Passive and Active Water Modules for the Fine Grained Detector

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Abstract

In order to best understand the nuclear effects of water vs. carbon in scintillator detection of the neutrino interactions in the T2K near detector, water modules are being included in one of the two near detector's Fine Grained Detectors. The current design for the water modules, using polycarbonate panels, will likely be implemented for the Fine Grained Detector (FGD), as there appear to be no compromising problems. A water bearing liquid scintillator upgrade is still considered a possibility as results of long term beam tests show that the previous problems with the incompatibility of the liquid scintillator and plastic cells which will be used are nearly resolved, and some biological growth inhibitors appear to have little adverse effect on light output. Considerations on apparatus for assembling the FGD are also underway and the possibility of using polypropylene strapping for suspending the components has been eliminated.

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1 Introduction

T2K (Tokai-to-Kamioka) is an international project to measure the neutrino oscillations of ν_μ to ν_e in the 295 km between Tokai and Kamioka. In order to do this the properties of the ν_μ beam must be measured at both ends of the beam. The Near Detector is located 280 m from the proton target in Tokai, and the Far Detector (Super-Kamiokande) is located 295 km away in the Kamioka mine. The Near detector consists of various modules including the Fine Grained detector, which is what my work was done on.

1.1 The Fine Grained Detector

The Fine Grained Detector (FGD) is the target mass for neutrino interactions in the Near Detector, tracking the path of short range particles in order to measure their energy and momentum. This is achieved by constructing the FGD out of a grid of scintillator bars. Each bar is composed of extruded polystyrene $(C_8H_8)_n$ polymer and is 9.65 mm $\times$ 9.65 mm $\times$ 185 cm. An XY layer consists of 192 bars side by side in one direction (call it X), and 192 bars placed on top, perpendicular to the others (in the Y direction). These are all held together by Plexus 590 glue, with a thin G10 layer glued on each side to increase the stiffness of the layer. Each bar has a 1.85 mm diameter hole through the center. A wavelength shifting fiber is fed through this to carry the light signal to a silicon PM at the end of the bar. The coincidence of a signal from a bar in the X and Y directions will give the position of a particle. The near detector will contain two FGDs. The plastic FGD will consist of 30 XY layers. The water FGD will consist of seven plastic XY layers, alternated with 6 water layers. The intent is to subtract the results of the water FGD from the plastic FGD to measure the interactions with water. This is required because the far detector is Super-Kamiokande, which detects the Cerenkov radiation emitted by relativistic electrons and muons produced by neutrinos interacting with the water. The systematic nuclear differences in the reactions between carbon (plastic scintillator) vs Oxygen (Super-K) need to be resolved. It is hoped that an upgrade to the FGD could eventually be done, replacing the plastic scintillator and water panels with active water panels, which would contain a water bearing scintillator. In this case there would be no "dead layers" from the passive water panels which would allow more particles of lower energy to be detected.

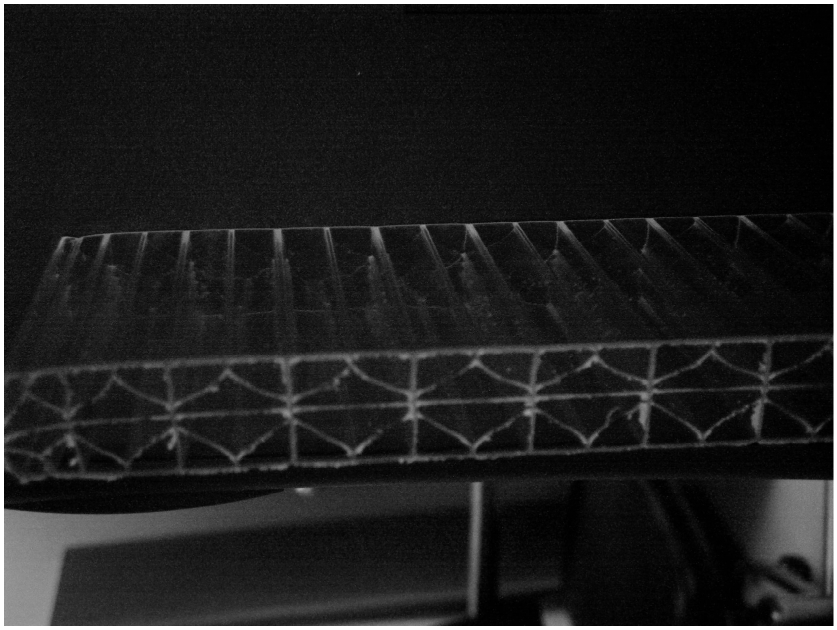


Figure 1: Photo of the endview of a polycarbonate panel

2 Passive Water Modules

In order to test if the proposed material would work for the water panel a prototype was constructed. I helped build a 211 cm $\times$ 17.4 cm $\times$ 2.5 cm water panel. This is approximately the same height, and $\sim \frac{1}{10}$ the width that the final water panels will be. The purpose of constructing this small version of the water panel is to test construction methods, to see if the epoxy will support the weight of the water for extended lengths of time, to measure how much the bottom of the panel bulges due to the weight of the water, and to see if water escapes the panel somehow over time, requiring the water levels to be closely monitored and adjusted. It was constructed using polycarbonate (also known as Lexan) panels which are used for greenhouses. These panels were chosen[1] to be used because their structural strength due to their internal columns (see Figure 1) and this type of plastic has a high oxygen content (polycarbonate = $(C_{16}O_3H_{14})_n$ polymer) compared with other types of plastic such as polypropylene (polypropylene = $(C_6H_{12})_n$ polymer). The high

[1]This choice was made prior to September 2006, before my arrival.

oxygen content is required in order to achieve the correct Oxygen:Hydrogen (O:H) ratio (1:2) in the panel so that the entire water-filled panel would have the elemental composition of polystyrene plus water. Because the mass ratio would still not be accurate with the polycarbonate panels, a thin layer of polypropylene will be glued to each side of the panel (0.8 mm on each side, 1.6 mm total) in order to correct it.[2] A direct comparison of the results from the plastic FGD (pure polystyrene) from the water FGD (polystyrene+water) allows us to extract the neutrino interactions on water alone. The ends were sealed using Stycast 1266. Stycast 1266 is a 2 part epoxy resin, parts A and B are mixed with a ratio A:B=100:33 by volume (100:28 by weight). A two part resin is required because a thick layer of glue is needed and a glue which reacts with air would not be able to properly cure since the middle of the layer would not be properly exposed to air.

