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by Christopher Peacock

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Table of Contents

Abstract	3
Introduction	3
Method	3
Description of model:	3
Velocities	3
Aluminium properties	3
Results:	5
250ms ⁻¹ :	5
Direct stress	6
Shear stress	8
400ms ⁻¹ :	9
Direct stress	10
Shear stress	11
600ms ⁻¹ :	12
Direct stress	13
Shear stress	14
800ms ⁻¹ :	15
Direct stress	16
Shear stress	17
Discussion	19
Limitations	19
Conclusions:	20
References	21

Table of figures

Figure 1:	Graph of velocity over time at an initial velocity of 250ms^{-1}	5
Figure 2:	Aluminium plate at 0.5ms at a velocity of 250ms^{-1} , top view	6
Figure 3:	Aluminium plate at 1.5ms at a velocity of 250ms^{-1} , top view	6
Figure 4:	Direct stress on the aluminium plate at 0.5ms at a velocity of 250ms^{-1} , cut view	7
Figure 5:	Direct stress on the aluminium plate at 1.5ms at a velocity of 250ms^{-1} , cut view	7
Figure 6:	Shear stress on the aluminium plate at 0.5ms at a velocity of 250ms^{-1} , cut view	8
Figure 7:	Shear stress on the aluminium plate at 1.5ms at a velocity of 250ms^{-1} , cut view	8
Figure 8:	Graph of velocity over time at an initial velocity of 400ms^{-1}	9
Figure 9:	Aluminium plate at 0.5ms at a velocity of 400ms^{-1} , top view	10
Figure 10:	Direct stress on the aluminium plate at 0.5ms at a velocity of 400ms^{-1} , cut view	10
Figure 11:	Shear stress on the aluminium plate at 0.5ms at a velocity of 400ms^{-1} , cut view	11
Figure 12:	Graph of velocity over time at an initial velocity of 600ms^{-1}	12
Figure 13:	Aluminium plate at 0.5ms at a velocity of 600ms^{-1} , top view	13
Figure 14:	Direct stress on the aluminium plate at 0.5ms at a velocity of 600ms^{-1} , cut view	13
Figure 15:	Shear stress on the aluminium plate at 0.5ms at a velocity of 600ms^{-1} , cut view	14
Figure 16:	Graph showing velocity over time at an initial velocity of 800ms^{-1}	15
Figure 17:	Aluminium plate at 0.5ms at a velocity of 800ms^{-1} , top view	16
Figure 18:	Direct stress on the aluminium plate at 0.5ms at a velocity of 800ms^{-1} , cut view	16
Figure 19:	Direct stress on the aluminium plate at 1.5ms at a velocity of 800ms^{-1} , cut view	17
Figure 20:	Shear stress on the aluminium plate at 0.5ms at a velocity of 800ms^{-1} , cut view	17
Figure 21:	Shear stress on the aluminium plate at 1.5ms at a velocity of 800ms^{-1} , cut view	18

Abstract

This report details the investigation into the performance of an aluminium plate to the impact of a bullet at varying velocities using an ABAQUS model. Velocities simulated at 250 ms^{-1} , 400 ms^{-1} , 600 ms^{-1} and 800 ms^{-1} . These were chosen to represent the muzzle velocities of a number of different weapons.

It was identified that there was direct stress and shear stress acting on the aluminium plate from the impact of the bullet and throughout its path in the plate. The direct stress caused bulging, petaling or spalling on the far side of the plate. The shear stress caused some of the material to be forced out of the aluminium plate against the direction of travel.

Introduction

This report details the investigation the performance of an aluminium plate to the impact of a bullet at varying velocities using an ABAQUS model. A number of pre-set properties were given in the supplied model and the properties of the aluminium plate were researched and inputted into the model. The velocities chosen for the model were based on muzzle velocities for a number of different weapons. These include a suppressed rifle, submachine gun, shotgun and a high velocity sniper rifle.

Method

Description of model:

A model was supplied in ABAQUS with the following properties pre-set:

- The bullet is represented by an analytical surface and as such was not meshed and is a rigid and non-deformable part
- An Explicit Dynamics Solver step was pre-set
- The edges of the aluminium plate was already fixed
- The surface to surface contact interaction was pre-set
- A mesh was created for the aluminium plate using hexahedral elements
- There is no resistance from friction acting on either the target or the bullet

