

CAE Assignment 1

by Jess Eardley

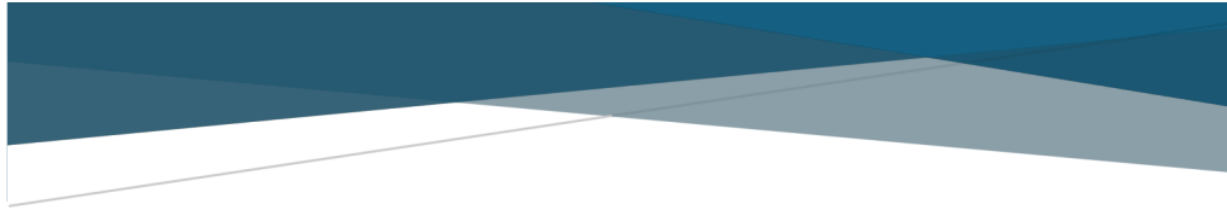
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Application of Computer Aided Engineering Processes

CAE ACDB5007

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Abstract

This report contains the simulations of a 30mm Tungsten Alloy Projectile, travelling at 700m/s and hitting a target plate of three different materials including, Steel 4340, Aluminium 6061-T6 and Polycarbonate. Each simulation was configured before the analysis of deformation and strain was conducted on each plate. The validation of the results was then discussed and compared to literature reports. The Polycarbonate plate behaved differently from what was theorised and the stain values were much less than predicted. CAE as a tool is then analysed using the simulations as a reference. This report concludes the benefits and limitations of using CAE tools. The benefits and importance of CAE tools are recognised.

1. Introduction to CAE

Computer-Aided Engineering (CAE) refers to the use of technology to assist in the tasks relating to engineering analysis. It requires using various tools and techniques that assist the engineers throughout the design process [1].

CAE is used across various industries such as automotive, aerospace, mechanical and chemical engineering. It is typically used for aiding in decision-making, reducing development time and improving the end product's performance [2]. Engineers use CAE tools to simulate fluid dynamics, structural mechanics, heat transfer and electromagnetic fields on designs created in 3D design software [1]. Using CAE tools, engineers can generate design iterations faster, allowing them to explore multiple design ideas virtually instead of building and testing many prototypes which is both costly and inefficient [2]. CAE can assist engineers in identifying design flaws early in the development process and improve product performance [1].

Types of CAE tools used:

- Finite Element Analysis (FEA)- used to perform stress analysis on components and assemblies to understand the effect of real-world stresses and environmental factors such as heat and vibration [1].
- Computational Fluid Dynamics (CFD)- used to simulate how fluids or gas flows around or through an object [1].
- Multibody Dynamics (MBD)- used to analyse the interactions between all the joints in a component work with each other [1].
- Computer Aided Manufacture (CAM)- uses tools and processes used to manufacture highly precise components and/or optimise the manufacturing process [1].
- Computer Aided Design (CAD)- uses 2D and 3D drawing software to create parts, assemblies and annotated drawings for machining or 3D printing [2].

2. Simulation and Modelling

Investigated in this report is the effect of deformation and strain by an Armour-Piercing (AP) Projectile on a target plate of different materials.

The software used to design the projectile and target plate was SOLIDWORKS by Dassault Systems [1]. Solidworks is a 3D Computer-Aided Design (CAD) software that includes design, simulation, cost estimation, manufacturability checks, Computer-Aided Manufacturing (CAM), sustainable design, and data management [3]. Solidworks creates fast and accurate designs [4] for the manufacturing and engineering industries such as mechanical, automotive, aerospace, and civil. Therefore, in this application, it was suited for the creation of the models.

The model comprises a 30mm diameter projectile (created using 2D sketches and extrudes) and a 500mm square plate (drawn in 2D sketches and extruded to thickness), 15mm thickness. The projectile is based on the design of the '30mm x 173 Ammunition Suite For MK44 Cannon' [5]. Using an engineering drawing of the ammunition and creating the design in Solidworks. These components were then added to an assembly to create the interaction between them, mates, to fix the projectile's position to the centre of the plate with a small offset between them. This was then saved as a 'STEP' File.

The simulation software used was Ansys [6]. Ansys has a variety of simulation options within the software. The best option was the Explicit Dynamics. Explicit Dynamics used for a high-velocity ballistic event will produce non-linear results [7]. The explicit dynamics suite allows the capture of the physics involved with short-duration events that undergo highly non-linear, transient forces [7]. Ansys gives the user insight into how the components respond under server loadings resulting in large material deformation, material failure, material fragmentation and penetration mechanics [7]. Ansys's algorithms are based on first principles to accurately predict these responses [8].

Each simulation was created and outlined further in this report as well as the challenges of using these CAE tools.

2.1 Simulation and Model Set-Up

The model in Figure 1 displays a 500 x 500 x 15 mm plate and 30mm x 173mm projectile designed in SolidWorks using a MK239 round [5], as design inspiration.

The setup conditions are input first. The control variables, the variables to stay the same in each simulation, the material, velocity (700m/s) and direction of the projectile, mesh sizes of both the projectile and the target plate, the fixed supports on the plate and impact area for each simulation. For each simulation, the solutions analysed are total deformation, deformation of the impact plate and maximum strain on the target plate. This allows for a comparison across the simulations.

Fixed supports are added to the edges of the plate as this is where the plate would be fixed in a real-world scenario. The faces are selected and added to the initial conditions.

For the simulation to work realistically and effectively the projectile had to be a ridged body as for the first few simulations, the projectile disintegrated. The damage investigation focuses on the target plate, the damage to the projectile didn't need to be measured so this could be changed to ridged.

Figure 6 displays the engineering material library within Ansys. The simulation materials were selected from the explicit materials section as they contained the relevant damage properties for the simulation requirements to obtain accurate solution results. This is not an exhaustive list of materials and new materials could be created using material data found in scientific literature. The level of accuracy of the material properties directly correlates to the accuracy of the strain and deformation results.

To increase the validity of the results, it is important to understand what materials are required beforehand and create new materials to not depend on the data already held in the Ansys software as this could contain errors, not the right material properties or not have the most up-to-date material data. This information could be obtained from literature or by conducting appropriate testing methods such as tensile testing and hardness testing.

Once the materials and fixed supports and the relevant analysis setting are set up the simulation can be run. The simulation provided the analysis of deformation and strain on the target plate. The data was also collected along with a graphic displaying the strain and deformation values in varying colours to represent the amount of deformation or stress the target plate is undergoing. This shows what is happening at a specific timeframe but if presenting to customers face to face a video clip can be produced to display all time steps.

