Impact Testing of Sandwich Panels

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Sandwich panels are becoming increasingly popular in the aerospace industry due to their lightweight. Research is continuously being conducted to better understand their behaviour and develop cheaper and better sandwich panels. Sandwich panels are composite materials made by bonding two stiffer face sheets to a lighter core material. The majority of the strength of a sandwich structure comes from the two face sheets the core is designed to hold the two face sheets together and relative to each other. Sandwich panels are frequently used in the aerospace industry and they may experience impact loading as a result of several different situations. Such as dropped tools, debris from the runway, collision with birds and munitions. Impact loading can cause significant damage to these panels and as a result the panels can lose stiffness and strength. Consequently it becomes critical that an understanding of how sandwich panels respond to impact loading is gained in order to design better sandwich panels. In order to contribute to these understanding this project will compare the damage of several different sandwich panels under low velocity impact.

The aim of this project is to compare the damage of the sandwich panels, made of different materials and subjected to low velocity impact. All the testing was conducted in the Impact Lab at UNSW@ADFA.

This projected is limited to a very selective range of material, aluminium face sheets and five different cores, 80 Balsa, 150 Balsa, Cork, Polypropylene and Polystyrene. Also the size and shape of the projectile that was used for the impact was also restricted to the equipment available in the impact lab at UNSW@ADFA. The Vertical Gas Gun was used to conduct the tests. The damage was measured in several different methods, how it failed during impact and the subsequent damage and how much energy was absorbed per volume of damage.

I. Review of Existing Literature

In order to better understand sandwich panels in general, a review of existing literature was done looking at how sandwich panels are made, the different type of materials used and previous impact tests conducted on sandwich panels.

A. Sandwich Panels

Sandwich panels are composite materials made by bonding two stiffer face sheets to a lighter core material. Usually the face sheets are of same geometry, thickness and material. The way a sandwich panel behaves under a load is that the face sheets take the bending loads, one face in compression and the other in tension. The core gives support to the face sheets by spreading them apart and resisting the shear and compression loads. This increases the stiffness of the structure. Adhesive is used to join the sandwich components together. The sandwich then acts as one unit with a high torsional rigidity.[2]

The core can be made of almost any material; most cores are made of materials that fall into these four categories. Foam core (a), honeycomb core (b), web core (c) and truss core (d) as shown in Figure 2.[3]

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[2] Engineering Materials Inc., *Structural Composites and Sandwich Panels*, accessed 04 March 2013, < http://www.engineeredmaterialsinc.com/products/structural-composites-and-sandwhich-panels/>

[3] Bernard, L.A., *Low Velocity Impact Testing of Sandwich Panels with Polymeric Cores,* UNSW@ADFA, 2011

Figure 1: Layers of Sandwich Panel[4]

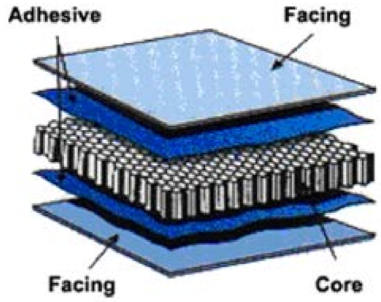
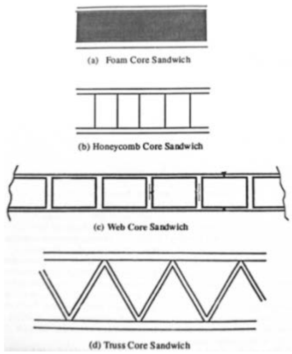


Figure 2: Different Cores of Sandwich Panel[5]



B. Impact Testing

In this part several different studies are reviewed. The aim of each study will be discussed as well as the conclusion that was drawn from the study.

Reddy, Wen, Reid and Soden's aim were to examine the performance of sandwich panels and panel elements under low-velocity impacts and the behaviour of sandwich panels and panel elements subjected to high-speed impacts by missiles designed to simulate explosively generated fragments. From their study they discovered that the core was very important for qasi-static indentation and low-velocity impact loading. The core controlled the order in which the various failure mechanisms occurred and predominated. Also the core's density and thickness were influential in this area. On the other hand they discovered that the core played little part at high-impact velocities. It was the face sheets that absorbed the kinetic energy of the projectiles through delamination, fracture and indentation.[6]

