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Modeling and Evaluation of the Generation Stresses during the Extrusion of Copper Matrix Composite

Abstract: - Composite materials provide low mass, good strength, and rigidity with high-performance products. However, combining many layers of material with different orientations by the addition of some reinforcements will enhance the material properties. Due to the nonlinear behavior of the extruded composite, the possibility of material failure will increase after generation stresses increase. The main objective of this work is to examine and determine the strength of a copper composite that is used in many applications such as aircraft and rocket motors. Due to the local discontinuity stiffeners that cause stress concentrations that impose high effects on the composite material, the analysis will be more complicated. Moreover, the presence of buckling can propagate through the structure to cause extra failures. The requested output in this model will allow the creation of plots of the model to give an indication of which regions are carrying the highest values of stress and strain. A cylindrical specimen with a diameter of (60 mm) and a (210 mm) length is considered in this study. This method is useful if we intended to use experiments based on this analysis. However, due to the nonlinearity of the material behavior, the computational solution costs would be greater. The distribution of axial pressure along the surface area and a nonlinear load-deflection analysis is used to predict the material behavior. Consequently, the shell element (CAX4R) type with (4-node) is used. The material orientation is defined by the relative angle of the model specification. The transverse shear effects are significant in the analysis of composites' cases, so the transverse shear stress along the element is calculated by using an approximation based on a numerical penalty. However, this type of analysis is interested in many fields of the industry.

Keywords: Copper Matrix Composite, Modeling, Evaluation, Stresses Generation, and F.E.M.

I. INTRODUCTION

Copper metal matrix composite is used in many engineering applications where good microstructural stability and higher temperature resistance are required. The Mechanical properties of extruded parts depend on many factors such as temperature and strain rate. Materials strength like the ultimate tensile strength and yield strength normally increases in the extrusion process due to plastic deformation. Moreover, severe plastic deformation results in better improvement in the microstructural and mechanical properties of many composite parts. [1]

During the extrusion of copper aluminum rods, material flow is possible to investigate by means of numerical analysis. This extrusion caused an inhomogeneous material flow and different flow stresses which cause deformation and fracture. The conical die is used to perform this work. The validation of this analysis made it possible to determine the conditions for a successful extrusion. [2].

In the paper [3], numerical simulations are adopted to study the induced residual stresses and transverse stress components to find their potential effect on strength of Cu-Al Composite Wires and their contribution to the axial stress-strain behavior. The results are discussed and concluded with a focus on the role of architecture and residual stresses.

In paper [4], corrosion-resistant behavior and mechanical properties of copper-based hybrid composites are analyzed by shaping in strip and stir casting form. The findings show that the prepared composites have greater strength, hardness, corrosion resistance, and ultimate tensile in comparison.

In work [5, 6], the numerical simulation is adopted for solving the defects problems such as the low utilization rate of materials, cracking, and fracture for the extrusion process of the W-25wt. %Cu composites under low temperatures. The results show that the cracking of canning was mainly caused by the flow speed between (W-Cu) billet and canning, and the difference in strain.

In work [7, 8], the extrusion process of the solid rod of composite copper is modeled by using the continuum mechanics method. Then commercial software LS-DYNA is used to simulate this process's geometrical parameters. The results approved that the properties are optimized.

A numerical method assisted by die cyclic oscillations is used to simulate a highly non-linear extrusion process (KOBO extrusion) by assuming viscoelastic and plastic effects in a wide range of temperatures and strain rates, which has been carried out in paper [9, 10]. Simulation results show the non-uniform strain distribution in the extruded material and the heterogeneous distribution of strain and stress inside the container. Also, an increase in temperature has been noted.

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In work [11, 12], the Conductivity of copper matrix composites reinforced with SiC whiskers has been investigated by testing the composite microstructure by using scanning electron microscopy. Results approved that the main factor affecting the electrical conductivity of the composites was whisker orientation and the SiC whiskers content. In this article, accurate modeling for the extrusion process of copper matrix composite has been implemented according to the design procedure. Then, generation stresses in weak points have been estimated as a result of the simulation process. The factors influencing the extrusion of this metal matrix composite on the product layout such as stresses and pressure were analyzed. Finally, some conclusions and recommendations points for this work are presented.

II. THE MAIN OBJECTIVES

The main objective of this work is to implement a finite element analysis for the extrusion process of a copper matrix composite. The findings of the simulation should be useful to investigate and clarify the problems and effects of the generation stress on product quality during this process. Also, to estimate the weak zones and avoid errors before investing in the actual tools.