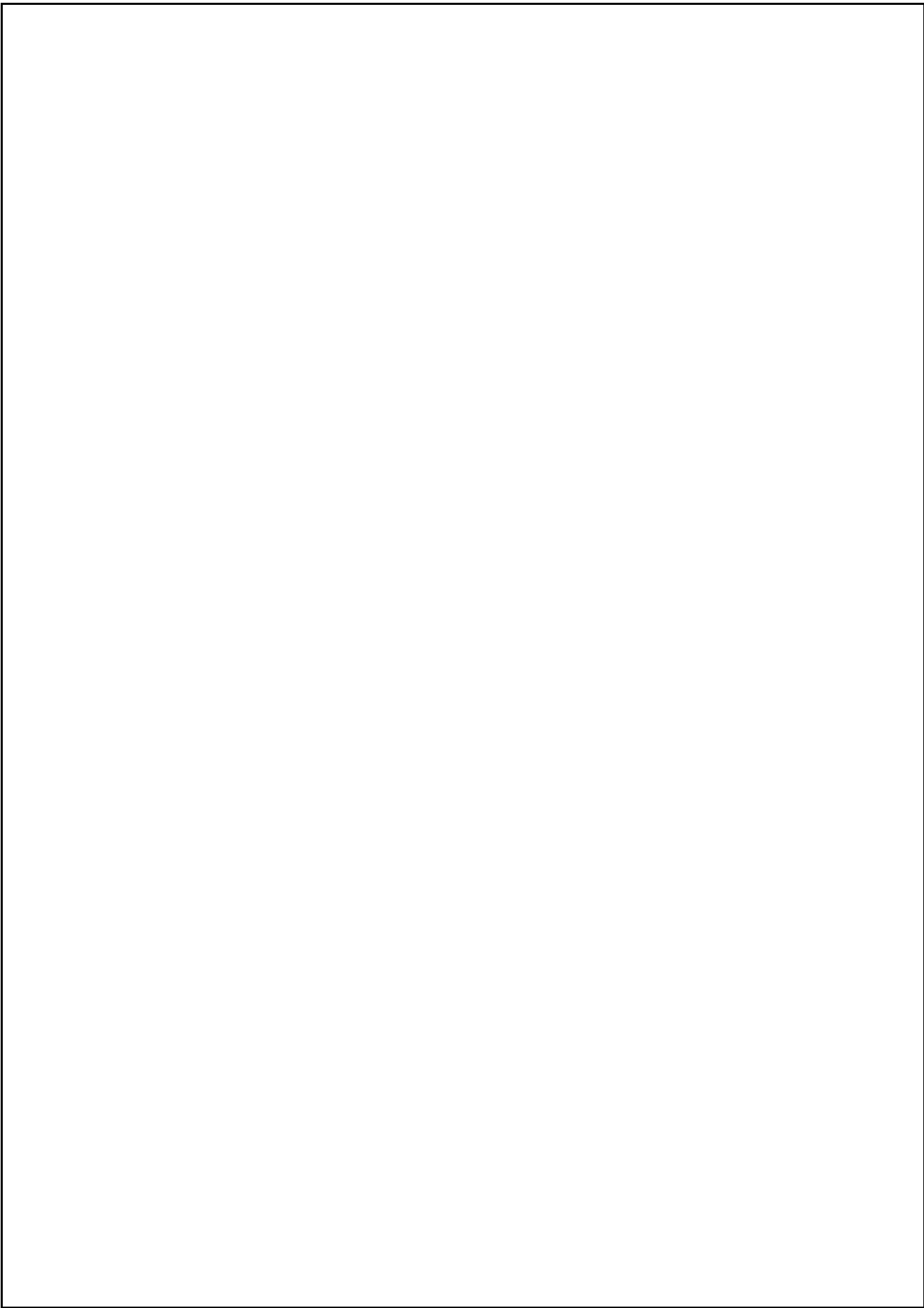
Velocities

The following velocities were simulated 250 ms^{-1} , 400 ms^{-1} , 600 ms^{-1} and 800 ms^{-1} . Each of these were chosen as they are indicative of the muzzle velocities of different weapons systems and calibres. 250 ms^{-1} for the 0.45 inch De Lilse Carbine [1], 400 ms^{-1} for the 9 x 19mm fired from a Heckler and Koch MP5 [2], 600 ms^{-1} for a 4.6 x 30mm FMJ fired from the Heckler and Koch MP-7 [3], 800 ms^{-1} for the 7.62 x 54mmR fired from the Dragunov sniper rifle, the SVD [4].

Aluminium properties

The figures used for the material properties of the aluminium plate are taken from 6000 series aluminium alloy. These are detailed as follows [5]:

- Density: 2700 kgm^{-2}
- Poisson's ratio: 0.33
- Young's modulus: $68.9 \times 10^9 \text{ Pa}$
- Ultimate tensile stress: 310MPa
- Yield strength: 276MPa



Results:

A simulation was run at each velocity against the target plate. For each simulation I will show the following:

- A velocity/time graph
- The top of the aluminium plate at the point of impact
- A cut at the point of impact
- A cut at 0.5ms and 1.5ms

250ms⁻¹:

250ms⁻¹ is indicative of the muzzle velocity of the 0.45 inch De Lilse Carbine [1].

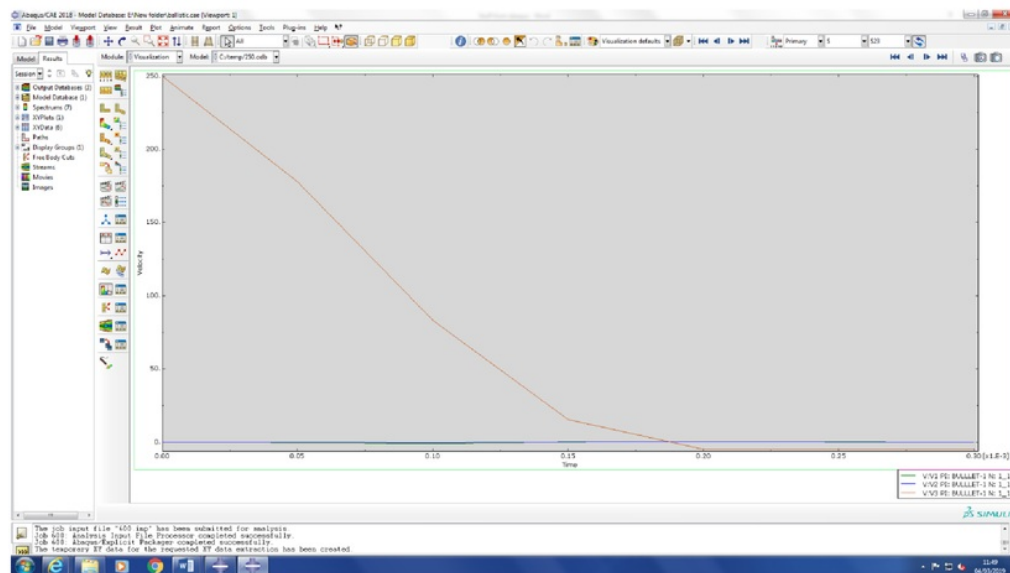


Figure 1: Graph of velocity over time at an initial velocity of 250ms⁻¹

The graph above (Figure 1) shows the velocity of the bullet over time in the X, Y and Z axis from its starting velocity of 250ms⁻¹ to the end of the simulation. The graph shows that there is negligible change in the velocity of the bullet in the X and Y axis as the bullet slows from the initial impact velocity of 250ms⁻¹ indicating that it hasn't started tumbling. There is a change in velocity in the Z axis which is in the direction of travel of the bullet on impact. The graph shows that the bullet slows to a velocity of 0ms⁻¹ at about 0.19ms before ricocheting back along the direction of travel.