2.1 Constructing the Panel

The first step in constructing the panel is to poke small holes in the partition walls which separate the inside columns in the panel (see Figure 1 to see the structure of the inside columns and see Figure 2 for a picture hole puncturing.). This is required so that water will be able to flow between columns, allowing for only one inlet valve and one outlet valve in the panel. Each wall should have holes every 0.5-1.0 cm from the end of the panel, extending up 10-15 cm inside the panel. Several holes are needed in case any get blocked. Also, depending on how far the epoxy ends up being inside the panel, this is needed so that so that the holes will be as close to the end as possible, but it is unknown where the hole will need to be to be closest to the end since the final level of epoxy is not precisely known. The holes need be as close to the end as possible because at the top of the panel air bubbles will get trapped above the top hole and no method is know to remove them.

In order to construct the panel a mold is needed for around the bottom of the panel in order to cast the epoxy seal. A two piece vinyl adjustable door-sweep (manufactured by RCR International) is currently used because it is easily available (one can be purchased at Home Hardware), has an easily adjustable size, and is inexpensive (see Figure 3 for a picture of the panel fit into the door-sweep). Other types of molds need to be tested because the

[2]These calculations were completed by Scott Oser and Daniel Roberge, and I will not include the details here.

Figure 2: Photo of puncturing holes in polycarbonate partition walls

Figure 3: Photo of polycarbonate paneling with the mold on the bottom.

final panel size ($\sim$2 m $\times$ $\sim$2 m) will be too large for this to work. The open ends of the mold are blocked with aluminum blocks that are the same width as the panel, and are held in place with C-clamps. The mold is sprayed with 811 Dry Film Vydax Mold Release (Manufactured by Sprayon) so that the epoxy will not bond to it. When casting the end of the panel, the aluminum ends are clamped in place, giving a mold length exactly the size of the panel. The Stycast 1266 is then poured into the mold and the panel is slid into this. The working time for Stycast 1266 is 30 minutes, allowing for any corrections to the mold or panel to easily be made when casting the seal at the end. Even for a few hours after this the Stycast remains quite runny, requiring the seals at the end of the mold to be very good, otherwise some will leak out of the mold and the seal at the end will not be thick enough. Putting petroleum jelly between the aluminum blocks and the mold helps to prevent them from being glued together, and helps with sealing the ends by filling any small gaps between the blocks and the mold. The cure time for Stycast 1266 is 8-16 hours at 25°C. Each time the end was cast it was left overnight before moving it, and extra time was left before filling it with water just in case. When sealing the other end it is important to first drill a hole in the sealed end for the pipe fitting (which can be inserted at this time or later). This is needed because in order for the epoxy to seal the end it must displace air inside the end of the panel, but if a hole is not drilled in the other end the air can not escape and the epoxy would be unable to displace much air. Because of this the epoxy would not be very thick. This is of concern since the weight of the water on the bottom of the panel will be quite large[3] once it is filled. When the epoxy is fully cured, a single $\frac{1}{4}$" diameter $\times$ 3" long copper pipe with Swagelok fittings pre-attached must be put in each end of the panel. It is best to put them on opposite sides (i.e. put one at the bottom left, and one at the top right of the panel or vice versa) since the flow rate between columns is slow. Otherwise, if both were at the top and bottom of the same column, if water were pumped in, it would immediately fill the one column before hardly any water entered the others. This diagonal configuration will pull the water across the panel as well as up (see Figure 4).

The valves were made using $\frac{1}{4}$ inch copper piping with appropriate fittings to connect to hoses to a water supply to the bottom valve and to the buffer tank above. When drilling the holes for the pipes it was important that the

[3] A 2 m $\times$ 2 m $\times$ 2.5 cm panel will contain $\sim$100 kg of water; 1.25 kg of water above every square inch of the seal.

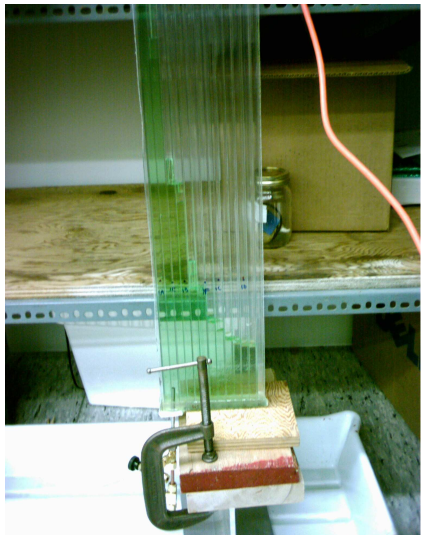


Figure 4: Photo of filling the panel. The unevenness of the water level is due to the low flow rate between columns. Note that the water contains green food coloring in order to make it easier to see.

top pipe not be inserted too far into that layer, so that a large air bubble is not left at the top of the column, as the water level in the panel will not rise above this pipe due to the trapped air above it. It is also important to use as small a drill bit as possible so that the hole is no larger than the pipe. A large hole will make it difficult to glue the pipe into place as the epoxy will drip through it and off of the pipe. The pipe was prepared by sanding to roughen the surface for better gluing, then it was cleaned using ethyl alcohol. When gluing the pipes in place 5-minute epoxy was used to initially hold the pipe in place and seal any gap between the pipe and the panel end. After this a small dam of putty was made around the pipe and Stycast 1266 was cast around the pipe. The 5-minute epoxy was initially used because it is not as runny and it cures much faster than the Stycast, so it would cure and stay in place better than Stycast, which would likely run into the panel, and not seal properly. The layer of Stycast 1266 is then added to ensure that there is a good bond between the pipe and the end seal since it is not known how strongly 5-minute epoxy bonds to Stycast 1266, and the Stycast should bond well to itself.

Once the panel and fittings are built a buffer tank is attached above, with a vacuum pump attached to that. A water supply (here a large bucket of water was used) is connected with a hose at the bottom. The vacuum pump is used to pull water up into the panel and buffer tank. Once the the panel was filled the valve at the bottom was closed, and the top was closed at the vacuum pump. This was to hold water in the panel for long term water level monitoring and deformation due to the pressure of the water on the panel.

