

OME first year physics

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Physics for OME

Dynamic Stress- Strain investigation

Year 1 assignment

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Table of Contents

ABSTRACT	2
OBJECTIVE	2
INTRODUCTION	2
Abaqus	2
Direct Stress	2
Strain	3
Stress and strain	4
Shear	4
Ballistic terminology.....	5
METHOD	5
RESULTS AND ANALYSIS	7
DISCUSSION	12
CONCLUSION	13
BIBLIOGRAPHY	14

ABSTRACT

This report outlines the use of Abaqus Finite Element Analysis (FEA) software to compare the direct and shear stress components in an aluminium target plate when struck by a projectile (bullet) from different velocities. The aluminium used was 6082 T6. The ballistic limit of the material is approximately 280 ms^{-1} . In the example used for this report, the direct stresses are greater than the shear stresses and when together causes fractures and eventually failure of the material.

OBJECTIVE

The purpose of this report was to use a suitable computer simulation package to model a pre-defined and constant projectile hitting a solid aluminium plate. For this report the simulation package Abaqus was used. The simulation package was used to then show the stress and strain components of the material as the projectile passed into or through the plate.

INTRODUCTION

Abaqus

Abaqus is a software package used for Finite Element Analysis (FEA). It is used for many applications across the engineering community to predict how materials react in different situations. Due to the increased computational abilities of FEA in modelling components of varying complexities there has been a wide spread increase in the use of FEA. Some examples of where FEA is used are in bullet/projectile impact, such as that on a bullet resistant vest material or a stone hitting the windscreen of a vehicle.

In the automotive industry engineering work groups are able to consider full vehicle loads, dynamic vibration, multibody systems, impact/crash, nonlinear static, thermal coupling, and acoustic-structural coupling using a common model data structure and integrated solver technology [1]

For this report an analysis was undertaken using Abaqus Unified FEA. A simulation had been pre-programmed i.e the elements of the projectile (30 g, 4.9 mm radius, 9.8mm length with 104° conical cone) and target (198.25 x 200 x 20 mm, 50000 gradient mesh) had already been created. Some materials data for the target had been researched for this analysis; the Aluminium used was 6082 [2]. This type of aluminium was selected as it is used at the author's workplace for making fixtures to hold explosive samples. In general this aluminium can be used for roof trusses, Milk Churns, bridges and cranes [3]

Direct Stress

Direct stress is one of the simplest forms of stress. In a very basic form it can be described as the push/pull stress which is more commonly known as tensile and compressive stress.

Take an individual item; through life it will be subjected to external forces. If load is placed on top of that item (consider it is sat atop a solid immobile surface) then the item will be placed under a compressive force, pushing in into the surface.

If that same load is attached under the same item (consider it being underslung of a solid immobile surface), then the item will be placed under a tensile force, pulling away from the surface.

An example of a material in tension, is a lift cable. The lift is the load placed on the cable and is pulling the cable from the rollers at the top of the lift shaft. The cable is being placed under tension, the weight of the lift is trying to stretch the cable. The mechanical properties of the cable prevent the cable from deforming/breaking due to the tension (up until the weight is too much for the cable).

Any object that is weight bearing will undergo compression. An example of compression is the supporting pillars of a building or bridge. The downward force created by the weight of the structure is putting a compressive force on the supports. The supports will hold the weight until the weight placed upon the structure becomes too great and overcomes the compressive strength and the supports break. [4]

Take the simple example of a bar, i.e. as shown below, [Figure 1], in tension the force is away from the center, and in compression the force is towards the center.

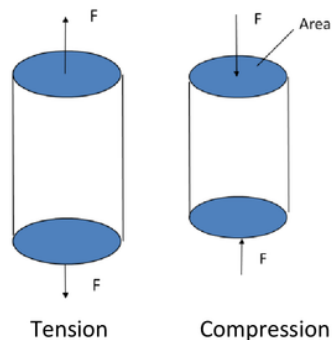


Figure 1

$$\text{Direct stress } (\sigma) = \frac{\text{Force } (F)}{\text{Area}}$$

Force is measured in Newtons (N)

Area is measured in metres (m²)

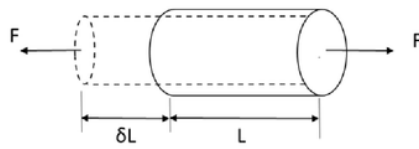
Therefore stress is measured in Nm⁻²
Or Pascals (Pa)

[5]

"It is important to realise that the above equation gives the average direct stress acting on the sectional area since it is assumed that the same force acts over the entire area." [6]