Direct stress

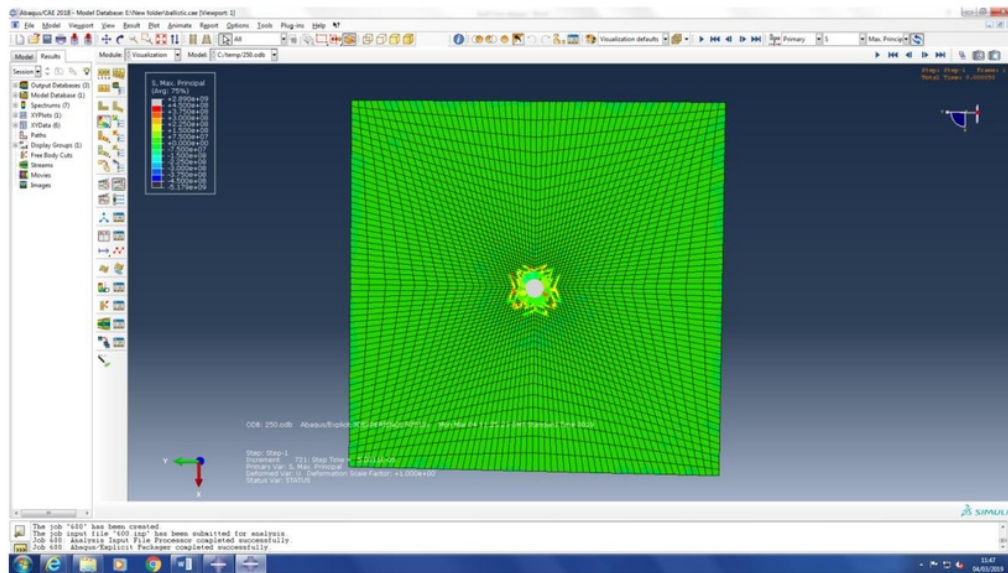


Figure 2: Aluminium plate at 0.5ms at a velocity of 250ms^{-1} , top view

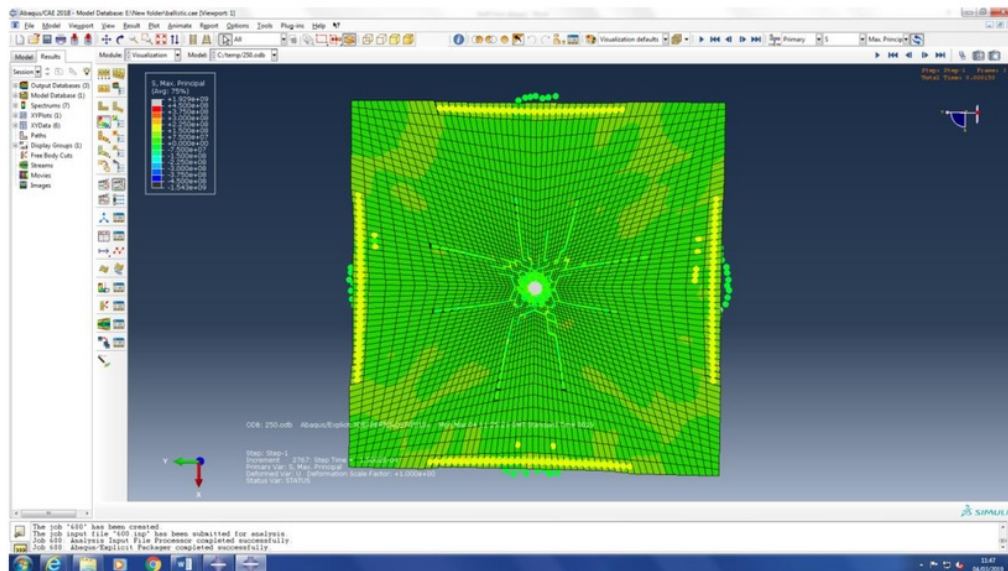


Figure 3: Aluminium plate at 1.5ms at a velocity of 250ms^{-1} , top view

The above images show the bullet at 0.5ms and 1.5ms through the bullet's path into the aluminium plate. Initially, there is direct stress of between $2.5 \times 10^8 \text{Pa}$ and $3 \times 10^8 \text{Pa}$, shown on the target plate by the orange and yellow, to either side of the bullet (Figure 2). As the bullet passes through the plate, the direct stress is reduced at the initial impact point as the bullet is applying force to the region in front of it (Figure 3). Both images also show stress radiating radially from the impact point, which at the point of impact is in the region of $1.5 \times 10^8 \text{Pa}$.

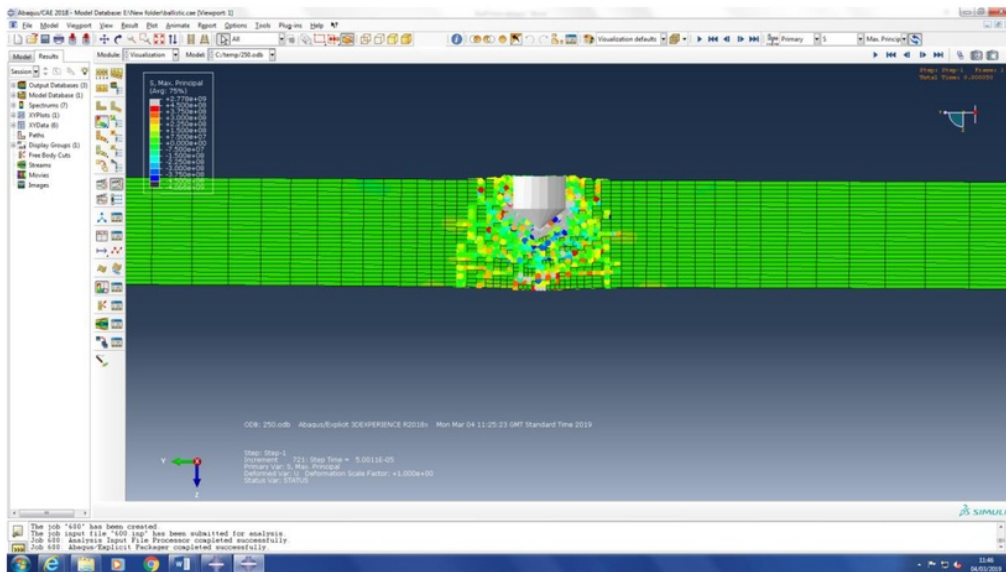


Figure 4: Direct stress on the aluminium plate at 0.5ms at a velocity of 250ms^{-1} , cut view

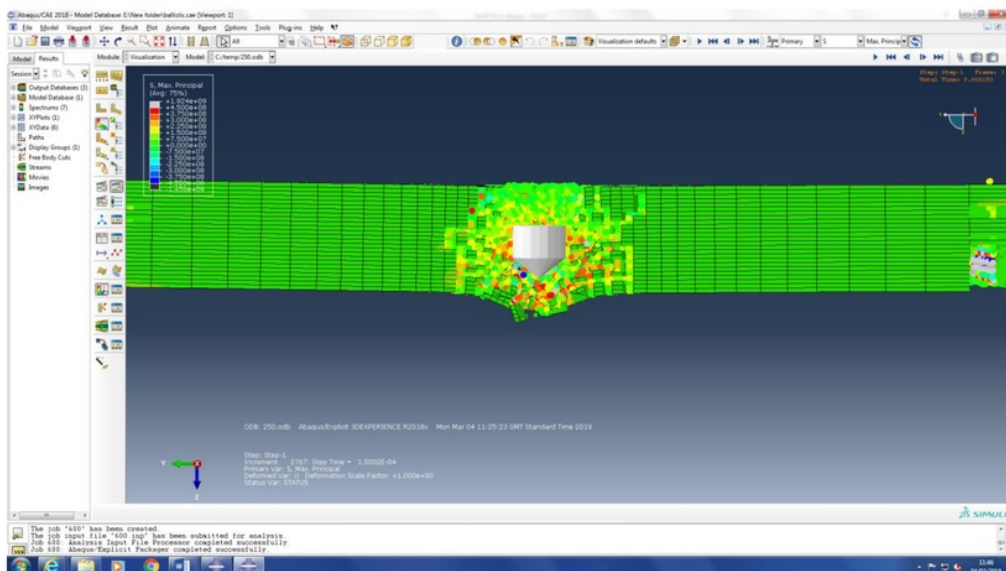


Figure 5: Direct stress on the aluminium plate at 1.5ms at a velocity of 250ms^{-1} , cut view

The images above show the direct stress within the plate as the bullet goes through the aluminium plate. There is a compression force which goes through the aluminium plate, in front of the bullet which has a magnitude of approximately $2.7 \times 10^9 \text{Pa}$ (Figure 4). As the bullet passes through the plate the stress radiates from the impact point of the bullet which is shown as a radial pattern on the front

face of the plate. When the force impacts the far side of the aluminium plate it reflects back into the plate causing tension and subsequently spalling on the back of the plate (Figure 5).

Shear stress

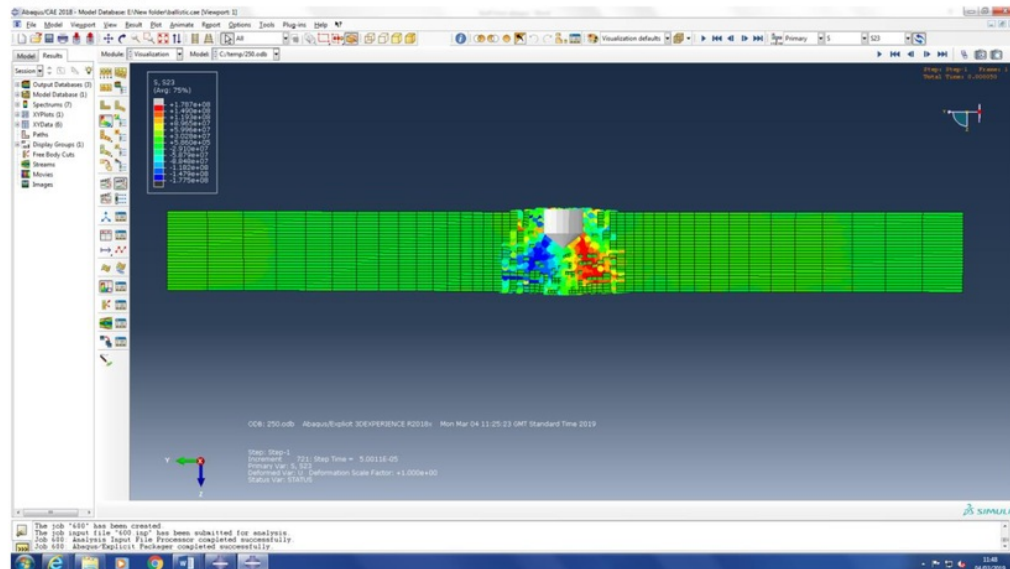


Figure 6: Shear stress on the aluminium plate at 0.5ms at a velocity of 250ms^{-1} , cut view

