

Physics Assignment Max Smith

by Max Smith

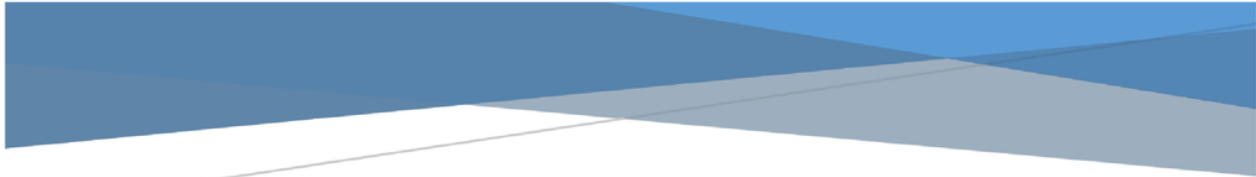
Submission date: 07-Mar-2019 02:52PM (UTC+0000)

Submission ID: 101856699

File name: 11931_Max_Smith_Physics_Assignment_Max_Smith_170540_1710896625.docx

Word count: 3004

Character count: 27196



PHYSICS ASSIGNMENT

Dynamic Stress-Strain Investigation

Abstract

Analysis of a non-deformable projectile impacting an aluminium plate at varying velocities. This assignment will be looking at the varying stresses and strains that affect an aluminium plate when struck by a non-deformable projectile at varying velocities, in relation to stress strain theorem and ballistic impact theorem.

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2 Abstract

Analysis of a non-deformable projectile impacting an aluminium plate at varying velocities. This assignment will be looking at the varying stresses and strains that affect an aluminium plate when struck by a non-deformable projectile at varying velocities, in relation to stress strain theorem and ballistic impact theorem.

3 Introduction

The context was the high speed ballistic impact of a bullet onto an aluminum plate. Through the use of a predefined Abaqus model 'ballistic.cae', which was provided with a full geometrical definition of the problem. To submit suitable material properties for the aluminum plate and investigate the performance of the plate when struck at varying speeds by the bullet. The investigation of direct and shear stresses in the plate and to demonstrate an understanding of the residual post impact velocity of the bullet.

4 Main Body

4.1 Material

There are many varieties of aluminium that could have been used for this experiment. The type chosen for the experiment was aluminium 5052. Aluminium 5052 is one of the highest strength alloys, with its fatigue strength being higher than most other alloys. This material has good resistivity to marine atmosphere and has high resistance to salt water corrosion. It has great workability and is able to be made into a vast amount of shapes. This material is used across many industries such as aerospace, marine, transportation and home ware. The material properties of the aluminium plate on the simulation was changed to match those of aluminium 5052. See below. [1] [2]

Density 2.68 kg/m^3

Young's Modulus 70.3 GPa

Poissons Ratio 0.33

Tensile Yield Strength 193 MPa

Ultimate Tensile Strength 228 MPa

Plastic Strain 18% [3]

4.2 Stress/Strain Theory [4]

One of the basic principles of stress strain is Hooke's Law. Hooke's Law states that stress is proportional to strain, this is demonstrated in the stress strain curve below. The stress strain curve below is indicative of steel.

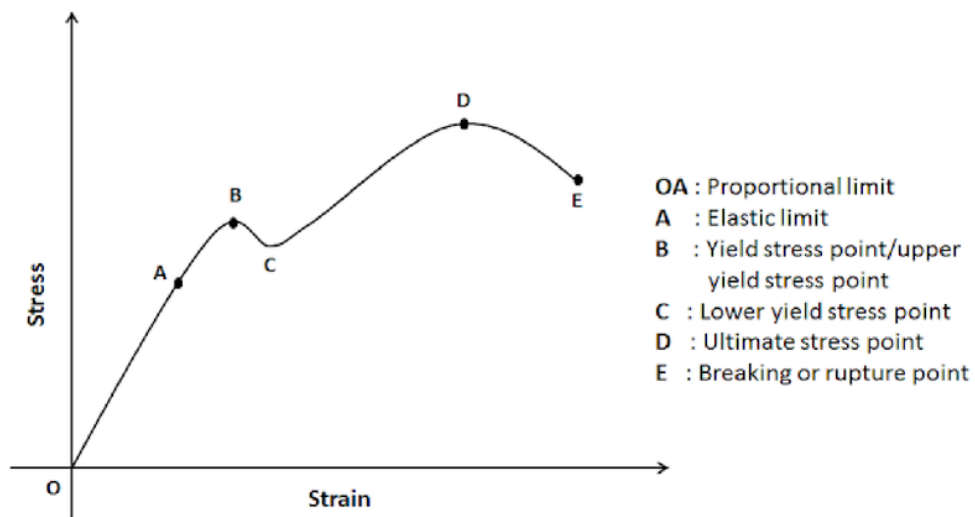


Figure 1 – Stress/Strain Curve Example

[5]. The proportional limit is the ratio of stress strain known as Young's Modulus. Young's Modulus is the ability for a material to withstand changes in length when under tension or compression stresses, this is also known as Modulus of Elasticity. [6]

Whilst a material is within the elastic limit it can return to its original state. When a material reaches yield point it starts to deform and enters the plastic region. The ultimate stress point is the maximum stress a material can handle before it starts to fail. Where the curve stops is where the material reaches critical failure and stops to be effective.

Shear Modulus, the numerical constant that describes elastic properties of a material under transverse forces. The Shear Modulus is $\frac{\text{Shear Stress}}{\text{Shear Strain}}$, where shear stress is the shearing force divided by the area parallel, and the shear strain is a measure in the change of geometry. [7].

Poissons ratio is the inverse of the ratio of lateral strain to the axial strain for a uniaxial stress state, Poissons ratio like strain is unitless [8]. *"Tensile deformation is considered positive and compressive deformation is considered negative."* [9]

The von Mises yield criterion suggests that the yielding of materials begins when the second deviatoric stress invariant reaches a critical value. This is part of the plasticity theorem which is best related to ductile materials such as metals. [10]

4.3 Ballistic Impact Theory

At low impact velocities the penetrative resistance of a material is governed by the deformation properties of the projectile and the target. At higher impact velocities, hydrodynamic effects dominate, meaning that the penetration is controlled by the density of the material and the projectile. For thin targets such as a plate, when struck with a projectile it bends creating tensile hoop stress in the plate. This leads to failure and is shown through the growth of radial cracks, which is a pedalling mode of failure. In some instances a 'plug' will be pushed out of the material as a result of impact. The plug is a result of high shear stresses. The best way to resist a projectile is by using a material that is harder than the projectile itself. In certain materials, upon impact from a projectile it can result in a Hertzian cone effect, however this occurs only under large tensile stress of a spherical indenter. [11] [12].