Freeda A. Amir, A.R Othman and H. Md. Akil researched the degrees of the impact response on the thermoplastic honeycomb sandwich. A sandwich panel with three different core thickness was tested and the characteristics of the sandwich was determined. After conducting the low velocity impacts they discovered that the thickness of the honeycomb does influence the extent of the damage which occurs. Before total failure occurred and during the core crushing the thicker core was able to sustain a higher load. They discovered that a sandwich with a higher rigidity and stability can provide better resistance to out-of-plane deformation. The higher rigidity and stability is achieved with a thicker core. By increasing the thickness of the sandwich, higher energy absorption was achieved.[7]

Eric and Anthony's objectives were to understand damage initiation and progress for sandwich panels subjected to low-velocity impacts. They also wanted to validate the simplification that for low-velocity impact testing the damage does not depend on the impact energy but upon the peak load reached in the process of transforming that energy. From their study they discovered that there exists a threshold impact energy, below which the absorbed energy is relatively low and above which a significantly larger portion of impact energy is absorbed. They also discovered that the assumption that low-velocity impact damage within a composite sandwich plate is independent of the loading rate is not valid.[8]

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[4] Engineering Materials Inc., *Structural Composites and Sandwich Panels*, accessed 04 March 2013, <http://www.engineeredmaterialsinc.com/products/structural-composites-and-sandwhich-panels/>

[5] Bernard, L.A., *Low Velocity Impact Testing of Sandwich Panels with Polymeric Cores,* UNSW@ADFA, 2011

[6] Reddy, T.Y., Wen, H.M., Reid, S.R., SOden, P.D., *Penetration and Perforation of Composite Sandwich Panels by Hemispherical and Conical Projectiles*, University of Manchester U.K., 1998

[7] Freeda A. Amir, A.R Othman and H. Md. Akil., *Damage Characterization of Polypropylene Honeycomb Sandwich Panels Subjected to Low-Velocity Impact,* Universiti Sains Malaysia, 14300 Nibong Tebal, Pulau Pinang, Malaysia., Oct 2013

[8] Herup, E. J., Palazotto, A. N, *Low-Velocity Impact Damage Initiation in Graphite/Epoxy/Nomex Honeycomb-Sandwich Plates,* Air Force Institute of Technology Northern Island, 06 May 1997

II. Methodology

In this project there are four essential parts the sandwich panels that are to be tested, the gas gun, the cage which the panels will be in during impact and the high speed camera which will be used to measure the displacement of the panels and velocity of the projectile.

A. Sandwich Panel Construction

Five different types of sandwich panels with six different materials were made. All the face sheets were made from a single material, Aluminium. For the cores five different materials were used. The panels were constructed in the Composite Lab at ADFA. First the panels were constructed 450 x 450 mm in dimension and then cut down into 9 panels of 150 x150 mm squares. The materials were cut in accordance with the safety and handling instructions provided by the MSDS sheets for each different material. An epoxy glue was used for the bonding of the Aluminium face sheets and the cores. A mixture of five part resin and one part hardener was used to make the glue.

Table 1 summarises the material used and their properties:

Table 1: Material Properties

Material	Company	Thickness (mm)	Microstructure	Density (kg/m^3)	Cell Size (mm)
Polystyrene Foam	Polyfoam NSW	9.52	Closed Cells	32.39	
Cork	Lavender ACT	10.23	Closed Cells	150.43	
Balsa Wood 80	Alan Fien ADFA	10.45	Fibres	101.7	
Balsa Wood 150	Alan Fien ADFA	10.32	Fibres	145.04	
Polypropylene Honeycomb	Polycore QLD	10.74	-	145.21	8
Aluminium 2024-T3	Alan Fien ADFA	1.06	-	2614.42	

B. Equipment Set Up

The vertical Gas Gun in the Impact Lab at UNSW@ADFA was used to impact the Sandwich panels. A high speed camera with a 5,000 f/s was used to capture the impact. The camera was used to measure the velocity of the projectile just before and after impact and the displacement that occurred during impact.

A projectile with an accelerometer mounted within it and with wires running from it, was used to capture the acceleration of the projectile during the impact. These wires were made to snap if the projectile rebounded out of the reach of the wire. The wires were soldered back on if they snapped. From the acceleration and the mass of the projectile the force exerted during the impact was calculated. A velocity sensor was used to trigger both the data acquisition system for the accelerometer and the high speed camera.

