Engineering | Lancaster University

ENGR445: Mechanical testing of recyclable sealants

Specialist Technical Products Ltd

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Executive Summary

At the request of Anthony Lowe at Specialist Technical Products Ltd. and with the assistance of both Professor Jianqiao Ye and Dr Armin Yousefi Kanani at Lancaster University, we performed a series of mechanical tests on several recyclable sealants. The sealants in question are butyl tapes that have been developed, manufactured, and provided by Specialist Technical Products Ltd. (HQB1, HQB2, HQB1P, HQB5HP).

A decision was made to perform a series of mechanical tests, based on a literature review of the applications of butyl tape and adhesive testing in addition to the advice provided by Anthony Lowe, Dr Armin Yousefi Kanani, and Professor Jianqiao Ye. Single lap joint tests were initially conducted on the butyl tape samples, which were adhered to both aluminium and carbon substrates. The Instron 3345 testing machine, in the Engineering building at Lancaster University, was used to apply the tensile loads on the samples. The single lap joint testing was used to show how several different variables affect adhesion and how the different butyl tape samples respond to different conditions. One such variable was the surface finish of the substrate used and to test this, the aluminium substrate test pieces were given 3 different surface finishes: polished, sanded (using P60 paper) and as delivered (no surface preparation at all). Another set of tests aimed to see how the area of adhesion affected the adhesiveness of the butyl tape samples using 5 different areas of overlap – 12.5x25mm, 25 x25mm, 37.5 x25mm, 50 x25mm and 62.5 x25mm. Additionally tests were carried out to test how weighting and leaving the testing samples overnight and different combinations of substrates affected the adhesion of the butyl tape.

Following these tests, a number of conclusions were drawn from the data obtained. HQB1P was shown to have the lowest physical strength of the butyl tapes tested with little change in adhesive performance across the different surface finishes tested. HQB1 and HQB2 were found to perform similarly in both tests, with properties between those of HQB1P and HQB5HP. Overall HQB5HP, whilst lacking the adhesion of the other butyl tapes, was shown to be significantly stronger but due to its poor adhesion, the group recommend that when it is used in future applications, it is allowed 24 hours under an applied load to ensure a greater level of adhesion.

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Introduction

Specialist Technical Products Ltd. is a butyl tape manufacturing company based in Winsford, Cheshire that is developing a new range of both sustainable and recyclable butyl tapes to be used in applications where preventing water and air ingress is imperative. The objective of this report is to investigate the adhesive properties of several butyl tape products being currently produced by the company and compare these results. In order to do this, the Instron tensile testing machine in the Engineering department at Lancaster University will be used to perform several different mechanical tests on the selection of butyl tapes provided by Specialist Technical Products Ltd. These tests will be performed to measure how factors such as the surface finish of the substrate and applied loads over time can affect the adhesive properties of these different butyl tapes as well as testing their different physical properties. The data obtained from these tests will be processed using MATLAB and then analysed in detail later in this report, along with future recommendations.

Literature Review

Butyl Tape

Butyl tape is a type of sealant tape that contains the hydrocarbon radical C_4H_9 and has a rubber-like consistency (Schmid, 2013, p. 85). The tape is used in numerous sealant applications which are detailed in this section.

The German Ministry of Traffic introduced using butyl rubber tapes to protect against corrosion of locked coil ropes, used for bridge cables. Originally, the cables would be coated with a 400 µm thick layer of paint which was applied by brush, and this would cause traffic access restrictions due to movable maintenance scaffoldings. Instead, the tape achieved a high resistance to mechanical damages and is virtually water-, vapour- and airtight (Reiner & Oswald, 2012).

Butyl tapes are also widely used in pipe protection and restoration technologies, welded joints, fittings and values (Chalykh, Petrova, Shcherbina, & Nenakhov, 2018). Due to its rubber-like properties, the tape is hand mouldable and effectively seals a variety of leaks, cracks, replace gaskets or seal leaking light conduits (Keim, 2005).

Additionally, butyl tape is used in a three-layer structure within residential and public building window-frame assemblies to function as: waterproof, vapour permeable; thermal and noise insulation; vapour sealing (Savchenkova, 2011) (New York: PR Newswire Association LLC, 2002). The tape also has residential and commercial uses in flexible HVAC applications (BNP Media, 2003).

Another common application for butyl tape is to seal vacuum bagging used for composite resin infusion processes (easycomposites, n.d.). The composite layers are covered with a nylon bag which has all of its edges sealed with butyl tape to ensure a vacuum seal and that no pressure drop can occur.

Specialist Technical Products produces a wide variety of butyl tape, but four types were the focus of this project:

- **HQB1** - A high performance polyisobutylene (PIB) based sealing tape which is used to form a water or airtight seal against air and water ingress. This non-toxic tape produces an instant seal without the use of tools (Specialist Technical Products, n.d.).
- **HQB2** - Very similar properties and characteristics to HQB1 but has improved adhesive capabilities. HQB2 is used in more demanding applications, such as polyethylene in damp proof/ jointing, in which bonding is particularly difficult. HQB2 has a lower water vapour permeability than HQB1 and therefore protects better against damp (Specialist Technical Products, n.d.).
- **HQB1P** - A high performance polyisobutylene (PIB), which is a high tack tape with self-wound sealing and is primarily used to form an overlap joint to protect against air, moisture, and water ingress (Specialist Technical Products, n.d.).
- **HQB5HP** - A high strength polyisobutylene (PIB) used to create a protective seal in joints against air and water ingress. HQB5HP requires no tools for application and due to its greater dimensional stability, it is utilised in applications where a greater modulus/ stiffness is required to ensure that material does not leak from joints (Specialist Technical Products, n.d.).

Adhesive Testing

Single Lap Joint

Single lap joint tests (shown in Figure 1) are the most widely used method of producing data on adhesively bonded joints, this is due to its simplicity and low cost (Duncan, 2010). The test involves two test pieces of chosen materials which are bonded together by an adhesive, the two test pieces are then pulled away from each other. The test is used to determine the mechanical properties of the adhesive.

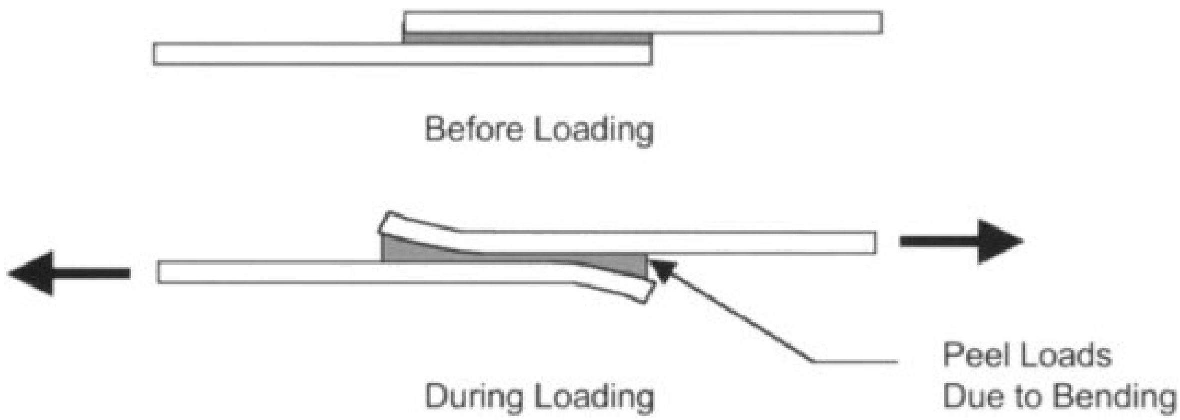


Figure 1 – A diagram of a lap joint test (Campbell, 2003)

Peel Testing

Peel testing is used to assess bond quality and to determine the adhesion strength of a material. Also, measuring the tension characteristics between the adhesive and the surface it is used on can show the effect of different processes such as surface finishes. There are multiple different methods of peel testing; 90-degree, 135-degree, 180-degree, climbing drum, floating roller, and T-peel testing.

The 90-degree, 135-degree and 180-degree peel tests involve keeping a constant 90°, 135° and 180° angle respectively, whilst the adhesive is pulled from a test piece. The 90-degree, 135-degree and 180-degree peel tests are used to determine the adhesive strength between a flexible tape and rigid substrate. A diagram of this can be seen in Figure 2.

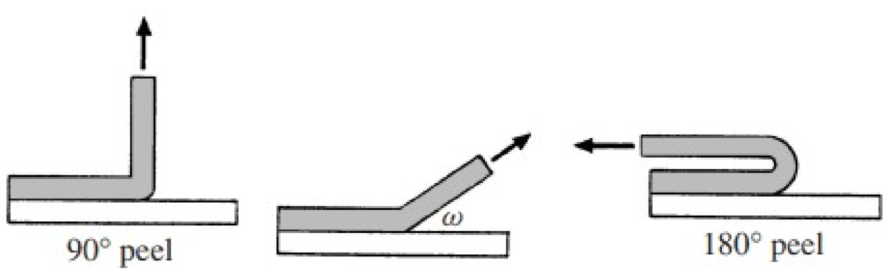


Figure 2 – Diagrams of 90-degree, 135-degree and 180-degree peel tests (Material-Welding, 2022)

A climbing drum peel test peels the adhesive off by attaching it to a rotating drum that pulls the adhesive off as it rotates, the force required to peel the adhesive off is measured as the drum is driven. The climbing drum test can be used to compare the adhesion between flexible and rigid components or between flexible facing of a sandwich structure and its core (ADMET, 2022) (Intertek, 2022). A diagram of this can be seen in Figure 3.

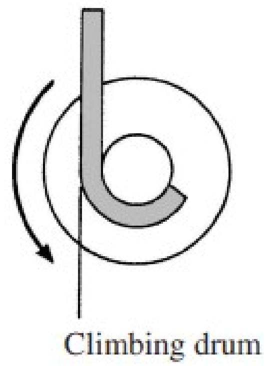


Figure 3 – A diagram of a climbing drum peel test (Material-Welding, 2022)

A floating roller peel test is an alternative to a climbing drum peel and is used to measure the strength of adhesive bonds between rigid and flexible components. The floating roller test uses two roller bearings in a frame that connects to the test machine using a pivoting adapter, this ensures the test piece is aligned when a force is applied and this force goes through the centreline of the fixture, the force required to peel the adherents apart is measured as the bearing is driven (Instron, 2021). A diagram of this can be seen in Figure 4.

