

PHYSICS ASSIGNMENT JM

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PHYSICS ASSIGNMENT

**Effect of different velocities on
aluminium plating and the comparison
of the resulting direct and shear
stresses.**

Date: 08/03/2019

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1 Abstract

The purpose of this report was to simulate a ballistics solution to projectiles of different velocities striking an aluminium plate and comparing the direct and shear stress forces on the plate. The results showed a general increase in all stresses on the plate as velocity increased, with tensile stress forces disrupting the plate more than the others.

2 Introduction

The simulation was completed on the Abaqus modelling software using pre-defined properties for the projectile and the size of the material. Only the dimensions and the projectile are preconfigured, material values for the plate such as density and poissons ratio were researched and inputted from a similar study conducted on aluminium plates conducted by Abdulhamid et al [1]. Once this data had been inputted, the simulation was run using different velocities. Stress can be described as “the deforming force per unit area of the object” [2] and the deforming force can be applied parallel and perpendicular to the object. Direct stress can be split into tensile and compressive stress which acts perpendicular to the object. Tensile stress is where an object increases in length subject to equal and opposite forces. Compressive stress is where a decrease in length is achieved when two equal and opposite forces are applied to an object [3]. Ogrodnik describes shear stress as when “the force acts parallel to the cross section” [4] and distorts the object along the parallel plain. Abaqus will be used to capture where direct and shear stress is acting on the plate.

3 Material values and methods

3.1 Material Values

Abaqus professional software was used to model the scenario, the steel projectile and 2cm plate were already modelled. Suitable material properties were researched and inputted into the simulation for the aluminium plate [1]. These values are detailed in Table 1 and taken from Figure 1 – Showing experimental quasi-static flow stress of the aluminium used in the Abdulhamid study. The values from this graph were input into the Yield stress and Plastic strain fields.

Elastic Modulus (youngs)	Poisson ratio	Mass Density	Yield Stress at plastic strain 0	Plastic strain	Yield Stress	Plastic Strain
2700	0.3	2700	150MPa	0	355MPa	0.2

Drogemuller et al give the definition of young’s Modulus as “The ratio of stress over strain $E = \sigma/\epsilon$ and is a measure for elastic deformation under

Table 1 –Showing material values taken to complete the ma

stress” [5]. A higher value for this field would indicate a brittle material, whereas a lower value would indicate a softer material. Poissons ratio is the relationship between width or transverse (ϵ_r) and length or longitudinal (ϵ_L) strain of a material. Greaves et al note that the properties with different poissons ratios differ mechanically “Properties

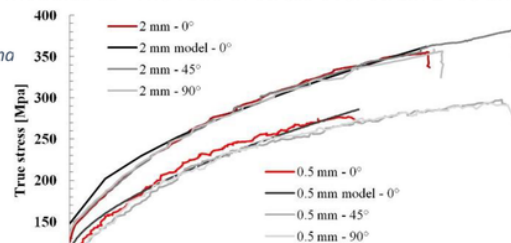


Figure 1 – Showing experimental quasi-static flow stress of the aluminium used in the Abdulhamid study. [1] The values from this graph were input into the Yield stress and Plastic strain fields.

range from 'rubbery' to 'dilatational', between which are 'stiff' materials like metals and minerals, 'compliant' materials like polymers and 'spongy' materials like foams" [6]. Density can be described as "the ratio between mass and volume or mass per unit volume" [7] and is a measure of how tightly packed the matter of the substance is. Elastic and plastic deformation can be seen in Figure 2, under elastic deformation a material will spring back. But once stress reaches a certain point, it will undergo plastic deformation, this point is known as the yield stress [8]. Finally, the region of plastic deformation mentioned in Figure 2, is the point at which the material will "no longer return to its original shape after the stress is removed" [9] and this point is the plastic strain.

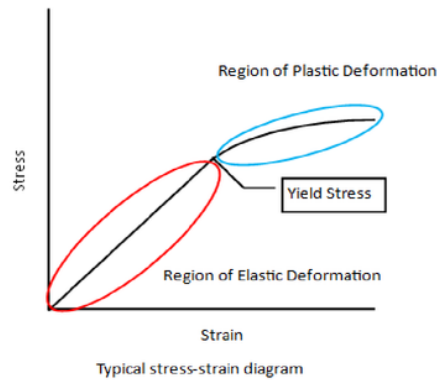


Figure 3 – Stress strain diagram showing elastic and plastic deformation [8]

Once these fields had been entered the simulation was ready. Some velocities for the steel projectile were researched according to different velocities found in similar ballistics research. Max principal and S23 were used in the visualisation of the results for analysis showing direct and shear stress respectively. A velocity graph was also taken to show the speed of the projectile travelling through the plate proportional to time.

When constructing the model first the researched material values were input into the material manager.

The five values in Table 1 were inputted into three fields in the material manager as seen in Figure 3, these being density, elastic and plastic. Once these fields have been entered, the velocity of the steel projectile could be inputted into the simulation and generation of results can begin. Desired velocity was inputted into the predefined field section of Abaqus. Under the job module, each velocity of the projectile striking the plate was simulated ready to be analysed. Below in Figure 4 is a representation of the model before the simulation has been run, with the steel projectile and the aluminium plates with the defined property values.

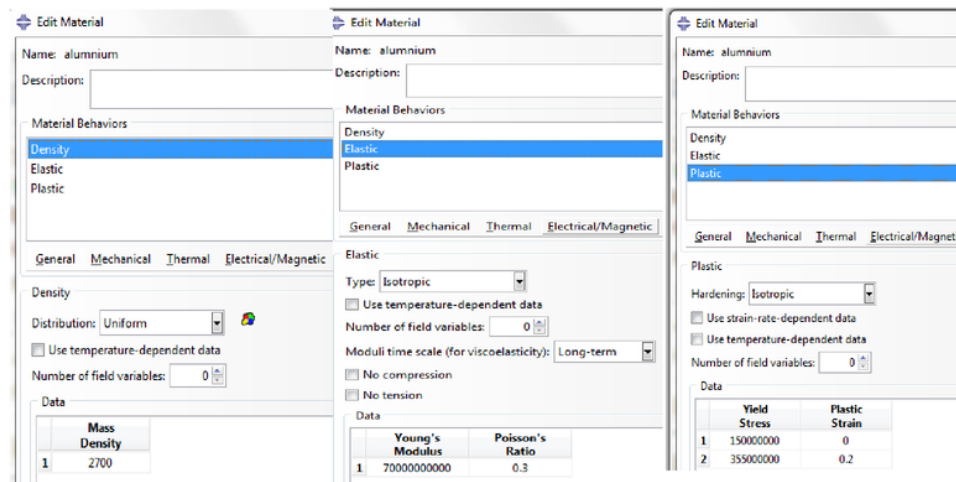


Figure 2 – Material Manager properties for each of the researched values in the Density, Elastic and Plastic fields

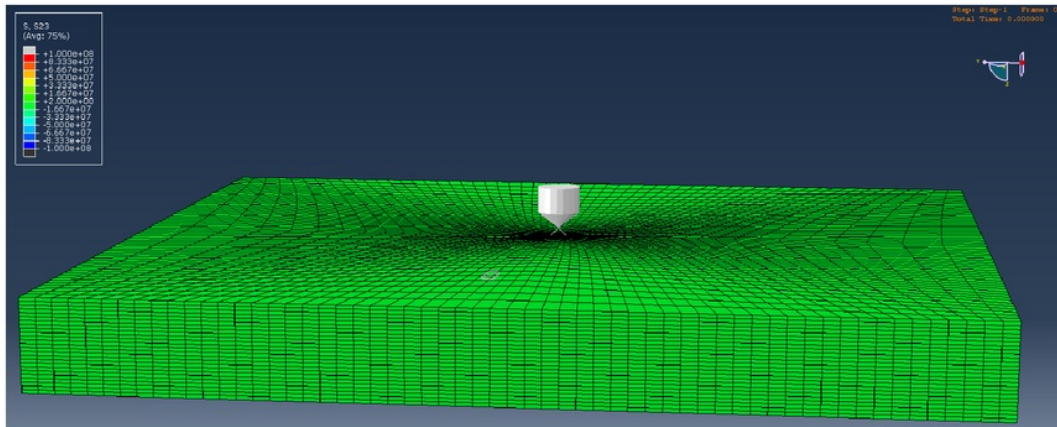


Figure 4 – showing the aluminium plate simulated in Abaqus with steel projectile

Once a simulation had been completed, several tools were used to capture the results midway through the simulation; a cutting tool that cut the plate in half to show the ballistic effect inside the plate (Figure 5), a tool that enabled frame by frame advancement in the simulation (Figure 6), a contouring tool to change the upper and lower ranges of the scale to accurately present the ballistic effect (Figure 7), and a tool to change the visualisation of the results from Direct stress to Shear stress, or from Max Principal to S23 as seen in Figure 8.