The sandwich panels were placed in a circular clamp situated on a stand. The panels were placed in a cage during the impact test. The purpose of the cage was to protect the surrounding equipment from getting damaged. The cage was constructed from steel, ply wood and Perspex. The steel was welded to construct a rectangular frame. Ply wood and Perspex were then used to enclose the sides of the frame. The top was constructed from a wire mesh and a rubber catcher. The purpose of the catcher is to allow the projectile to pass through but not rebound out.

The vertical Gas Gun can be set up to propel the projectile at different speeds. This is done by adjusting the pressure of the air that operates the Gas Gun. Figure 3 shows the cage with the sandwich panel inside, the trigger mechanism and the projectile connected to the data acquisition system and Figure 4 shows the Gas Gun.

Figure 3: Cage with the sandwich panel, and projectile

Figure 4: Gas Gun

C. Impact Testing

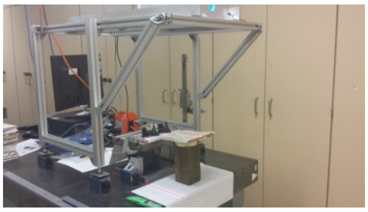
Before any testing occurred the gas gun was calibrated to determine what velocities the projectile can be fired at and what the kinetic energy of the projectile would be. Two velocity sensors attached to a data acquisition system was used to determine the velocity of the projectile at different pressures. A high speed camera was used in conjunction to verify the velocities and to determine if the high speed camera could be used to measure the velocity of the projectile before and after impact. The velocities determined from the sensor and camera varied on average by 0.95%. The high speed camera was determined to be acceptable for measuring the velocity of the projectile.

It was also discovered that the velocity of the projectile did not change linearly with the gas gun pressure and it was a power model that had the best correlation. The velocity calibration is included in Annex F.

Fifteen samples were tested in total. Before tests were conducted dummy samples were used to ensure that everything worked properly. The projectile had a weight of 0.3844kg and was able to reach velocities of up to 31 m/s. After the impact tests the samples were scanned with a 3D scanner to allow modelling in MATLAB. The projectile and 3D scanner are shown in Figures 6 and 7 respectively.

Figure 5: Projectile

Figure 6: 3D Scanner



D. Data Processing

The data acquisition system collected the data from the projectile and the velocity sensors as voltage signal. The voltage was converted into m/s^2 by first multiplying by 1000 to convert it into mV and the multiplying by the conversion factor 0.005 ${mV}/{(m/s^2)}$ to change it into m/s^2. From the acceleration the force was determined by F=ma. A force versus time graph was then produced to analyse how the force changed with time during the impact. From this the peak force was determined. Force time history can be found in Annex A and B.

The images from the high speed camera were used to determine the displacement of the impactor. Each image was 512 x 512 pixels. For the samples tested at 1Bar there were 3.72 px/mm, for 2Bar there were 2.77px/mm and for 3Bar there were 2.55px/mm. There was two datum points painted on the impactor to allow tracking of the impactor. For every impact test the displacement was measured

manual by measuring the position of the datum in each frame. The error in this method was calculated to be ±1 px which is equivalent to ±0.22 mm. The capture rate of the high speed camera was 5000 f/s.

Using both the force versus time graph and displacement versus time graph a force versus displacement graph was created. The area under the graph was calculated which is equal to the energy absorbed during the impact. The kinetic energy before impact was determined from the projectiles velocity before impact. Having both the kinetic energy before impact and the energy absorbed during the impact a comparison was made to determine what percentage of the kinetic energy before impact was absorbed by each panel .The force versus time graph the displacement versus time graph and the force versus displacement graphs for each impact can be found in Annex B.

It was found that the 5000f/s frame rate of the high speed camera was too slow for determining the displacement during impact. The camera produced a frame (image) every 0.2ms. For example if you had two consecutive images frame 118, time = 23.6ms and frame 119, t = 23.8ms and the start of impact occurred anywhere between t = 23.6 and 23.8ms. there would be no image to represent it. As a result the displacement vs time graph would not be accurate and hence the energy absorbed calculated from the force vs displacement graph would not be accurate. The energy absorbed calculated in this manner was not used for comparison in this study.

III. Results

The results from this project presents how much energy each panel absorbed and how much damage it concurred as a result. It was assumed that the less energy a panel absorbs the less it is damaged. The samples were compared in five different methods, the time taken to reach peak force, the energy absorbed as a percentage of the impact energy, the volume of deformation of the impact surface as a percentage of the volume of the whole sample, the after impact core thickness as a percentage of the initial core thickness, and the amount of energy absorbed per millimetre cubed by each sample.