The final water panels for the FGD will likely be under negative pressure. A negative pressure system is desired because if adequate pressure is used, small holes or cracks that could develop due to damage to the panel (perhaps due to an earthquake) will result in sucking air bubbles into the panel, not water leaking out, which could do significant damage to the electronics of the FGD. A buffer tank is used above the water panel so that if the water level drops it will not result in partial emptying of the panel. Because layers of polypropylene will be glued to the panel for the O:H correction, testing of various glues for this is currently under way (see section 2.5).

*****add picture or figure with all the components of the panel labeled (holes, layer of Stycast, copper pipes etc)********

2.2 Positive Pressure Measurements of Panel Deformation

Once the panel was filled with water, measurements were taken at many points on the panel in order to quantify the changes in thickness due to deformation from the weight of the water in the panel (see Figure 5. These points were distributed as follows: there were 9 points on each of 5 rows on the panel (numbered 1-5, starting at the bottom). The rows were at 32 cm, 78 cm, 124 cm, 171 cm, and 194 cm from the bottom. In each row there were 3 sets of 3 points (labeled A-I from the right). Each set of three points had a point positioned on three different structural locations (see Figure 6). These structural locations are at the center of the columns, on the heavier dividers between the columns, and a point in between. This is because the internal structure may effect the amount of deformation. It can be seen that the internal structure is repeated in 2.5 cm^2 columns. The distance from the edge of points A-I respectively are 1.3, 1.9, 2.5, 6.2, 6.8, 7.4, 11.3, 11.9, and 12.1 cm. In summary, this leads to points having labels such as 1A, 1B... 5I.

Measurements of each point were taken 1-2 times on October 5-6, 2006 when the panel was empty and when it was filled. For the points with mul-

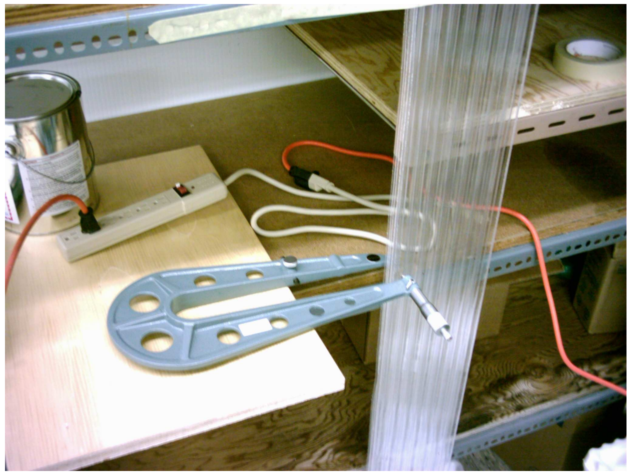


Figure 5: Photo of measuring the thickness of the water panel.

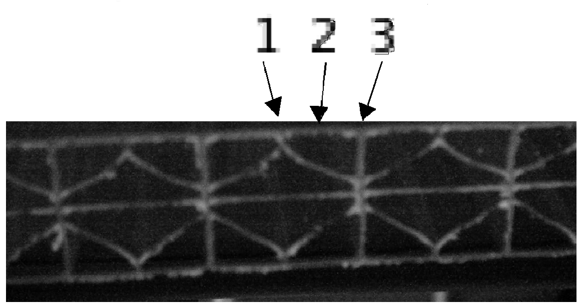


Figure 6: Photo of the endview of a polycarbonate panel with location on internal structure of thickness measuring points labeled. Points A, D, and G on each row are on structural locations like 1 in the picture. Points B, E, and H are on points like 2. Points C, F, and I are like location 3.

	Column A	Column B	Column C	Column D	Column E	Column F	Column G	Column H	Column I
Row 5	-1	-1	-2	-1	0	0	1	1	***
Row 4	1	2	0	1	-1	0	0	0	-1
Row 3	4	1	1	1	1	0	-1	1	-1
Row 2	6	5	0	4	3	0	3	4	1
Row 1	5	5	1	4	3	0	6	4	-1

Table 1: Summary of the change in thickness in each point measured on the panel (units of 10^{-3} inches). Rows are numbered starting with 5 at the top because this is the orientation of the numbering on the panel, as it gives a more intuitive understanding of the thickness for various points on the panel since the ordering of the cells in the table is the same as on the panel (right to left and top to bottom).

tiple measurements the average was taken. If the error on the measurement was half the smallest increment the error should be only 0.0005" on any measurement, but, because the surface of the panel was not completely flat, and because the panel could be compressed slightly under pressure, the error is larger than that. The average difference between two measurements of the same point taken within a day of each other $(M_1 - M_2)$ was 0.00094" while filled or empty, but for any given point, two measurements could differ by as much as 0.006". The average filled thickness minus the average empty thickness for each point is shown in table 1. The panel had an average thickness when empty of 0.9621 inches, an average full thickness of 0.9614 inches, resulting in an average change of $1.3 * 10^{-3}$ inches. This was not a uniform change (see Table 1). The thickness of the panel was remeasured on November 20th after standing filled for 36 days. The average change in thickness was $-1 * 10^{-3}$ inches, which is comparable the error of the measurement.

Conclusions and Future Tests

The water panel thickness will continue to be monitored for long term change in its thickness due to the weight of the water and to see that the epoxy seal at the end hold well for long periods of time. Since the FGD will be under negative pressure, negative pressure tests should be done to see if the panel would deform. These tests have been temporarily suspended while measurements are made of how much the panel bends when only the ends are supported when held horizontally.

2.3 Long Term Water Level Monitoring

While the water panel was sitting between thickness measurements the water level was monitored in order to see if water was leaving the panel somehow, either through absorption by the polycarbonate, or by somehow evaporating through the panel. Over the first 34 days (October 4-November 7, 2006) the water dropped 8±1 mm, corresponding to a 50±6 ml loss in volume (average of 1.5±5 ml/day). Over the next 14 days an additional 3±1 mm drop was observed (19±6 ml, 1.4±0.4 ml/day).

