

Dynamic Stress Strain Analysis of Bullet Impacts

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2. Abstract

Using the ABAQUS program, the student will test a projectile impact event and compare the effect that differing material properties, and differing geometric properties, will have on the results of the simulation, making critical assessments regarding both the target plate, and the projectile.

3. Description of the Problem

The student will simulate:

- The impact of a generic 7mm brass bullet projectile impacting a steel plate, at 1200 metres per second, modeled with Johnson-Cooke (JC) plasticity on the bullet, and smooth particle hydrodynamics (SPH) on the bullet.
- The impact of a basic (differently shaped) brass bullet projectile impacting a steel plate, at 1200 metres per second, modeled with Johnson-Cooke (JC) plasticity on the bullet, and smooth particle hydrodynamics (SPH) on the bullet.
- The impact of a generic 7mm brass bullet projectile impacting an aluminium plate, at 1200 metres per second, modeled with JC plasticity, and SPH.

4. Representation of the problem in a model

Using the ABAQUS program, the student can simulate this problem to a high degree of detail. It allows control over a range of properties and interactions. In the case of this problem, we will use it to simulate an impact of a bullet into a metal plate, testing various materials for both components, various geometries including a thicker/thinner armour plate, and a sharper/blunter bullet, observing the effect this has on the success of the projectile to defeat the armour.

Bullet Geometry

The student has designed two bullets of the same material, but different geometries.

The first bullet geometry is 7.1mm in diameter, and 9.6mm in length. It is a basic cylinder with a pointed cone tip. The sharpness and depth of the bullet tip may have a large influence on the interaction at collision.

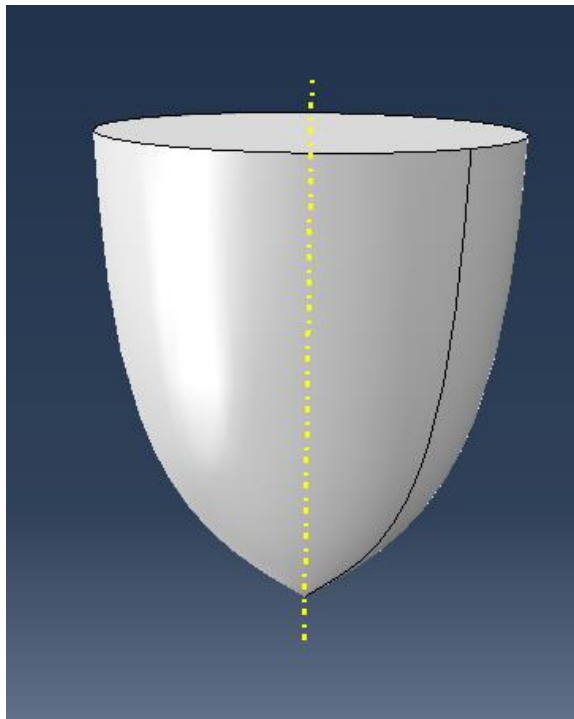


Figure 1 - 7mm Bullet Version 2.

I have based the design and dimensions of the bullet on the following diagram. (Note that this diagram shows the entire bullet and cartridge design – the bullet itself is the right-most component.)

