

Physics Stress Strain Report

by Fergus Russell

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ACAD 4007 PHYSICS

Dynamic Stress Strain Investigation

Abstract

The report outlines a target plate material choice and properties along with a selection of velocities taken from real life materials and projectiles. The report presents the results obtained from the simulations in ABAQUS and discusses the findings. It was found that the simulation method is valid for obtaining results however properties such as projectile material, geometry and spin would have had an effect on the results and that if the experiment were to be repeated these properties should be added.

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1. INTRODUCTION

The science of ballistics is incredibly important in the modern world for a variety of applications. From how a cricketer throws a ball to the impact of a shaped charge on a tank hull, ballistic science is around us in many forms. Understanding how ballistic impacts affect materials is incredibly important to design engineers as it allows them to properly select a material for the desired application, failure to do this can have potentially disastrous consequences for personnel who use the equipment which may lead to negative consequences for the manufacturer and designer. This report aims to investigate a set ballistic problem and investigate how velocity of a projectile affects a material.

2. PROBLEM SETUP

Figure 1 shows the problem setup that will be investigated:-

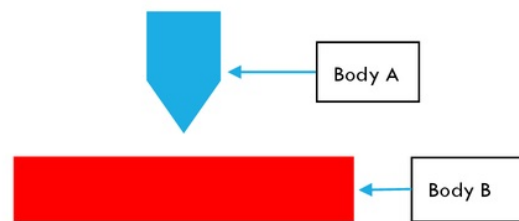


Figure 1-Problem Diagram

Figure one shows Body A, a projectile, pointing down towards Body B, a target plate. Body A is a conical-cylindrical projectile measuring 9.8mm in diameter, 10mm from base to cone tip and the angle of the cone is 103.5° . These parameters would be suitable to represent 10mm calibre ammunition and as such the velocities used will reflect this. Body B is a material target plate with dimensions 198.75mmX198.75mmX20mm.

As this model is representing the impact of small arms ammunition then this application must be taken into account in the material selection of the target plate. Aluminium has been utilised in recent years in armoured fighting vehicles, one notable example being the hull of the British Army's FV510 Warrior Armoured Fighting Vehicle[1].



Figure 2-UK Army FV510 Warrior [1]

It allows designers to build lightweight yet strong and tough vehicles that can easily be air transported into theatre. At present the specific aluminium used in Warrior's construction isn't in the public domain however some aluminium alloys have been certified for use in American armour applications and have corresponding standards that are publically accessible. Set out in standard MIL-DTL-46027K(MR)[2] are a series of properties and requirements for 5083, 5456 and 5059 aluminium alloys. Table 1 shows the element composition of the alloys as set out in the standard [3]:-

Table 1-Elements in Alloys [3]

Elements	Alloys		
	5083 Class 1	5456 Class 2	5059 Class 3
Silicon	0.40	0.25	0.45
Iron	0.40	0.40	0.50
Copper	0.10	0.10	0.25
Manganese	0.40-1.0	0.50-1.0	0.6-1.2
Magnesium	4.0-4.9	4.7-5.5	5.0-6.0
Chromium	0.05-0.25	0.05-0.20	0.25
Zinc	0.25	0.25	0.40-0.90
Titanium	0.15	0.20	0.20
Other Max Each	0.05	0.05	0.05
Other Max Total	0.15	0.15	0.15
Aluminium	Remainder	Remainder	Remainder

As well as dictating the elemental makeup of the alloys the standard also sets out the minimum requirements for the mechanical properties for a given thickness of material. These properties are shown in Table 2 [3]:-

Table 2-Mechanical Properties of Material [3]

Thickness (Inches)	Tensile Strength (Ksi)			Yield Strength, 0.2% offset (Ksi)			Elongation Percentage		
	5083	5456	5059	5083	5456	5059	5083	5456	5059
Alloys>									
0.250-0.499	45.0	45.0	53.0	35.0	35.0	39.0	8	8	8
0.500-2.00	45.0	45.0	52.0	37.0	37.0	39.0	8	8	7
2.001-3.00	44.0	44.0	47.0	35.0	35.0	39.0	9	9	8

Table 3 shows these properties but converted to SI units:-

Table 3-SI Unit Conversion

Thickness (mm)	Tensile Strength (MPa)			Yield Strength, 0.2% offset (MPa)			Elongation Percentage		
	5083	5456	5059	5083	5456	5059	5083	5456	5059
Alloys>									
6.35-12.67	310.26	310.26	365.42	241.31	241.31	268.89	8	8	8
12.7-50.8	310.26	310.26	358.52	255.10	255.10	268.89	8	8	7
50.8254-76.2	303.36	303.36	324.05	241.31	241.31	268.89	9	9	8

From this table 5059 Aluminium will be selected as the material to be simulated. As aluminium alloys normally have some form of tempering then a suitable temper needs to be selected for the 5059 alloy. 5059 H111 is an example of such. Table 4 [4] shows the material properties for 5059 H111 aluminium:-

Alloy	Young's Modulus (GPa)	Ultimate Tensile Strength (MPa)	Yield Stress (MPa)	Elongation at Break (%)	Poisson's Ratio	Density (kg/m ³)
5059 H111	69	360	180	25	0.33	2700

As previously discussed the problem set up is suitable to model 10mm ammunition. As the geometry is fixed to that given to the projectile then the velocity of the projectile is a variable that can be modified. For this a variety of muzzle velocities were selected from manufacturer's data for .40 Smith & Wesson ammunition types. All data is for ammunition manufactured by Corbon/Glaser. Table 5 shows the ammunition type and their respective muzzle velocities:-

Table 5-Data for Ammunition

Bullet	Mass (Grains)	Velocity (fps)	Energy (ftlbs)
.40 S&W 135gr Pow'RBall [4]	135	1325	526
.40 S&W 140gr DPX[5]	140	1200	488
.40 S&W 165gr Subsonic FMJ[6]	165	850	265

Table 6 shows the data from table 5 converted into SI units:-

Table 6-Ammunition data in SI units

Bullet	Mass (g)	Velocity (m/s)	Energy (Joules)
.40 S&W 135gr Pow'RBall [5]	8.747	403.86	713.16
.40 S&W 140gr DPX[6]	9.071	365.76	661.639
.40 S&W 165gr Subsonic FMJ[7]	10.6918	259.08	359.292

The scope of this problem does not cover projectile mass therefore the mass of the projectile shall be discounted and only the projectiles velocity will change.

3. ABAQUS SETUP

Abaqus is a Finite Element Analysis software developed by Dassault Systems. It is capable of running simulations on designed components and testing how they will react in a digital environment. This enables engineers to design and test components prior to manufacturing them to ensure they will withstand the conditions expected of them.

Within Abaqus the problem is set up using 3D models. Initial conditions and boundary conditions are then applied to the models which will form the basis of the simulation. Figure 3 shows the model set up in the Abaqus environment.

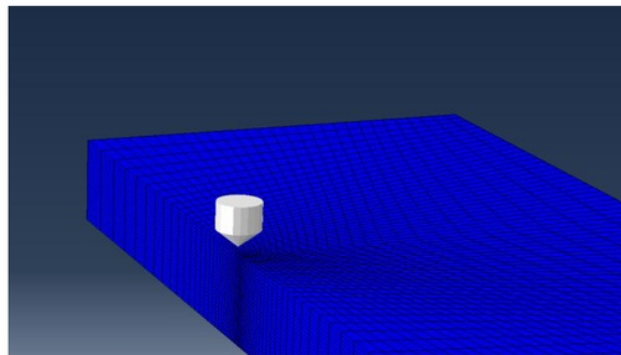


Figure 3-Model Setup in Abaqus

The blue model is the aluminium plate and has the material properties of 5059 H111 aluminium alloy as described in section 2. The boundary conditions applied to the aluminium are such that it is clamped on all edges. The grey model is the projectile and is modelled as being completely rigid and incapable of deformation. The grey model is assigned the velocities selected in section 2 and then the simulation is run. The simulation is carried out for all velocities and the results are then analysed. For the analysis two forms of stress will be analysed the principal stresses (compression and tensile) and shear stresses.