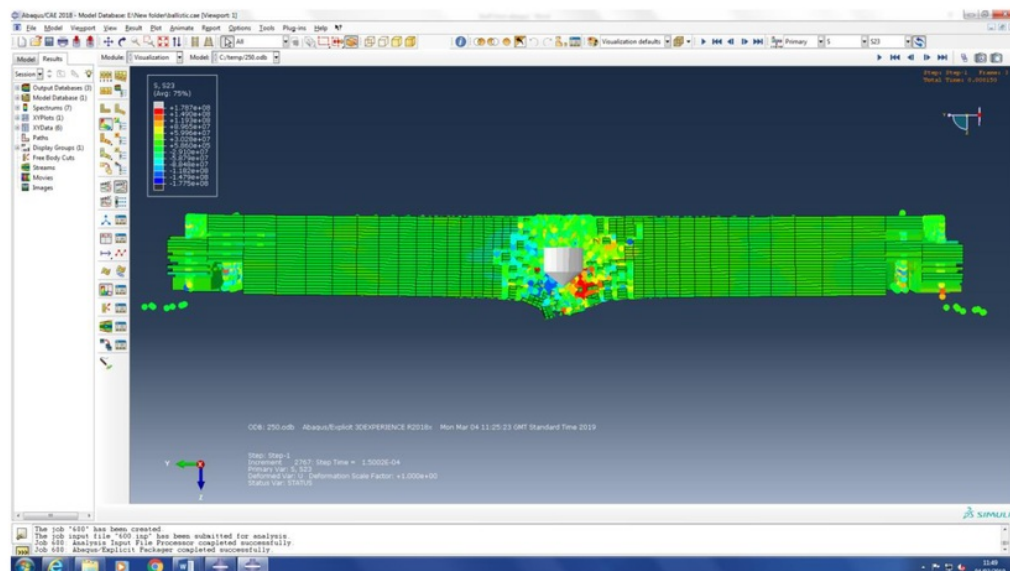


Figure 7: Shear stress on the aluminium plate at 1.5ms at a velocity of 250ms^{-1} , cut view

The images above (Figure 6 & Figure 7) show the shear stress on the aluminium plate as the bullet passes through it at 0.5ms and 1.5ms. The red/orange and blue areas show the shear stress on either side of the bullet to be in the region of $1.5 \times 10^9 \text{Pa}$. The red and blue are of the same magnitude but are different colours as it is acting in opposite directions.

400ms^{-1} :

400ms^{-1} is indicative of a 9 x 19mm fired from a Heckler and Koch MP5 [2].

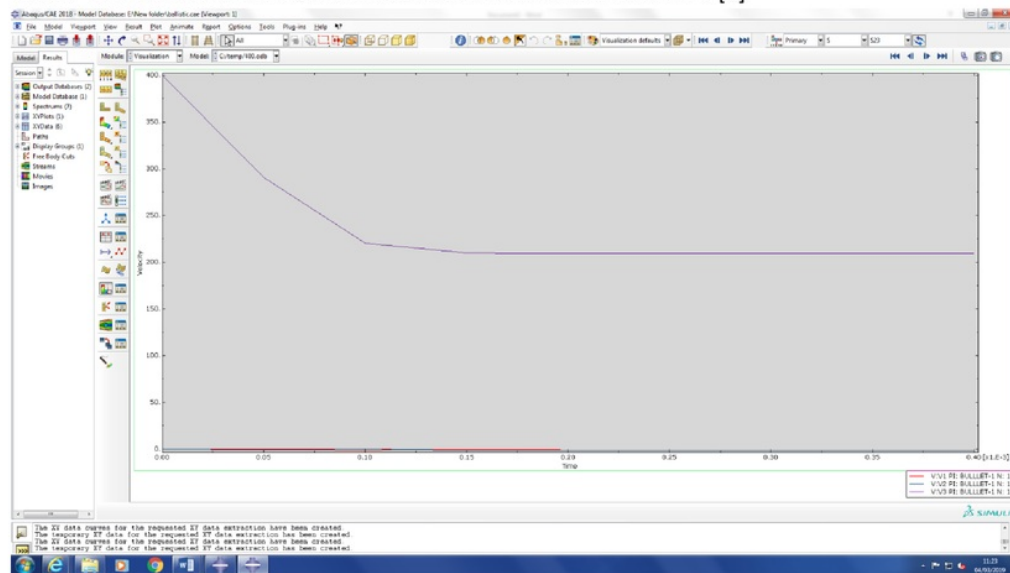


Figure 8: Graph of velocity over time at an initial velocity of 400ms^{-1}

The graph above (Figure 8) shows the velocity of the bullet over time in the X, Y and Z axis from its starting velocity of 400ms^{-1} to the end of the simulation. The graph shows that there is negligible change in the velocity of the bullet in the X and Y axis as the bullet slows from the initial impact velocity of 400ms^{-1} indicating the bullet hasn't started to tumble. There is a change in velocity in the Z axis which is in the direction of travel of the bullet on impact as it passes through the aluminium plate. By 0.15ms the velocity falls to approximately 220ms^{-1} .

Direct stress

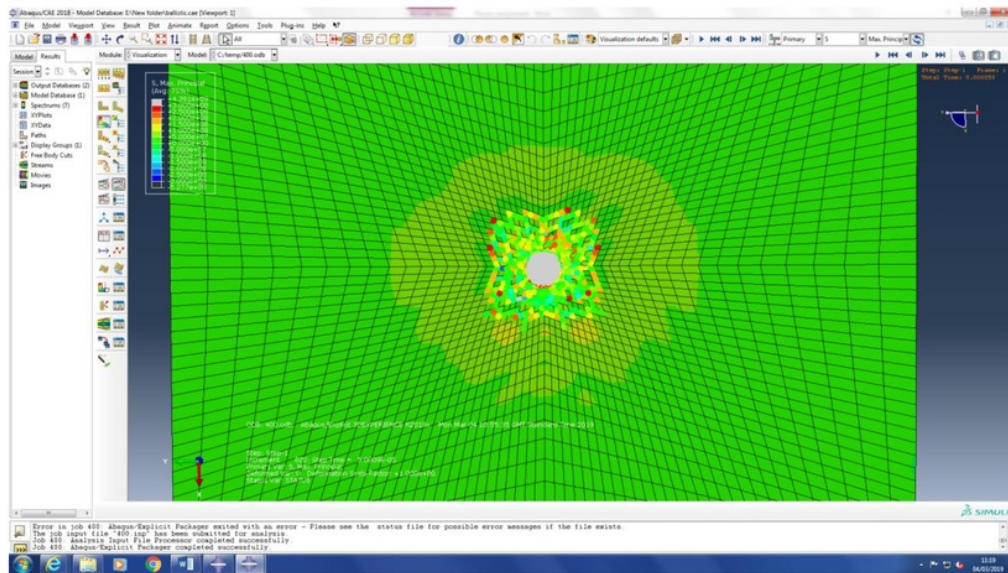


Figure 9: Aluminium plate at 0.5ms at a velocity of 400ms⁻¹, top view

The above image shows the direct stress on the aluminium plate at 0.5ms. There is a direct stress of a maximum of 3×10^8 Pa, shown on the target plate by the red, radiating from the point of impact (Figure 9).