Figure 5 – Plane cutting tool



Figure 6 – Time tool to move forward frame by frame at 0.01 milliseconds

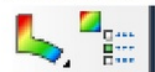


Figure 7 – Contour tool to set lower and upper limits for the scale in visualisation

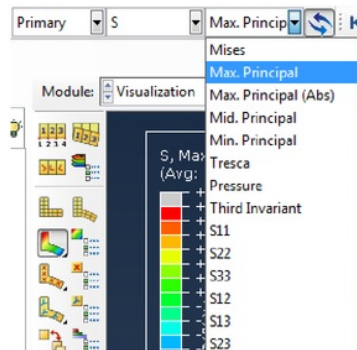


Figure 8 – Visualisation tool to differentiate model results between Direct and Shear stress.

4 Results

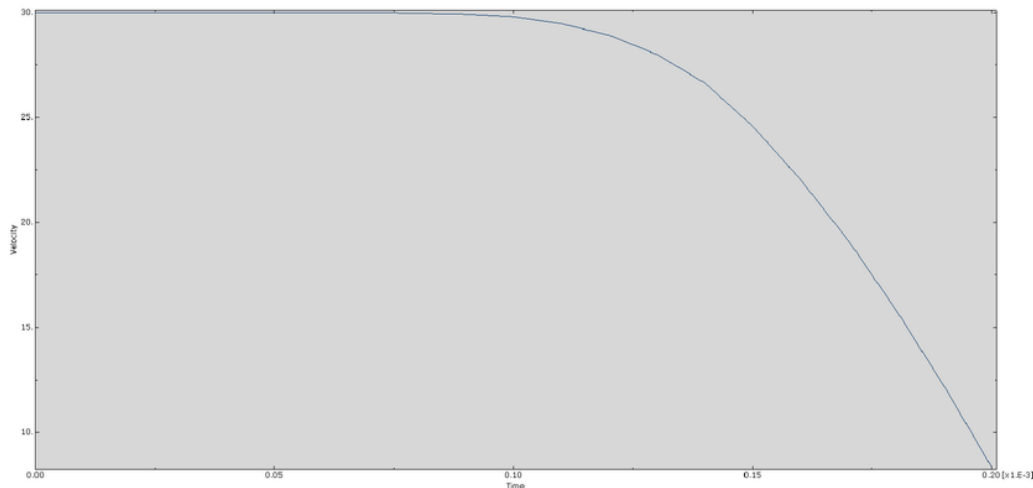
Once the simulation had been created, each velocity was then simulated. These were visualised for direct stress and shear stress. Each stress was represented in each scale as positive and negative values respectively. Two different sets of screen captures were taken for all velocities except for at 30mps. These were taken at different times, one set at differing times to show maximum stress values and the rest at 0.2milliseconds (ms) to show the final position of the projectile.

4.1 30 mps

30 mps is the first and lowest of the velocities selected and was selected based on a paper on shrapnel effect on the human body where it was stated that “the efficient minimum velocity for a particle to penetrate the human skin is determined at 30m/s” [10]. The results were taken at 0.2 ms. The results compiled in Table 2 and Figure 9 and Figure 10 in the appendix, show tensile stress across the area where the projectile has impacted and along the bottom of the plate where it has begun to bend in response to the force. There was also some compressional stress noted around the projectile after impact. Shear stress can also be seen acting in Figure 10 but is not as intense as the direct stress occurring. Graph 1 shows a steep decline in velocity once the projectile has struck the plate.

Stresses	Maximum stress value (Mpa)	Upper Contour boundary (Mpa)	Lower Contour Boundary (Mpa)
Max Principal – compressive stress	12.5	250	-250
Max principal – tensile stress	442.5	250	-250
S23 – Shear stress	66.67	100	-100

Table 2 – Showing upper and lower limits in Megapascals (MPa) for the results of 30mps velocity. As well as the stress values for both Direct and Shear stress



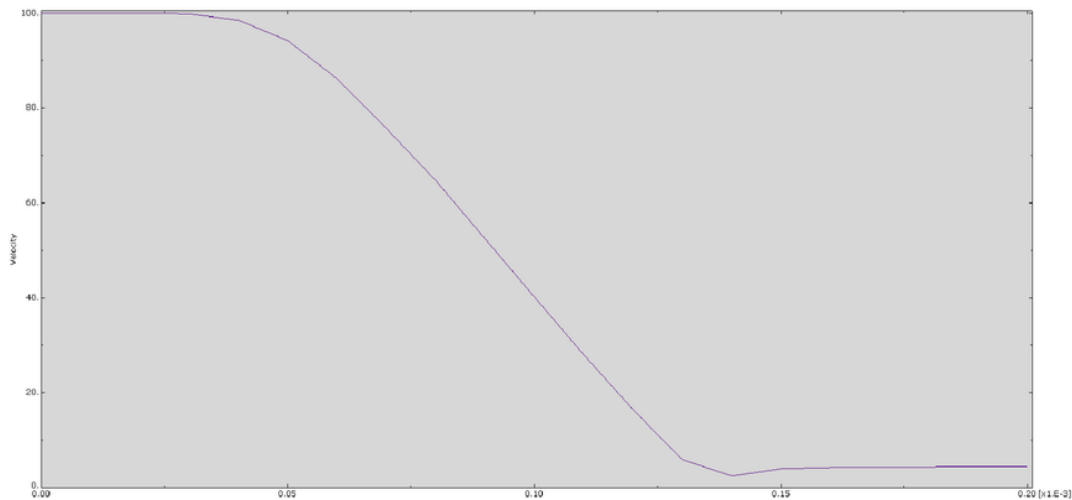
Graph 1 – Velocity – time graph showing speed of projectile throughout 30 mps simulation.

4.2 100 mps

At 100 mps the results taken from Figure 11 at 0.06 ms show an increase in tensile stress of the plate at the site of impact, with some tension showing at the bottom of the plate. At 0.2 ms the compressional stress on the plate has eased off as the plate retained its natural state with some residual stress remaining - Figure 13. No compressional stress was noted at this velocity. Shear stress visible at 0.06 ms in Figure 12 as the projectile first impacted the plate with some residual shear stress left over at 0.2 ms - Figure 14. Values can be seen in Table 3. Shock waves can be seen still running through the plate at both speeds. Graph 2 shows a decrease in velocity until 0.14 ms followed by a slight increase in velocity.

Stresses	Maximum stress value (Mpa)	Upper Contour boundary (Mpa)	Lower Contour Boundary (Mpa)
Max Principal – compressive stress	N/A	90	-90
Max principal – tensile stress	1720	90	-90
S23 – Shear stress	75	90	-90

Table 3 - Showing upper and Lower limits in Megapascals (MPa) for the results of 100 mps velocity. As well as the stress values for both Direct and Shear stress.



