

Physics Report

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Introduction to the Laboratory Exercise

Abstract:

This report provides a perspective into the examination of kinetic stresses and strains, simulated within the environment of a high-speed projectile bullet colliding with a targeted plate. This was achieved through ABAQUS, a software simulator that analysis finite elements. By doing this, it was possible to also measure the ballistic impact, for example the materials penetration process, or tensile strength. Although the bullet was modelled with a rigid body and the targeted plating was modelled as a finite elemental structure, to be able to study the effects of the parameters modelled variables and constants must be in place to ensure the test is fair. For this report materials and velocity of the bullet were the variable and the aluminium plating maintained constant throughout the duration of runs. From this, data was gained, and velocity graphs were constructed. Discussion of results concurs in brief once velocity increased so did resulting forces. Furthermore, which forces cause failure to the structured plating. From this report one might be able to optimise the design of structures to improve their resistance to ballistic impacts. Finally, the material properties chosen for simulation will be discussed to conclude.

Learning Outcomes:

Much knowledge and skills can be gained from this laboratory exercise, such as.

- Create various material components within ABAQUS
- Create surface-to-surface contact interactions within ABAQUS
- Run the simulation within ABAQUS
- Plot velocity within ABAQUS
- Analyse results from a ballistic impact

Material Properties:

Three simulations were conducted using an aluminium plate, assigned properties including,

- Johnson-Cook damage
- Elastic
- Plastic
- Density

The Johnson-Cook damage section comprised of 5 damage values, transition and melting temperatures, with reference to strain rate. The Elastic section contained values for Young's Modulus and Poisson's Ratio. The plastic section had the melting and transition temperatures. While the density section contained only the mass density of the material. [1] [2]

The screenshot shows the 'Material Behaviors' dialog box with the 'Johnson-Cook Damage' section selected. The 'Damage Evolution' sub-section is active, displaying a table of damage parameters. The table has columns for d1, d2, d3, d4, d5, Melting Temperature, Transition Temperature, and Reference Strain Rate. The values are: d1 = -0.77, d2 = 1.45, d3 = 0.47, d4 = 0, d5 = 1.6, Melting Temperature = 900, Transition Temperature = 293, and Reference Strain Rate = 1.

	d1	d2	d3	d4	d5	Melting Temperature	Transition Temperature	Reference Strain Rate
1	-0.77	1.45	0.47	0	1.6	900	293	1

Figure 1 Plate Parameters

The screenshot shows the 'Material Behaviors' dialog box with the 'Density' section selected. The 'Distribution' is set to 'Uniform'. The 'Use temperature-dependent data' checkbox is unchecked. The 'Number of field variables' is set to 0. The 'Data' table shows a single row for 'Mass Density' with a value of 2699.

	Mass Density
1	2699

Figure 3 Plate Parameters

Material Behaviors

- Johnson-Cook Damage
- Damage Evolution
- Density
- Elastic**
- Plastic

General Mechanical Thermal Electrical/Magnetic Other

Elastic

Type: ▼ Suboptions

☐ Use temperature-dependent data

Number of field variables: ▲ ▼

Moduli time scale (for viscoelasticity): ▼

☐ No compression

☐ No tension

Data

	Young's Modulus	Poisson's Ratio
1	68000000000	0.36

Figure 4 Plate Parameters

Material Behaviors

- Johnson-Cook Damage
- Damage Evolution
- Density
- Elastic
- Plastic**

General Mechanical Thermal Electrical/Magnetic Other

Plastic

☐ Use scale stress value:

Hardening: ▼ ▼ Suboptions

Data

	A	B	n	m	Melting Temp	Transition Temp
1	324100000	113800000	0.42	1.34	925	293.2

Figure 5 Plate Parameters

The Projectile bullets such as copper and steel were both given properties for,

- Elastic

This contained values for Young's Modulus and Poisson's Ratio.

- Density

This contained the density mass values. [1] [2]

Material Behaviors

Density

Elastic

General Mechanical Thermal Electrical/Magnetic Other

Density

Distribution: Uniform

☐ Use temperature-dependent data

Number of field variables: 0

Data

	Mass Density
1	7860

Figure 5 Steel Projectile Parameters

Material Behaviors

Density

Elastic

General Mechanical Thermal Electrical/Magnetic Other

Elastic

Type: Isotropic

☐ Use temperature-dependent data

Number of field variables: 0

Moduli time scale (for viscoelasticity): Long-term

☐ No compression

☐ No tension

Data

	Young's Modulus	Poisson's Ratio
1	210000000000	0.3

Figure 6 Steel Projectile Parameters

Material Behaviors

Density

Elastic

General Mechanical Thermal Electrical/Magnetic Other

Density

Distribution: Uniform 

☐ Use temperature-dependent data

Number of field variables: 0  

Data

	Mass Density
1	8930

Figure 6 Copper Projectile Parameters

Material Behaviors

Density

Elastic

General Mechanical Thermal Electrical/Magnetic Other 

Elastic

Type: Isotropic 

☐ Use temperature-dependent data

Number of field variables: 0  

Moduli time scale (for viscoelasticity): Long-term 

☐ No compression

☐ No tension

Suboptions 

Data

	Young's Modulus	Poisson's Ratio
1	110000000000	0.343

Figure 7 Copper Projectile Parameters

Theory

This section aims to provide coherent reasoning for parameters chosen.

Analysis approach

Comparing different projectile materials and velocity is needed to determine effectiveness of various materials. This could be in terms of accuracy, penetration, or deformation. This report compares steel a dense and very hard material against copper which is a much softer, malleable material. From this each materials prime condition can be determined as whether suitable for use depending on what it may be intended for. By testing these penetrable one might gain valuable insights into each performance. To further the projectile research, a comparison run was carried out to find the difference of conditions and performance between the two velocities of the copper projectile hitting the aluminium plate.

Application

This section aims to provide a concise summary of the process behind creating simulated runs a high ballistic impact.

Firstly, to begin creating the projectile and plate create a new model database within ABAQUS. Next, create a part by adding defined part geometry by creating a sketch or importing a CAD (computer-aided design) file. Then either extrude your file or sketch to make the model 3D. After, assign materials specific properties to achieve the desired material, for examples see figures 9-17. After specifying the cross-sectional properties of the projectile and plate to define the parts sections. To later analyse these parts using the finite element method, all parts must be meshed this means both the projectile and plate are divided up into small, finite sized elements. Note the quality of the mesh can have a noticeable effect on the quality of the part you are making. Finally, run the simulation by creating a job and submit for execution, once complete. Analysisation may take place to inspect various stresses applied.

Discussion of results

In this Section, all runs will be compared and examined. Run 1 will consist of a steel projectile, and titanium Plate. Run 2 will consist of a copper projectile and titanium plate, finally Run three will be an increased velocity of run 2. 290 MPa UTS of aluminium converts to 42,000psi and a yield strength of 35,000psi, 241MPa.

