EXPLICIT COUPLED THERMO-MECHANICAL FINITE ELEMENT OF 5182 H111 ALUMINUM ALLOYS.

EL Amri Abdelouahid and Mounir El Yakhloufi haddou

Condensed matter, radiation and numerical simulation laboratory, Faculty of Sciences, M'hannech II 93002 – Tetouan – Morocco

Issam hanafi

National School of Applied Sciences (ENSAH), BP 03 Ajdir, Al Hoceima, Morocco

ABSTRACT:

The paper presents a method to estimate workpiece-die heat transfer coefficient is presented using FEM simulations. Simulation using finite element method shows the die heating along time for various heat transfer coefficients. However, the formation of the defect could be successfully suppressed by changing the frictional Conditions of the workpiece/dies interface. The aim of the research is to reach consistent value for heat transfer coefficient between workpiece-die; to later study ways to minimize it, decreasing thus the thermal gradient in the dies and, as a consequence, minimizing the fatigue effect for each tree blows only two parts are produced.

Keywords:

Aluminium alloy, friction, extrusion, finite element analysis, ductile fracture, thermo-mechanical finite element simulation.

1. INTRODUCTION:

The simulation of hot metal forming processes in most cases can be done using the assumption that the deformed material is a rigid-plastic continuum while the dies are rigid bodies (Alexey Vlasov,). Nevertheless there are many cases where such simplification may result in inadequate accuracy. The die deformation in cold foring may be significant comparing to the product tolerances and must be taken into account during simulation of such processes. In case of hot foring the location of the die cavity with respect to press central axis may vary significantly. This causes non-axial loading of the press that in turn results in its uneven deformation. To provide control of press deformation that is vital for precision forging technology the whole system (workpiece-die-forging press) is to be simulated using coupling of both mechanical and thermal problems. The ABAQUS software gives the ability to solve such kind of problems. The meshing technique used in this work was developed to solve the remeshing stage in large deformations (T.Coupez, 1992 et 1994).Several examples of applications in material forming process can be found in [T.Coupez,1998].

The coefficient of thermal expansion for 5182 H111 aluminum alloy and Young's modulus of the structure are actually functions of temperature. The coefficient of thermal expansion increases with temperature while modulus decreases. In the structure, the decrease in stiffness produces decreases in maximum stress, but this is overcome by the increase in stress due to the increase in coefficient thermal expansion (Wei H. Ng, Peretez.Friedman, 2006). Failure of ductile materials is involved in a wide range of applications including the optimization of fast manufacturing process and the security of structures exposed to impact. Naturally, when subjected to dynamic loading the behavior of metallic is quite distinct from that observed under quasi-static conditions [1]. There have been many experimental studies reported in the literature about dynamic fracture process in large scale engineering structures [2].

In current computational engineering practice, there are essentially three approaches to simulate fracture by adjusting the topology structure of a FEM mesh in order to represent a ongoing material surface separation in the computational domain. There are two main challenges in simulating ductile fracture in 3D engineering plate/shell structures. First, the evolving crack surface loads to time-evolving traction-free boundary growth in computational domain, hence the finite element of evolving material geometry and topology have to change accordingly. Ductile fracture is often accompanied with enormous high plastic deformation, and in turn the material plastic flow will generate a large amount of heat at the local area where material exhibits viscoplastic behavior. However, the various Gurson models do not consider thermo-mechanical coupling effect. To take into account the rate – dependent and thermal-mechanical coupling effects, Johnson and Cook (1983, 1985) proposed a rate dependent plasticity constitutive model, which is referred to as the Johnson-Cook model. We briefly introduce the Johnson-Cook model and its constitutive update.

A coupled thermo-mechanical model for aluminum alloy 3003-h111 was developed using Barlat's YLD96 anisotropic model (Barlat et al., 1997) and then implemented into the element program LS-DYNA as a user material soubroutine (UMAT). Aluminum sheet, in particular, has much lower formability at room temperature than typical sheet steel (Ayres,1979a).