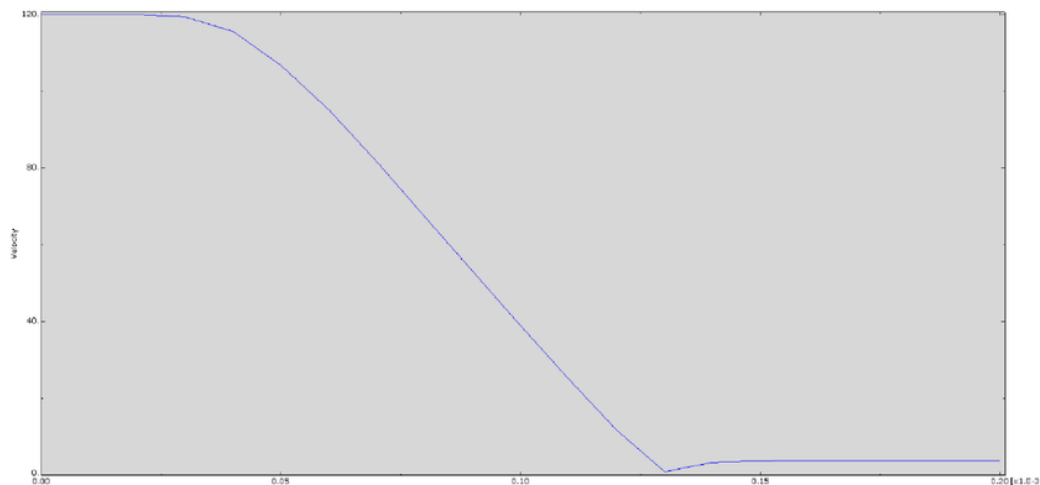
Graph 2 - Velocity – time graph showing speed of projectile throughout 100mps simulation.

4.3 120 mps

This velocity was selected as it was one of the velocities used in the study from where the material values for the aluminium plate were taken [1]. At 0.13 ms the plate has begun to fracture at the bottom caused by tensile stress of the projectile striking the plate - Figure 15. A prominent buckle is noted where the plate has been bent. At 0.2 ms in Figure 17, the plate shockwaves can still be seen moving through the plate along with some residual tensile stress and some compression beneath the projectile. Shear stress is evident around the projectile at both 0.13 ms in Figure 16 and 0.2 ms in Figure 18. The values for these are visible in Table 4. Graph 3 shows the projectile coming to a stop before regaining some velocity at the end of the simulation. Graph 3 - Velocity – time graph showing speed of projectile throughout 120mps simulation.

Stresses	Maximum stress value (Mpa)	Upper Contour boundary (Mpa)	Lower Contour Boundary (Mpa)
Max Principal – compressive stress	15	90	-90
Max principal – tensile stress	963	90	-90
S23 – Shear stress	90	90	-90

Table 4 - Showing upper and Lower limits in Megapascals (MPa) for the results of 120 mps velocity. As well as the stress values for both Direct and Shear stress



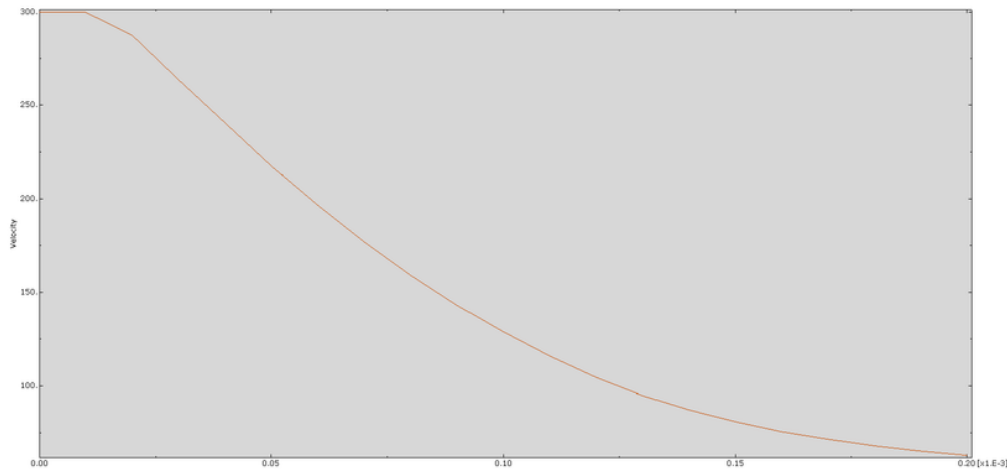
Graph 3 - Velocity – time graph showing speed of projectile throughout 120mps simulation.

4.4 300 mps

At 300 mps the projectile pierces through the plate completely, at 0.12 ms the projectile is still moving through the plate and large tensional stresses are visible in Figure 19. Some compressional stress is visible at the entry point of the projectile. Shear stress can be seen throughout the plate as at 0.12 ms - Figure 20. At 0.2 ms the projectile has broken through the plate and residual tensile stress can be seen throughout the plate in Figure 21. Shear stress has also decreased but a visible wave can be seen horizontally through the plate. The values for these are seen in Table 5. Graph 4 shows a steady decline in velocity in the projectile, consistent with its passing through the plate.

Stresses	Maximum stress value (Mpa)	Upper Contour boundary (Mpa)	Lower Contour Boundary (Mpa)
Max Principal – compressive stress	45	80	-80
Max principal – tensile stress	2605	80	-80
S23 – Shear stress	66.67	80	-80

Table 5 - Showing upper and Lower limits in Megapascals (MPa) for the results of 300 mps velocity. As well as the stress values for both Direct and Shear stress.



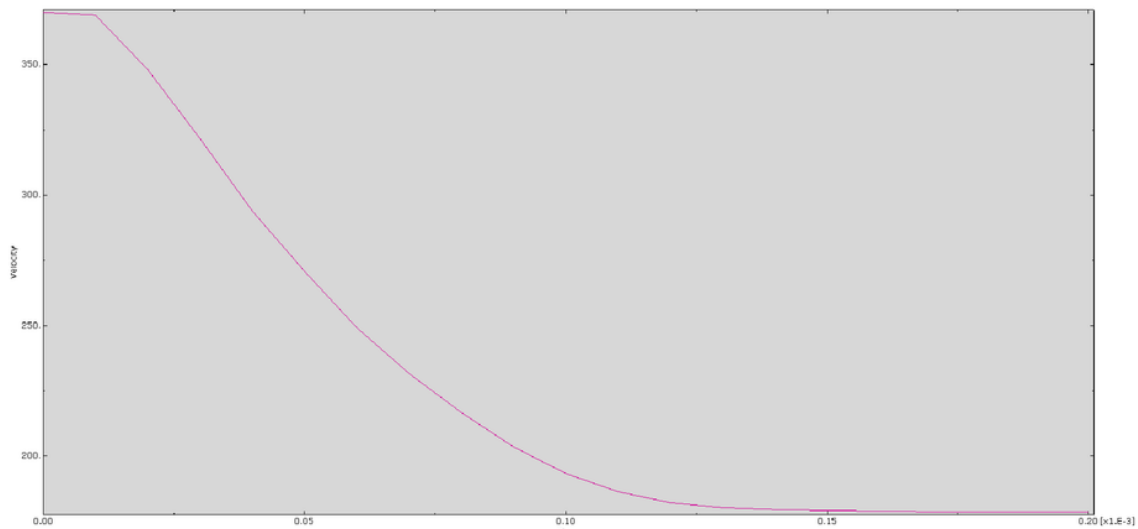
Graph 4 - Velocity – time graph showing speed of projectile throughout 300mps simulation.