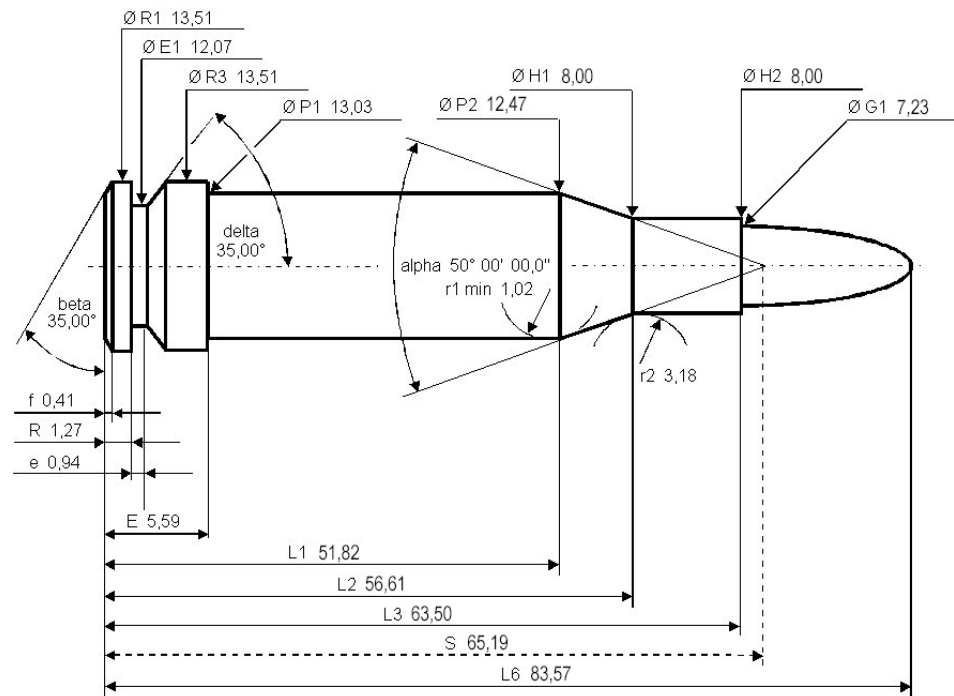


Figure 2 - The 7mm Remington Magnum bullet:

<https://en.wikipedia.org>

[/wiki/7mm Remington Magnum](/wiki/7mm_Remington_Magnum)

The second, simpler bullet design, seen in figure 2, has a similar cone-tip but with more weight and structure behind the bullet. This will affect the way it interacts in the simulation.

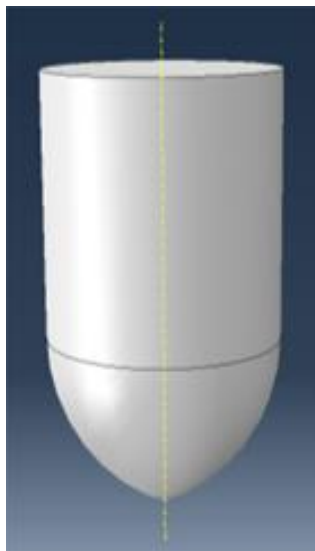


Figure 3 - Basic Bullet Design

Armour Geometry

The steel armour plate is a basic cuboid with dimensions of 76mm x 76mm, with a thickness of 20mm. One of the effects the student is investigating is 'spalling', which in this case requires a thickness with dimensions larger than the bullets penetrative ability, but not so large that the opposite side of the armour plate is not exposed to forces great enough to cause spalling.

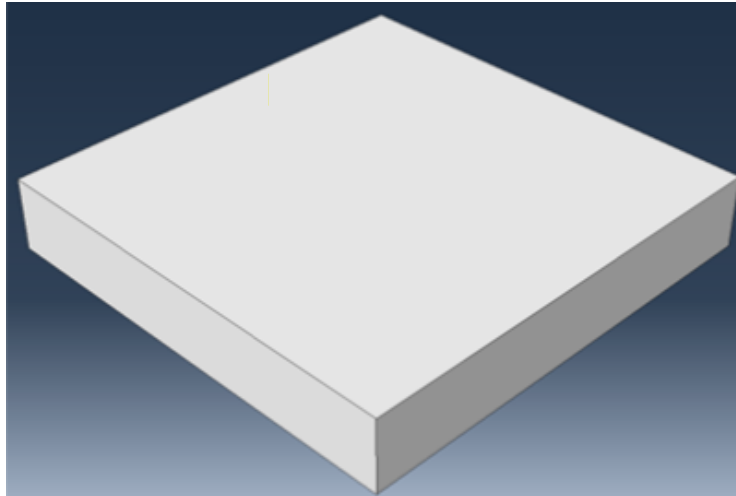


Figure 3 – Armour Plate Design

Historically, various dimensions and constructions of steel plate armour were used throughout both world wars and onward in the construction of armoured vehicles. One notable example is the use of 20mm steel plate as the stand-off component in spaced armour, used on late model German Panzer III tanks. A larger calibre shell or bullet would be damaged due to

impacting the stand-off layer first, which decreases its armour penetration and damaging capacity against the hull armour.

