

DYNAMIC STRESS-STRAIN INVESTIGATION

by Luke Savin

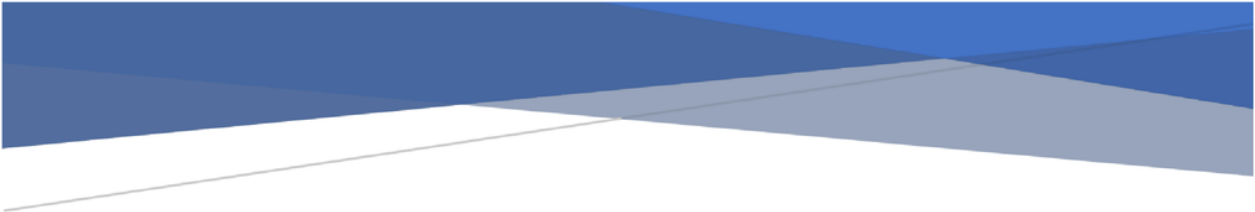
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OME - PHYSICS

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Abstract

This report looks at the finite element analysis using ABAQUS to investigate the direct and shear stresses on an aluminium plate as a projectile is being fired at it at different velocities and when the residual velocities were.

The aluminium plate material properties were based on aluminium 6063-T6. The size of the plate was 198.25mm x 200mm x 20mm. The projectile was a solid rigid body with no material properties. It was fired at the centre of the plate at 100ms^{-1} , 200ms^{-1} , 250ms^{-1} , 300ms^{-1} and 400ms^{-1} .

From the analysis it shows that direct tensile is the most dominate force being applied to plate, causing spalling around the projectile and the edges. Only at speeds of 300ms^{-1} and 400ms^{-1} did the projectile exit through the other side.

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Introduction

To find the strength of a solid material, a force is applied to it that will then start to cause the material to deform and change in shape. The material will deform, and it will eventually reach a point where it can only take so much, at this point it will break and fail. This can be expressed in engineering terms of stress and strain.

Stress can be defined as the force that is being applied per unit area of the material. Stress can be worked out as '*Stress = force / cross sectional area*'

$$\sigma = \frac{F}{A} [1]$$

There are two forms in which stress can be applied to an object, Direct and Shear. Direct stress comes in two forms, Tensile and Compressive. Tensile stress happens when the forces are under tension and the material is being stretch. Compressive on the other hand is are opposite to tensile. It is the force that pushes onto a material causing it to be crushed. Shear stress is the force that causes '*deformation of a material by slippage along a plane or planes parallel to the imposed stress.*' [2]

Strain is defined as the response caused by the stresses. When a material is subjected to a stress, the reaction of the material causes it to change shape and deform. Strain can be calculated to produce a unitless number by the '*formation in the direction of the applied force divided by the initial length of the material.*' [3]

$$\varepsilon = \frac{e}{l_0} [1]$$

Stress and strain can be proportional at relatively low stresses. This is also known as Hooke's Law. His theory stated that '*for relatively small deformations of an object, the displacement or size of the deformation is directly proportional to the deforming force or load*' [4]. This can be explained on a stress strain graph.

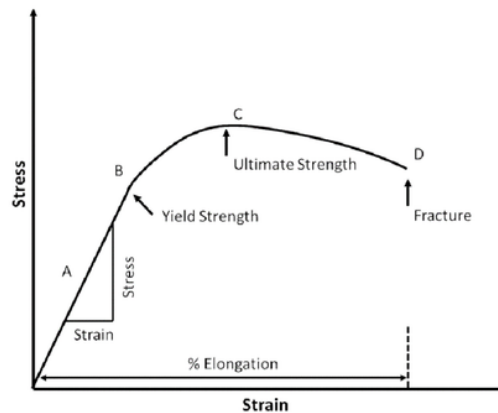


Figure 1 Stress/Strain Graph [5]

The graph above shows a typical stress strain curve of a rigid material. When plotting a graph with stress strain, the straight line at the beginning (A) is the elastic stage of the material. This is when a solid material has undergone a stress but then returns to its original length and shape once the stress is removed. This is known as Young's modulus. The gradient of the line A is the Young's Modulus. It can be worked out by dividing the stress by the strain.

$$E = \frac{\sigma}{\epsilon} [6]$$

At point B shows the yield strength of the material. Past this point on the graph the material will stay deformed if the stress is removed. The ultimate strength on the graph shows where the material can take the maximum amount of stress and begins to ultimately fail.