Homogeneous materials when impacted at a high enough velocity can result in planar shockwaves, where the stresses/strains upon impact ripple out across the material. Some FEA software can demonstrate this through colour coding of simulated impact results, such as Abaqus. [13] [14]. Bullets can react in a variety of ways upon firing, and no two bullets fire exactly the same. There will be different variants of drag, wind resistance, possible yaw, precession and nutation. Most bullets are made of lead and covered with a copper jacket to increase efficiency of the projectile. [15]. Projectiles can act in different ways upon impact, they can ricochet (rebounds off a surface), perforate (goes all the way through), embed (enters the surface but gets stuck) and penetration (enters the surface).

5 Method

5.1 ABAQUS

Abaqus is a simulation software widely used across a multitude of industries. It is a finite element analysis and computer aided engineering software which enables detailed analysis of routine and sophisticated engineering problems. [16]

5.2 Original

The experiment was carried out using a pre-existing Abaqus model 'Ballistics.cae' created by Kelvin Donne. The parts consisted of a projectile, represented by an analytical surface which did not require meshing due to it being non deformable and a rectangular plate which was appropriately meshed with hexahedral elements. The values for the plate were changed to matched to the chosen material as specified in 3.1. The assembly was already assigned an instance per part and an explicit dynamics solver step created in the step module. The edges of the plate were fixed in the load module. A variation of velocities were trialled to determine the results of the projectile impacting the target. The time period for which each simulation was recorded was 0.4 milliseconds. The recorded velocities were as follows:

100mps

200mps

300mps

400mps

500mps

1000mps

These were individually created as jobs and submitted for execution, the results then viewed in the visualizer module and the various direct and shear stresses inspected. The velocity of the bullet before impact and the post impact velocity were recorded.

5.3 Additional

The pre-existing explicit dynamics were edited to include extra real world effects. In addition to the elements already being recording, the following was added:

Stresses – stress in the elastic viscous network, stress in the elastic-plastic network

Strains – Viscous strain in the elastic-viscous network, plastic strain magnitude

Forces/Reactions – uniformly distributed gravity loads

Failure/Fracture – Tensile damage, compressive damage, shear damage [17]

These were added to incorporate more realistic scenarios into the mix. The extra applications to the stress/strain areas refer to Creep Law. Creep is not an intrinsic material response because it is performance based, creep comes about over time and is related to the temperature of the material. The application of this experiment is to determine whether the chosen material would be acceptable under

ballistic impact [18]. Gravity is a constant which affects everything so it was deemed necessary to include as a factor. The failure/fracture factors were included to better determine the stresses and strains as a result of impact.

6 Results

6.1 Stress Analysis

A multitude of snapshots were taken across all the simulations.

6.1.1 Velocity at 100mps

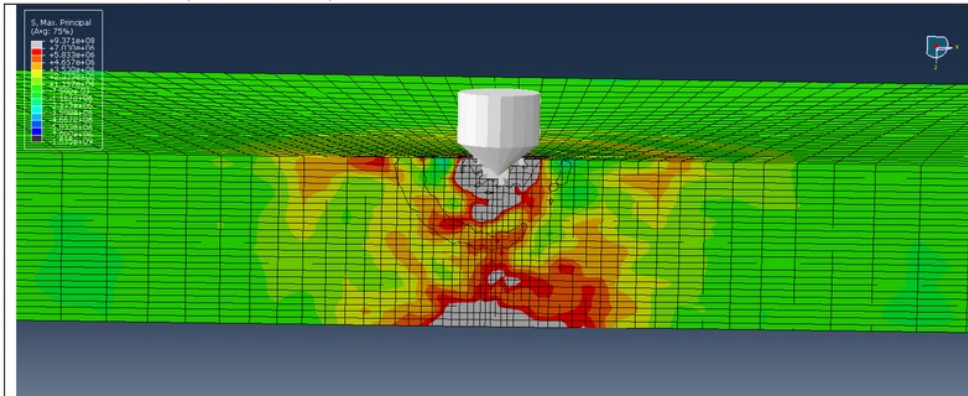


Figure 2 - Tensile stress at point of impact at 100mps

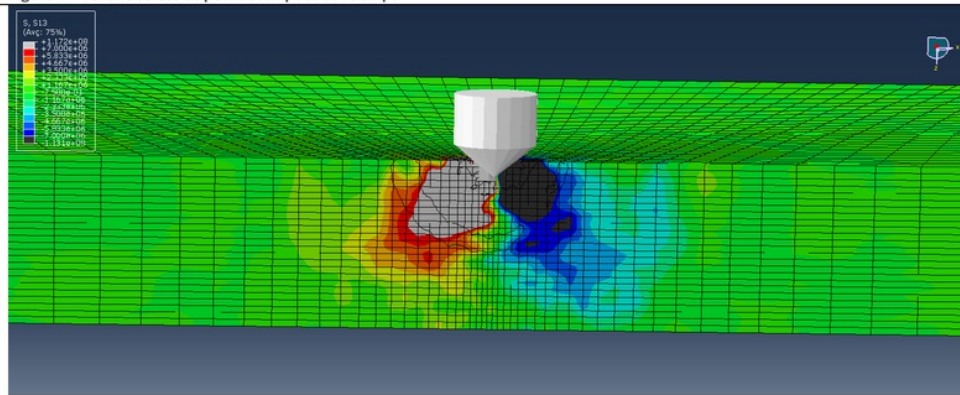


Figure 3 - Shear stress at point of impact at 100mps

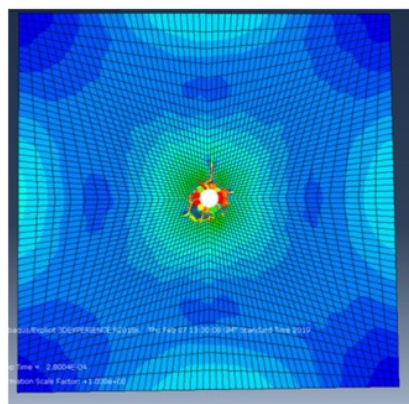


Figure 4 - Von Mises stress at 0.28ms at 100mps

Figure 2 shows the tensile stress upon initial impact, it can be seen that the peak of tension is directly at point of contact with the projectile and on the open face of the plate. The grey region directly underneath the projectile and at the bottom indicates where the maximum tensile stress is. Figure 3 shows the shear stresses leading in front of the projectile at approximately 45°, at the centre of impact it can be seen there is no or little shear stress affecting the plate. The grey and black regions show where the maximum shear stress at point of impact. Figure 4 shows Von Mises stress across the whole plate. The projectile at this speed penetrates the plate. The main stress affecting the plate is tensile stress as opposed to shear or compressive.

