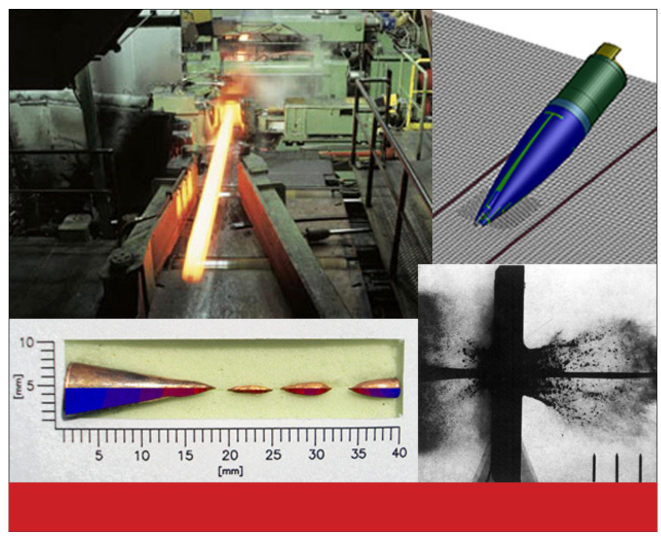
Case Study: **TECHDYN Engineering**

Marc Accurately Predicts Results of Dynamic Tensile Extrusion Test

Overview



In a wide range of industrial and defense applications, materials are required to perform at extreme operating conditions involving large plastic deformation, high strain rates, elevated temperatures and severe dynamic pressure. For example, materials used in armor and anti-armor technology experience deformations of 500% and higher, strain rates up to 106 per second, temperatures above the material's melting point and pressure of several gigapascals (GPa). Likewise, in industrial applications such as forging, hot rolling, extrusion, wire drawing and sheet metal forming, workpieces undergo plastic deformations ranging up to 100%, temperatures from 500oC to 800oC, strain rates up to 100 per second and pressures up to several hundred Megapascals (MPa). Other examples of applications where high deformations, temperatures, strain rates and pressures are experienced include perforating guns in the oil and gas industry, debris impact in aerospace engineering and ship collisions in naval engineering.

“Marc simplifies the process of implementing complex material models with its user defined function capabilities,”

Nicola Bonora, CEO, TECHDYN Engineering

Key Highlights:

Product: Marc

Industry: Engineering Services

Benefits:

- Reduce physical tests
- Improve accuracy of material behavior prediction
- Improve product performance

Challenge

The high cost of building and testing prototypes for applications operating under extreme conditions and the difficulty of acquiring data during physical testing makes accurate simulation critical. A key challenge is the development of material models that maintain their accuracy while the material is subjected to extreme conditions. There are two basic approaches to the development of such material models. The first approach is to use traditional characterization tests such as traction and compression tests with limited ranges of controlling variables to evaluate material response. Then mathematical expressions, generally not supported by any physical background, are developed to fit the experimental observations. Because of their physical nature, these models are generally limited to relatively narrow application ranges. The second approach combines characterization tests with validation tests in which the material is subjected to a much wider range of deformation, strain rate, temperature and pressure up to and including values expected in the application, which makes it impossible to control these values during the test. For this reason, much of the information about the response of the material is obtained after the fact and is used to validate the model and tune its material characteristic parameters.

TECHDYN researchers set out to develop a new material model that could be used to accurately predict the performance of materials under extreme conditions. To validate their model, they selected the dynamic tensile extrusion (DTE) test which was developed by Los Alamos National Laboratory to probe material response under large deformations, strain rates and temperatures. In this test, a projectile is shot into a conical die with an exit opening smaller than the diameter of the projectile. As the material enters the die, it is subjected to very large deformations and high strain rates.

