

Ballistics Stress and Strain

by Scott Ling

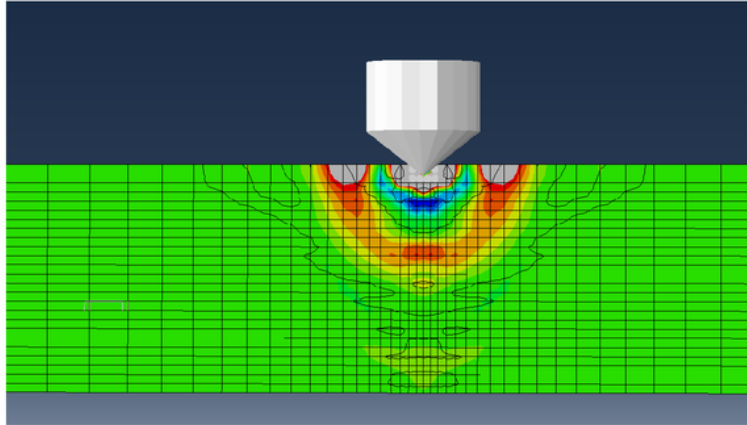
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Stress and Strain Investigation.

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Abstract.

When stress is applied to a material, the force that is then applied to this is measured per unit area, which is then applied to the material. The ratio of extension to original length, is called strain it has no units as it is a ratio of two lengths measured in metres.

To comprehend the relationship between stress and strain. Analysis of the data generated from the simulations will be used in this report.

A simulated experiment in an FEA software called ABAQUS CAE was used. This required researching a type of Aluminium. For this investigation Aluminium 6061-T91 was used. The properties of the plate are then in-putted into ABAQUS CAE. The simulation of a projectile striking the plate was carried out at various speeds.

From the data obtained, it can be noted that Aluminium 6061-T91 reaches its ballistic limit between 300ms^{-1} and 330ms^{-1} .

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2. Introduction

For this assignment of dynamic stress and strain investigation, analysis was supported using Abaqus software. A target plate of Aluminum 6061-T91 was used for this investigation to see how it performed as a target plate whilst simulating in Abaqus software whilst a projectile was striking the plate at various speeds.

This type of aluminum is used within the aerospace industry for the construction of various parts these range from camera lens mounts to aircraft fittings. [1]

Information for this investigation was provided with a predefined ABAQUS BALLISTICS.CAE file which contained an explicit dynamic solver. There are predefined fixed edges for the target plate in the load module, and there is also a surface to surface interaction module.

A mesh Module with hexahedral element was also created within the BALLISTICS.CAE file.

Within this simulation various speed were executed in the ABAQUS software to be able to carry out this investigation and obtain results. These were as follows: 100ms⁻¹, 300ms⁻¹, 330ms⁻¹, 400ms⁻¹ as a baseline.

Whilst carrying out these baseline experiments it was noticed in the graphs that there was an anomaly after initial impact, where the projectile showed an increase of speed whilst penetrating the target plate.

Physical Properties	Metric	English	Comments
Density	2.70 g/cc	0.0975 lb/in ³	AA, Typical
Mechanical Properties	Metric	English	Comments
Hardness, Brinell	103	138	500 kg load with 10 mm ball. Calculated value.
Hardness, Knoop	137	137	Converted from Brinell Hardness Value
Hardness, Rockwell A	44.1	44.1	Converted from Brinell Hardness Value
Hardness, Rockwell B	69	69	Converted from Brinell Hardness Value
Hardness, Vickers	123	123	Converted from Brinell Hardness Value
Tensile Strength, Ultimate	405 MPa	58700 psi	
Tensile Strength, Yield	395 MPa	57300 psi	
Elongation at Break	12 %	12 %	In 5 cm; Sample 1.6 mm thick
Modulus of Elasticity	69.0 GPa	10000 ksi	Average of Tension and Compression. In Aluminum alloys, the compressive modulus is typically 2% greater than the tensile modulus
Poissons Ratio	0.33	0.33	Estimated from trends in similar Al alloys.
Fatigue Strength	95.0 MPa @# of Cycles 5,000-8	13800 psi @# of Cycles 5,000-8	
Shear Modulus	26.0 GPa	3770 ksi	
Shear Strength	230 MPa	33400 psi	Estimated from similar Al alloys.

Figure 1 Aluminium 6061-T91 properties [2]

4. What is Stress and Strain?

Stress

When stress is applied to a material the force, that is then applied to this is measured per unit area which is then applied to the material. Once this has been applied, there is a maximum stress within a materials property that it will be able to handle before it breaks. When this happens, it means the material has reached breaking stress or ultimate tensile stress.

Tensile stress denotes that the material that is being used is under tension. This would mean that the forces that are acting on the material are trying to stretch the material being used. Compression will occur when the force that is acting on the material or the object are trying to Compress it.

$$Stress = \frac{FORCE}{AREA}$$

$$\text{Stress} = \frac{F}{A}$$

Stress = stress measured in Nm^{-2} or pascals (Pa),
 F = force in Newton's (N),
 A = cross-sectional area in.

Strain

The ratio of extension to original length is called strain it has no units as it is a ratio of two lengths measured in metres.

$$\text{Strain} = \frac{\text{EXTENSION}}{\text{LENGTH}}$$

$$\text{Strain} = \frac{\Delta L}{L}$$

Strain = strain it has no units,
 ΔL = extension measured in Meters,
 L = original length measured in Meters.