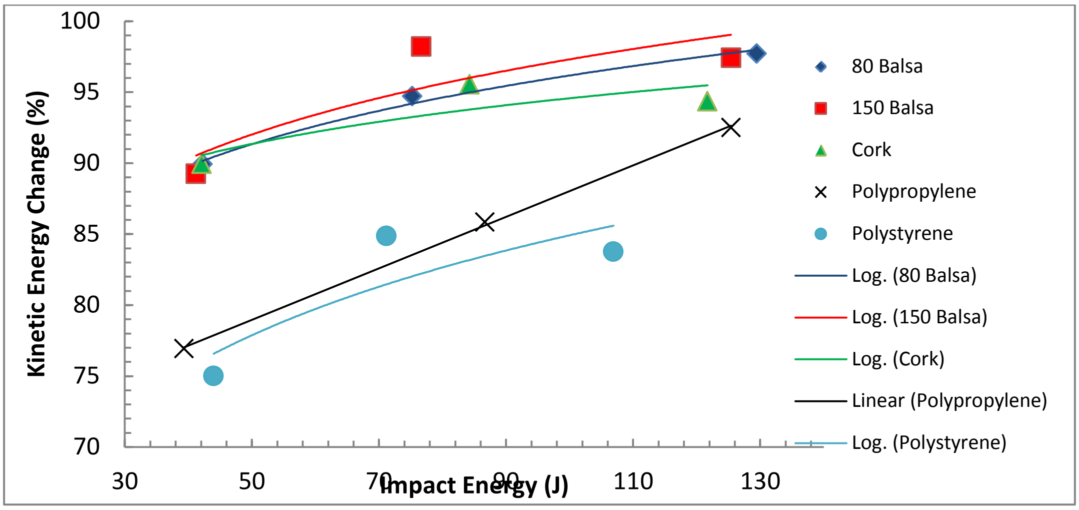
A. Energy Absorbed

The energy absorbed during impact was calculated by determining the kinetic energy of the projectile before and after impact. This was achieved be determining the projectile's velocity before and after impact and calculating the kinetic energy from:

$$Ke = \frac{1}{2}mv^2$$

This was done in order to be able to compare the different panels as to how much energy each panel absorbed. The comparison was presented as a percentage of the impact energy this is shown below in Figure 7. For the complete set of calculations refer to Annex C.

Figure 7 – Energy Absorbed (%)



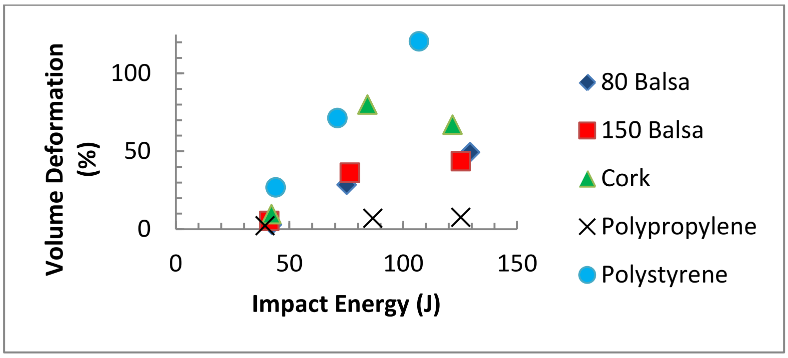
From Figure 7 it is evident that Polystyrene is the core material that absorbs the least percentage of the energy it was impacted with. This is due to the fact that the impact facesheets of the Polystyrene panels were not perforated. The Polypropylene honeycomb demonstrated the same behaviour when its impact facesheet was not perforated and very similar percentage of energy was absorbed for the first two tests (order of test is left to right). In the third test its impact facesheet was perforated and hence a much larger energy absorption. The Cork, Balsa 80 and 150 panels absorbed greater than 89% of their impact energies in all three tests. Their impact facesheets were perforated in both the second and third tests. As can be seen from the trend lines that Balsa 150 absorbed the highest percentage of its impact energy followed by Balsa 80.