Conclusions and Future Tests

This effect will not be a problem for the water level to be topped up before it becomes to low. Because water is escaping somehow it must be determined if the water is escaping the panel, or being absorbed by it since the exact water content of the FGD is important in order to accurately analyze the signal from the near detector. Water Permeability tests were carried out in order to better understand how water is escaping (see below). Water escaping the panel is also a concern because it would increase the humidity in the light tight FGD box where some of the electronics are located. Understanding the amounts of and routes water escaping are therefore important.

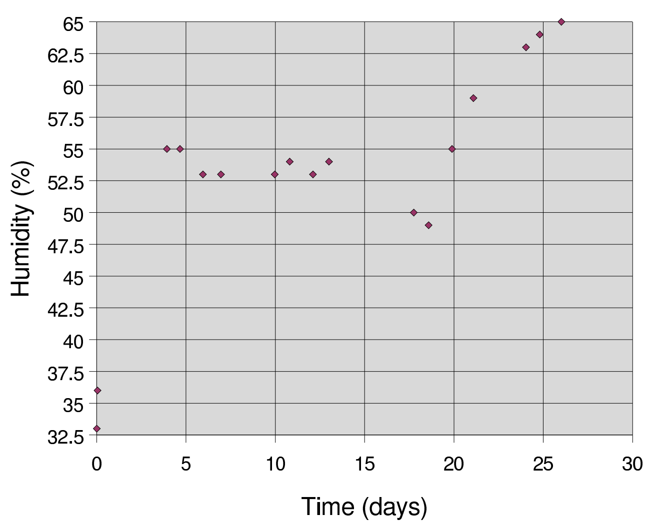
2.4 Water Permeability Tests

Because of the water level drop could be due to water evaporating through the panel, it was decided to test how much was escaping[4]. A miniature version of the panel ($20cm \times 17cm \times 2.5cm$) was made and put in a plastic zip-lock bag. The humidity and temperature were monitored to see how humidity changed with time. After 20 days the panel was double bagged to see if the stability of the humidity was due to some equilibrium between the water escaping the panel and the bag. This was found to be true as the humidity once again

[4]The other possibility, that the panel was absorbing the water, is being investigated by PhD student Daniel Roberge

Date/time	Time (days)	Humidity (%)	Temperature (C)	Comments
Nov.10/2006 14:55	0	33	23	
Nov.10/2006 16:00	0.05	36	23	
Nov.14/2006 13:15	3.93	55	22	
Nov.15/2006 8:55	4.67	55	22	
Nov.16/2006 13:40	5.95	53	22	
Nov.17/2006 13:50	6.95	53	23	
Nov.20/2006 14:10	9.97	53	23	
Nov.22/2006 10:20	10.81	54	22	
Nov.23/2006 17:30	12.11	53	22	
Nov24/2006 15:00	13	54	22	
Nov.28/2006 14:40	17.75	50	19	
Nov.29/2006 14:20	18.58	49	20	
Nov.30/2006 12.25	19.9	55	20	Double bagged after measurement
Dec.1/2006 17:05	21.09	59	20	
Dec.4/2006 15:45	24.03	63	21	
Dec.5/2006 10:10	24.8	64	21	
Dec.6/2006 15:15	26.01	65	21	

a)



b)

Table 2: Permeability Tests: a)Humidity and Temperature inside the zip-lock bag with the small water panel. b)Plot of Humidity vs. Time

began to climb. A humidity and temperature measurements can be seen in Table 2.

Conclusions and Future Tests

This small water panel will continue being monitored. Because there was some minor damage to the epoxy at the base during demolding, an extra coating of epoxy should be applied to confirm that the water escaping the panel is due to water escaping through the polycarbonate or epoxy, and not due to a damaged seal. Due to the fact that water is escaping, and for general humidity control of the FGD, it is likely that some sort of forced air system will be implemented for the FGD.

2.5 Glue tests

In order to have the correct elemental abundance ratio in the water panel, a 1.6 mm layer of polypropylene will be glued to it. Glue must be used because space restrictions prevent any possibility of trying to clamp this layer into place. Glue tests were begun in order to assess what type of glue would work best between these types of plastic. The glues tested were 5-minute epoxy, Stycast 1266, Vulkem 116 (with TREM Prime primer), Vulkem 45 (with TREM Prime primer), Lexel, CLR 1625/CLH 6330, CLR 1390/CLH 6025, Stycast 2850 with catalyst 9, Plexus 590, and Lexel. To narrow it down to the best glues 1 cm $\times$ 6 cm strips were glued together with a 2 cm^2 glue area. Two types of stresses were put on the glue joint. The first was the peel test. The polycarbonate bar was held horizontally in a vise and weights were hung 1 cm from the end of overlap on the polypropylene. The second was the sheer tests. The polycarbonate bar was held vertically in a vise, and weights are hung from the polypropylene (see figure 7. Initially a larger amount of weight was used, and smaller weights were added at two minute time intervals. For peel tests, the initial weight was 500 g, and $\sim$100 g weights were added every $\sim$2 minutes until the glue broke. For sheer tests, the initial weight was 2000 g, and $\sim$200 g weights were added every $\sim$2 minutes until the glue broke. For the first set of glue tests one sample was tested horizontally, and one vertically for each type of glue. For the initial tests the surfaces of the polypropylene and polycarbonate strips were sanded before gluing in order to increase bond strength, but this sanding was discontinued in later tests because it would be too time consuming to sand the actual water panels before gluing. The results of the breaking tests are summarized in table 3. The properties of the five best glues are given in table 4.