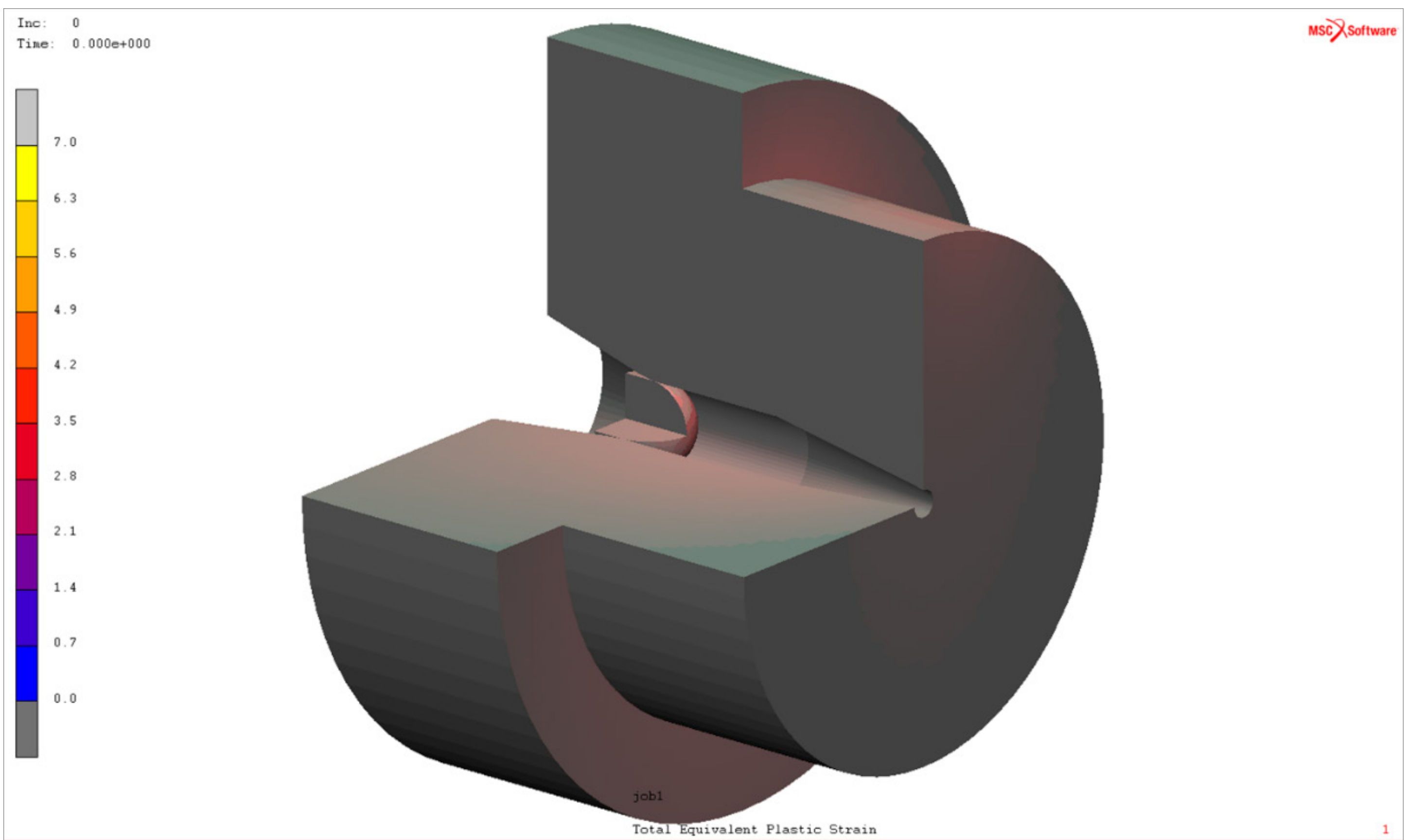


Figure 1: Simulation of DTE test at 400 m/s

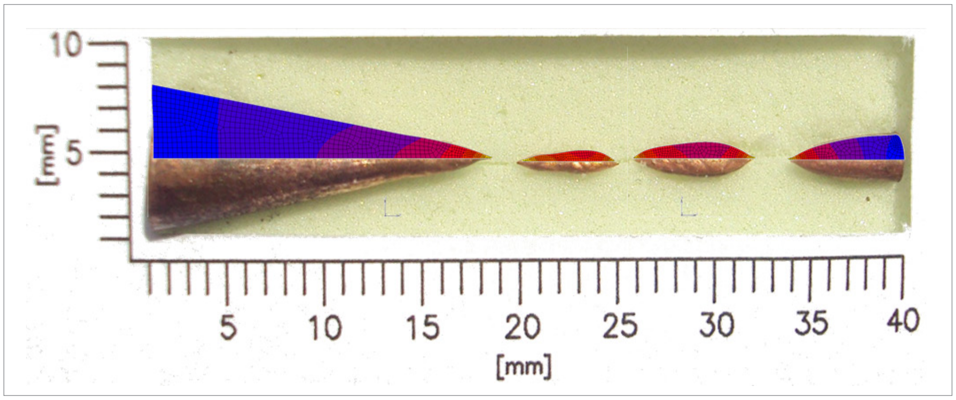


Figure 2: Comparison of DTE test fragments predicted by simulation and produced by test

As the projectile deforms, the material is dynamically extruded, producing a material jet that travels as much as twice as fast as the initial speed of the projectile. TECHDYN researchers recently modeled the DTE test with a projectile made of oxygen-free high conductivity (OFHC) copper. They used a Modified Rusinek-Klepaczko (RK) material model. The RK model is a physical-based model based on the additive decomposition of stress. The total stress is derived by adding two terms which define the strain hardening and thermal activation processes. TECHDYN researchers needed to find a finite element analysis code that could handle the large deformations and strains involved in the problem.

Solution

"Many researchers who are attempting to accurately simulate performance under extreme conditions utilize explicit finite element analysis codes," said Nicola Bonora, Chief Executive Officer of TECHDYN Engineering. "Explicit codes offer the advantage of reduced computational times but in our experience their accuracy is limited. We prefer Marc implicit finite element software because we have found it provides substantially greater accuracy than any alternative we are aware of. We have found computational times to be reasonable considering the complexity of the underlying physics. For example, we can simulate the DTE test in 2D in an hour or in 3D in a week on a multiple core workstation. Marc also simplifies the process of implementing complex material models with its user defined function capabilities."

TECHDYN researchers implemented their new material model as a user defined function in Marc. The parameters in the material model were identified using data coming from characterization tests and published results. Numerical simulations of DTE tests of OFHC copper at different impact velocities were simulated with Marc. Both the projectile and die were modeled as deformable bodies coming into contact during the extrusion process. Dynamic transient analysis was