linear prediction of nonlinear response is made, and subsequent iterative corrections are performed in order to restore equilibrium by elimination of the residual forces. It is necessary to activate geometrical non linearity option [NLGEOM] in order to update the geometry in each increment (sub-step). In Ansys, the non-linear solution is based on the Newton-Raphson procedure.

IV. Results and Discussion

The aim of this work is to shape defect less products made of the selected material using closed die forging process.

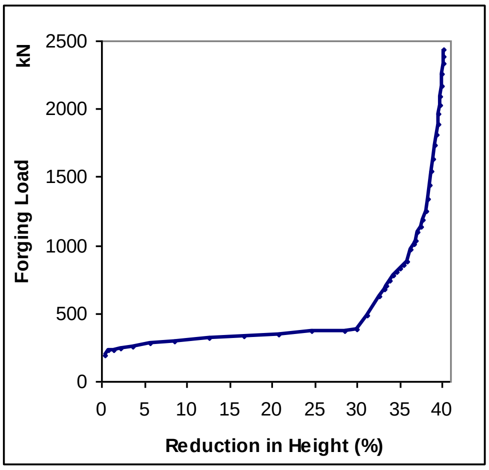

Fig. 4. Load displacement curve

The load displacement curve for the optimal design set obtained from the simulation is shown in Fig. 4. The forging load increases gradually until the beginning of the flash formation, after that it starts increasing sharply due to the increase of the flow resistance at the flash region. This resistance, force the material to fill the die cavity.

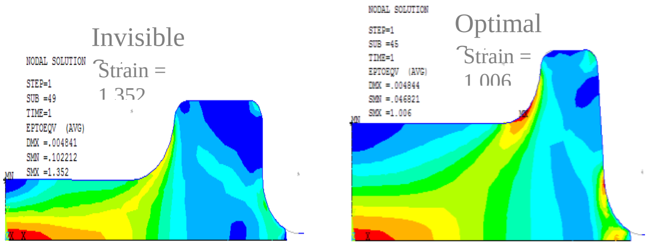

Fig. 5. Effective strain distribution

The maximum strain that the material AA2618 + 20% Al_2O_3 can sustain with out fracture is equal to (1.05). The strain distribution for optimal (best visible) and invisible design sets are shown in Fig. 5, their maximum strain values are 1.006 and 1.352 respectively.

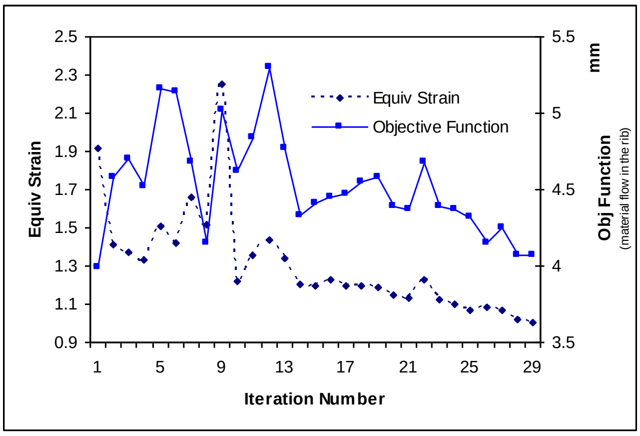

Fig. 6. The Equivalent Strain and Objective Function vs. Optimization Iteration Number

The optimization module is searching for the minimum objective function within the specified limits of the state variables. Fig. 6 shows how the objective function is been minimized by changing the Design variables, and the equivalent strain is also plotted in order to show how is the optimization module is going towards a save equivalent strain (ε<1.05).

The effect of the design variable (billet radius) on the equivalent strain is shown in Fig. 7, and it can be seen that while the optimization module is searching for a minimum objective function, the billet radius is increasing to force the strain value towards a value lower than the fractural strain.

In closed die forging process, there are two types of material flow deformation, upsetting and extrusion, which are controlled by the profile of the die cavity. The volume of the die cavity to be filed by displacing billet material by upsetting is constrained by the billet radius and the maximum equivalent fractural strain. As the ratio of the volume of the rib to the volume of the billet is bigger the closed die forging process is constrained by upsetting more than the extrusion deformation and vice versa. Fig. 8 shows the deformed mesh at final stage and displaced volume.

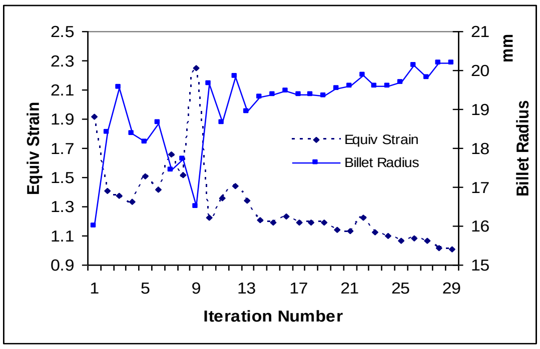

Fig. 7. The Equivalent Strain and Billet Radius vs. Optimization Iteration Number

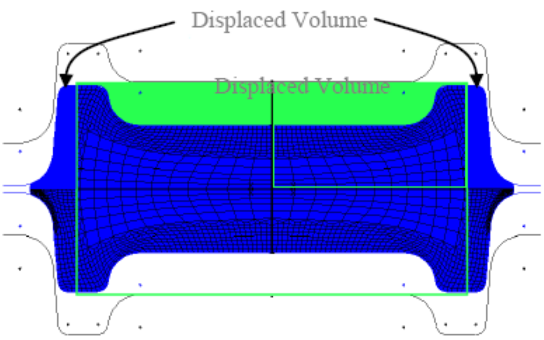

Fig. 8. Deformed Mesh Final Stage and displaced volume

V. CONCLUSION

In this work, the closed die forging process of Al-MMC was simulated using commercial finite element software (called Ansys) to investigate the metal flow behavior and to predict the forging load and the strain distribution. The forging process was optimized using Ansys optimization module. The optimization process was conducted in a selected design space, which is defined by intervals of some geometrical variables and state variables in order to find out visible design sets and select the best set based on the minimization of the objective function.

Finite element analysis in conjunction with optimization techniques, are used to develop a system for the design of optimal die shape of closed die forging process. The finite element model was built parametrically using Ansys Parametric Design Language. The optimization module uses the analysis file to search for the optimal die and billet shapes by changing the geometrical parameters (design variables) keeping the state variables within the specified limits. Performing this task wouldn't be easy with out combining the finite element analysis and the optimization techniques.

ACKNOWLEDGMENT

The authors would like to thanks to Universiti Putra Malaysia and Ministry of Science and Technology, Malaysia for their support throughout the project.

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S. Sulaiman was born in Jan 4, 1963, who is a Professor in the Department of Mechanical and manufacturing Engineering, Universiti Putra Malaysia. His major field is Manufacturing Engineering especially in Metal Forming includes simulation/modeling and experimental works. He managed to supervise more than 20 PhD students and published more than 200 International journal and conference papers. He received many recognitions from various organizations, national and international level. Currently he concentrates on processing of new materials include metal and nonmetal composite products.