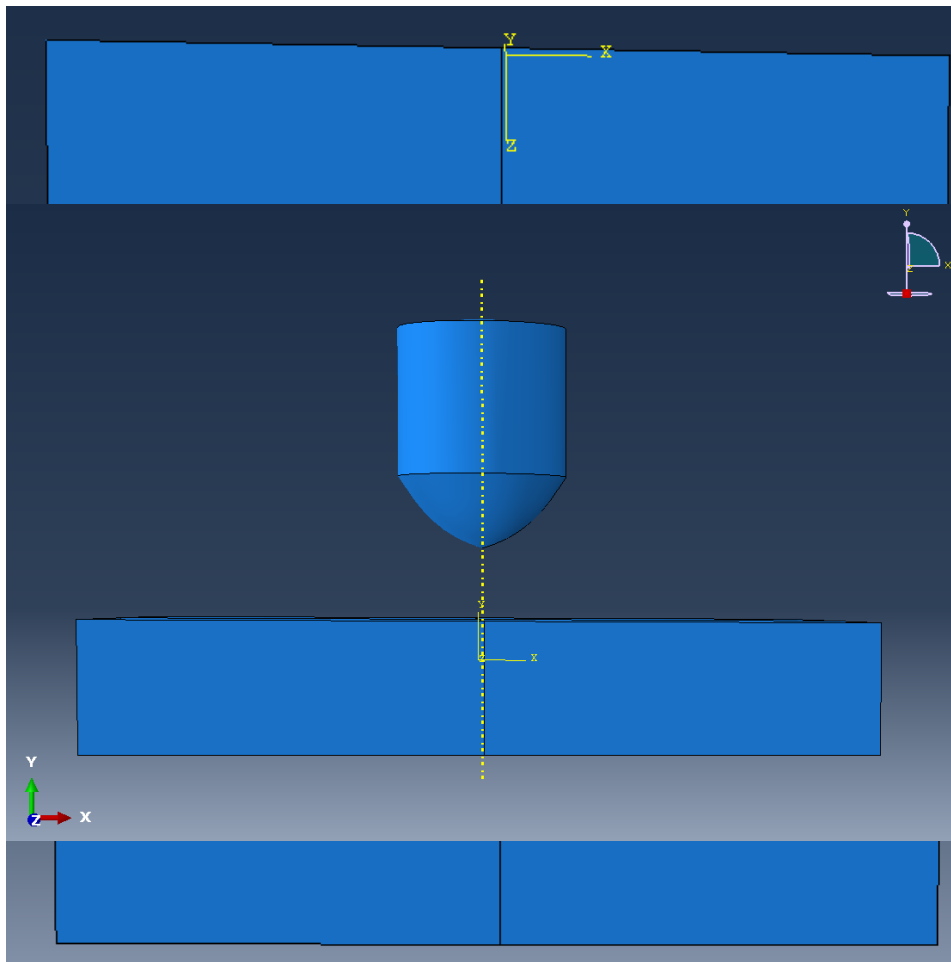


Figure 4 - The generic projectile top-view.

Figure 5 - The generic projectile side-view.

5. Description of the Material Models used based on literature review

The materials in use for the simulations will be the following:

Simulation No.	Projectile Material	Armour Plate Material	Projectile Velocity	Projectile Shape
1	Brass	Steel	1200 metres per second	7mm Remington Magnum Bullet
2	Brass	Steel	1200 metres per second	Basic Bullet

Table 1 - Simulations

Brass

The material properties used in this model for Brass sections is primarily based on Brass 260 (70% Copper, 30% Nickel), using the MatWeb [2] entry for 'Cartridge Brass', as well as the research papers [1] and [3], which were consulted to compare the provided values. Paper [3] matched the context of the problem moreso than paper [1], and so the data it provided was selected for this model. Using these parameters, the problem can be simulated with simple damage modelling in place.

The parameters used for brass in this model are as follows:

Parameter	Value
<i>Young's Modulus</i>	110 GPa
<i>Poisson's Ratio</i>	0.375
<i>Mass Density</i>	8.53 g/cc
<i>A (MPa)</i>	112
<i>B (MPa)</i>	505
<i>n</i>	0.42
<i>m</i>	1.68
<i>Melting Temp (K)</i>	1189
<i>Transition Temp (K)</i>	373
<i>d1</i>	0.54
<i>d2</i>	4.89
<i>d3</i>	3.03
<i>d4</i>	0.014
<i>d5</i>	1.12
<i>Reference Strain Rate (1/s)</i>	1

Table 2 - Brass Material Properties

Steel

Values from MatWeb [4] and ResearchGate [5] were used here.

