MODELLING HOT DEFORMATION OF Fe-Ni ALLOYS FOR THE AEROSPACE INDUSTRY

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ABSTRACT

Hot forging of an Fe-Ni-Co alloy used for aeronautical purposes has been modeled using the commercial software ABAQUS™/Explicit in order to obtain all the mechanical and thermal information to proceed with piercing and ring rolling. The material used is a 909 Incoloy type super alloy and it is used for the energy generation industry. Information of the constitutive behaviour of the alloy was introduced into the package using experimental data from mechanical testing at different temperatures and strain rates. A thermo coupled analysis was carried out, temperature, stress and strain distributions were evaluated in order to use the results of the model for the further simulation of the ring rolling of the material.

INTRODUCTION

Hot forging of Fe-Ni-Co alloys takes place before piercing and ring rolling, as for other super alloys (Park et al. 1997). The selection of the forging route (temperatures and total strain per step) depends on the requirements of microstructure and final mechanical properties of the product (Cho et al. 2005).

Table 1 shows the chemical composition of the alloy under study and Table 2 its thermal properties. Figure 1 presents the experimental flow behavior of the alloy under mechanical deformation at different strain rates, ranging from 0.001 to 1000, all tests were carried out at a temperature of 1100 ºC, other authors have report similar results but for a different material (Sinczak et al. 1998, Thomas et al. 2006).

After forging, piercing takes place, for this particular case a schedule of three steps are necessarily for the piercing, the first step used a tooling to start the hole in the forge piece, a second step includes a correcting tool for the started hole and the last step makes the final cutting. After the piercing has been finished ring rolling continues and sometimes heat treatment to finish with machining. The model here presented includes the forging and the fisrt step of the piercing process.

Table 1: Chemical Composition of Incoloy 909

	Fe	Ni	Nb	Co	Al	Ti	Si
Wt%	40.6	38.2	4.80	13.0	0.15	1.50	0.40

Table 2: Thermal Properties of Incoloy 909 at 1100ºC

Thermal Conductivity	16.206 W/m ºC
Expansion Coefficient	2.075 E -5 1/ ºC
Specific Heat	610 E 6 mJ/ Ton K

FINITE ELEMENT MODEL

The model is designed for hot forging of Fe- Ni-Co alloys prior to piercing and ring rolling operations, hot forging is carried out at 1100 °C, the starting dimensions of the billet are 25.4 and 108.6 cm of diameter and length, respectively, which is deformed 76%, at a forging speed of 0.4cm/s. A 2D dynamic axisymmetric explicit thermocoupled model was developed, using symmetry as to model one quarter of

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the whole geometry, Fig. 2. The software used for the analysis is Abaqus/Explicit. The model included a total of 2806 nodes and 2674 elements, type CAX4RT, 4-node thermally coupled axisymmetric quadrilateral, bilinear displacement and temperature, reduced integration, hourglass control, mass scaling factor of 100,000 was used. Different friction coefficients at the interface tool-workpiece were used, for the lower tool a coefficient of 0.15 was considered and for the upper tool 0.3 and 0.5. An Adaptive Langrangian Eulerian (ALE) mesh was used. Also convection and radiation to the environment were taken into account for the model, with an emissivity coefficient of 0.7 and convection coefficients of 0.1 for the interface tool-workpiece and 0.01 for the interface workpiece-environment.

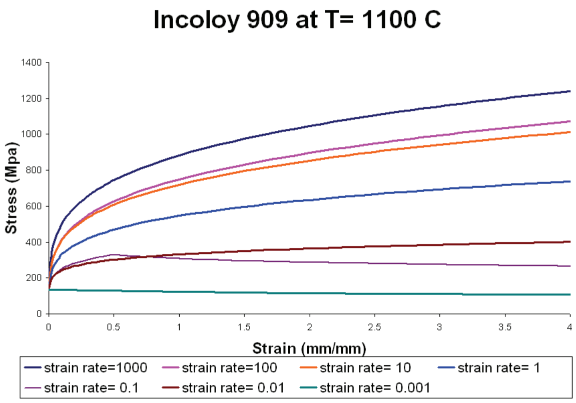

Figure 1: Mechanical behavior of 909 Incoloy at different strain rates for T=1100ºC.