4.5 370 mps

This velocity was taken from a Home office report on body armour standards “for an armour submitted for HO1 testing, the mean of all shots must be 365mps or greater” [11]. At 0.07 ms some small compressional stress is visible at the entry point - Figure 23, but the tensile stress has increased again showing significant stress along the centre of the plate where the projectile strikes. Also seen is the shear stress rapidly moving through the plate with the projectile - Figure 24. At 0.2 ms residual tensile stress can be seen in the perforation created by the projectile and the bottom of the plate where some bending has occurred in Figure 25. Shear stress has dissipated through the plate and some waves can be seen. The values for this stress can be seen in Table 6. As seen in Graph 5 the projectile begins slowing down rapidly once it strikes the plate and keeps slowing until the end of the simulation.

Stresses	Maximum stress value (Mpa)	Upper Contour boundary (Mpa)	Lower Contour Boundary (Mpa)
Max Principal – compressive stress	50	150	-150
Max principal – tensile stress	3107	150	-150
S23 – Shear stress	150	150	-150

Table 6 - Showing upper and Lower limits in Megapascals (MPa) for the results of 370 mps velocity. As well as the stress values for both Direct and Shear stress.

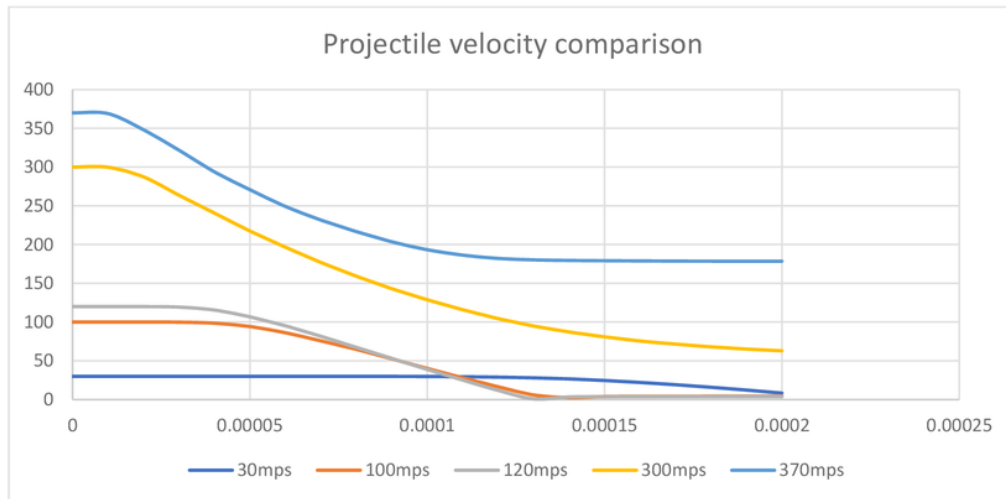


Graph 5 - Velocity – time graph showing speed of projectile throughout 370mps simulation.

5 Discussion

5.1 Velocities over time

The results shown in Graph 6 compare different velocities over time. At 30 mps the projectile took longer to strike the plate compared to the other velocities as seen in Graph 1. At velocities 100 mps and 120 mps we see a similar curve for both showing a noticeable decline once the projectile has struck the plate, both display a slight increase in velocity at 0.14 ms. This could be due to the impact of the projectile causing the plate to bend initially, then as the plate begins to revert to its original state the projectile embedded in the plate moves slightly, causing a slight increase in velocity. The final two velocities at 300 mps and 370 mps were able to perforate the plate, this would mean the ballistic limit of this material would be between 120 mps and 300 mps. As seen in in Graph 4, Graph 5 and Graph 6 at 300 and 370 mps, the initial impact is visible at around 0.01 ms before a smooth decline in velocity. At 370 mps the velocity levels out once the projectile has penetrated the plate. Pilal et al conducted a study into the effect of different velocities in FEM and concluded “It was found that for lower velocities the deformation of the target plates is increased” [12], as seen in Figure 15 and Figure 23 the plate bends more at 120 mps.



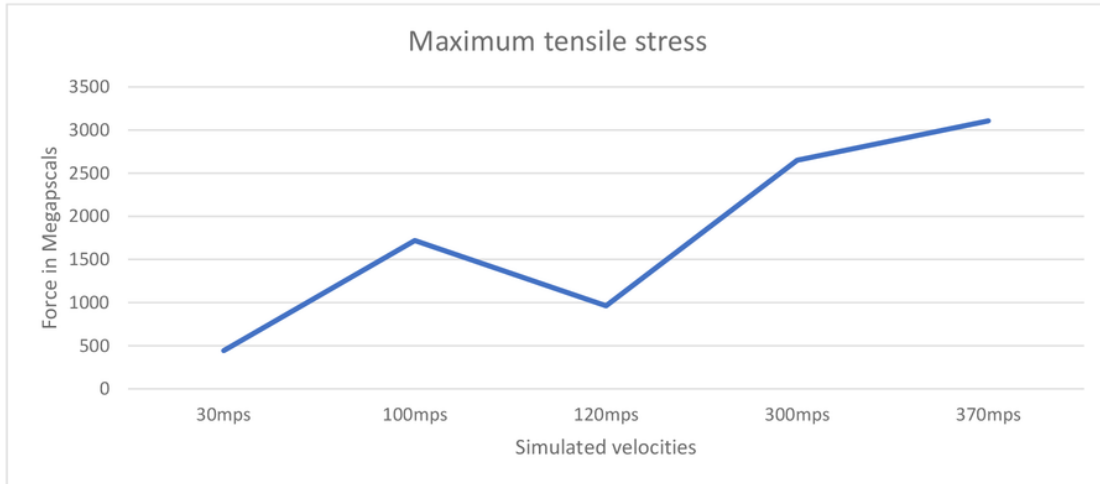
Graph 6 – Graph comparing the 5 velocities used in the simulations over time.

5.2 Comparison of forces

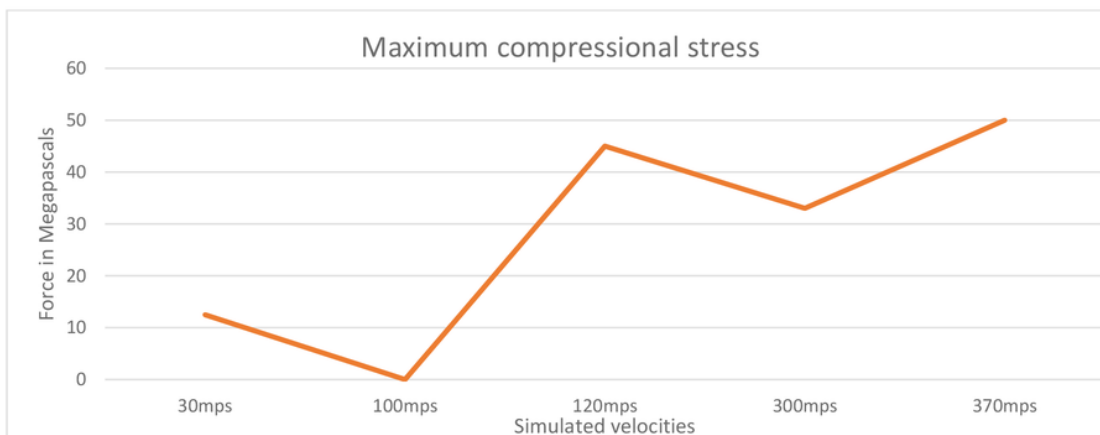
Graph 7 shows tensile stress acting on the plate for each velocity simulated. There is an average increase in tensile stress (Mpa) as velocity increases with the exception of 120 mps, where tensile stress drops to 963 Mpa, as seen in Figure 15 we can see the plate flexing at 120 mps and this has taken some of the impact speed away from the projectile. Graph 6 seems to confirm this as the velocity decreases to zero faster than the 100 mps simulation. At all velocities, shockwaves are visible moving through the plate and tensile stress is focused around the impact site of the projectile and in the case of the non-perforating velocities at the bottom of the plate where it has begun to flex and bend.