Four of the panels (Cork, Polystyrene, Balsa 80 and 150) demonstrated a logarithmic trend in the percentage of energy absorbed. It seems that the Cork, Polystyrene, and Balsa 150 all have reached a saturation limit after the second test. Although the Balsa 80 demonstrates a logarithmic trend it has not yet reached a saturation limit for the energies tested. The Polypropylene demonstrated a strong linear trend and no saturation limit for the energies tested. There were too few tests completed to be able to define a trend for each panel. If more tests were conducted at higher energies maybe the Polypropylene would demonstrate a logarithmic trend as well. Also more tests could have been done at closer energy intervals.

B. Volume of Deformation

The impacted samples were scanned with a 3D scanner which produced a data file that represented the samples in terms of 3D Cartesian Coordinates. The data was imported into MATLAB and a digital model of the sample was then produced with MATLAB. The MATLAB code can be found in Annex G. This was done in order to be able to compare the different panels as to how much their impacted facesheets deformed. The comparison was presented as a percentage of the total volume of the panels. This is shown below in Figure 8.

Figure 8: Volume of deformation compared to impact energy.



From Figure 8 it is evident that Polystyrene had the highest percentage of volume deformation. Polystyrene was able disseminated the energy across the whole surface of the panel. As a result it had very small local damage at the point of impact as compared to the other panels this also meant that the impact surface of the panel was not perforated. The Polypropylene had the least volume deformation. The damage was very local to the point of impact and in test three the impact surface was perforated. As can be seen from the Figure 15 the Cork had a higher volume of deformation in the second test then the third even though the third test had higher impact energy. The reason for this is that the impact surface in the second test separated from the core and as a result had much more bending which led to the higher volume deformation. With the exception of this unique case the Cork, Balsa 80 and 150 had very similar volume deformation for all three tests. All the samples displayed an increasing linear trend of volume deformation with increasing impact energy (ignoring the unique case in test two of the cork).

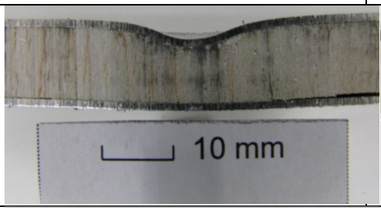
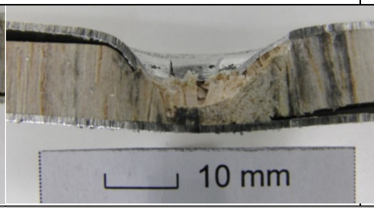
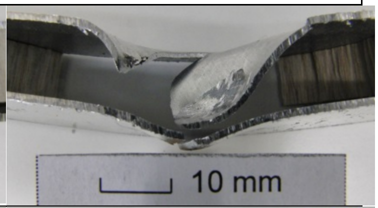
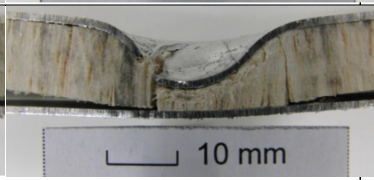
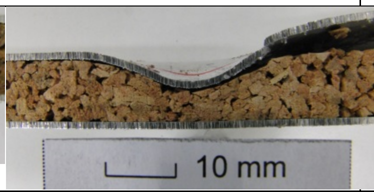
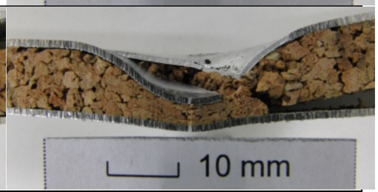
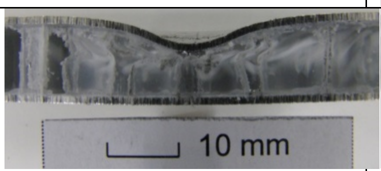
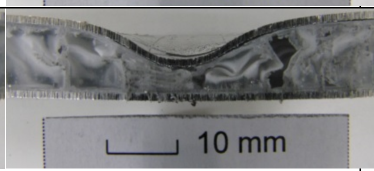
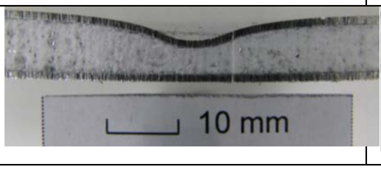
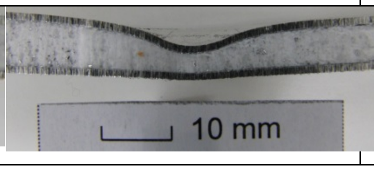
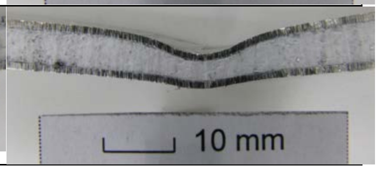
C. Observed Damage and Core Compression

