

Dynamic StressStrain Report

by Luke Penny

Submission date: 08-Mar-2019 08:37PM (UTC+0000)

Submission ID: 101969891

File name: 12112_Luke_Penny_Dynamic_StressStrain_Report_170540_1796731359.docx

Word count: 2348

Character count: 12254

Dynamic Stress/Strain Investigation

Luke Penny - 1810356

1. Objective

This assignment emphasises the 'complementary analysis of appropriate examples' aspect of this module. In this report the topic of high-speed ballistic impact of a bullet onto an aluminium plate will be assessed. A predefined Abaqus model has been provided with full geometrical definition of the problem. A suitable material property for aluminium will be researched and inputted into Abaqus and then investigations will take place to analyse the performance of the ballistic projectile onto the plate at varying striking speeds. Once the data is gathered from Abaqus, detailed investigations into direct and shear stresses onto the plate and understanding the residual post impact velocity of the projectile will be analysed.

2. Abstract

This report covers the topic of stress/strain and how it occurs when a projectile impacts a plate in a software program Abaqus. After running the simulations for varying speeds, we can conclude that a high velocity is required to impact the dense aluminium I chose for the simulation. Stress occurs in many forms across the material, from tensile and compressive stress and direct strain.

3. Introduction

This report will cover the topic of direct and shear stress onto an aluminium plate from a ballistic projectile. Before we can go into depth on the stresses present in the plate after running the simulation on Abaqus, it is vital to understand direct and shear stresses.

A simple direct stress can be defined as either tension or compression of the material, a simple strain of a material is defined as the change in length of the material from its original length. It is a measure of the deformation produced by an applied load. Direct stress produces a change in length in the direction of the stress. [1]

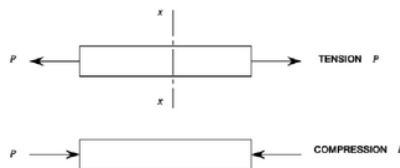


Figure 1 - Tension/Compression [1]

Tensile stress can be defined as a stress that stretches or lengthens the material. Compressive stress tends to compress or shorten the material and shearing stress tends to shear the material and acts in plane with the stressed area at right-angles to the compressive or tensile stress. [1]

Poisson's ratio is the ratio of the relative strain in any angle normal to the applied load, to the relative extension strain in the direction of the applied load. When a material is stretched in one direction it tends to get thinner in the other two directions. [2]

Young's modulus sometimes referred as Modulus of Elasticity is a measure of stiffness of an elastic material. It is used to describe the elastic properties of objects when they are stretched or compressed. It can be used to predict the elongation or compression of an object as long as the stress is less than the yield strength of the material. [3]

"ratio of stress (force per unit area) along an axis to strain (ratio of deformation over initial length) along that axis" [3]

$$E = \frac{\text{Stress}}{\text{Strain}}$$

Hooke's Law is a law of physics that states that the force needed to extend or compress a spring by some distance scales linearly with respect to that distance. He noticed that the stress/strain curve for many materials has a linear region. The force required to stretch an elastic object such as a metal spring is directly proportional to the extension of the spring. Pulling down on a spring will cause an extension of the spring downwards, which in turn will result in an upward force due to the spring and the restoring force. [4]

A Hertzian cone, is the cone produced when an object such as a projectile pass through a solid material, like a bullet through glass. It is a cone of force that propagates through the brittle material at the point of impact, showing through an impact wave passing through the material.

All solid materials can be measured in an elastic and plastic region when put under certain stress/strain. As the strain and stress both increase when putting a material under load, it will go through a phase known as the elastic region. Elastic region occurs when a material under load will return to its original form when the load is removed, the deformation caused is reversible. Whereas the plastic region is irreversible, this is a permanent deformation or change in shape under the action of a sustained force. There becomes a point in the plastic region where the material will reach its yield point and the material will fracture.