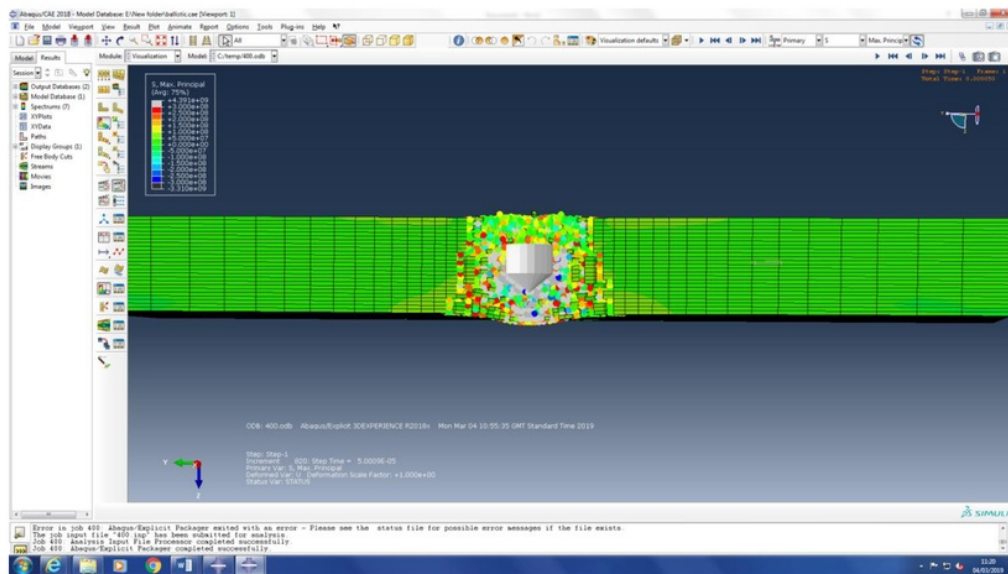


Figure 10: Direct stress on the aluminium plate at 0.5ms at a velocity of 400ms⁻¹, cut view

The image above shows the direct stress within the plate as the bullet goes through the aluminium plate. There is a compression force which goes through the aluminium plate, in front of the bullet which has a magnitude of approximately 4.39×10^8 Pa (Figure 4). As the bullet passes through the plate the stress radiates from the impact point of the bullet which is shown as a radial pattern on the

front face of the plate. When the force impacts the far side of the aluminium plate it reflects back into the plate causing tension. The far side of the aluminium plate shows that there is bulging (Figure 10).

Shear stress

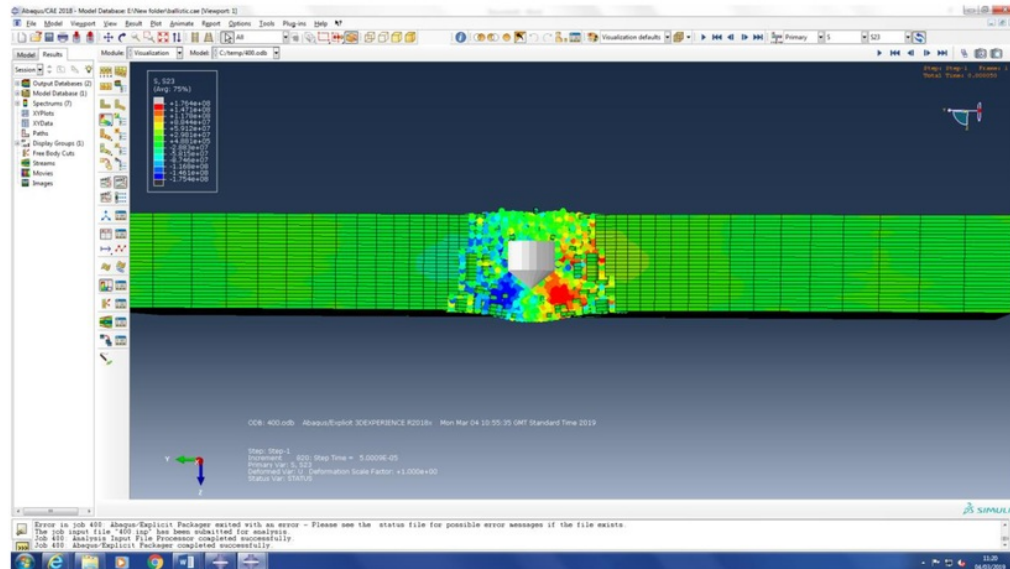


Figure 11: Shear stress on the aluminium plate at 0.5ms at a velocity of 400ms^{-1} , cut view

The image above (Figure 11) shows the shear stress on the aluminium plate as the bullet passes through it at 0.5ms. The red/orange and blue areas show the shear stress on either side of the bullet to be in the region of $1.47 \times 10^9 \text{Pa}$. The red and blue are of the same magnitude but are different colours as it is acting in opposite directions.

600ms^{-1}

600ms^{-1} is indicative of a $4.6 \times 30\text{mm}$ FMJ fired from the Heckler and Koch MP-7 [3].

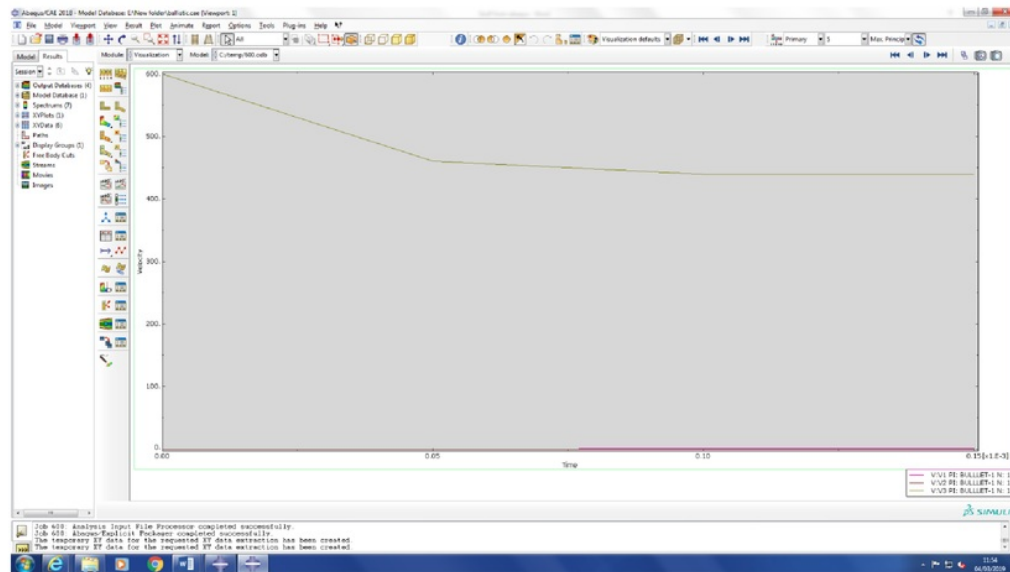


Figure 12: Graph of velocity over time at an initial velocity of 600ms^{-1}

The graph above (Figure 12) shows the velocity of the bullet over time in the X, Y and Z axis from its starting velocity of 600ms^{-1} to the end of the simulation. The graph shows that there is negligible change in the velocity of the bullet in the X and Y axis as the bullet slows from the initial impact velocity of 600ms^{-1} indicating the bullet hasn't started to tumble. There is a change in velocity in the Z axis which is in the direction of travel of the bullet on impact as it passes through the aluminium plate. By 0.05ms the velocity falls to approximately 450ms^{-1} .