To demonstrate direct and shear stress acting on a body at the same time a simulation was designed on a FEA program. A simple plate of aluminium was modelled with a projectile being fired into it at different velocities. This should show that when the projectile hits the plate, the plate undergoes the direct and shear stress. This in turn creates a shock wave through the material causing it to come under Tensile stress. Any spalling that happens to come off the aluminium plate will also be under tensile stress as it is getting pushed away. Depending on the simulated velocities of the projectile, analysis was undertaken to see if the projectile travels through the plate.

Method

To find the stress and strain values of a material being struck by a ballistic projectile, a model was simulated on a computer program called Abaqus. This program is used in engineering companies for finite element analysis. With Abaqus two models were made, one of an aluminium plate, the other was a projectile.

The projectile was modelled in the shape of a bullet. It was given a solid rigid body with the properties of it left undefined. This was so that the projectile if going fast enough would be able to penetrate all the way through the aluminium plate without the projectile itself deforming. 5 velocities were set for the projectile, these were, 100ms^{-1} , 200ms^{-1} , 250ms^{-1} , 300ms^{-1} and 400ms^{-1} . This was to give a good range of data that would show the projectile penetrating the plate and whether it exited the plate on the other side.

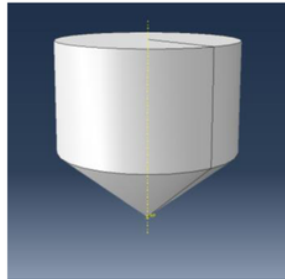


Figure 2 Model of Projectile

When modelling the aluminium plate, the properties that were used were based on Aluminium 6063-T6. This type of aluminium is predominantly used applications such as architectural applications and intricate extrusions. This is due to its characteristics with having 'medium strength and high corrosion resistance'. [7] The Aluminium 6063-T6 has been heat treated making it stronger than the standard Aluminium 6063.

The mechanical properties of Aluminium 6063-T6 were found from the data sheet and entered into Abaqus. The values that were required for the model were Young's Modulus, Poisson's Ratio, Ultimate Tensile Strength, Yield Strength and Elongation at Break.

Hardness, Brinell	73
Hardness, Knoop	96
Hardness, Vickers	83
Ultimate Tensile Strength	241 MPa
Tensile Yield Strength	214 MPa
Elongation at Break	12 %
Modulus of Elasticity	68.9 GPa
Ultimate Bearing Strength	434 MPa

Bearing Yield Strength	276 MPa
Poisson's Ratio	0.33
Fatigue Strength	68.9 MPa
Machinability	50 %
Shear Modulus	25.8 GPa
Shear Strength	152 MPa

[8]

The aluminium plate was modelled to the size of 198.25mm x 200mm x 20mm with a 50,000-node gradient mesh. The small size of the mesh was towards the centre of the target where the impact of the projectile would be. This was so that there would be more data to collect at the critical area.

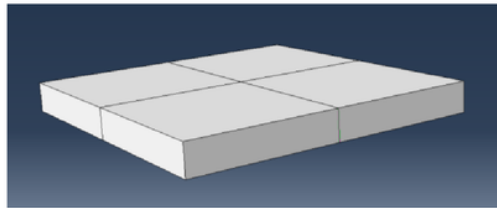


Figure 3 Model of Plate

The velocity of the projectile was measured throughout the simulation to see what the residual speed became. To find the direct stress the Max Principles were looked at and the S13 view for finding the Shear stress.

Results

100ms⁻¹

The first of the 5 simulations that were run, the projectile was set to a velocity of 100ms⁻¹. The projectile pierced the aluminium plate but did not penetrate all the way through and ended up getting embedded in the plate.