III. MATERIAL AND METHODS

A. Geometry and Modelling process

The model consists of a deformable blank (Copper Matrix Composite rod), and two rigid tools, the upper side mold, and the lower side mold. The geometry of the matrix composite rod with all dimensions is shown in "Fig. 1".

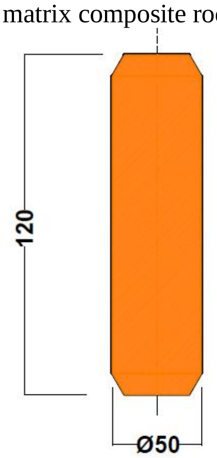

Fig. 1. The composite rod with all dimensions.

The rigid tools are modeled as analytical rigid bodies, and all contact and interactions between surfaces are assumed to be frictionless and lubricated. Also, the copper blank is modeled as a von Mises plastic-elastic material with isotropic hardening. The Properties of the copper metal matrix composites used in this work are illustrated in Table 1.

Table 1. Properties of the copper metal matrix composite product Cu-10% Al2O3

Property	**UTS (MPa)**	**Elongation (%)**	***Tensile toughness (J/m^3)***	***Density g/cm3***	***Porosity (%)***
Value	200 ± 6	10 ± 1.0	200 ± 6	10 ± 1.0	200 ± 6

The sequence steps of extrusion are illustrated in "Fig. 2, 3, and 4" respectively.

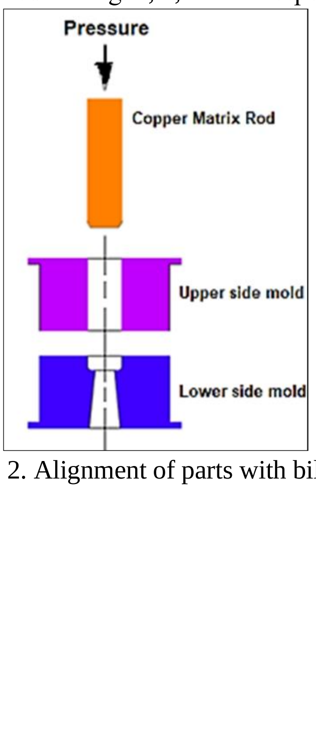

Fig. 2. Alignment of parts with billet.

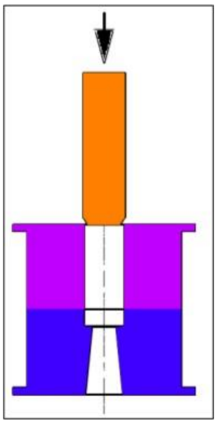

Fig. 3. Applying extrusion force.

Steps 1 and 2 are involving alignment and centering the upper and lower side mold with the billet and applying pressure on the upper surface of the billet to push it inside the cavity.

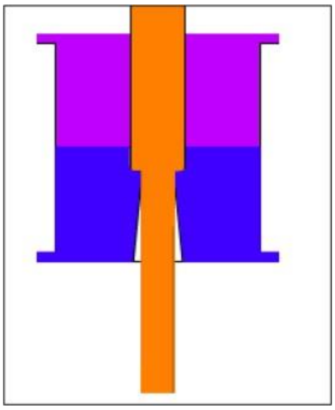

Fig. 4. Final extrusion step.

Step 3 is the final step which includes extruding the billet to the final shape by continuously pressing on the top surface. The completed assembly model which includes the press, mold, and billet is shown in “Fig. 5”.

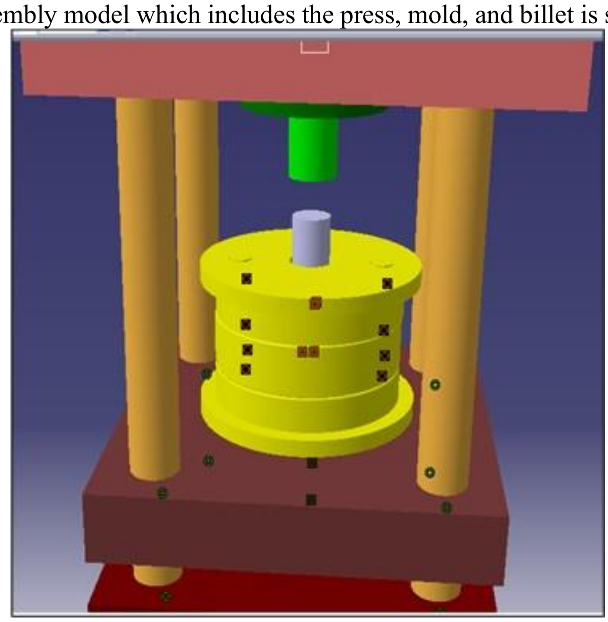

Fig. 5. The completed assembly model.

