

Dynamic Stress - Lab report

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Dynamic Stress-Strain **investigation**

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Contents

Abstract 2

Introduction 2

Methodology 4

Results 6

Conclusion..... 11

Referances..... 11

Abstract

The objective of the report was to cover the outcomes of a 7.62 x 39 projectile fired at different velocities against an aluminum T1 6061 target. Throughout the report it will contain different observations of the target and projectile impact with simulations done for this report and references to compare the results of simulations done.

Three separate simulations were completed with Abaqus, each one at different velocities. Each projectile at different speeds penetrated the target with ease but some carried a larger force than others as described below. Each of the simulations gave off visual images of the Stress and Strain as well as the Tensile Stress of the target and projectile, in Abaqus these are called Max Principle and S23. The report will include graphs which will give an indication and visible example of either the energy lost over time or the strain on the target.

INTRODUCTION

The aim of this report, as stated above, is to observe the effects of projectiles on Aluminum 6061 targets. This will and has produced varied outcomes with the use of different velocities and materials, this is because of the force which would be generated by the projectile and the material used for the impact will cause different results. For example, if you had an aluminum projectile and it impacted a tungsten plate at 200m/s it would not do much as tungsten is very dense and aluminum very malleable.



Figure 1 7.62 Round

The projectile used throughout the report was a 7.62x39 bullet.

This was due to it being a common round and therefore being able to perform simulations through Abaqus. However, for the simulation to work as is in real world applications the projectile would have to be just the projectile rather than the casing and the projectile.

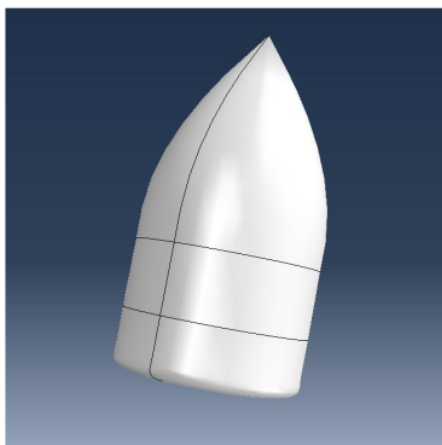


Figure 3 Projectile Model

The model of this was given steel parameters as to give it realistic material properties.

The properties will be discussed later in the report. This Projectile represents the component of the bullet which does the impacting on the target. The only variable which was changed in the simulations was the velocity of this projectile model against the plate.

The projectile was made using Abaqus, which is the software used for these simulations. This software was used because it was the easiest and most reliable software to hand.

Figure 4 Projectile Model

The affects the simulations are aiming to show are common but vital to understanding the limits of the simulation. These are some examples:

shear stress, tensile strength and strain on the plate target when the projectile impacts it. Within Abaqus it also gives the option to add a parameter model into it so for this

¹ ALL BULLETS ON WHITE PAPER ARE TAKEN INTERNALLY AND DO NOT NEED REFERENCES

report the chosen one was the Johnson-Cook model.

	d1	d2	d3	d4	d5	Melting Temperature	Transition Temperature	Reference Strain Rate
1	-0.77	1.45	0.47	0	1.6	900	293	1

Figure 5 Johnson-Cook table

This model gave the ability to accurately measure the effects on the target. The Johnson-cook model is explained here: “The Johnson-Cook model is a function of von mises tensile flow stress, in accordance with strain hardening, strain rate hardening, and thermal softening” [2]. Shear stress is when two forces act against each other in a pulling force, creating a shearing motion. Tensile strength is the amount of force an object can withstand without being indented or fractured. Strain is the effect of the material ripping or weakening under pressure. These are all shown in simulations via different colors which will represent the strain and stress.

Methodology

The process of setting up these simulations is complex and lengthy, as the simulations had to be set up to measure 2 different mechanical properties: Max Principle (Tensile Stress) and S23 (Shear Stress).

The first step to creating the simulation was to create the separate parts, this was done by selecting module, part and then using the drawing features to design a projectile first. It was important to label these correctly so as not to confuse the parameters later and to only make half of the projectile as Abaqus has a feature to revolve the shape to make it a 360-degree object. The projectile used in these simulations was a 7.62 x 39 projectile. The plate (Target) model was created the same way except using the extrude tool, with the dimensions of 0.304 (length) and 0.026 (height).