Numerical analysis is a critical tool for understanding the complex deformation mechanics that occur during sheet forming processes. Finite element analysis (FEA) and simulations are used in automotive design and formability processes to predict deformation behavior accurately during stamping operations. Confidence in the numerical analysis of formability depends on the accuracy of the constitutive model describing the behavior of the material (Chung and Shah, 1992). A coupled temperature and strain rate dependant material model for the dynamic deformation of material using von Mises Yield function proposed (Voyiadjis and Abed, 2006). The evolution of the yield surface of 5182 H111 aluminum alloy as a function of temperature and its effect on the anisotropy coefficients have not been fully explored.

Multiple material models can be used for representing the anisotropic behavior of 5182 Aluminum alloy. Vegter and Boogaard (2006) proposed a plane stress anisotropic yield function for sheet metal by using the method of interpolation of biaxial stress states. The aim of this work is to show the application of state of the art thermomechanically coupled simulation methods and their validation for 5182 H111 aluminum alloy.

2. MODELING AND FINITE ELEMENT ANALYSIS

a. Coupled thermo-mechanical finite element model

Finite element analysis (FEA) was performed using the commercial finite element Software to understand the deformation behavior of the 5182 H111 aluminum alloy during the thermo-mechanical loading. The full size finite element model used four-and three-node shell elements.

The thermal analysis was performed first, during which the temperature of each element was calculated. Using the temperature value for each element, the temperature dependent isotropic material model coefficients were calculated. In the numerical simulation, no heat transfer was allowed to occur with the surrounding air since in the experimental setup the heaters maintained the temperatures of the material at a constant level.

b. Johnson-Cook model and its constitutive update

The Johnson-Cook model (Johnson-Cook,1983,1985), is a rate-dependent thermo-mechanical constitutive model, which has been extensively used in simulations of ductile fracture induced by high strain rate loading such as shock waves and high speed impacts. The thermo-mechanical coupled mesh free Galerkin formulation are not described in this paper, and interested readers can refer to Ren and Li (2010) for details.

In the Johnson-Cook model, the effective plastic strain rate is defined as:

$$\dot{\bar{\varepsilon}} = \dot{\varepsilon}_0 \exp\left\{\frac{1}{C}\left(\frac{\sigma_M}{g(\bar{\varepsilon},\mathrm{T})} - 1\right)\right\} \qquad (1)$$

$$g(\bar{\varepsilon},\mathrm{T}) = (A + B\bar{\varepsilon}^{n})(1-\Gamma^{m}) \qquad (2)$$

$$\Gamma = \frac{\mathrm{T}-\mathrm{T}_0}{\mathrm{T}_m - \mathrm{T}_0} \qquad (3)$$

Where ε_0 is referential strain rate, and normally it is chosen as $1.0s^{-1}$, n and m are strain hardening and thermal softening parameters. T_0 and T_m are room and melting temperature respectively.

For thermo-mechanical coupled problem, the total deformation can be decomposed to elastic, plastic, and thermal parts.

c. Heat properties of 5182 H111 aluminum alloy

- **Thermal conductivity**

$$\lambda_s = \begin{cases} -0.022T + 48(W/m.^{\circ}C) \\ 28.2(W/m.^{\circ}C) \end{cases} \qquad (4)$$

- **Heat transfer**

The heat transfer between the faces exposed to fire of 5182 H111 aluminium alloy and the atmospheric temperature proceeds by heat convection and heat radiation. This kind of boundary condition belongs to the third boundary condition.

$$-\kappa\frac{\partial T}{\partial n}=\alpha_1(T-T_f)+\varepsilon\sigma\left[\left(T+273\right)^4-\left(T_f+273\right)^4\right] \quad (5)$$

In which,

n Normal vector of members' surface
ε_1 heat convective coefficient, is taken as 25 (W=m^2.K).

T_f Temperature of environement (°C)

- Heat emissivity coefficient, is taken as 0.5
- Stefan-Boltzman constant, is taken as 5.67x10^{-8} (W=m^2.K^4).