4. [Material Properties](#)

From background research of different grade aluminium, I chose 6061-T6, which is a very dense grade aluminium and has a very high yield stress, this can affect the way the material acts when placed under a certain stress/load. The chosen material will be subjected to several simulations run on Abaqus at different velocities to see how it performs. From figure 2, we can see the different values for the Aluminium. It shows all the values needed to input the data onto the simulation software Abaqus. [5]

Aluminium 6061-T6 [5]	
Density	2698.790709kg/m ³
Youngs Modulus	68.9 GPa
Poisson's Ratio	0.33
Yield Strength	310 a

Figure 2- Material Property Values

5. [Abaqus Procedure](#)

- Open the predefined model onto the Abaqus software (All parts have been created, with the bullet represented by an analytical surface, this part is rigid and will not required meshing, thus not being a deformable part.)
- Using research about different Aluminium properties, a suitable material will be selected and inputted into Abaqus (elastic and plastic regions).
- The predefined module will contain one instance of each part, and an Explicit dynamic solver has been created in the *STEP* module.
- The edges of the plate have been fixed, to allow the plate to stay fixed in position when the impact of the projectile takes place.
- In the pre-defined field output, the velocity of the bullet can be edited for different striking speeds of the projectile.
- The job has been created on Abaqus and once all data for the material properties are inputted, the task can be submitted to record data.
- The visualizer can then be opened and the various direct and shear stresses can be inspected, also the velocity of the projectile.

6. [Results](#)

The speeds selected for the velocity of the projectile were 100ms⁻¹, 200ms⁻¹ and 400ms⁻¹. At these speeds we can establish whether there is penetration of the projectile onto the aluminium plate. This can be shown by either positive tensile stress and negative compressive stress acting across the plane of the impact area.

The Abaqus software allows you to view the simulation in various different planes/angles to show the different forms of stress that are taking place. The Max Principal setting shows the maximum tensile and compressive stress denoted by a scale of colour to indicate the amount of given stress. Another viewpoint is called S23 which indicates shear stresses.

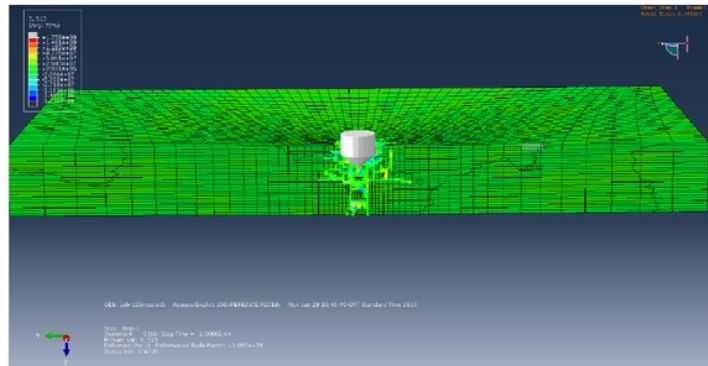


Figure 3 - Max Principal 100ms^{-1}

Figure 3 shows the impact velocity onto the plate of aluminium at 100ms^{-1} . This image shows the positive and negative tensile and compressive stress taking place. The light/dark blue shows the negative compressive stress and the positive tensile stress is shown by the light green colour. The scale is shown in Pascals, so a range of $5.861\text{e}07\text{ Pa}$ - $-1.455\text{e}08\text{ Pa}$ is shown from the projectile hitting the plate at 100ms^{-1} .

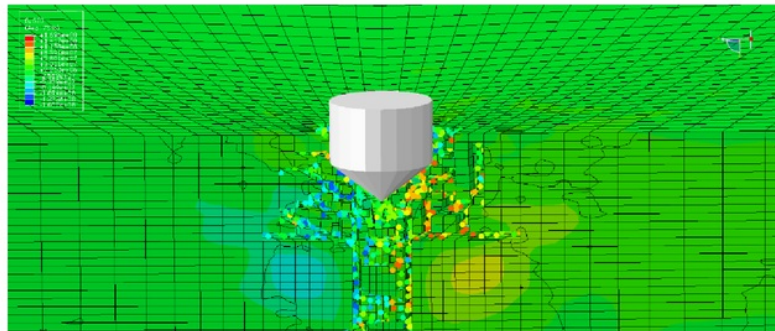


Figure 4 - S23 100ms^{-1}

Figure 4 shows the S23 view from Abaqus and the shear stress into the plate. The patches of colour show the range of force in pascals applied to the material. The projectile did not penetrate the material but shear stresses have occurred in the material past the point of impact. From the image you can see stress waves formed, compressing the material. The mesh of the material has been altered due the force applied, shown from the nodes of material moving from the place of origin.