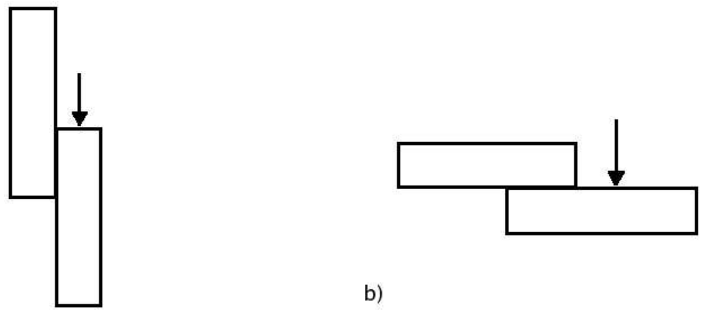


Figure 7: a) Sheer tests b) Peel tests

	Weight to break (g)			
	Sanded samples		Unsanded Samples	
Glue	**Peel Test**	**Sheer Test**	**Peel Test**	**Sheer Test**
5-minute epoxy	2200	6170	N/A	N/A
Stycast 1266	1960	6350	2080 to 2340	2910 to >12640
Vulkem 116	1950	5220	N/A	N/A
Vulkem 45	990	~6000	N/A	N/A
CLR 1625/CLH 6330	1970	5860	2070 to 4220	N/A
CLR 1390/CLH 6025	2560	7080	3700 to 6620	7380 to 8820
Stycast 2850 (catalyst 9) (black)	1500	6480	N/A	N/A
Plexus 590	650	3000	N/A	N/A
Lexel	820	<2000	N/A	N/A

Table 3: Results of the glue breaking tests. All glues were not retested for unsanded surfaces, only the three strongest which had other suitable properties. The sheer test was never completed for one sample. Note that one sample never broke, I ran out of weights. For the Unsanded tests the range of results are given.

Glue	Working time	Comments
5-minute epoxy	~5 minutes	-working time too short -Discontinued tests
Stycast 1266	30 minutes	-Very runny, even for a few hours after mixing. -Clear, colorless
Vulkem 116	unknown	-Cures due to reaction with moisture in air. -Discontinued tests.
CLR 1625/CLH 6330	20 minutes	-Very runny; still liquid >1 hour after mixing. -Clear, colorless
CLR 1390/CLH 6025	90 minutes	-CLR is very thick, difficult to measure. -Easier to work with when mixed. -Opaque/beige

Table 4: Properties of the 5 best glues tested.

Although five glues proved to have quite strong bonds, since the 5-minute epoxy has much too short of a working time, and the Vulkem 116 needs to react with air in order to cure which will not be possible in the center of the 2m^2 panel, only tests for Stycast 1266, CLR 1625/CLH 6330 and CLR 1390/CLH 6025 were continued. Two samples were made up for the 2nd set of tests in order to average results to help ensure that the results were representative.

Conclusions and Future Tests

All three glues continued to perform well. It should be noted that the results of the two sets of tests should not be directly compared since in the 2nd set the surfaces were not sanded, and glue was not properly wiped away from around the edges when the pieces were glued together. It is apparent from these tests that having glue around the outside edges of the pieces being glued together increases the strength of the bond between the two pieces. It may be a good idea when gluing polypropylene to the water module to put glue over the edges to help prevent peeling. This may be because it helps prevent the edges from beginning to peel, which always happened before the pieces came apart, which didn't occur until the polypropylene began to buckle under the weights. In all but one sample the glue peeled away from the polypropylene surface (the one exception was one of the CLR 1625/CLH 6330 samples). The one strip that did not break (I ran out of weights) had a lot of glue on the edges. Generally the inconsistency of the results for the unsanded set of tests was due to unevenly applied glue, and/or large amounts of glue on the edge of the piece.

The tests have been suspended until the arrival of a sample of the polypropylene which will be used on the water panel. The polypropylene used in the tests thus far was the Matraplast paneling used to make cells for liquid scintillator tests. Because of manufacturing differences the type used for the panel may have different surface properties, so no decision will be made until more tests can be done. Larger scale tests are required in order to evaluate which are easier to handle, and perform best in larger tests. It also must be checked to see whether a thin layer of the glue is easily broken when bent, as the water panel has some flexibility.

3 Active Water Modules

Active water panels are an alternative to the current design, using a water bearing liquid scintillator instead of plastic scintillator and passive water panels. It is preferable because it would not have any of the dead layers created by the passive water layers. It was previously determined that a solution containing 70% water, 25% Quicksafe A (a liquid scintillator), and 5% Triton X-100 (TX-100) (percentages by volume) (called the "standard solution") is one possibility for such a water bearing scintillator. QSA is a commercial liquid scintillator from Zinsser Analytic. TX-100 is a surfactant used to help dissolve QSA in water.

3.1 Beam tests

In order to determine the long term performance of a liquid scintillator, light output of various types of samples have been tested over several months in a 120 MeV/c Muon, Pion and Electron beam using the M11 beam-line at TRIUMF. The type of particle hitting the sample was determined by measuring the time of flight between two plastic scintillators separated by 4.4 m. In addition to the standard solution, samples including various biological inhibitors have been tested because mold could grow in the samples if one was not used. Samples of 100% QSA were also tested for comparison, but are not being considered for the FGD. In order to test the samples they were placed in $0.8 \times 0.8 \times 50$ cm (approximate interior dimensions) white polypropylene cells which were then sealed in light tight tubes (see figure 8). The cells contain wavelength shifting fibers running through the cell, and through the bottom of the cell in order to carry the light from the scintillator to the photomultiplier which the cell's were mounted on. It was also previously found that the QSA caused a degradation and yellowing of the white polypropylene, so all types of samples were repeated in cells that were sanded inside and painted with Eljen-520, a commercially available reflective paint, in order to prevent this. Another advantage of the reflective paint is it increases the light output of the cell. In total there are 50 samples that were included in the beam tests (see Table 5).