Temperature elevation in 5182 H111 aluminum is governed by the general heat transfer principale. To analyse the three-dimensional temperature field of 5182 H111 aluminium alloy, an 8-node heat transfer linear 3D solid element (DCC3D8D) was used for concrete and a 4-node heat transfer quadrilateral shell element (DS4R) was utilized for the steel hollow section. The '' Tie'' constraint was selected to simulate th e heat transfer between the surface od die and workpiece. The influence of die on temperature field was ignored (Z.H. Guo and X.D. Shi,2003).

d. Thermal and mechanical material properties:

The problem below shows the cross-sectional view of an 5182 H111 Aluminium alloy cylindrical bar placed within an extrusion die. The bar has an initial radius of 100 mm and a length of 300 mm, and its radius is to be reduced by 33% through an extrusion process. The die can be assumed as an isothermal rigid body. During the extrusion process, the bar is forced downwards by 250 mm at a constant displacement rate of 25mm s^{-1}. The generation of heat attributable to plastic dissipation inside the bar and the frictional heat generation at the die-work piece interface cause temperature of the work piece to rise. When extrusion is completed, the work piece is allowed to cool in the ambient air. The ambient surrounding is at 20°C, with a coefficient of heat transfer of 10 Wm^{-2}K^{-1}.

Formulate an axis symmetric FE model to predict the geometry of the deformed bar, the plastic strain distribution and the temperature evolution, at various stages of the extrusion process.

The die and the cylindrical sample are maintained at the same temperature so that die chilling, with its influence on thermal flow, is prevented.

The plastic model so-called flow stress data was created from the measurement test used in the simulation. The advantage of this method is the possibility of calculating the flow stress directly from the force measurement during compression test. Flow stress data are influenced by deformation temperature, strain and strain rate (Taylan Altan, 1983).

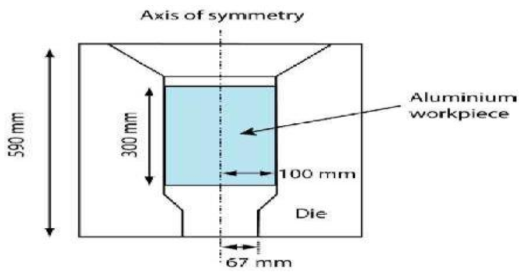

Figure 2: Geometry of the tested specimens 5182 H111 Aluminium alloy

Table 1. Mechanical and thermal properties of the tested specimens

Thermal and mechanical properties	5182H111 Aluminum alloy	Die material
Density(kgm^{-3})		2700
Specific heat($JKg^{-1}K^{-1}$)		880
Young's modulus MPa	2700	$200x10^9$
Expansion coefficient-alpha (K^{-1})	$8.42x10^{-5}$	
Tensile strength (Nmm^{-2})	284	
Yield stress (MPa)	154	
Mass thermal capacity ($Jkg^{-1}K^{-1}$)	909	
Thermal conductivity ($Wm^{-1}K^{-1}$)	209-232	200

The example output is shown in (Figure 3).

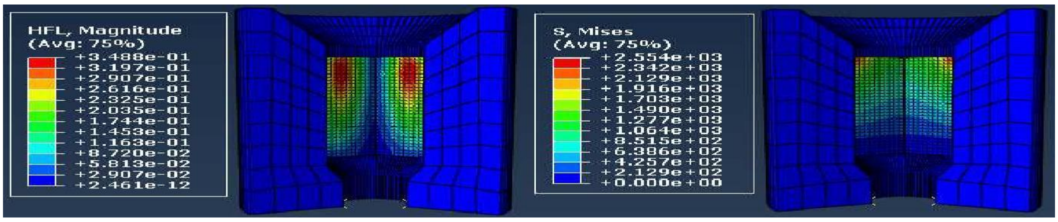

Figure 3: example of an output results

3. RESULTS AND DISCUSION:

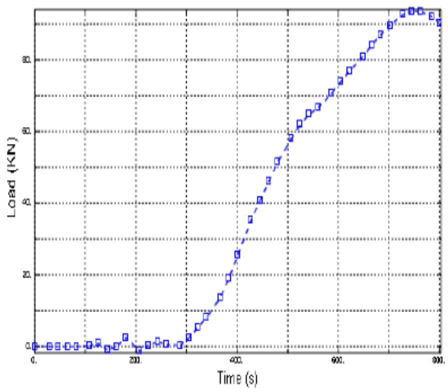

Figure 3: load vs.