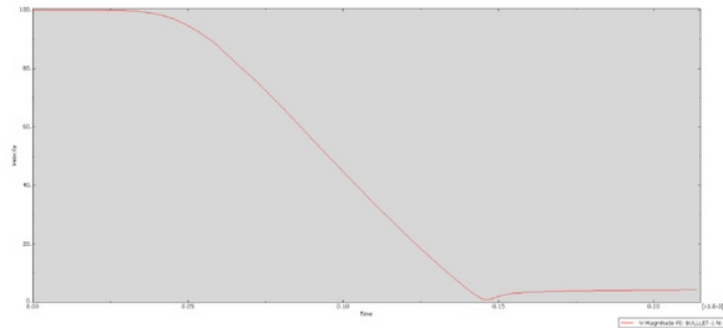


Figure 4 Velocity 100

From looking at the velocity of the projectile from the graph, the projectile stops before 150µs into the simulation. The projectile stopped after 14µs from hitting the aluminium. It also shows that there was a slight rebound of the projectile. This was likely caused by the plate absorbing the energy of the projectile, as the properties of the aluminium is still in its elastic stage.

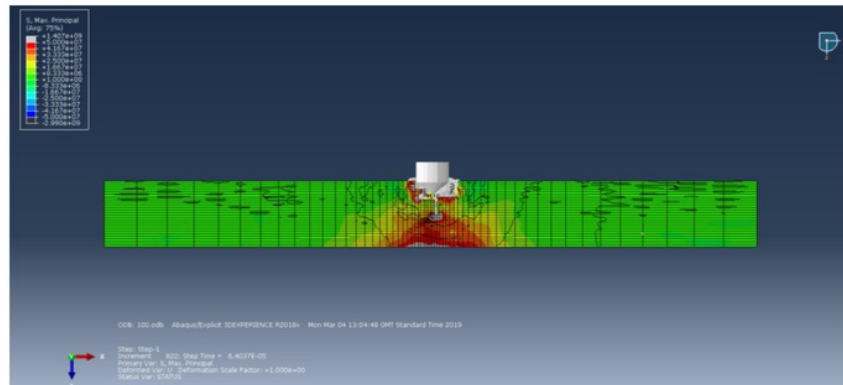


Figure 5 Direct Stress at 100

Figure 1 shows that the plate under tensile stress of up to 1.4 GPa. As the projectile has hit the plate, it has caused a shock wave through and has started to reflect from the bottom.

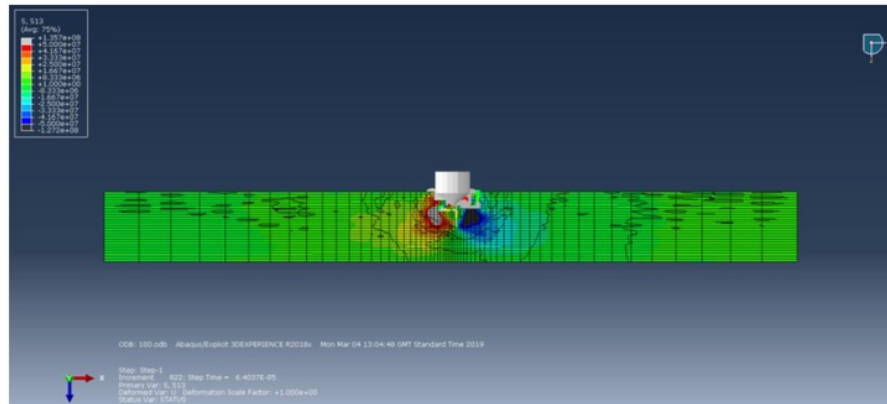


Figure 6 Shear Stress at 100

At 6.5us, the force of the projectile is starting to cause shear stress local to the projectile. The maximum shear stress at this moment is 1.3MPa. This shows that direct stress is the more prominent stress.

200ms⁻¹

When the projectile was simulated at the speed of 200ms⁻¹ it gets embedded into the plate like the one at 100ms⁻¹.

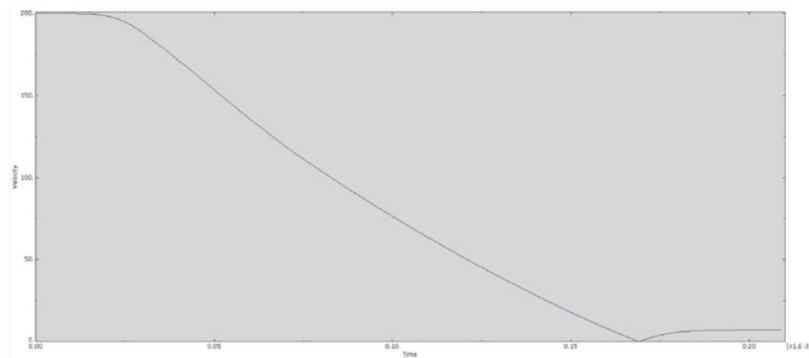


Figure 7 Velocity at 200

The projectile at this velocity kept more of its speed and for longer than at 100ms⁻¹. From hitting the plate the projectile took around 17us to reach 0ms⁻¹ but was then again rebounded from the returning elasticity still in the plate.