Strain

When a load is placed on an item the stress allows the item to change in size; the change in size compared to its original length this is known as strain. Taking the bar already discussed [Figure 2], when the bar is placed under tension the length of the bar increases. The length of the increase of the bar is known as the tensile strain and is considered positive. Similarly, if the bar is put under compression the length of the bar decreases. This is known as compressive strain and is considered negative. Strain has no unit of measure as it is a ratio comparing the change in length to the original length [7].



$$\text{Direct strain } (\epsilon) = \frac{\text{change in length } (\delta L)}{\text{original length } (L)}$$

[5] [6]

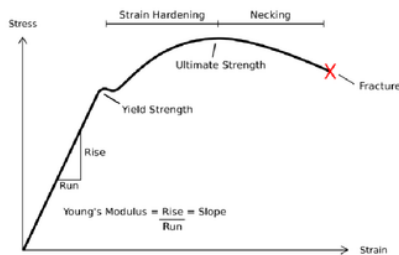
Figure 2

When the bar is put under tension and it becomes longer the diameter becomes smaller (assuming tension is equal along the whole bar). The change in diameter compared to the change in length is known as Poisson's Ratio.

$$\frac{\text{Lateral strain}}{\text{Longitudinal strain}} = \text{Poisson's ratio}$$

[5]

Stress and strain



$$\frac{\text{stress}}{\text{strain}} = \text{Young's Modulus } (E)$$

[8]

Figure 3- stress vs strain curve

Figure 3 shows a basic stress against strain graph. From the origin to the yield strength the line is ~straight. Of a material, this is known as the elastic region. In this region, if the material is put under stress it will deform, and if the stress is removed, the material will return to its original dimension. While in the elastic region, the comparison of stress against strain gives the Modulus of elasticity, or Young's Modulus which is a constant, this is derived from Hooke's law

When the stress/strain passes the yield strength, the material enters the plastic region. In this region the material has passed through its elastic region and will not return to its original state. The material will deform, and if put under more stress, will eventually fracture/break. [4]

Shear

If it can be said that the direct stresses are along the plane of the material, then shear can be said to be across the plane of the material [Figure 4].

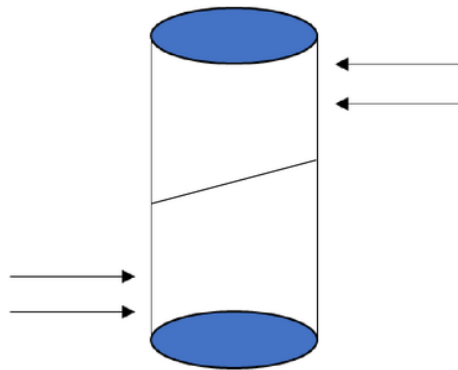


Figure 4, shear stress

$$\frac{\text{Force}}{\text{Area}} = \text{Shear stress } (\tau)$$

Ballistic terminology

This list provides an explanation of words used to show how the bullet interacts with the target plate [9].

Ricochet	The Indentation of the target plate with no penetration.
Penetration	The Bullet enters plate instead of simply indenting it.
Embedment	The Bullet enters target plate but does not exit.
Perforation	The bullet has sufficient force to pass directly through the target plate
Ballistic Limit	The velocity below which bullet fails to perforate plate

METHOD

The Abaqus simulation boundaries had been set up as part of the experiment by the lecturer. The properties of the aluminium target plate had to be researched. In this experiment the properties had been chosen using a common aluminium used at the author's work place [2]. The properties were loaded into the Abaqus software as follows [Table 1]:

Density:	2700 GPa
Young's modulus:	70 GPa
Poisson's Ratio:	0.33
Yield stress:	240 MPa
Ultimate Tensile Stress:	295 MPa
Elongation at break	8%

Table 1 - Material properties

Once all the material properties of the aluminium had been added into the Abaqus software then the model could be run. Velocities were selected as per instruction; other velocities were also selected to investigate further the differences that velocity can make. After the model had completed its run, the results could be viewed. This was a video simulation of the projectile as it impacted the target plate. The changes in the properties of the material were viewed as different colours on the target plate as the projectile hit the target. For the analysis, the projectile was simulated as a solid object and so would not deform or change during the simulation. The only material properties that could change were those of the target plate.

The target plate was 'cut through' to show the properties through the central plane. The video was stopped at various times so the results could be analysed. The analysis looked at the changes in the colouration of the test piece and determining the stresses as shown in the example below [Table 2].

