Simulating Fracture with Abaqus

Co-simulation with XFEM technology evaluates safety of hand grenade drop

It's a common enough moment. One person sighs after a lost game or a missed pitch, "It was close," and another will reply, "'Close' only counts in horseshoes and hand grenades."

But 'close' doesn't count at all for designing a hand grenade. The weapon must have proven reliability and predictable performance even when subject to rough handling or accidental dropping. Realistic simulation with finite element analysis (FEA) can be a powerful tool for helping establish those safeguards.

At the U.S. Army Armament Research, Development and Engineering Center (ARDEC) at Picatinny Arsenal in New Jersey, design engineers are constantly exploring ways to refine their use of FEA to verify design strength. They recently evaluated the eXtended Finite Element Method (XFEM) technology in Abaqus. The XFEM enriched environment can be used to look closely at fracture failure (a mode of material breakage under a load), even when the cracks don't follow element boundaries. No matter how finely meshed, a standard FEA model only simulates cracks as they propagate along element boundaries. But XFEM is a powerful tool for accurately modeling "the cracks that fall in the cracks" between elements.

ARDEC engineers were already using Abaqus to model design behavior, since many of their loading scenarios involve highly dynamic, transient events. As such, ARDEC engineers are well versed in the use of Abaqus/Explicit, SIMULIA's best-in-class transient simulation software. However, XFEM works only in Abaqus/Standard, so for

Figure 1. M67 hand grenade

the most complete picture of fracture failure, the designers turned to a technique called co-simulation—simultaneously running two different solvers on the same model. This gave them the best of both worlds: XFEM accuracy in an implicit analysis, and simulation over time in an explicit environment.

To prove out their analysis approach, the engineers simulated a drop test of an M67 fragmentation grenade—the type currently used by the U.S. military (Figure 1). In physical tests, the grenade is dropped in several orientations to ensure safety and functionality (Figure 2).

Looking for a worst-case scenario, the ARDEC engineers ran an explicit analysis and discovered that the highest stress occurred when the grenade hit the ground on the upper corner of the safety handle. Also the material failure model was modified to simulate the effect of substandard material. The stress concentration in the notched region of the handle, near the safety pin, was selected as an area of interest.

For this analysis, engineers modeled the handle with an elastic-plastic material model using the properties of ASTM A109 Steel (Table 1). All other grenade materials were modeled as linear elastic.

They then formulated a material failure simulation (Table 2) using the maximum principal stress criteria ("Maxps Damage" in Abaqus). Starting the analysis at the beginning of the drop, with a downward velocity of zero and continuous acceleration, would have been complex and time-consuming. It was also unnecessary; during the downward fall, nothing important happens to the grenade. Instead, the engineers modeled the grenade at the moment before impact and used its final velocity. The grenade hit with a damage energy of 5.3 kiloNewtons/meter (almost 1200 lb./meter) after being dropped from a height of 1.219 meters—roughly the height of an object held at arm's length. The grenade assembly was deformable, but the impact surface was rigid and constrained in all directions.

To ensure accuracy, the designers meshed the handle model very finely (four elements thick) and carefully lined up the mesh in the implicit and explicit boundary regions. The notched area on the handle (where fracture occurred) was the XFEM enriched zone. It was kept small to eliminate the possibility of XFEM elements near the co-simulation boundary.

Yield Strength, MPa	*305.3*
Ultimate Tensile Strength, MPa	437.7
Young's Modulus, GPa	204.8
Strain at Ultimate Failure, percent	18.0
Poisson's ratio	0.29
Density kg/m3	7,823.0

Table 1. Material Properties, M67 Handle

ASTM A109 Steel	
Maxps Damage	Maximum Principal Stress: 345 MPa
Damage Evolution	Type: Energy
	Softening: Linear
	Degradation: Maximum
	Mixed mode behavior: Mode-Independent
	Mode mix ratio: Energy
	Fracture Energy: 5.3 kN/m

Table 2. Material Failure Model

The run time for the co-simulation was dramatically reduced from the implicit dynamic analysis: 10 minutes for co-simulation versus 6 hours for the implicit analysis.

Three analyses were used to validate the co-simulation method (Figures 2-3):

- In the first, Abaqus/Standard and XFEM were used to analyze a continuously meshed model of the handle.
- The second split the model in two, running dynamic analyses in Abaqus/Standard with tied regions to an enhanced XFEM region. The two-part structure would later facilitate co-simulation.
- The final analysis was the co-simulated drop test. Most of the model was analyzed in Abaqus/Explicit. The area of interest on the handle was still modeled in implicit so that the XFEM technique could be applied.

