National Institute of Applied Sciences of Rennes (INSA Rennes)

PhD THESIS (07/07/2006)

Study concerning the quasi-static and the dynamic behavior of metallic materials at high temperature. Numerical simulations of a hot forming process

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ABSTRACT

The plastic deformation of materials at high strain rate is often described by a constitutive law expressing the stress as a function of deformation, strain rate and sometimes of temperature. The main objective of this thesis is to characterize the thermomechanical behavior of aluminum at different temperatures and strain rates. A secondary objective is to apply results for a sheet hot forming in quasi-static conditions. To do this, it was necessary to develop the tools necessary for this characterization: test methodologies, analytical analysis, behavior laws description, identification by inverse analysis and validation of the parameters identification through a finite element modeling.

The first chapter presents the literature review on the general laws of metallic materials behavior under severe deformation loadings. The study of these laws for various metallic materials demands to use dynamic tests. We propose in this chapter, a summary presentation of different dynamic compression tests. As part of the dynamic behavior of materials, a suitable device is the Split Hopkinson Pressure Bars (SHPB), often used by scientists to characterize the material constitutive equations.

The second chapter is devoted to the geometry and thermal analysis of the specimen used by a dynamic compression Hopkinson bar test at higher temperatures. SHPB experiments are often done with cylindrical shape samples. The geometry of the specimen is extremely important to obtain reliable results with the SHPB technique. In this chapter we will study a new geometry based on the dumbbell-shaped specimen. The ability of the dumbbell shaped specimen to keep its temperature between disconnection of the heating system and the impact of the projectile (with or without contact during the first moment of the impact) was compared to those of a cylindrical specimen using experiment results and finite element simulations made by Castem2000®. The shape of the specimen was optimized by comparing all the results obtained experimentally and by simulation with both types of specimen. Important improvements have been obtained concerning the heat transfer in the useful part of the specimen, especially for the thermal conditions evolution during the tests.

The third chapter is devoted to the experimental and numerical study of the dynamic behavior of an AA5083 aluminum alloy at high temperature. From SHPB test results at temperatures ranging from 20 to 400 ° C, the parameters of the Johnson-Cook and two other laws have been identified using the method of inverse analysis. It is based on the estimation of loads and velocities at the contact interface of the sample, starting from the classical analytical model of the elastic waves

propagation in the bars (DAVID® software) and the inverse analysis of a finite element model reduced to a specimen model using the software FORGE2®/Implicit. The new proposed constitutive laws use a classical hardening law and a Voce-type one, introducing the influence of the strain rate as a formulation of a ArcSine-Hyperbolic function. The strain rate and temperature sensitivity on the dynamic behavior of alloy AA5083 were studied using also the classical Johnson-Cook JC law. We observed a low sensitivity to strain rate and a high sensitivity to temperature. When the flow stress as a function of temperature is compared to the flow stress as a function of strain rate, there is no doubt that the effect of temperature on the flow stress is more pronounced than the strain rate one. The model behavior identified by inverse analysis has been validated by a complete simulation of the Hopkinson Bars test using the finite element software ABAQUS ®/ Explicit. The methodology of validation of the constitutive law identified in this thesis is mainly based on the comparison of elastic deformation signals recorded in the bars. The simulation showed that the ArcSine-hyperbolic law allowed to a better modeling of the dynamic behavior of AA 5083 aluminum alloy at high temperature.

The final chapter presents a study based on the numerical simulation to study the behavior of a new sheet hot forming processes for an aircraft fuselage panels. The objective of this work is to study the potential of the hot forming process for an welded stiffened structures to simplify the existing manufacturing process. After a brief presentation of the problem, we propose the thermomechanical characterization of an aluminum alloy used in the fabrication of structures which are concerned here. Subsequently, a model of the rheological behavior of the material and process for a hot sheet forming is proposed. From this analysis, several numerical investigations have been conducted to assess the potential performance of the proposed method. Spring back at the end of the forming process is studied for different boundaries conditions of the stiffened panel. Finally, the numerical simulation tool has been used, to analysis the possibilities of a panel forming with real dimensions. Starting from this work we can consider the following future developments:

* The finite element code ABAQUS / Explicit has been able to model high strain rate deformation at high temperature. This code uses only a classical JC law. Improvements could be made by writing a custom subroutine (in UMAT) with the proposed laws. Similarly, a subroutine could be used to introduce a variation of the parameters of constitutive equations based on temperature.
* The heat generated by plastic deformation in the specimen during testing at high strain rates does not have time to dissipate during the charging. It is for this reason that such tests can be considered adiabatic. It is therefore particularly important to know the temperature if we wish to study the dynamic behavior. A measure of the temperature of the specimen can be performed using an infrared camera or infrared radiometric apparatus to monitor and estimate the temperature increase in the specimen.
* For tests at high strain rate, to obtain information on the strain distribution in the specimen it is necessary the use a high speed photography method. This method is used to visualize and measure the plastic deformation and the fracture of the specimen during the impact test. In a first time it can be also used to study qualitatively the behavior of materials. The new proposed geometry of the specimen required absolutely the use of the high speed photography method.
* The numerical simulation of a double curvature panel could be made to optimize the cycles of pressure and temperature to obtain a minimum spring back at the end of the sheet hot forming process.