Graph 8 shows the compressional stress caused by each velocity on the plate, it is noted that the compressional stress values for these simulations are much lower than the tensile stress values and are only visible around the entry site of the projectile. With the exception of the 30 mps simulation where a small amount of compressional stress can be seen in Figure 9. Of interest are the values for 100 mps and 120 mps simulations. There did not appear to be any compressional stress in the 100 mps simulation but there was a large increase in compressive stress at 120 mps, this may have been down to misinterpretation of the results. However a study from Mahfuz et al concluded in their FEM analysis that stress waves generated by the impact may have altered their results “ Reflection of the stress wave at the ceramic-rubber interface causes instantaneous shift of the incoming compressive pulse to a tensile pulse” [13], it is possible that reverberating waves throughout the plate may have disrupted any compressional stress forming.

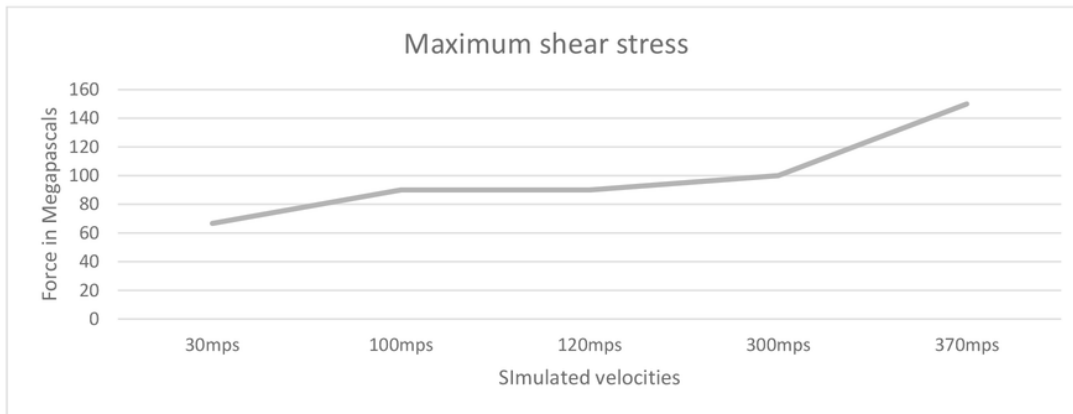
Shear stress and velocity is compared in Graph 9, where a positive trend can be seen as velocity increases. Shear stress appears to have more of an impact on the plate than compressional stress but less than tensile stress. In Figure 20 and Figure 22 A horizontal wave can be seen in the plate in the simulation for 300 mps with shear stresses acting on the edges of the plate.



Graph 7 – Line graph showing general increase in tensile stress as velocity increases



Graph 8 – Line graph showing general increase in compressional stress as velocity increases



Graph 9 – Line graph showing increase in shear stress as velocity increases

6 Conclusions

6.1 Experimental results

In conclusion, at every velocity tensile stress has more of an effect on the plate than compressional or shear stress. Compressional stress was barely visible in each of the simulations, this may have been due to user error in the software or the aforementioned shockwaves cancelling out the compressional stress. As velocity increases, on average each of the three stresses increased too with the exception of the 100 mps and 120 mps velocities.

6.2 Limitations of simulations

The Abaqus software package is “Finite Element Analysis – FEA” software. This is software that can predict how an object is affected by variables such as ballistic trauma, heat, abrasion, fluid flow and other forces. It does this by taking the geometrical problem and splits it into tiny parts that react to each other [14]. There are merits and limitations to this method of modelling. The firm Sparta engineering describes one such problem in stress concentration (large increase in stress in a small location) of linear FEA models and determined that the model was useful in determining the properties of ductile metals in the plastic zone under loading but that it could not predict the effects of repeated loading [15]. A report by Nordendale et al looked into different issues of modelling the high impact of projectiles on surfaces. Smoothed particle hydrodynamics (SPH) and traditional Lagrangian finite elements modelling were compared against a laboratory experiment. Nordendale et al found that “FEM cannot account well for secondary contact of spalled fragments” [16]. However, SPH was not as accurate as traditional FEM when the deformations in the model aren’t large.

7 Recommendations

- It would be beneficial to repeat the experiment but use a different type of aluminium with different material properties for comparison
- In conjunction with the simulations experimental data alongside the simulations would be useful for further comparison
- A greater familiarity with the software would allow for less user error while running the simulation providing greater accuracy in the results.

8 References

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9 Appendices

9.1 30 mps Screen Captures

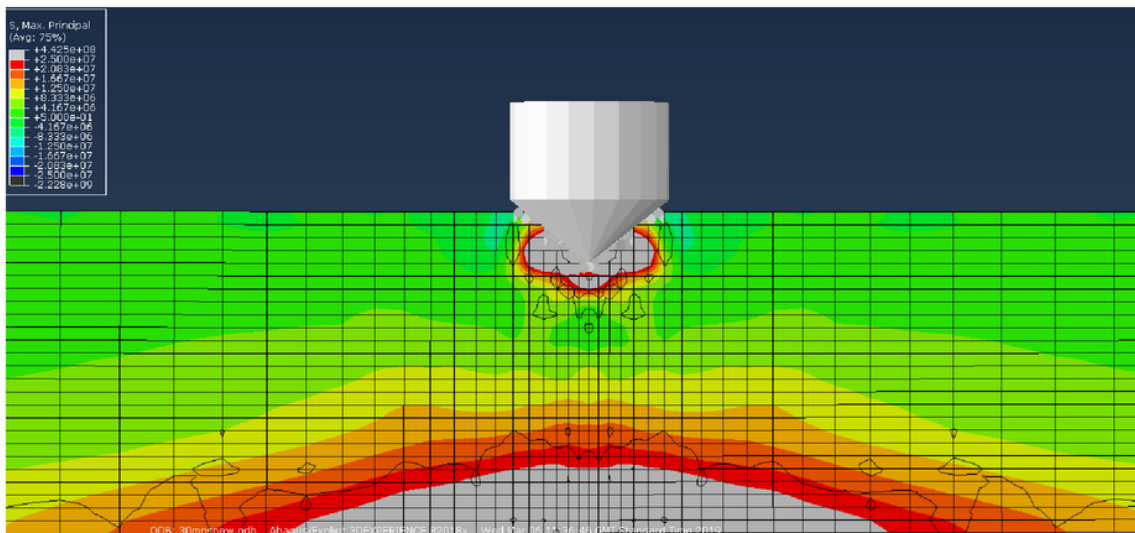


Figure 9 – Screen capture of Max principal (Direct Stress) 30 mps simulation at 0.2 ms. Scale set to +250 Mpa to –250 Mpa

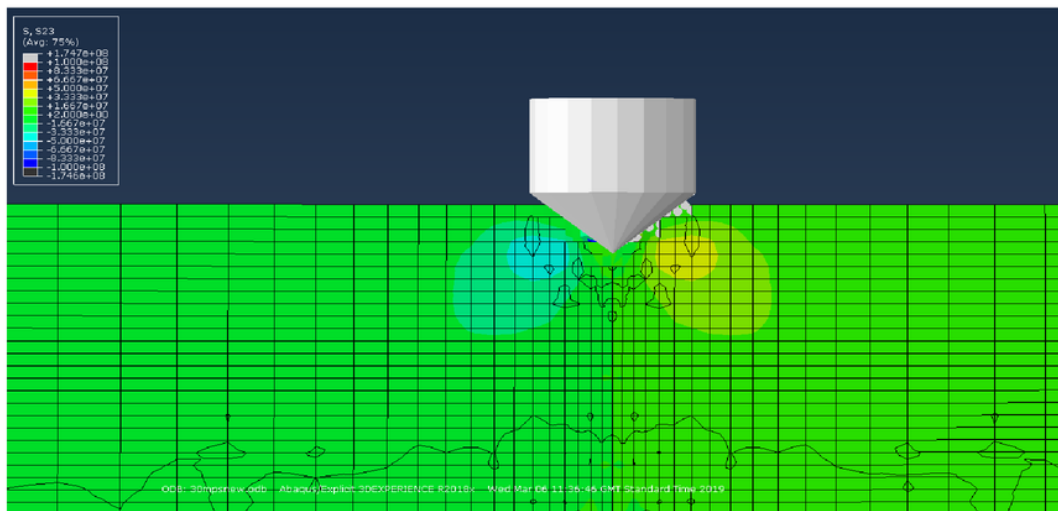


Figure 10 - Screen capture of S23 (Shear Stress) 30 mps simulation at 0.2 ms. Scale set to +100 Mpa to -100 Mpa