Parameter	Value
<i>Young's Modulus</i>	
<i>Poisson's Ratio</i>	0.3
<i>Mass Density</i>	7860 (7.86g/cc)
<i>A (MPa)</i>	792

<i>B (MPa)</i>	510
<i>n</i>	0.26
<i>m</i>	1.03
<i>Melting Temp (K)</i>	1800
<i>Transition Temp (K)</i>	293
<i>d1</i>	n/a
<i>d2</i>	n/a
<i>d3</i>	n/a
<i>d4</i>	n/a
<i>d5</i>	n/a
<i>Reference Strain Rate (1/s)</i>	n/a

Table 3 – Steel Material Properties

Aluminium

Again, using information from MatWeb [6] and ResearchGate [7], the values for Aluminium were determined.

Parameter	Value
<i>Young's Modulus</i>	68 GPa
<i>Poisson's Ratio</i>	0.36
<i>Mass Density</i>	2.6989 g/cc
<i>A (MPa)</i>	520
<i>B (MPa)</i>	477
<i>n</i>	0.52
<i>m</i>	
<i>Melting Temp (K)</i>	893
<i>Transition Temp (K)</i>	293
<i>d1</i>	0.096
<i>d2</i>	0.049
<i>d3</i>	-3.465
<i>d4</i>	0.016
<i>d5</i>	1.099
<i>Reference Strain Rate (1/s)</i>	

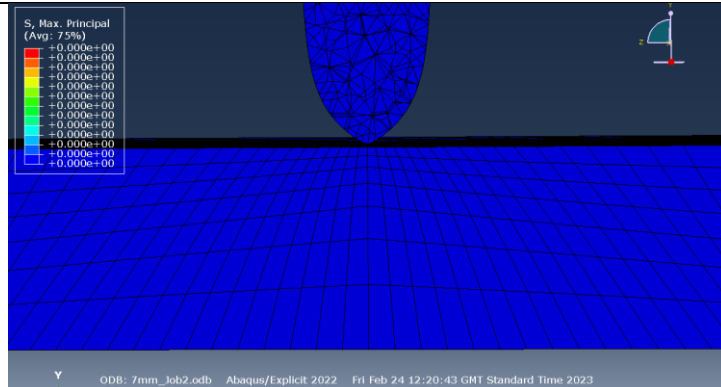
Table 4 - Aluminium Material Properties

6. Simulation One: Generic 7mm Brass Bullet Against Steel Plate

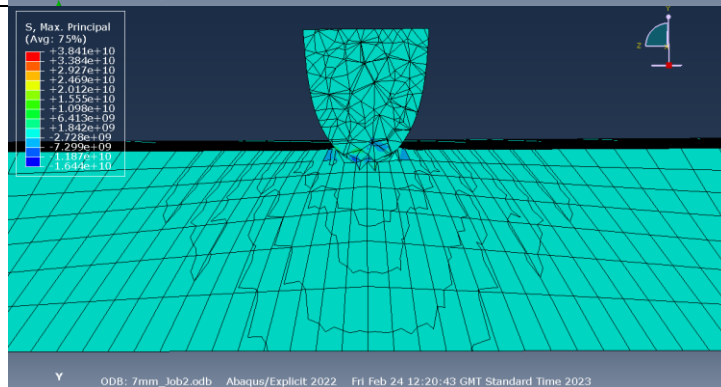
Below, the progression of the brass bullet into the steel surface can be observed. (The settings 'S', 'Mises' are selected, showing us the **tensile forces acting up** on both the bullet and the armour, according to Johnson-Cook damage and plasticity modelling.)