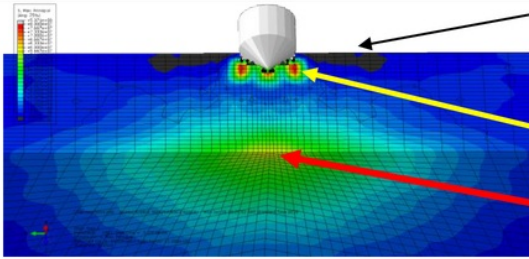
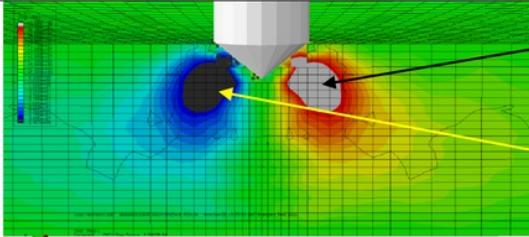
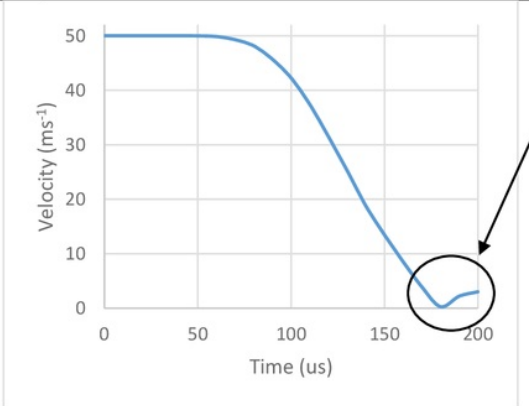
	Areas of compressive stress on the top of the target plate (black) Tensile stress directly under bullet (red at max) Tensile stress wave on the open face of the rear of target plate (yellow through blue)
	Areas of shear. The difference in colour (black-blue/grey to yellow) represents the direction the stress is in. Black and grey representing where the value falls outside the set limits, with the max values in the key.
	On some of the graphs showing the velocity of the bullet, the bullet appears to stop and then speed up again going backwards. This happens when the bullet has not perforated the target plate. Once it has come to a stop it relaxes backwards (similar to a bounce), hence speeds up for a short amount of time in reverse. Before stopping again. This is possible evidence of the target plate (under the bullet) being in the elastic region, deforming and returning to its original dimension.

Table 2 - Example of what to look for

RESULTS AND ANALYSIS

It should be noted that when converting the direct stress images, the grey dots turned black. They represent tensile stress, not compressive stress as indicated.

