VERIFICATION AND VALIDATION OF THE FLAG HYDROCODE FOR IMPACT CRATERING SIMULATIONS.

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Introduction: Impact cratering is the dominant geologic process in the solar system [1]. Crater size and geometry depend on many factors, among them the size and velocity of the impactor, the materials of the impactor and target, local gravity, and impact angle[2]. The strength of the target material can affect geomorphology of impact craters. Strength models incorporate stress, strain, and fracture in addition to other material properties. In order to effectively model crater formation, these properties must be considered for some impacts.

Early stages of crater formation are driven by thermodynamic properties, while later stages are governed by additional factors such as internal friction and local gravity [3]. The role of material strength depends on the mass and velocity of the impactor. Once the impactor meets or exceeds a threshold velocity of about 12 km/s, the target material is subjected to melting. Once a material has melted, its strength is no longer a factor [1].

Hydrocode simulations have been used to model the impact cratering process, but these methods are often unable to capture the solid mechanics necessary to understand crater formation. The FLAG hydrocode [4], developed at Los Alamos National Laboratory (LANL), allows for the incorporation of various strength models that can be applied to solid materials. FLAG also allows for solids to be treated as strengthless when running simulations.

Verification: Here we show verification of the FLAG hydrocode when implemented with solid material strength models. We simulate an aluminum projectile impacting an aluminum target at velocities of 5 km/s and 20 km/s, and we compare the results to those found using other hydrocodes. We also compare these results to the analytical impedance matching solutions for each impact velocity.

We treat aluminum as strengthless using a tabular equation of state from the LANL database SESAME in order to recreate the conditions set forth in the hydrocode verification by Pierazzo, et al. [5]. We then consider four different strength models to both the impactor and target materials, and we compare these results to the analytical solutions.

The Preston-Tonks-Wallace model represents metallic plastic flow in numerical simulations of high velocity impacts [6]. The Steinberg-Guinan model describes shear modulus and yield strength at high-strain rates [7]. We also employ perfect plasticity and linear hardening models.

For the 5 km/s impact velocity, the hydrocodes tested by Pierazzo, et al. produced results with maximum pressures ranging from 28.4 GPa to 48.0 GPa, with a mean maximum pressure of 40.4 GPa and a mean relative error of 33.3%. Using the FLAG hydrocode in the strengthless regime and SESAME EOS, our simulation resulted in a maximum pressure of 66 GPa, with a relative error of about 9%. Employing strength models, our results produced maximum pressures ranging from 62 GPa to 63 GPa, with relative errors ranging from 2.4% to 4.1%.

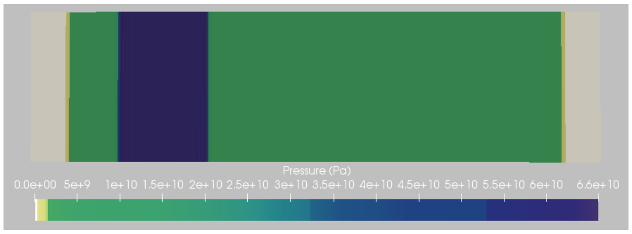

Figure 1: Visualization of a pressure wave propagating through strengthless aluminum after a 5 km/s impact with a strengthless aluminum projectile.

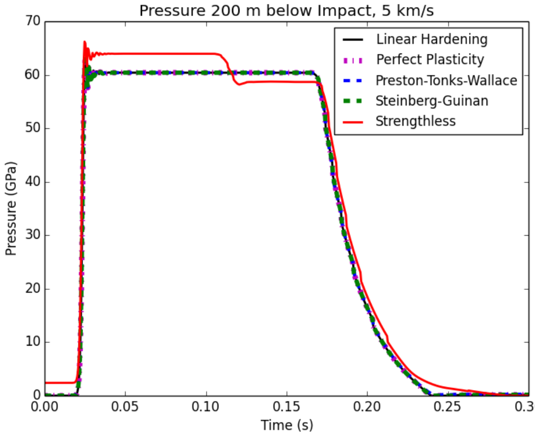

Figure 2: This figure shows the pressure in GPa at a target material depth of 200 m below the point of impact for the aluminum on aluminum verification test employing various strength models. The maximum pressure obtained analytically is 60.543 GPa.