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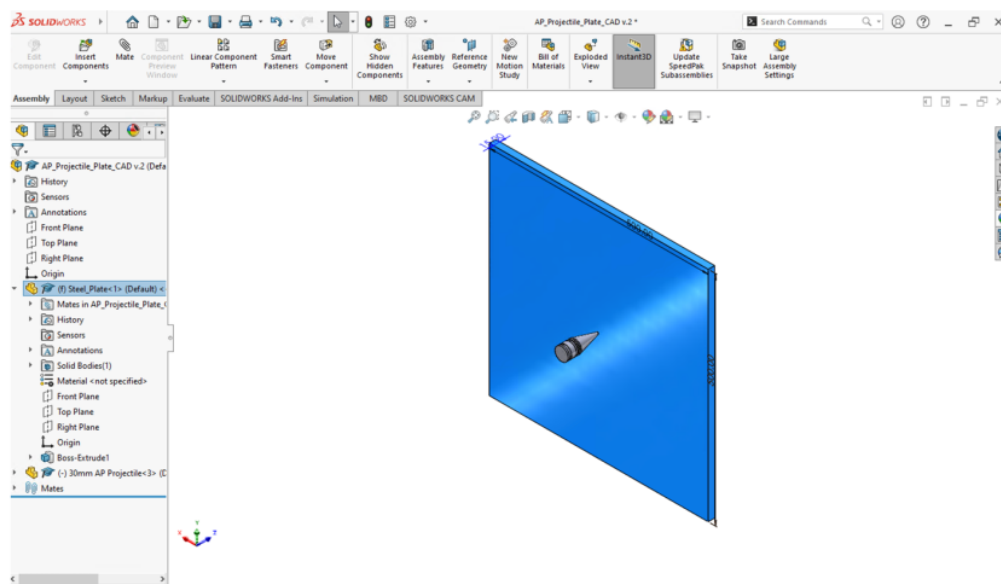


Figure 1 SolidWorks CAD model of projectile and target plate.

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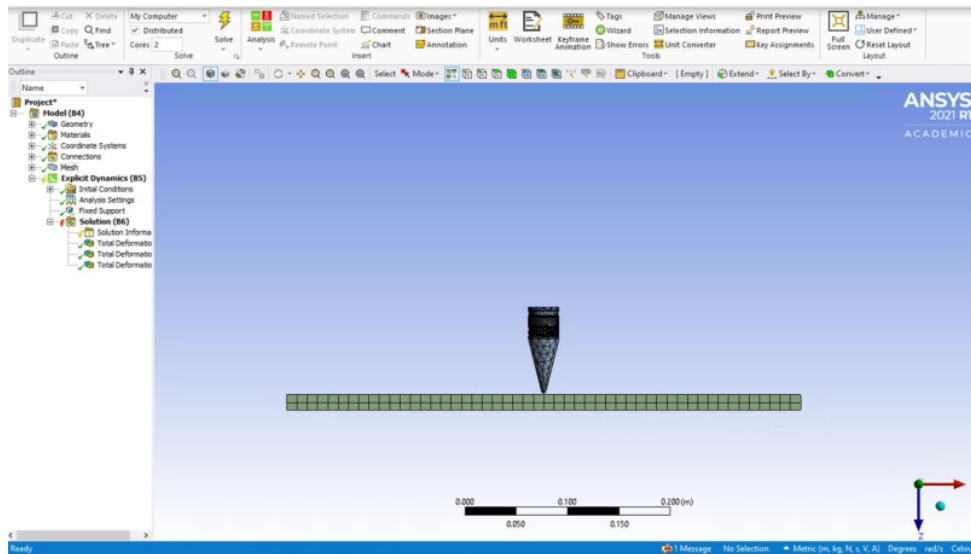


Figure 2 New project in Ansys of the projectile and plate.

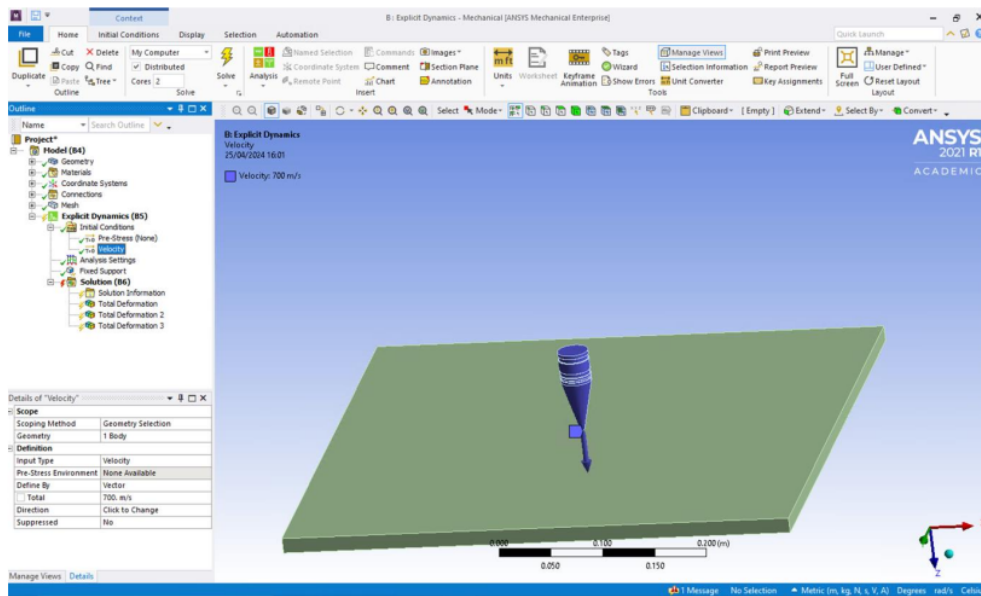


Figure 3 Simulation Set-up Velocity and direction on the projectile.