IV. Finite Element Analysis

The main geometry model consists of a rigid punch, a rigid die, and a deformable blank. The loading and Boundary conditions include fully constraining the die, and constraining the blank to prevent it from any radial direction, with vertical motion exception of the punch (82) mm downward and (5) mm/ sec velocity. The punch will constrain from any radial motion, but allow it to move downward and push the copper blank downward with a constant velocity along the die. As the blank is forced to push down, the copper rod will extrude and flows through the die with a (10) mm diameter to form a new solid rod, and during extrusion, the diameter of the blank will narrow and decrease to (7) mm. The basic criteria of interaction between the punch and die are based on considering the punch and die (non-deformable part) as masters, and the billet (deformable part) as a slave. "Fig. 6".illustrates this relationship.

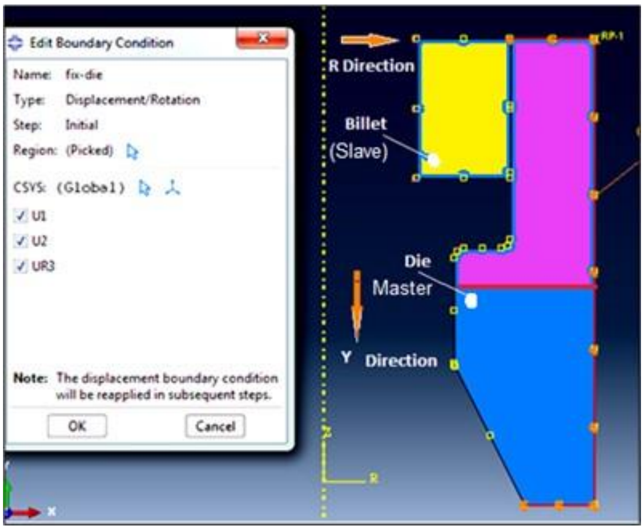

Fig. 6. Constrain and boundary conditions relationship.

The constraint of the deformable part (blank) will be in the direction of the axis symmetry (Y axis). Also, the radial expansion will be prevented by the strict contact between the die and the blank. However, the section is defined by giving the material thickness, and orientation, to obtain the section stiffness properties.

Due to the high deformation that occurs in this extrusion process, adaptive meshing is required especially in this type of geometry. Throughout the simulation steps, the mesh should be chosen to be suitable and work for the duration with the same mesh topology. This a necessary due to the high deformation that occurs during this process. The quadrilateral-dominated elements are the element type used by ABAQUS/CAE and the free meshing technique is adopted. The elements type of copper blank has meshed with (CAX4R) elements with a dimension (28 × 89) mm.

Instead of the default mesh, sweep mesh is used due to the extremely large deformation expected in this simulation by using the option (ADAPTIVE MESH). However, at the same time, a higher computational cost may result due to the increased number of advection sweeps. Before the analysis is performed, and to avoid any distortion, the initial smoothing mesh is required by easing sharp transitions and rounding out corners.

To increase the pressure linearly, the model is symmetrically constrained from the center about the Y-axis, and concentrated forces from the upper side and along the x-axis of a datum. It's modeled as a surface pressure toward the y-axis. To investigate the effect of the loading on the composite layers, the loading is considered to be uniform during static analysis. In the final extrusion step, a symmetrical load (5500) N is applied at the top surface of the billet.

V. Results and Discussion

The simulation for the forward extrusion is performed for a circular die geometry, by using an adaptively Eulerian mesh domain. The flat-nosed die geometry is used adaptively on a Lagrangian mesh domain.

At the start of the extrusion process for the composite material, the overall deformation is very little and the material flow speed is less than the required due to the Eulerian domain. At this point, and due to a multi-point constraint, the boundary is defined to keep the uniform extrusion velocity of (5) m/sec in the vertical direction. The nonlinear extrusion analysis is carried out by imposing a reduction on the specimen.

The simulation results show that the peak pressure is slightly above the predicted load and the overall prediction response is significantly lower than the peak load. In addition, the results show that the strength is slightly increased after the initial peak. The plots show the response results are symmetric but, the load is non-symmetrical.

Initially, at the onset of extrusion, the required force to compress the composite bar (2) mm is (100.2) kN. The axial load distribution is localized over the area subjected to high-stress values. The prediction generation stresses are one of the aims of this analysis. In this step, the normal load magnitude is applied, and since deformation is a linear perturbation, the stress

Thinning the billet and extreme deformation at the punch fillet will be faster at the end of the final analysis step. At this step, plastic strains and stress generation will reach their maximum values. Contours of equivalent Von Mises stresses are shown in "Fig. 7".