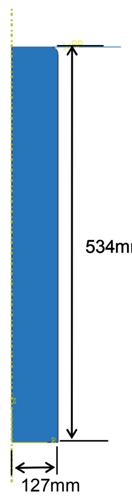

Figure 2: Modeled Geometry, Axial and Radial Symmetry.

The results obtained for the forging are the temperature, the stress and the strain distributions, this information was used in a model to continue modeling the piercing, the ring rolling will be modeled in a further model.
The mesh produced after forging was exported as an orphan mesh, which was remeshed, Figure 9. The piercing takes place also at 1100 ºC and by three steps, as explained before, only the first step is presented. The piercing is performed in the first step by a tool of 97.5 mm top diameter and 92.5 mm bottom diameter, the time for this step is of 29 seconds, same mass scale factor of 100, 000 was used, also friction was used at the interfase of the upper and lower tools as before, 0.15 and 0.5. For the piercing tool a damage theory was used, same thermal conditions as in forging for convection and radiation were used. A total of 1878 nodes and 1793 elemnts type CAX4RT were included for this model.

RESULTS

Figures 3 to 8 show the results obtained of temperature, equivalent Von Mises stress and plastic strain distributions for the two different values of friction coefficient used, 0.3 and 0.5, at the interface of the upper tool workpiece, the latter gave a slightly bigger concentration of stresses at the tool interface, however at plant process a coefficient of 0.15 is considered, so the presented results must be corrected to the assumed plant value. Also the final dimensions of the billet obtained with the FEM model for the forging are in agreement with those measured at plant, as the final dimensions were constrained.
Results from the piercing model are presented in Figures 10 to 12.
All images presented are generated rotating the 2D axi-symmetric geometry.
The speed used for the forging is equivalent to the strain rate of 0.01. The maximum values for the stresses found using μ of 0.3 were of 313 MPa and for μ 0.5 of 315 MPa. A maximum displacement value of 243.3 mm was found for both cases and the maximum temperature was of 1103 ºC for both cases.

CONCLUSIONS

A model for the production of forgings for the aerospace industry has been achieved, as well as a model for the first step of the piercing process, further work is needed to obtain the models for finishing the piercing and for the ring rolling, all models must be validated.
It was found that the friction coefficients used do not extern influence on the strain or temperature distribution only on the stress distribution.

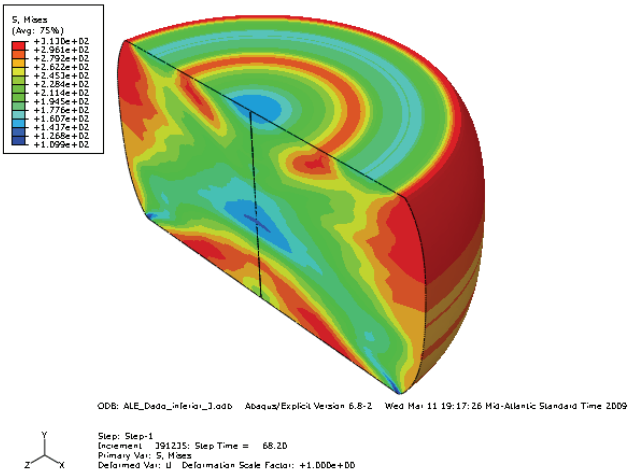

Figure 3: Stress distribution using μ 0.3.