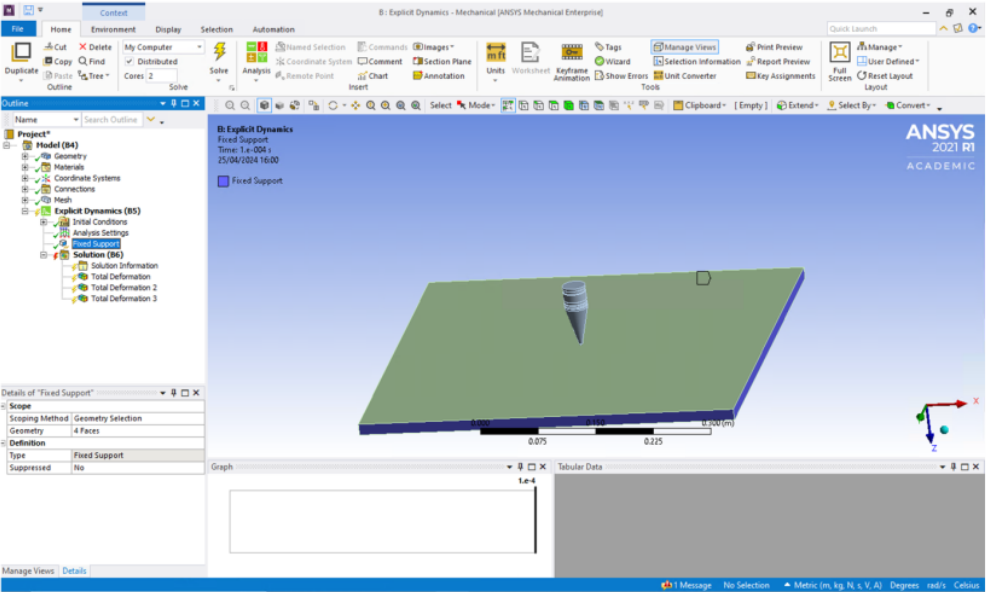


Figure 4 Simulation Set-Up fixed support added to 4 faces.

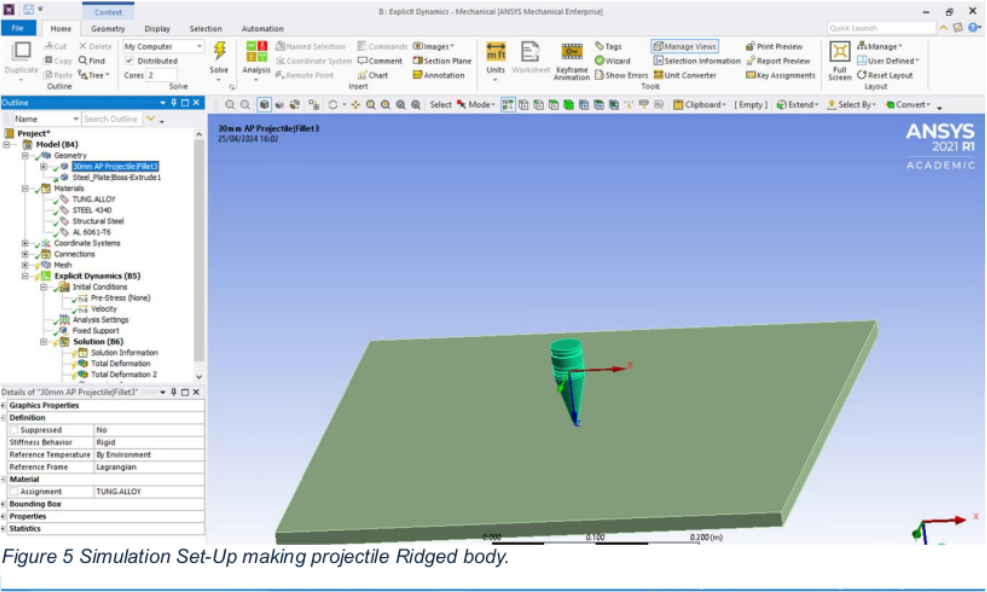


Figure 5 Simulation Set-Up making projectile Ridged body.

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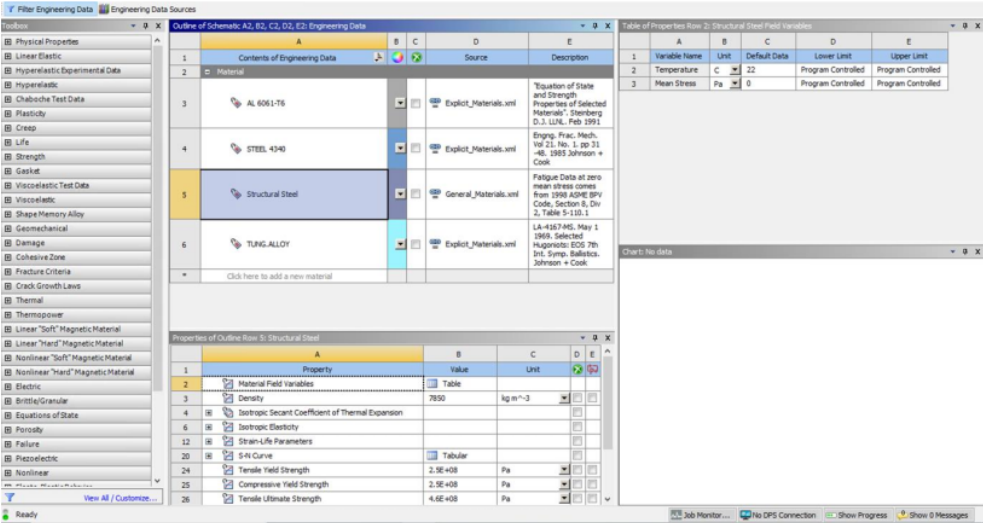


Figure 6 Ansys material data.

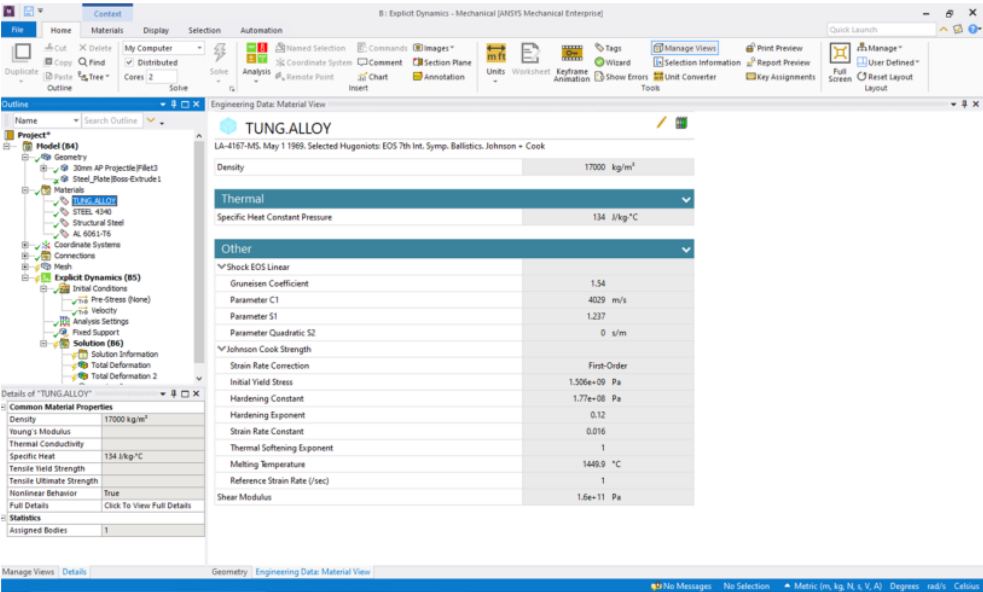


Figure 7 Ansys Explicit Material chosen for projectile.