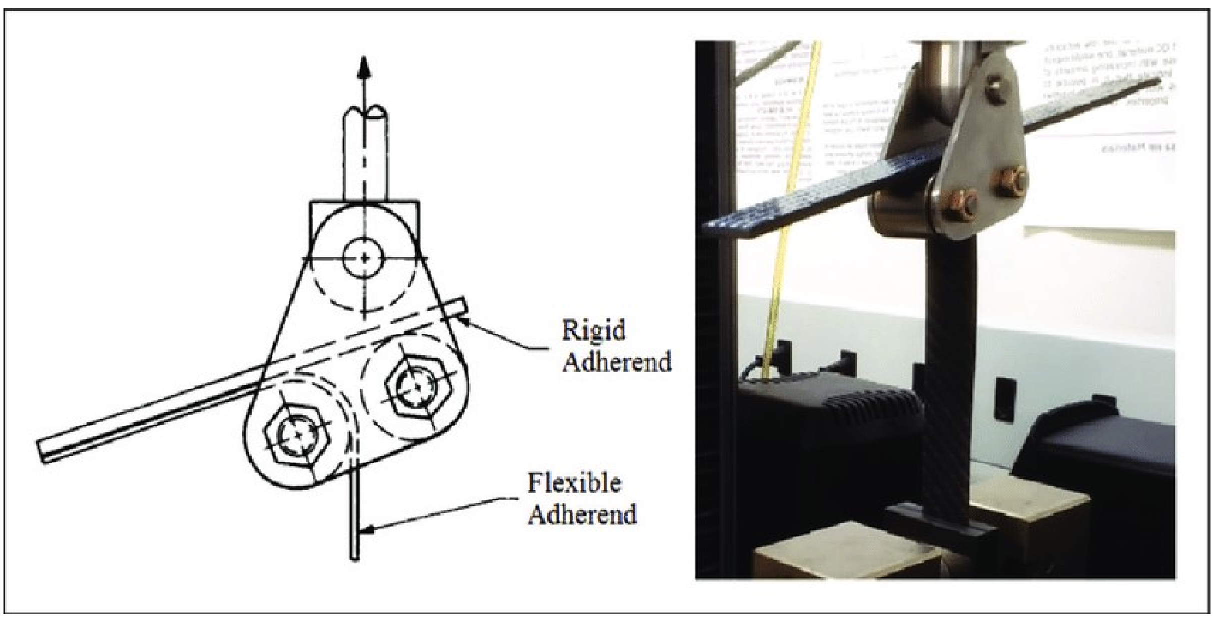


Figure 4 – A technical drawing (right) and a photograph (left) of a floating roller peel test (Arouche, Budhe, Banea, Teixeira de Freitas, & de Barros, 2018)

The T-peel test is used on two flexible substrates that are bonded together, the two substrates are clamped so that one is sticking up and one is sticking down while the adhesive that bonds them sticks out horizontally, so the setup creates a ‘T’ shape, the two clamps are then pull the two substrates apart which peels the adhesive off, and the force required to do this is measured (Wang & Wang, 2019). A diagram of this can be seen in Figure 5.

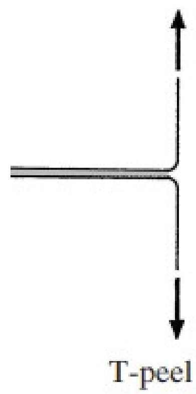


Figure 5 – A diagram of a T-peel test (Material-Welding, 2022)

Method

Sample Preparation

The tape we received was 2 mm in thickness. And for the single lap joint test, the materials were cut into 100x25mm strips, and then for the aluminium, different finishes were also applied. The finishes chosen to test on the aluminium were: as delivered, polished, and sanded, as it was felt these provided a good basis for comparison by having a rough finish, a smooth finish, and one in between the two. Once the finishes had been applied, adhesion areas were marked out onto the strips. For the majority of them only a 25x25mm area was marked, however it was also decided that the effect the adhesion area ought to be investigated so the aluminium samples also had 12.5x25mm, 37.5x25mm, 50x25mm and 62.5x25mm.

Once the test trips were prepared, the adhesive was then applied to them in the marked-out area. The other variables were also introduced here as three variations of the strips were combined, aluminium-aluminium, carbon fibre-carbon fibre and aluminium-carbon fibre, with each of the combinations involving aluminium having the finish used noted. This was done for each type of sealant provided, HQB1, HQB2, HQB1P and HQB5HP, and an example of the samples produced is shown in Figure 6. This shows a photograph of the samples prepared, where two rectangular pieces of aluminium and/or carbon fibre were joined together by butyl tape.

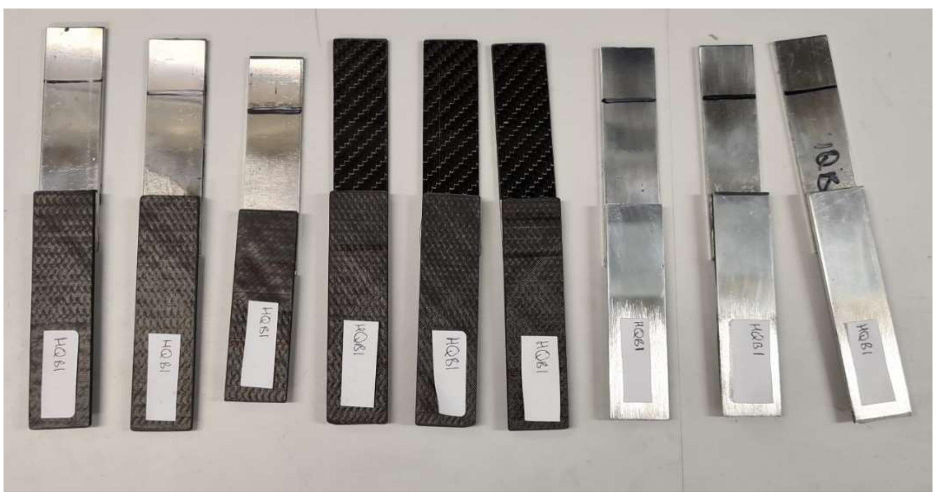


Figure 6 – A photograph of out HQB1 test samples with aluminium finish "As Delivered"

For the 'as delivered' finish, and the carbon fibre samples, another variable was introduced as each combination of materials had two sets of samples prepared, one that was left under weights overnight, as shown in Figure 7, and another that was just hand pressed, to investigate whether that had any impact on the strength of adhesion. Figure 7 shows the set-up used for the cured samples. These were left for at least 24 hours prior to the testing and used within an hour of removal.

Figure 7 - Set Up for Weighted Samples

All the different combinations of the variables used can be seen in Appendix 1 – Testing Variables.

Testing Method

The Instron 3345 test machine was used for the lap joint tests, with a load cell of 500N as similar tests had been done previously that suggested the samples would not exceed 500N. Each of the two test pieces were clamped 20mm from the edge as to hold the joint vertically, as shown in Figure 8, and each time they were secured by the same person, to ensure consistency in the test set up. The top clamp was then moved away from the bottom clamp at a rate of 50mm per minute, with the failure conditions set at: a displacement equal to the overlap length used (as at this point the samples would no longer overlap), or until there was a force decrease of 50% from the peak value, either of which would indicate failure.

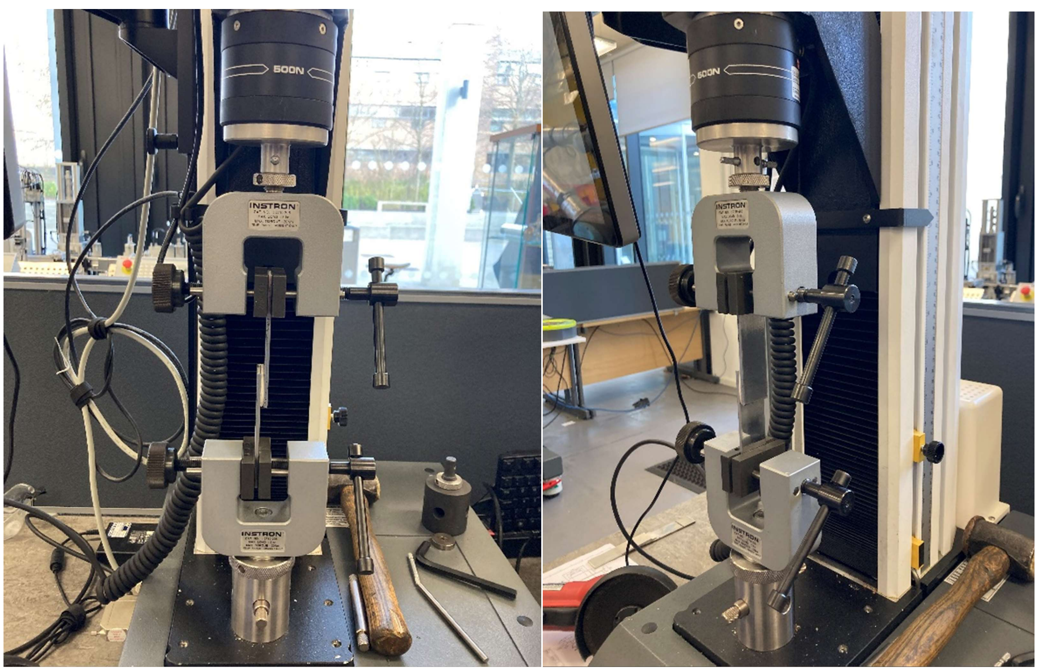
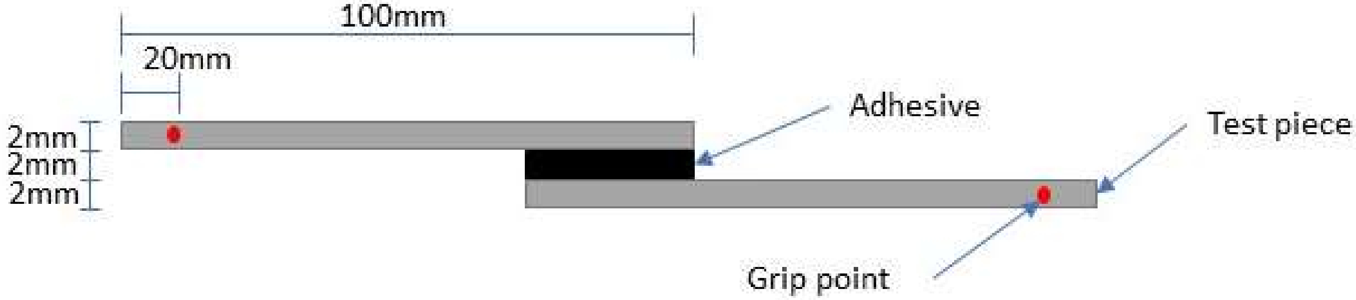


Figure 8 – A photograph of the testing set up used.



It was found after the initial tests on the butyl tape, that to get a good adhesion with the HQB5HP tape curing for 24 hours was required. Therefore, for the secondary tests which explored the effects on area, the HQB5HP sample was left to cure for 24 hours.

Results analysis

Once the tests were run, the machine gave the results in the form of a CSV file (comma delimited) that could then be subject to analysis. Three sets of data were given in the file: time, displacement, and force. Since three repeats were run for each experiment, all three data files were used to plot a line onto a single graph to check for anomalies, if found they would be discarded and not used for any further data analysis. Afterwards, each of the remaining data files would have their displacement and force averaged at each timestep to create a new set of data. This was then plotted onto a new graph and from here the maximum load was taken. The load could then be divided by the area of adhesion for a maximum stress. These conditions were set under the advice of Dr Armin Yousefi Kanani from Lancaster University Engineering Department, and Anthony Lowe, the company contact from Specialist Technical Products.