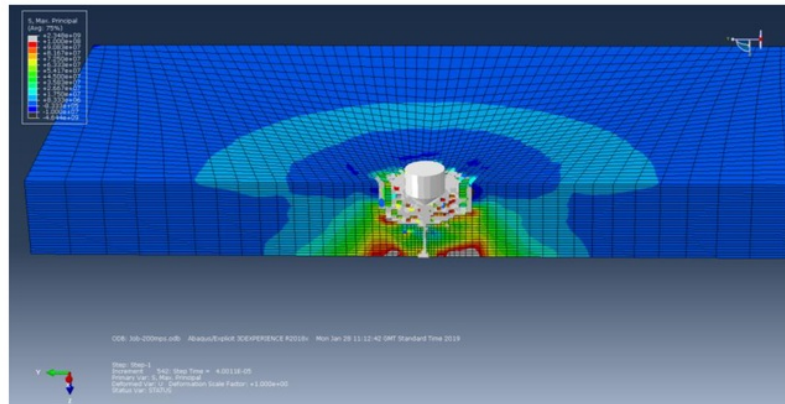


Figure 5 - Max Principle 200ms^{-1}

Figure 5 shows the projectile at a velocity of 200ms^{-1} . We can see the projectile has impacted the plate causing large stress waves to propagate through the material. The force applied ranges from $-4.644\text{ GPa} - 2.348\text{e}08\text{ Pa}$, the negative compressive stress is denoted by the blue/grey colour on the scale and the positive tensile stress shown by the green/red colour. Positive tension dominates shear stress and can cause spalling of material from the impact.

Spalling occurs when the material reaches its yield point in the plastic region and starts to shatter and break away from the original piece of material. As the projectile is not forced all the way through the plate, we can see the plate bowing the opposite side of the impact.

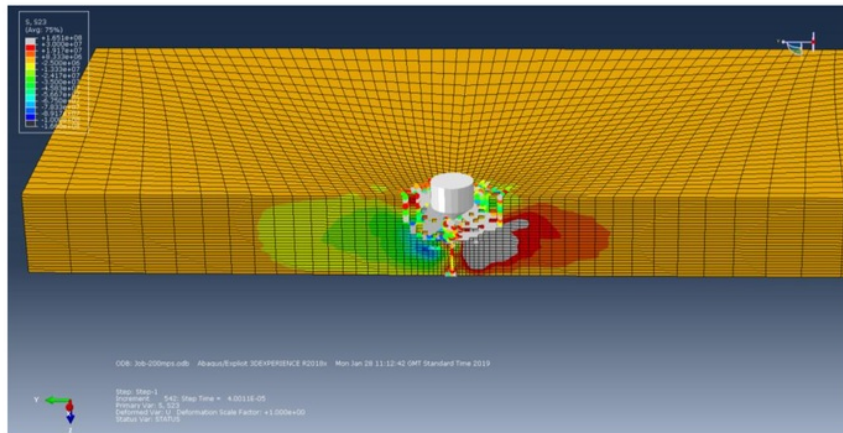


Figure 6 - S23 200ms^{-1}

Figure 6 shows the S23 viewpoint for 200ms^{-1} . It shows the shear stresses acting on the plane upon impact of the projectile. The grey area shows a saturated area of stress where it is above the scale. This shows the stress wave propagating through the plate as the projectile is embedded into the aluminium. The image shows a screenshot just after the projectile hits the plate, due to the density of the plate the projectile is stopped from passing all the way through but still causes fragments of material to break away.

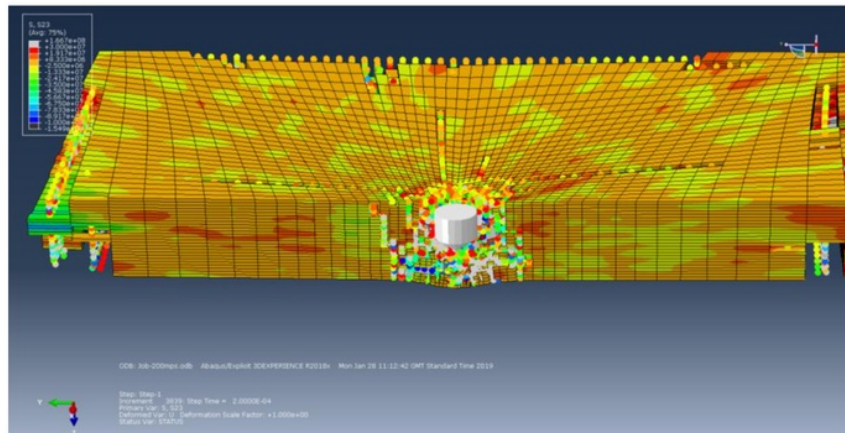


Figure 7 - S23 200ms^{-1}

Figure 7 shows the projectile embedded into the plate to its final point from the chosen speed. It shows the projectile has not penetrated through the plate fully but has caused deformation of the plate shown by the bowing opposite the impact area. Although the impact was central to the plate, it can clearly be observed that further damaged has occurred towards the edge of the plane. This could be due to stress waves propagating through the material causing scabbing/spalling of material from impact. The impact causes a rippling effect in the plate causing the damage to carry further through the material.