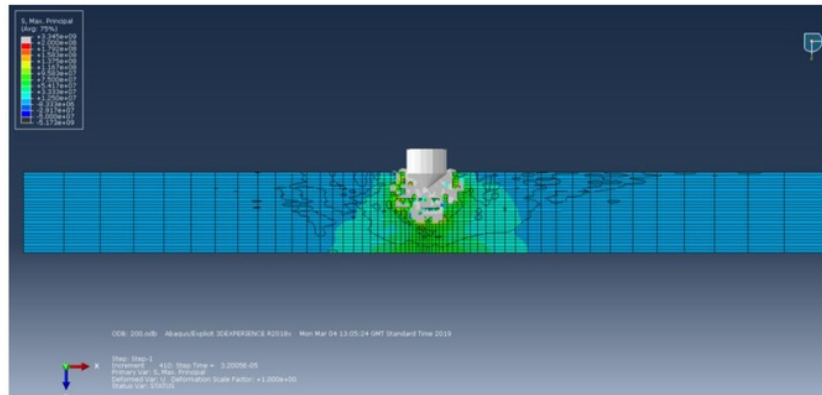


Figure 8 Direct Stress at 200

Figure 5 shows the projectile at the same position as 100ms^{-1} but at different time. This screenshot was taken at the earlier time of $32\mu\text{s}$. It shows that the tensile stress at 7.5GPa and the shock wave has reflected to the top surface and out towards the edges.

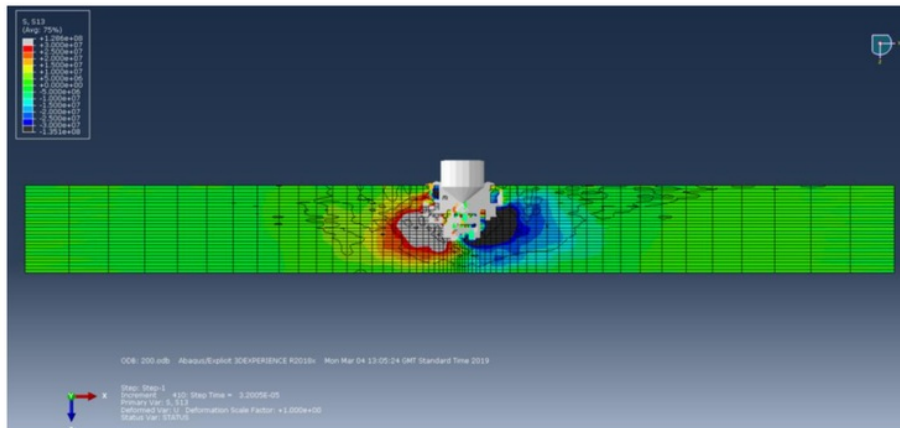


Figure 9 Shear Stress at 200

Shear stress appears in the same position but at higher readings. The shear stress that is being applied to the plate is 1.2MPa . This is the same at 100ms^{-1} but there is a larger area.

250ms⁻¹

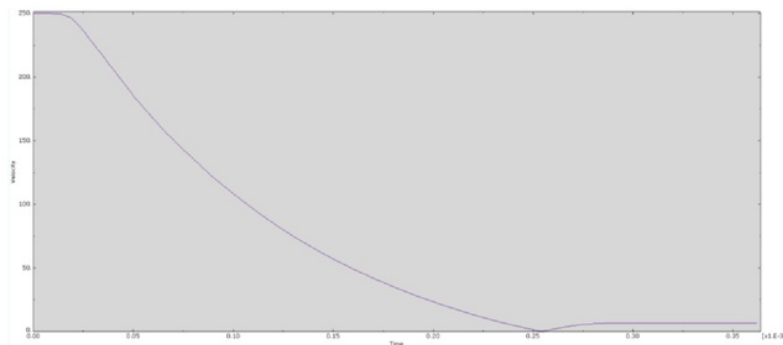


Figure 10 Velocity at 250

When the projectile is traveling at 250ms⁻¹, the time it takes for the projectile to reach 0ms⁻¹ was around 26μs. The projectile once again gets embeds into the plate after a total traveling time of over 250ms.