Detector	Cell	Fiber	Solution	Reflector	Filled on	PMT	Base	Voltage (V)	Attenuator	Comment
LT#1	Unpainted Matraplast	1.0mm	70/25/5 (water/QSA/TX-100)		Jun.22/05	Patrick	PAT2	-2300	1	sealed at top with RTV
LT#2	Unpainted Matraplast	1.0mm	70/25/5 (water/QSA/TX-100)		Jun.24/05	Patrick	PAT2	-2300	1	sealed at top with RTV
LT#3	Unpainted Matraplast	1.0mm	100%QSA		Jun.24/05	Patrick	PAT2	-2300	0.3	sealed at top with RTV
LT#4	Unpainted Matraplast	1.0mm	100%QSA		Jun.24/05	Patrick	PAT2	-2300	0.3	sealed at top with RTV
LT#5	Painted Matraplast	1.0mm	70/25/5 (water/QSA/TX-100)		Jul.18/05	Patrick	PAT2	-2300	1	endplug at top holding fiber centered
LT#6	Painted Matraplast	1.0mm	70/25/5 (water/QSA/TX-100)		Jul.18/05	Patrick	PAT2	-2300	1	endplug at top holding fiber centered
LT#7	Painted Matraplast	1.0mm	100%QSA		Jul.18/05	Patrick	PAT2	-2300	0.3	
LT#8	Painted Matraplast	1.0mm	100%QSA		Jul.18/05	Patrick	PAT2	-2300	0.3	
LT#9	Unpainted Matraplast	1.0mm	70/25/5(water/QSA/Tx-100)		Jul.20/05	Patrick	PAT2	-2300	1	plugged at top with black plexiglass plug
LT#10	Unpainted Matraplast	1.0mm	70/25/5(water/QSA/Tx-100)		Jul.20/05	Patrick	PAT2	-2300	1	plugged at top with black plexiglass plug
LT#11	Unpainted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100)	No		Patrick	PAT2	-2300	1	
LT#12	Unpainted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100)	No		Patrick	PAT2	-2300	1	
LT#13	Unpainted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100)	No		Patrick	PAT2	-2300	1	
LT#14	Unpainted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100)	No		Patrick	PAT2	-2300	1	
LT#15	Unpainted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100) + 0.5%Germall Plus	No	Nov.24/05	Patrick	PAT2	-2300	1	
LT#16	Unpainted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100) + 0.5%Germall Plus	No	Nov.25/05	Patrick	PAT2	-2300	1	
LT#17	Unpainted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100) + 0.5%Germall Plus	No	Nov.25/05	Patrick	PAT2	-2300	1	
LT#18	Unpainted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100) + 0.5%Germall Plus	No	Nov.25/05	Patrick	PAT2	-2300	1	
LT#19	Unpainted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100) + 0.5%Germall Plus + ZnAcetate(3000ppm)	No	Nov.25/05	Patrick	PAT2	-2300	1	
LT#20	Unpainted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100) + 0.5%Germall Plus + ZnAcetate(3000ppm)	No	Nov.26/05	Patrick	PAT2	-2300	1	low light ouput
LT#21	Unpainted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100) + 0.5%Germall Plus + ZnAcetate(3000ppm)	No	Nov.26/05	Patrick	PAT2	-2300	1	
LT#22	Unpainted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100) + 0.5%Germall Plus + ZnAcetate(3000ppm)	No	Nov.26/05	Patrick	PAT2	-2300	1	
LT#23	Unpainted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100) + 0.5%Germall Plus + ZnAcetate(3000ppm)	No	Nov.26/05	Patrick	PAT2	-2300	1	
LT#24	Unpainted Matraplast	2*1.0mm	100%QSA	No	Nov.27/05	Patrick	PAT2	-2300	0.3	RTV on fibre
LT#25	Unpainted Matraplast	2*1.0mm	100%QSA	No	Nov.27/05	Patrick	PAT2	-2300	0.3	
LT#26	Unpainted Matraplast	2*1.0mm	100%QSA	No	Nov.27/05	Patrick	PAT2	-2300	0.3	
LT#27	Unpainted Matraplast	2*1.0mm	100%QSA	No	Nov.27/05	Patrick	PAT2	-2300	0.3	
LT#28	Painted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100)	No	Nov.27/05	Patrick	PAT2	-2300	1	
LT#29	Painted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100)	No	Nov.27/05	Patrick	PAT2	-2300	1	
LT#30	Painted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100)	No		Patrick	PAT2	-2300	1	
LT#31	Painted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100)	No		Patrick	PAT2	-2300	1	
LT#32	Painted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100) + 0.5%Germall Plus	No	Nov.28/05	Patrick	PAT2	-2300	1	
LT#33	Painted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100) + 0.5%Germall Plus	No	Nov.28/05	Patrick	PAT2	-2300	1	
LT#34	Painted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100) + 0.5%Germall Plus	No	Nov.28/05	Patrick	PAT2	-2300	1	
LT#35	Painted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100) + 0.5%Germall Plus	No	Nov.28/05	Patrick	PAT2	-2300	1	
LT#36	Painted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100) + 0.5%Germall Plus + ZnAcetate(3000ppm)	No	Nov.28/05	Patrick	PAT2	-2300	1	
LT#37	Painted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100) + 0.5%Germall Plus + ZnAcetate(3000ppm)	No	Nov.28/05	Patrick	PAT2	-2300	1	
LT#38	Painted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100) + 0.5%Germall Plus + ZnAcetate(3000ppm)	No	Nov.28/05	Patrick	PAT2	-2300	1	
LT#39	Painted Matraplast	2*1.0mm	70/25/5(water(boiled distilled) QSA/Tx-100) + 0.5%Germall Plus + ZnAcetate(3000ppm)	No	Nov.28/05	Patrick	PAT2	-2300	1	
LT#40	Painted Matraplast	2*1.0mm	100%QSA	No	Nov.29/05	Patrick	PAT2	-2300	0.3	
LT#41	Painted Matraplast	2*1.0mm	100%QSA	No	Nov.29/05	Patrick	PAT2	-2300	0.3	
LT#42	Painted Matraplast	2*1.0mm	100%QSA	No	Nov.29/05	Patrick	PAT2	-2300	0.3	
LT#43	Painted Matraplast	2*1.0mm	100%QSA	No	Nov.29/05	Patrick	PAT2	-2300	0.3	
LT#44	Painted Matraplast	2*1.0mm	100%QSA	No	Dec.1/05	Patrick	PAT2	-2300	0.3	
LT#45	Unpainted Matraplast					Patrick	PAT2	-2300		
LT#46	Unpainted Matraplast					Patrick	PAT2	-2300		
LT#47	Unpainted Matraplast					Patrick	PAT2	-2300		
LT#48	Unpainted Matraplast					Patrick	PAT2	-2300		
LT#49	Unpainted Matraplast					Patrick	PAT2	-2300		
LT#50	Unpainted Matraplast					Patrick	PAT2	-2300		

Table 5: Table summarizing all the samples of liquid scintillator tested in the M11 beam, and apparatus used.