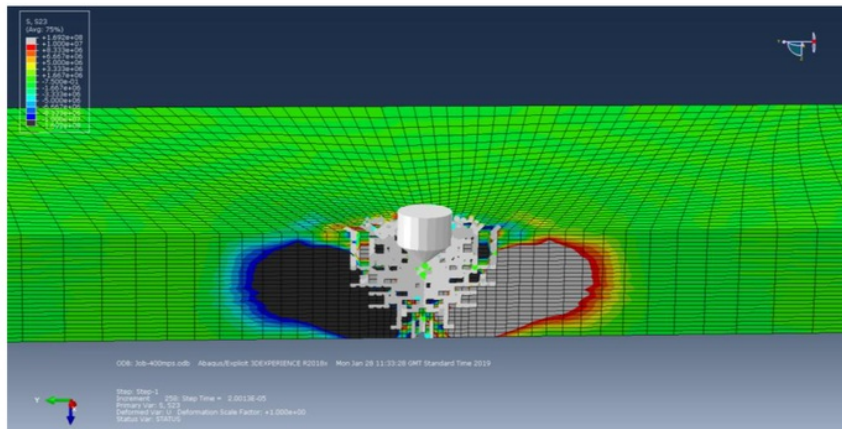


Figure 8 - S23 400ms^{-1}

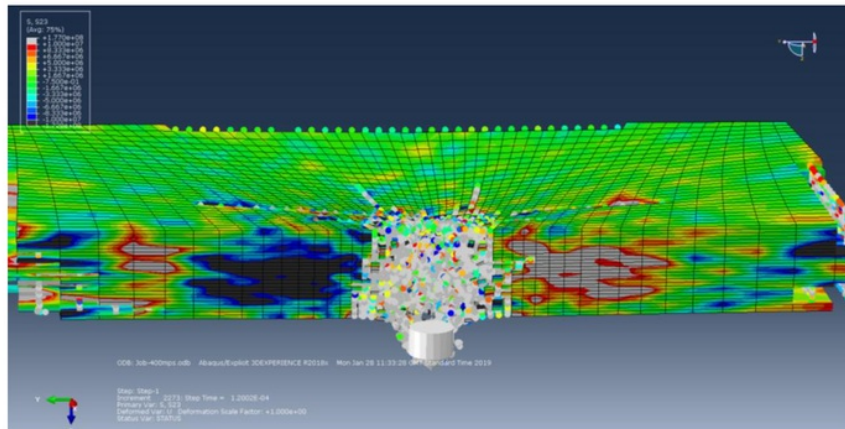


Figure 9 - S23 400ms⁻¹

Figure 8 & 9 show the final speed of 400ms⁻¹ in S23 view. As the projectile impacts with the plate, a huge amount of shear stress occurs across the plate and propagates through the material, this could be likened to a Hertzian cone, where there is rounding at the point of impact. There was enough force from the projectile at this speed to penetrate through the plate. It has caused scabbing of material to be ejected through the point of entry and exit.

The projectile has perforated the underside of the plate due to the amount of force generated at the higher speed. The colour blue denotes the negative shear stresses occurring in the plate and the red/orange show the positive shear stress. This ranges from 1.770e08 Pa - -1.720e08 Pa.