2.2 Simulation Steel Target Plate

Figure 8 displays the results after a Tungsten Alloy AP Projectile is fired at a Steel 4340 target plate. The material for the target plate is shown in Figure 10. The velocity and direction of the projectile can be seen in Figure 3.

The simulation results show the projectile passing through the target plate displaying the amount of deformation and strain. The maximum deformation of the plate is 0.325m (3 d.p), as seen in Figure 8. "The efficiency of a metal plate can be estimated from its plastic deformation after impact. This is an important mechanism of kinetic energy absorption from the projectile during penetration" [9]. The max deformation value shows the elements that have broken off the plate as fragmentation. As the centre section of the plate has excessively deformed, it can be seen from Figure 8 that a hole has been left behind of approximately 30mm, which was the size of the projectile, therefore displaying some petaling. Due to the majority of the force being concentrated through the centre of the plate, it can be noted that there is little to no deformation around the outside edges. Due to steel having some ductility, it allows only the centre of the plate to catastrophically fail while maintaining integrity on the outer edges.

Figure 9 displays the max strain value on the plate. The strain values increase as the projectile moves through the plate creating a ripple effect. The plate undergoes a max strain value of 0.0051 and from the change of colours on the plate, the strain ripples to the outside edges where some of the strain then reflects towards the centre.

These values can be compared to this source [10], however, the projectile and thickness of the target plate are much smaller, and the materials have different properties. For this simulation, it is best practice to perform the same simulation using a different simulation software to validate the results.

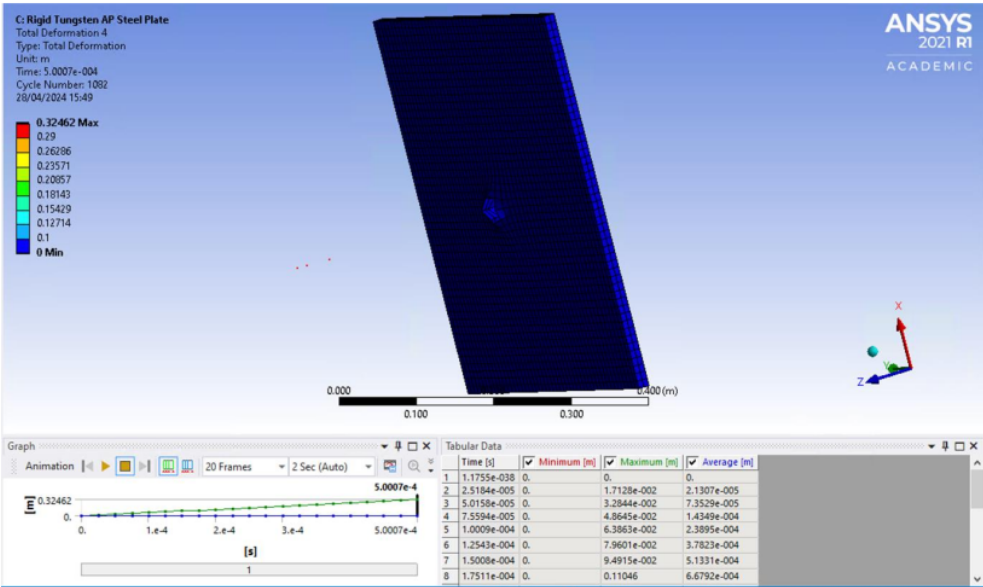


Figure 8 Simulation results of deformation on Steel 4340 plate.

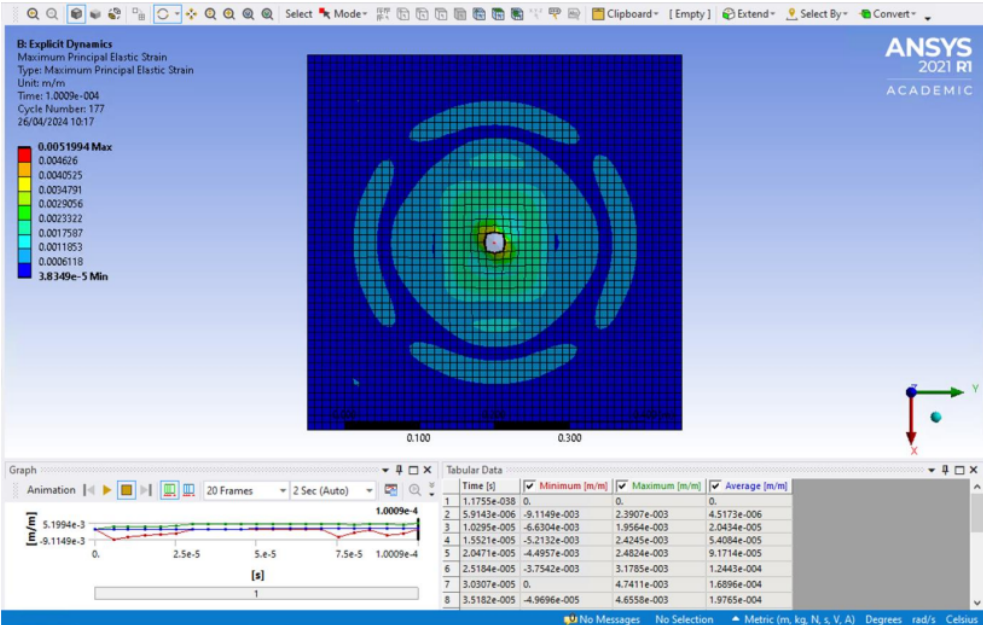


Figure 9 Simulation results of strain on Steel 4340 plate.