Using the above equations, it can be seen that strain has no units this is because it is a ratio of lengths.

From the above definitions of stress and strain for forces causing tension or compression.

Having applied tensile force, there will now be tensile stress and tensile strain present.

Having applied compressive force, you will now have compressive stress and compressive strain. [3][4][5][6]

5. Young's Modulus

Young's modulus of a material is a property of every material that cannot be changed. There are two values it is dependent on and this is temperature and pressure.

Young's modulus is the stiffness of a material, which is how easily it can be bent or stretched.

This is worked out by the equation below:

$$\text{Youngs modulus} = \frac{\text{Stress}}{\text{Strain}}$$

$$\text{Stress} = \frac{\text{FORCE}}{\text{AREA}}$$

$$\text{Strain} = \frac{\text{EXTENSION}}{\text{LENGTH}}$$

Once a material has reached a certain stress level that material will then begin to deform. It is at this point that the materials structures in itself are now stretching and not deforming. However if the material is consistently applied to the material the molecules or atoms will now begin to deform and they will be permanently damaged. [3][4][5][6]

6. Poisson's Ratio.

Poisson's ratio can be defined as longitudinal and the lateral strain. The ratio of the lateral axial strain is called Poisson's ratio after the discover Siméon Denis Poisson. This is usually symbolized with a V. [3][4][5][6]

$$V = \frac{\text{Strain in direction of load.}}{\text{Strain at right angle of load.}}$$

7. Ballistic Limit

A Ballistic limit of a material, is defined as the velocity required for a projectile to penetrate the target material. A projectile will not penetrate a target material when the velocity of the projectile is lower than the ballistic limit of the plate itself. For a projectile to perforate a target plate the Velocity needs to be higher than that of the ballistic limit of the target material. [3][4][5][6]

8. Hertzian cone.

A Hertzian cone occurs when an object passes through a solid material, such as a projectile through a target. From the S23 images in this report it can be seen the start of a Hertzian cone this also shows the sheer stress. [3][4][5][6]

9. Results from ABAQUS.

100ms-1

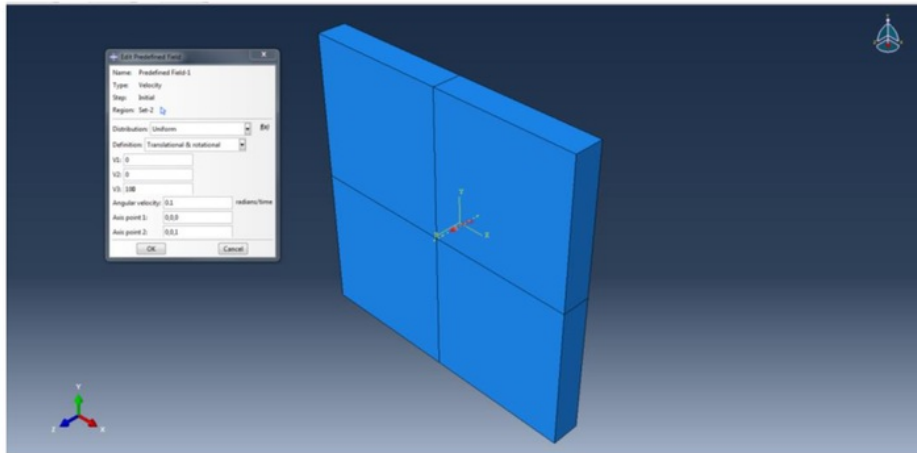


Figure 2 Velocity settings 100ms^{-1}

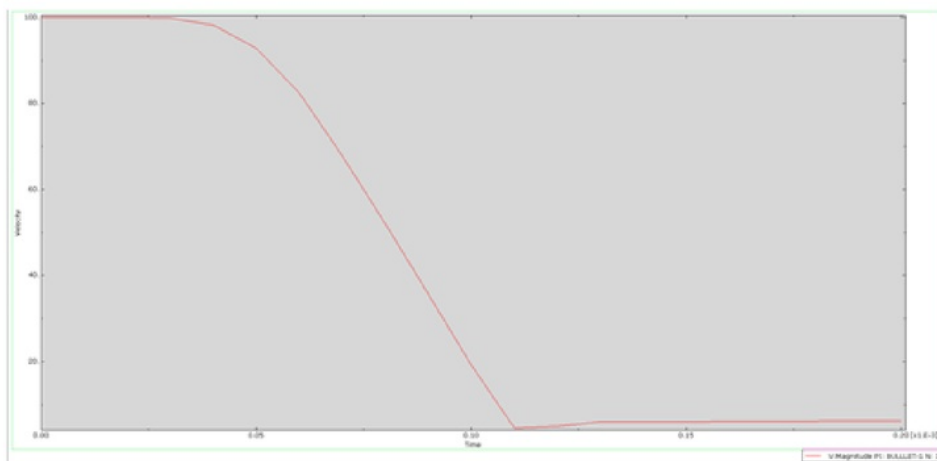


Figure 3 V magnitude P1.