Results

Finish and curing tests

The method was carried out and the results were formatted into five tables and a graph for each set of conditions. The first four tables of results contain the maximum loads and stresses achieved by each adhesive under the conditions stated in Appendix 1 – Testing Variables. The results for the HQB1, HQB1P, HQB2 and HQB5HP adhesives can be seen in Table 1, Table 2, Table 3, and Table 4 respectively. For all of these tests the area was kept constant at 625 mm^2 with an overlap length of 25 mm. The graphs from which the values in the tables were generated can all be found in Appendix 2 – Finish and curing tests: force / displacement graphs.

Table 1 - The maximum loads and stresses from the HQB1 adhesive tests

HQB1			Maximum Load / N	Maximum Stress / Pa
Al-Al	Unfinished	Not Cured	19.2	30720
		Cured	21.9	35040
	Sanded		18.57	29712
	Polished		17.8	28480
Al-C	Unfinished	Not Cured	18.67	29872
		Cured	20.1	32160
	Sanded		20.95	33520
	Polished		19.73	31568
C-C	Unfinished	Not Cured	18.4	29440
		Cured	20.17	32272

Table 1 shows that for the HQB1 tape, the results remain relatively consistent with minor improvements if left to cure for 24 hours. As expected, polishing the aluminium negatively affect the adhesion strength. However, the aluminium-carbon sanded test performed slightly better than expected. This could be due to impurities on the unfinished piece of aluminium that would potentially reduce adhesion, which were subsequently removed during sanding. Inconsistences in the method of applying the adhesion could also be a cause for this and in future research it would be advisable to apply constant force when adhering the two samples.

Table 2 - The maximum loads and stresses from the HQB1P adhesive tests

HQB1P			Maximum Load / N	Maximum Stress / Pa
Al-Al	Unfinished	Not Cured	15.33	24528
		Cured	17.60	28160
	Sanded		15.13	24208
	Polished		14.50	23200
Al-C	Unfinished	Not Cured	13.23	21168
		Cured	17.77	28432
	Sanded		15.77	25232
	Polished		15.17	24272
C-C	Unfinished	Not Cured	15.03	24048
		Cured	17.73	28368

Table 2 shows the results for the HQB1P tape. The cured samples once again have seen an increase in maximum stress. Additionally, as expected, as the aluminium finish becomes smoother, the adhesive strength diminishes. The overall strength of this tape appears lower than that off the other tapes. During testing it was clear that this tape was the most readily adhesive however the results show that the overall strength of the bond is much lower than the other tapes. This may indicate that the strength of the adhesive itself was a dominant factor in the testing, not the strength of the adhesion to the samples.

Table 3 - The maximum loads and stresses from the HQB2 adhesive tests

HQB2			Maximum Load / N	Maximum Stress / Pa
Al-Al	Unfinished	Not Cured	21.90	35040
		Cured	23.45	37520
	Sanded		20.60	32960
	Polished		18.97	30352
Al-C	Unfinished	Not Cured	21.40	34240
		Cured	20.90	33440
	Sanded		20.43	32688
	Polished		20.73	33168
C-C	Unfinished	Not Cured	21.23	33968
		Cured	21.37	34192

Table 3 shows the results acquired from the HQB2 tape tests. The tests show an unexpected decrease in strength due to curing between aluminium and carbon however this change is very minor. Since the difference in strength between the other curing tests is very small, this drop in maximum strength could be explained by general variation in adhesion application.

Table 4 - The maximum loads and stresses from the HQB5HP adhesive tests

HQB5HP			Maximum Load / N	Maximum Stress / Pa
Al-Al	Unfinished	Not Cured	N/A	N/A
		Cured	54.60	87360
	Sanded		47.00	75200
	Polished		43.47	69552
Al-C	Unfinished	Not Cured	N/A	N/A
		Cured	48.47	77552
	Sanded		49.40	79040
	Polished		47.80	76480
C-C	Unfinished	Not Cured	48.50	77600
		Cured	52.70	84320

Table 4 shows the results from the HQB5HP tests. These tests had the highest levels of variance and for two of the tests, each repeat varied so significantly that no average could be drawn. However, the tests that were completed, show that the strength of this tape is much higher than that off the others. The effects of curing are difficult to comment on due to the loss of data here, however the carbon-carbon cured test displays a reasonable increase in strength.

The reason the tests on this tape were the hardest to carry out was due to the difficulty in getting a good adhesion. This tape was by far the least readily adhesive, however once adhesion was achieved it performed the best out of all out samples. For applications and further tests with this material, we would recommend curing under pressure or using significant force (potentially with a vice) to form a good adhesion.

Area tests

Tests to find how the area of adhesion effected the strength of adhesion were carried out. The following tests all used the same width of 25 mm and had a varying overlap length. These multiplied together gives an overall area of adhesion. The maximum load is the maximum force the adhesion held the samples together with, the values for these can be seen in Figure 9. This maximum load has also been normalised into a maximum stress by dividing by the area, the values of these can be seen in Figure 10. The 37.5 mm – HQB5HP and 50 mm – HQB1 results both had two much variation between repeats to give a reliable average and so were omitted from both Figure 9 and Figure 10. The graphs from which these values were obtained can be found in Appendix 3 – Area tests: force / displacement graphs.

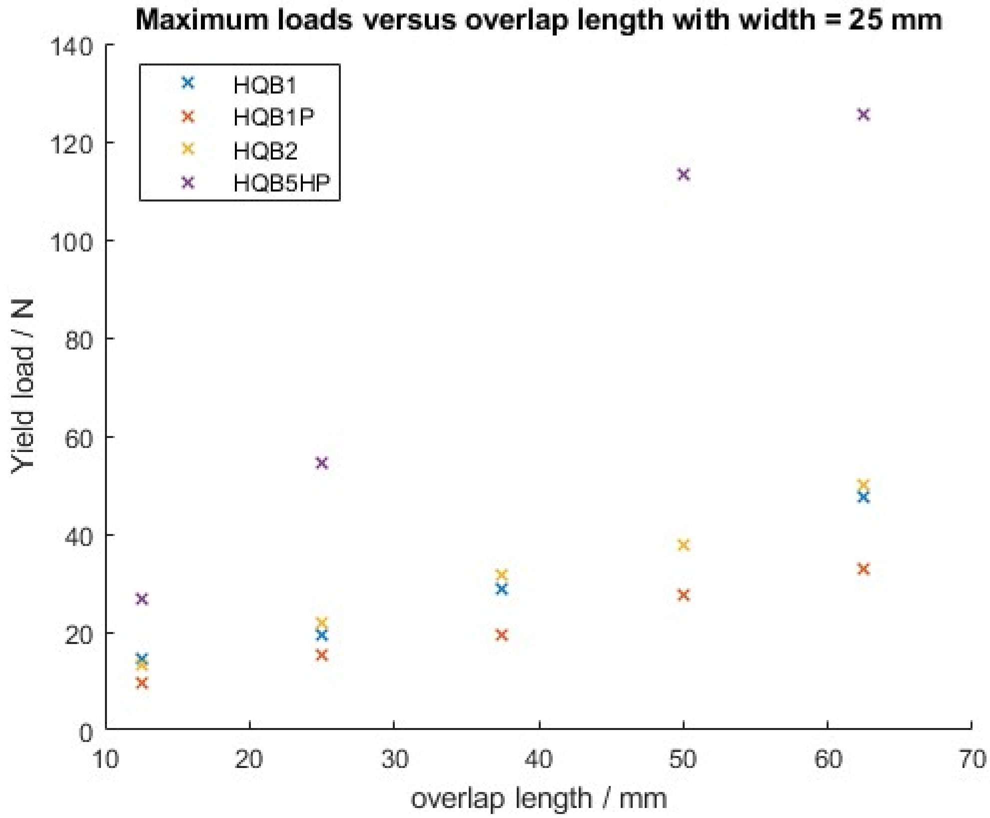


Figure 9 - The change in maximum load versus the overlap length of the lap-joint

Figure 9 shows that in the case of all samples, the larger the contact area, the higher the maximum load achieved. Additionally, the order of strength remains similar for all overlap lengths, where HQB5HP is the strongest, HQB1 and HQB2 are similar in strength and HQB1P is the weakest. Further analysis in the effectiveness of increasing the overlap length will require normalizing these values over their areas, which is shown in Figure 10.

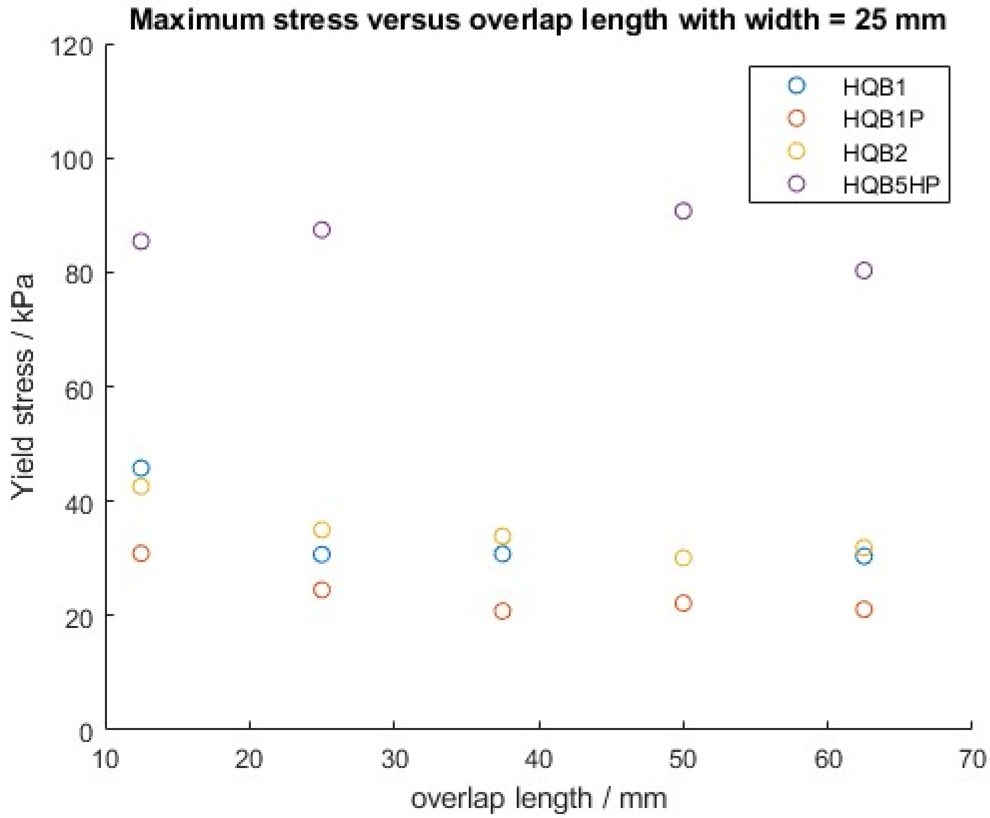


Figure 10 - The change in maximum stress versus the overlap length of the lap-joint

Figure 10 shows the maximum stress of each adhesive. This compares the strength of each adhesive layout adjusted for the increase area. For HQB1, HQB1P, and HQB2 there is a subtle downwards trend which shows there is diminishing returns in the maximum stress as overlap length is increased. HQB5HP shows an inconclusive relationship meaning more data points would be required to establish a conclusive correlation.