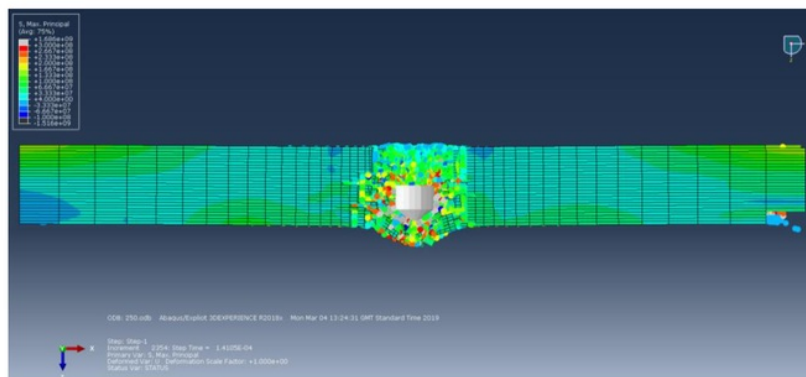


Figure 11 Direct Stress at 250

The direct stress occurring at 14ms shows both compression and tensile. Tensile reaches a maximum of 1.6GPa, whereas compression stress only reaches 6.6MPa. This can clearly be seen towards the edges of the plate. The pressure from the projectile causes the plate to start flexing from its fixing point. It can also be seen that at this time the aluminium has start scabbing where the projectile is trying to break through.

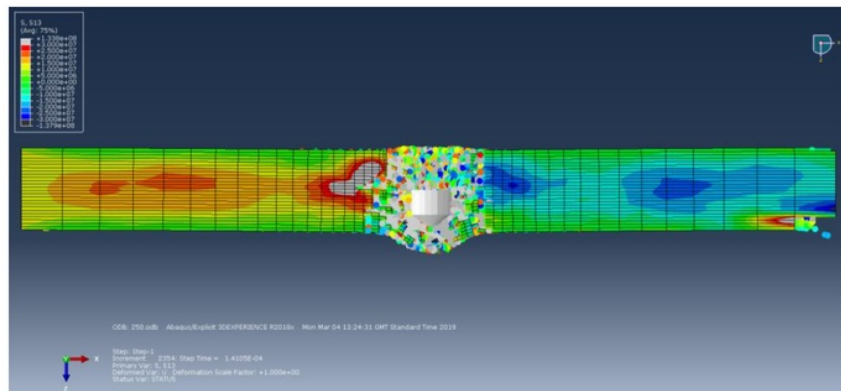


Figure 12 Shear Stress at 250

The shear stress in figure 9 is more space out across the plate. This is due to the plate moving and flexing more from the projectile. The maximum shear value reaches 13MPa.

300ms⁻¹

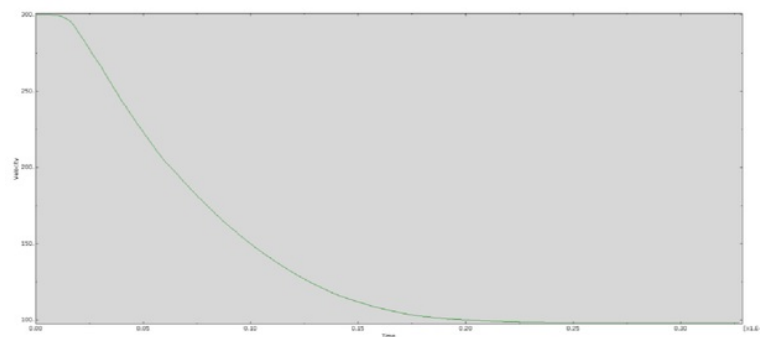


Figure 13 Graph of Velocity at 300

When the projectile was traveling at 300ms⁻¹ it took a time of 22.5us to penetrate the way through and exited the aluminium plate. The residual velocity after it exited the plate was 100ms⁻¹.