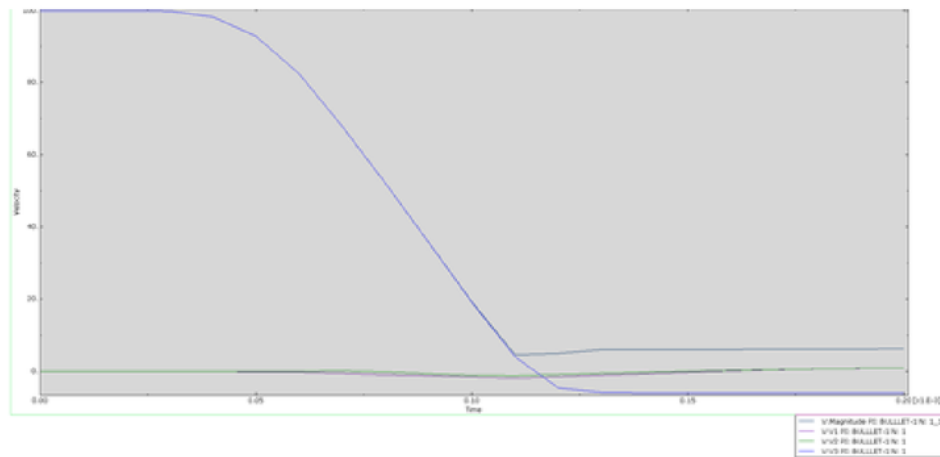


Figure 4 Magnitude, V_1, V_2, V_3 .

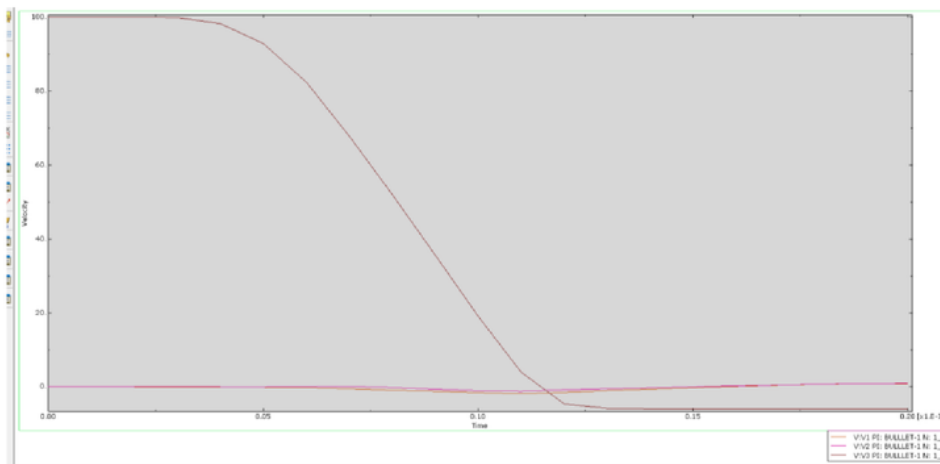


Figure 5 V_1, V_2, V_3 .

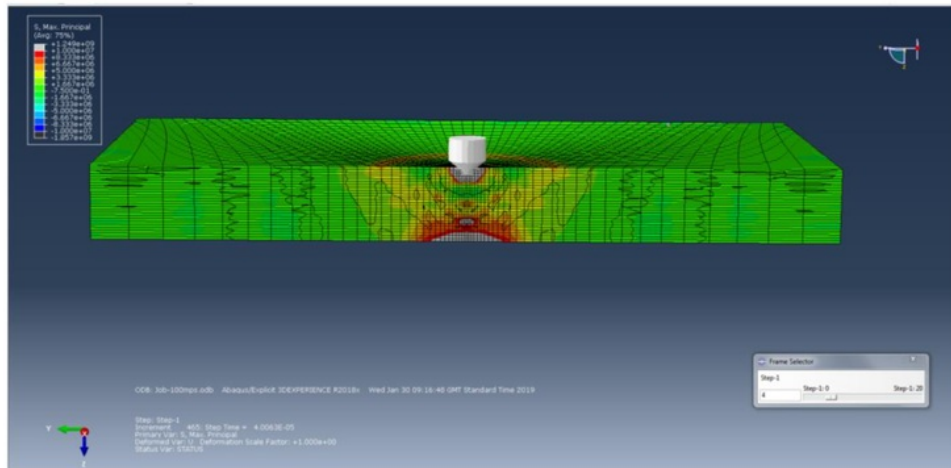


Figure 6 Max principle screenshot of 100ms^{-1}

In figure 6, it shows that after the initial impact from the projectile that there is a clear tensile wave which can be seen in red to the amount of 8.333MPa and the orange color is that of 6.667MPa at the top off the plate. The grey coloring indicates a maximum 1.249GPa of positive tensile stress and the contour graph indicates a maximum and negative tensile stress of 1.857GPa , though it is not evident on the display. It can be seen that there is a tensile wave at the back of the plate which can be seen that it has started to return and could interfere with the projectile. For this simulation the projectile penetrated however it did not perforate.