RESULTS

Figures 4-23 are results for the projectile fired at 259.08m/s:-

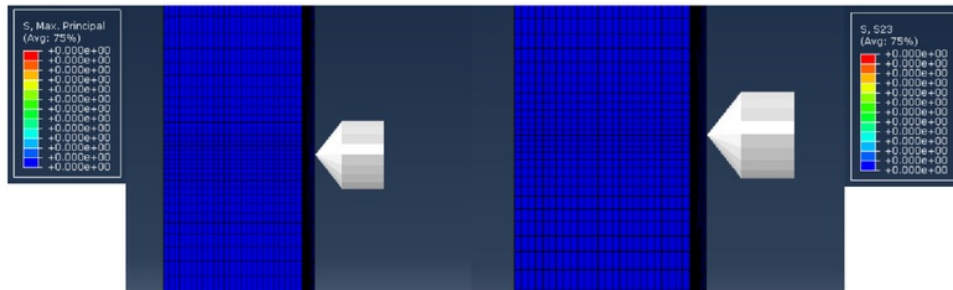


Figure 4-259.08m/s Principal and Shear Stress Frame 1

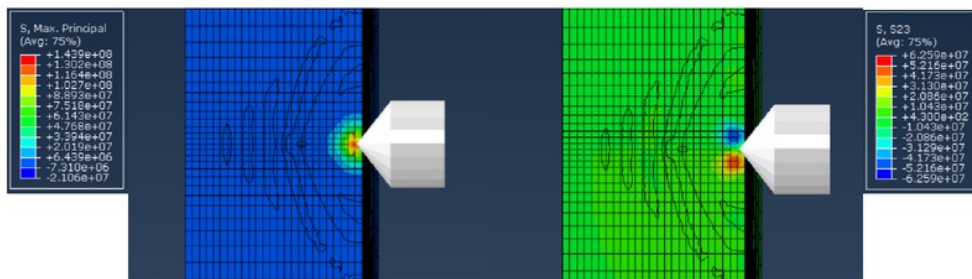


Figure 5-259.08m/s Principal and Shear Stress Frame 2

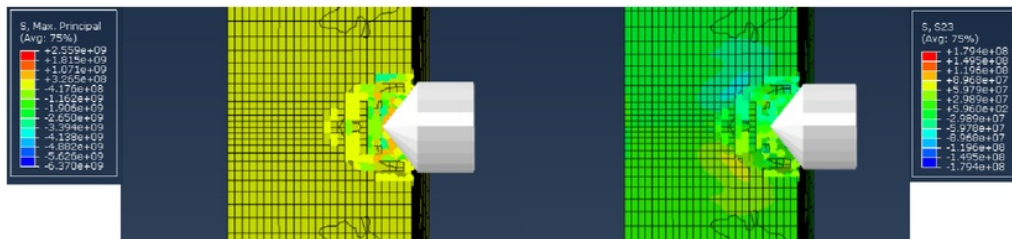


Figure 6-259.08m/s Principal and Shear Stress Frame 3

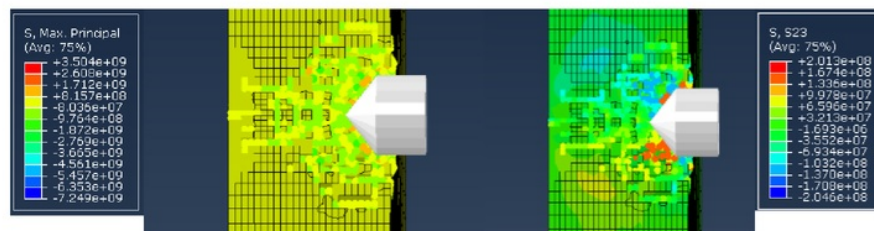


Figure 7-259.08m/s Principal and Shear Stress Frame 4

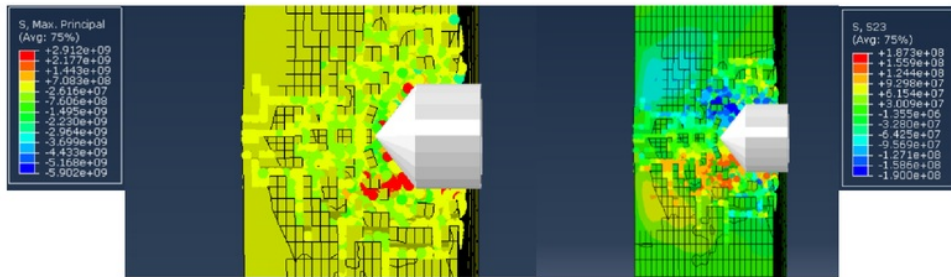


Figure 8-259.08m/s Principal and Shear Stresses Frame 5

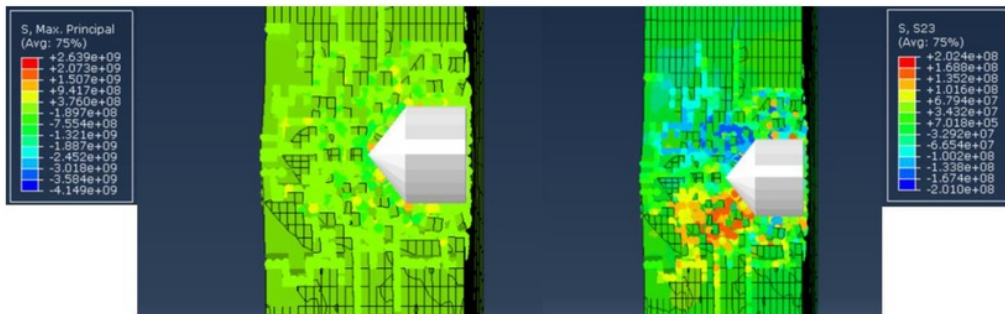


Figure 9-259.08m/s Principal and Shear Stresses Frame 6

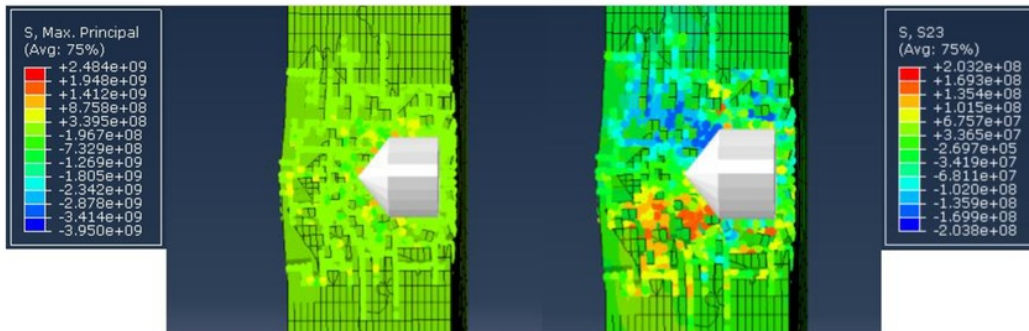


Figure 10-259.08m/s Principal and Shear Stresses Frame 7

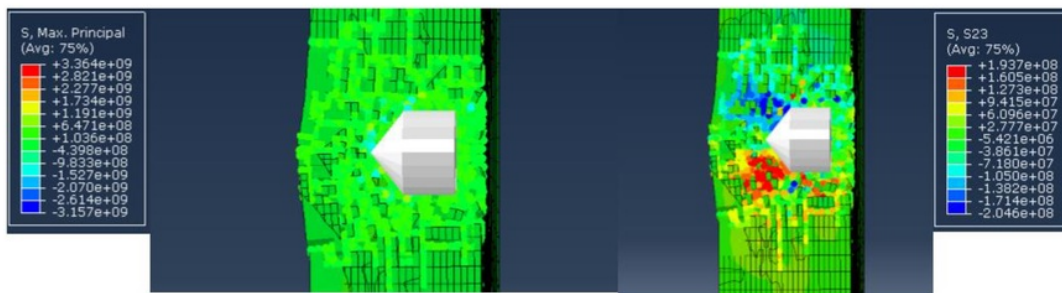


Figure 11-259.08m/s Principal and Shear Stresses Frame 8

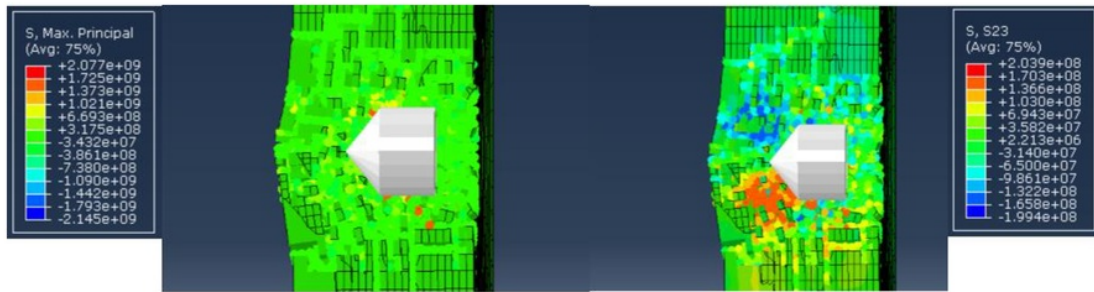


Figure 12-259.08m/s Principal and Shear Stresses Frame 9

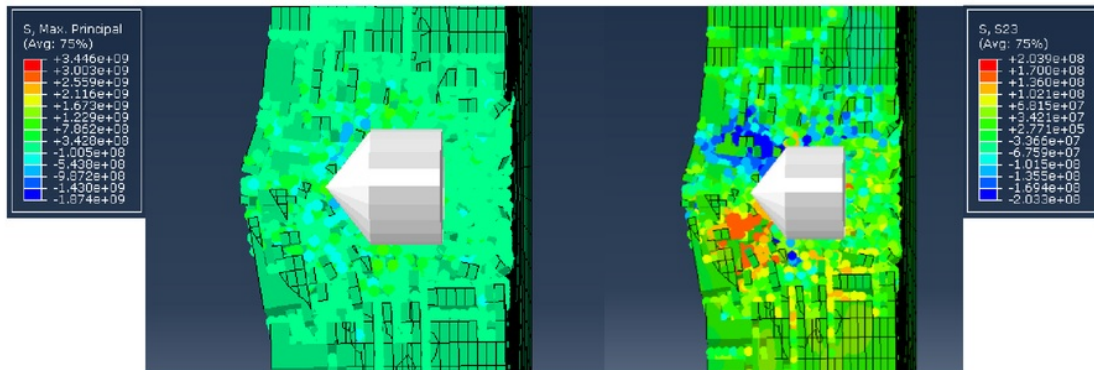


Figure 13-259.08m/s Principal and Shear Stresses Frame 10

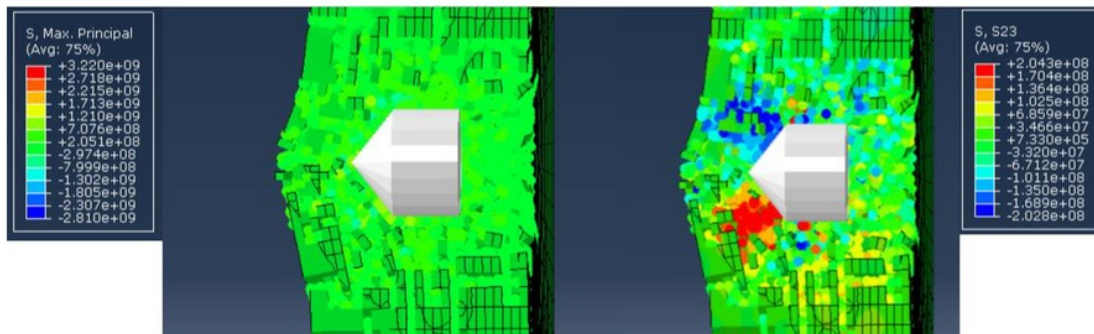


Figure 14-259.08m/s Principal and Shear Stresses Frame 11