Note	S – Max Principal (Tension)
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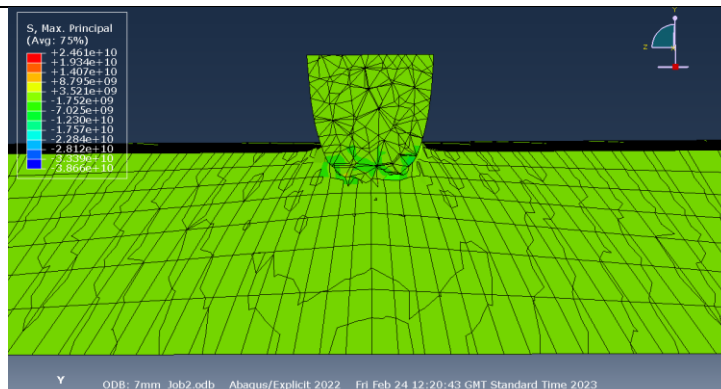
Bullet before entry. Notice the pointed edge at the tip of the bullet, which will predictably deform, especially as it is soft brass.



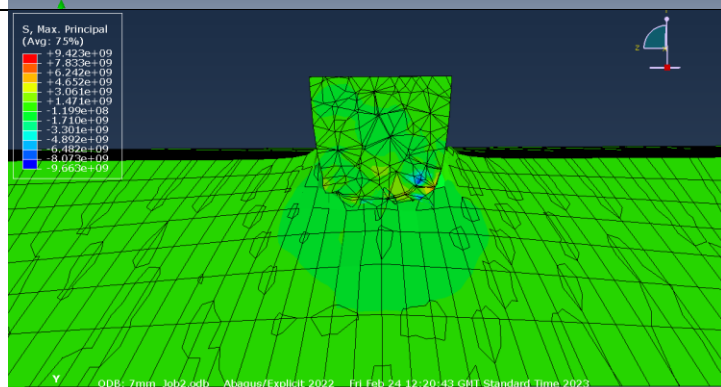
First impact – the pointed edge deforms instantly, the brass bullet quickly begins to squash and break apart upon impact. This can be observed in the dark blue colouring at the impact site, on both the bullet and the armour. The tensile forces at the end of the bullet are too great. This is expected, as brass is softer than steel.

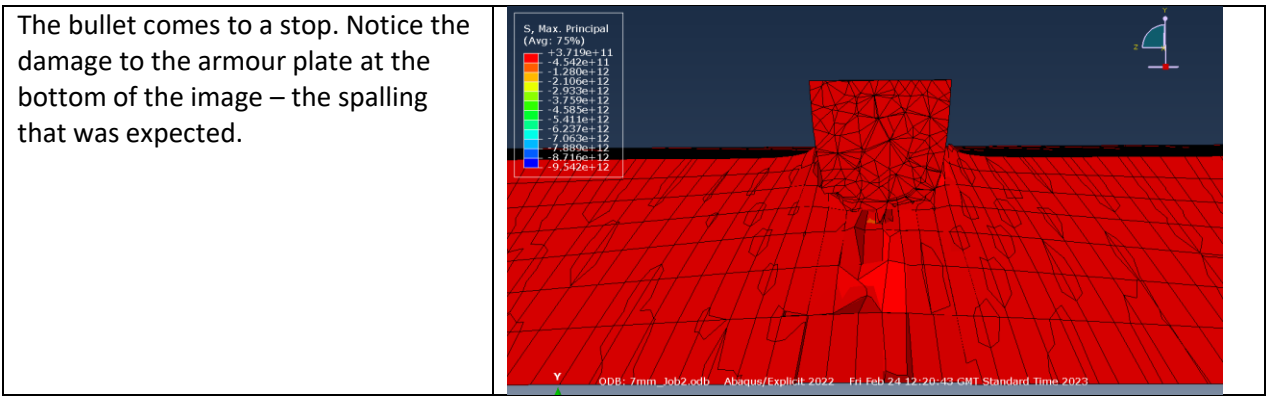


The bullet has further degraded, though it has entered the armour plate. The tensile stress has increased across the bullet.