Observation of data

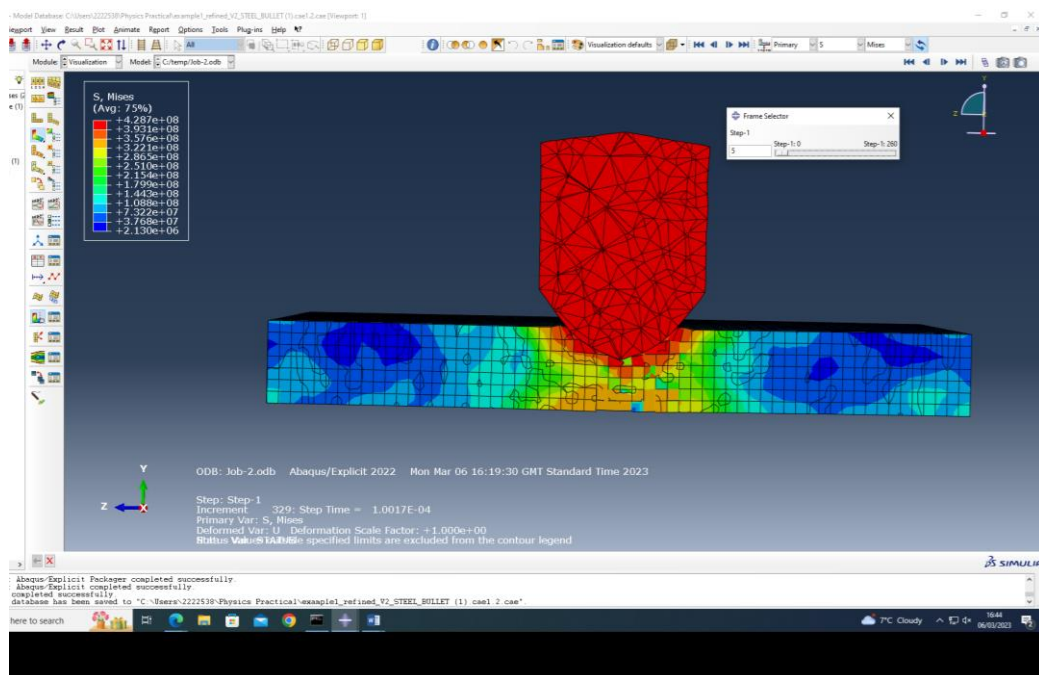


Figure 8 Steel Projectile

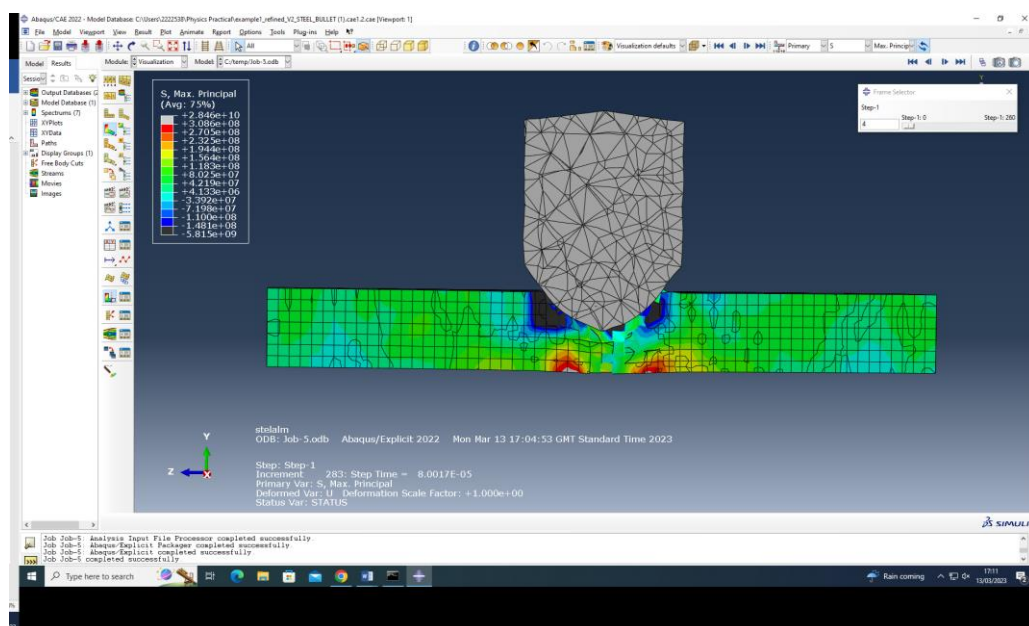


Figure 9 Copper Projectile

Steel Projectile Impact

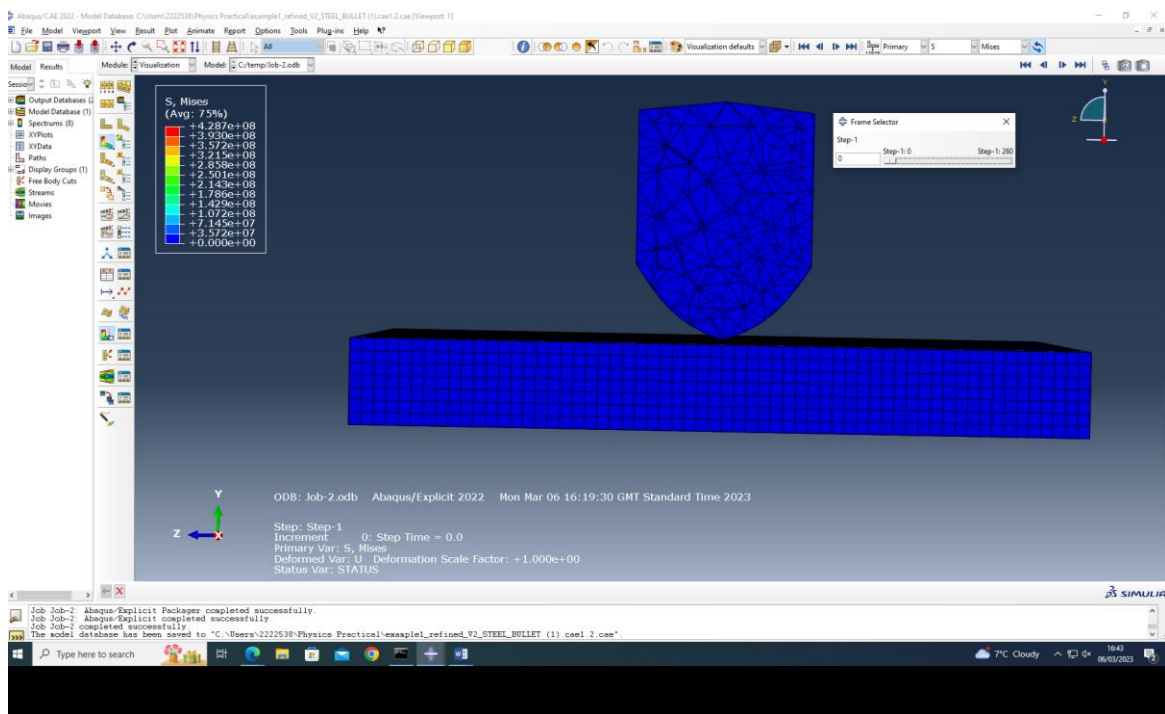


Figure 10 Projectile and Plate Model

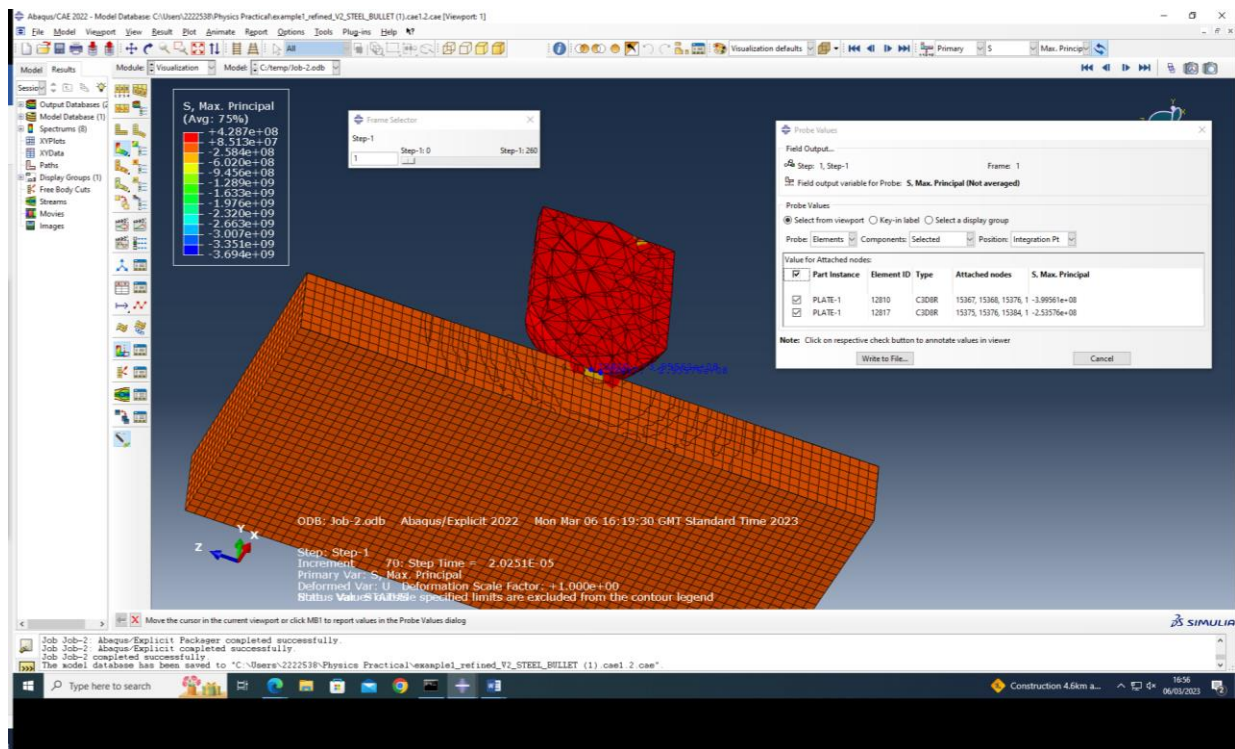


Figure 11 Steel Projectile 1000m/s Max Principle

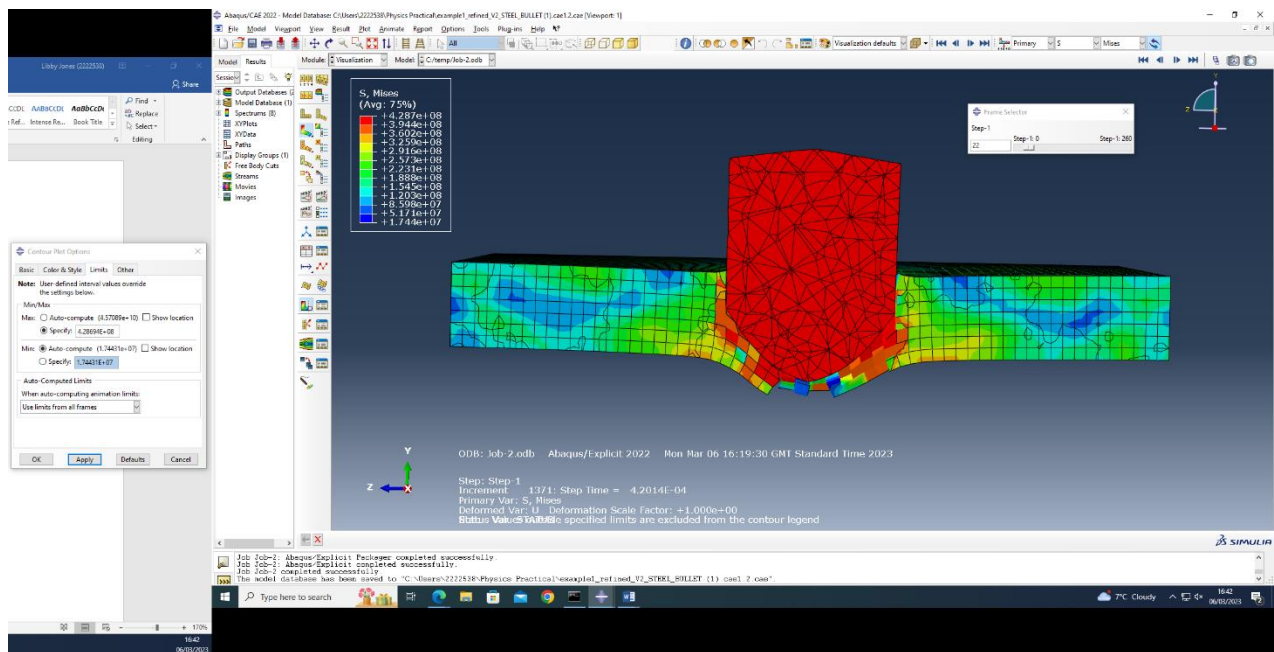


Figure 12 Steel Projectile 1000m/s Mises

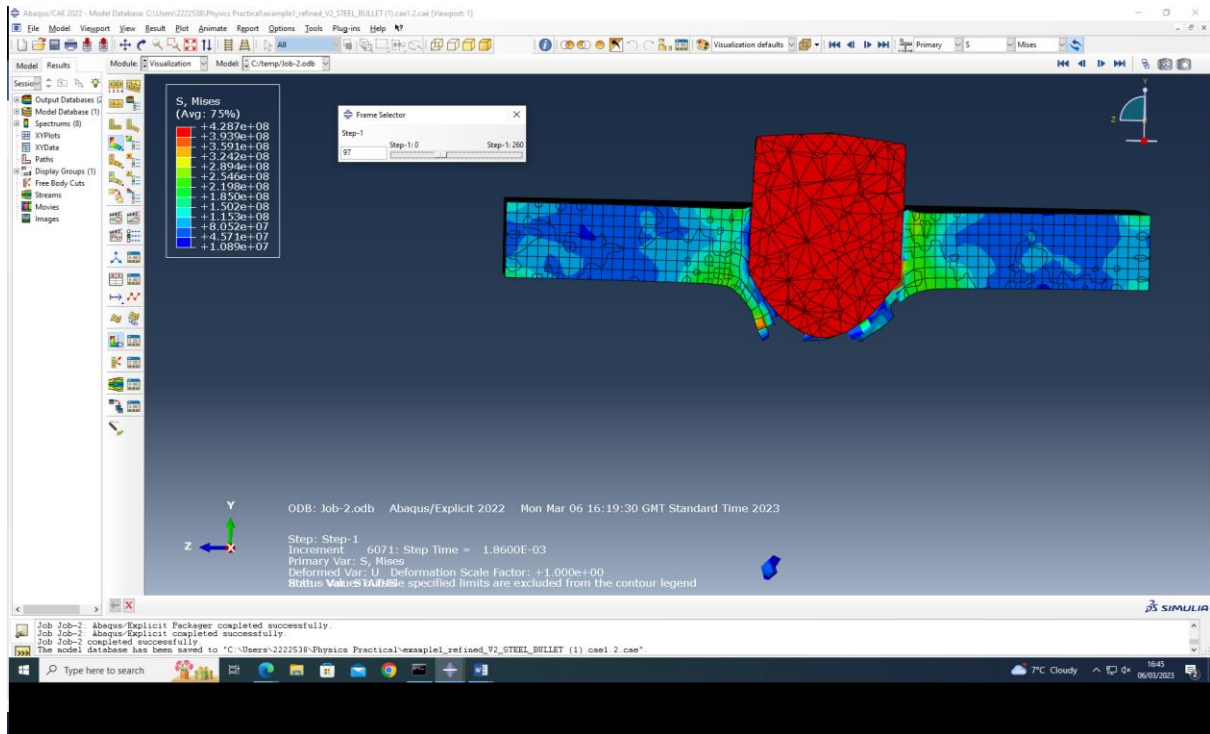


Figure 13 Steel Projectile 1000m/s Resulting Damage

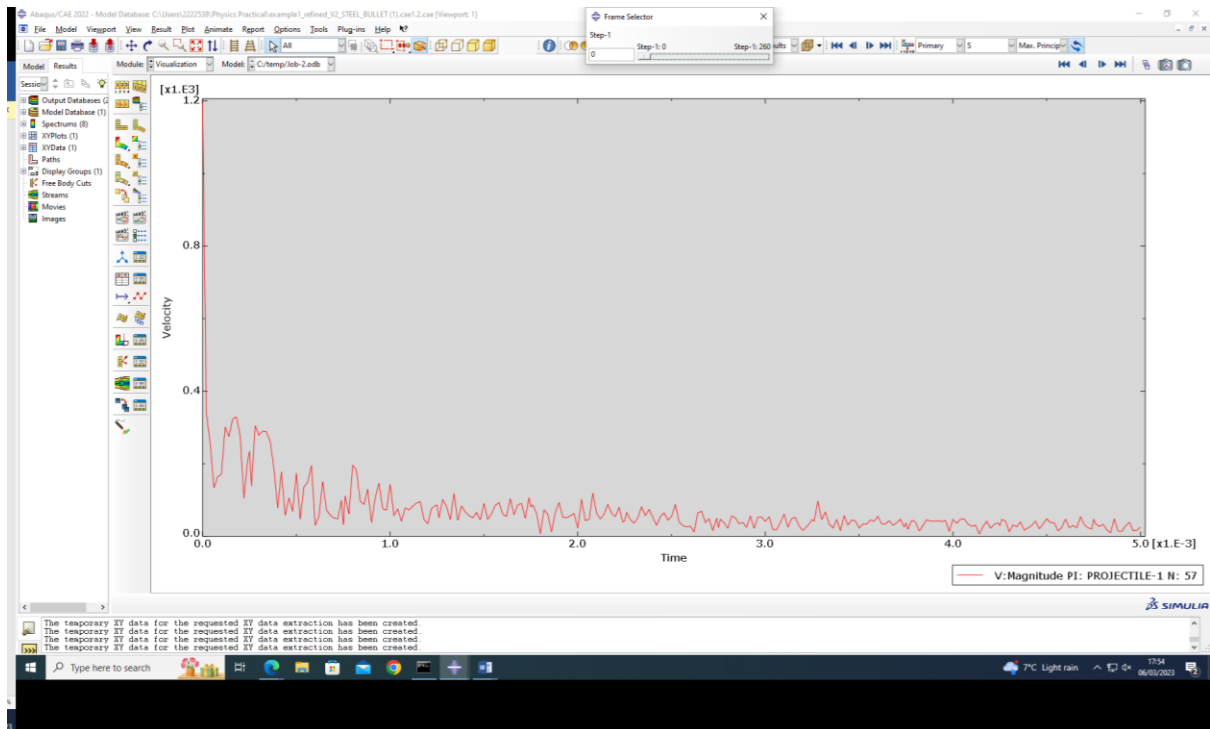


Figure 14 Steel Projectile 1000m/s Velocity Graph

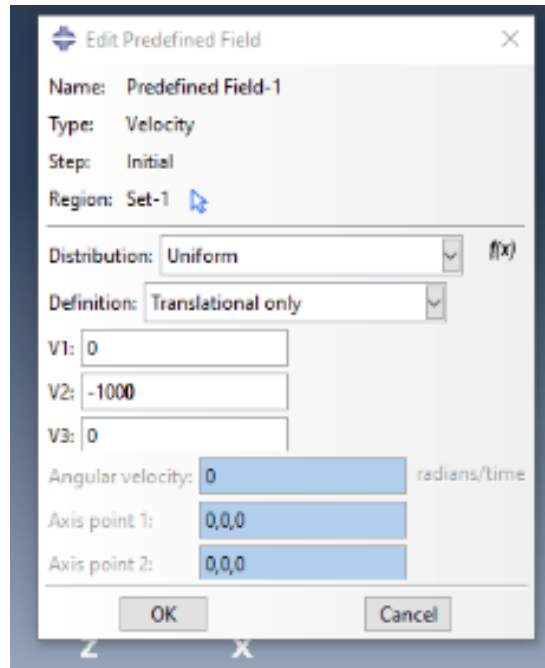


Figure 15 Predefined field of velocity

Copper Projectile Impact