The manner in which the impacted panels absorbed energy and behaved under impact was different in comparison to each other. Visual examination of the impacted panels in Figure 9 Test 1, all cases highlighted a small amount of damage in the impact facesheet and no damage in the bottom facesheet. No damage in the bottom facesheet signifies that more energy can be absorbed before complete failure of the sandwich panel. From Figure 9 Test 1, it is evident that there was core crushing for all panels with the greatest compression in Polystyrene. This is due to the fact that it has high air content in its structure as compared to the others which makes it more compressible. For Balsa 80 and 150 cracks had also started to develop in the core and debonding of the bottom facesheet was also evident in both cases. The cracks were due the high rigidity of the Balsa and the cracks in the Balsa 150 were greater in number and size as compared to the Balsa 80. Also the debonding between the bottom facesheet and the core had spread over a larger area in Balsa 150.

From Figure 9 Test 2 perforation of the impact facesheet is achieved for Balsa 80. The Aluminium facesheet has initially failed due to the large tensile force exerted during loading and then greater damage has occurred as it has sheared. As compared to Test 1 there is significantly more compression of the core largely due to the perforation of the impact facesheet. The cracks are greater in size and number, the debonding between the bottom facesheet and the core is spread over a greater area and also debonding of the impact facesheet and the core has started to occur. Similarly for Balsa 150 perforation of the impact facesheet has been achieved, the number and size of cracks are greater, there is more compression of the core and the debonding between the bottom facesheet and the core is spread over significantly more area. For the Cork there is significantly more compression of the core and perforation has been achieved however not to extent of the Balsa 80 and 150. The perforation of the impact surface has caused debonding between the impact facesheet and the core. The Polypropylene and Polystyrene highlights no perforation, but more compression and crushing of the core, no debonding between the facesheets and the core and almost no change in the bottom facesheet. There was no damage in the bottom face sheet unless perforation was achieved in the impact surface.

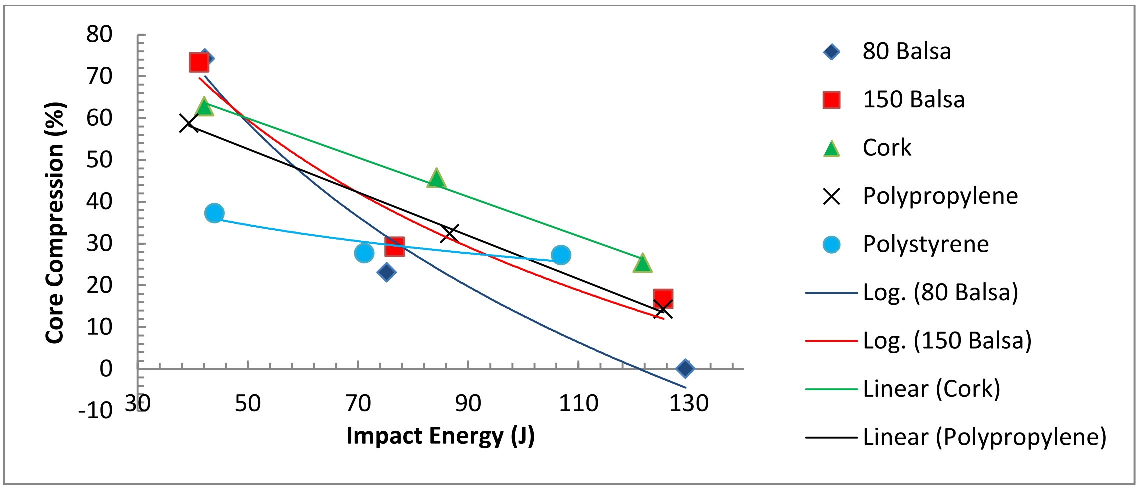
Figure 9 Test 3 shows that for Balsa 80 perforation of both facesheets were achieved. The impact facesheet had made contact with the bottom facesheet and the core was broken into small segments, the core is not seen in the image as the sample was damaged during sectioning and the small core segments were destroyed and not recoverable. The bottom factsheet being perforated means that the integrity of the panel is highly compromised further increase in energy could result in greater perforation of the bottom facesheet and eventually the impactor completely penetrating through the panel. Balsa 150 showed perforation had only occurred in the impact facesheet, further compression of the core had occurred which had led to a complete debonding of the bottom facesheet from the core. Balsa 150 is 150% greater in density then Balsa 80. The impactor was able to push through the Balsa 80 core and perforate through the bottom facesheet, but was unable to do the same in the Balsa 150 core due its greater density. The Cork showed that the impact facesheet had perforation, there was a large compression of the core and cracks had occurred in the core. Also debonding of the bottom facesheet from the core had occurred. Polypropylene demonstrated that the impact facesheet had perforation. The core was extensively crushed as compared to Test 2 and contact between the impact facesheet and bottom facesheet had almost occurred. Compared to Test 2 there was significant damage to the bottom facesheet. Like Test 2 there was no debonding between the facesheets and the core. Polystyrene showed greater compression of the core compared to Test 2, no perforation or debonding between the facesheets and the core had occurred. There was significantly more deformation of the bottom facesheet.