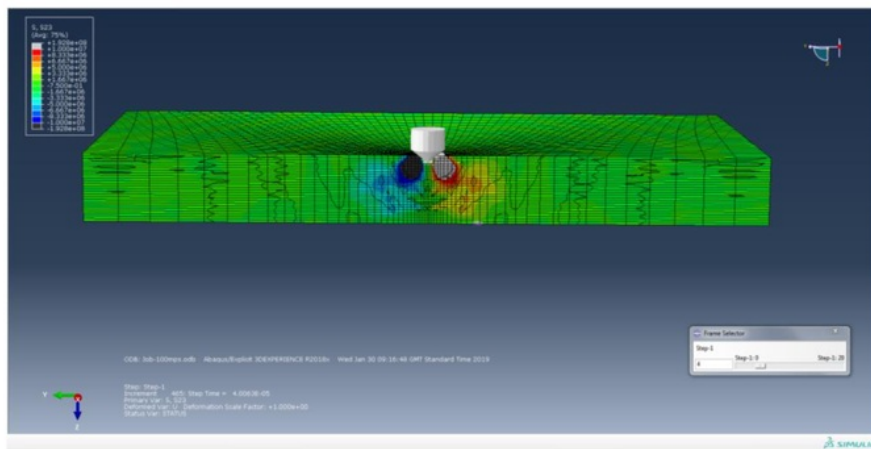


Figure 7 S_{23} screenshot 100ms^{-1}

In figure 7, it shows that there are positive and negative shear stress values, and the start of a Hertzian cone.

300ms⁻¹

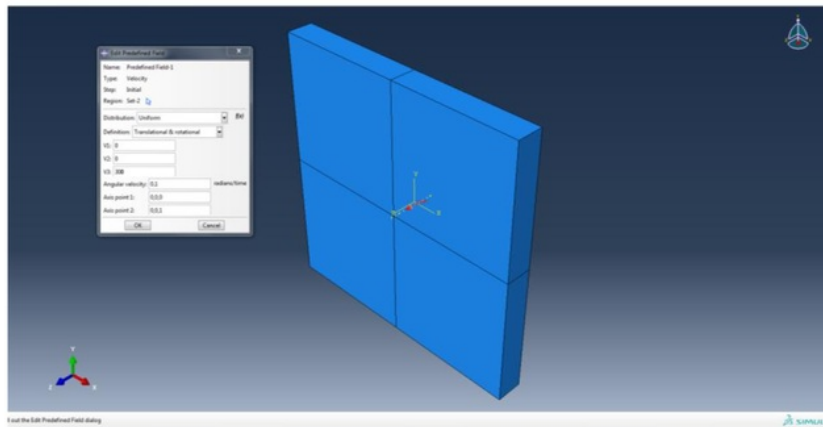


Figure 8 Velocity settings 300ms⁻¹

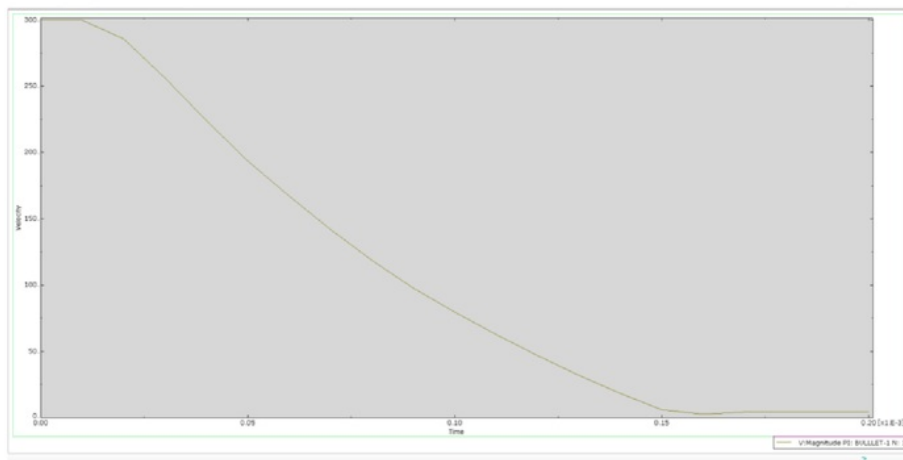


Figure 9 Magnitude.

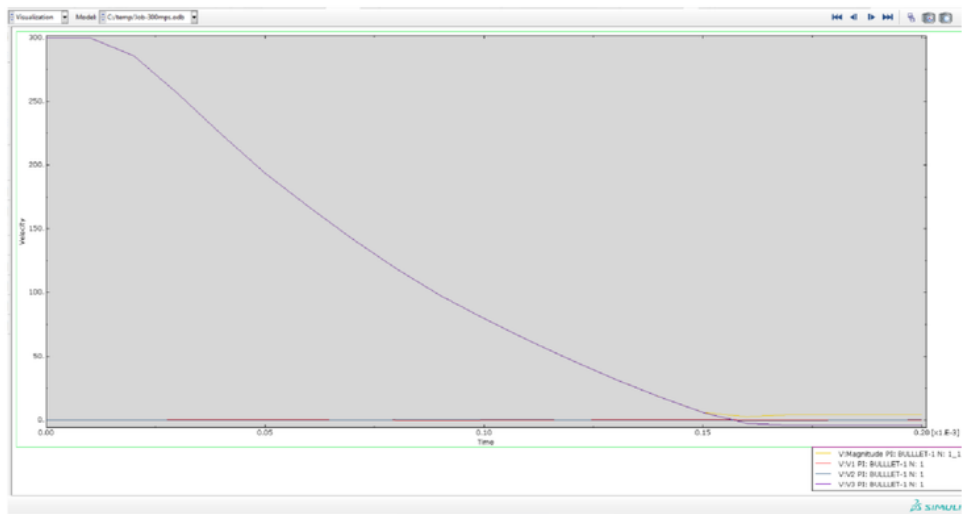


Figure 10 Magnitude, V_1 , V_2 , V_3 .