After this the target was made and both ‘Parts’ needed mechanical properties such as Elasticity and Plasticity. These mechanical properties were Elasticity, young’s modulus, Poisson’s ratio, density and Johnson-cook model. Each of these are shown below with their property’s values:

	Mass Density
1	2699

Figure 6 Mass Density

	d1	d2	d3	d4	d5	Melting Temperature	Transition Temperature	Reference Strain Rate
1	-0.77	1.45	0.47	0	1.6	900	293	1

Figure 7 Strain Rate, Melting temperature, Transition temperature. (Johnson-Cook)

These are the parameters of J-C damage equation, plasticity equation parameters not included

	Young's Modulus	Poisson's Ratio
1	110000000000	0.343

Figure 8 Young's Modulus, Poisson's Ratio

Young's modulus refers to $E = \frac{\sigma}{\epsilon}$. Poisson's ratio refers to the stretching strain of the material, in this case Aluminum 6061. For the target is shown below:

	Young's Modulus	Poisson's Ratio
1	680000000000	0.36

Figure 9 Target

After the parts have been programmed on their parameters, the assembly of the simulation can start. To construct this the tool: Create instance. This is because this tool will allow free movement of the projectile and therefore choose where the impact will occur. During the movement the goal was to manipulate the projectile to impact the center of the target. This was done by using the create instance tool and moving the projectile so it was aimed at the corner of the aluminum plate, this would then be set to $(-0.152, 0.002, 0.152)$ [3]. This then put the projectile to a suitable point in the center so the most information can be retrieved and simulated. After this the velocity was input into the Predefined Field section, it was first set to 800 m/s^2 . Then the simulation needed to be meshed (both the target and the projectile) and assigned various other credentials such as: Stress Elements and assigning nodes. The nodes will help portray a better view of the impact and give better visual readings for the result.

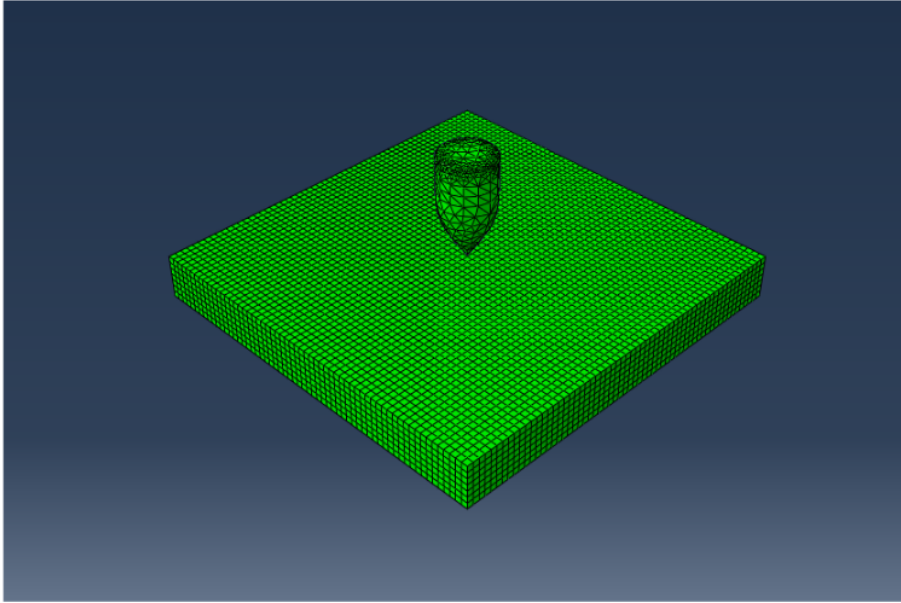


Figure 10 Plate and Projectile

Now to achieve a working, moveable simulation the Job section is needed; this will allow the simulation to run and the two parts to impact. This will need to be submitted as a Job and we can then use the Visualization Module to review the results and identify key areas of shear stress (S23) and Tensile Strength (Max Principle).

Results

The outcome of the simulation varied as mentioned above due to the different velocities chosen. These different velocities are as follows: 1000 m/s², 850 m/s² and 800 m/s². The velocity 1000 m/s² was chosen to show the effects of a high-speed projectile that has a relatively small two have similar velocities (50 m/s² ±) and an outlier would positively show the effects and speeds of the projectile. The results of this were expected to be massively different to the other two speeds due to the 200 m/s² tolerance (±). The pre-simulation estimate was that it would go clean through the Aluminum 6061 plate and have little deformation on the projectile but major deformation on the exit hole of the plate.