Direct stress

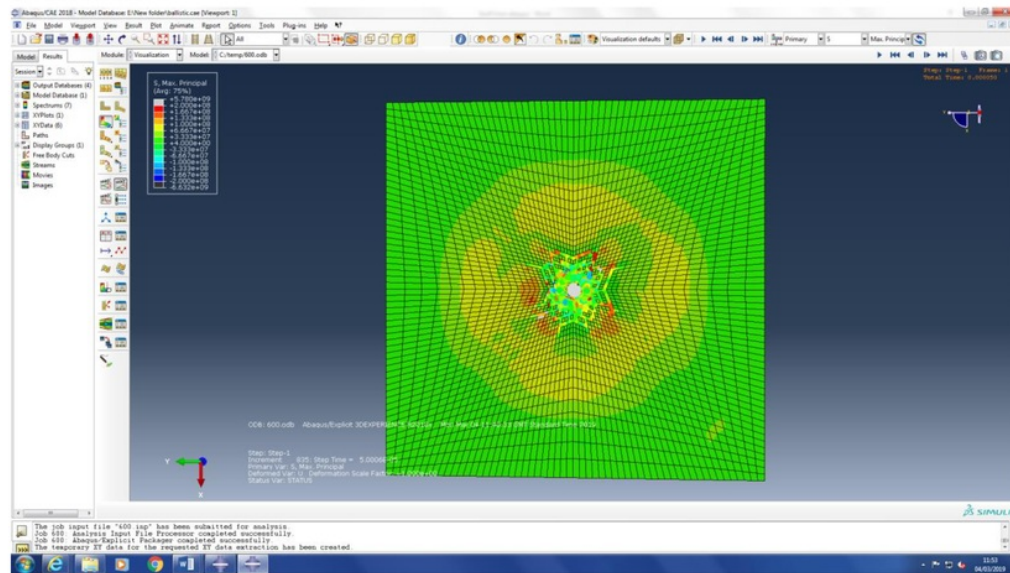


Figure 13: Aluminium plate at 0.5ms at a velocity of 600ms-1, top view

The above image shows the direct stress on the aluminium plate at 0.5ms. There is a direct stress of a maximum of $2 \times 10^8 \text{ Pa}$, shown on the target plate by the red, radiating from the point of impact (Figure 13).

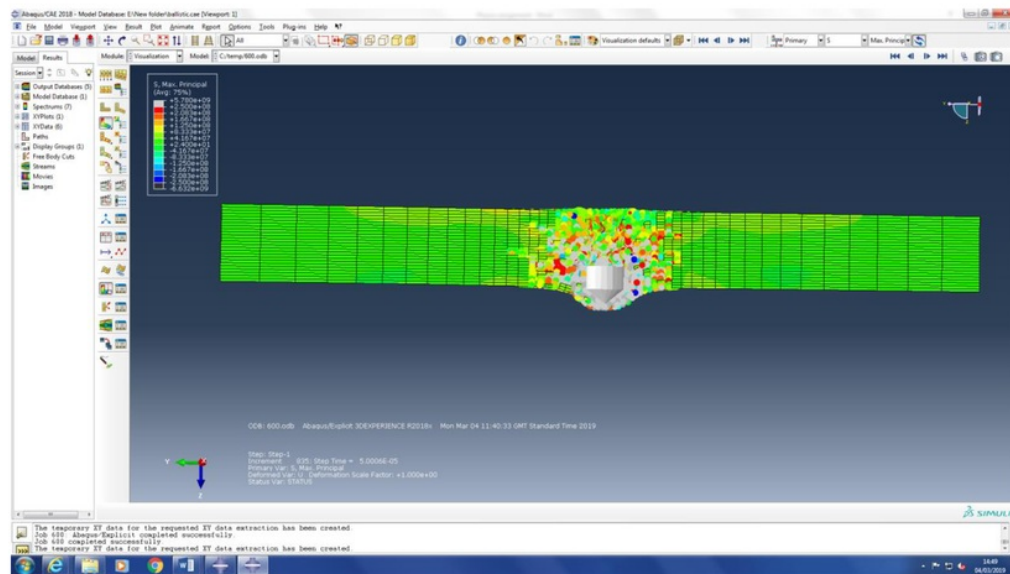


Figure 14: Direct stress on the aluminium plate at 0.5ms at a velocity of 600ms-1, cut view

The image above shows the direct stress within the plate as the bullet goes through the aluminium plate. There is a compression force which goes through the aluminium plate, in front of the bullet which has a magnitude of approximately $5.78 \times 10^9 \text{ Pa}$. As the bullet passes through the plate the stress radiates from the impact point of the bullet which is shown as a radial pattern on the front

face of the plate. When the force impacts the far side of the aluminium plate it reflects back into the plate causing tension. The far side of the aluminium plate shows that there is bulging (Figure 14).

Shear stress

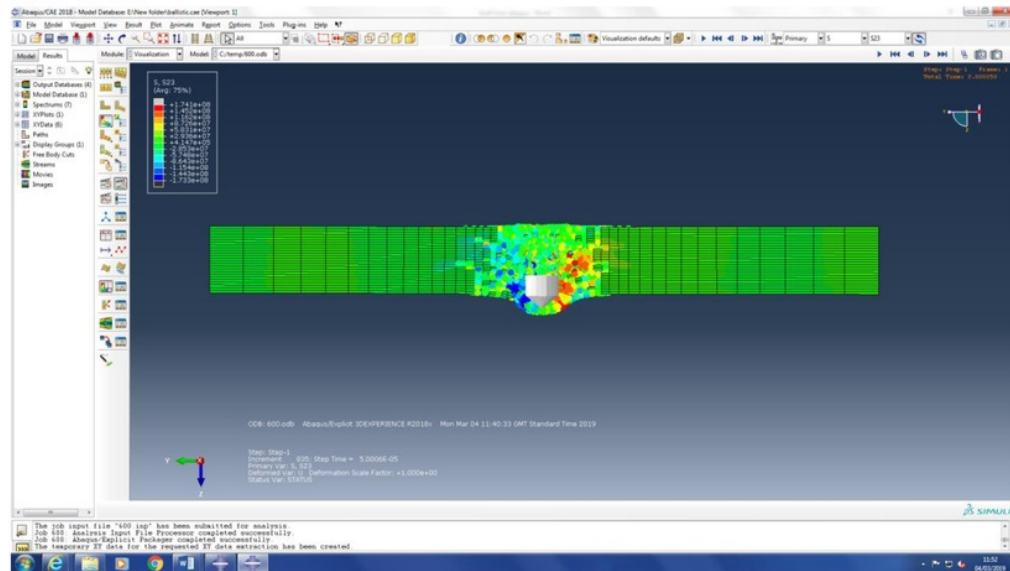


Figure 15: Shear stress on the aluminium plate at 0.5ms at a velocity of 600ms-1, cut view

The image above (Figure 15) shows the shear stress on the aluminium plate as the bullet passes through it at 0.5ms. The red/orange and blue areas show the shear stress on either side of the bullet to be in the region of $1.45 \times 10^9 \text{ Pa}$. The red and blue are of the same magnitude but are different colours as it is acting in opposite directions.

800ms^{-1} :

800ms^{-1} is indicative of a 7.62 x 54mmR fired from the Dragunov sniper rifle, the SVD [4].