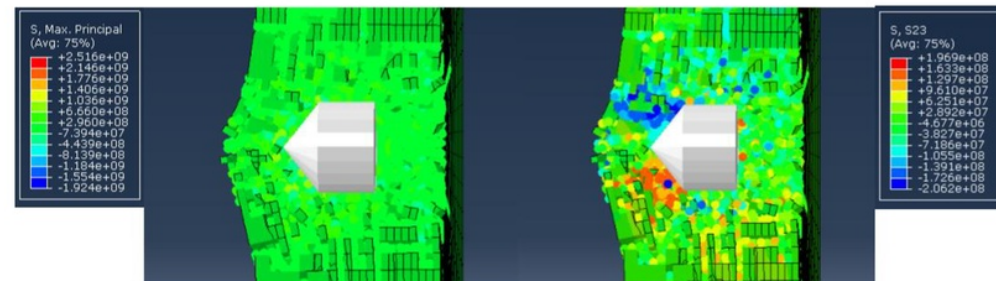


Figure 15-259.08m/s Principal and Shear Stresses Frame 12

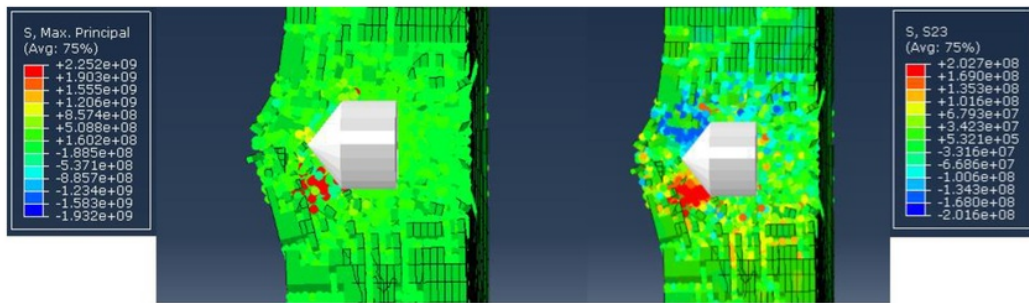


Figure 16-259.08m/s Principal and Shear Stresses Frame 13

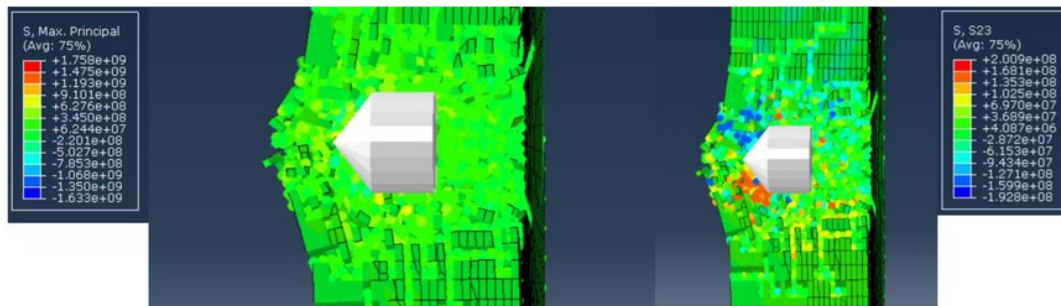


Figure 17-259.08m/s Principal and Shear Stresses Frame 14

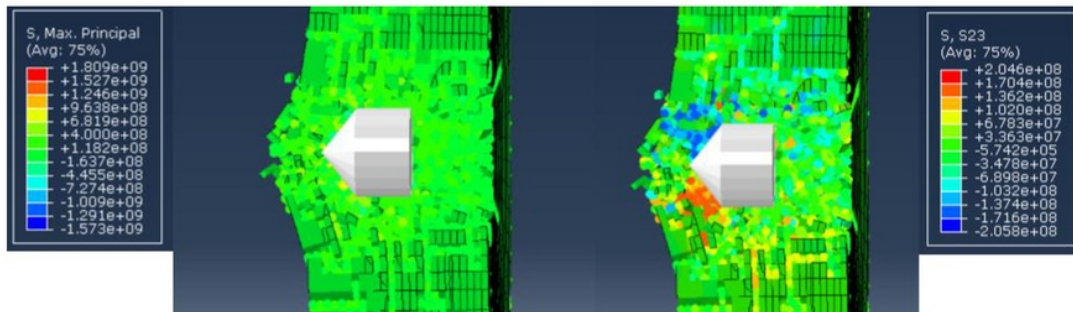


Figure 18-259.08m/s Principal and Shear Stresses Frame 15

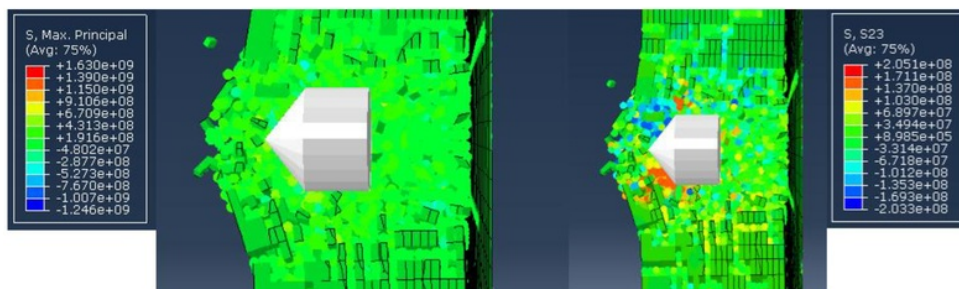


Figure 19-259.08m/s Principal and Shear Stresses Frame 16

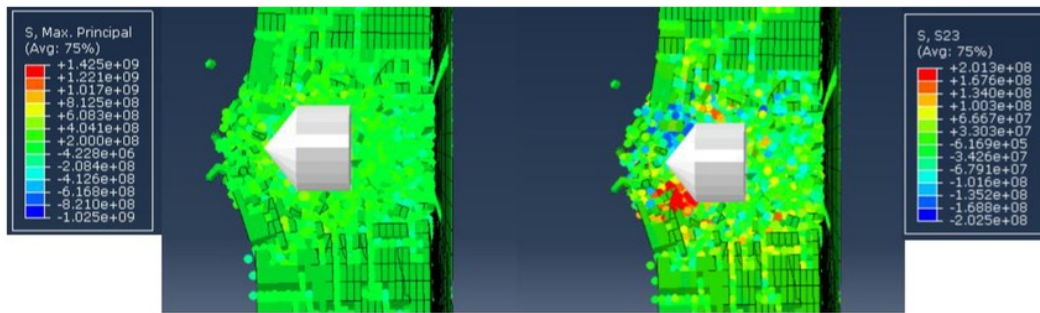


Figure 20-259.08m/s Principal and Shear Stresses Frame 17

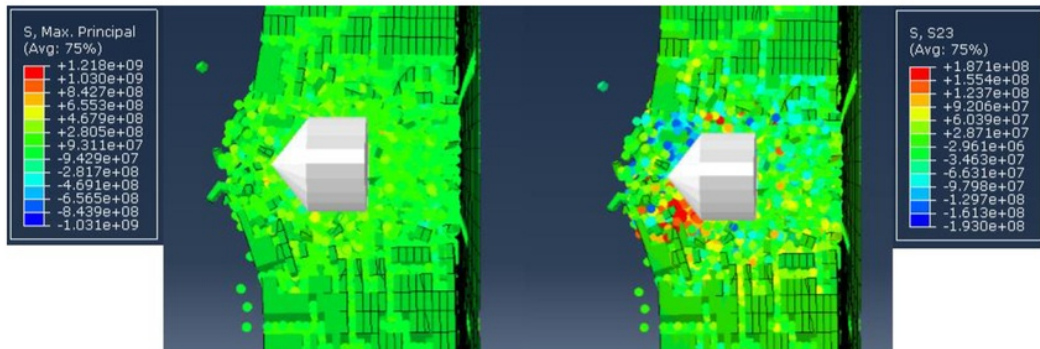


Figure 21-259.08m/s Principal and Shear Stresses Frame 18

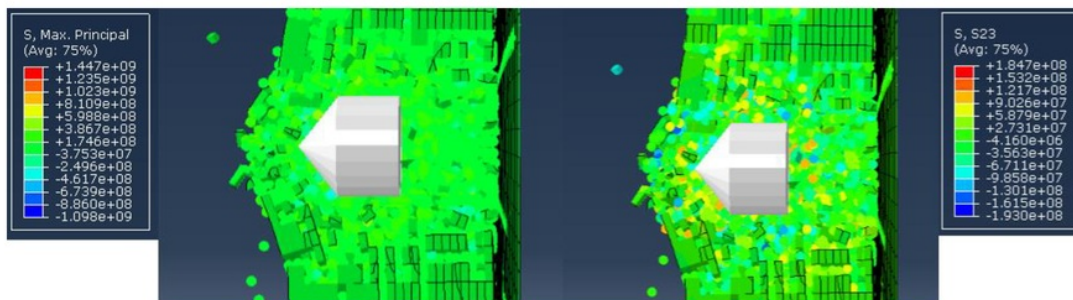


Figure 22-259.08m/s Principal and Shear Stresses Frame 19

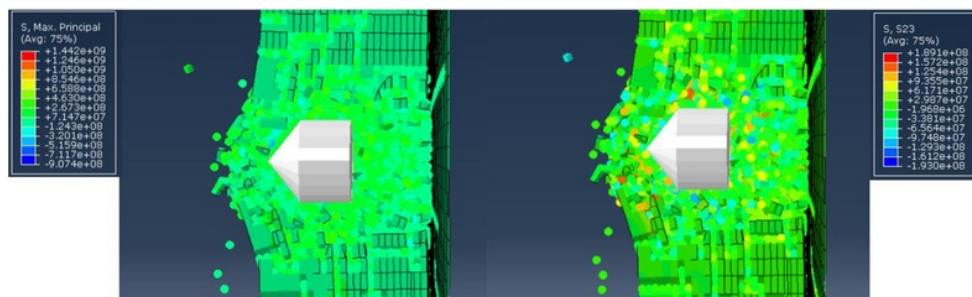


Figure 23-259.08m/s Principal and Shear Stresses Frame 20

Figure 24 plots the velocity of the projectile with respect to time.

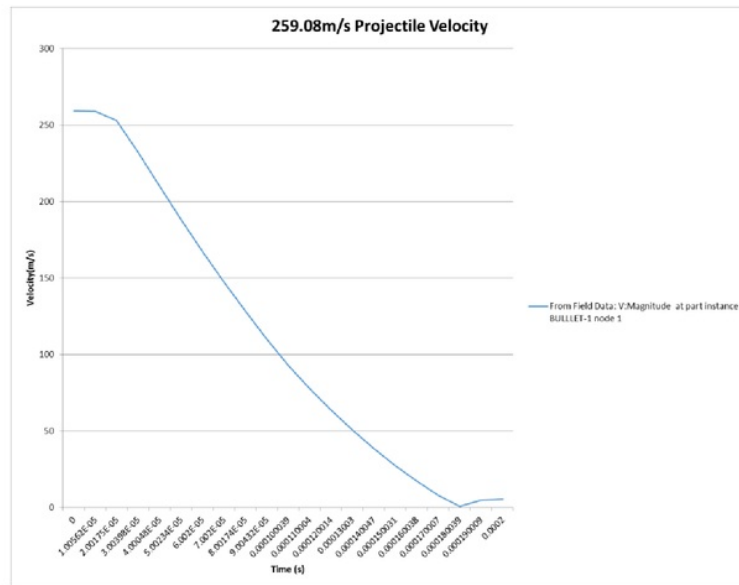


Figure 24-Velocity of 259.08m/s Projectile

Figures 25-44 show the results of the projectile fired at 365.76m/s.