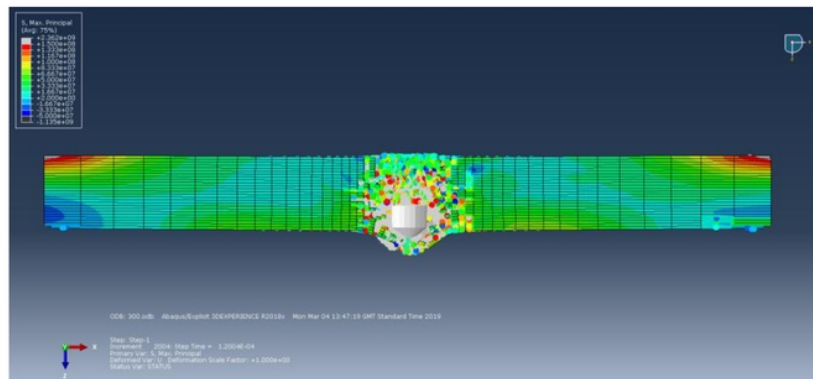


Figure 14 Direct Stress at 300

At 300ms^{-1} figure 14 shows high values for tensile and compression stress. The highest tensile stress occurring at 12ms is 2.3GPa and for compression 1.3GPa.

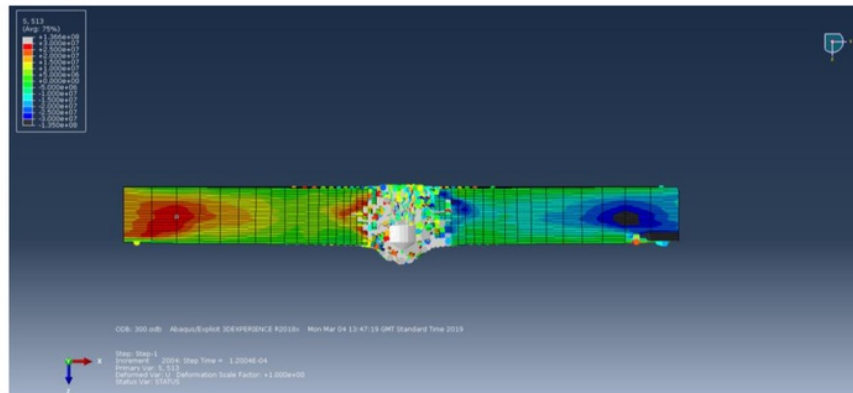


Figure 15 Shear Stress at 300

As the plate is flexing more from the force of the projectile the more shear stress appears. At this time the highest value of shear stress is 12MPa.

400ms⁻¹

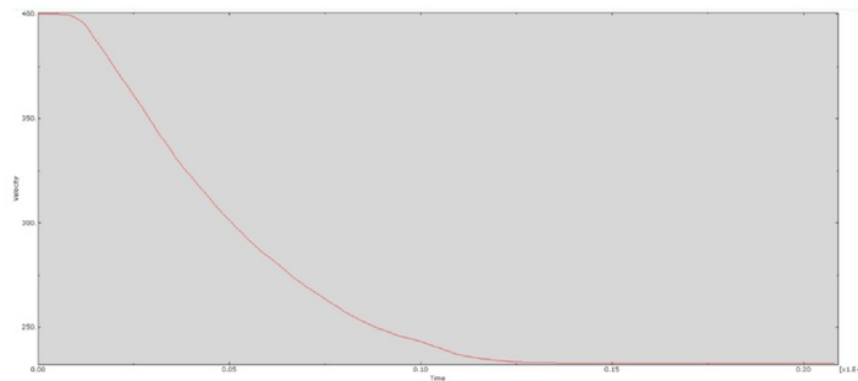


Figure 16 Graph of Velocity at 400

At 400ms⁻¹ the projectile penetrated through the aluminium plate at 12us and a residual speed of 240ms⁻¹.