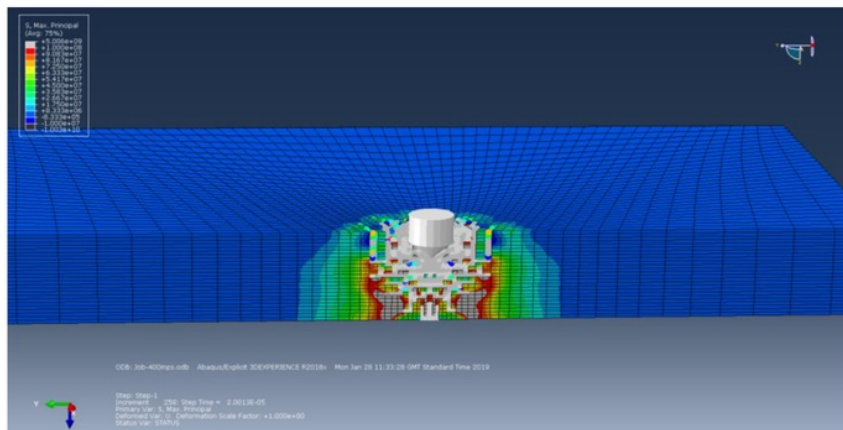


Figure 10 - Max Principal 400ms⁻¹

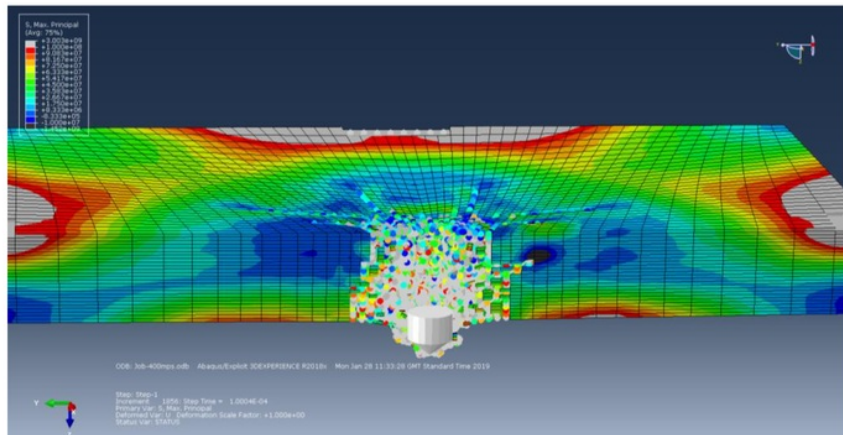


Figure 11 - Max Principle 400ms^{-1}

Figure 10 & 11 show the positive tensile and negative compressive stress taking place at 400ms^{-1} . Figure 10 shows the projectile just coming into contact with the plate, it shows how the positive and negative stresses form through the plate with the greatest force being that in contact with the tip of the projectile. The grey areas show saturation from the scale not registering the amount of force being applied.

Figure 11 is the post impact from the projectile, it has clearly perforated through the underside of the material and caused huge amounts of spalling as material is ejected from the exit hole. The grey saturated areas are now nearer the edge of the material where the waveform has propagated through and caused damage. As positive tension dominates the shear stress this is what causes the spalling of the material.