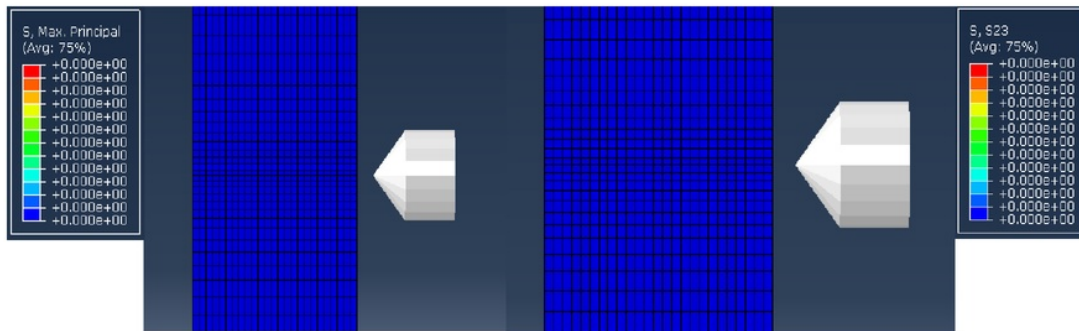


Figure 25-365.76m/s Principal and Shear Stress Frame 1

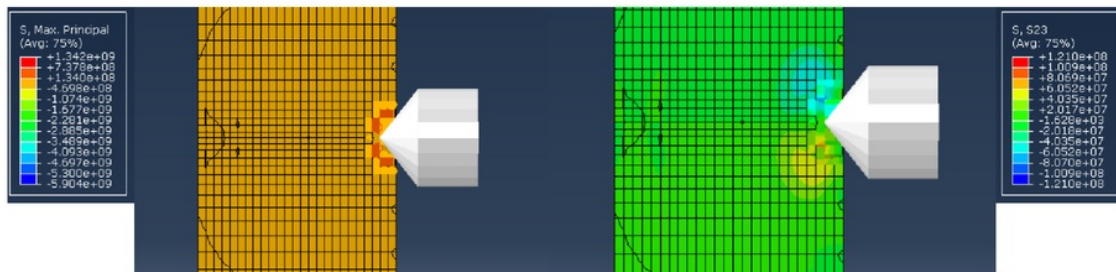


Figure 26-365.76m/s Principal and Shear Stress Frame 2

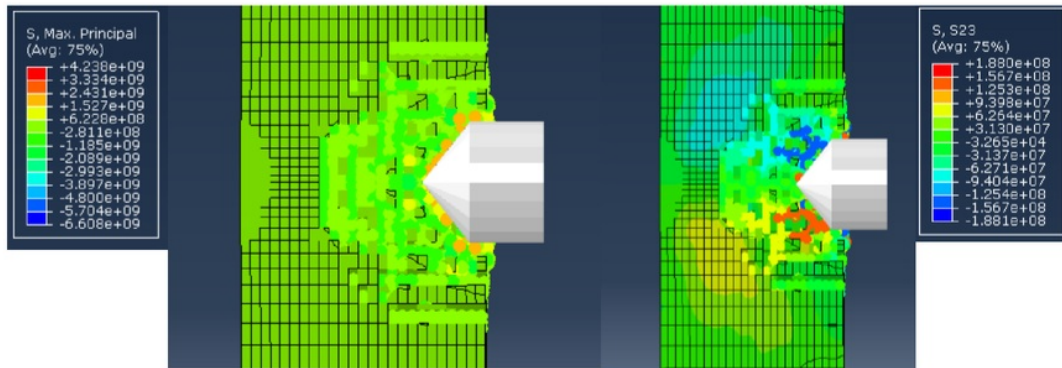


Figure 27-365.76m/s Principal and Shear Stress Frame 3

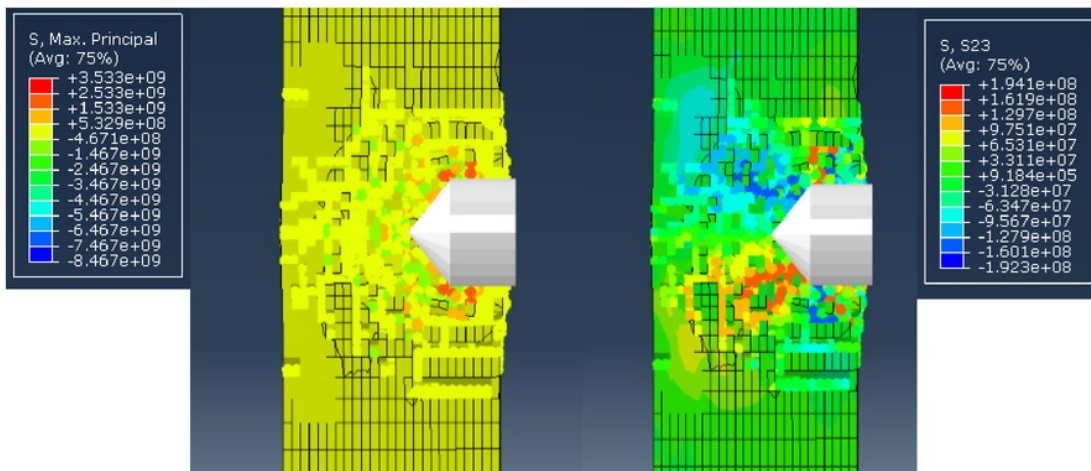


Figure 28-365.76m/s Principal and Shear Stress Frame 4

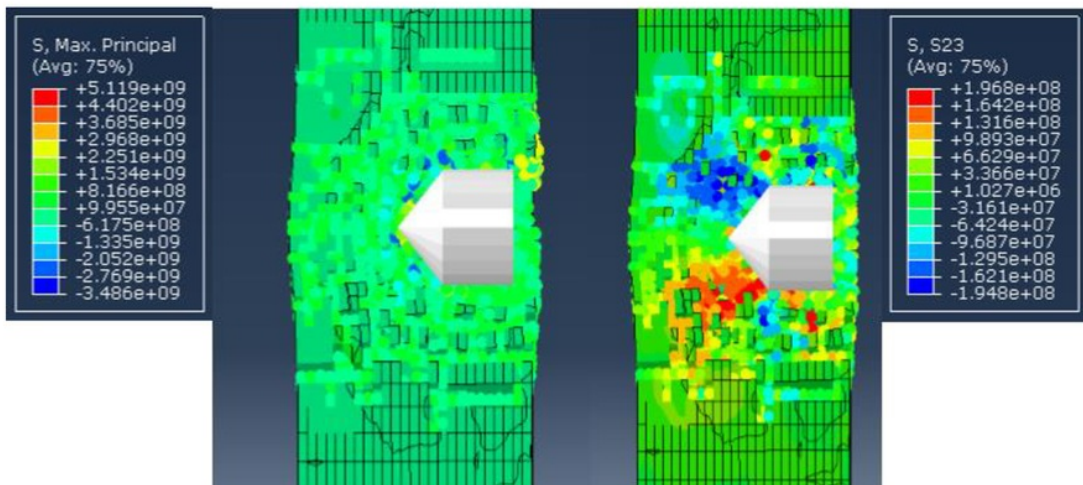


Figure 29-365.76m/s Principal and Shear Stress Frame 5

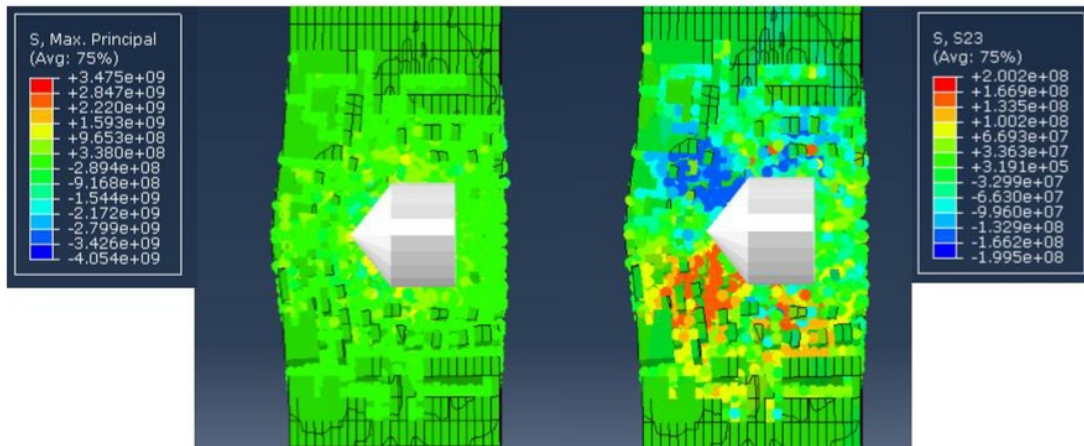


Figure 30-365.76m/s Principal and Shear Stress Frame 6

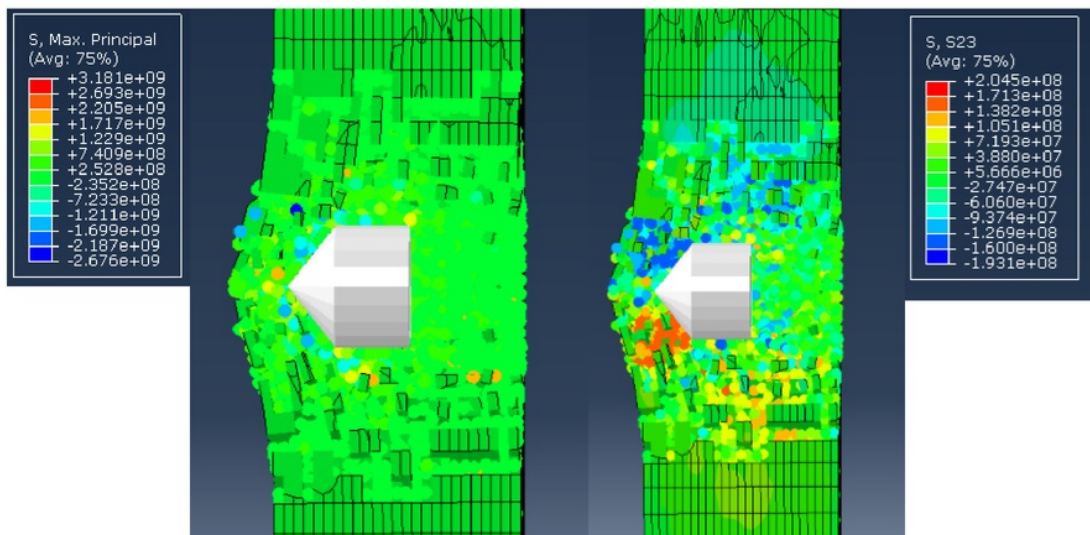


Figure 31-365.76m/s Principal and Shear Stress Frame 7

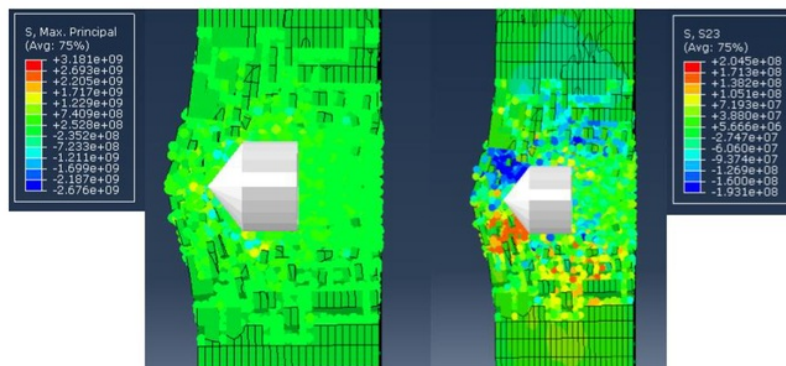


Figure 32-365.76m/s Principal and Shear Stress Frame 8

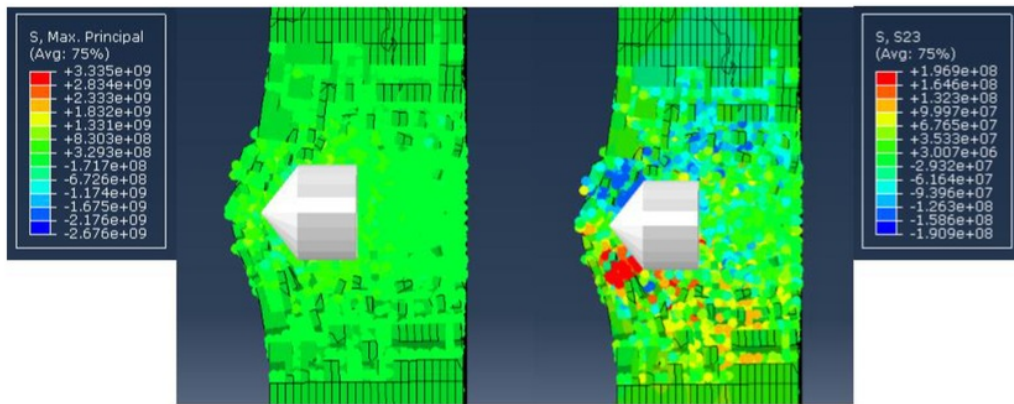


Figure 33-365.76m/s Principal and Shear Stress Frame 9

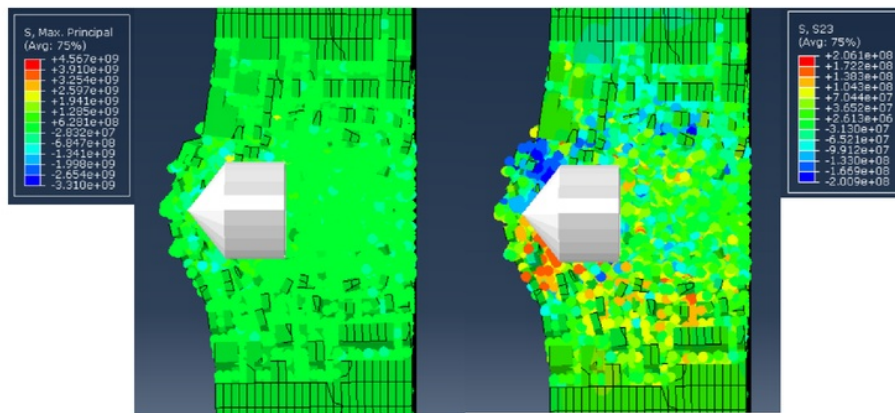


Figure 34-365.76m/s Principal and Shear Stress Frame 10

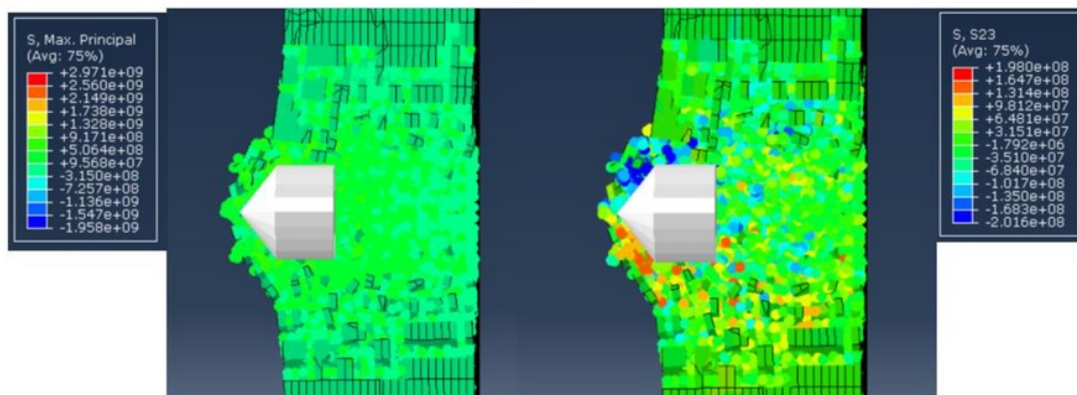


Figure 35-365.76m/s Principal and Shear Stress Frame 11

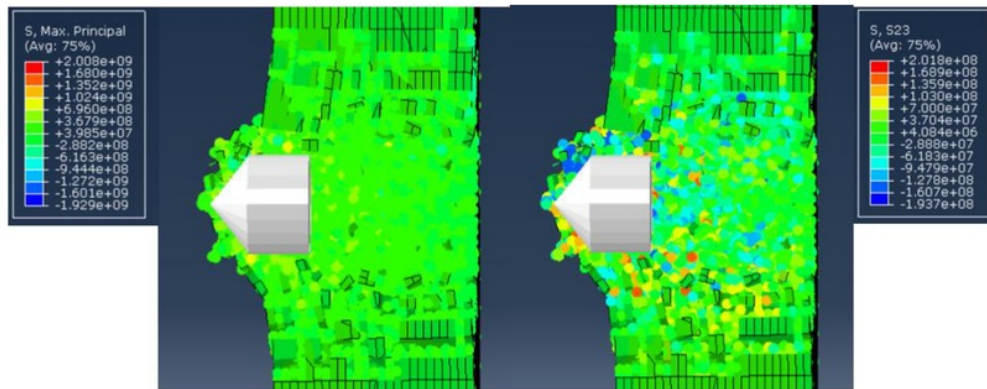


Figure 36-365.76m/s Principal and Shear Stress Frame 12

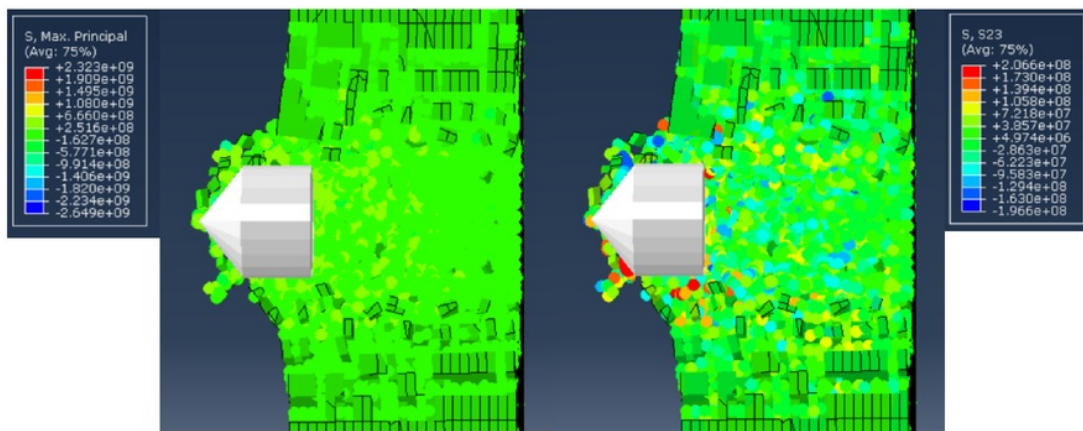


Figure 37-365.76m/s Principal and Shear Stress Frame 13

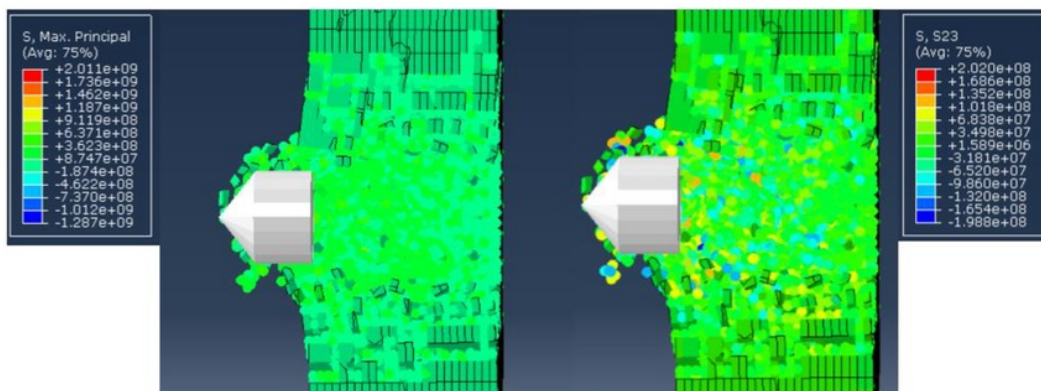


Figure 38-365.76m/s Principal and Shear Stress Frame 14