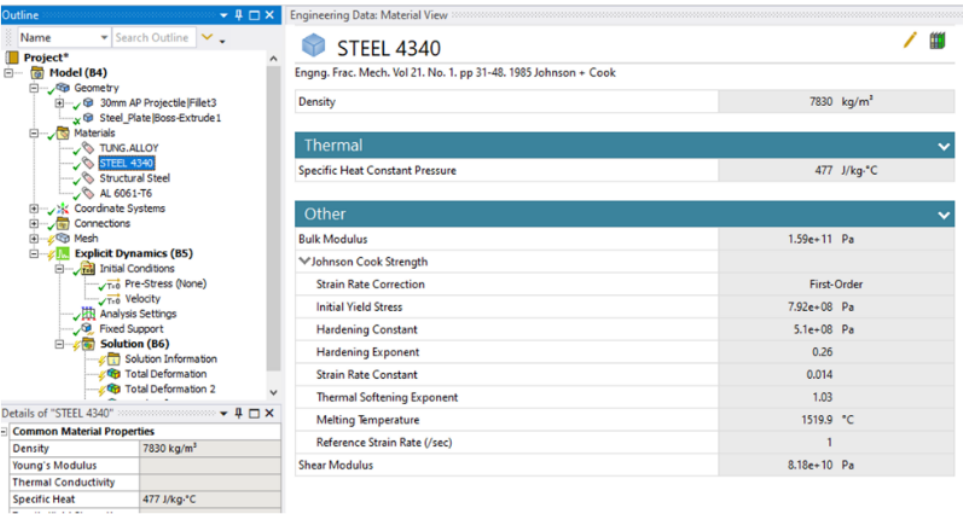


Figure 10 Ansys Explicit material Steel 4340 for target plate.

2.3 Simulation Aluminium plate

Figure 12 displays the test of the Tungsten Alloy AP Projectile, fired at an Aluminium 6061-T6 (AL) target plate. The material for the target plate is shown in Figure 11. The velocity and direction of the projectile can be seen in Figure 3.

Figure 12 displays the deformation of the AL plate. The max deformation is 0.354m (3 d.p). The max value of deformation refers to the nodes projected away from the plate as they have changed to most shape and travelled the furthest. The petaling is similar to that of the Steel 4340 plate as well as the value of deformation almost being the same. The projectile was able to perforate the plate leaving a hole around 30mm, the size of the projectile, in the centre.

Figure 14 displays the stain on the AL plate from the ballistic impact of the projectile. The Maximum strain is 0.011 (3 d.p) a larger strain than the Steel 4340 plate. This is due to the differences in material properties and the metal at a molecular level.

To validate this model, a similar test was performed in the literature. In this literature, Figure 16, page 609 [9], is a similar visual result to the result of this simulation that displays the plastic strain and deformation of the plate. However, the literature source uses Aluminium 6061-T651, Aluminium 1100-H12 and Magnesium ZK61m [9]. Using the materials consecutively as the target plate. This is not an ideal test to validate against but literature specific to the test modelled in this report is hard to find. If testing new ideas, there will be no literature to support the validation. In this case, a live test or trial will be required.

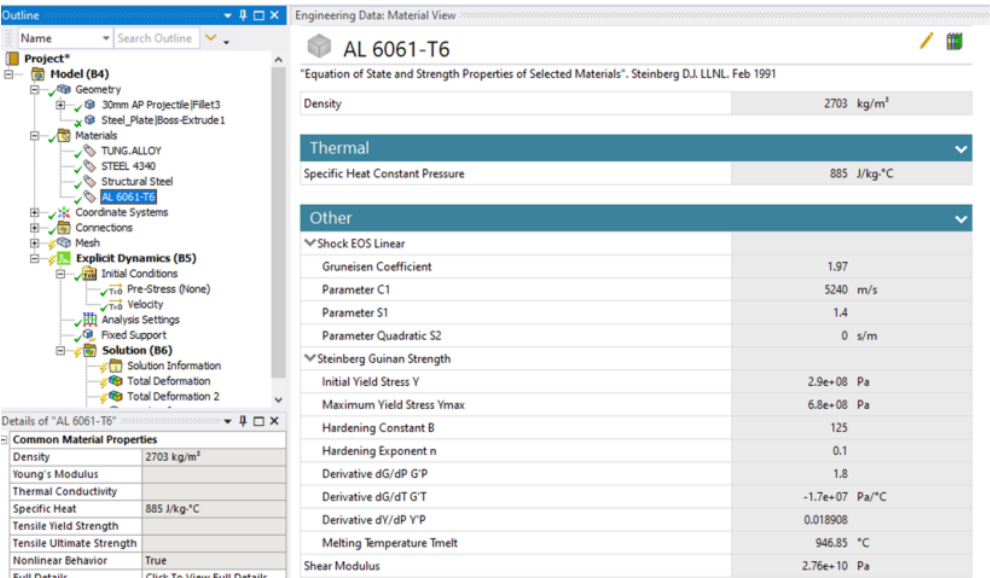


Figure 11 Ansys Explicit material Al 6061-T6 for target plate.

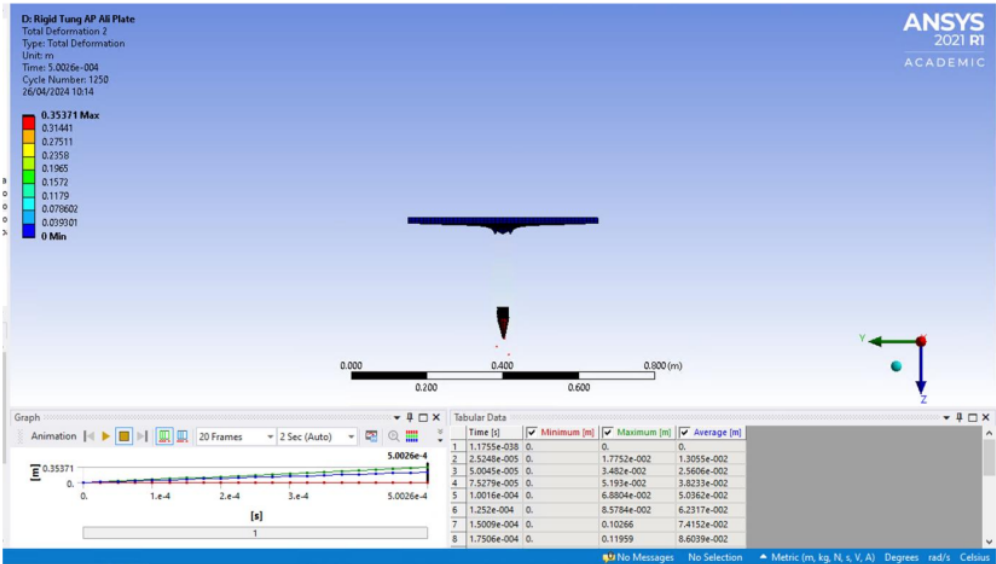


Figure 12 Simulation results of deformation on Al 6061-T6 plate.