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Afterward, the ARDEC engineers compared simulation results by plotting averages for eight elements in the area of concern on the grenade handle. Charts of the averaged results for plastic equivalent strain (Peeq) and Von Mises stress showed that the stress values between the tied implicit model and the co-simulation model matched well. Crack growth in the second and third analyses was similar as well.

Subsequently, the engineers were able to fine-tune the co-simulation analysis in a number of ways. They used matching meshes at the co-simulation boundaries because, if the nodes were not nearly coincident, no loads would be applied to them. Starting both analyses with the same initial time step improved the convergence of the implicit XFEM analysis. And keeping the XFEM enriched area away from the co-simulation interaction boundary also promoted convergence and prevented cracks from starting right at the boundary.

Co-simulation enabled the ARDEC engineers to retain their preferred explicit environment for transient analyses and augment it with the fracture failure capabilities of XFEM in implicit. The significant run-time savings will help ARDEC continue to explore the potential of using co-simulation in the future. In addition to simulating drop tests with XFEM, ARDEC engineers are interested in using it for concrete penetration, gun launch, recoil, and interaction of gun supports with the ground.

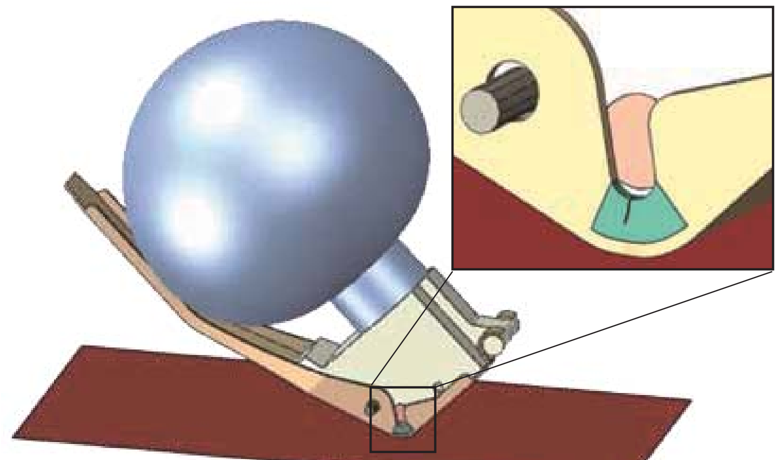

Figure 2. Abaqus simulation of a drop test showing notched area of the safety handle (in green), analyzed using XFEM technique and showing crack formation

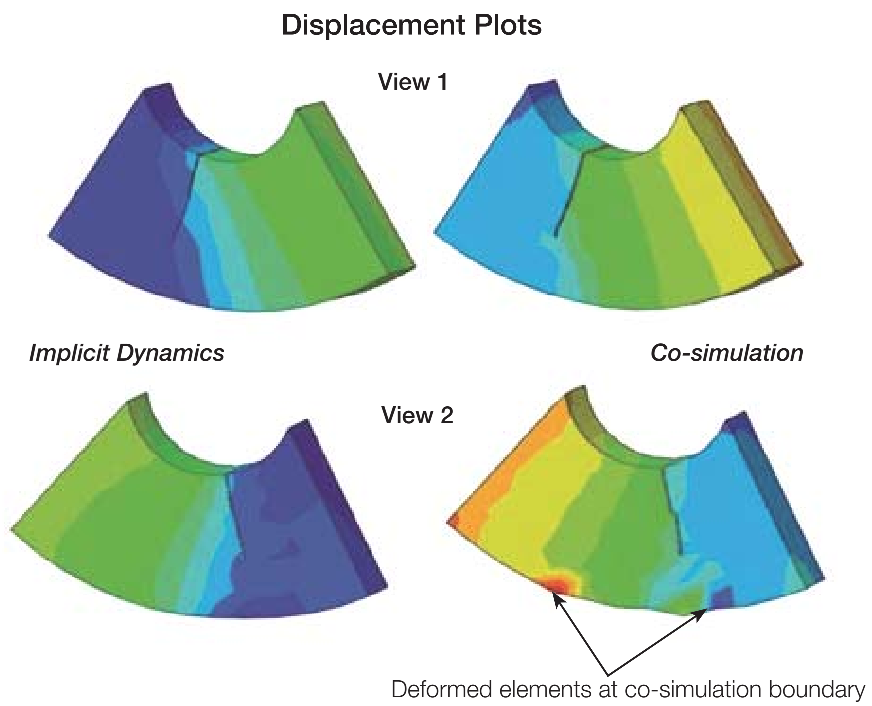

Figure 3. Side-by-side comparisons of the implicit dynamics and the co-simulation analyses, showing the areas of element deformation at the co-simulation boundary.

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