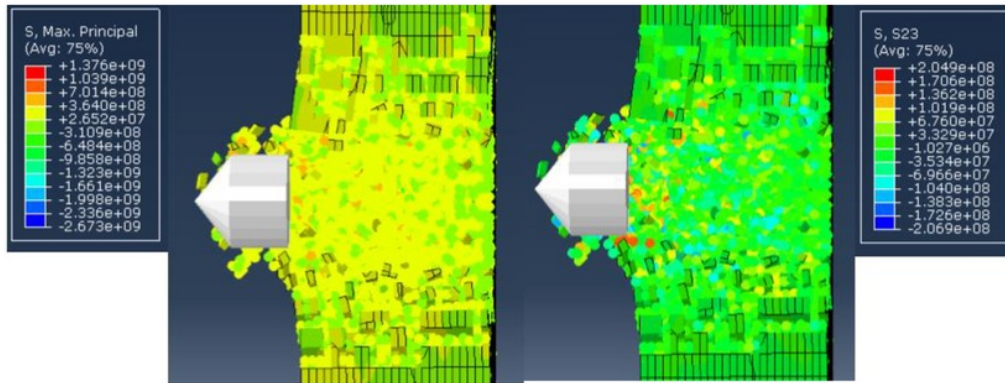


Figure 39-365.76m/s Principal and Shear Stress Frame 15

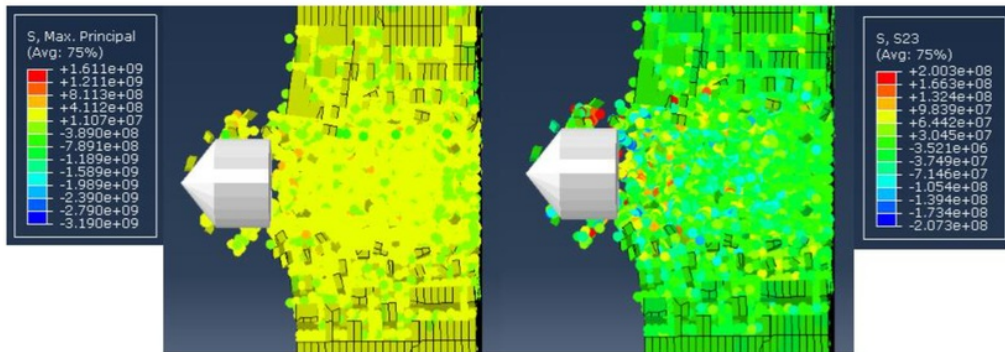


Figure 40-365.76m/s Principal and Shear Stress Frame 16

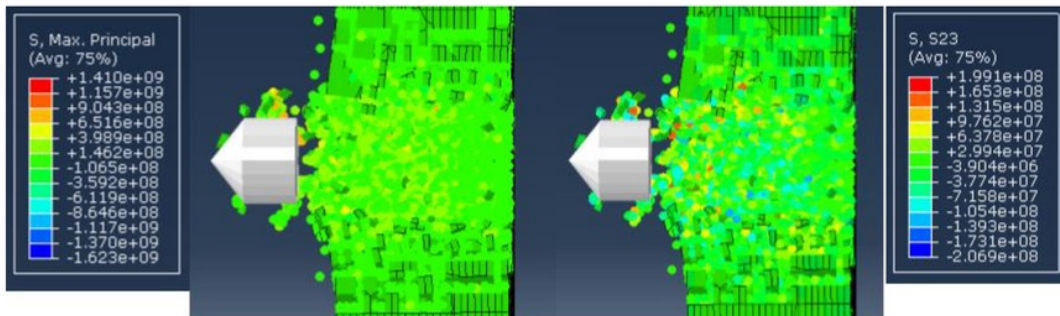


Figure 41-365.76m/s Principal and Shear Stress Frame 17

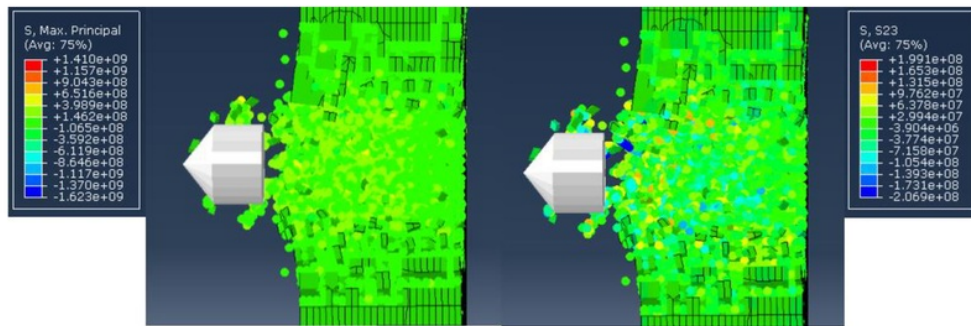


Figure 42-365.76m/s Principal and Shear Stress Frame 18

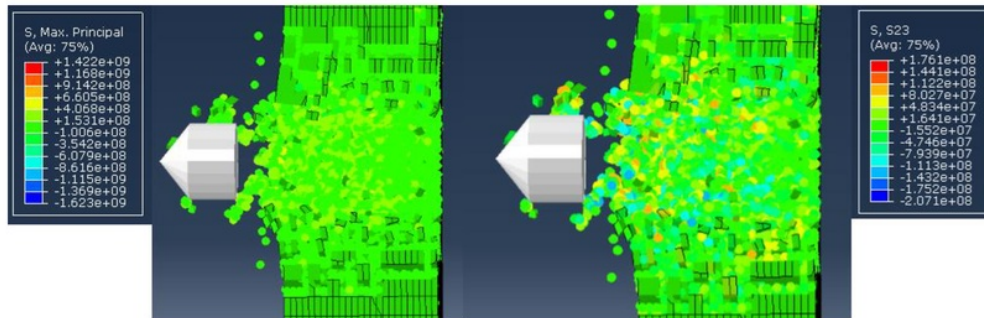


Figure 43-365.76m/s Principal and Shear Stress Frame 19

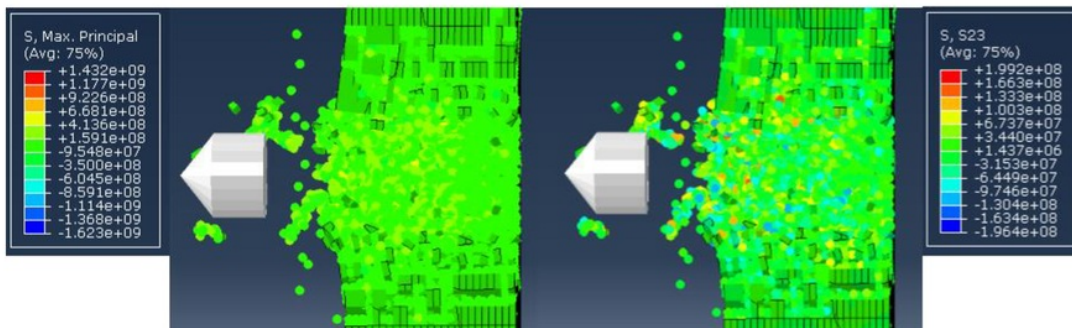


Figure 44-365.76m/s Principal and Shear Stress Frame 20

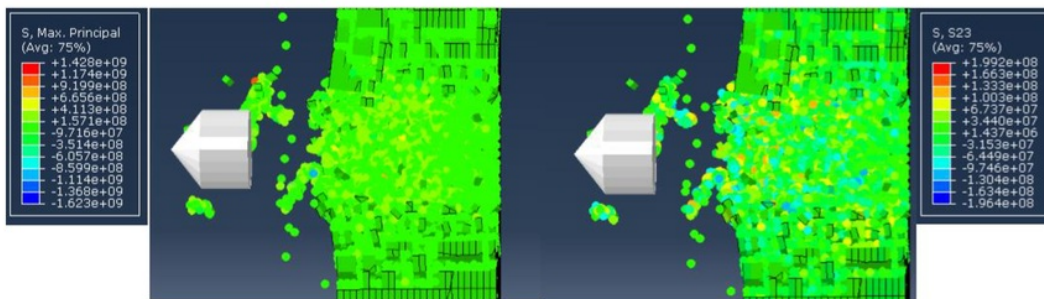


Figure 45-365.76m/s Principal and Shear Stress Frame 21

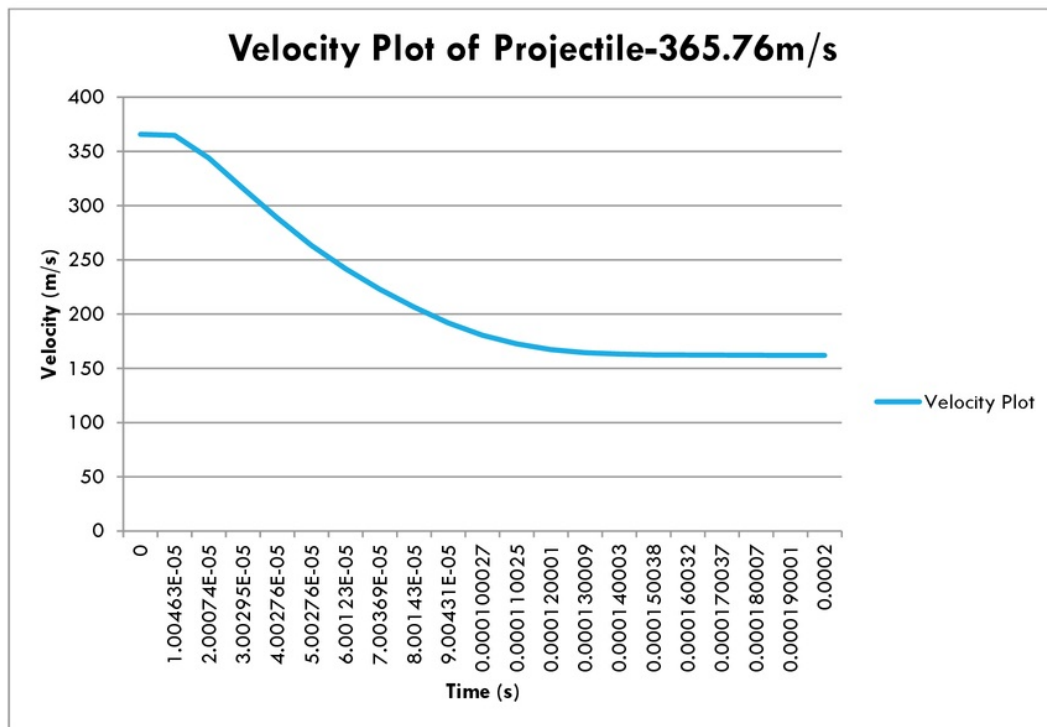


Figure 46-Velocity plot of 365.76m/s Projectile

Figures 47 to 61 show the results captured for the projectile fired at 403.86m/s

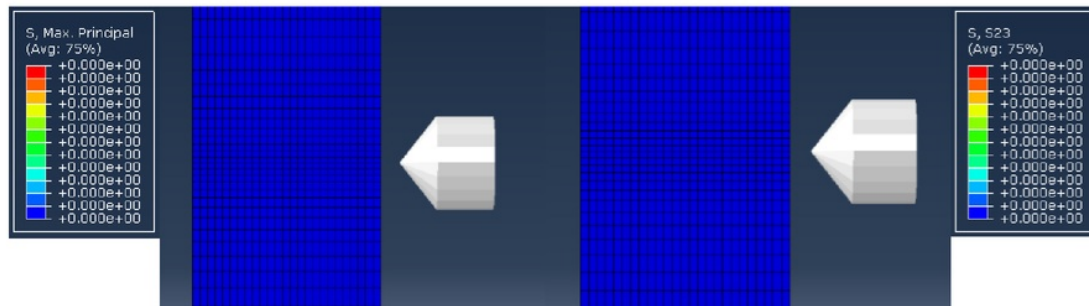


Figure 47-403.86m/s Principal and Shear Stress Frame 1

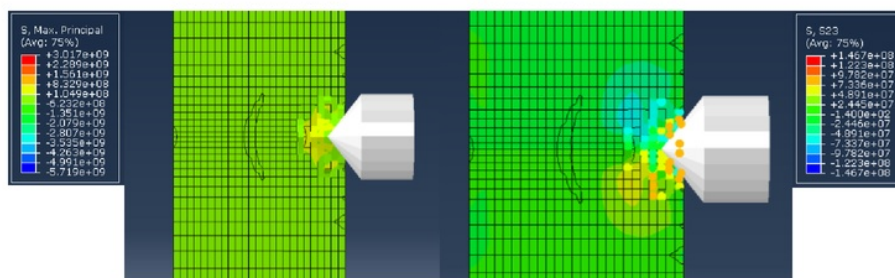


Figure 48-403.86m/s Principal and Shear Stress Frame 2

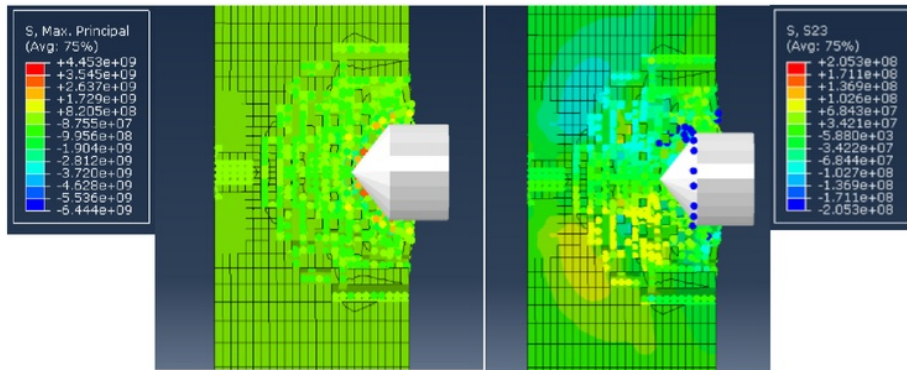


Figure 49-403.86m/s Principal and Shear Stress Frame 3

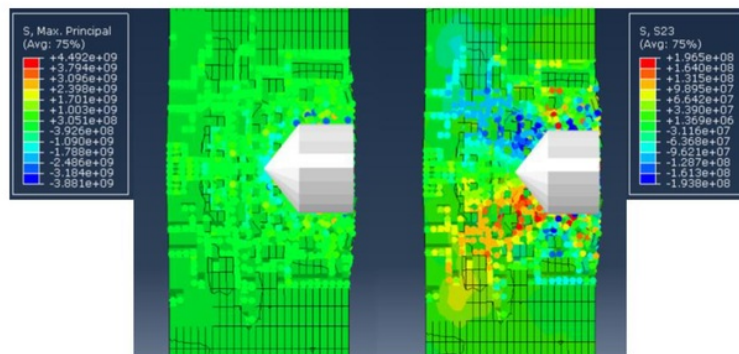


Figure 50-403.86m/s Principal and Shear Stress Frame 4

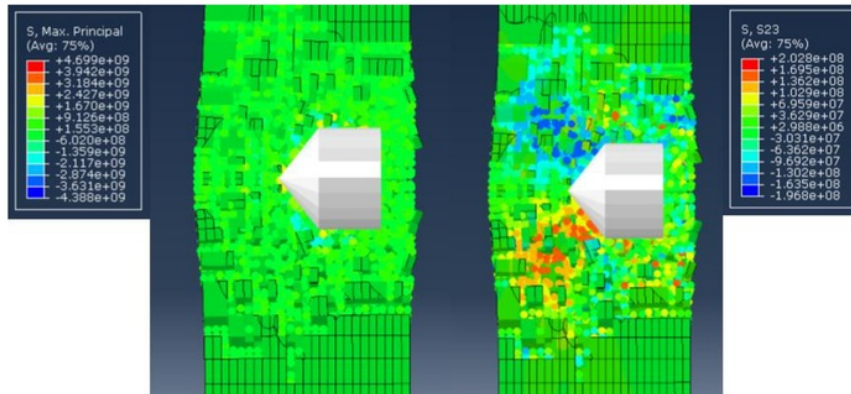