The data shows diminishing returns on increasing the overlap length meaning for high strength applications that require high maximum loads then it may be beneficial to focus more on increasing the width of adhesion as opposed to the overlap length as this will increase the strength proportionally.

Critical Reflection

Overall, the tests carried out were useful as there was a good variety with different surface finishes and curing times being used, this means the results could be used to figure out the ideal scenario for each individual tape. Such as, the fact the HQB1P's adhesion strength is mostly unaffected by curing time, which means it might be more ideal to use for quick application where there is not time to leave things to cure. However, as with most projects there are a few things we could have done better as well as some other types of testing that could have been done if we had the equipment and time. A discussion on the project plan and how well it was followed can be found in Appendix 4 – Project Gantt chart.

With regards to the tests that we carried out, we could have performed more iterations which would have helped as we had a few tests that contained anomalies which had to be ignored. This meant the data for some of the conditions are incomplete. Also, it would most likely have given more consistent results if the samples were prepped in a clean room as getting dirt on the tape or the test piece surfaces might affect the adhesion. In addition, the curing of the tapes could have been improved by using a more uniform weighting method, so each sample is under the exact same load. Additionally, instead of applying weight overnight, we could have used a clamping method to quickly put the sample under a load without needing to wait for prolonged periods of time.

With regards to other tests we could have done, a peel test was originally meant to be carried out but this was not possible due to there not being a suitable test machine to carry one out in the university. Also, the fact the project was only 2 weeks meant that even if we had the equipment, we would not have had time to do thorough peel tests without reducing the amount of shear tests we did.

Conclusion

Many tests were conducted to calculate the strength of adhesion for a selection of butyl tapes under many different conditions. The first set of tests focussed on the surface which the tape was applied to. The results showed that as surfaces became more finished and smoother the adhesion strength diminished. It was found that for strong aluminium bonding: sanding and polishing typically produced inferior bonds. And so, for industrial application, it would not recommended to apply surface finishes to the aluminium. Additionally, the strength of the adhesion to carbon was typically less than that of aluminium.

The adhesion strength was then tested as overlap area varied. The width was kept constant however the length of the overlap was varied between 12.5 mm and 62.5 mm with intervals of 12.5 mm. It was found that the maximum load did increase with the increase in area however not proportionally to the amount of tape used. It was found that as the amount of tape increases, there effectiveness per unit area decreased. Therefore, when attempting to increase the strength of an adhesion it is recommended to increase the width of adhesion as opposed to the overlap length.

The project took measurements of four different types of tapes. These tapes varied in adhesion strength as well as the strength of the adhesive itself. It was found that HQB1P was the weakest tape. Its performance varied very little between surfaces however had an overall far lower strength across all conditions. The conclusion to be drawn from this is that the strength of the adhesion remains similar, and it is the strength of the adhesive itself that is dominant in the results. In the case of the HQB1P butyl tape, the physical strength was relatively low as it could be moulded very easily when handling.

HQB5HP was the hardest tape to achieve adhesion with, however once this was achieved it was far stronger than any of the other tapes. For future work on this tape, we advise that any experiments to allow 24 hours of curing under pressure or apply significant force for a short time. This tape felt the least readily adhesive and the least mouldable. This is represented in the results, by its much higher maximum loads.

HQB1 and HQB2 behaved very similarly in both tests. Their properties both fall between the strength and adhesion quality of HQB1P and HQB5HP. It was shown that they both benefit from curing and rougher surface finishes however these changes were not as substantial as the HQB5HP results.

As can be seen in Figure 1, deformation in the tape can cause additional forces to be applied perpendicular to the samples. These are called peel loads and may affect the measurements for the lap joint tests. This could potentially be reduced by decreasing the thickness of the tape; however, this could cause an increase to the error as the measurements would be smaller. This would require more sensitive equipment to gain accurate results from this new setup.

Recommendations for future work

As peel tests were not completed due to a lack of equipment, it would be useful if they were carried out in the future. If a peel test were to be carried out it would be ideal to do some kind of climbing drum test were the adhesive is directly peeled off of a surface, rather than something like a t-peel test were an adhesive is connected to two test pieces and they are pulled away from each other. This is because these tests would most likely end up testing the strength of the adhesive and not the adhesion strength due to the fact the tapes would most likely just stretch until they tore in the middle rather than until they peeled off the test piece.

In regard to future work with shear tests, more materials could be tested, such as on glass or wood, as the results showed the tapes performed differently on different materials and so having data on a larger range would give better insight into how the tapes would hold up for different applications. Single lap joint tests could also be performed using different widths of tape as we only tested 25mm wide samples of tape due to our test pieces all being 25mm wide. Finally, double lap joint tests could be carried out to generate more shear test data which would give more accurate data for a larger variety of applications.

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Appendices

Appendix 1 – Testing Variables

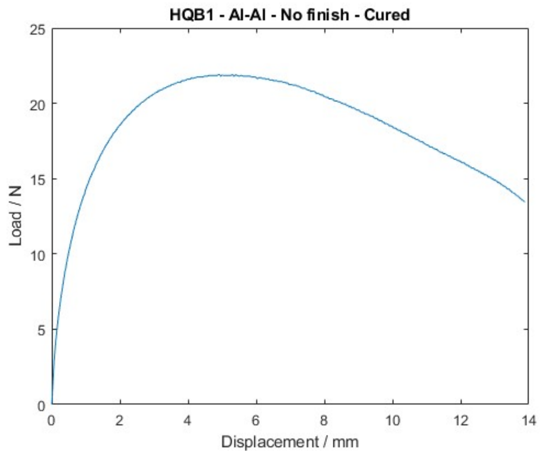
Table 5 - A Table of All the Different Combinations of Variables Used in Testing (a "//" symbol demonstrates that the value is the same as above)

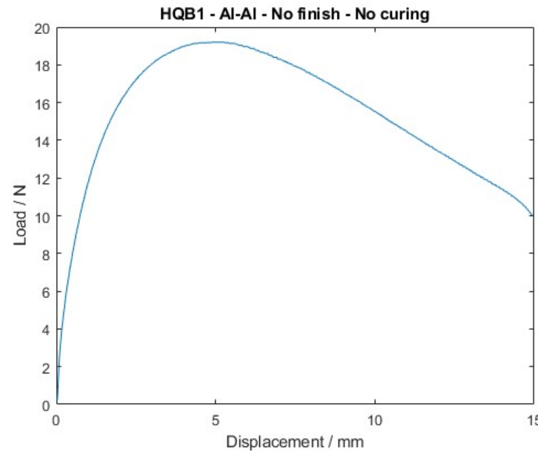
Butyl Tape	Material Combination	Aluminium Finish	Weighted	Overlap length (with 25 mm width)
HQB1	Al-Al	As Delivered	No	12.5
//	//	//	//	25
//	//	//	//	37.5
//	//	//	//	50
//	//	//	//	62.5
//	//	//	No	25
//	//	Sanded	Yes	//
//	//	//	No	//
//	//	Polished	Yes	//
//	//	//	No	//
//	Al-C	As Delivered	Yes	//
//	//	//	No	//
//	//	Sanded	Yes	//
//	//	//	No	//
//	//	Polished	Yes	//
//	//	//	No	//
//	C-C	N/A	Yes	//
//	//	//	No	//
HQB2	Al-Al	As Delivered	No	12.5
//	//	//	//	25
//	//	//	//	37.5
//	//	//	//	50
//	//	//	//	62.5
//	//	//	No	25
//	//	Sanded	Yes	//
//	//	//	No	//
//	//	Polished	Yes	//
//	//	//	No	//
//	Al-C	As Delivered	Yes	//
//	//	//	No	//
//	//	Sanded	Yes	//
//	//	//	No	//
//	//	Polished	Yes	//
//	//	//	No	//
//	C-C	N/A	Yes	//
//	//	//	No	//
HQB1P	Al-Al	As Delivered	No	12.5
//	//	//	//	25
//	//	//	//	37.5

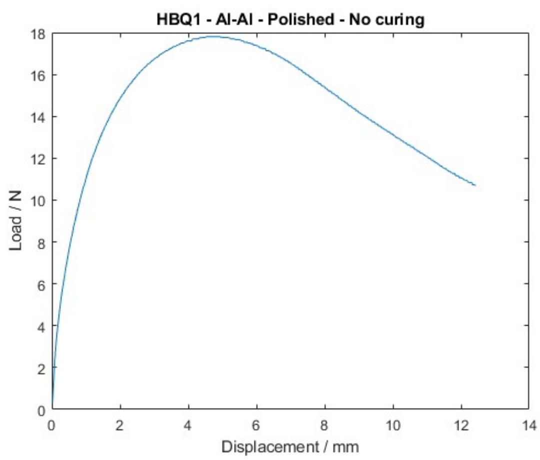
//	//	//	//	50
//	//	//	//	62.5
//	//	//	No	25
//	//	Sanded	Yes	//
//	//	//	No	//
//	//	Polished	Yes	//
//	//	//	No	//
//	Al-C	As Delivered	Yes	//
//	//	//	No	//
//	//	Sanded	Yes	//
//	//	//	No	//
//	//	Polished	Yes	//
//	//	//	No	//
//	C-C	N/A	Yes	//
//	//	//	No	//
HQB5HP	Al-Al	As Delivered	Yes	12.5
//	//	//	//	25
//	//	//	//	37.5
//	//	//	//	50
//	//	//	//	62.5
//	//	//	No	25
//	//	Sanded	Yes	//
//	//	//	No	//
//	//	Polished	Yes	//
//	//	//	No	//
//	Al-C	As Delivered	Yes	//
//	//	//	No	//
//	//	Sanded	Yes	//
//	//	//	No	//
//	//	Polished	Yes	//
//	//	//	No	//
//	C-C	N/A	Yes	//
//	//	//	No	//

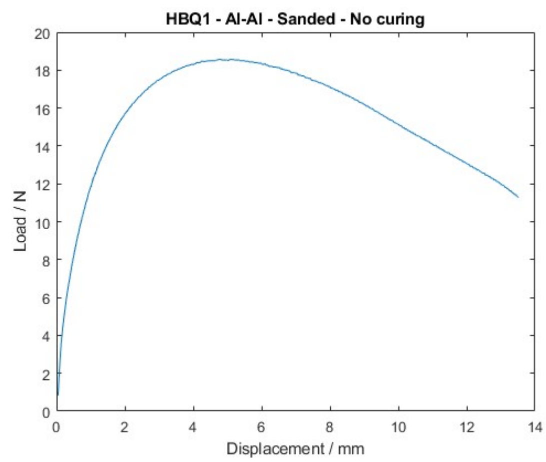
Appendix 2 – Finish and curing tests: force / displacement graphs