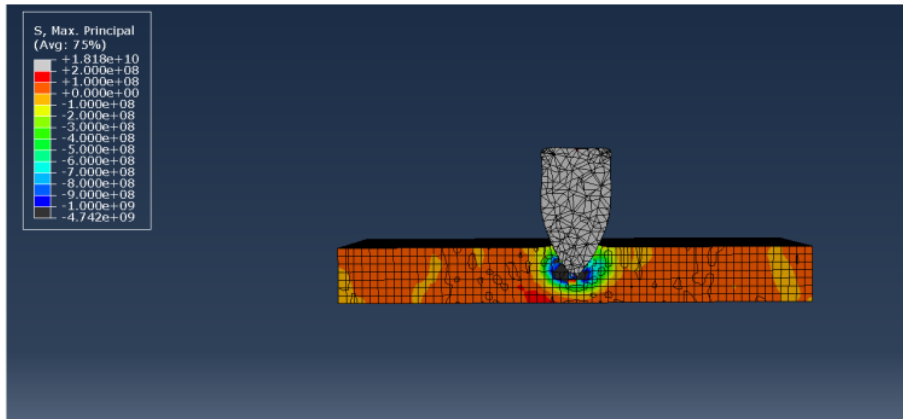


Figure 11 1000 m/s² Impact.

As shown on Figure 9, this image was measuring the Max Principle of the impact and as shown by the image it enters and causes the front face of the plate to create mounds around the ogive tip of the projectile as the target material is being pushed away from the impact zone.

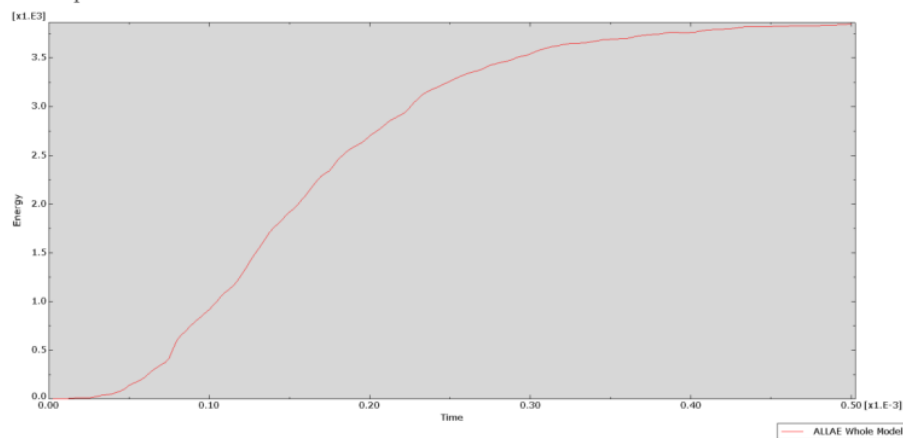


Figure 12 1000 m/s² impact graph.

The graph in Figure 10 shows the increase in energy output over the time spent impacting the Target plate. The energy of the impact would be dissipated into the plate target, this is due to the Law of conservation of Energy (energy cannot be destroyed, only transferred), and the energy from this is used to deform the target plate.

The 850 m/s² was used to compare to the velocity stated by Teijin-Aramid-International-hard-ballistic-standards which was “895 m/s² “ [4]. Below in Figure 11

shows the impact of the projectile on this speed against the target plate.