6.1.2 Velocity at 200mps

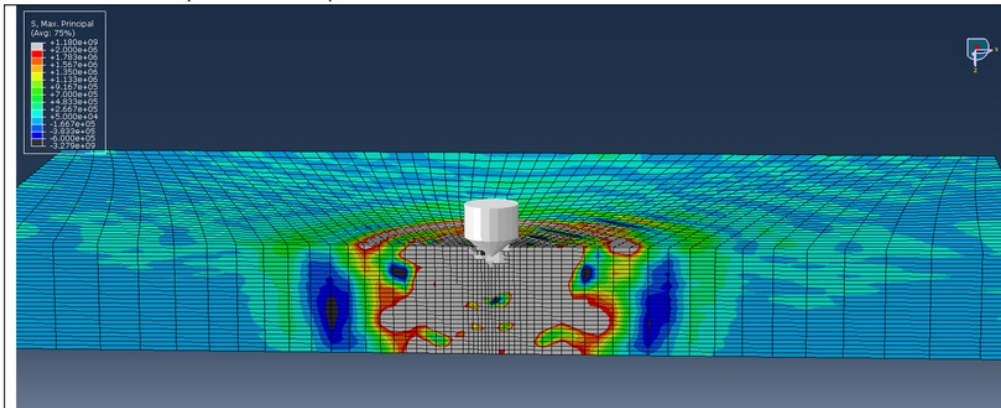


Figure 5 – Tensile stress at point of impact at 200mps

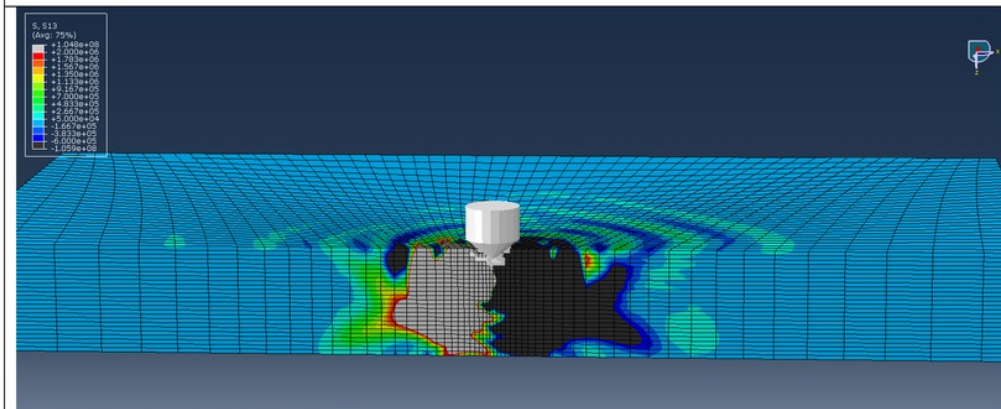


Figure 6 – Shear stress at point of impact at 200mps

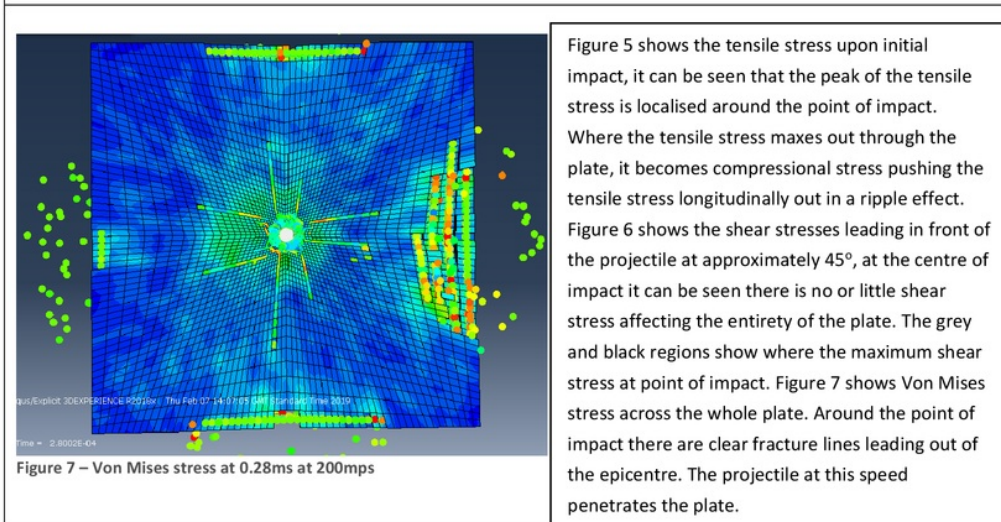


Figure 7 – Von Mises stress at 0.28ms at 200mps

Figure 5 shows the tensile stress upon initial impact, it can be seen that the peak of the tensile stress is localised around the point of impact. Where the tensile stress maxes out through the plate, it becomes compressional stress pushing the tensile stress longitudinally out in a ripple effect. Figure 6 shows the shear stresses leading in front of the projectile at approximately 45°, at the centre of impact it can be seen there is no or little shear stress affecting the entirety of the plate. The grey and black regions show where the maximum shear stress at point of impact. Figure 7 shows Von Mises stress across the whole plate. Around the point of impact there are clear fracture lines leading out of the epicentre. The projectile at this speed penetrates the plate.