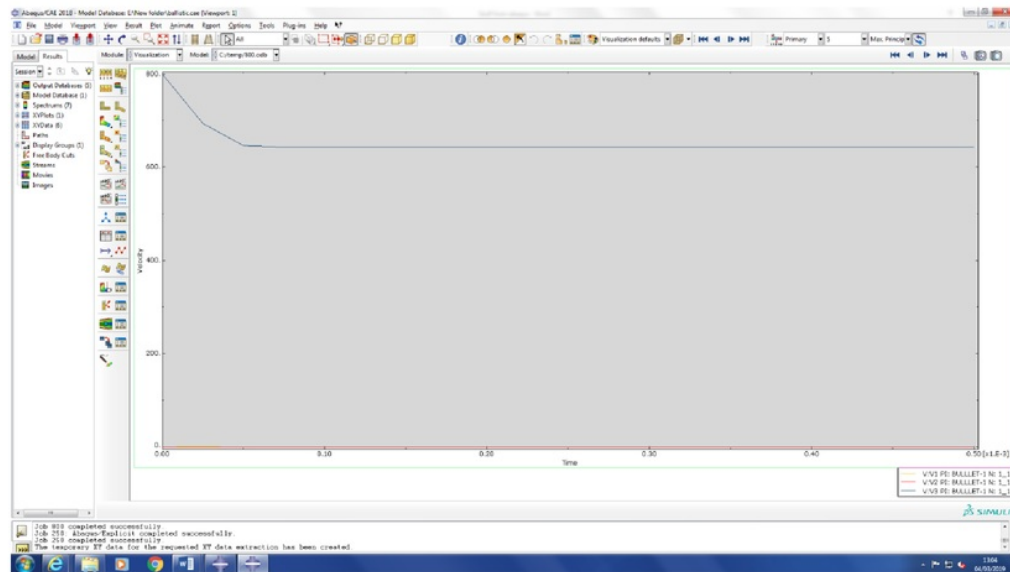


Figure 16: Graph showing velocity over time at an initial velocity of 800ms^{-1}

The graph above (Figure 16) shows the velocity of the bullet over time in the X, Y and Z axis from its starting velocity of 800ms^{-1} to the end of the simulation. The graph shows that there is negligible change in the velocity of the bullet in the X and Y axis as the bullet slows from the initial impact velocity of 800ms^{-1} indicating the bullet hasn't started to tumble. There is a change in velocity in the Z axis which is in the direction of travel of the bullet on impact as it passes through the aluminium plate. By 0.05ms the velocity falls to approximately 650ms^{-1} .

Direct stress

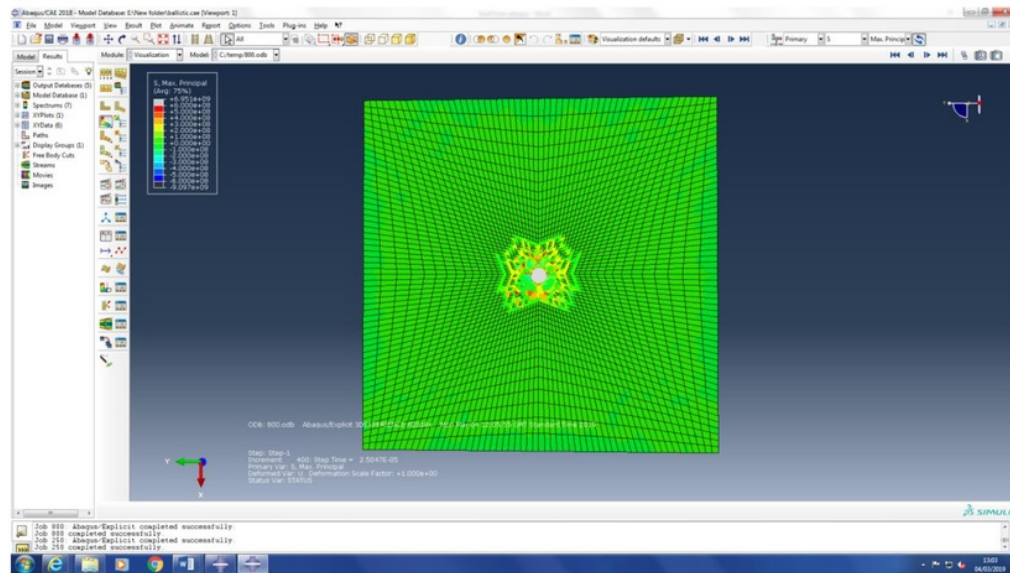


Figure 17: Aluminium plate at 0.5ms at a velocity of 800ms-1, top view

The above image shows the direct stress on the aluminium plate at 0.5ms. There is a direct stress of a maximum of $5 \times 10^8 \text{ Pa}$, shown on the target plate by the red, radiating from the point of impact (Figure 17).

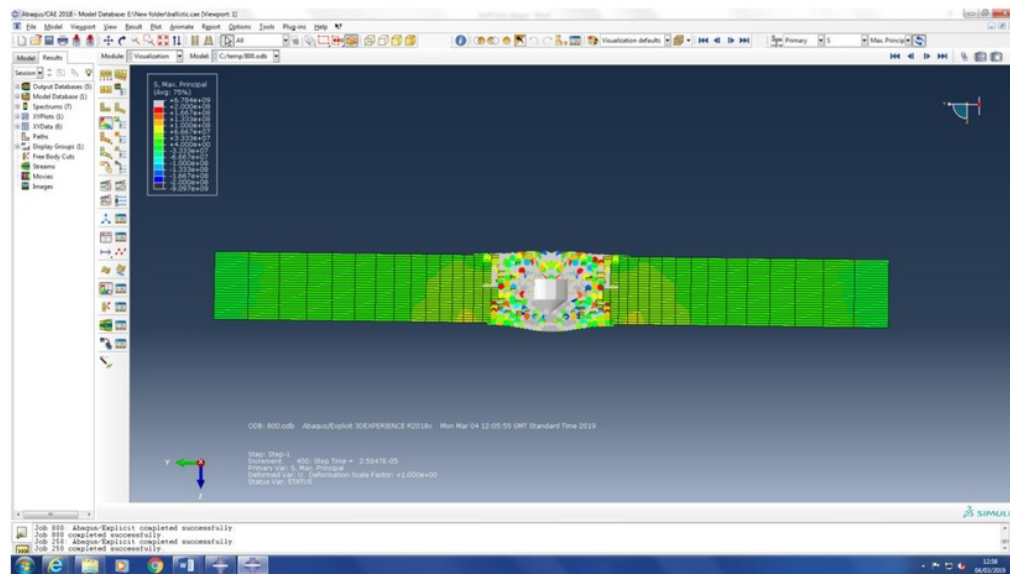


Figure 18: Direct stress on the aluminium plate at 0.5ms at a velocity of 800ms-1, cut view