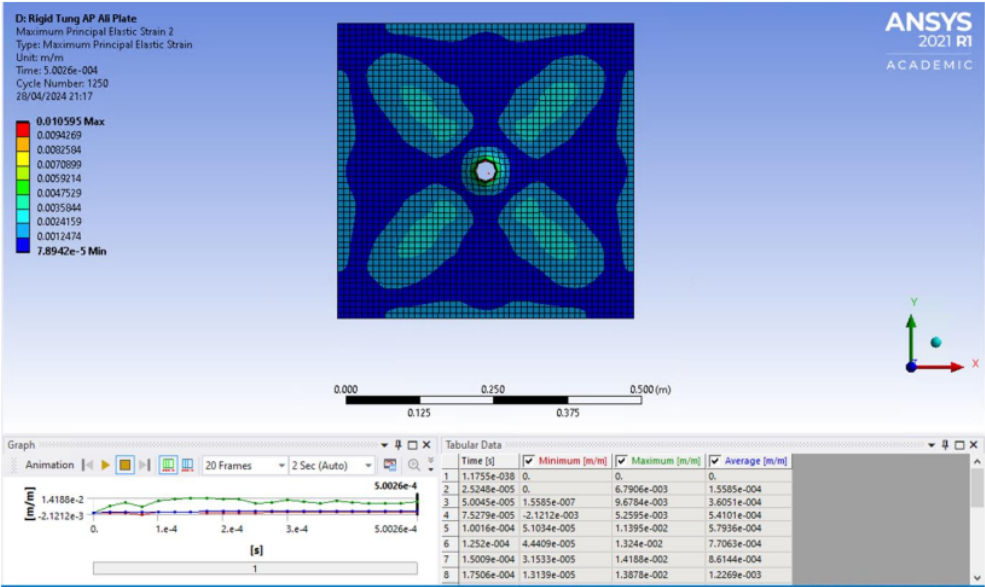


Figure 14 Simulation results of strain on Al 6061-T6 plate.

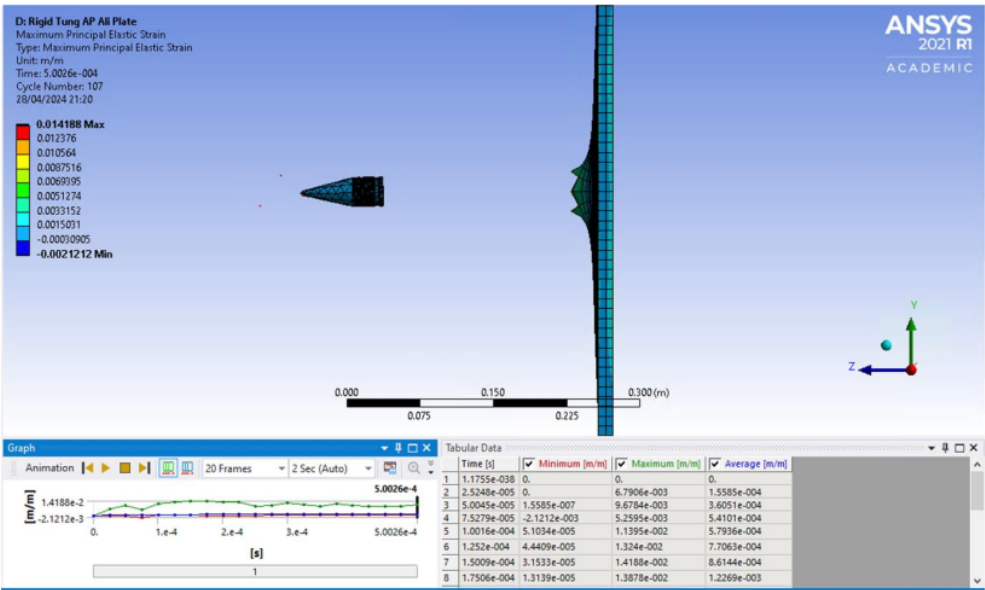


Figure 13 Simulation results of strain on Al6061-T6 plate and Projectile.

2.4 Simulation Polycarbonate Plate

Figure 15 displays the test of the Tungsten Alloy AP Projectile, fired at a Polycarbonate (PC) target plate. The material for the target plate is shown in Figure 17. The velocity and direction of the projectile can be seen in Figure 3.

Figure 15 and Figure 16 displays the deformation of the PC plate after perforation by the projectile. The max deformation is 0.077m (3 d.p). The max value of deformation refers to the nodes projected away from the plate as they have changed to most shape and travelled the furthest. The petaling is similar to the other simulations but the petaling is sharper and less curled than the others. The plate did not deform as expected the possibility of it shattering completely was theorised however this is not the case.

Figure 18 displays the strain on the PC plate from the ballistic impact of the projectile. Max strain is 0.016 (3 d.p) the largest strain value of all of the materials simulated in this report. This material is a thermoplastic used for its strength and flexibility [11], hence the strain value will be much different to the metals also simulated.

Polycarbonate laminated with glass is used as Bullet resistant glass [11] however, without the lamination polycarbonate is unable to capture or stop the 30mm projectile from perforating through the plate. It should not on its own be used as a protective shield against 30mm projectiles as the material will fail catastrophically.

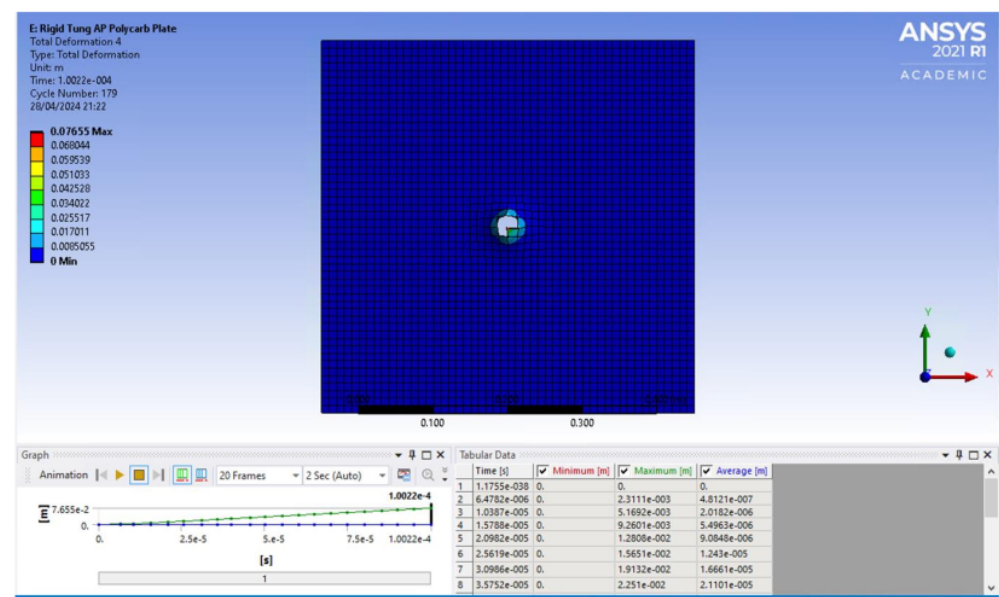


Figure 15 Simulation results of deformation on Polycarbonate plate.