9.2 100 mps Screen Captures

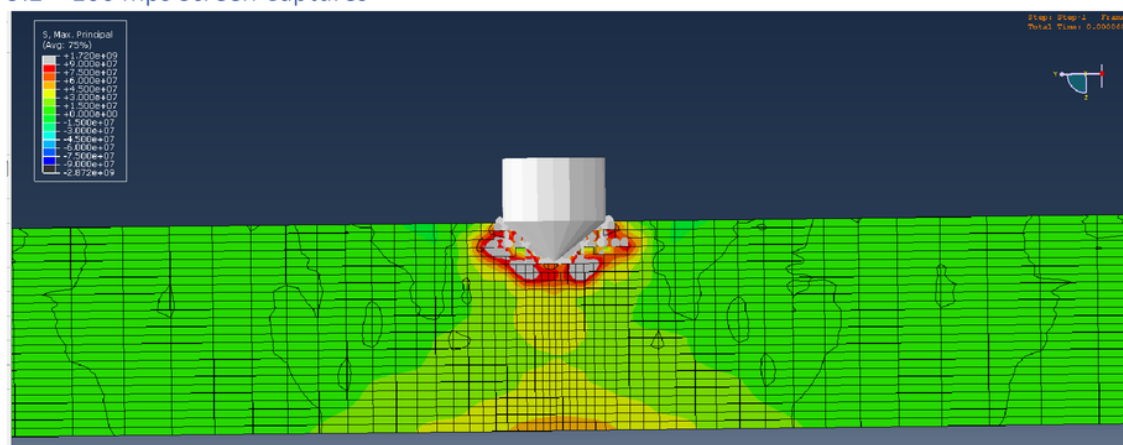


Figure 11 - Screen capture of Max principal (Direct Stress) 100 mps simulation at 0.06 ms. Scale set to +90 Mpa to -90 Mpa

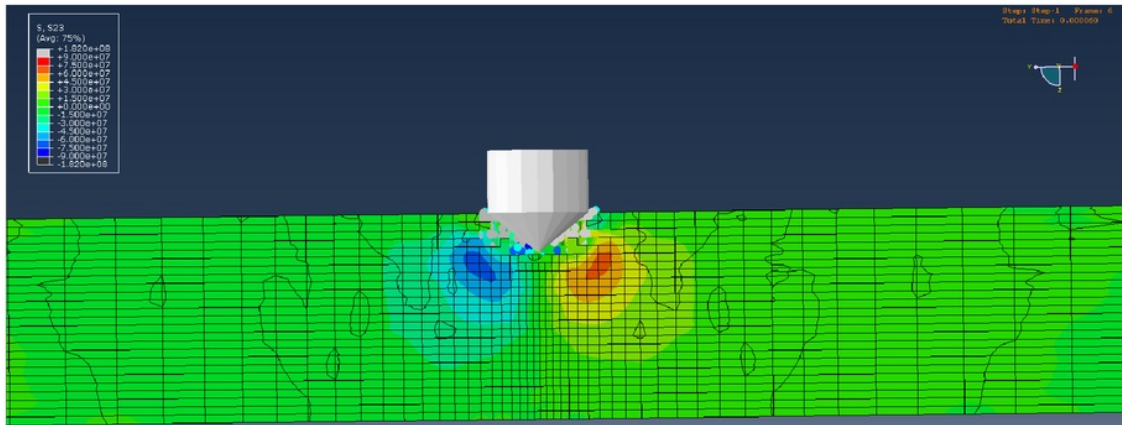


Figure 12 - Screen capture of S23 (Shear Stress) 100 mps simulation at 0.06 ms. Scale set to +90 Mpa to – 90 Mpa

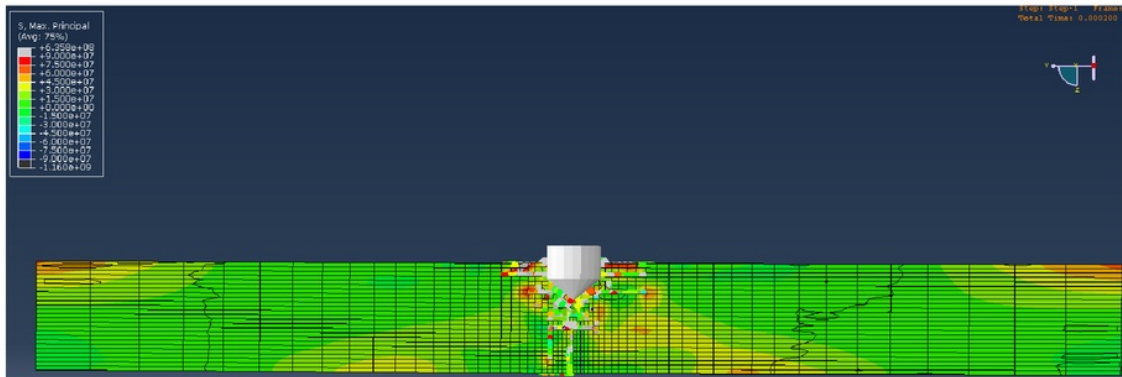


Figure 13 - Screen capture of Max principal (Direct Stress) 100 mps simulation at 0.2 ms. Scale set to +90 Mpa to – 90 Mpa

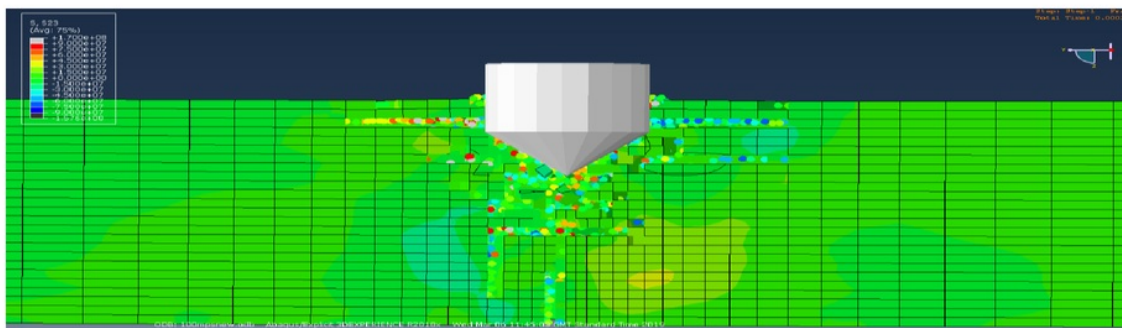


Figure 14 - Screen capture of S23 (Shear Stress) 100 mps simulation at 0.2 ms. Scale set to +90 Mpa to – 90 Mpa

9.3 120 mps Screen Captures

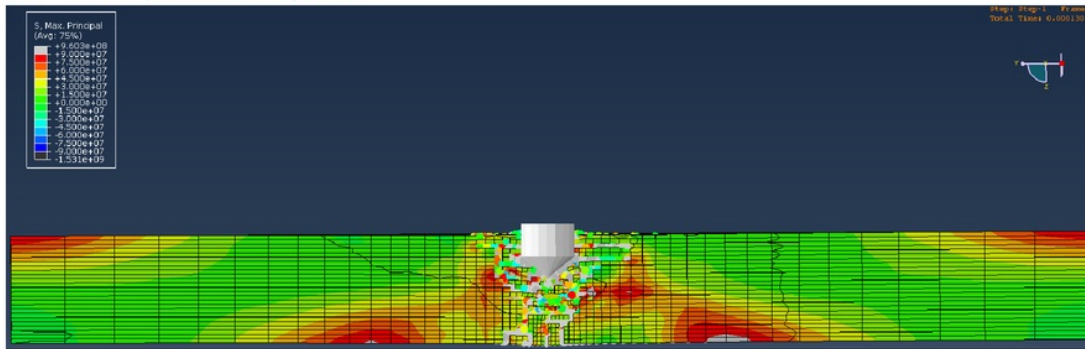


Figure 15 - Screen capture of Max principal (Direct Stress) 120 mps simulation at 0.13 ms. Scale set to +90 Mpa to – 90 Mpa