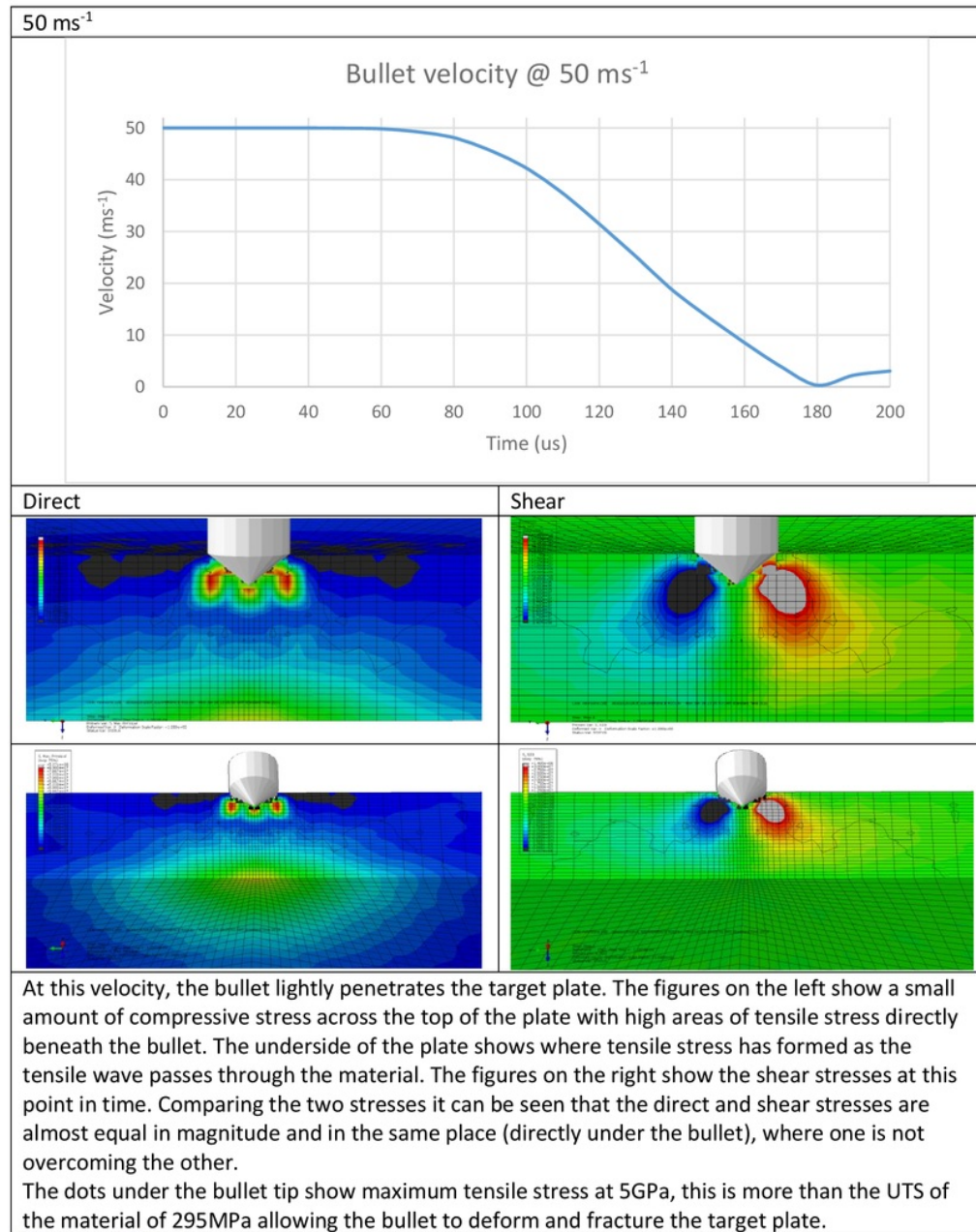


Table 3 - results 50 ms⁻¹

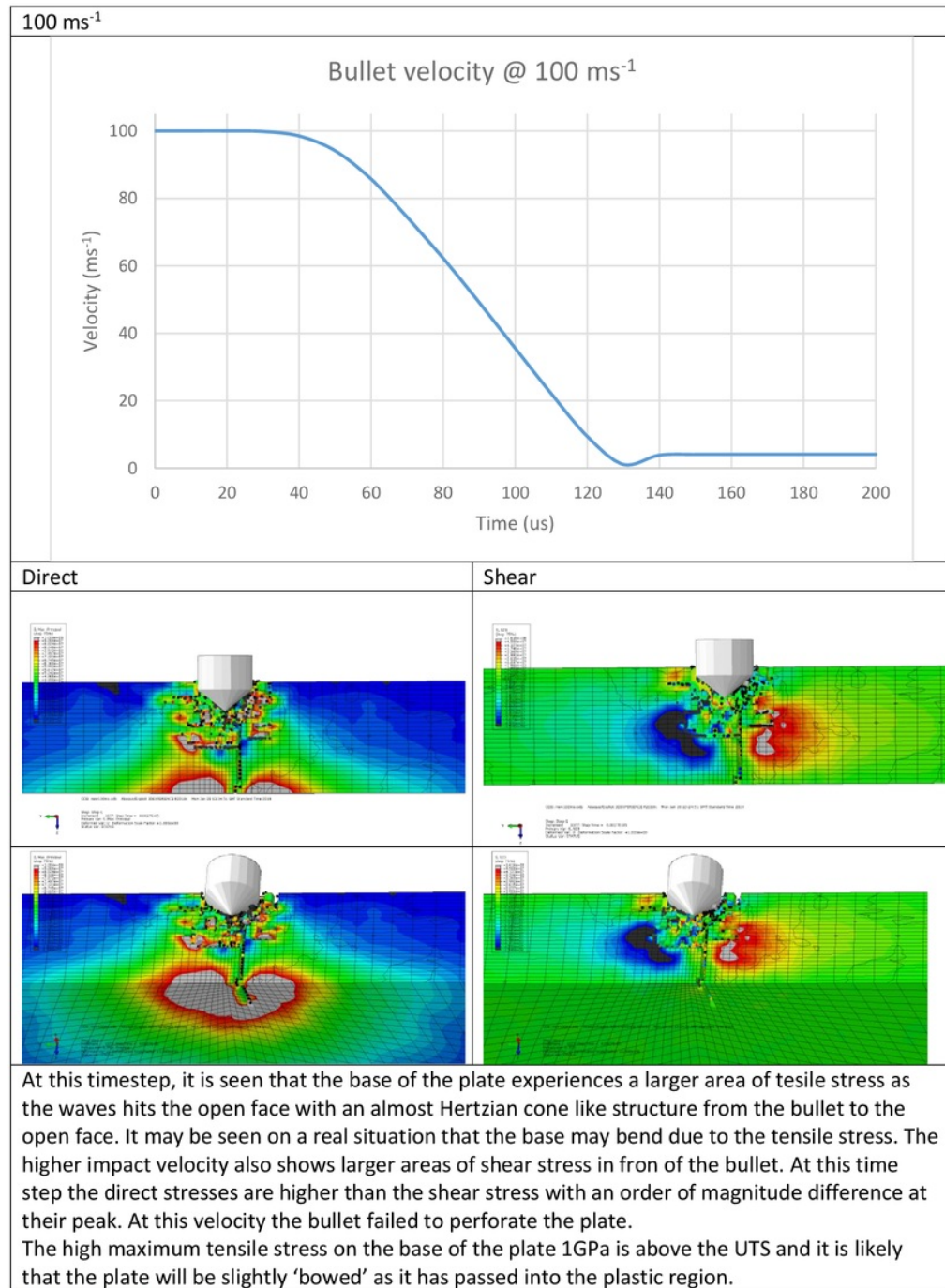