Figure 51-403.86m/s Principal and Shear Stress Frame 5

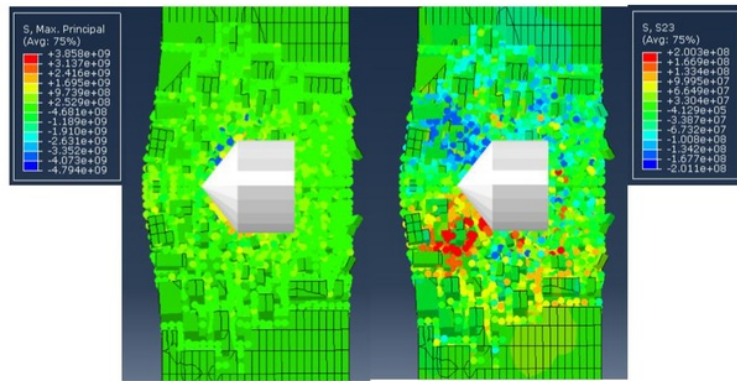


Figure 52-403.86m/s Principal and Shear Stress Frame 6

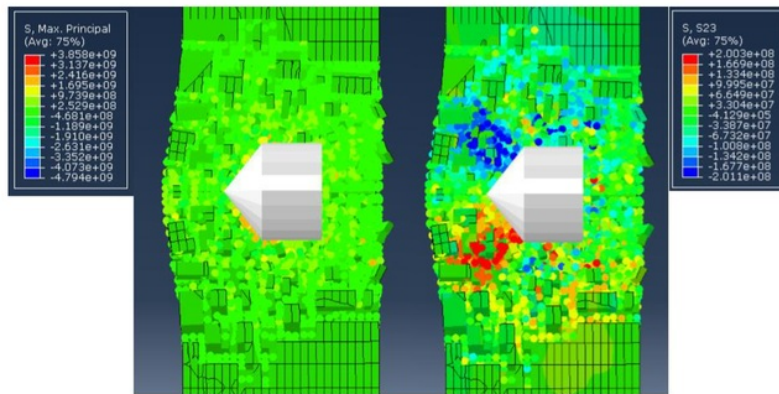


Figure 53-403.86m/s Principal and Shear Stress Frame 7

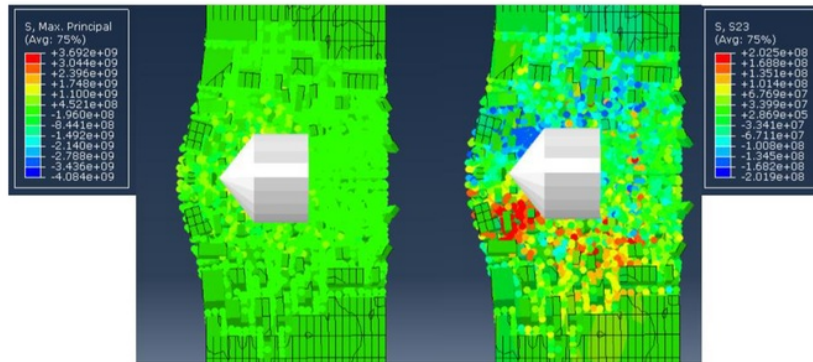


Figure 54-403.86m/s Principal and Shear Stress Frame 8

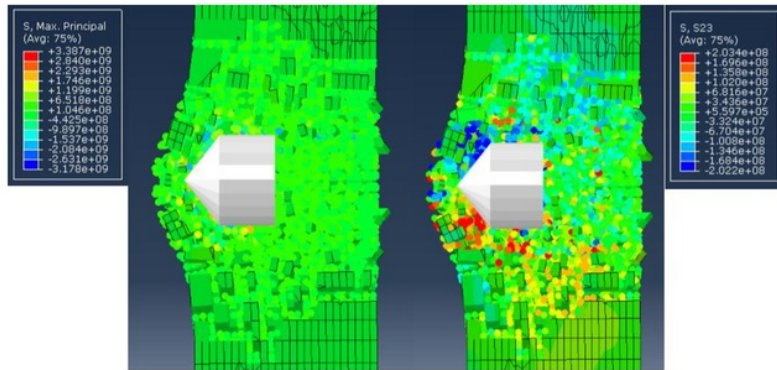


Figure 55-403.86m/s Principal and Shear Stress Frame 9

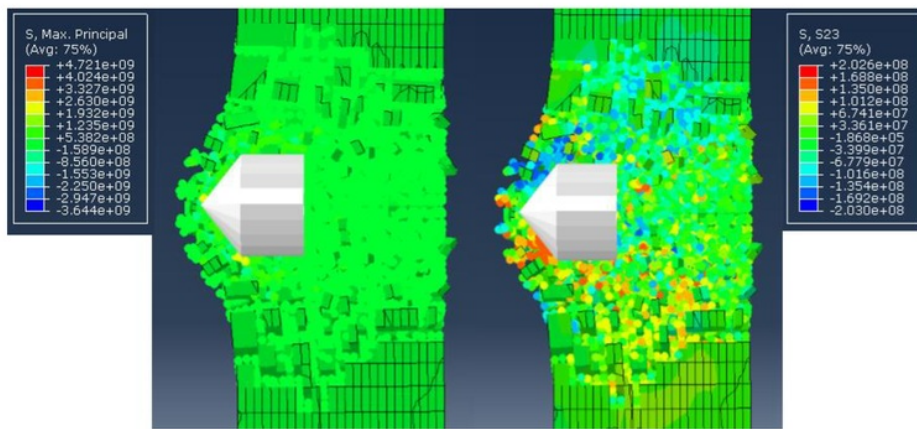


Figure 56-403.86m/s Principal and Shear Stress Frame 10

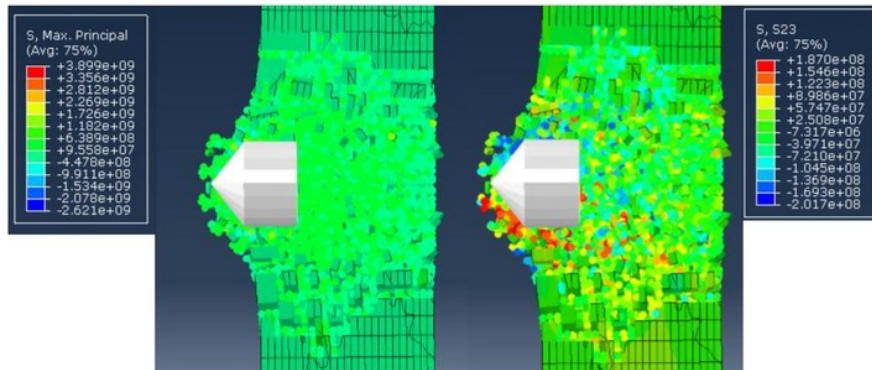


Figure 57-403.86m/s Principal and Shear Stress Frame 11

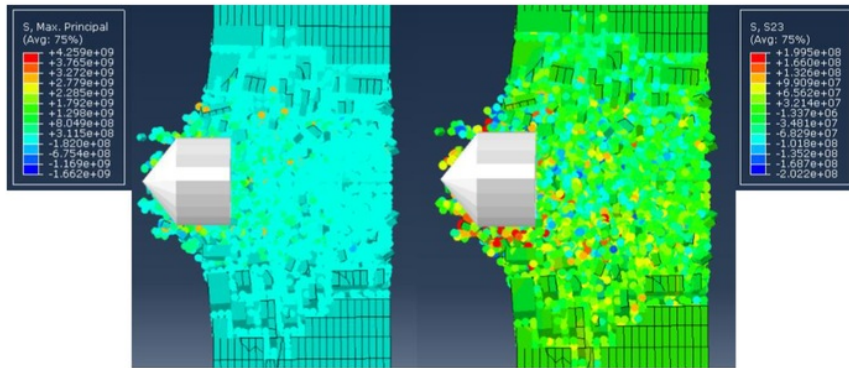


Figure 58-403.86m/s Principal and Shear Stress Frame 12

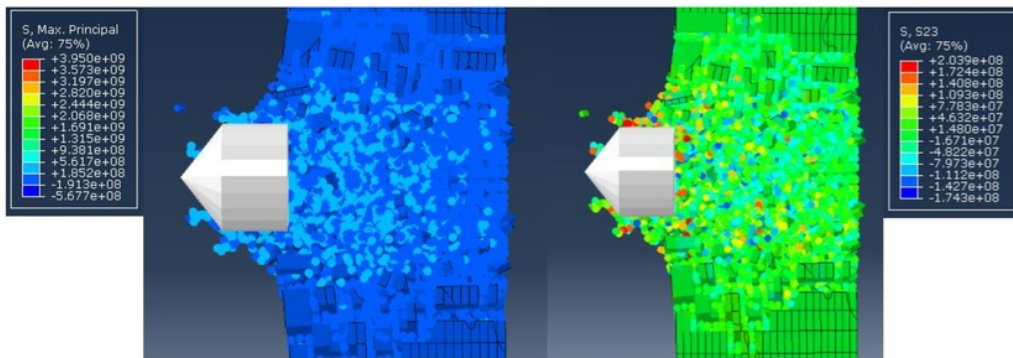


Figure 59-403.86m/s Principal and Shear Stress Frame 13

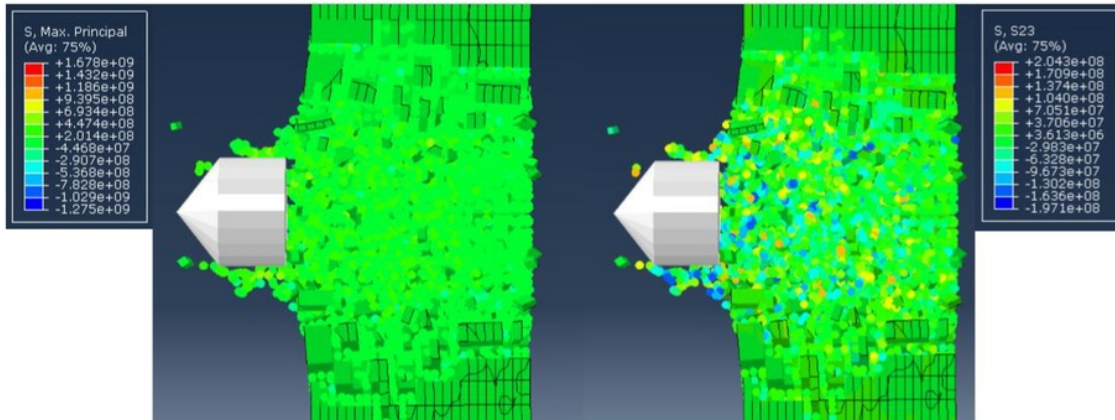


Figure 60-403.86m/s Principal and Shear Stress Frame 14

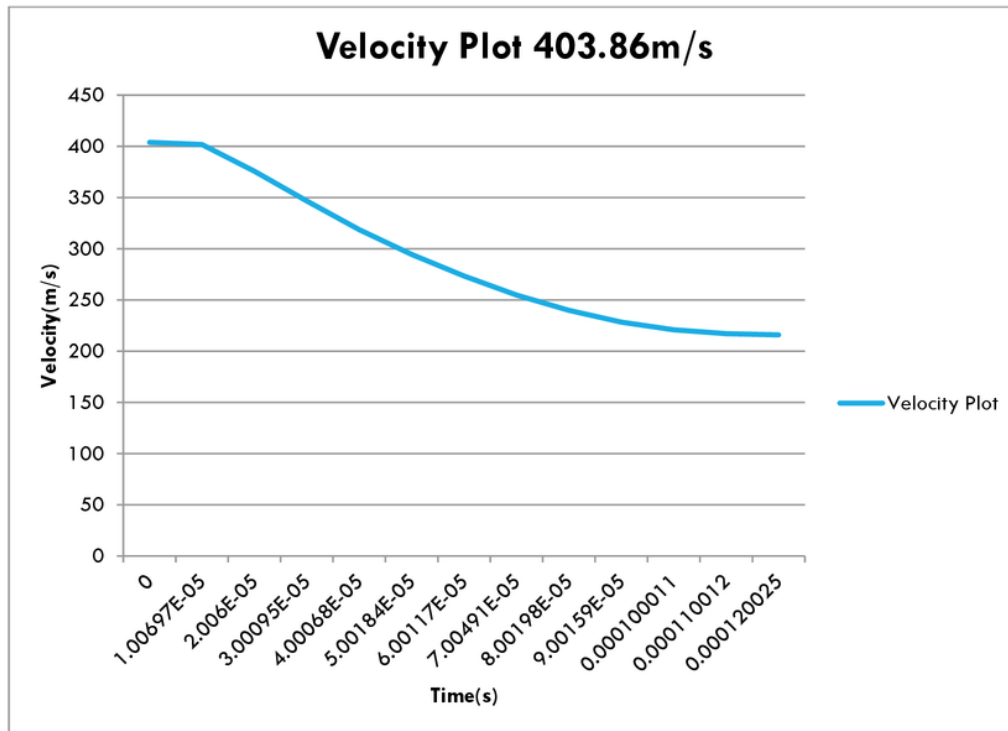


Figure 61-Velocity Plot of 403.86m/s Projectile

DISCUSSION

From the results obtained it is possible to understand the mechanics of the projectiles impact on the plate for various impact velocities. Although the plate completely stops the slowest projectile the mechanics observed for all three projectiles are the same. As the projectile impacts the plate it causes a compressive stress