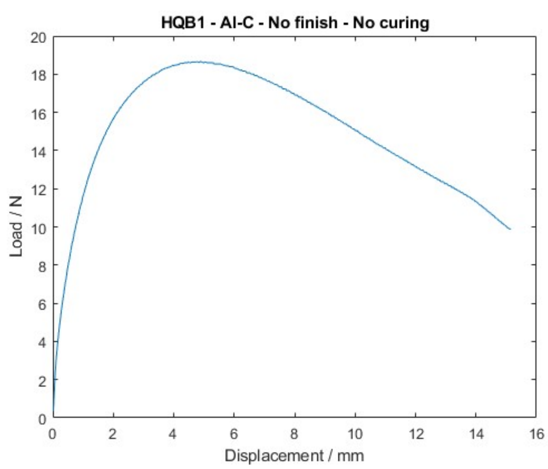
HQB1 tests

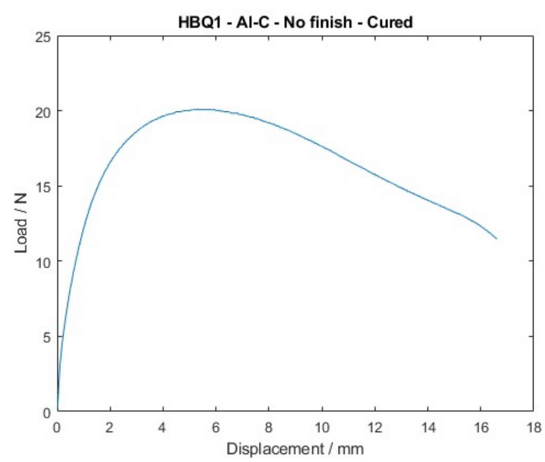


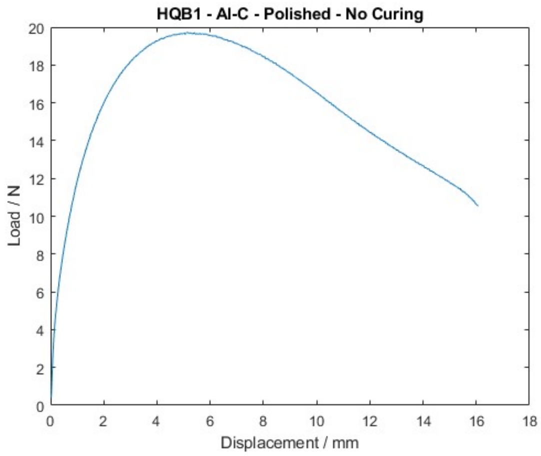


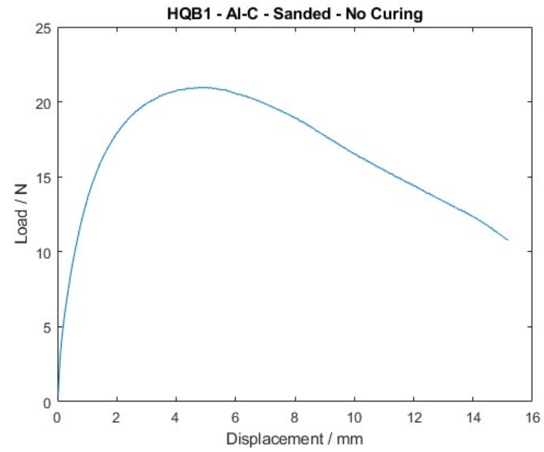


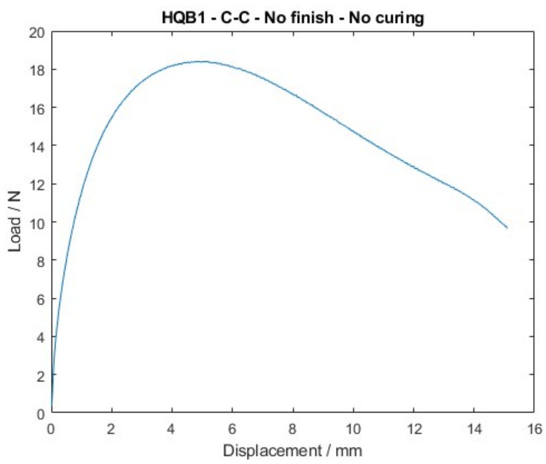


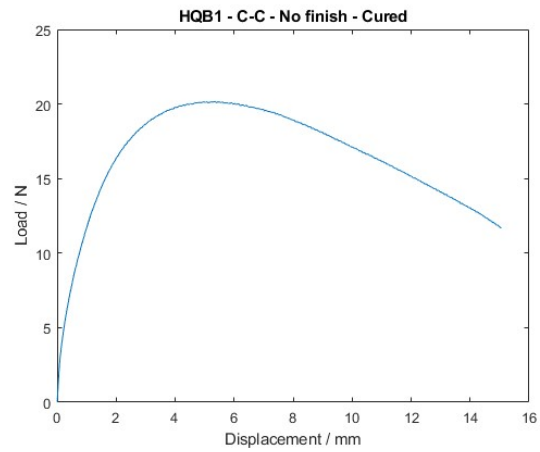




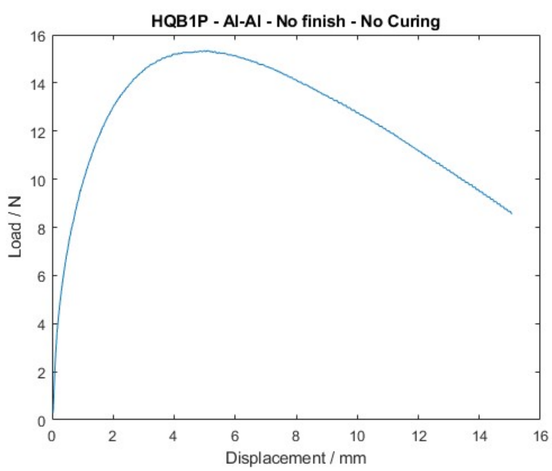

HQB1 - Al-C - Polished - No Curing
Load / N
Displacement / mm

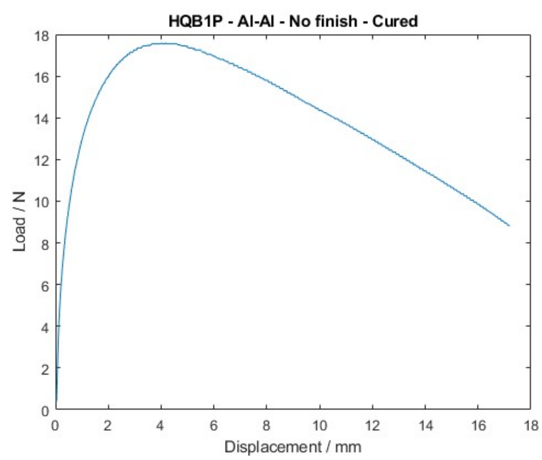

HQB1 - Al-C - Sanded - No Curing
Load / N
Displacement / mm

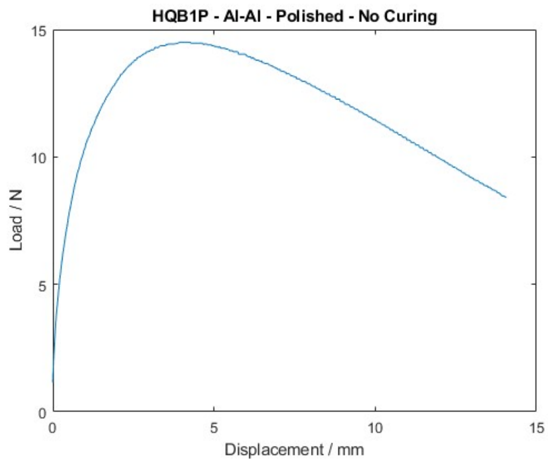

HQB1 - C-C - No finish - No curing
Load / N
Displacement / mm

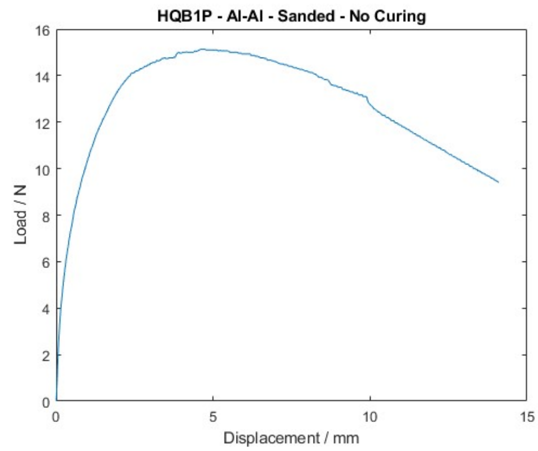

HQB1 - C-C - No finish - Cured
Load / N
Displacement / mm

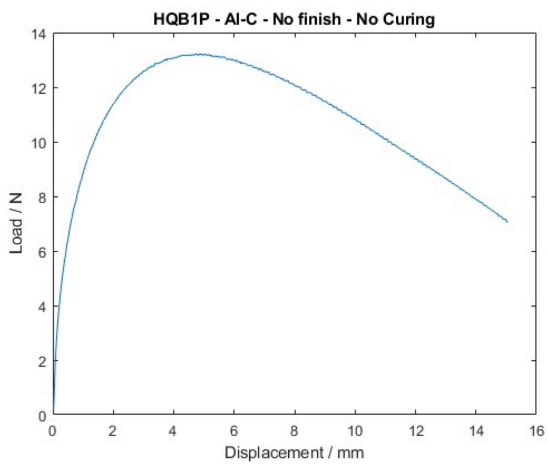
HQB1P tests

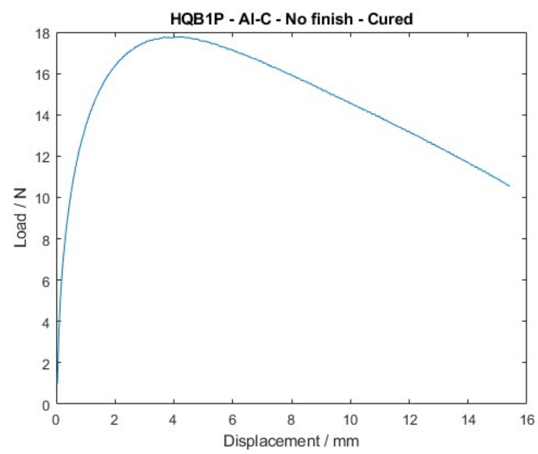

HQB1P - Al-Al - No finish - No Curing
Load / N
Displacement / mm

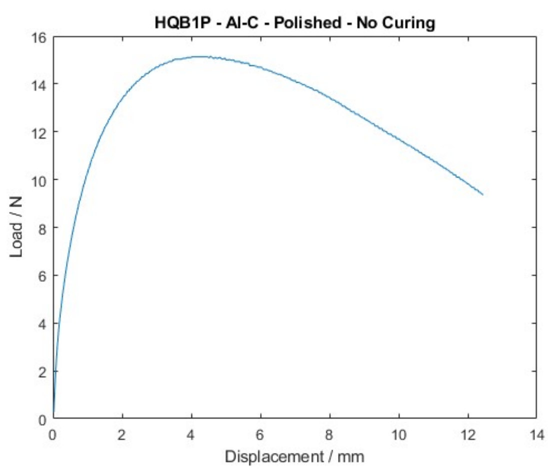

HQB1P - Al-Al - No finish - Cured
Load / N
Displacement / mm

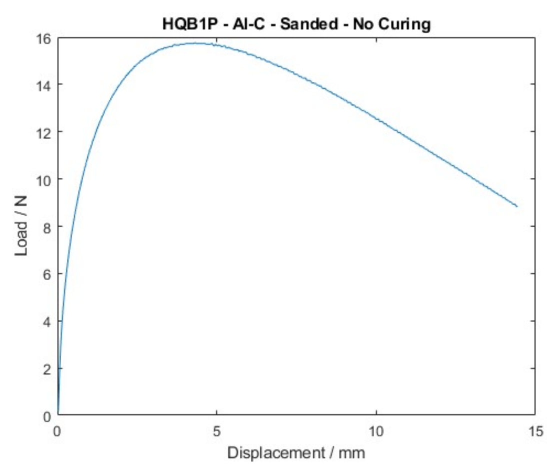

HQB1P - Al-Al - Polished - No Curing
Load / N
Displacement / mm

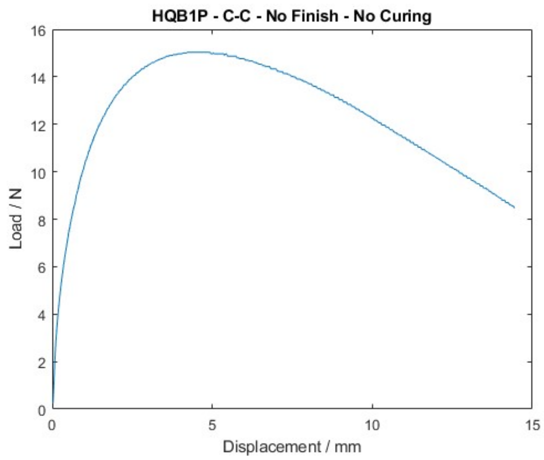

HQB1P - Al-Al - Sanded - No Curing
Load / N
Displacement / mm