Figure 9: Comparison of cross section of sandwich panels.

Aluminium Face Sheet Panels	**Test 1 (< 44 J)**	**Test 2 (< 88 J)**	**Test 3 (< 130 J)**
80 Balsa			
150 Balsa			
Cork			
Polypropylene Honeycomb			
Polystyrene			

From the section view the core compression was measured. This was done to quantify the compression of the core for the different panels and compare them. The compression was presented as a percentage of the non-impacted core thickness against the impact energy. This is shown below in Figure 10.

Figure 10: Core compression against impact energy.



The core compression presented here is the core compression at the centre of impact not over the whole width of the panel. Polystyrene had a consistent level of compression between Test 1 and 3. This is due to the fact that Polystyrene was able to disseminate the impact energy over the whole sample. Although not as good Cork performed similarly in that it was able to disseminate the impact energy over the whole surface of the panel and this is evident in Figure 10 as the percentage of core compression between Test 1 and 3 are not as large as Balsa or Polypropylene. Polypropylene, Balsa 80 and 150 did not disseminate the energy very well. As a result they had very local damage at the point of impact and hence the large difference in the percentage of the core compression. Although Polypropylene did not disseminate the energy over the whole surface of the panel its high stiffness allowed it to perform a lot better than the Balsa.

Four of the panels (Polystyrene, Balsa 80 and 150) demonstrated a decreasing logarithmic trend in the percentage of core compression this same trend was observed in the percentage of energy absorbed. The Polypropylene and Cork demonstrated a strong linear trend and no saturation limit for the energies tested. There were too few tests completed to be able to define a trend for each panel. If more tests were conducted at higher energies both Polypropylene and Cork would demonstrate a logarithmic trend as well. As all samples have a set thickness and once the core is compressed 100% there can only be penetration of the bottom facesheet after this point. Also more tests could have been done at closer energy intervals.

D. Impact Energy absorbed per volume of deformation

Figure 11: Impact energy absorbed per volume of deformation vs impact energy.