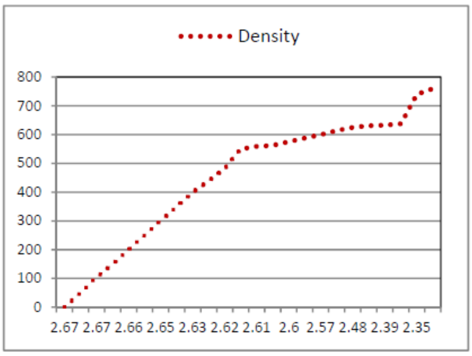

Figure 4: Density vs.

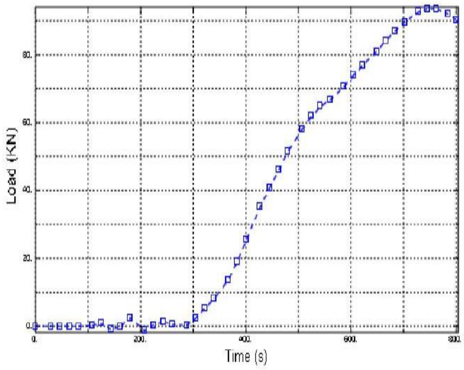

Figure 5: conductivity vs temperature

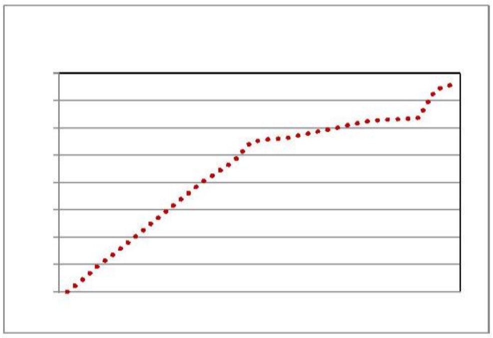

Figure 6: Specific heat variation vs temperature

In the heat treatment of metals, high temperature generally cause large grains to develop; depending in the metal and application, large grains may have undesirable attributes. The properties of coarse-grain metals are impaired by the size of the grains and by changes that occur at the grain boundaries. In 5182 H111 aluminum alloy, solution heat treatment improves mechanical properties by developing the maximum practical concentration of the hardening constituents in solid solution. Fatigue cracking is identified by the presence of numerous small cracks adjacent to the fracture. Crack-Propagation paths in 5182 H111 aluminum alloy may be intergranular or transgranular depending on the frequency, temperature. The conductivity of 5182 H111 aluminum alloy as a function of pressure and temperature and its other material properties are shown in Table 1.

Furthermore, a change in the loading curve during time was obtained. Load start, i.e. elastic strain start, then plastic strain start point where the maximum force is reached, i.e. the end of homogenous plastic strain. Figure 6 shows that the maximum elongation before final failure line started. Figure 1 shows the load vs. time the beginning of elastic deformation, the beginning of plastic deformation, reaching maximum force 95 KN, the homogeneous plastic deformation to the final fracture of the specimen.

4. CONCLUSION:

Thermal coupling allows more accurate calculating of the distribution of the temperature in the dies and work piece and provides the background for prediction of the thermal cracks and fatigue in case if respective material models can be incorporated. The thermo mechanical analyses of the 5182 H111 obtained with the refined assumptions produce a substantial number of important results. These results indicate that the presence of thermal and mechanical damage is capable of increasing the maximum temperature in the 5182H111 aluminium alloy to its melting point and may result is structural damage in the underling structure. Therefore the findings of this particular numerical simulation are summarized as the loads increase with the time up to a particular aging time which depends on the alloy composition and aging temperature. The density, specific heat and conductivity are increases gradually with increase in the temperature.

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