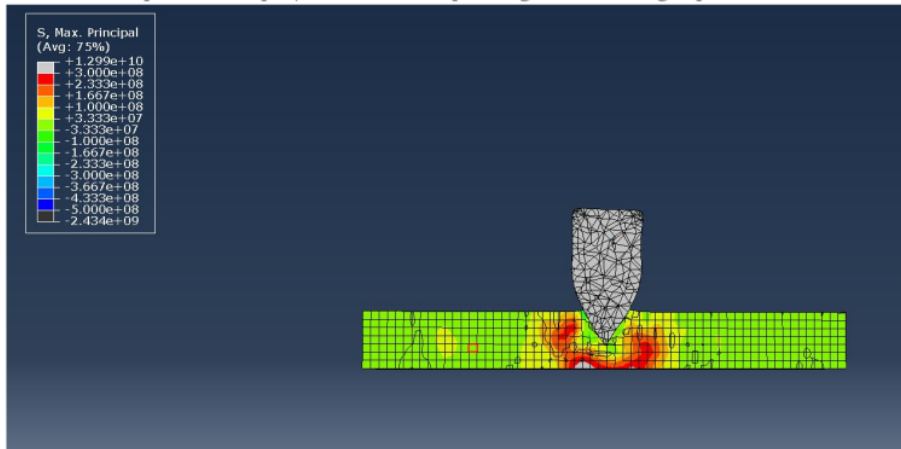


Figure 13 850 m/s² Velocity

At this image you can see how the projectile causes tensile stress to the plate whilst not fully penetrated but its indicating that the red areas (which simulate the stress on the plate) are under immense stress and will suffer from torsion and could potentially break. This shows that the 850 m/s² speed can and will cause significant stress and penetrate the plate.

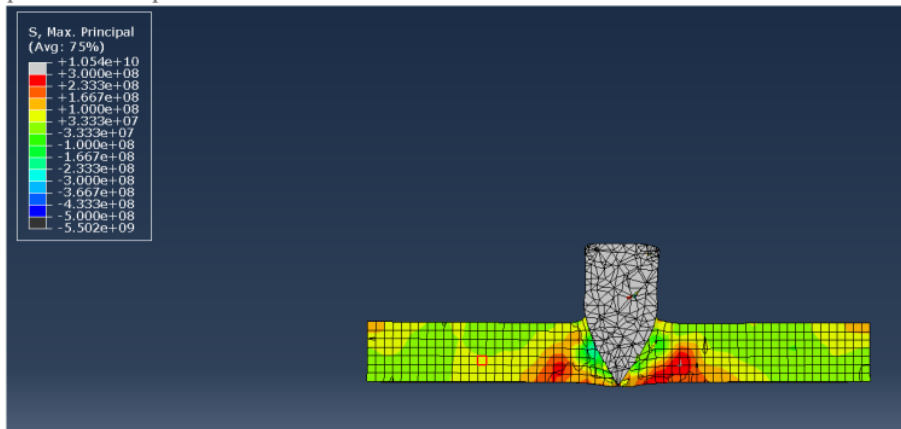


Figure 14 Major impact, 850 m/s²

In figure 12, the reader can see the stress which is inflicted on the lower levels of nodes (red and orange). This could infer that the stress of the impact doesn't affect the touching faces of the projectile or plate, but the force carries through the plate and affects other areas within.

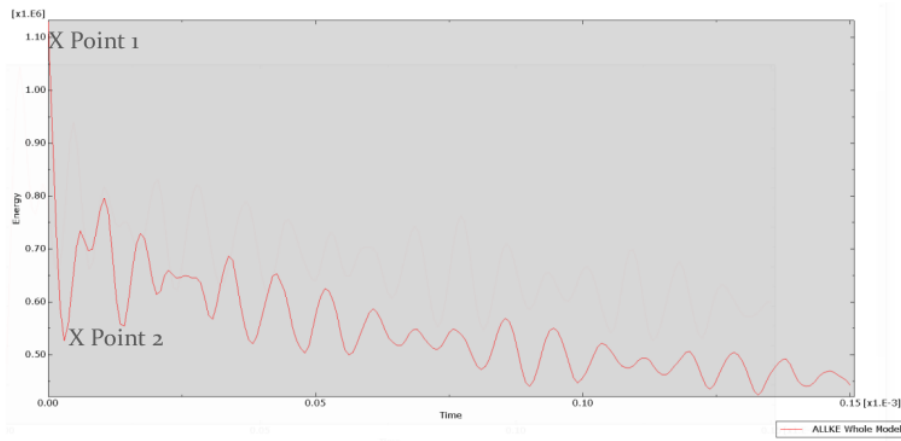


Figure 15 Kinetic Energy Graph

In Figure 12, it represents the energy which is lost over time in the 850 m/s² simulation. In this we can infer that the peak at the start (Labelled point 1) is the impact point and point 2 is when the projectile loses momentum and starts to come under resistance from the target plate. The rest of the table shows the release of energy as the projectile comes to a full stop. At 0.0015s it still has $>4 \times 10^5$ J of KE