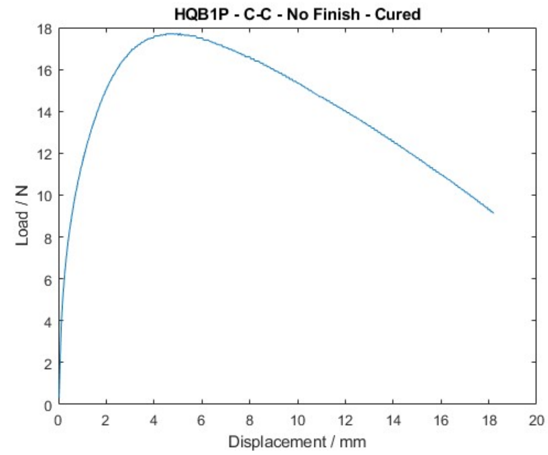

HQB1P - Al-C - No finish - No Curing
Load / N
Displacement / mm


HQB1P - Al-C - No finish - Cured
Load / N
Displacement / mm

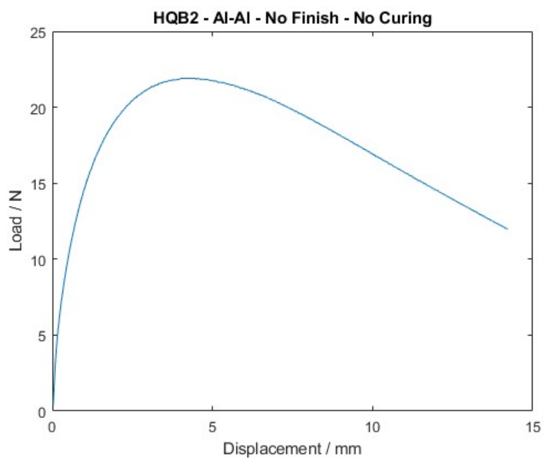

HQB1P - Al-C - Polished - No Curing
Load / N
Displacement / mm

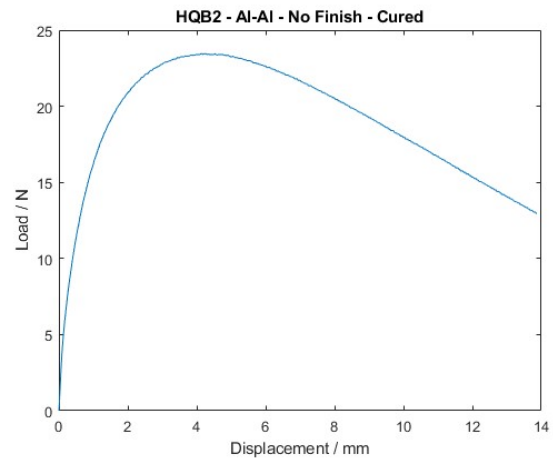

HQB1P - Al-C - Sanded - No Curing
Load / N
Displacement / mm

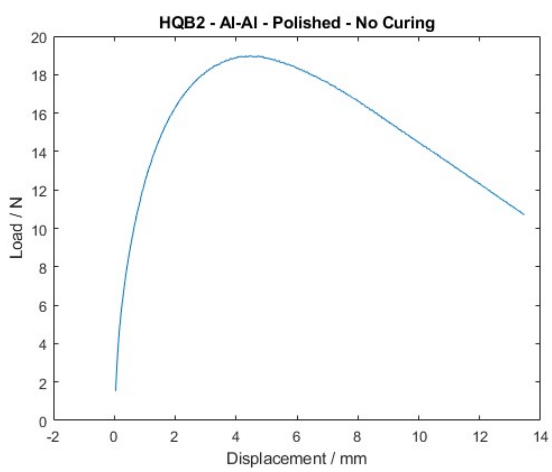

HQB1P - C-C - No Finish - No Curing
Load / N
Displacement / mm

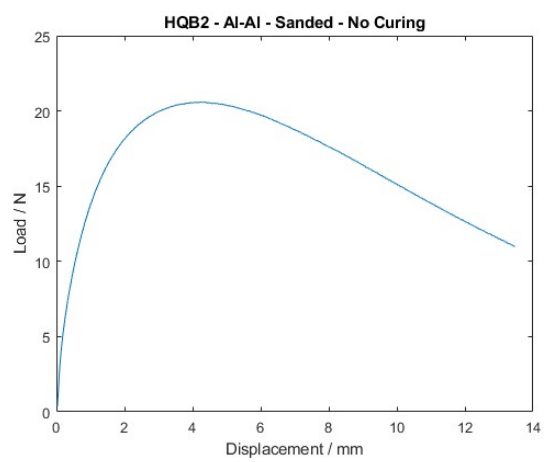

HQB1P - C-C - No Finish - Cured
Load / N
Displacement / mm

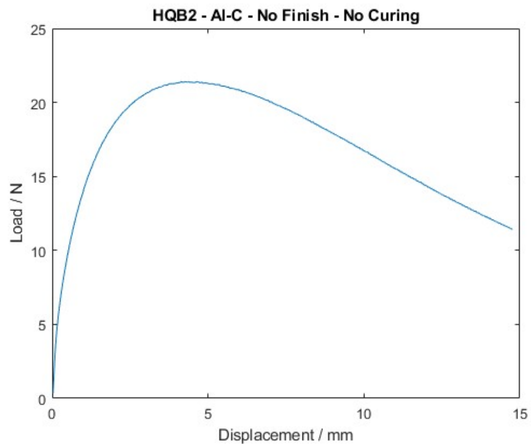
HQB2 tests

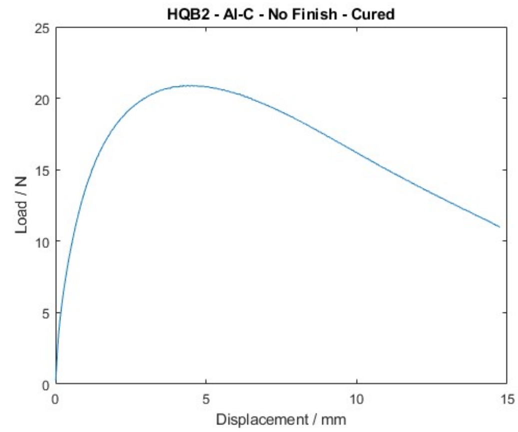

HQB2 - Al-Al - No Finish - No Curing
Load / N
Displacement / mm

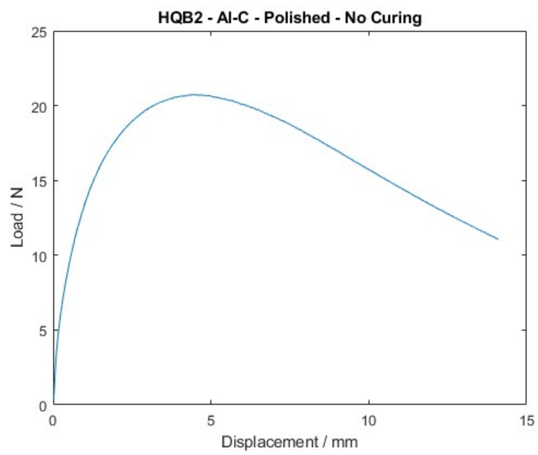

HQB2 - Al-Al - No Finish - Cured
Load / N
Displacement / mm

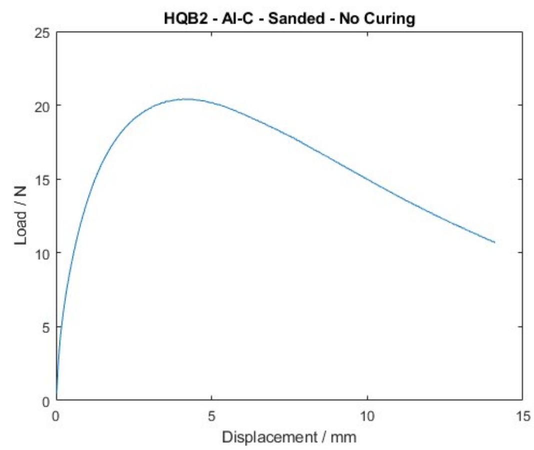

HQB2 - Al-Al - Polished - No Curing
Load / N
Displacement / mm

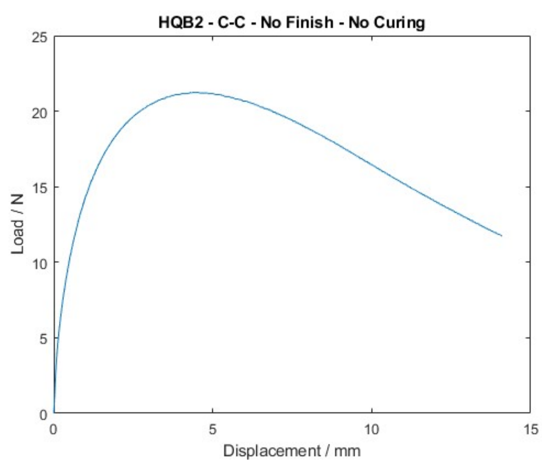

HQB2 - Al-Al - Sanded - No Curing
Load / N
Displacement / mm

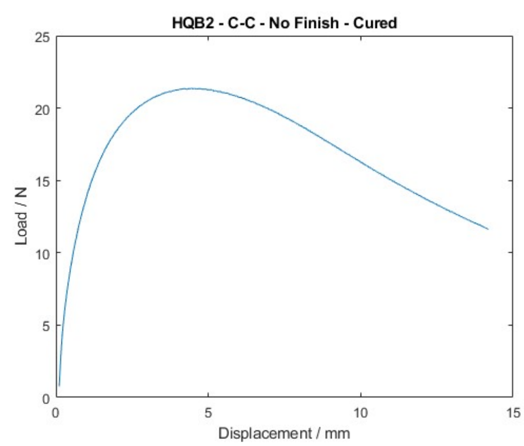

HQB2 - Al-C - No Finish - No Curing
Load / N
Displacement / mm
0
5
10
15
20
25
0
5
10
15