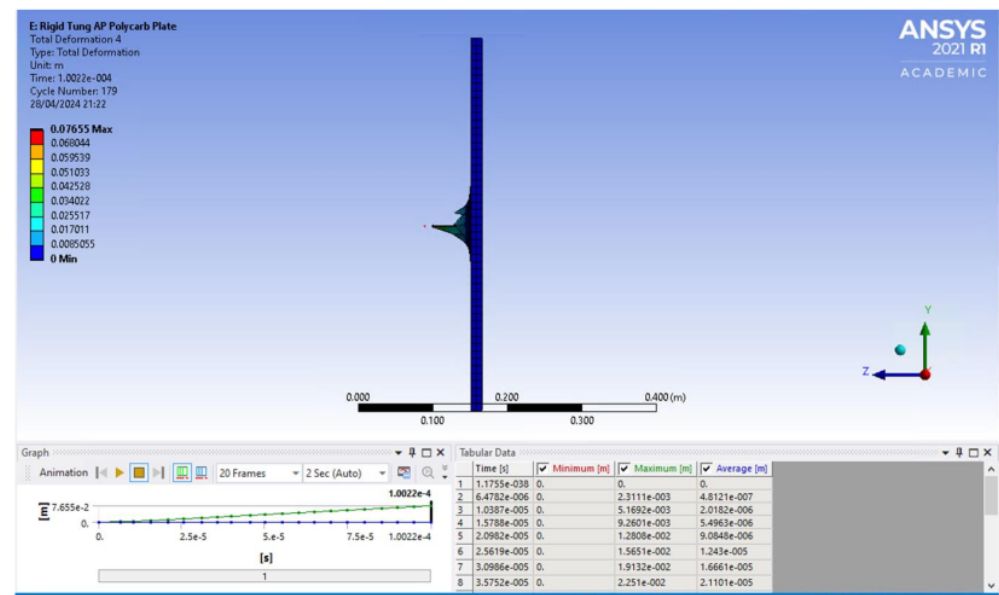


Figure 16 Simulation results of deformation on Polycarbonate plate.

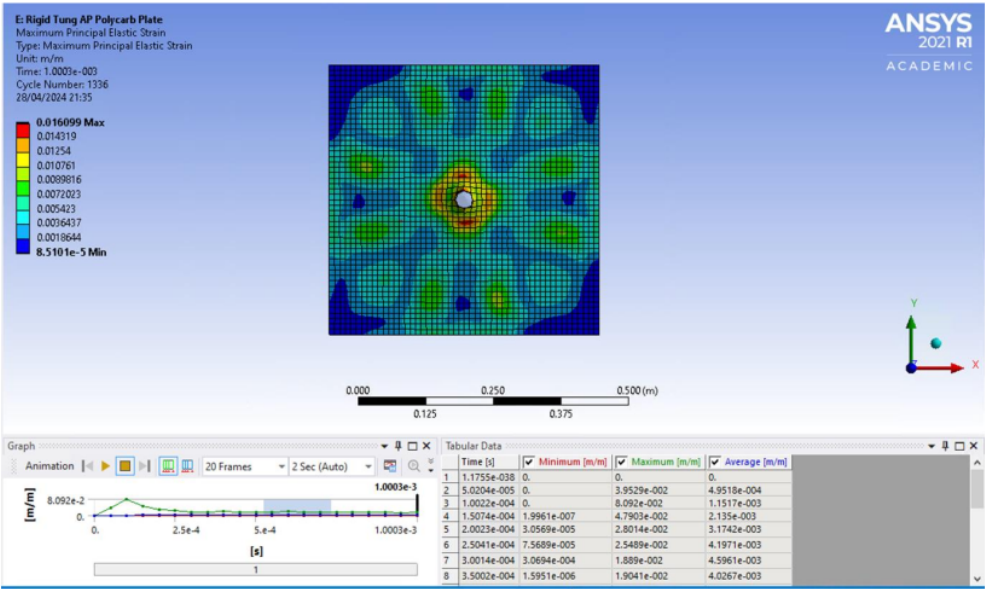


Figure 18 Simulation results of strain on Polycarbonate plate.

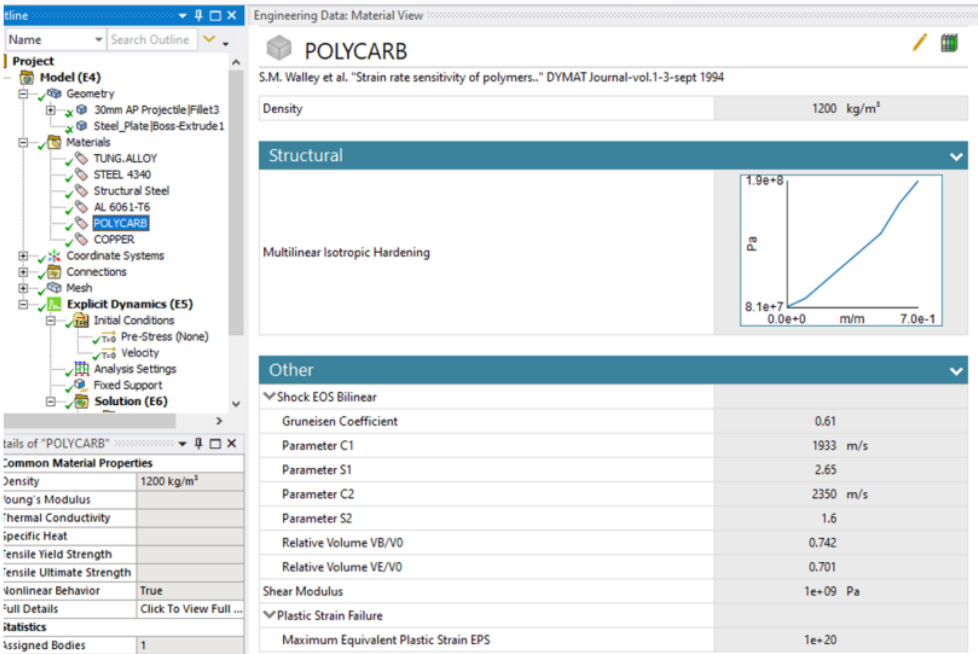


Figure 17 Simulation results of strain on Polycarbonate plate.

2.5 Simulation Analysis

The results from the simulations for aluminium and steel were very similar. The deformation values were 0.354m and 0.325m. Both metals also had a similar breakage pattern in the plate and had similar petaling. The polycarbonate plate had a deformation of 0.077m. This was as theorised as there was an expectation for the plate to completely shatter. The material properties were not as extensive as the aluminium and steel data from the Ansys materials data sources. For best results the simulation should be run again with a more defined material, this information could be gathered from literature sources.