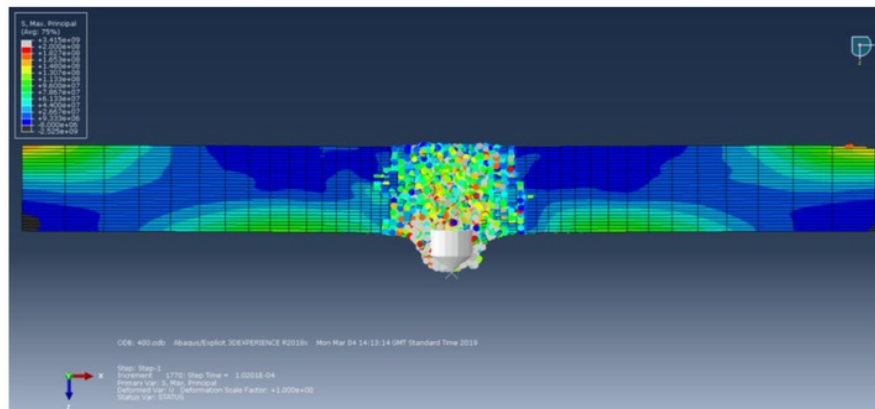


Figure 17 Direct Stress at 400

The maximum tensile stress occurring was at 3.4GPa. These number occurred around where the projectile had almost broken through. There was less compressions stress occurring but was at a higher pressure of 2.5GPa

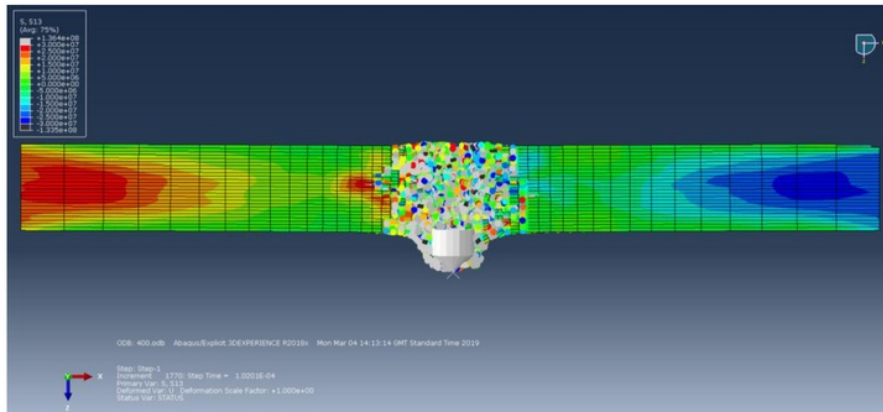


Figure 18 Shear Stress at 400

The shear stress being applied to the plate is mainly appearing on the edges. This is where the plate is being held, and the centre is being forced down. When compared with the values of tensile the pressure is much lower at 10MPa

Discussion

After analysing the screenshots of the simulations, the most predominant stresses that were acting on the aluminium plate was direct stress. In the areas on high tensile stress the plate starts to shatter and break. This can be seen in the trajectory of the projectile and at the edges of the plate where the pressure waves reflex back. The compression stress that was being applied to the plate was making it deform. Compression was not seen as much as tensile stress from the pressure wave was the primary stress. [9]

The shear stresses that occurred during the simulation was lower than the direct stresses that were being applied. Shear only appeared across the whole plate as it bends and reflexes from the shock impact of the projectile.

From the analysis of the velocities of the projectile it was discovered that between 100ms^{-1} and 250ms^{-1} , there was not enough force behind the projectile to punch through to the other side of the plate. Whereas over 300ms^{-1} the projectile can exit through the aluminium and carry a residual speed of 100ms^{-1} . To find the exact velocity of when it does break through the plate, more simulations need to be run between 250ms^{-1} and 300ms^{-1} .

Conclusion

Whilst running the simulation, there were several ways to improve the way the model was designed and the way the simulation was ran to ensure better results. The first improvement would be to give the projectile material properties. This will cause the projectile to deform and react differently to the plate giving and a more realistic reaction between the two.

The model of the aluminium plate was given a gradian mesh, with a finer mesh at the centre and spacing out towards the edges. To get a better understand of where the stresses are occurring to the plate, a finer mesh with higher node count would be required across the whole plate.

To help understand what was happening during the simulation, the number of timestamps that were recorded should be increased. This would make it easier to see important events, such as the pressure wave going through the plate and reflecting.

Another improvement to consider when running the simulation was the user's ability and understand of the program itself. To use the program at full capabilities the user would need a more comprehensive knowledge of the program and how it full works.

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