Table 4 - results 100 ms⁻¹

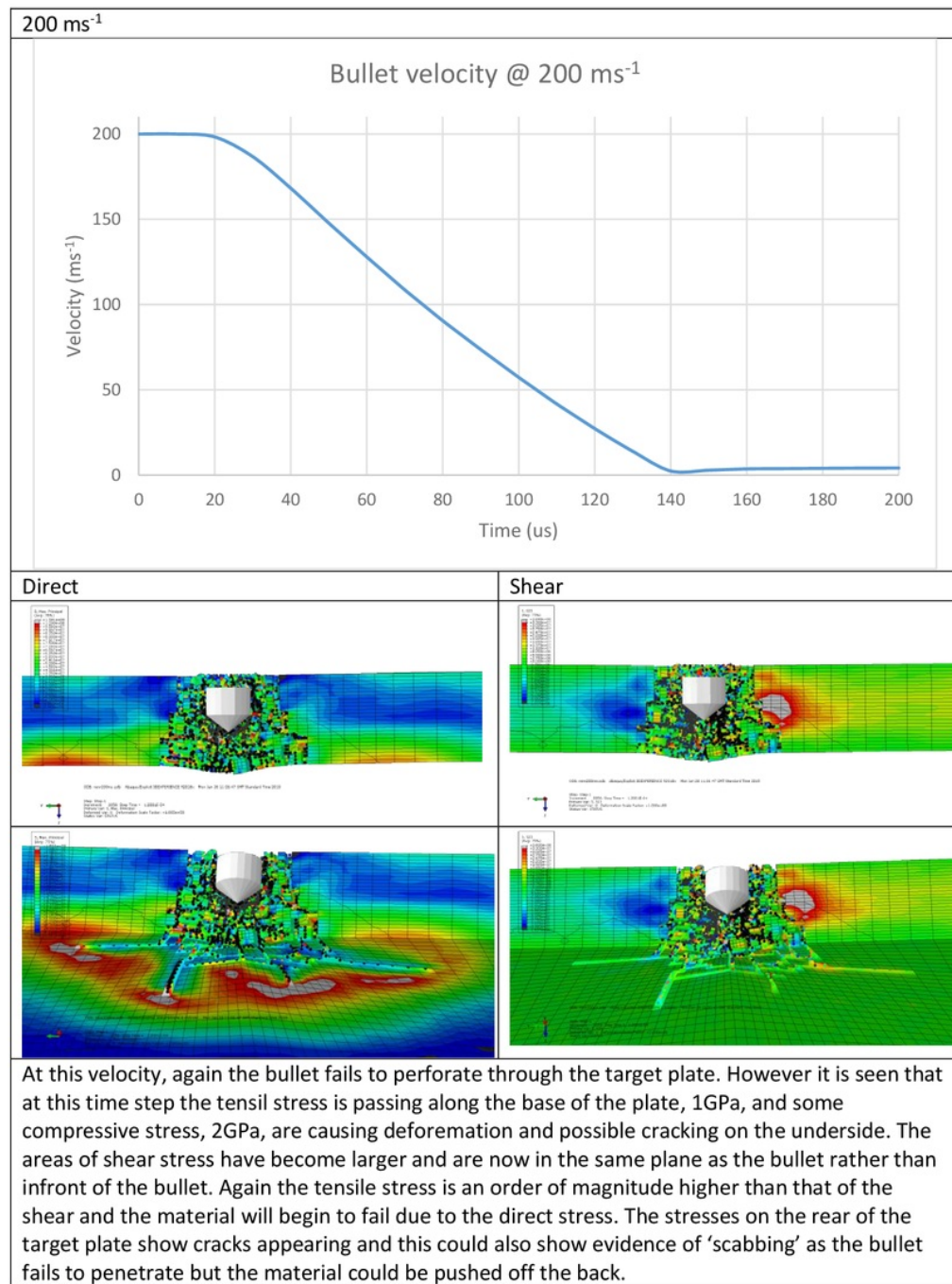