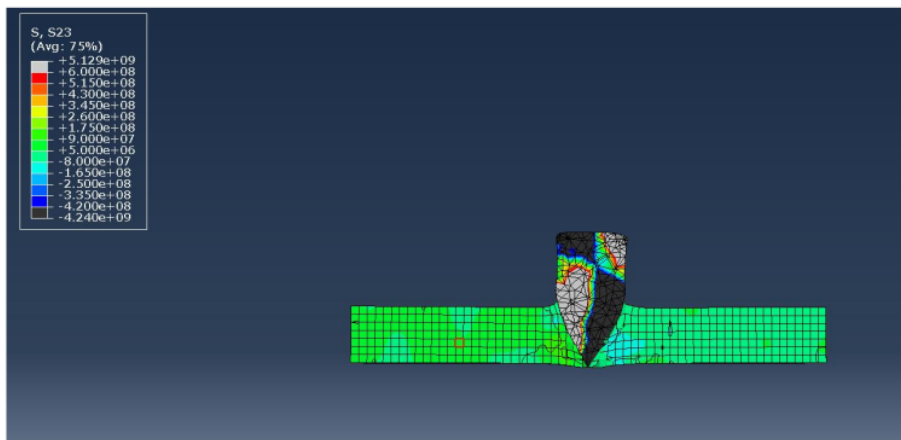


Figure 16 S23 850 m/s²

Shown in Figure 13 is the outcome of the 850 m/s² velocity but measuring Shear Stress (S23) rather than tensile stress. In the image above it shows that most of the shear stress is focused between the $-8.000e+07$ to $2.600e+08$ range, which could imply that the main destructive force for the plate being attacked by a projectile being fired at 850 m/s² is more focused around hardness.

X Point 1

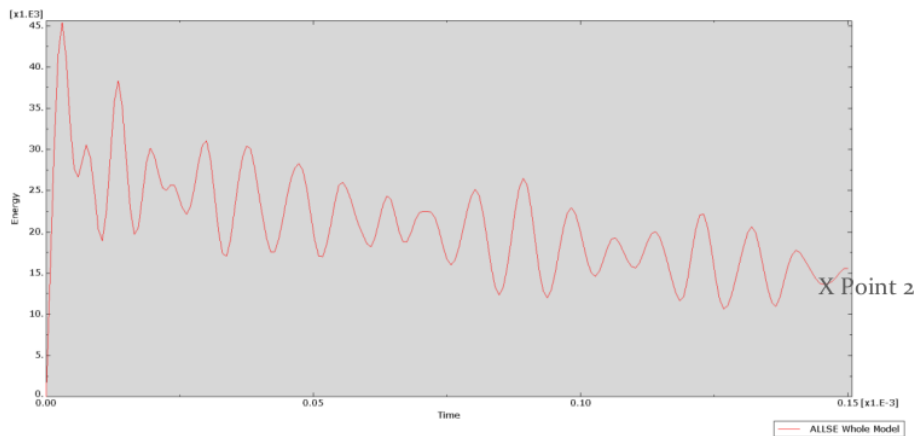


Figure 17 Strain Rate, 850 m/s²

Figure 14 shows the relation between the Energy and the time within the simulation for 850 m/s² velocity impact. To calculate strain, it is done by having $\epsilon = \frac{\text{change in length}}{\text{original length}}$. This graph helps show the energy dissipation that occurred within a certain time of the impact, in this instance $0.15 \times [1.E-3]$. Figure 14 shows the impact points and the points where the projectile was firmly embedded into the target, this is shown at points 1 and 2.

When using 800 m/s² velocity which compares to the High_Speed_Projectile_Impact instruction guide. This is because it was the base value to experiment and adjust the simulations, but it is also a common speed for more larger rounds such as .308 Winchester [4].