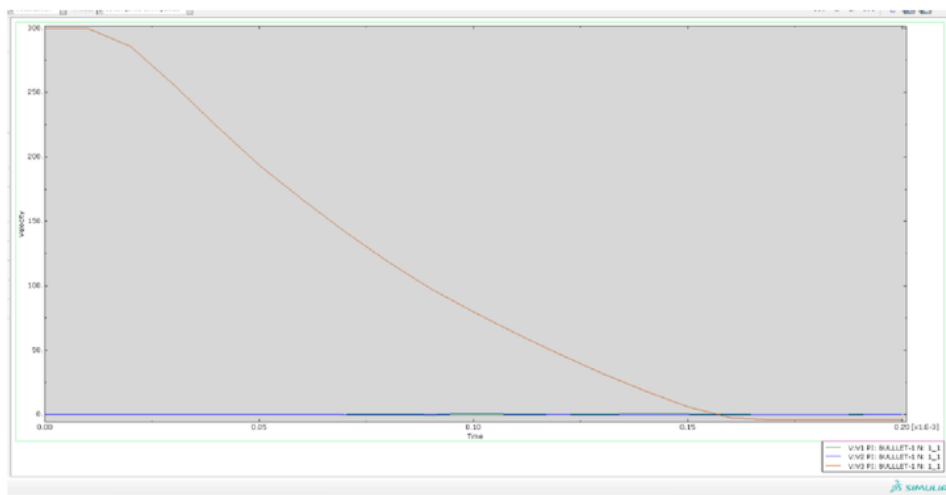


Figure 11 V_1 , V_2 , V_3 .

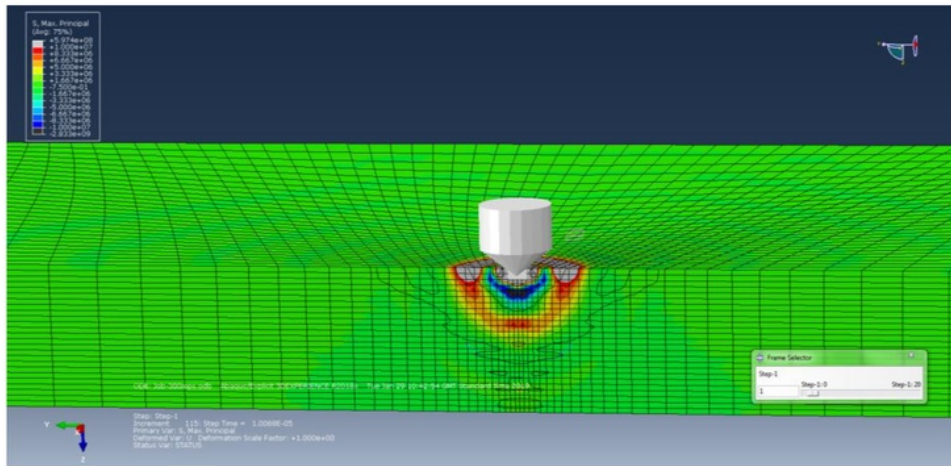


Figure 12 Max principle screenshot 300ms^{-1}

In figure 12, it shows that after the initial impact from the projectile that there is a clear tensile wave which can be seen in red to the amount of 8.333MPa and the orange color is that of 6.667MPa at the top off the plate. The grey coloring indicates a maximum 1.249GPa of positive tensile stress and the contour graph indicates a max negative tensile stress of 1.857GPa, for this simulation the projectile penetrated, however it did not perforate.

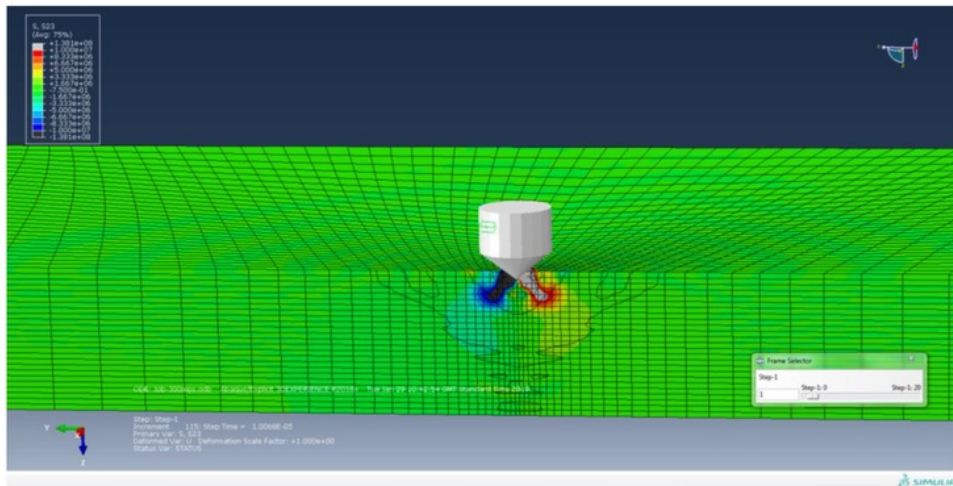


Figure 13 S_{23} screenshot 300ms^{-1}

In figure 13, it shows that there are positive and negative shear stress values, and the start of a Hertzian cone.