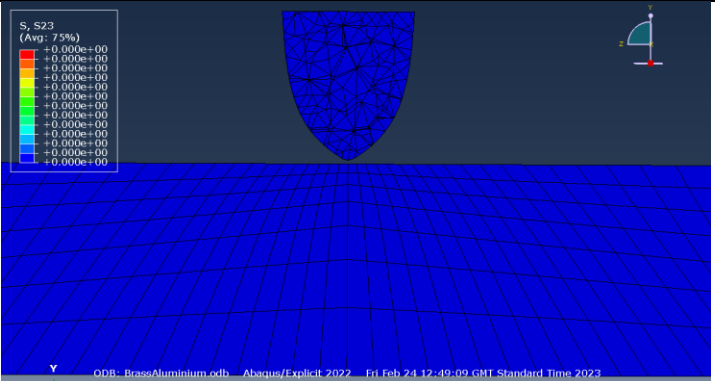
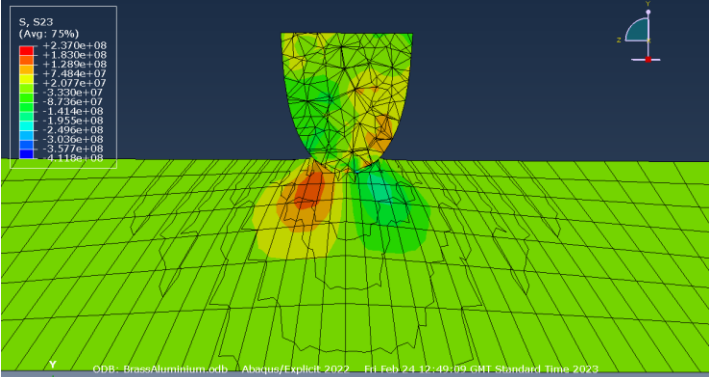


The bullet is deeper into the structure, though it is completely breaking apart at this point due to the high tensile stress. Hot spots of stress can be seen on the right-hand side of the bullet, from this perspective.

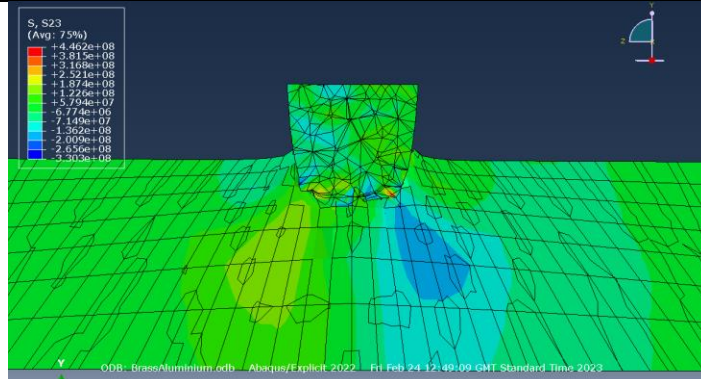




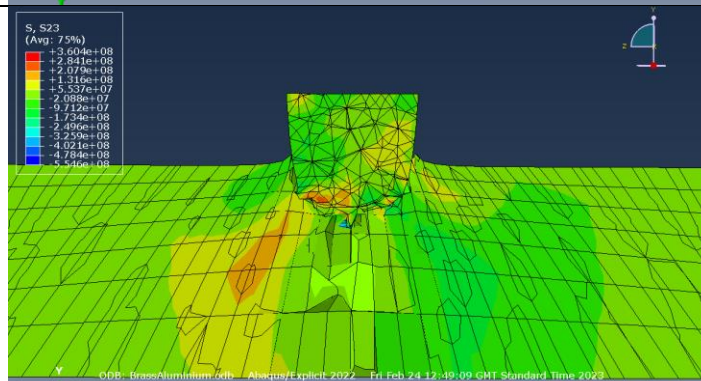
In this table, the same simulation is observed, though it instead represents the shear stresses (across the Y-Z coordinates – flat from this perspective) that are acting upon both objects.