performed to simulate the deformation experienced by the projectile and die. Global remeshing was used to address extreme element distortion while avoiding convergence problems and loss of accuracy. The material jet stretches as a result of the velocity difference between the tip and tail, eventually breaking into small fragments. The number, size and shape of the fragments produced at an initial velocity of 400 m/s was used to validate the simulation. The test resulted in four fragments, one that remained in the die and three that were dynamically extruded. The calculated fragment number, size and shape correlated very closely to the test results. A quantitative comparison of fragment length showed that the simulation predicts fragment length within a +5%/-10% error band.

Results/Benefits

Now that TECHDYN has validated their material model and ability to simulate extreme conditions, the company is preparing to offer engineering consulting services using Marc with the new material model to provide accurate simulations of extreme conditions. "The ability to accurately simulate extreme conditions will help improve product performance by making it practical to evaluate many more design alternatives than would be practical using the build and test method while at the same time reducing product development cost and leadtime," Bonora said.

About TECHDYN

TECHDYN Engineering is a research and development spin-off from the University of Cassino and Southern Lazio in Italy. The company specializes in design, analysis and testing of materials and components operating under extreme loading and environmental conditions that produce high strain rates, elevated temperature and impact dynamics. TECHDYN Engineering provides consulting services including stress analysis and numerical simulation, structural integrity design and assessment, fracture mechanics analysis, constitutive modeling of materials, material modeling validation, composite materials and structures design, and design and simulation of structures under impact.

For more information on Marc and for additional Case Studies, please visit **www.mscsoftware.com/marc**

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