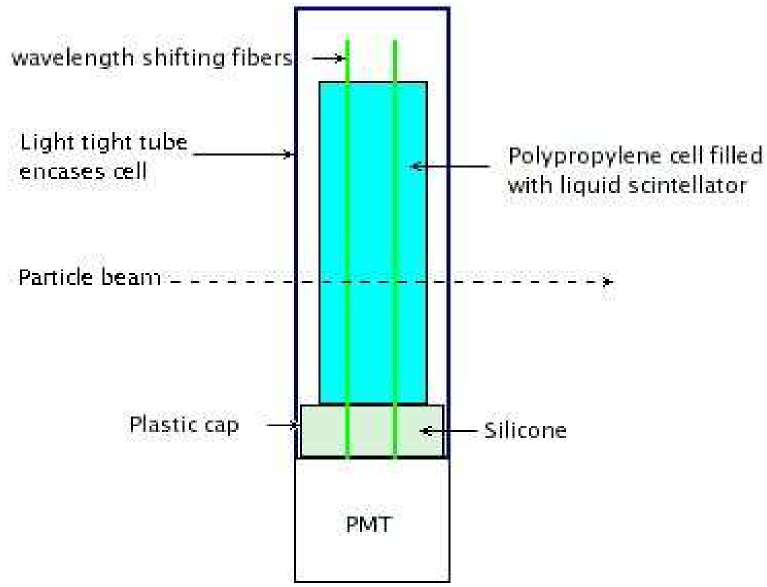


Figure 8: Diagram of a liquid scintillator setup with the PMT (Not to scale)

Construction of Polypropylene Cells for Liquid Scintillator Tests

A polypropylene cell consists of a 52 cm strip of polypropylene paneling (wide enough to contain only one complete channel), two wavelength shifting fibers, and a plastic cap. Using a #58 drill bit two holes, 3 mm apart are drilled in the cap for the fibers. The cap is then filled with DOW RTV 732 Multi-Purpose Silicone Sealant, the fibers are fed through the sealant and holes, then the polypropylene channel is put in place over fibers and into the sealant, and left to cure. The fibers are then cut to ~0.5 mm from the cap surface and sanded with 400, 600, 1000, and 2000 grit sandpapers respectively until smooth. The end is then polished with a motorized polishing wheel and polishing compound.

3.2 Results and Conclusions

It is apparent that the painted Matraplast cells are better than the unpainted because they prevent the yellowing of the plastic, resulting in a much lower percentage of light yield loss over time (see Figure 9). Using the painted cells, the solution which performed the best was the Standard solution (see

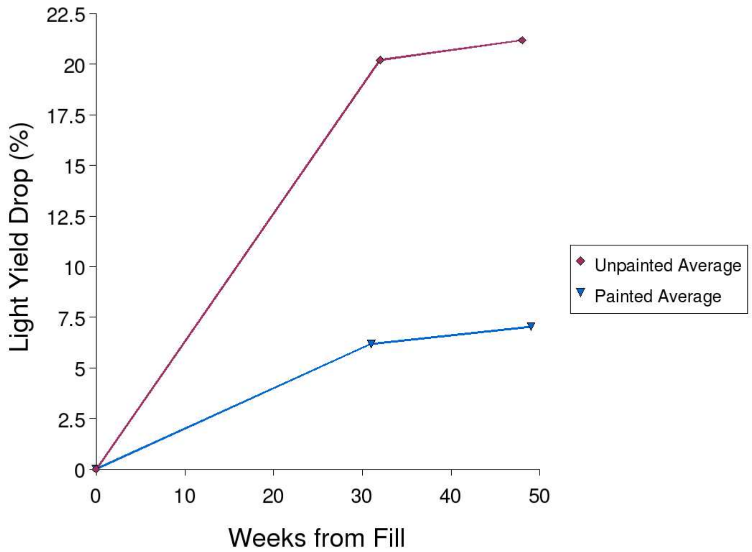


Figure 9: Plot of average light yield drop for unpainted Matraplast and painted Matraplast.

figure 10). It is likely due to luck that we see no biological growth in these samples, since it has been found that mold will grow in this solution when left standing for significant periods of time. Since the solution containing 0.5% Germal Plus (GP) performs nearly as well as the standard solution, it is likely that this will be used for a liquid scintillator upgrade for the FGD.

Overall it appears that by using painted cells, and Germal Plus as a biological inhibitor, both problems (chemical attack by the QSA and biological growth) can be overcome.

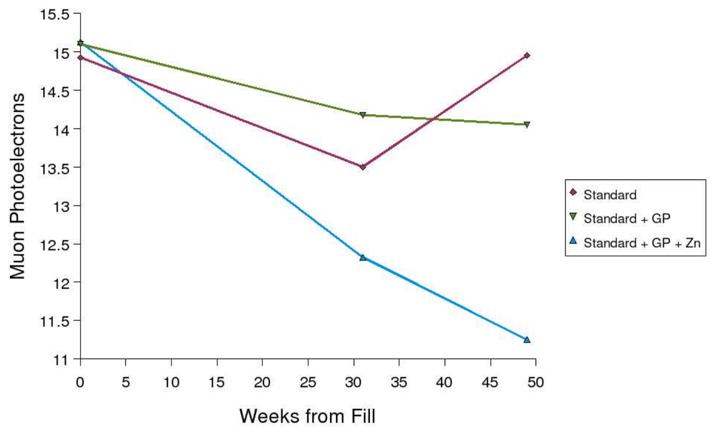


Figure 10: Plot of average light yield muon signal (number of photoelectrons) for various scintillator solutions in painted cells.

4 Straps for the FGD

When the FGD is constructed it will be done so in a light tight box. In order to be able to mount the large number of electronics needed for every bar in the FGD to have a silicon photomultiplier, the electronics must be mounted on every edge of each XY layer. In order to achieve this and to still be able to access and remove any layer for maintenance purposes, it was decided that the pieces of the FGD would be hung from an overhead bracket. This will require several thin strong straps wrapped around each component FGD. These components include each XY layer and each water module. The straps must be very thin because the available space between each layer is only 1.7 mm. To avoid putting large amount of stress on any one point of each FGD module it is preferable to use several straps since the point of contact of each strap at the bottom of each FGD will be the only supporting points. Each FGD weighs $\sim$100 kg, so 5 straps, each supporting 20 kg, will be used. In order to fulfill these requirements Polypropylene straps were suggested and tested to see if they would stretch under the weight of the FGD, since the position must be extremely well known for each component in order to achieve the desired accuracy in the T2K experiment and a large change of position over time would not be acceptable.