6.1.3 Velocity at 300mps

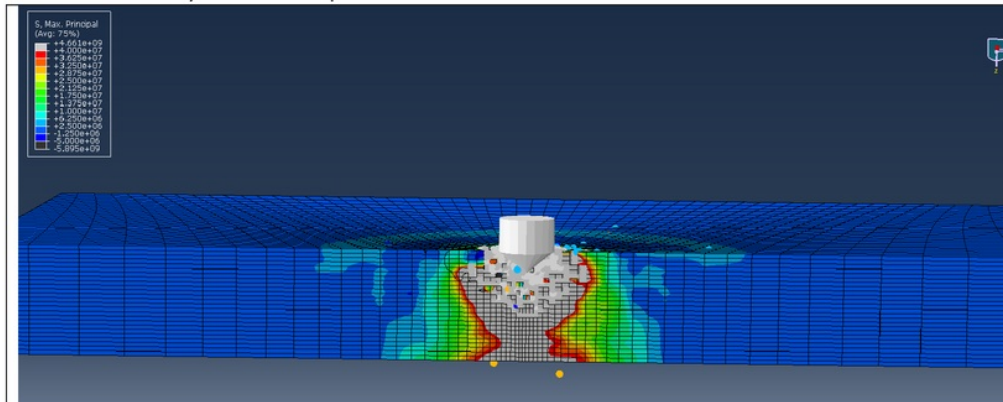


Figure 8 – Tensile stress at point of impact at 300mps

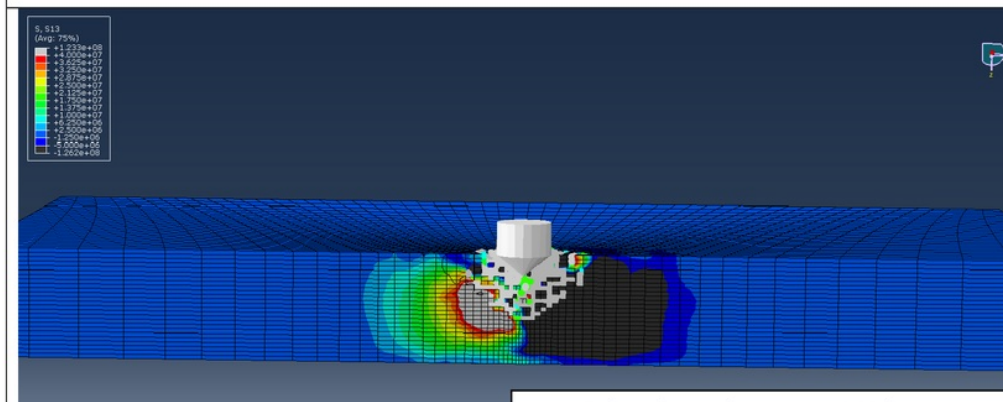


Figure 9 – Shear stress at point of impact at 300mps

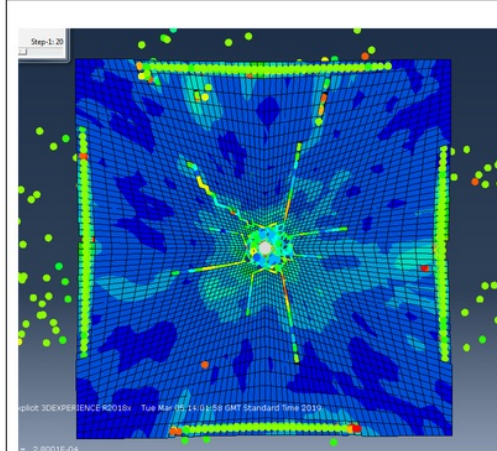


Figure 10 – Von Mises stress at 0.28ms at 300mps

Figure 8 shows the tensile stress upon initial impact, it can be seen that the peak of the tensile stress is localised around the point of impact. At the bottom of the plate it spalling can be seen by the loss of material. Figure 9 shows the shear stresses leading in front of the projectile at approximately 45°, at the centre of impact it can be seen there is no or little shear stress affecting the plate. The grey and black regions show where the maximum shear stress at point of impact. Figure 10 shows Von Mises stress across the whole plate. Around the point of impact there are clear fracture lines leading out of the epicentre. As the velocity has been increased the fracturing and damage to the fixed edges increased. It is to be noted at this speed the projectile perforates the plate. The impact velocity and the rebounding velocity both act on the plate resulting in tensile stress waves. [21]