HQB2 - Al-C - No Finish - Cured
Load / N
Displacement / mm
0
5
10
15
20
25
0
5
10
15

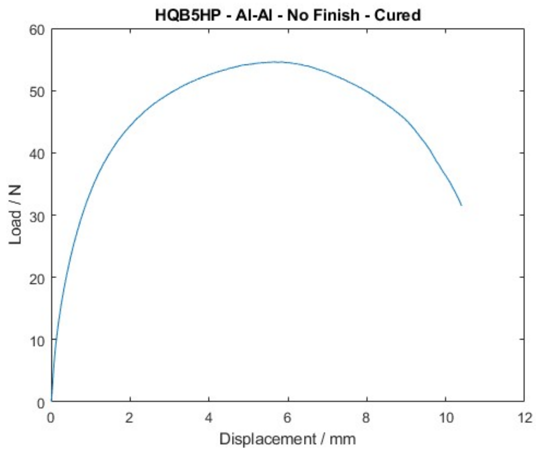

HQB2 - Al-C - Polished - No Curing
Load / N
Displacement / mm
0
5
10
15
20
25
0
5
10
15

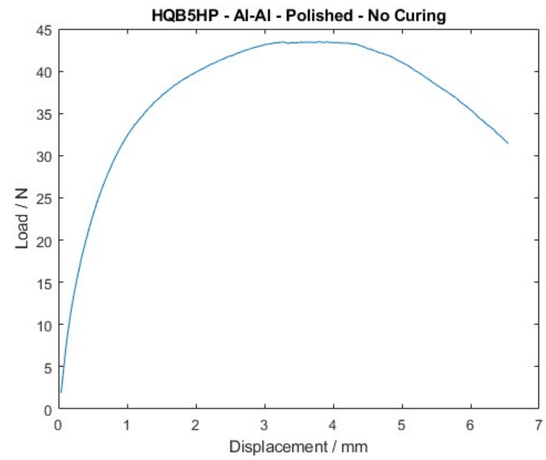

HQB2 - Al-C - Sanded - No Curing
Load / N
Displacement / mm
0
5
10
15
20
25
0
5
10
15

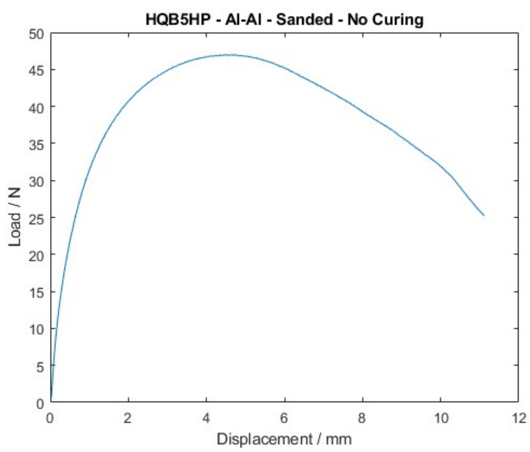

HQB2 - C-C - No Finish - No Curing
Load / N
Displacement / mm
0
5
10
15
20
25
0
5
10
15

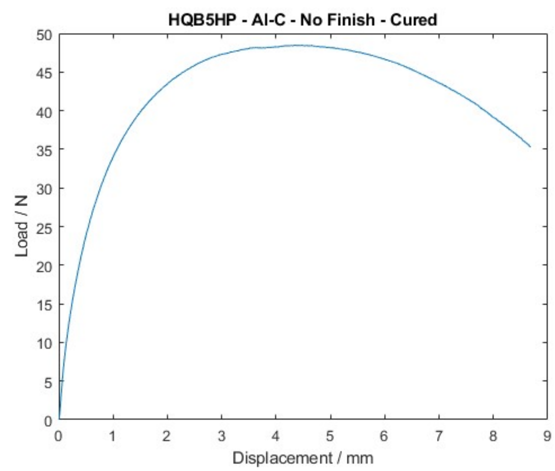

HQB2 - C-C - No Finish - Cured
Load / N
Displacement / mm
0
5
10
15
20
25
0
5
10
15