330ms⁻¹

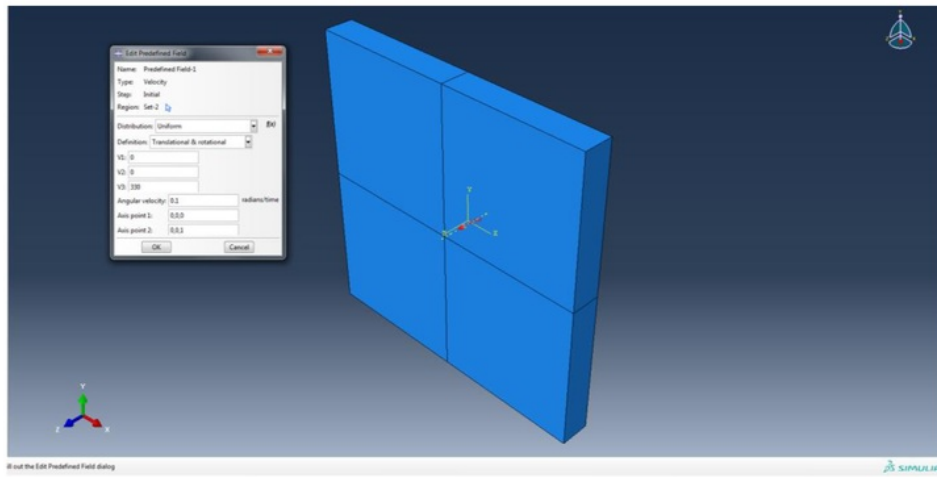


Figure 14 Velocity settings 330ms⁻¹

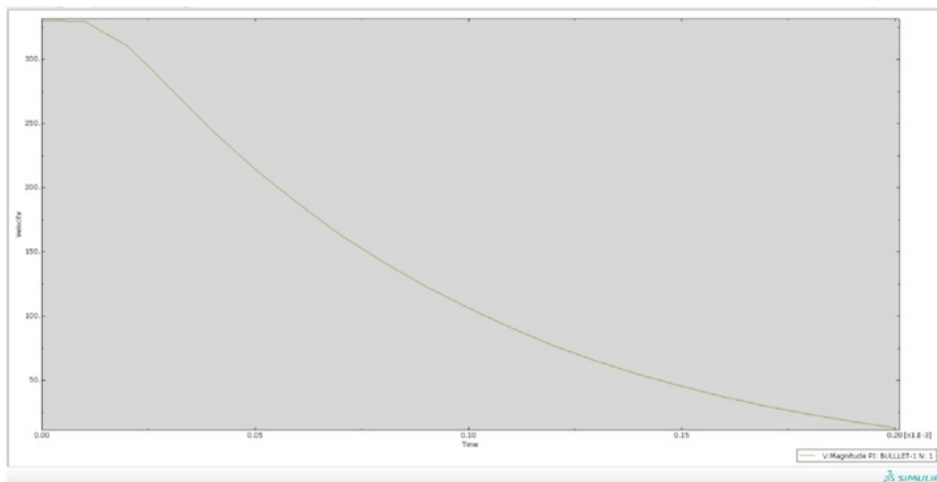


Figure 15 Magnitude.

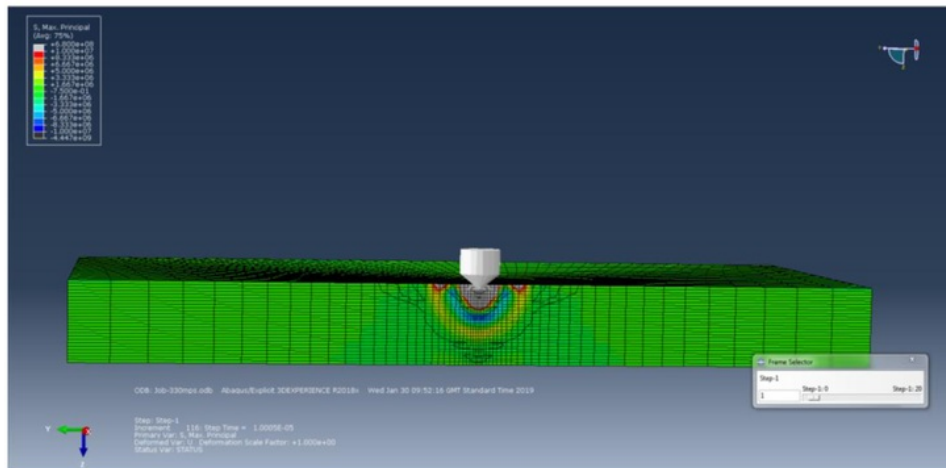


Figure 16 Max pricipcle screenshot 330ms⁻¹

In figure 16, it shows that after the initial impact from the projectile that there is a clear tensile wave which can be seen in red to the amount of 8.333MPa and the orange color is that of 6.667MPa at the top off the plate. The grey coloring indicates a maximum 1.249GPa of positive tensile stress and the contour graph indicates a max negative tensile stress of 1.857GPa. There is a tensile wave at the back of the plate which you can see it has started to return and from this you can now see that there is compressive stress with in the plate this is indicated by the blue color with a value of -8.333MPa and could interfere with the projectile. For this simulation the projectile penetrated and it also perforated. This could mean that a projectile fired at 330ms⁻¹ has hit the ballistic limit for Aluminum 6061-Tg1.