6.1.4 Velocity at 400mps

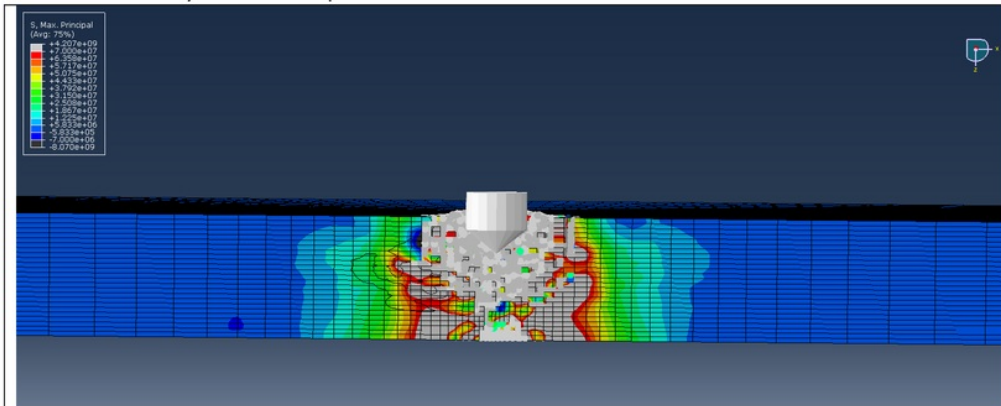


Figure 11 – Tensile stress at point of impact at 400mps

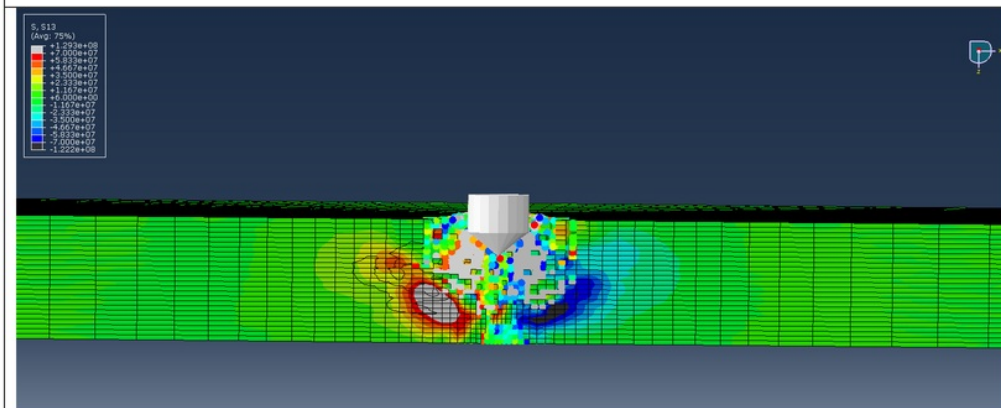


Figure 12 – Shear stress at point of impact at 400mps

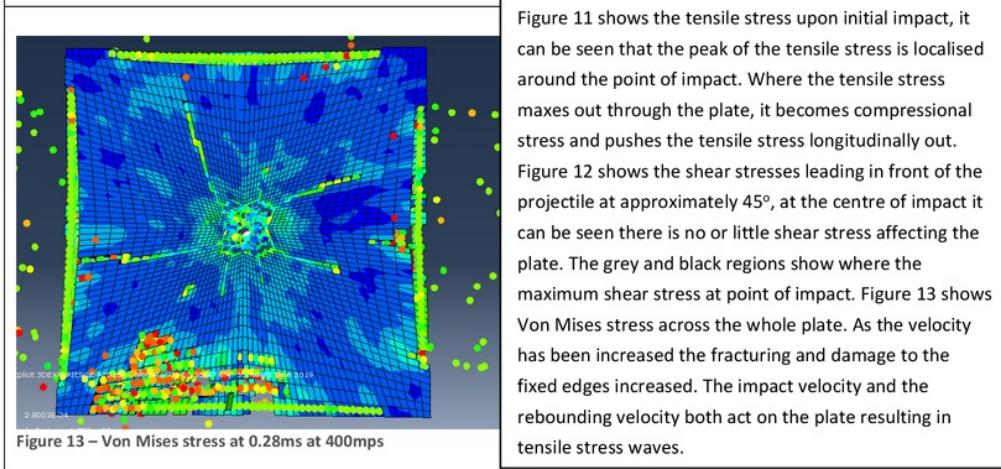


Figure 13 – Von Mises stress at 0.28ms at 400mps

Figure 11 shows the tensile stress upon initial impact, it can be seen that the peak of the tensile stress is localised around the point of impact. Where the tensile stress maxes out through the plate, it becomes compressional stress and pushes the tensile stress longitudinally out. Figure 12 shows the shear stresses leading in front of the projectile at approximately 45°, at the centre of impact it can be seen there is no or little shear stress affecting the plate. The grey and black regions show where the maximum shear stress at point of impact. Figure 13 shows Von Mises stress across the whole plate. As the velocity has been increased the fracturing and damage to the fixed edges increased. The impact velocity and the rebounding velocity both act on the plate resulting in tensile stress waves.

6.1.5 Velocity at 500mps

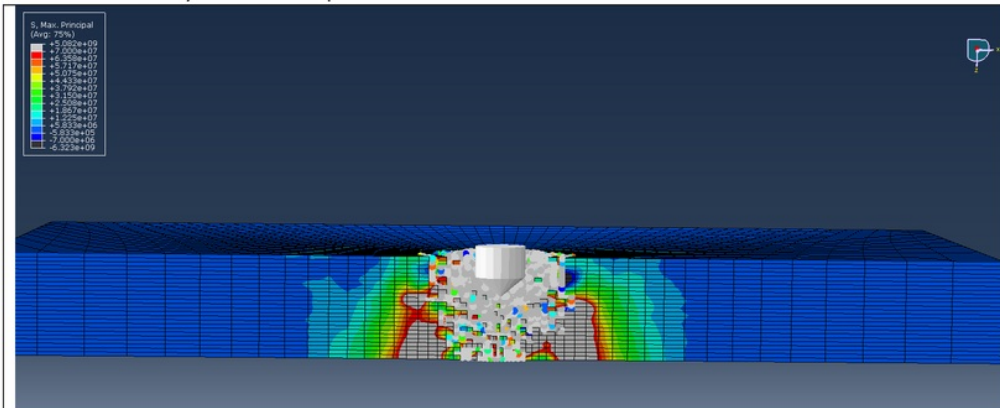


Figure 14 – Tensile stress at point of impact at 500mps

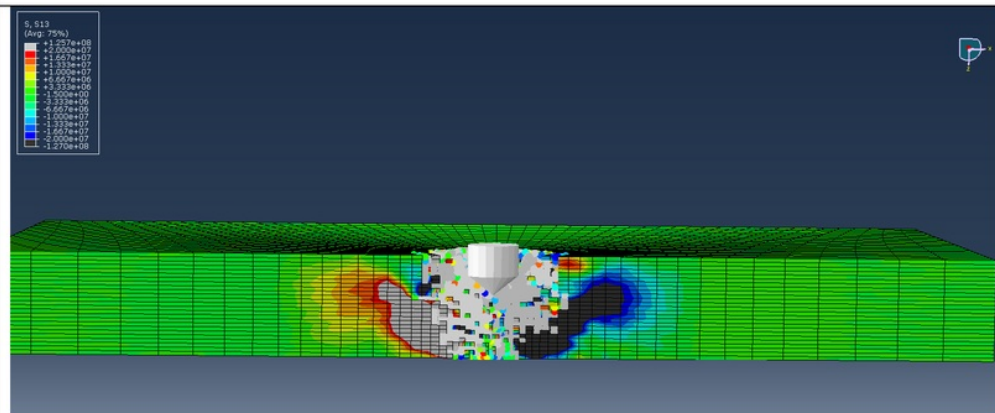


Figure 15 – Shear stress at point of impact at 500mps

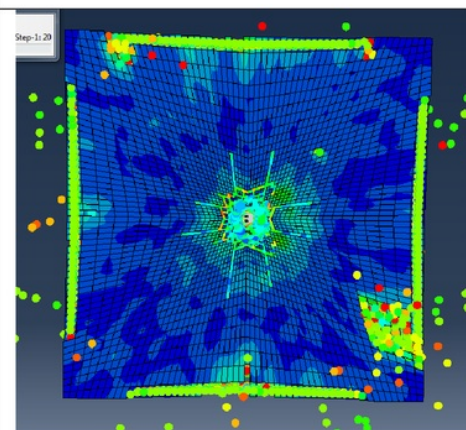


Figure 16 – Von Mises stress at 0.28ms at 500mps

Figure 14 shows the tensile stress upon initial impact, it can be seen that the peak of the tensile stress is localised around the point of impact. Where the tensile stress maxes out through the plate, it becomes compressional stress and pushes the tensile stress longitudinally out. Figure 15 shows the shear stresses leading in front of the projectile but spreads further longitudinally than previously. The grey and black regions show where the maximum shear stress at point of impact. Figure 16 shows Von Mises stress across the whole plate. As the velocity has been increased the fracturing and damage to the fixed edges increased. The impact velocity and the rebounding velocity both act on the plate resulting in tensile stress waves.