4.1 Stretching Tests

In order to test how the straps would stretch, a strap was put under tension comparable to the amount due to the weight of the FGD, with one end fixed, and the other allowed to move as it stretches, held tight with a spring scale which monitors the tension of the strap. Dial gauges were put at both ends to monitor movement of either end of the strap to make sure the fixed end didn't slip and to measure how much the strap stretched. The strap was then put under 23 kg of tension and the change in length and tension were monitored over a several weeks, with the strap re-tightened after 12 days to increase the tension closer to the load required by the FGD.

It can be seen that the tension drops off and strap length increases over time (see figure 11). It appears that re-tensioning the strap does not cause it to stretch at the same rate as initially, but higher tensions do still lead to more stretching, but that this is dropping off over time.

Conclusions

It is apparent that polypropylene straps will not be sufficient as they stretch too much. It is possible that these straps will be used for storage and during assembly of the FGD, so it is still important to understand how much the straps will stretch so that an XY layer doesn't end up on the ground, damaging the electronics mounted on the end. It is recommended that the straps be tightened more frequently to ensure that the amount of stretching is significantly dropping off as the strap is stretched. Stainless steel straps are suggested as an alternative and will be considered next. The thickness being considered is .003". Such a strap would stretch only a small fraction of a mm under the weight of the FGD. Stainless steal is easily ordered and not too expensive.

Date/time	Time since tensioning (hours)	Total time since start (days)	DG1	Total change DG1	DG2	Total change DG2	Total change = Change before + Change after tensioning	Tension (kg)
Oct 24 15:40 (dst)	0.0000	0.0000	0.271	0	0.6840	0.0000	0.0000	23
Oct 25 8:45 (dst)	17.0833	0.7118	0.271	0	0.3325	0.3515	0.3515	15
Oct 26 10:10 (dst)	42.5000	1.7708	0.271	0	0.2860	0.3980	0.3980	14
Oct 27 10:50 (dst)	67.1667	2.7986	0.271	0	0.2640	0.4200	0.4200	14
Oct 30 9:20	138.6667	5.7778	0.271	0	0.2320	0.4520	0.4520	13.5
Oct 31 11:35	164.9167	6.8715	0.271	0	0.2250	0.4590	0.4590	13.25
Nov 1 8:17	185.6167	7.7340	0.271	0	0.2210	0.4630	0.4630	13.25
Nov 2 11:20	212.6667	8.8611	0.271	0	0.2160	0.4680	0.4680	13.25
Nov 3 14:10	239.5000	9.9792	0.271	0	0.2115	0.4725	0.4725	13
Nov 6: The strap was retentioned. The amount of stretching between previous and next measurement was lost.								
Nov 6 10:20	0.0000	12.4861	0.270	0	0.6480	0.0000	0.4725	19
Nov 6 16:15	5.9167	12.7326	0.270	0	0.4300	0.2180	0.6905	17
Nov 7 13:30	27.1667	13.6181	0.270	0	0.3920	0.2560	0.7285	16
Nov 9 16:00	77.6667	15.7222	0.270	0	0.3520	0.2960	0.7685	15.5
Nov 10 16:40	102.3333	16.7500	0.270	0	0.3430	0.3050	0.7775	15.5
Nov 14 10:35	192.2500	20.4965	0.270	0	0.3210	0.3270	0.7995	15
Nov 16 14:30	244.1667	22.6597	0.270	0	0.3120	0.3360	0.8085	15
Nov 17 14:15	267.4167	23.6285	0.270	0	0.3090	0.3390	0.8115	15
Nov 20 15:30	340.6667	26.6806	0.270	0	0.3000	0.3480	0.8205	14.5
Nov 22 15:30	388.6667	28.6806	0.270	0	0.2970	0.3510	0.8235	14.5
Nov 29:15:50	557.3333	35.7083	0.270	0	0.2900	0.3580	0.8305	14.5
Dec 6 12:45	722.2500	42.5799	0.270	0	0.2840	0.3640	0.8365	14.25

Table 6: Strap stretching measurements.

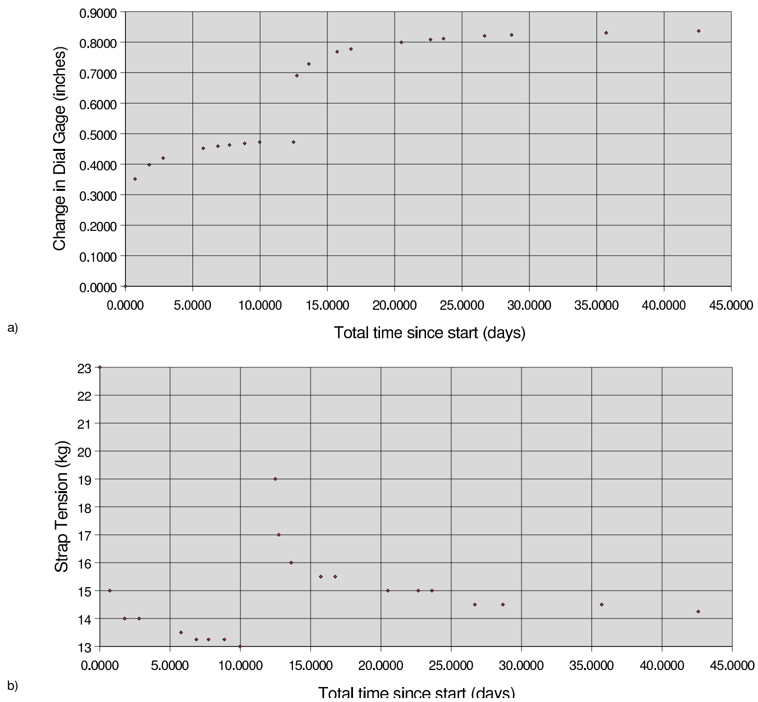


Figure 11: a)Plot of Change in dial gauge (inches) vs. time (days) of the strap being stretched. b)Plot of tension (kg) vs. time (days) of the strap being stretched.

5 Acknowledgments

I would like to thank my supervisor Rich Helmer, for all his help. I would also like to thank Stanley Yen, who I worked extensively with, for all his help this term and for his extensive editing of this report. I would also like to thank the the entire FGD group, which is too many people to name without forgetting someone, for making this a great work term.