Table 5 - results 200 ms⁻¹

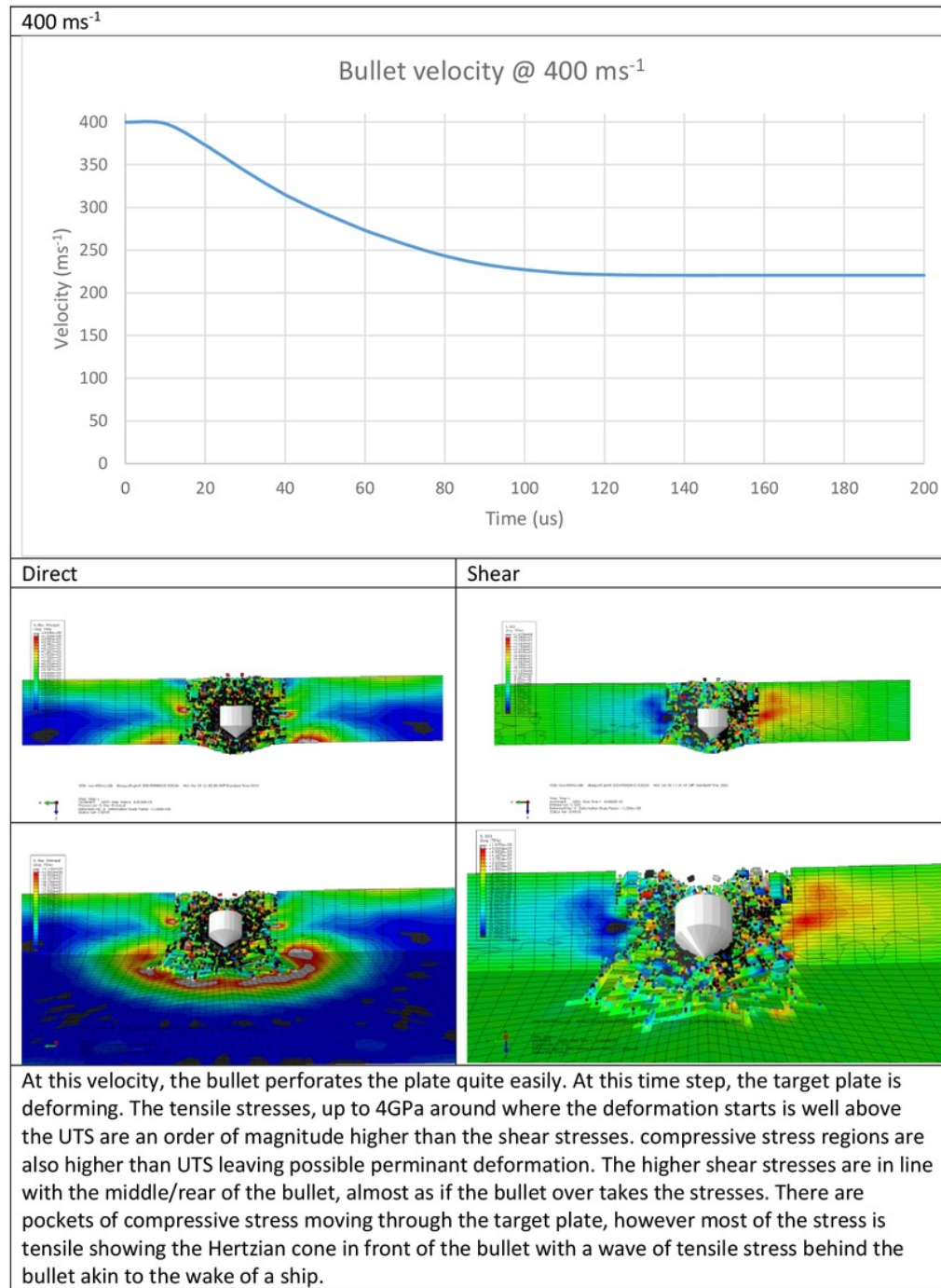
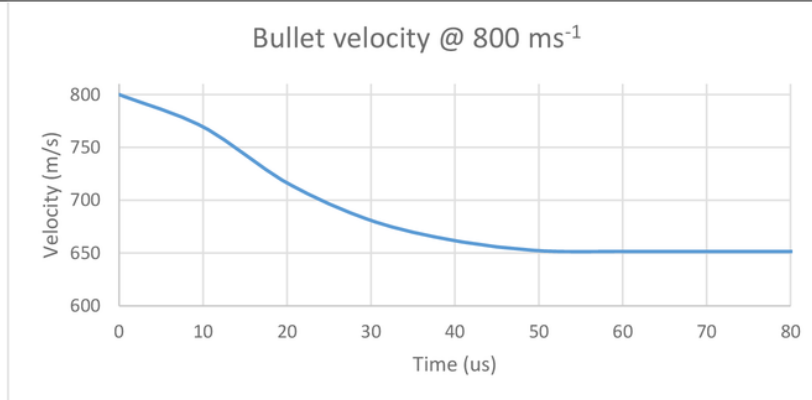