6.1.6 Velocity at 1000mps

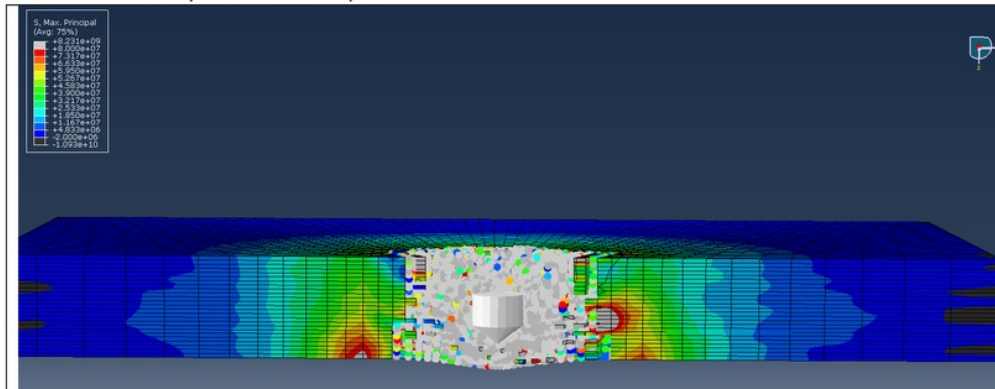


Figure 17 – Tensile stress at point of impact at 1000mps

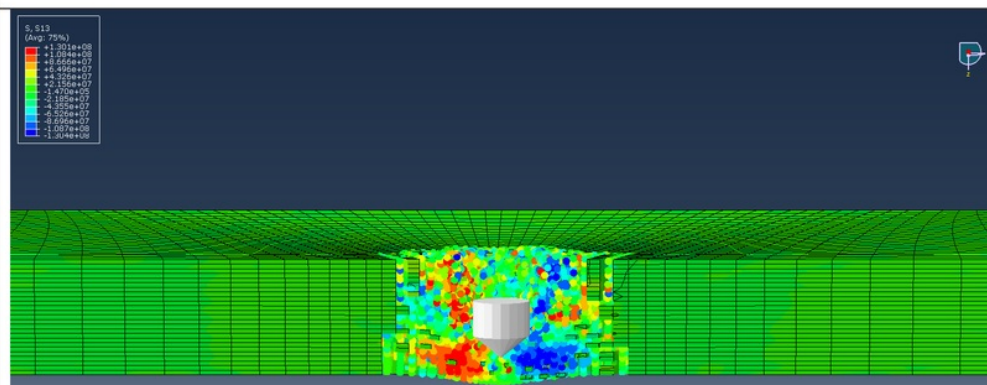


Figure 18 – Shear stress at point of impact at 1000mps

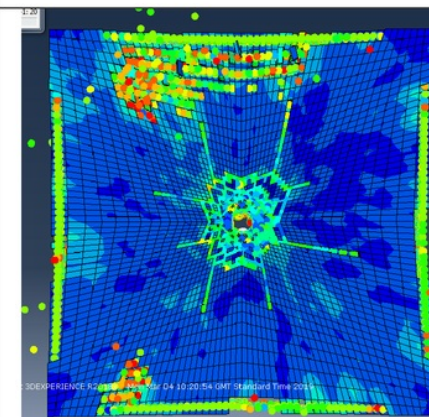


Figure 19 – Von Mises stress at 0.28ms at 1000mps

Figure 17 shows the tensile stress upon initial impact, it can be seen that the peak of the tensile stress is localised around the point of impact. When a projectile reaches approximately 1000mps, it becomes hydrodynamic, where the projectile is treated like a fluid. It is clear that the tensile stresses reverberate across the plate, this could be interpreted as dynamic rupturing [22]. The base of the plate upon impact shows bulging which demonstrates the compressive force ahead of the projectile. The limits in Figure 18 were not edited to better emphasise the areas of the plate affect by shear stress. Shear stresses are seen approximately 45° above and below the centre of the projectile. Figure 19 shows Von Mises stress across the whole plate. As the velocity has been increased the fracturing and damage to the fixed edges increased. Because hydrodynamics takes over, the projectile emits a shockwave in front and behind the projectile. The plate is no longer submitted to the impact of the projectile but that of the shockwaves as well, resulting in the impact hole being larger than the size of the projectile. The impact velocity and the rebounding velocity both act on the plate resulting in tensile stress waves.

6.2 Post Impact Velocity

6.2.1 Projectile 100mps

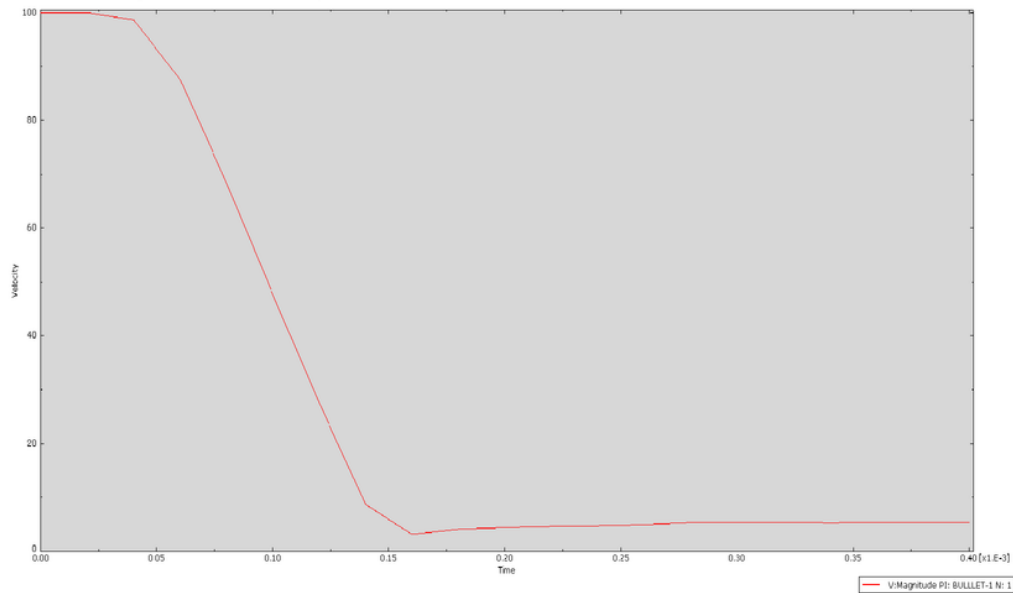


Figure 20 – Velocity Graph at 100mps

The above figure shows the velocity of the projectile before impact and post impact. The slight dip in the base of the curve is where the projectile penetrated the plate, the residual energy of the projectile generated slight reverse momentum which is why the velocity isn't at zero.