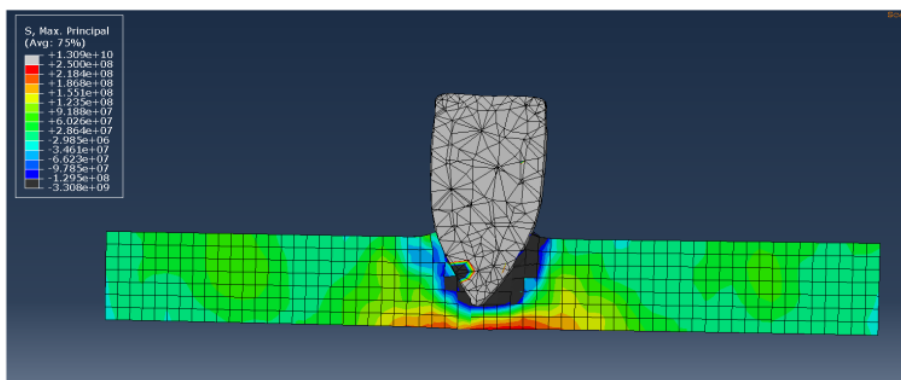


Figure 18 800 m/s².

In Figure 16 the image shows the max principle of the projectile impacting the plate. In Figure 12 the image shows that the projectile can cause tensile stress upon sections of

the plate without being in contact with them, this is shown here in Figure 16 as well.

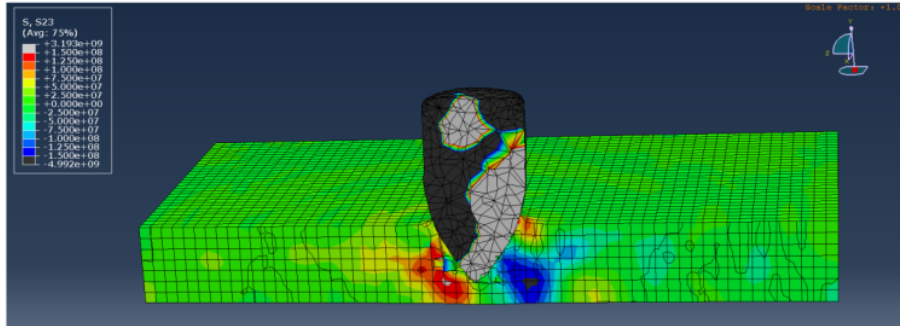


Figure 19 s23, 800 m/s²

Here the simulation shows the strain of the impacted plate. On the left side of the projectile, it is redder than on the right side indicating that there is an increase of strain on one side which could be suggesting where the first point of contact was.

Conclusion

The main objective throughout these simulations was to compare and assess the impact of the projectile on the Target plate (Aluminum 6061). The 1000 m/s² velocity simulation showed that the projectile would deform the face of the plate as expected but also did not do as much damage as expected. The 850 m/s² was majorly the best out of the three simulations, this was due to the information which it output and the effect it had on the target plates. The 800 m/s² simulations were used to compare the 850 m/s² but also to see how the effects of larger calibers would impact the plates.

The improvements which could be made to these simulations are finer nodes to give a more detailed, accurate view. Another point would also be to have a larger collection of images to reference as there were IT complications which prevented me from using the software routinely. I would also correlate the information from the graph into a more specific readable graph.

References

- [1] D. P., "Understanding Calibers | Bullet Sizes," 14 06 2022.

[2] H. Nam, Recent Advances in Structural Integrity Analysis - Proceedings of the International Congress, 2014.

[3] K. Donne, "Hlgh_Speed_Projectile_Impact," Swansea , 2023.

[4] Teijin, "Teijin-Aramid-International-hard-ballistic-standards.pdf," 2017.

Figure 1 7.62 Round.....	3
Figure 1 7.62 Round.....	3
Figure 2 Projectile Model	3
Figure 2 Projectile Model	3
Figure 3 Johnson-Cook table.....	4
Figure 4 Mass Density	4
Figure 5 Strain Rate, Melting temperature, Transition temperature. (Johnson-Cook)...	4
Figure 6 Young's Modulus, Poisson's Ratio	5
Figure 7 Target.....	5
Figure 8 Plate and Projectile	6
Figure 9 1000 m/s ² Impact.....	7
Figure 10 1000 m/s ² impact graph.....	7
Figure 11 850 m/s ² Velocity.....	8
Figure 12 Major impact, 850 m/s ²	8
Figure 13 Kinetic Energy Graph	9
Figure 14 S23 850 m/s ²	9
Figure 15 Strain Rate, 850 m/s ²	10
Figure 16 800 m/s ²	10
Figure 17 s23, 800 m/s ²	11