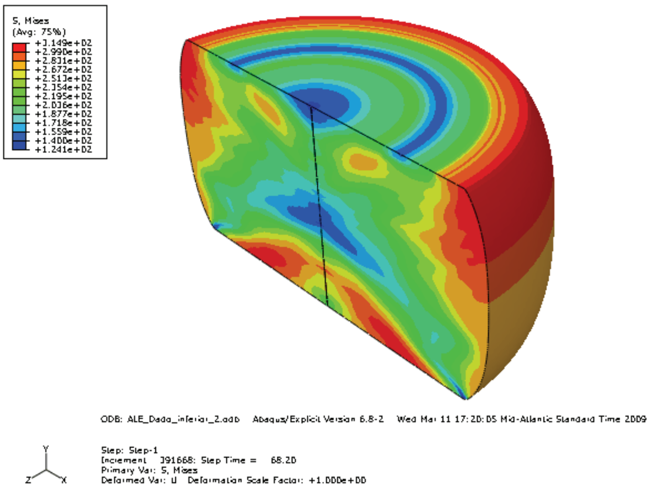

Figure 4: Stress distribution using μ 0.5.

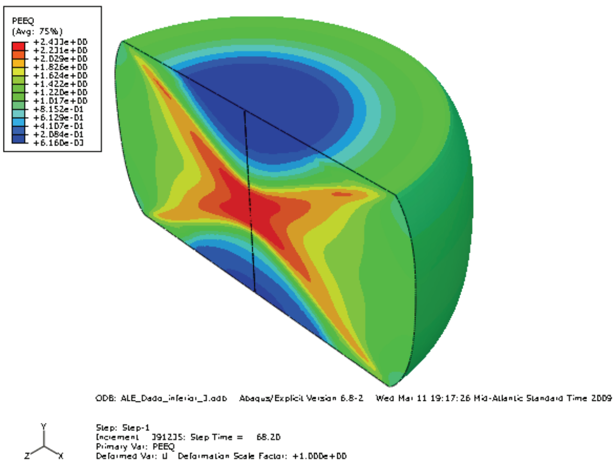

Figure 5: Plastic Strain Distribution using μ 0.3.

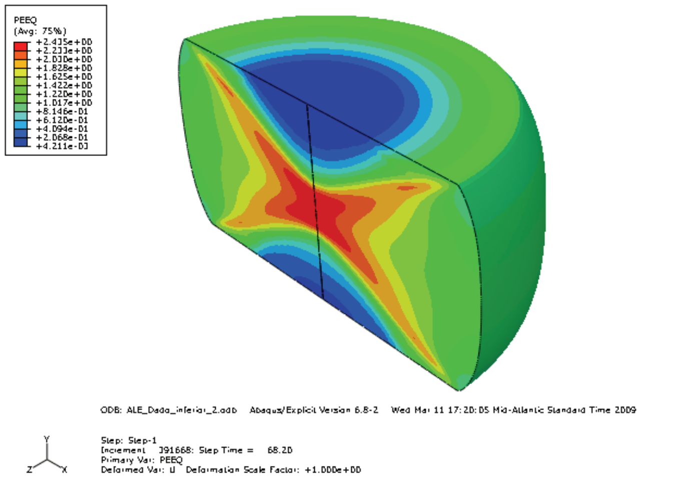

Figure 6: Plastic Strain Distribution using μ 0.5.

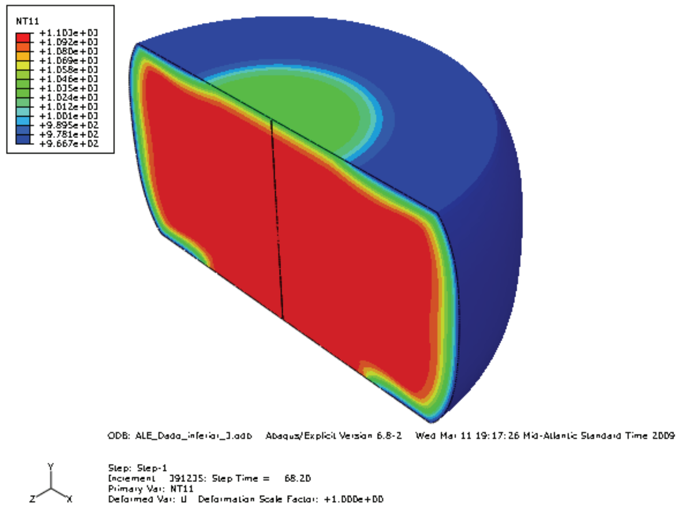

Figure 7: Nodal Temperature Distribution using μ=0.3.