Note	S – S23 – Shear Stress about the Y and Z co-ordinates
Bullet before entry.	 ODB: BrassAluminium.odb Abaqus/Explicit 2022 Fri Feb 24 12:49:09 GMT Standard Time 2023
Here, the shear stress is acting upon the sides of the impact site, as the material is forced away from the bullet's entry.	 ODB: BrassAluminium.odb Abaqus/Explicit 2022 Fri Feb 24 12:49:09 GMT Standard Time 2023

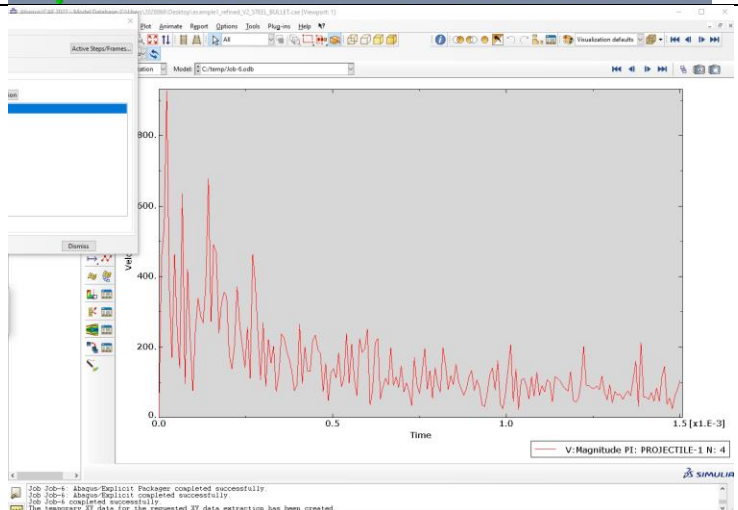
Here, the bullet has deeply entered the armour, and the shear stresses in the armour itself are starting to reduce, as the velocity of the projectile nears zero.



The bullet impact has concluded.