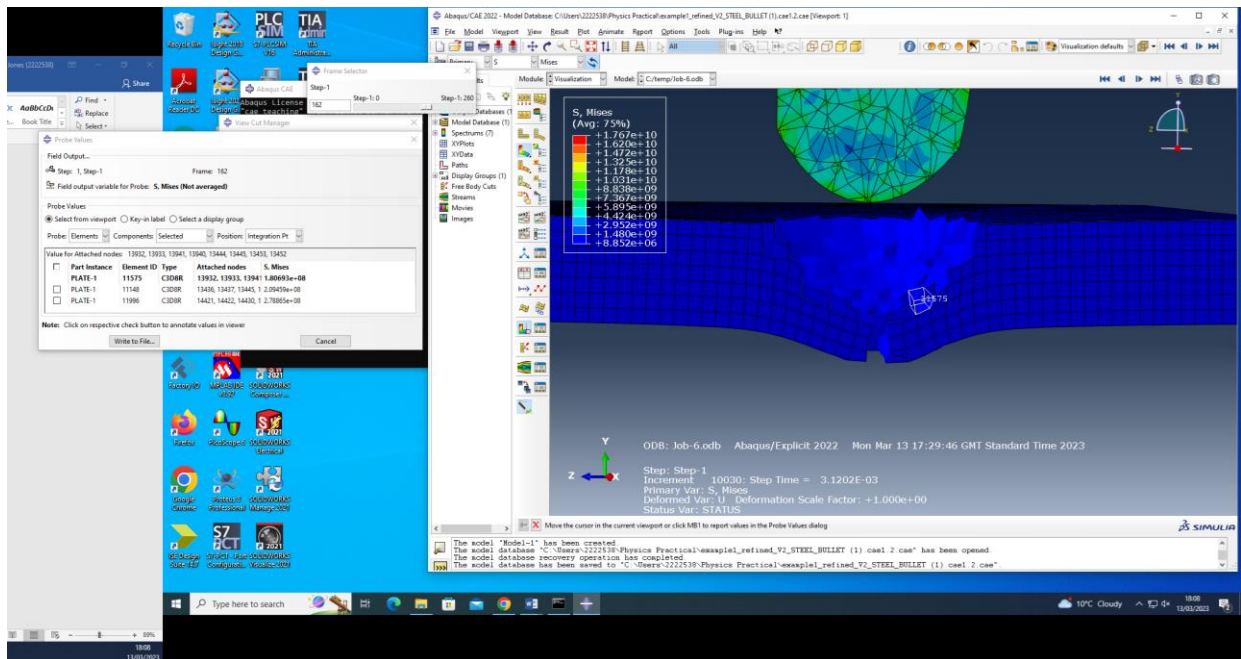


Figure 16 Copper Projectile 1000m/s S. Mises

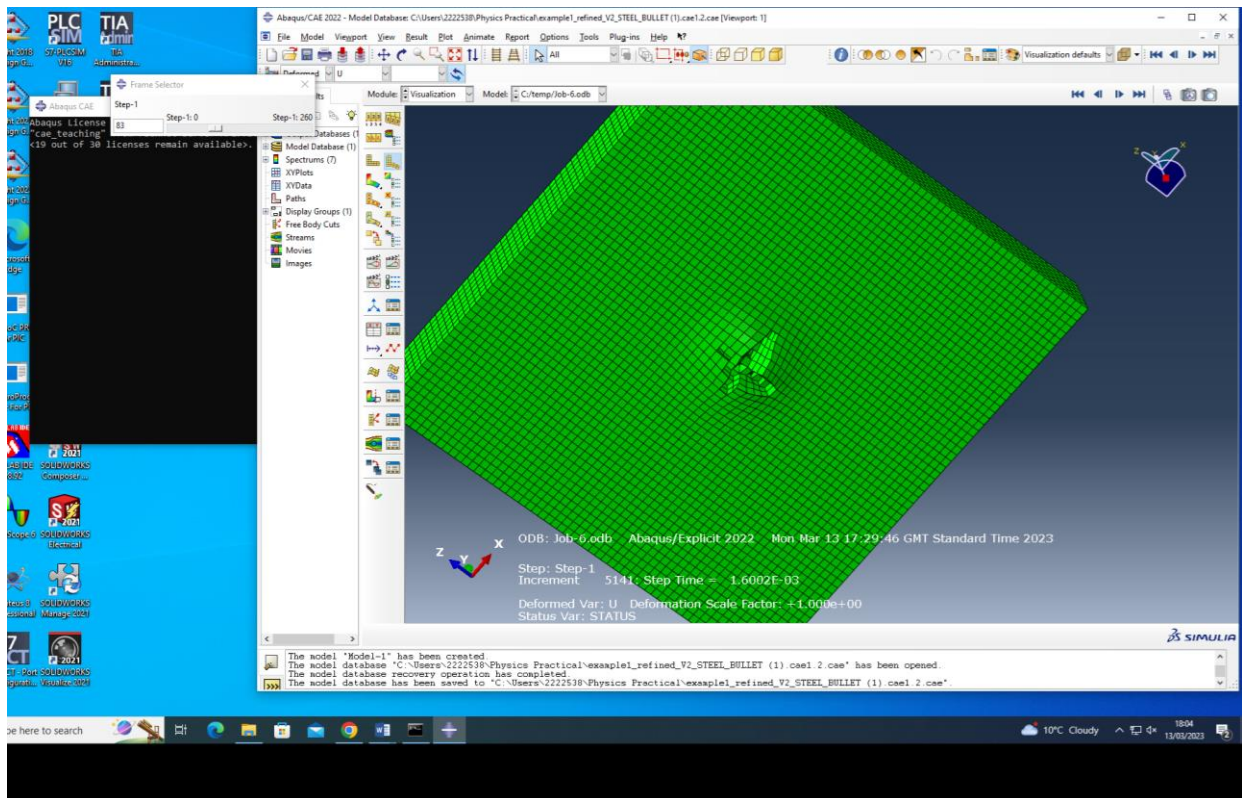


Figure 17 Copper Projectile 1000m/s Resulting Damage

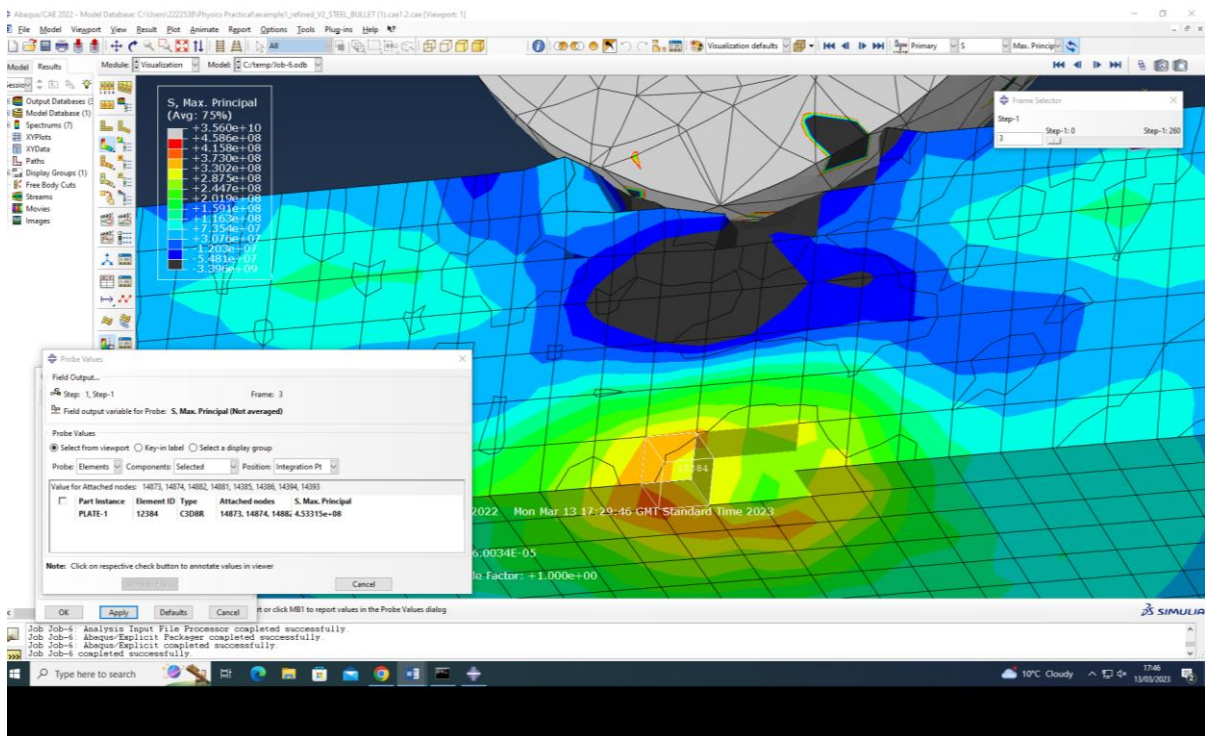


Figure 18 Copper Projectile 1000m/s S.Max Principle

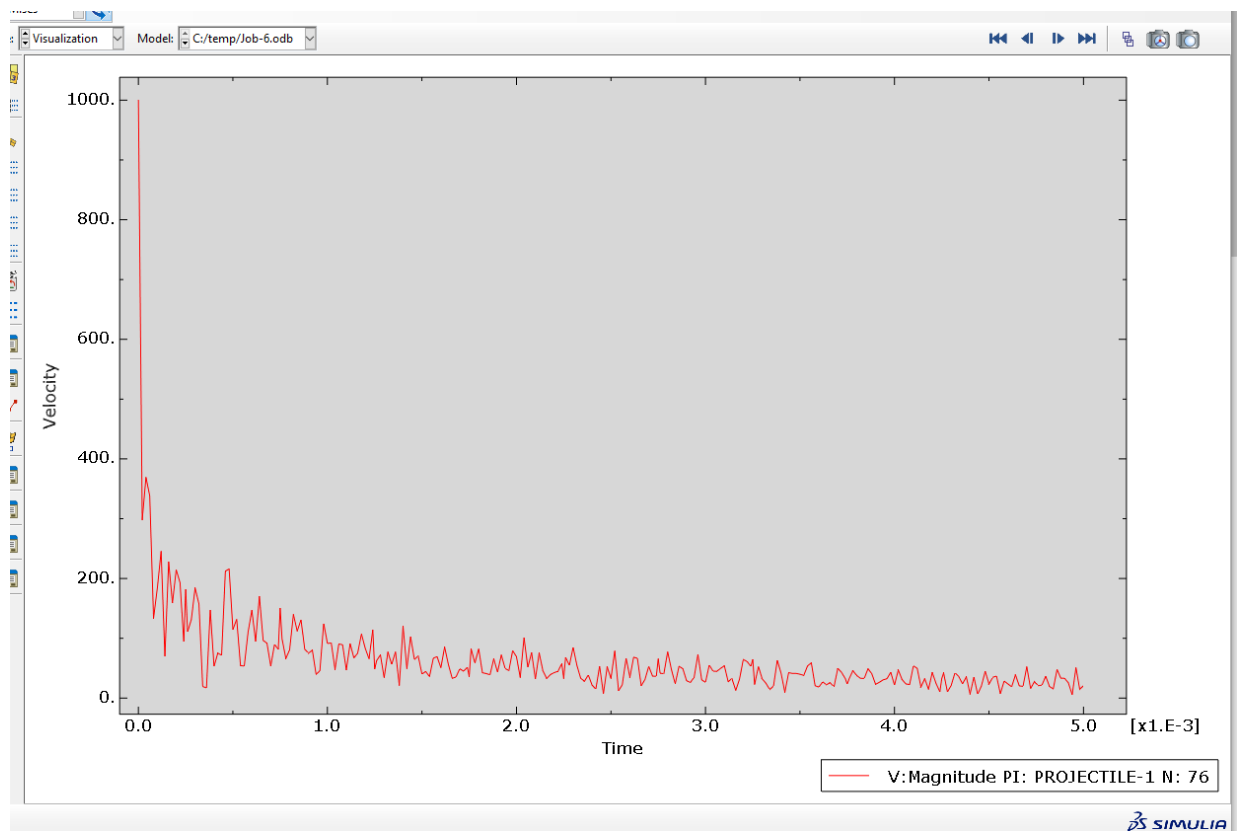


Figure 19 Copper Projectile 1000m/s Velocity Graph

Change Velocity to Copper Projectile

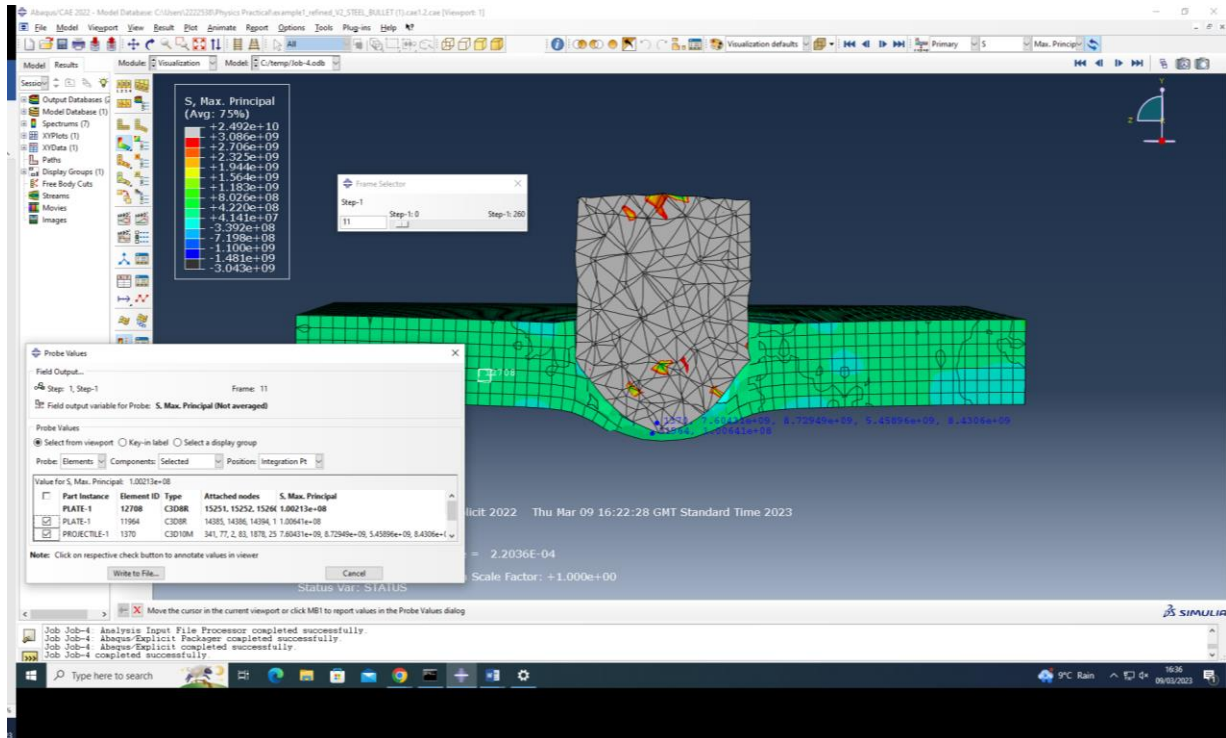


Figure 20 Copper Projectile 1800m/s S.Max Principle

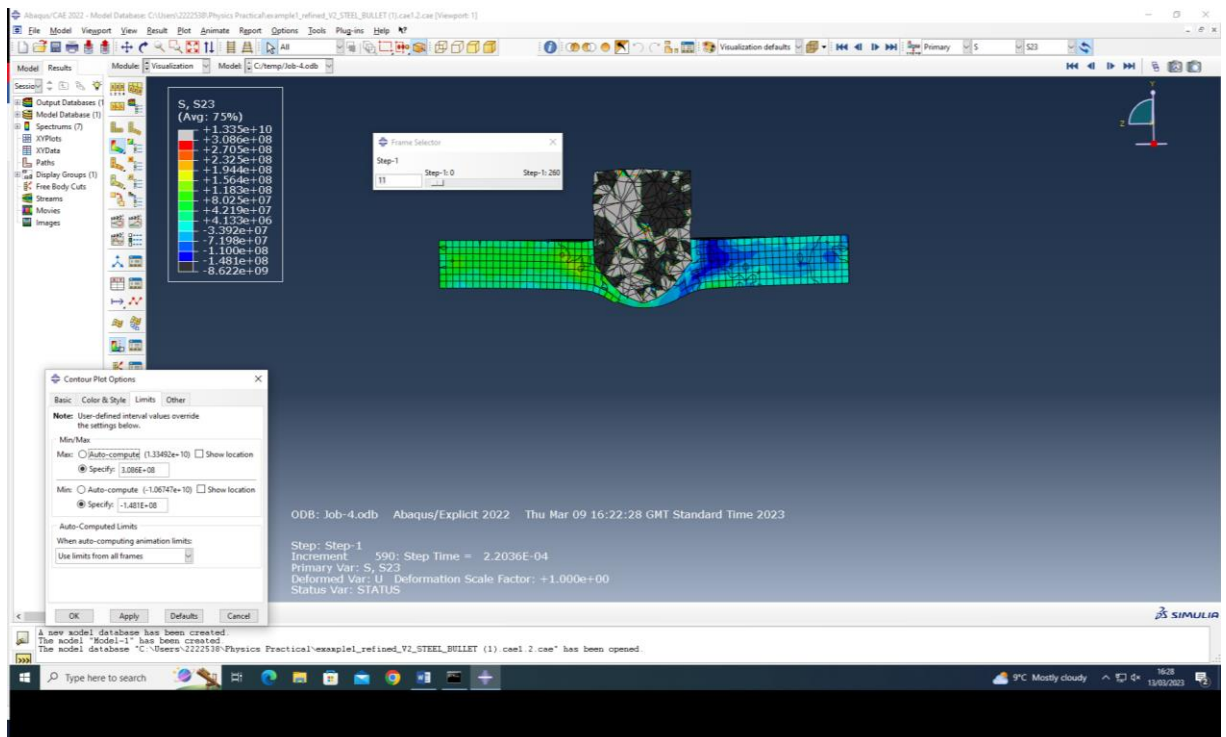


Figure 21 Cooper Projectile 1800m/s S.23

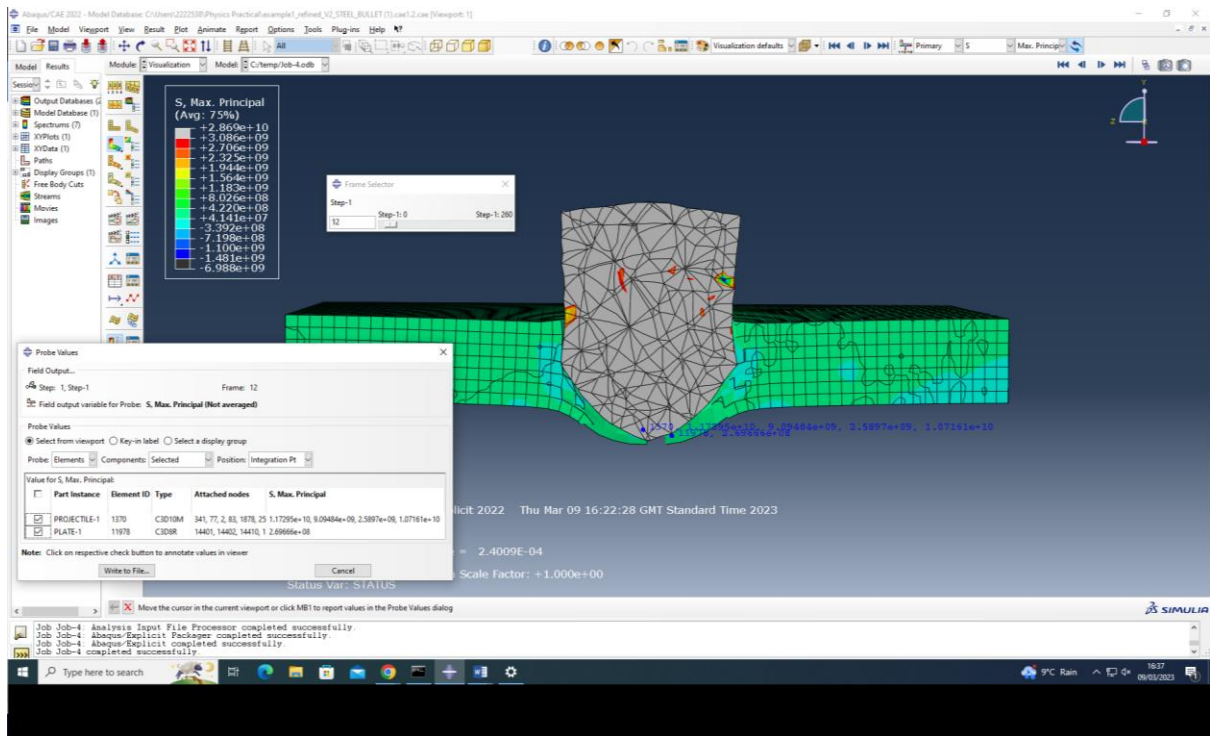


Figure 22 Copper 1800m/s Material Fail

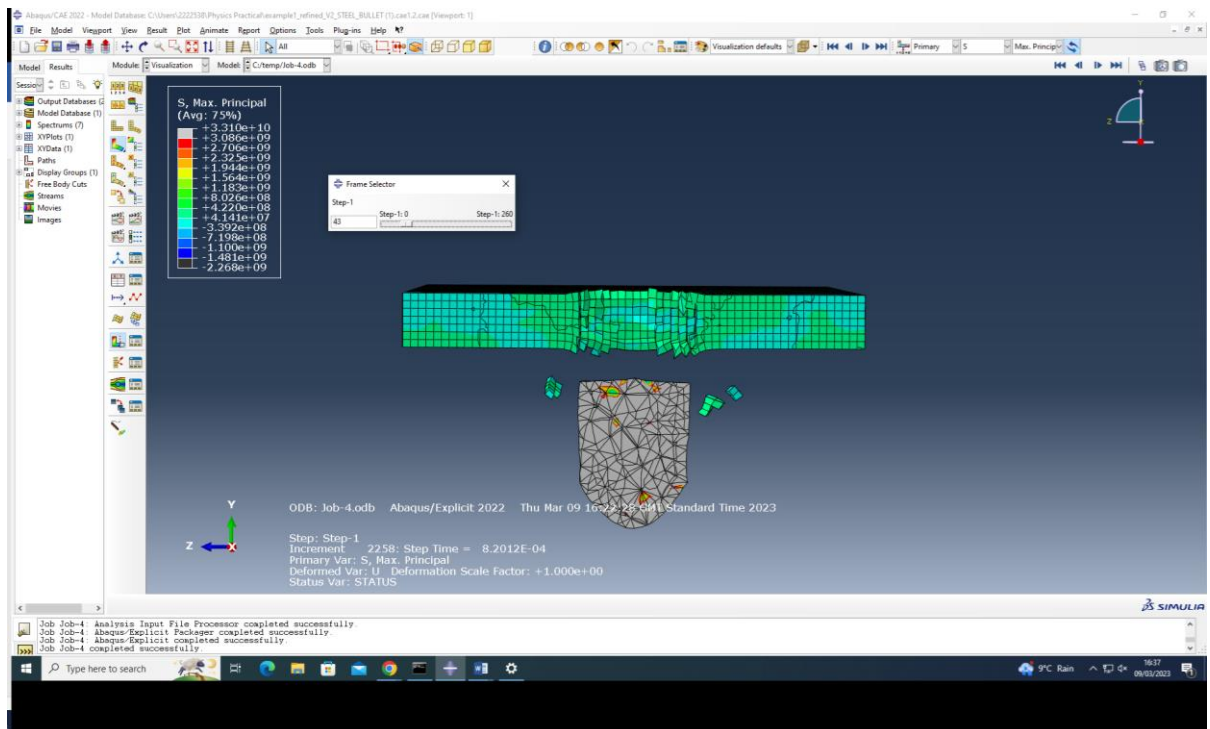


Figure 23 Copper Projectile 1800m/s Resulting Damage