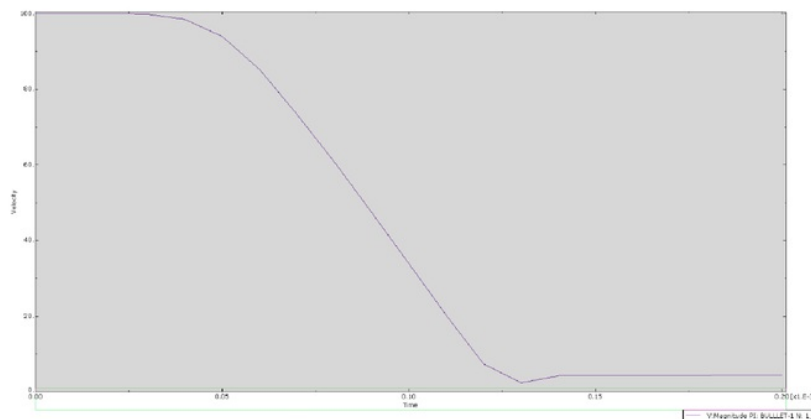


Figure 12 - Velocity Graph 100ms^{-1}

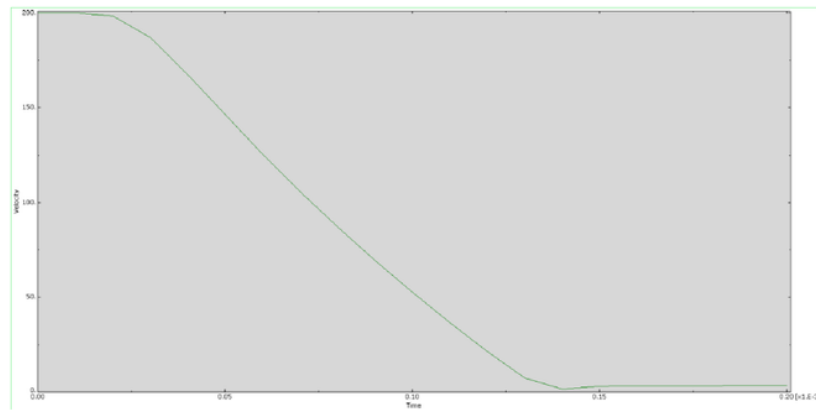


Figure 13 - Velocity Graph 200ms^{-1}

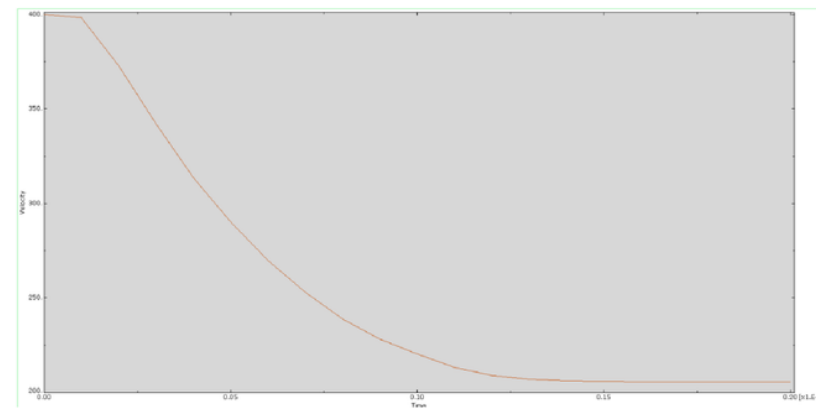


Figure 14 - Velocity Graph 400ms^{-1}

The above graphs show the velocity of the projectile at each given speed. It shows the point of impact and how the projectile slows down as it passes through the material. We can see from figure 12 & 13 that at the lower speeds the projectile loses its speed very rapidly, there is some sort of bounce back of the projectile as it becomes embedded into the plate. At the higher speed we can see from figure 14 that the projectile is still travelling at around 200ms^{-1} after exiting the plate and never comes to a stop.

7. Conclusion

The experiment has shown the different forces that occur when firing a projectile at different velocities into an aluminium plate. With varying speed comes varying stress and force applied onto the plate. We can see waveform propagation occur in every run speed but the damage amassed from the impact is widely different.

We can clearly see direct stress and strain from the material as it is being compressed from the initial impact from the projectile, passing through the elastic range of the material property and into the plastic range, where we can see catastrophic failure of the material when scabbing/spalling occurs. From both the slower velocity runs, we can observe that the projectile velocity was too low to penetrate fully through the target. The 400ms^{-1} run has a higher projectile velocity and it is higher than the ballistic limit of the plate, shown by the projectile passing fully through the plate. From this we can establish that the velocity of the projectile needs to be between $200 - 400\text{ms}^{-1}$ in order to penetrate the aluminium plate.

The data produced from running the simulations show a scale of colour denoting the force applied in Pascals, to make this more accurate, the scale was altered for each shot to show a better scale of force applied in the simulation. There are some discrepancies in the fact that the grey/black colour shows the saturation points so not a true measurement of the force applied.

The size/thickness of the plate will make a difference to the simulation, due to the stress waves propagating through the material, there could be some stress waves reflected from the edge of the plate back into the middle, causing more damage. The projectile itself was a rigid non-deformable object and in the real world would deform on impact. Some of the force applied into the plate would be absorbed into the projectile, to get a truer representation of this model, more experiments would need to be run in order to account for the non-deformable projectile.

References

- [1]. *CodeCogs*. (n.d.). Retrieved from <https://www.codecogs.com/library/engineering/materials/direct-stress-and-strain.php> (Accessed 03/03/2019)
- [2]. *Engineering Toolbox*. Retrieved from https://www.engineeringtoolbox.com/poissons-ratio-d_1224.html (Accessed 04/03/2019)
- [3]. *Engineering Toolbox*. Retrieved from https://www.engineeringtoolbox.com/young-modulus-d_773.html (Accessed 04/03/2019)
- [4]. *Khan Academy*. Retrieved from <https://www.khanacademy.org/science/physics/work-and-energy/hookes-law/a/what-is-hookes-law> (Accessed 04/03/2019)
- [5]. <http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=ma6061t6> (Accessed 24/02/2019)