Table 6 - results 400 ms⁻¹

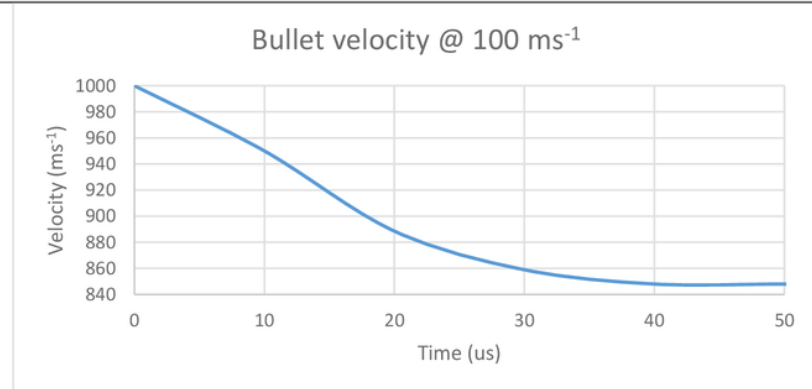
This table shows velocities measured from further simulations to be able to consider how the velocity of the projectile is affected by the aluminium plate. Stresses were not compared at these velocities.

800 ms⁻¹



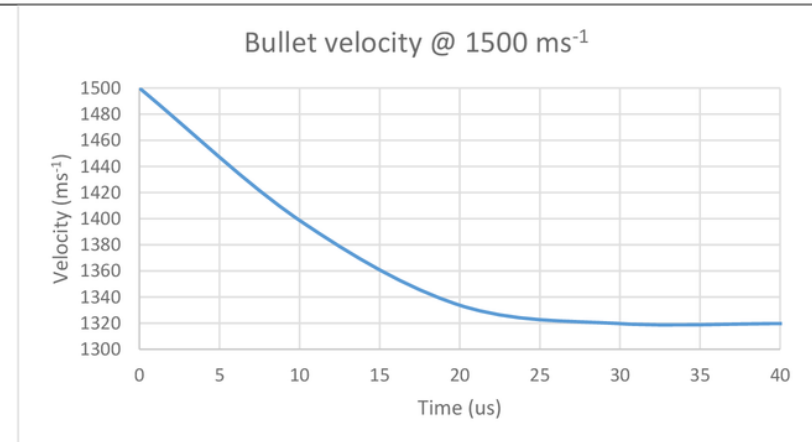
As the bullet passes through the target plate the velocity reduces by approximately 18.75%

1000 ms⁻¹



As the bullet passes through the target plate the velocity reduces by approximately 15.5%

1500 ms⁻¹



As the bullet passes through the target plate the velocity reduces by approximately 12%

Table 7 - further velocities experimented

DISCUSSION

When compared to a much more advanced model developed specifically to compare how an Aluminium responds to fragment attack. It can be seen that the shear stress in that model are similar to those produced by the model used for the purpose of this report.