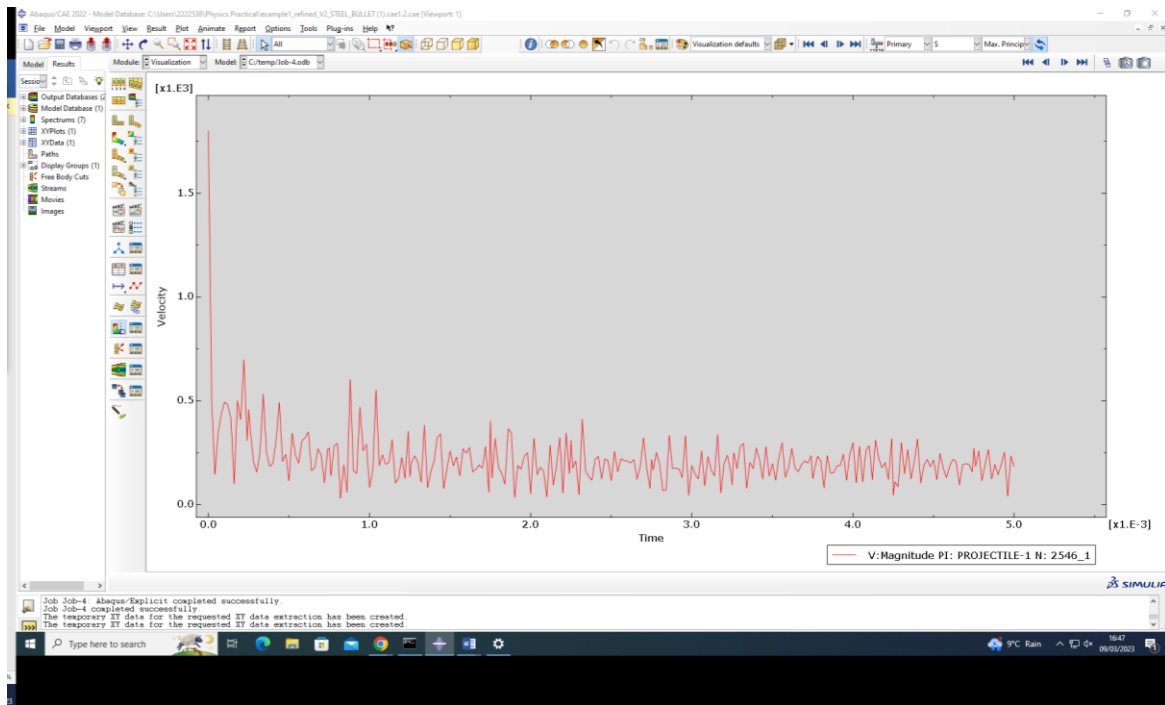


Figure 24 Copper Projectile 1800m/s Velocity Graph

Conclusion

To conclude three runs were achieved and vast data was obtained, A noticeable observation that stayed consistent between all runs carried out showed if velocity of a material increased, so did the damage. Although there is no one specific way to give defining damage parameter numbers with the pairing velocity, we could use equations such as the momentum equation, or the Kinetic energy equation, this can be seen in equation 1 and equation 2.

$$P=MV$$

Equation 1 Momentum

$$KE=1/2mv^2$$

Equation 2 Kinetic

These Equations are both valuable as they can be used to calculate the amount of momentum or energy transferred from a