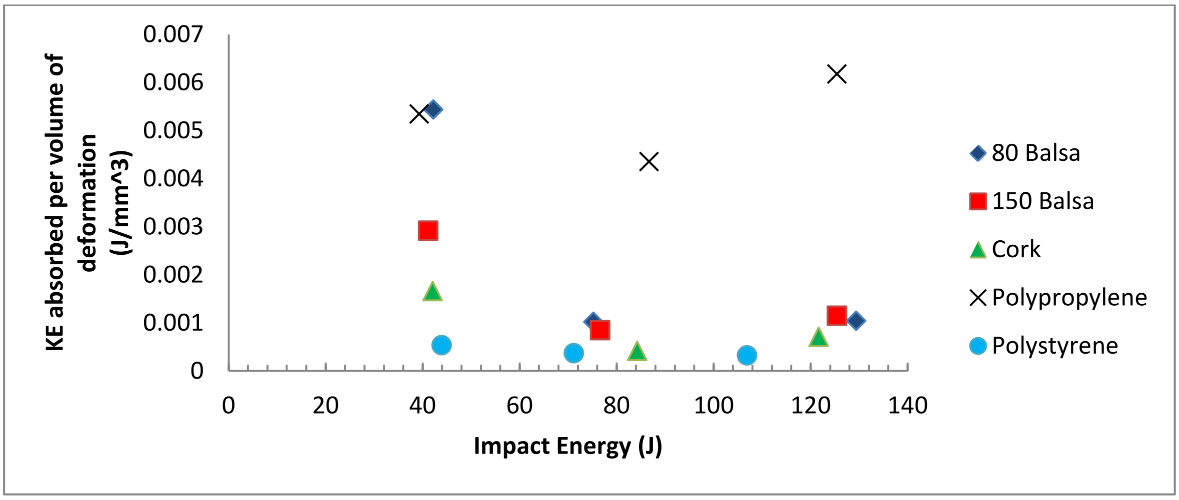
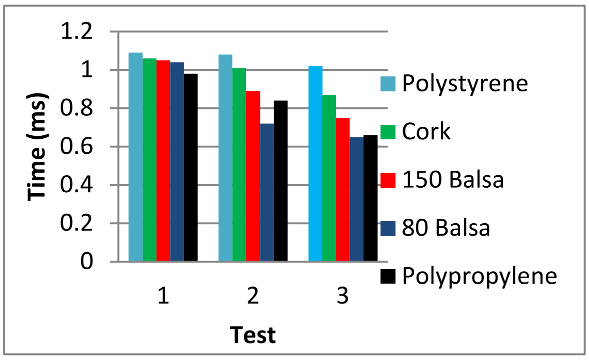


Figure 11 shows that Polypropylene has the best absorption of energy per volume of damage. This was due to the fact that the damage was very local to the centre of impact and its high stiffness allowed the core to perform better. On the other hand Polystyrene had the worst energy absorption per volume of damage. The reason for this was that it disseminated the energy over the whole surface of the panel allowing more of the panel to be damaged. The trend displayed in all panels were similar. All panels had better energy absorption per volume of damage in Test 3 (< 130 J) then in Test 2 (< 88 J). This corresponds to the fact that in Test 2 most of the energy absorbed and subsequent damage was in the impact facesheet and the core. The bottom facesheet played little role in the absorption of the energy. In Test 3 at higher energy the bottom facesheet played a greater role in absorbing the energy and hence the better performance.

E. Time to Peak Force

From the Force vs Time graphs in Annex D, the panels were compared in the time taken to reach peak force. This was done to understand the effects of the core on the time taken to reach these peak forces.

Figure 12: Time taken to reach peak force



As seen in Figure 12, in Test 1 Polystyrene had the longest time taken to reach peak force followed by Cork, Balsa 150, Balsa 80 and Polypropylene. This trend continued for Test 2 and 3 with the Balsa 80 and Polypropylene exchanging positions. The longer time to peak force is a desirable characteristic when designing safety equipment such as helmets as it allows a gradual absorption of the force.

IV. Conclusion

This project looked at impact testing of sandwich panels. The panels were compared to each other to determine which panel performed the best in terms of energy absorption, how it failed during impact and the subsequent damage and how much energy was absorbed per volume of damage. If was found that the core controlled the order in which the various failure mechanisms occurred. However it was the facesheets that absorbed the majority of the impact energy of the projectile through deformation, indentation and perforation.

From among the panels tested polystyrene proved to be the best in energy absorption (the lower energy absorbed the better) and resistance to perforation. It was predicted that the less energy the panels absorb the less damaged the panel would be however this was not the case as proven by Figure 8 and Polystyrene absorbed the least amount of energy and it had the greatest volume deformation. The reason that Polystyrene was so resistant to perforation was due to the fact that it was able to disseminate the energy over the whole surface of the panel. This also meant that a more surface area was damaged and hence the higher levels of volume deformation. Also Polystyrene had the longest time duration to reach peak force. This is a very desirable characteristics when designing automobile bumpers.

The other notable performer was Polypropylene Honeycomb which had the second least amount of energy absorbed and the least amount of volume deformation. As a result it had the best performance in respect to amount of energy absorbed to volume of deformation ratio as demonstrated in Figure 11. The material that absorbed the most energy was the Balsa 150.

The aim of this project was achieved in order to determine which panel performed best under impact and how they failed. The overall best performer was the sandwich panel with the Polystyrene core it absorbed the least amount of energy, had the longest time to reach peak force and the impact facesheet was not perforated. As each core material showed different characteristics under impact it is important to understand the application when you choose what cores to use.

Acknowledgment

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