The stain on all plates showed the stain values increasing in different patterns across the plate. Using the simulation data this way gives a visual representation of where the stain is felt across the target plates. This aids the analyst in understanding the forces acting upon the plate to make better conclusions on the data set. The stain values of the steel 0.0051, Aluminium 0.011 and polycarbonate 0.016 show that the aluminium and polycarbonate plates have the most similarity. However, the steel could have been an anomaly or down to the material properties having differences. The range between the strain results is 0.0109.

All the simulations show the projectile perforating the target plates, small fragments breaking off and leaving behind a similar-sized hole in the centre approximately the diameter of the projectile.

From the simulations it can be seen that the Polycarbonate deformed the least, however, the steel had the lowest strain value. All target plates in these dimensions would be a poor choice of protective material against a 30mm tungsten alloy projectile.

For each simulation, a validation was searched for to compare the results of the simulation to other trials, tests, and simulations. Finding literature material for each simulation was difficult as for each literature source there were many differences in conditions, materials, velocities of projectile and size of projectile. To validate these simulations, it would be advised to use real-life trials and tests to validate the results. This testing however comes with many risks and is costly. Therefore, not all simulations will be able to have real live trials as validations of the simulation's performance.

The simulations can prove helpful with the correct validation techniques such as theory calculations and other trials and test data. These validation techniques have their limitations, as it cannot be determined how accurately the trials are conducted and the exact extent of environmental factors. Trials and tests completed by others may have been conducted 10 years prior and many theories and equipment have changed drastically since then. Therefore it is unfair to compare a simulated model too as the information is dated.

3. Analysis of CAE

3.1 Benefits

CAE tools such as CAD make designing much simpler and faster using software such as Solidworks [4] compared to manual drafting techniques allowing changes or improvements to be implemented earlier in the development process [12]. The designs can then be sent to a 3D printer for additive design manufacture for rapid prototyping [12]. This aids the engineering design team to visualise the design and develop the manufacturing process before mass-producing the final product [12]. CAD software allows for the creation of designs and continuous updates, designs can be shared between users provided they have access to the software with the relevant licence [1]. Access to the designs can be conducted on an international level, with the additional benefits of remote working and software like Microsoft Teams, enabling organisations to conduct their work on a much larger scale in shorter time frames.

Using CAE tools for simulating environmental factors reduces the number of real-life tests required or testing on a smaller scale to be completed and scaled up. This speeds up the testing process and reduces the costs of multiple large-scale tests [2]. Combining various CAE software e.g. Solidworks and Ansys enables a fast-paced, iterative process without the requirement of physical prototyping and testing. Thus, reducing time and resources as it reduces the requirement for testing [2].

3.2 Limitations

The simulation software requires training and engineering knowledge to complete and analyse the results. To set up the software knowledge of the material is required as well as knowledge of how to complete CAD modelling. Therefore, having a trained and experienced person to use and understand CAE tools requires time and money. Completing one simulation also isn't enough to conclude the results. There is not enough data to positively determine that the modelled example would happen in real life. Simulations are often backed up by real-life testing and trials as it is the only way to determine if the model will work as expected if it is used in a real-life scenario.

Other limitations to consider while using CAE tools are the limitations of using computer dependant software:

- Hardware failure, without proper back-ups the work can be lost, or the hardware may not be powerful enough to complete the task.
- Security risks, the computer or removable hardware could be infected with computer viruses that plant malware on the device to obtain information or corrupt files.
- Cost, CAE tools and software are not cheap and many companies such as Solidworks [3] charge more for extra packages.
- Updates, with new developments of software and bug fixes there is always a new version of the software on the market, it is best practice not to have dated versions of the software as this leaves the software with virus risks and unfixed bugs. [2] [3]

4. Conclusion

To conclude, simulations should be used as an advanced theory tool or highly educated guess as to what may happen in real life. Using CAE tools can reduce the time and cost of a project for a company however it must be noted that there is a significant cost of the system in the first instance along with continuous updates.

Thus, with technology advancements, CAE continues to improve product development through the use of simulations and CAD. Reducing the cost of multiple tests run or tests being conducted on a scaled product to validate simulation data.

Furthermore, with more information being stored on electronic devices connected to the internet there must be more security for these systems to control the use of malware. This can come at a continued cost. Systems must be backed up continuously to remove the possibility of work becoming lost, this increases the requirement for larger data storage.

Finally, CAE tools cannot be used on their own, infrastructure in the form of powerful computers, must be input, monitored and updated to run, store and protect data by CAE software. This creates job opportunities for engineers and designers that may have thought to be last when converting from analogue processes.

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CAE Assignment 1

GRADEMARK REPORT

FINAL GRADE

60/100

GENERAL COMMENTS

The layout and presentation of the report was good, it followed a logical structure and conveyed the information contained to a good standard. Where the text refers to figures, it would have been clearer if the figures were placed with the relevant text. Some minor errors in places, but generally good.

A reasonable overview of CAE tools is given in the early section of the report, this could have been a bit more specific and contextualized to this scenario, with more focus on the understood and accepted limitations of CAE. This would have then allowed your main results to be compared to earlier hypothesis.

Discussion of how the simulation was set up was logical, some more in-depth discussion about the materials used and some of the damage model information would have been nice to have seen. Also, more discussion about the meshing approach used would have been beneficial since it seems that some of the results being obtained may have been influenced by different mesh density levels being set on the target plate. This may have led to more representative results and would have been an interesting point to study. It would also have been good to have found similar studies from published sources to then make direct comparison of your results to theirs as a means of performing comparative analysis between data sets. This would have allowed for a greater level of critical analysis to be performed. You do discuss a similar test, but the visual results would have made this comparison clearer.

The difference in response between the target materials did follow some of the expected trends, with the polycarbonate plate displaying more brittle failure tendencies as would be expected. There were still discrepancies that were noted

which were perhaps worthy of further investigation to try and ascertain exactly what was causing them.

It would have been good, given that some of your results were proving to be anomalous, to then have conducted some very basic studies on simplistic case studies in a linear material range to determine if the software was capable of basic levels of accuracy prior to looking at the more complex non-linear studies.

Discussions of CAE as an engineering tool had some merit to them, and there were statements in there that were perfectly valid. This section could have had a more detailed and focused discussion drawing on the data you had generated in more depth to generate a more technical section of discussion with supporting evidence.

Literature has been used to a good standard in support of the document, although there was scope to use sources in a more specific way to generate comparative analysis points in the discussions.

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