For the 20 km/s impact velocity, Pierazzo, et al. produced results with maximum pressures ranging from 334.7 GPa to 411.1 GPa, with a mean maximum pressure of 379.0 GPa and a mean relative error of 27.5%. Using the FLAG hydrocode in the strengthless regime, our simulation resulted in a maximum pressure of 527 GPa, with a relative error of about 0.8%. Implementing strength models, our results produced maximum pressures of about 530 GPa, with relative error 4.1%. We attribute the increase in error when implementing strength models to the high impact velocity of 20 km/s. This velocity exceeds the melt threshold, so the target material exhibits strengthless properties.

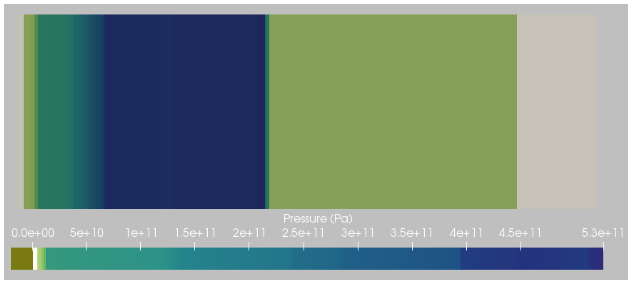

Figure 3: Visualization of a pressure wave propagating through strengthless aluminum after a 20 km/s impact with a strengthless aluminum projectile.

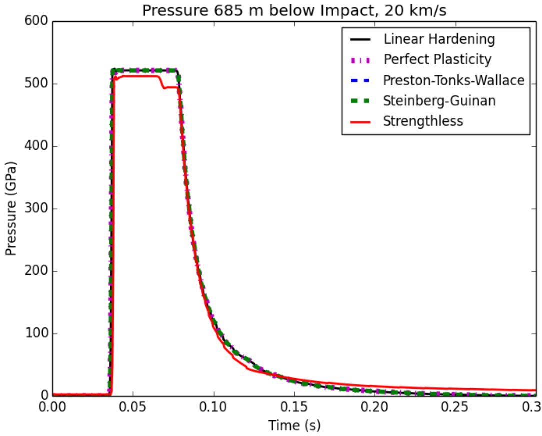

Figure 4: This figure shows the pressure in GPa at a target material depth of 685 m below the point of impact for the aluminum on aluminum verification test employing various strength models. The maximum pressure obtained analytically is 522.567 GPa.

Mesh Resolution Using the 5 km/s aluminum-on-aluminum impact, we conduct a mesh resolution study on FLAG. We vary the resolution from five cells-per-projectile-radius (cppr) to 45 cppr. Our mesh resolutions include 5 cppr, 10 cppr, 20 cppr, 40 cppr, and 45 cppr. We compare these results with the resolution results from Pierazzo, et al. to show convergence of FLAG with a sufficiently refined mesh [5].

Validation: We demonstrate validation of the FLAG hydrocode by simulating laboratory impacts and comparing to experimental data.

Water We simulate a glass sphere impacting a water target. We compare the resulting crater radius and depth to experimental results. This simulation requires no strength model, although gravity does play a role and must be included.

Aluminum We simulate an aluminum sphere impacting aluminum alloy cylinders. Again, we compare the resulting crater radius and depth to experimental results. We run simulations in both the strengthless regime as well as employing various strength models to the materials.

Conclusions: Our results show that FLAG can be used to model impacts of solid materials as well as the craters formed from those impacts.

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Acknowledgments This work was supported by the Advanced Simulation and Computing (ASC)–Integrated Codes (IC) program at Los Alamos National Laboratory. Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by Los Alamos National Security, LLC, for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396.

LA-UR-18-20109