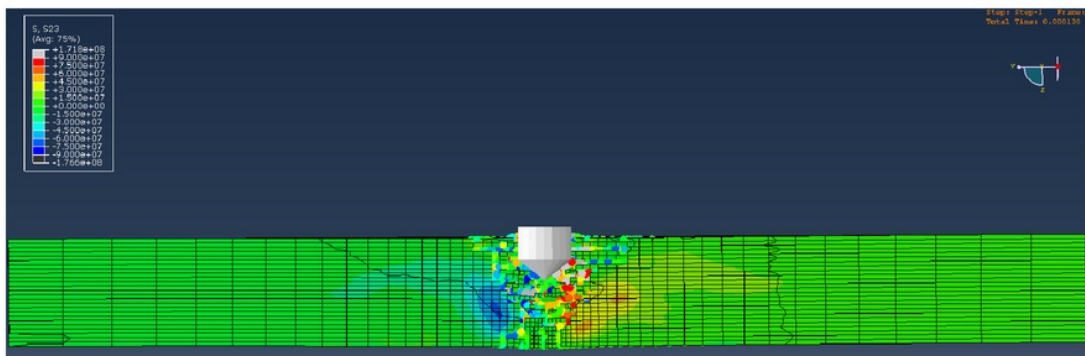


Figure 16 - Screen capture of S23 (Shear Stress) 120 mps simulation at 0.13 ms. Scale set to +90 Mpa to – 90 Mpa

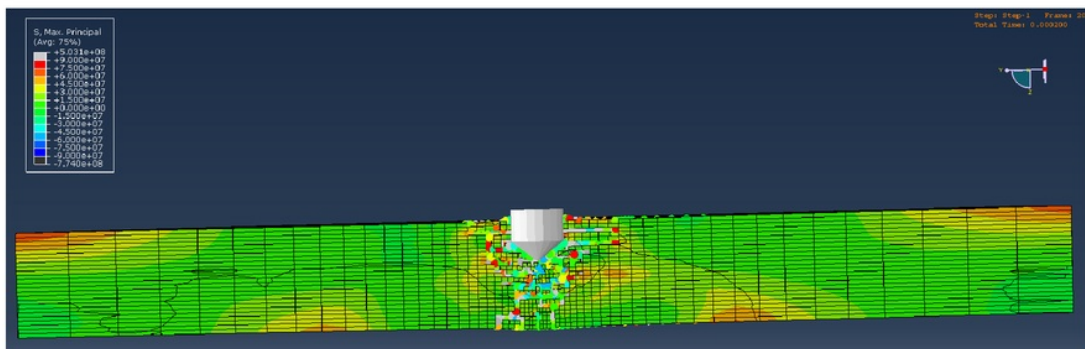


Figure 17 - Screen capture of Max principal (Direct Stress) 120 mps simulation at 0.2 ms. Scale set to +90 Mpa to – 90 Mpa

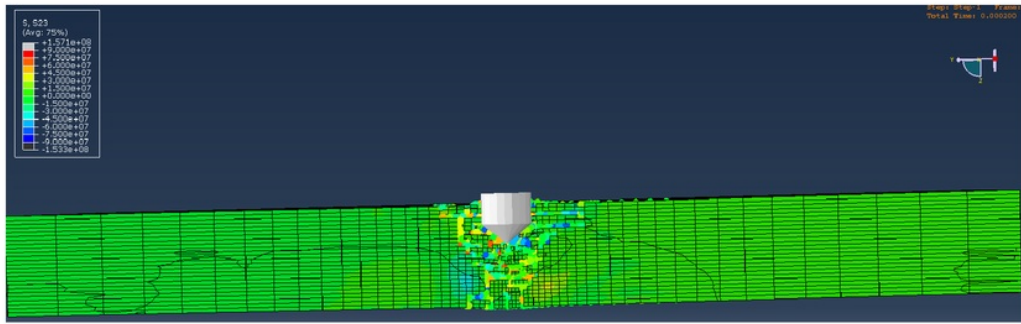


Figure 18 - Screen capture of S23 (Shear Stress) 120 mps simulation at 0.2 ms. Scale set to +90 Mpa to - 90 Mpa

9.4 300 mps Screen Captures

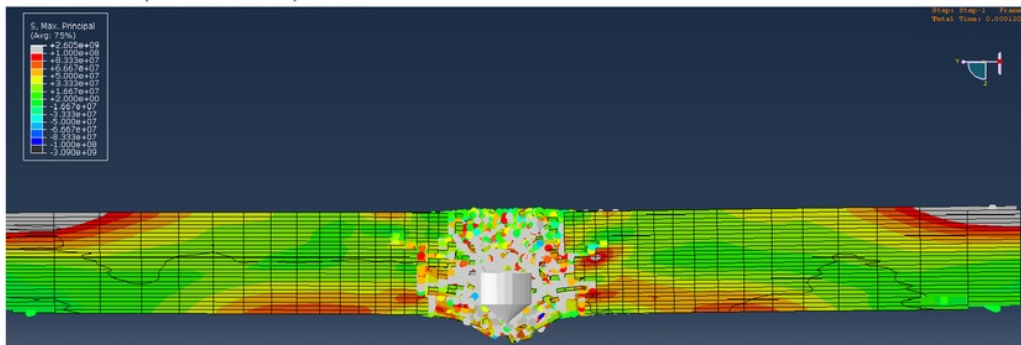


Figure 19 - Screen capture of Max principal (Direct Stress) 300 mps simulation at 0.12 ms. Scale set to +100 Mpa to - 100 Mpa

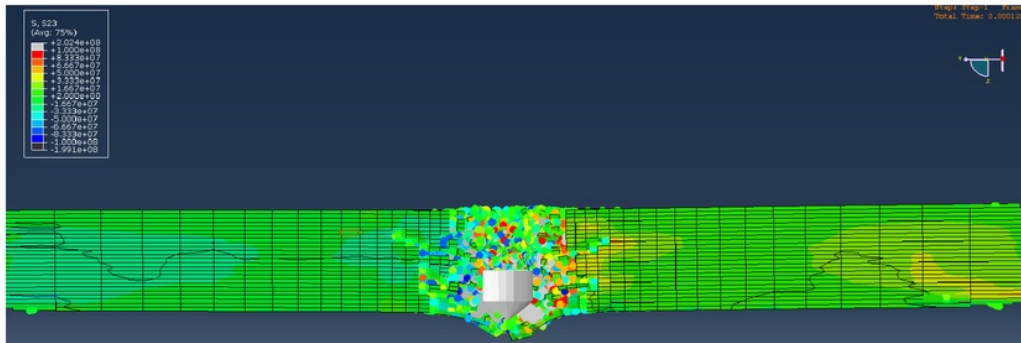


Figure 20 - Screen capture of S23 (Shear Stress) 300 mps simulation at 0.12 ms. Scale set to +100 Mpa to - 100 Mpa