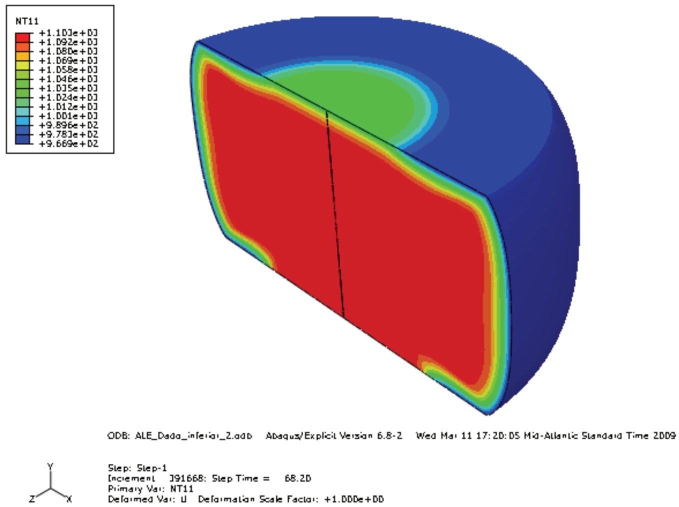

Figure 8: Nodal Temperature Distribution using μ 0.5.

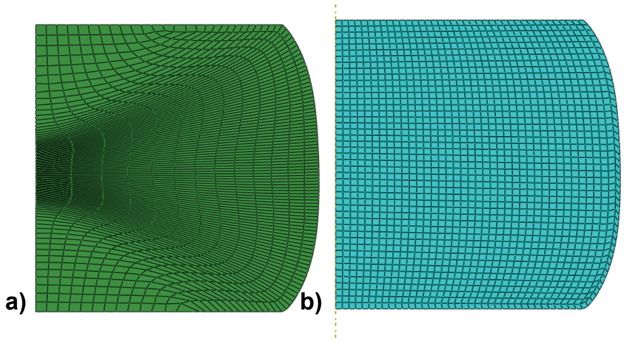

Figure 9: a) Orphanmesh after forging using µ 0.5 and b) Remeshed geometry for the piercing model .

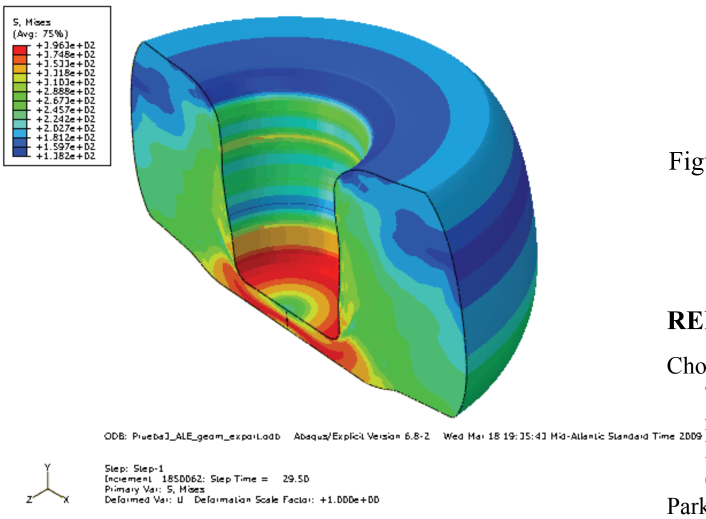

Figure 10: Stress distribution for the first step of piercing using µ 0.5.