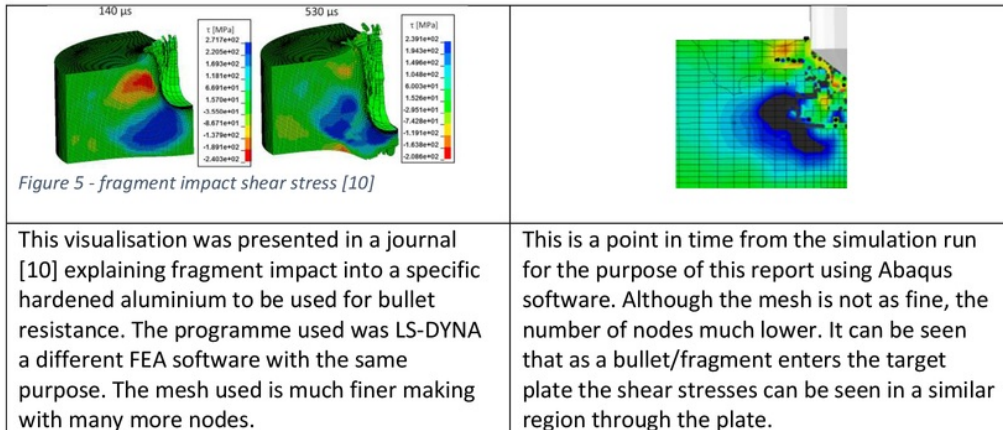
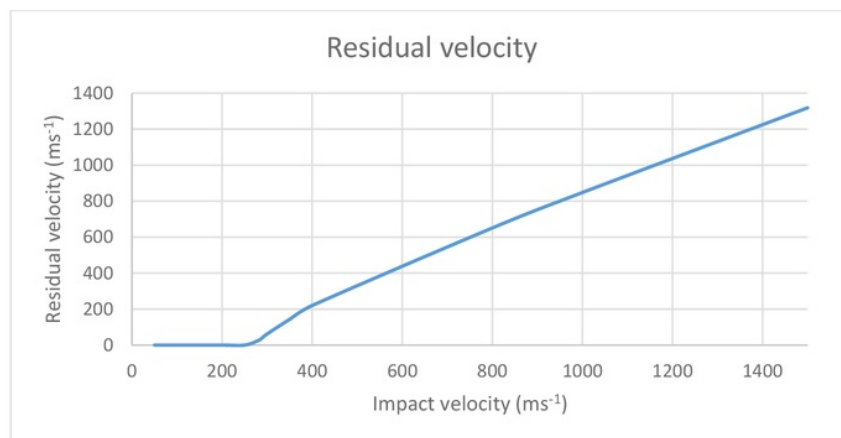


Table 8 - comparison of feature from journal to results found in this project

Seeing how the stresses from the impact of the projectile have traversed through the target plate has been discussed in the results section. As the projectile passes through the target plate it is slowed down.

Further simulations were run identifying that perforation doesn't take place until approximately 280 ms^{-1} . This is the "ballistic limit" of the aluminium used. As the velocity increases, the percentage of velocity that is lost by impacting the target is seen in the table of further velocities [Table 7].

Below is a graph [Graph 1] created by measuring all of the impact velocities compared to the residual velocity. Apart from when perforation begins to take place, the relationship is almost linear. As velocities increase past the graph it can be predicted that, at some point the target plate will have a negligible effect on the velocity of the projectile.



Graph 1 - graph of initial against residual velocity

CONCLUSION

An FEA software package is a very useful tool. It allows predictions to be made on how a material will react under set conditions. In order to make full use of the software, having the elements set up correctly to begin with will allow the simulation to accurately depict what is happening to the materials (in this case) as the bullet moves through the impact plate. It is very important that a user knows how to use the software correctly. It is easy to misapply results by setting up the programme incorrectly.

This analysis concentrated specifically on the target plate so that understanding of how the FEA software works could be established. Concentrating specifically on the target plate, approximations are added into the simulation, which in real world scenario would need to be considered. As the projectile was treated as a rigid body, there was no effect on it. In reality the projectile would have its own materials properties - these would need to be considered as the projectile would most likely deform. This could then stop the projectile passing through the target plate, whereas when it is considered rigid, it does pass through.

In order to get the most out of the FEA, a very fine mesh should be used. This would allow for more elements and nodes in the simulation, thus the simulation may be more accurate, compared to real life. More elements and finer mesh would have a drawback however; time. The more elements that exist, the greater the computational demand and hence longer simulation time. For this reason, specific high performance computers are used for engineers, to get the most out of the FEA software when high element simulations need to be run.

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