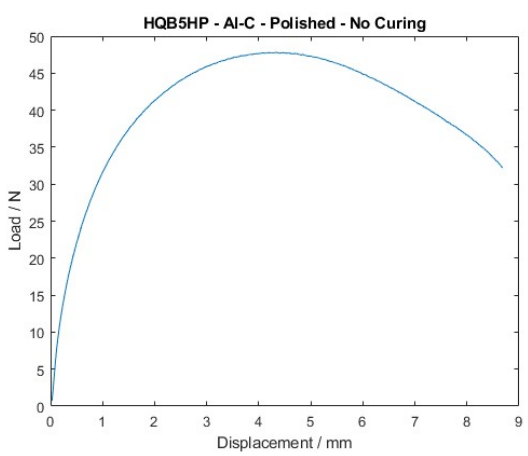
HQB5HP tests

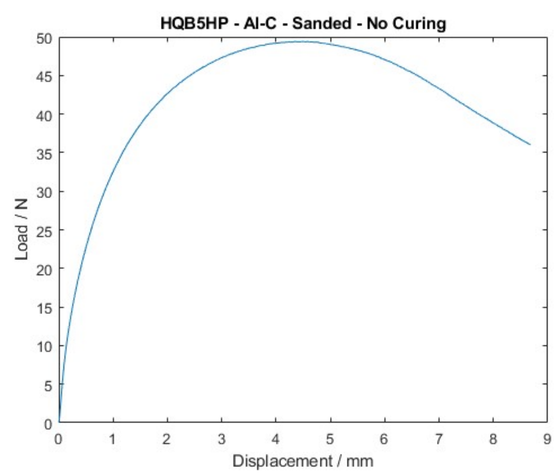


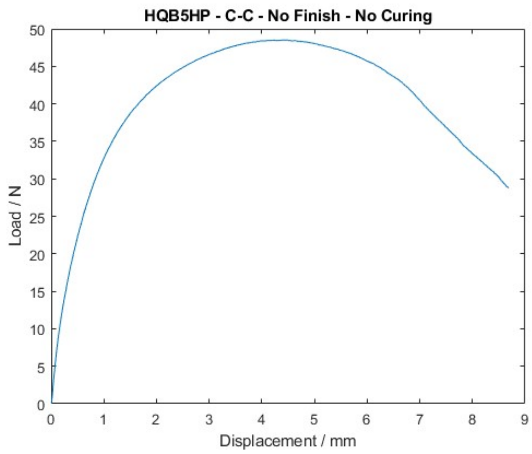


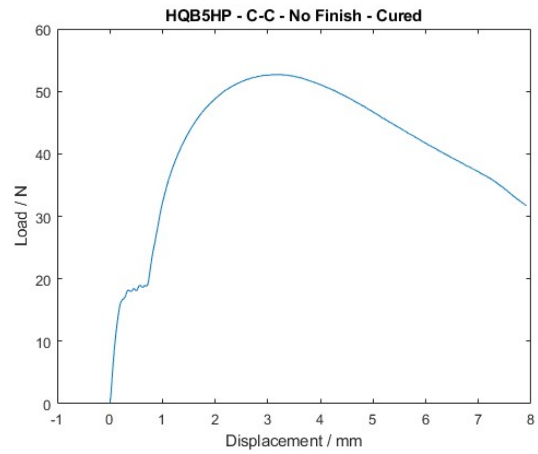






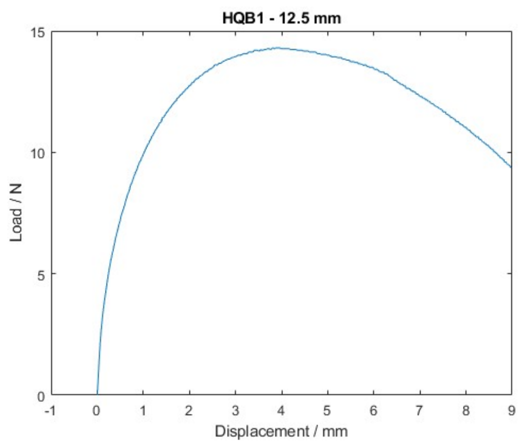


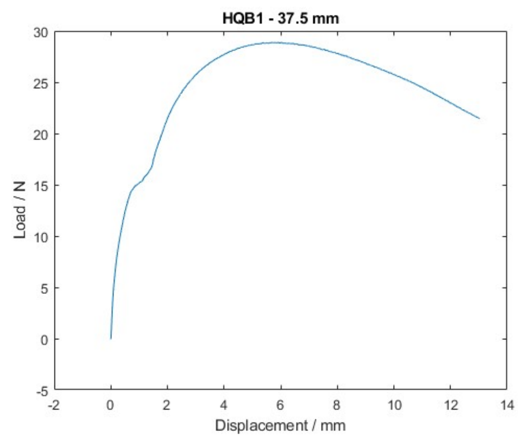


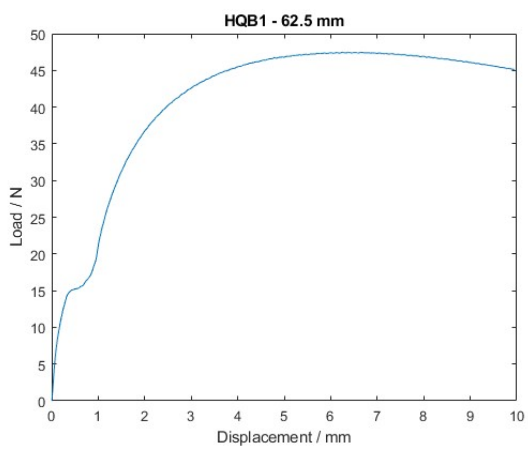


Appendix 3 – Area tests: force / displacement graphs

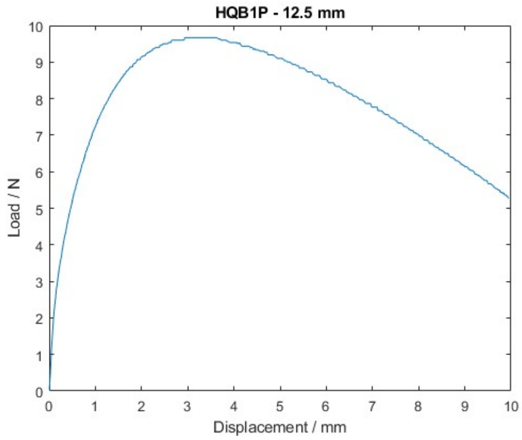
HQB1 tests

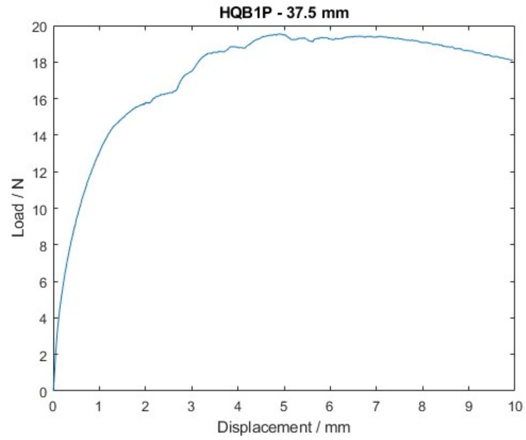


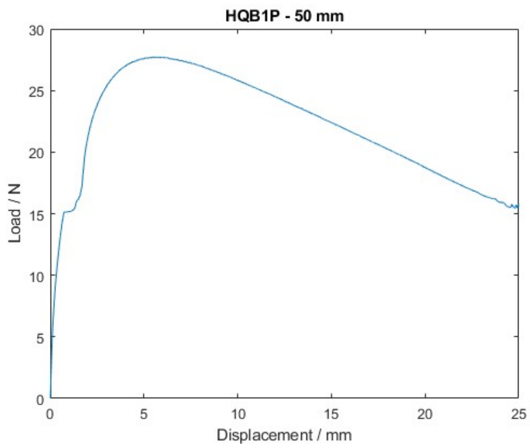


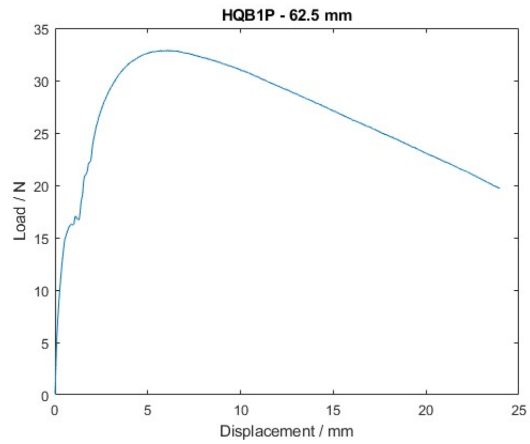


HQB1P tests

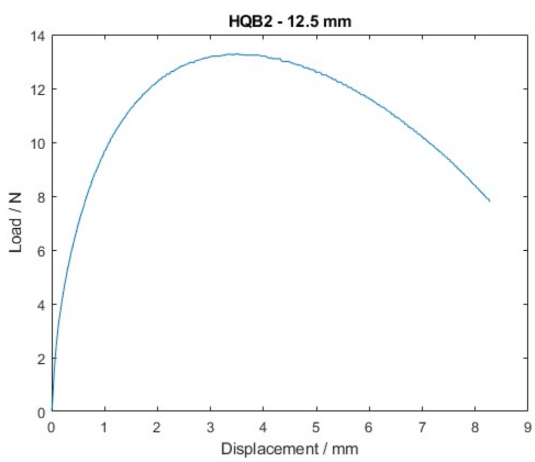


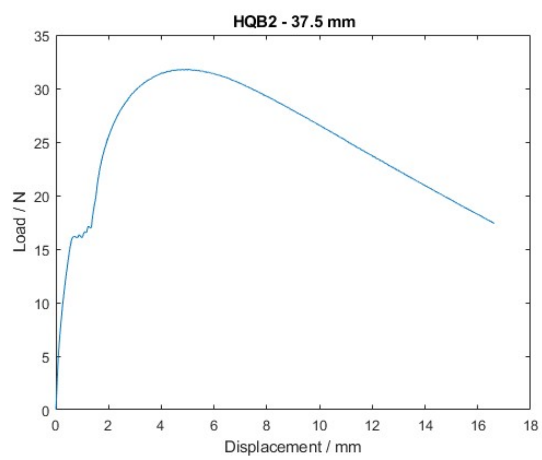


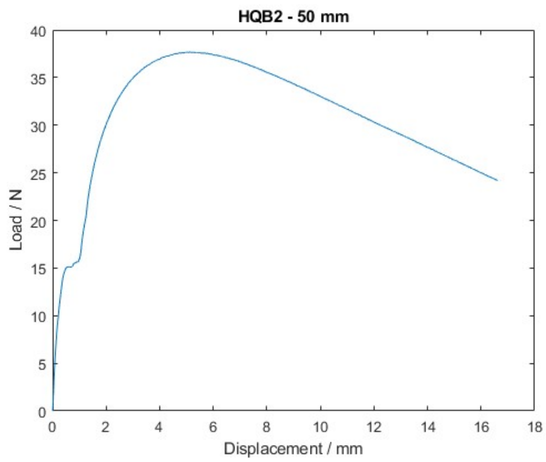


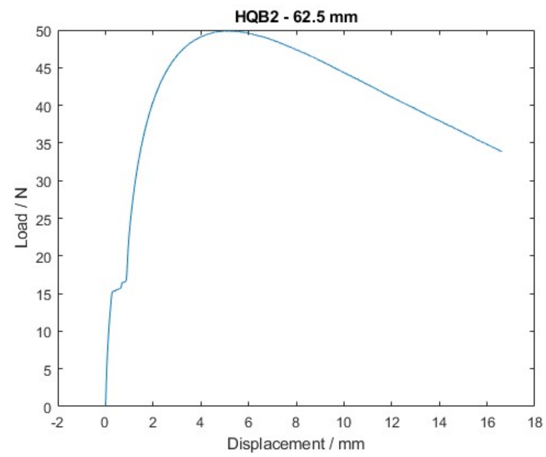


HQB2 tests

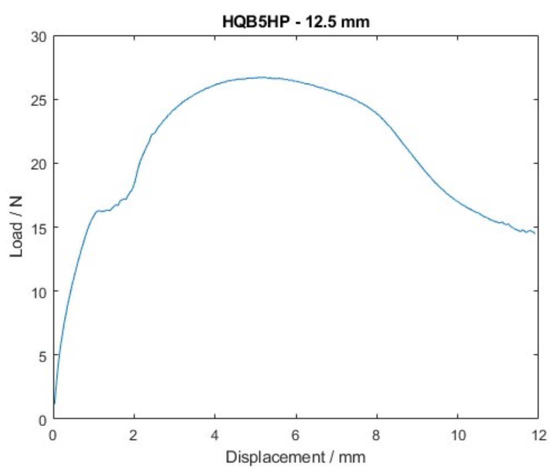


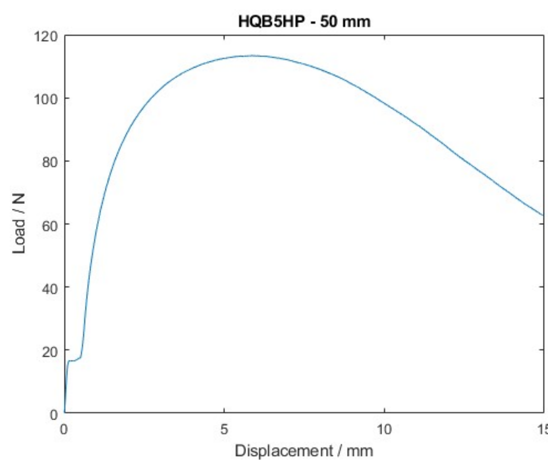


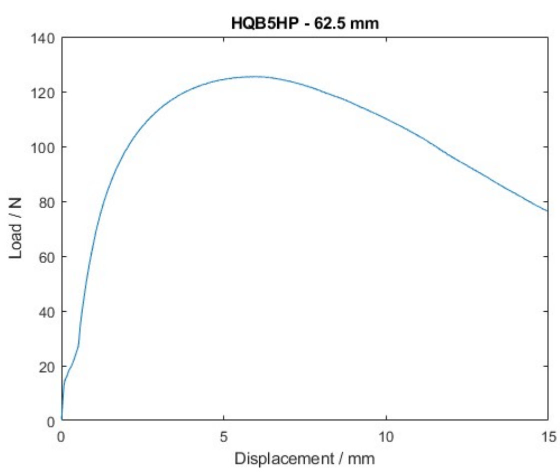

HQB2 - 50 mm
Load / N
Displacement / mm


HQB2 - 62.5 mm
Load / N
Displacement / mm

HQB5HP


HQB5HP - 12.5 mm
Load / N
Displacement / mm


HQB5HP - 50 mm
Load / N
Displacement / mm


HQB5HP - 62.5 mm
Load / N
Displacement / mm

Appendix 4 – Project Gantt chart

Task/ Date	Monday 07/03/2022	Tuesday 08/03/2022	Wednesday 09/03/2022	Thursday 10/03/2022	Friday 11/03/2022	Saturday 12/03/2022	Sunday 13/03/2022	Monday 14/03/2022	Tuesday 15/03/2022	Wednesday 16/03/2022	Thursday 17/03/2022	Friday 18/03/2022
Preliminary background research												
Meeting with Anthony												
UTM tutorial												
UTM familiarisation												
UTM practice and trial runs												
Polished sample prep												
Cured sample prep												
Write up methodology												
Cured Test												
Unprepared sample test												
Sanded sample test												
Polished sample test												
Report write up												
Results analysis												
Presentation Writing												
Presentation												

The above Gantt chart was developed on the Wednesday of week 1 and was used to plan what tasks we would achieve by which days. The actual execution of the project did vary from the Gantt chart slightly since we had achieved far more testing in the lab on the Friday week 1 than we had initially anticipated. Specifically, we had achieved all the testing for the different finishes for HQB1 and HQB2. So, we had achieved half of our planned tests by the end of week 1. On the Monday we completed the rest of the measurements and do additional tests which were the area tests, where we varied the overlap length. This was carried out on the Wednesday due to the lab being busy on the Tuesday. Subsequently, the report write-up was pushed back to the Thursday of week 2, which did not leave much time for the results analysis however it was achieved. Due to this, we did not have time to go back and run more tests to fill the gaps in our data.