projectile to a target although it is important to note that kinetic energy measures an objects motion not its velocity, however the kinetic energy when applied to an object is directly proportional to its velocity. Following this one could then estimate the amount of damage the projectile could cause as if a projectile hit a plate with enough kinetic energy, it has enough energy required to break the bonds within the aluminium causing the molecular structure of the plate to become fractured or deformed or overall damaged. [3]

Each run has a key to represent the Max Principal of the material. This gives readings for tensile stress and compression. The keys colours correlate to those represented in the plate. In simple terms this shows how the projectile is forcing the plate to deform on impact. Run one, material had high density

and mass, causing the Projectile to be under compression, resulting in less damage. Whereas the plate was under tension because of high stress causing the aluminium to fail.

Comparing this to the second run where velocity was equivalent, however the material for the projectile was copper not steel, there is a noticeable difference due to the change of material. As copper is less dense the impact gets evenly distributed resulting in a high shear and tensile strength. This can be seen in figure 19, as elements have deleted due to exceeding the maximum tensile strength. It can also be seen in figure 18, where a star shaped crack is formed at the bottom of the plate. This is because of the compression of the crater being formed from the projectile impact. Causing the aluminium to behave as a liquid this is because metal is subject to a high-impact force, this causes the atoms within the aluminium to shift and move past each other. They can do this because of their crystalline structure.

By reason of curiosity, a third run was carried out to determine if the same results would occur if velocity was increased by 800m/s with the copper projectile and aluminium plating. Results in figure 23, showed that the projectile experienced high levels of deformation this is because the increased velocity caused the bullet to become compressed as it penetrates through the plate. Simultaneously the plate experienced very high amount of shear stress and tensile strength that resulted in the damage of the plating, this is seen in figure 22, as some elements delete due to exceeding the maximum tensile strength. Another way to prove this is by looking at the colours of the impact with the key S.23.

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References

- [1 [Online]. Available:
] https://moodle.uwtsd.ac.uk/pluginfile.php/614374/mod_resource/content/1/better_Bullet_ma
.

- [2 [Online]. Available:
] https://moodle.uwtsd.ac.uk/pluginfile.php/614375/mod_resource/content/1/ballistics_penetration.pdf.

- [3 N. E. Dowling, "Mechanical Behaviour of materials," in *Mechanical Behaviour of materials*, 2012.
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