6.2.2 Projectile 200mps

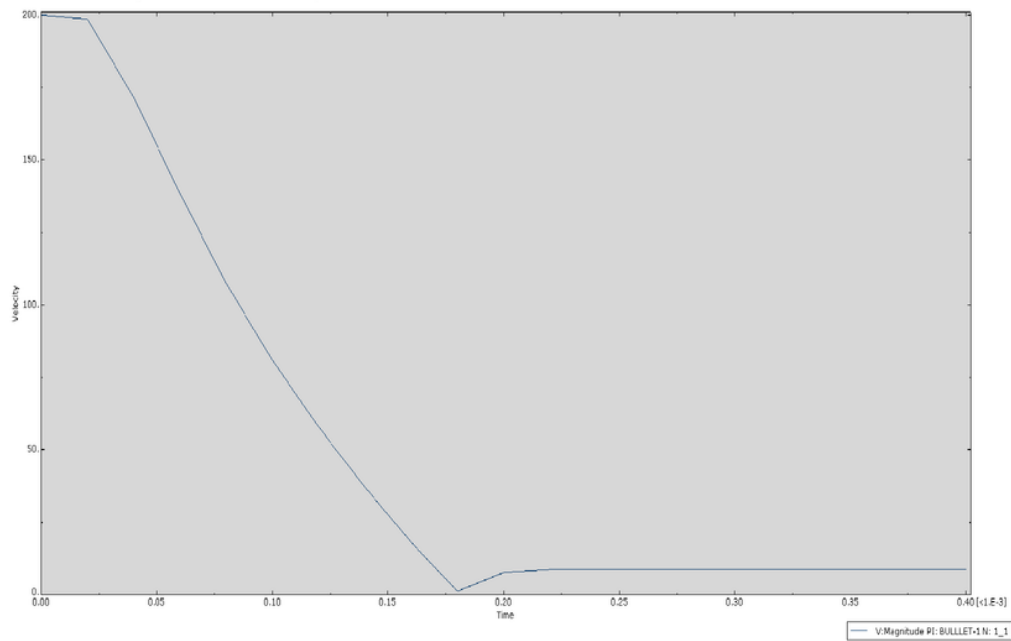


Figure 21 – Velocity Graph at 200mps

The above figure shows the velocity of the projectile before impact and post impact. The time of impact occurs at approximately 0.02ms where the velocity decreases. The velocity at point of impact drops by approx. 190mps. The dip in the base of the curve is where the projectile penetrated the plate. The velocity is not at zero due to residual energy.

6.2.3 Projectile 300mps

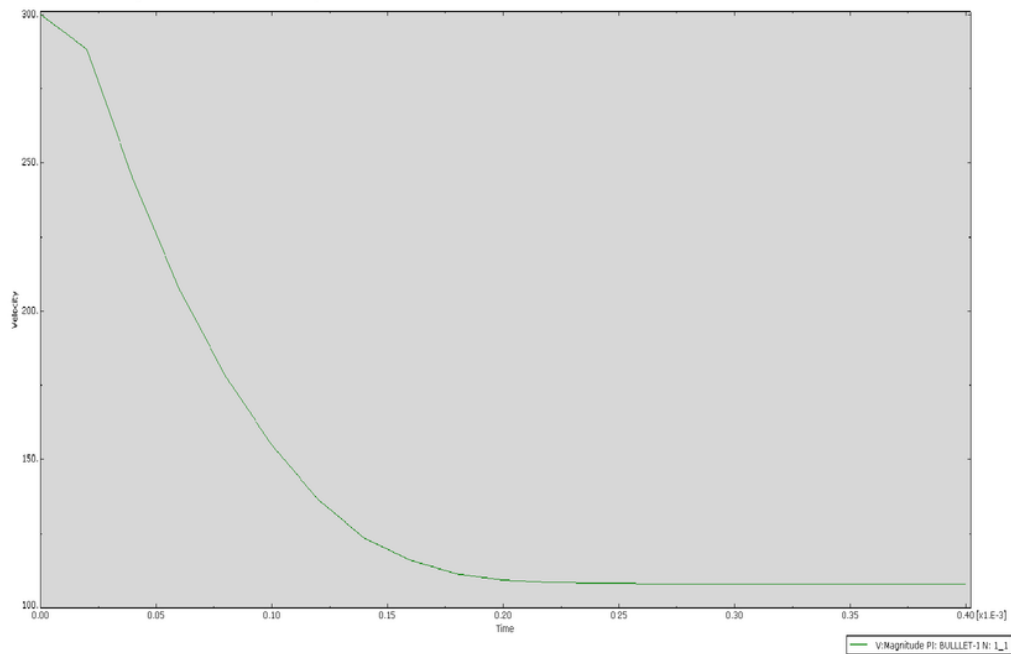


Figure 22 – Velocity Graph at 300mps

The above figure shows the velocity of the projectile before impact and post impact. The velocity at point of impact drops by approx. 150mps. The time of impact occurs at approximately 0.02ms where the velocity decreases. Due to the projectile perforating the plate at 300mps, in the time frame the simulation was run for the projectile doesn't stop.

6.2.4 Projectile 400mps

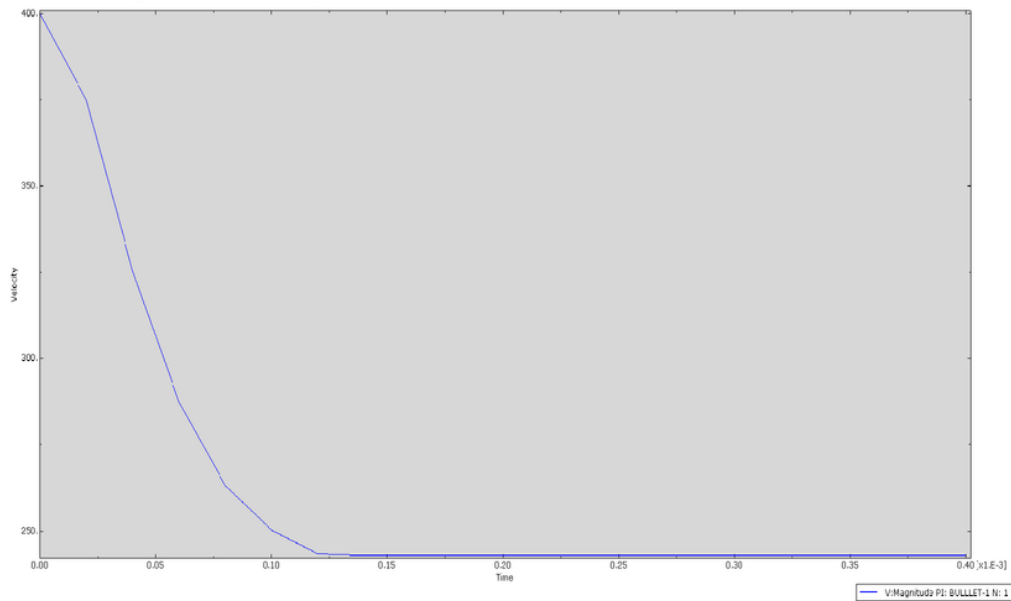


Figure 23 – Velocity Graph at 400mps

The above figure shows the velocity of the projectile before impact and post impact. The velocity at point of impact drops by approx. 135mps. The time of impact occurs at approximately 0.02ms where the velocity decreases. Due to the projectile perforating the plate at 400mps, in the time frame the simulation was run for the projectile doesn't stop.