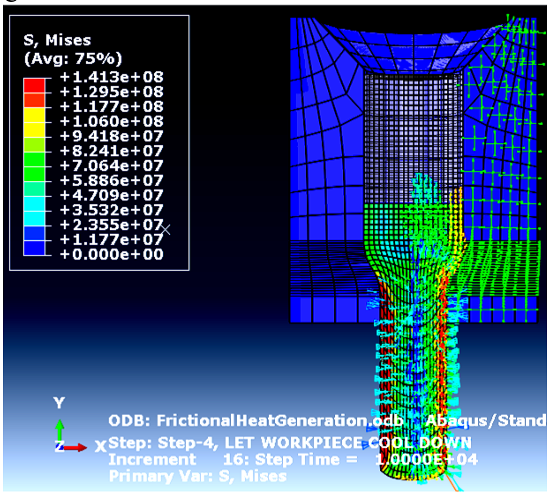

Fig. 7. Contours plot of equivalent Von Mises stresses.

At this stage, the elements become too distorted, and the analysis cannot be continued and will stop after pushing the billet (80) mm through the die. Since the cross-sectional area of the opening die has less area than the original billet, the final measuring rod will be three times the length of the original billet.

The extrusion velocity will approximately reach a steady value of (5) m/s, and this is consistent with the extrusion ratio in using the opening die and the assumption size of incompressible billet material. Hence, the collision between the particle's decrease and the value of principal stresses will come down. The contour of the resultant velocity is shown in "Fig. 8".

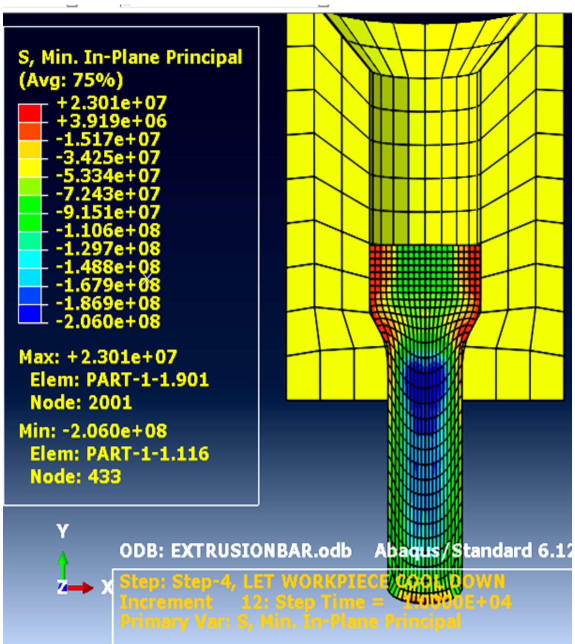

Fig. 8. The contour plot of the principal stresses in plane.

The contour of principal stresses in Figure (7) is an indication of the particle movement due to displacements and dislocations between the crystals in the last extrusion step. The particles will gain a strain energy due to this dislocation and the copper matrix rod will extrude smoothly at regular speed.

Extrusion speed is positively propriospinal with extrusion force as shown in "Fig. 9".

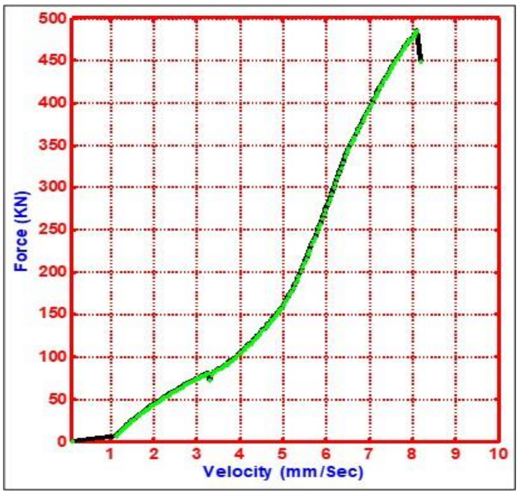

Fig. 9. The propriospinal between extrusion speed and extrusion force.

VI Conclusions

The following items have been concluded from this analysis:

It's found that the generation stresses are always concentrated at the fillet, rounded and sharp zones in both die and punch. Consequently, reducing the stress concentration which has a huge drawback on the product quality is possible through careful design for the profile of extruded dies. It's also found that the extrusion load is inversely proportional with the die angle. Hence, when the die angle decrease the load is increase and vice versa. The dead metal zone is always formed due to the small die angle which causes high friction and severe contact between the billets and dies surfaces. The other important variables are the temperature and ram speed. Controlling the temperature and ram speed will give a significant impact on the mechanical properties of the extruded part.

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