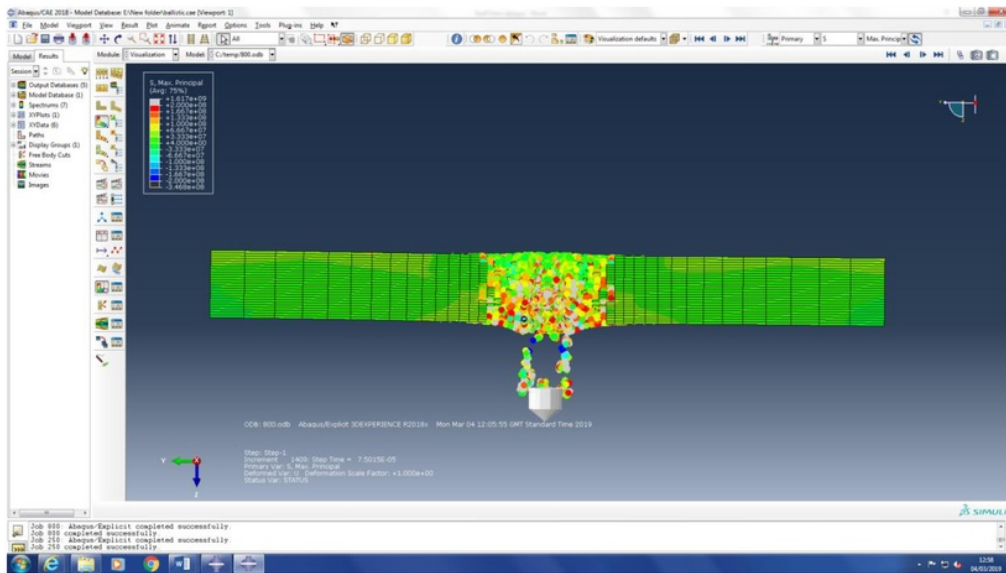


Figure 19: Direct stress on the aluminium plate at 1.5ms at a velocity of 800ms-1, cut view

The images above show the direct stress within the plate as the bullet goes through the aluminium plate at 0.5ms and 1.5ms. There is a compression force which goes through the aluminium plate, in front of the bullet which has a magnitude of approximately $4.39 \times 10^9 \text{ Pa}$ at 0.5ms (Figure 18) dropping to $2 \times 10^9 \text{ Pa}$ after the bullet leaves the aluminium plate (Figure 19). As the bullet passes through the plate the stress radiates from the impact point of the bullet which is shown as a radial pattern on the front face of the plate. The tension force is observed being reflected back into the aluminium plate. The far side of the aluminium plate shows that there is bulging at 0.5ms and by 1.5ms the bullet has penetrated the plate and there is spalling (Figure 18 & Figure 19).

Shear stress

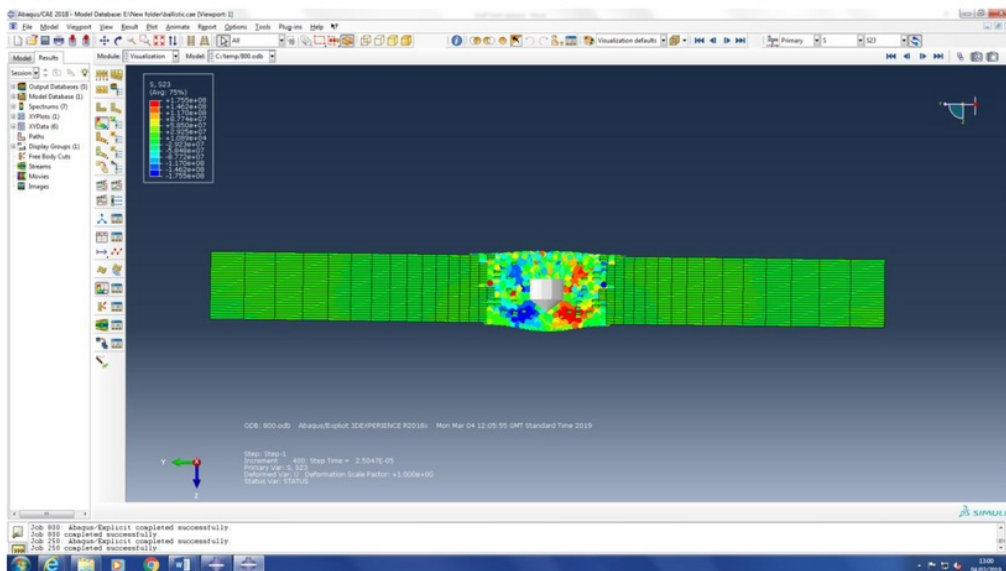


Figure 20: Shear stress on the aluminium plate at 0.5ms at a velocity of 800ms-1, cut view

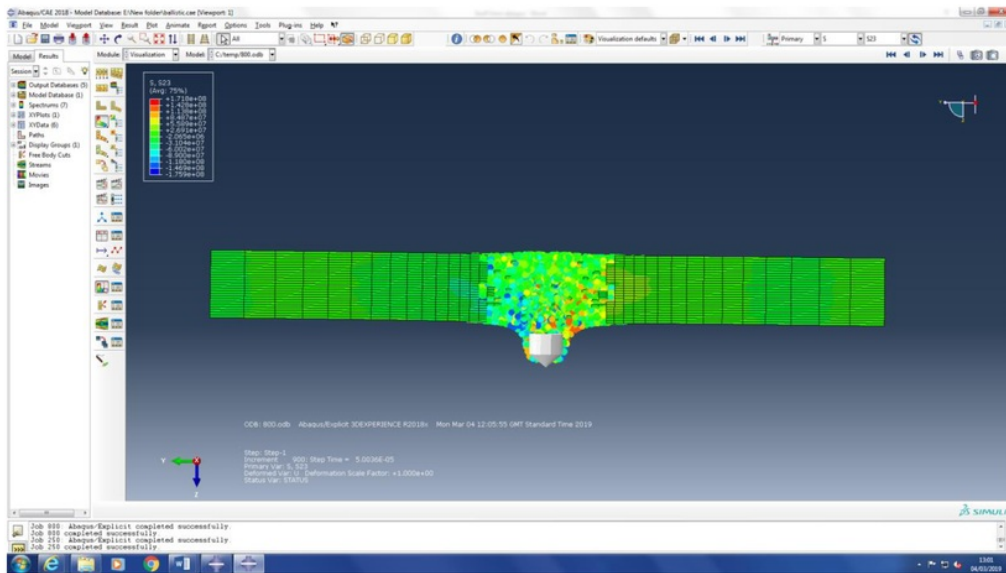


Figure 21: Shear stress on the aluminium plate at 1.5ms at a velocity of 800ms-1, cut view

The images above (Figure 20 & Figure 21) show the shear stress on the aluminium plate as the bullet passes through it at 0.5ms and 1.5ms. The red/orange and blue areas show the shear stress on either side of the bullet to be in the region of $1.75 \times 10^8 \text{ Pa}$ at 0.5ms (Figure 20) and approximately $1.4 \times 10^8 \text{ Pa}$ at 1.5ms (Figure 21). The red and blue are of the same magnitude but are different colours as it is acting in opposite directions.

Discussion

There are three stresses which are acting on the aluminium plate as the bullet impacts and passes through it, one parallel to the direction of travel of the bullet and two perpendicular to the direction of travel. The perpendicular stresses are direct stresses from tension and compression and the parallel stress is shear stress. [6, pp. 25-26]

As the bullet impacts, and passes through, the aluminium plate it causes the material in front of it to be compressed. This is shown in the images by the radial, spider web like, stress areas. When this compression force reaches the rear of the plate it is reflected back into the plate [7]. This causes tension within this area and results in bulging or spalling if the bullet does not fully penetrate and gives petaling and spalling when it does penetrate [8]. As the bullet passes through the aluminium plate it creates a shear force and results in the material in front of the bullet deforming [6, pp. 171-2]. Some of the material which has been deformed will be forced back along the path of the bullet causing some back scattering.

Limitations

There are a few limitations on the experiment which impact on the accuracy of the results. The bullet does not deform as it passes through the material and moves only in one direction. As a result of this phenomenon such as tumbling of the bullet does not occur. If this was taken into account it is likely that the forces acting within the aluminium plate would be different.

Conclusions:

The stresses which are acting on the aluminium plate are a result of the compression of the bullet and the shear stress caused as the bullet interacts with the material in the plate. These forces cause petaling and spalling on the rear side of the aluminium plate as well as some back scattering of material against the direction of travel.

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