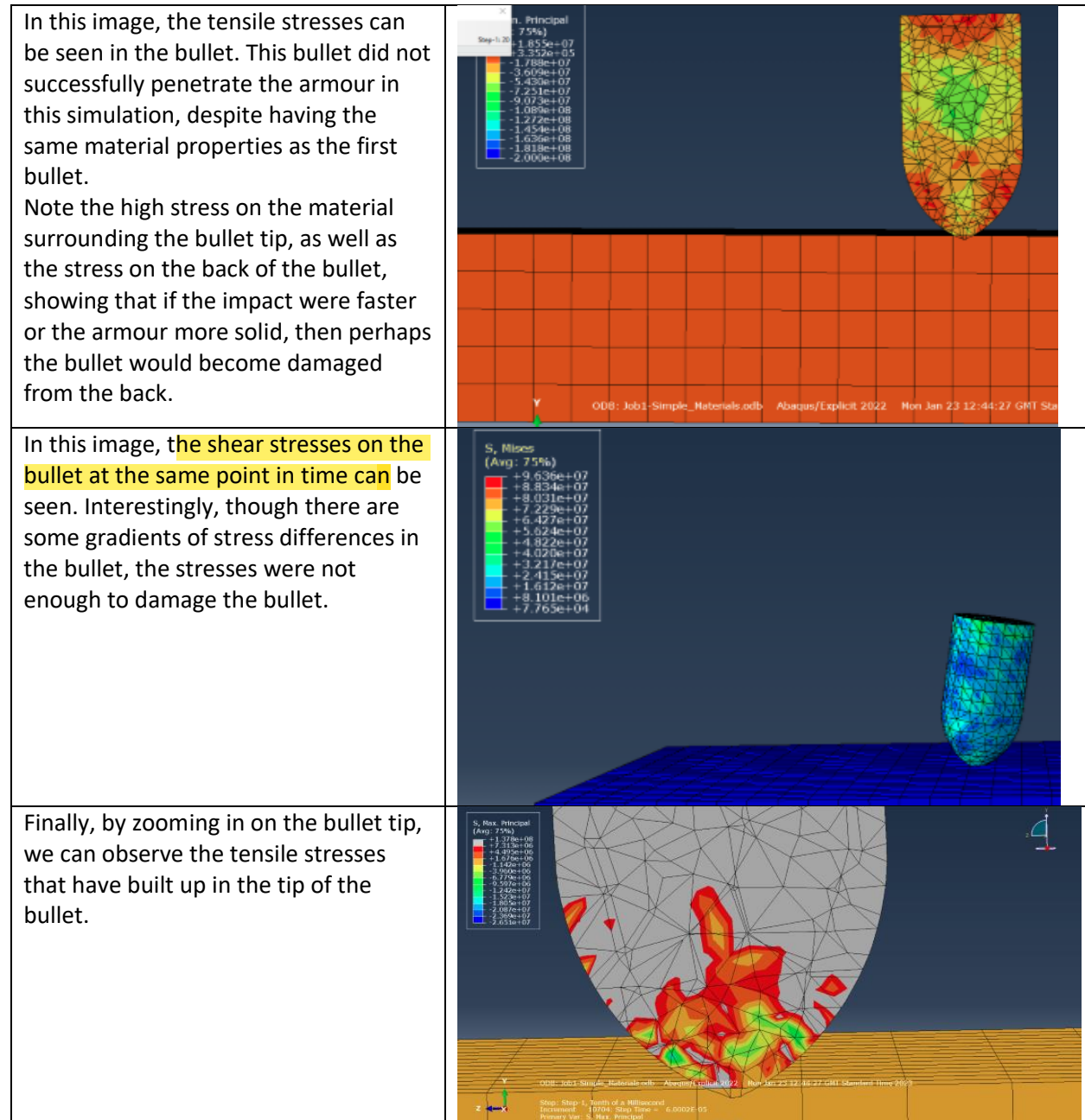


Note here the graph displaying the velocity of the bullet over time. It is interesting that it fluctuates, as in real life, it would be unlikely for the projectile to speed up after impact whatsoever. This is perhaps a limitation of the software.



7. Simulation Two: Basic Brass Bullet Against Steel Plate

In the following table, the simulation of the basic bullet will be explored in more detail. We will focus on the stresses that take place in the bullet itself.



8. Critical Commentary on Limitations and Approximations of Simulation

Whilst the ability to simulate the physics of stress and strain relationships is most certainly of benefit to engineers and scientists, it does not replace the need for physical tests, due to the limitations of the simulation in accurately providing information regarding certain topics.

The software must simplify physics to compute any results – there will always be an abstraction compared to the physical reactions and properties, due to the bottleneck that processing power and computational power have on the software. Software cannot simulate every atom, every interaction, and so there must be compromise, to carry out simulations.

Additionally, the ideal material properties that are used in Abaqus and other simulation software do not accurately represent the slight differences in real world objects. Steel, in real life, may all be of different ages, be made with slightly varied ratios or compounds, or have been stored in different temperatures or humidities. There are simply environmental and provenance factors that are impractical at best to simulate, and impossible at worst.

Finally, there is the ultimate fact that due to these limitations, a simulated test alone is not enough to guarantee the safety or efficacy of the object – real life testing must take place to determine the true limits of these materials and objects. Simulations, however, can be used to approximate these tests beforehand, which allows a degree of experimentation for a low cost, before high-cost physical testing begins.

9. Conclusion

Many simulations and different bullet geometries were experimented with during this investigation – the results showing the damage and spalling of the armour, as well as the focus on the tensile/shear stress of the basic bullet upon impact, provide an interesting viewpoint on where the bullet/armour is at its weakest and strongest when impacted/impacting.

10. References

- [1] https://www.epj-conferences.org/articles/epjconf/pdf/2012/08/epjconf_dymat2012_01060.pdf
- [2] <https://www.matweb.com/search/datasheet.aspx?MatGUID=83677ae92338456da4d4fe8fe4b815c5>
- [3] https://www.researchgate.net/publication/264461561_Ballistic_Impacts_of_a_Full-Metal_Jacketed_FM_J_Bullet_on_a_Validated_Finite_Element_FE_Model_of_Helmet-Cushion-Head Tse, Kwong Ming & Long Bin, Tan & Yang, Bin & Tan, V B C & Lim, Siak & Lee, Hp. (2014). Ballistic Impacts of a Full-Metal Jacketed (FMJ) Bullet on a Validated Finite Element (FE) Model of Helmet-Cushion-Head.
- [5] https://www.researchgate.net/figure/Johnson-Cook-model-material-parameters_tbl1_282894247
- [6] <https://www.matweb.com/search/DataSheet.aspx?MatGUID=0cd1edf33ac145ee93a0aa6fc666c0e0>
- [7] https://www.researchgate.net/figure/Material-properties-and-Johnson-Cook-model-parameters-for-aluminium-alloy_tbl1_261219169

11. Annex A