6.2.5 Projectile 500mps

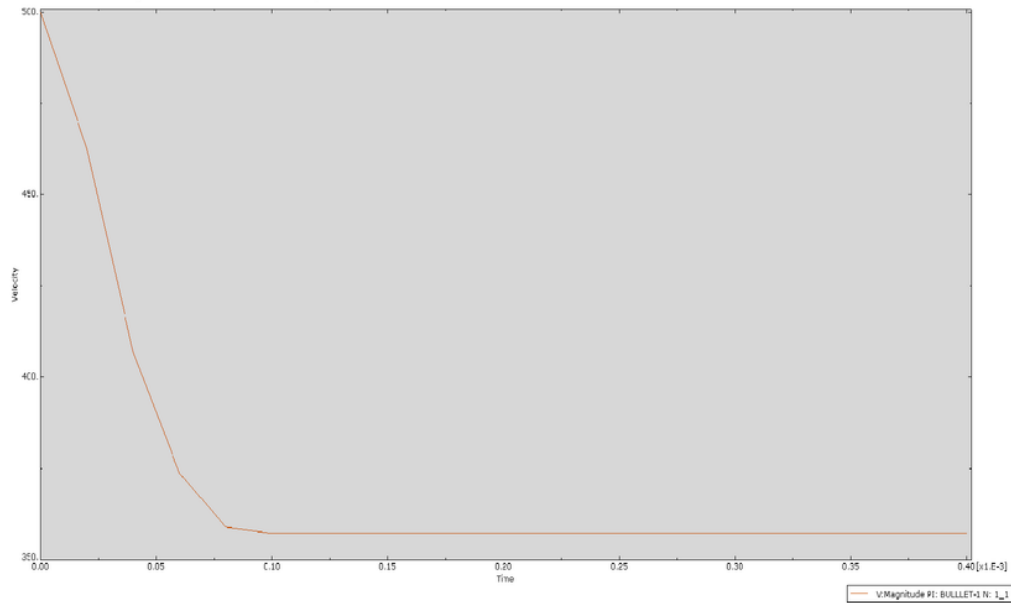


Figure 24 – Velocity Graph at 500mps

The above figure shows the velocity of the projectile before impact and post impact. The velocity at point of impact drops by approx. 60mps. The time of impact occurs at approximately 0.02ms where the velocity decreases. Due to the projectile perforating the plate at 500mps, in the time frame the simulation was run for the projectile doesn't stop.

6.2.6 Projectile 1000mps

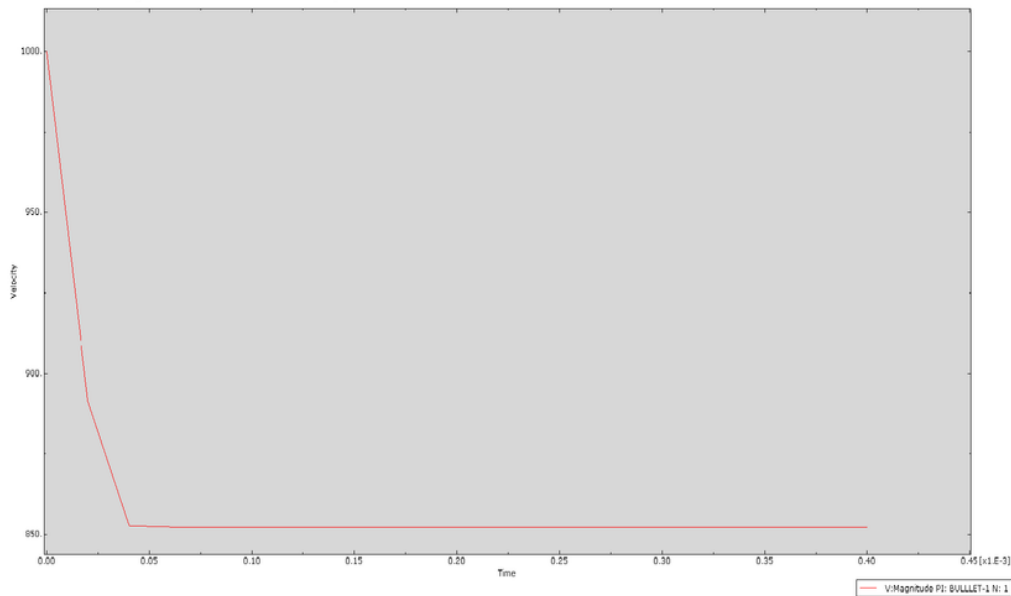


Figure 25 – Velocity Graph at 1000mps

The above figure shows the velocity of the projectile before impact and post impact. The velocity at point of impact drops by approx. 30mps. The time of impact occurs at approximately 0.02ms where the velocity decreases. Due to the projectile perforating the plate at 1000mps, in the time frame the simulation was run for the projectile doesn't stop.

7 Evaluation

7.1 Conclusion

For the purpose of the simulated experiment aluminium 5052 was used to define the aluminium plate in the Abaqus model. Aluminium 5052 is one of the highest strength alloys, with its fatigue strength being higher than most other alloys. This material has good resistivity to marine atmosphere and has high resistance to salt water corrosion. It has great workability and is able to be made into a vast amount of shapes. This material is used across many industries such as aerospace, marine, transportation and home ware. This material type is able to withstand impact velocities of up to 200mps as the projectile only penetrates, whereas at 300mps the projectile perforates the plate. Therefore the ballistic limit is between 200 and 300mps. The main failure of the plate for this simulation was tensile stress, as can be seen in 5.1, the limits set for the tensile snapshots was considerably higher than that of the shear limits. The residual post impact velocity before perforation meant that the projectile would slightly retreat from the plate due excess energy. Once perforation was achieved, as velocity increased the residual post impact velocity decreased.

7.2 Recommendations

The energy of the projectile generates heat which would affect the way the plate reacts, so would incorporate thermodynamic principles in the simulation if it was to be carried out again. Though this would bring about new issues such as the Johnson-Cook failure model which takes into account the adiabatic conditions [19]. The projectile would be made deformable as to real life scenarios, this would impact the shape and damage caused to the plate. It would be interesting to run the simulation using different FEA software to fully determine the accuracy of the results. Using FEA software though, without a full understanding of the software and how it works could lead to input errors of the required data. The projectile in this simulation was that of a spear tip, it would be interesting to run with a varied type of projectile to determine if the resultant effects would be vastly different. This simulation works for a singular projectile, not for something that fires multiple projectiles at once i.e. a shotgun. It would be interesting to run the simulation to enable that possibility to determine if the plate would act the same when struck at multiple points. It would be interesting to incorporate things like wind resistance, drag, range the projectile would have to travel prior to impact. [20]

8 Bibliography

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