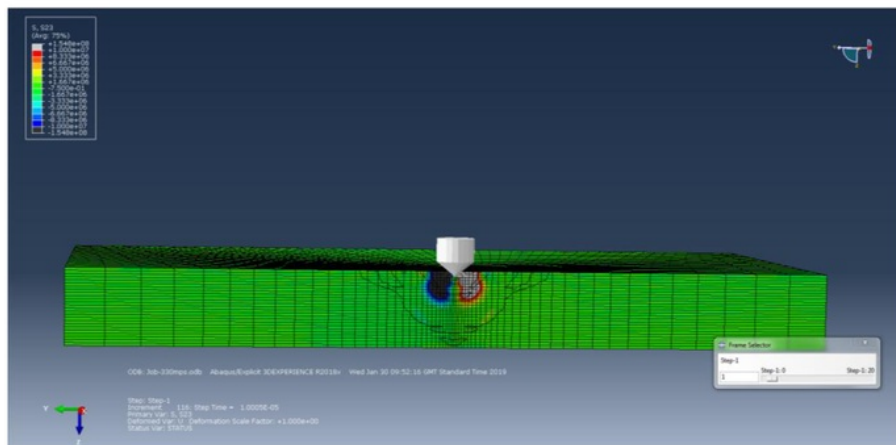


Figure 17 S23 screenshot 330ms⁻¹

In figure 17, it shows that there are positive and negative shear stress values, and the start of a Hertzian cone.

400ms⁻¹

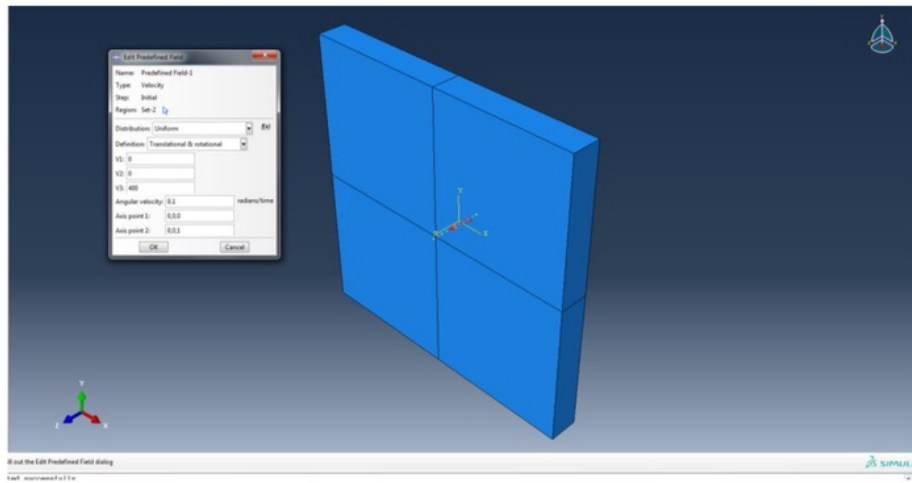


Figure 18 Velocity settings 400ms⁻¹

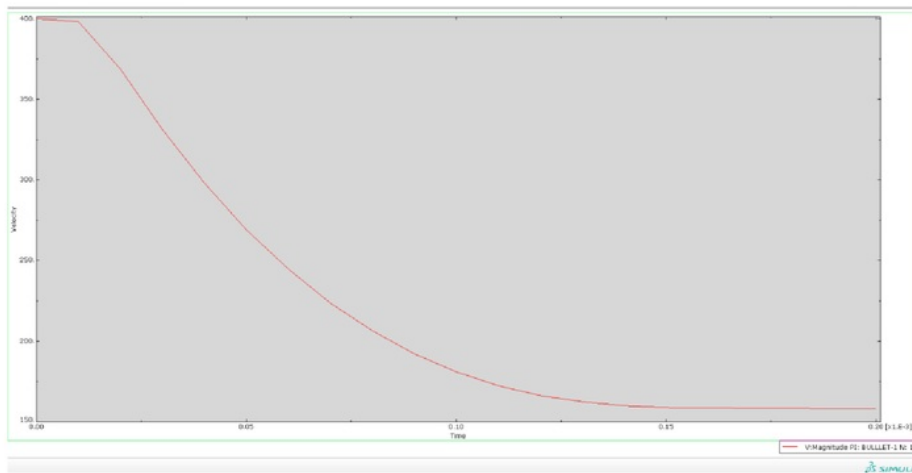


Figure 19 Magnitude.