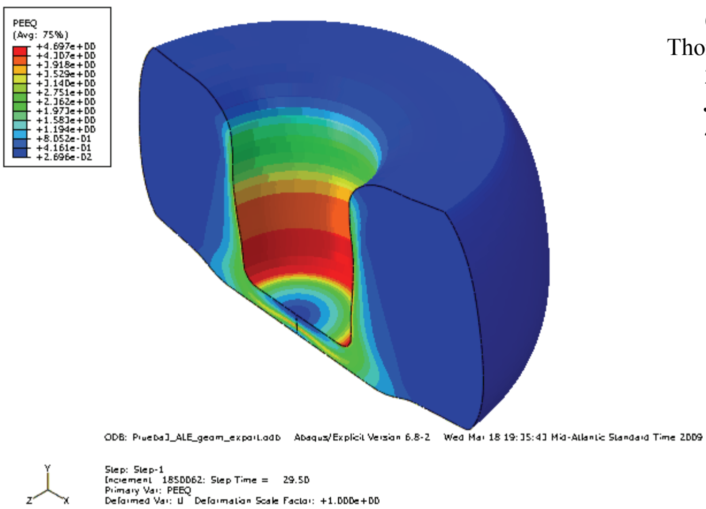

Figure 11: Nodal Temperature Distribution for the first step of piercing using µ 0.5.

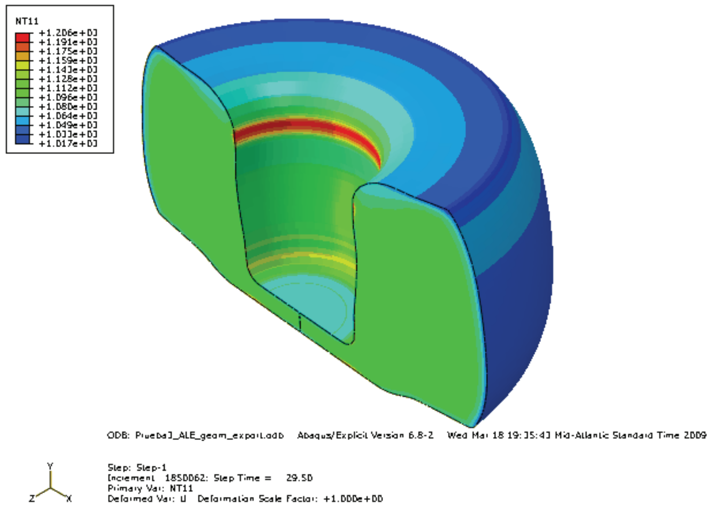

Figure 12: Plastic Strain Distribution for the first step of piercing using µ 0.5.

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MARTHA GUERRERO got her PhD in the University of Sheffield, UK. She has been working at Universidad Autonoma de Nuevo Leon since 1997, lecturing for postgraduate students and working on different research projects either supported by the Mexican government, local industry or International Institutions. She has been invited professor at Ghent University in Belgium and at The Ecole de Mines de Nancy in France. Her team has been working on the finite element modelling of thermomechanical processes since 1998 collaborating with various industries and universities.

VICTOR PARAMO was born in Monterrey, Mexico and went to the Autonomous University of Nuevo Leon, Mexico, where he studied electromechanical engineering obtaining his BSc degree in 1996, and his master degree in Material Science in 1998. Afterwards, he went to the Technical University of Munich, Germany, making his research on Materials, and he obtained his PhD degree in 2003. He worked for four years at Celestica de Monterrey leading the Failure Analysis Lab. Right now he works at Frisa Aerospace as Chief Metallurgist for forging rings in the Energy Turbines Division. His e-mail address is: vparamo@frisa.com and his Web-page can be found at http://rolledrings.frisaaero.com

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