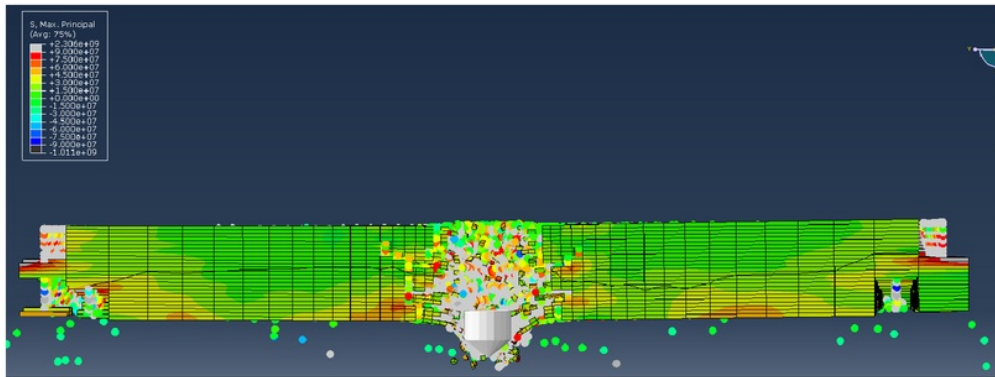


Figure 21 - Screen capture of Max principal (Direct Stress) 300 mps simulation at 0.2 ms. Scale set to +90 Mpa to – 90 Mpa

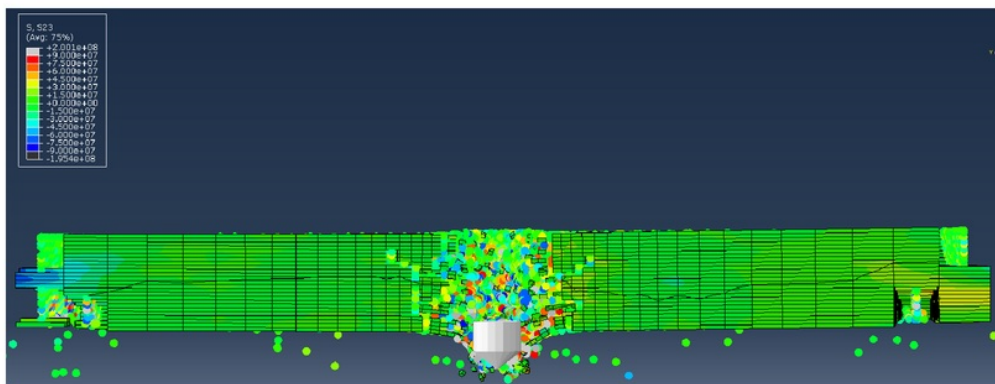


Figure 22 - Screen capture of S23 (Shear Stress) 300 mps simulation at 0.2 ms. Scale set to +90 Mpa to – 90 Mpa

9.5 370 mps Screen Captures

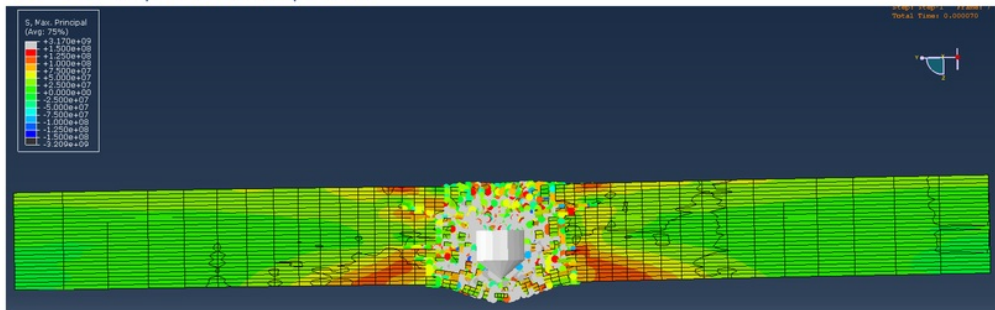


Figure 23 - Screen capture of Max principal (Direct Stress) 370 mps simulation at 0.07 ms. Scale set to +150 Mpa to – 150 Mpa

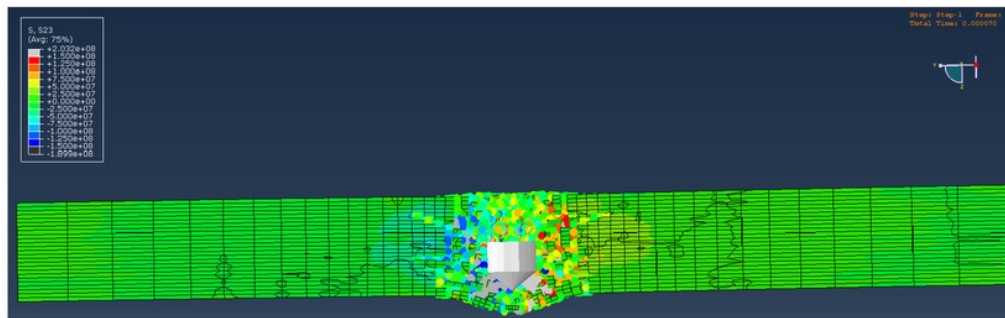


Figure 24 - Screen capture of S23 (Shear Stress) 370 mps simulation at 0.07 ms. Scale set to +150 Mpa to - 150 Mpa

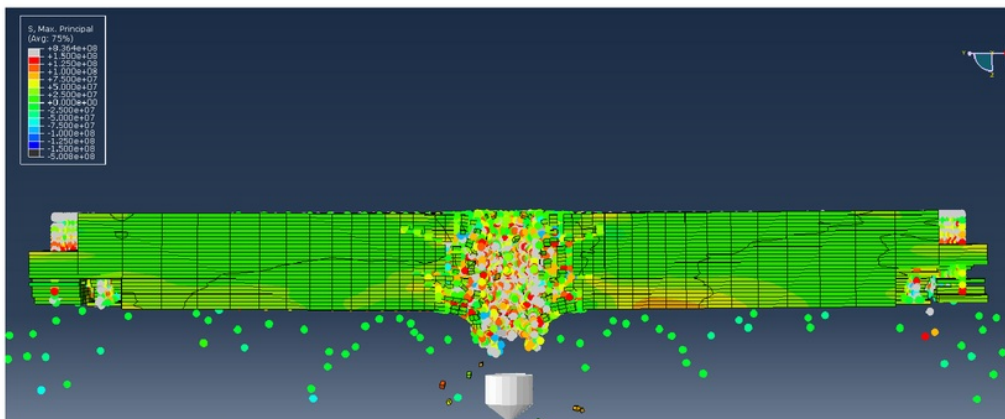


Figure 25 - Screen capture of Max principal (Direct Stress) 370 mps simulation at 0.2 ms. Scale set to +150 Mpa to - 150 Mpa

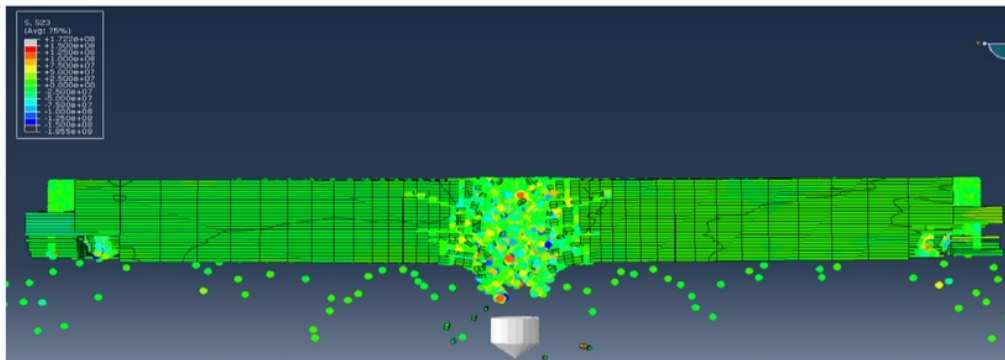


Figure 26 - Screen capture of S23 (Shear Stress) 370 mps simulation at 0.2 ms. Scale set to +150 Mpa to - 150 Mpa