at the point of impact along with a shear stress in equal and opposite magnitudes away from the projectile. As the projectile penetrates further the shear stress increases in magnitude and compressive stress becomes localised under the point of the projectile and the plate becomes tensile trying to stop the projectile from penetrating further.

There are a number of points of interest that bring some points of inaccuracy to the simulation. The first point is how the projectile is modelled. In the simulations it is assumed that the projectile is completely solid and incapable of being deformed under impact, in real life the projectile would deform under impact and under deformation would absorb some of the impact energy, this would have a direct effect on the level of deformation in the aluminium plate and the amount of residual velocity left in the projectile as it passes through the plate. There is another property of the projectile that would have an effect on the deformation of the plate, the deformation of the projectile and the velocity of the projectile. As the projectile is a model of a rifled projectile then there would also be a spin component to be imparted on the projectile. To simplify the modelling process this spin wasn't modelled and as such it is not completely accurate. Modelling of the spin would impart torsional stresses on the projectile and the plate and would have a potentially beneficial effect on the stopping power of the aluminium plate against higher velocity rounds as they penetrate and deform. Geometry of the projectile is another point that would have an effect on plate penetration. The rounds in question have an ogive profile or a hollow point profile, both profiles are significantly different from the conical projectile that was modelled in the simulation and would have an effect on the penetration of the projectile on the plate.

CONCLUSION

The report has outlined a series of simulations carried out on a material with defined properties. The simulations have proven that the simulation set up in ABAQUS is valid for obtaining results of principal and shear stresses and that the aluminium plate would be suitable for stopping sub sonic projectiles. The simulation modelling however is simple and only reflects certain aspects of what would occur in real life. To improve the simulation a series of recommendations to improve the simulations have been made. These are to better model the projectile material and geometry and to better model the projectile spin rate. These improvements would better improve the simulation and produce more accurate results more reflective of real life projectile testing.

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