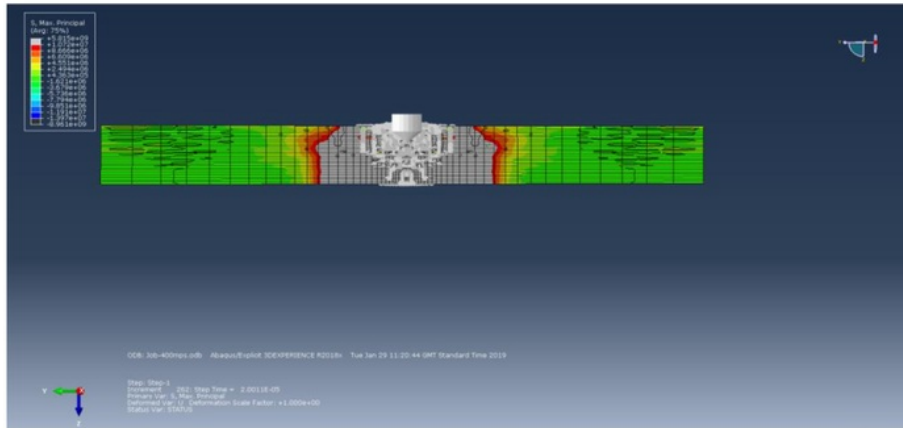


Figure 20 Max principle screenshot 400ms⁻¹

In figure 20, it shows that after the initial impact from the projectile that there is a clear tensile wave which can be seen in red to the amount of 8.666MPa and the orange color is that of 4.551MPa at the top off the plate. The grey coloring indicates a maximum 1.0702GPa of positive tensile stress and the contour graph indicates a max negative tensile stress. There is a tensile wave at the back of the plate which you can see it has started to return and from this you can now see that there is compressive stress within the plate this is indicate by the blue color with a value of -8.961MPa. From this image you can see the plate starting to fail. This means the plate has now passed its elasticity range and now in the stage of its brittle range. For this simulation the projectile penetrated and it also perforated the target plate. This means that a projectile fired at 400ms⁻¹ has hit the ballistic limit for Aluminum 6061-T91.

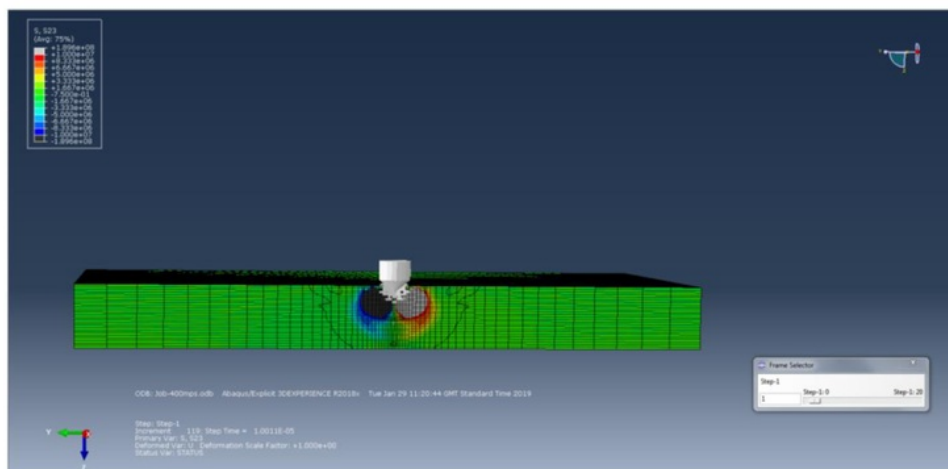


Figure 21 S23 screenshot 400ms⁻¹

In figure 21, it shows that there are positive and negative shear stress values, and the start of a Hertzian cone.

10. Discussion

So, After carrying out the simulated experiment using ABAQUS CAE, the data has now been retrieved, and analysis of the quantitative data from the simulations can be executed. The max values were taken as $1E9$ and the minimum were taken as $-1E9$

Using the images [figures 6,12,16 and 20](#), it can be noted that there is tensile [stress within the target plate](#). This is shown with the around red and grey colors in the figures. Tensile force has a higher magnitude than shear stress which can be seen in the max principle's figures and the S_{23} figures.

From the data that has been obtained from the experiment it can be seen that the ballistic limit for Aluminum 6061-T91 is between 300ms^{-1} and 330ms^{-1} . To gain a definitive Data set for this more investigation and analysis would need to be carried out.

11. Conclusion

In conclusion to this experiment, data has now been obtained and analyzed.

From the data obtained it can be seen that the below 300ms^{-1} Aluminum 6061-T91 does not reach its ballistic limit and remains within its elasticity range. However, above 300ms^{-1} Aluminum 6061-T91 does reach its ballistic limit and moves to a brittle state which can be seen in figure 20.

In the simulation for 100ms^{-1} and 300ms^{-1} there is an anomaly in the graphs which can be seen in figures 3 and 9. After the initial impact between the projectile the projectile should lose momentum however in the graphs it can be seen that the projectile gains momentum again. This could be caused by a tumbling effect or it could have hit one of the meshes within the plate, further research and analysis would need to be carried out to find the exact cause of this.

12. Reference's

1. <http://www.ratnamsteels.com/aluminum/aluminum-6061-t91/> 30/01/19
2. <http://www.matweb.com/search/DataSheet.aspx?MatGUID=e6212a3df98d4a7eb51edc1bd3927ed&ckck=1> 30/01/2019
3. <HTTP://PHYSICSNET.CO.UK/A-LEVEL-PHYSICS-AS-A2/MATERIALS/STRESS-STRAIN/> 30/01/2019
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