Glue Selection of the Plastic Fine Grained Detector

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Summary

In building the FGD, layers of 2m by 2m x-y modules will be built from extruded polystyrene bars that have a square profile of side 1cm. The method of joining is by gluing, epoxies as well as solvent cement being the candidate adhesives. Tensile strength tests have been conducted with Epon/Versamid, West System, and Weld-on 4807 Styrene Cement by the cross-bar test. The test compares not only glue strength but also the effects of pre-gluing treatment, such as solvent cleaning and sanding, on adhesion. According to the test, the most appropriate solution is to use Epon/Versamid with degreasing by alconox. In addition to providing sound glue bonds for the FGD, this combination is favoured because of many other reasons. Epon/Versamid has a relatively long working time, and does not generate heat upon curing, both of which are deemed important for a large job such as FGD. Alconox degreasing produces consistent results, and does not attack surface. Sandpapering is recommended in all cases as long as the abrasion does not endanger the function of TiO_2 coating.

With the above result, more tests are carried out to determine the shear strength and tensile strength of longer, more realistic size joints. These tests confirm that the glue behaves acceptably in shear, and that the prediction on area-strength linearity is reasonably valid.

Epon/Versamid shows impressive result in the small prototypes; it appears to be strong enough for the half size prototypes as well. However, as the half size prototype has only been recently built, further mechanical testing is recommended. Furthermore, prototyping FGD has solved some gluing issues. By having a peeler layer and layers of breather cloth, the final glue amount can be controlled such that there remains no excess glue and the surface is in general epoxy free. This method has been successfully utilized in the construction of the half size layers and small prototypes.

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Glossary

Terms/Abbreviation	Definition
Alconox	Brand name of a cleaning detergent powder
Cross Talk	Leakage of signal to other channels; In FGD, refers to light particles that goes to adjacent bars
Epon/Versamid	A unique blend of epoxy using Epon 846 resin and Versamid 140 hardener at 1:1 ratio
FGD	Fine Grained Detector: consisting of 15 modules, each consisting of 2 orthogonal layers of approximately 200 polystyrene bars
Neutrino Oscillation	A quantum phenomenon whereby a neutrino with a specific lepton flavor (ν_e, ν_μ, or ν_τ) can later be measured to have a different flavor
Solvent Cementing	A method of joining plastics in which the solvent softens the substrate surface to allow diffusion and entanglement of polymer chains from jointed parts

1 Introduction

1.1 The T2K Long Baseline Experiment and ND280

The T2K experiment will study oscillation of an off-axis neutrino beam between JPARC and the Super-K detector. The neutrino produced at JPARC will travel through a set of detectors, currently named ND280, 280m away. The purpose of ND280 is to predict the neutrino interactions at Super-K by measuring the neutrino energy spectrum, flavor content and interaction rates of the unoscillated beam. ND280 will consist of a Pi-Zero Detector, three Time Projection Chambers (TPC), and two Fine-Grained Detectors (FGD). In this document, only FGD will be discussed.

1.2 FGD & gluing

TRIUMF's involvement in ND280 primarily surrounds TPC and FGD. FGD consists of an all-plastic part and a water-based part. The plastic part is aimed towards studies of neutrino interactions with carbon while the water-based part studies the interaction with oxygen. Currently the plastic FGD is to consist of 30 x-y scintillator modules spaced 5 mm apart. Each x-y module is made of two orthogonal layers of polystyrene bars, each 2m long with a square 1cm×1cm cross-section. The latest polystyrene bars, extruded in Surrey, BC, were co-extruded with 0.3mm TiO_2 coating (the white perimeter in Figure 1). A sample from the latest extrusion run is shown here in Figure 1.The profile is expected to be square with a centred hole where the wavelength shifting fibres will be placed.

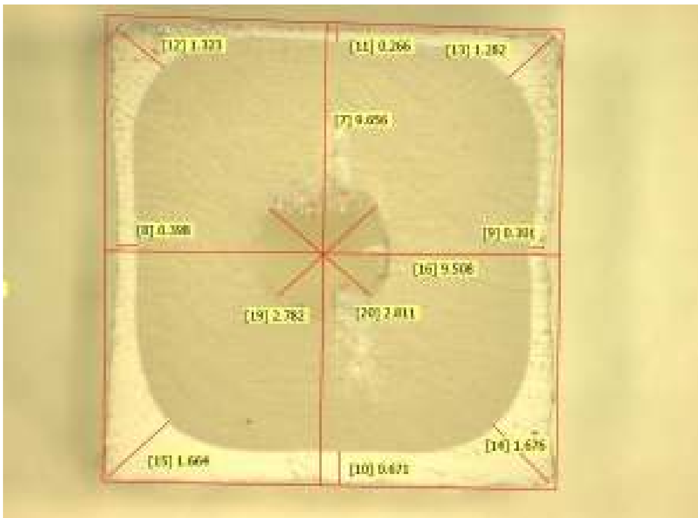


Figure 1: Scintillator Profile, from extrusion run Feb.16 2006

Photo courtesy of Martyn Bryant

2 Gluing test – Cross-Type

To ensure that gluing will meet the mechanical requirements of the FGD, tests are conducted to find the appropriate adhesive. Among all candidates, Epoxies Epon 846/Versamid (140), West System 105/205, and Solvent Cement IPS Weld-On 4807 are evaluated. To determine which glue is stronger, the first step is to determine the tensile strength of each type of glue to the scintillator bars. Given the geometrical specification for the FGD, the minimum required static tensile strength is roughly calculated as follows:

Approximate Linear Density of polystyrene at 10 mm width $\times$ Length of bar $\times$ numbers of bars per layer.

$$1\text{g/cm} \times 200\text{cm/bar} \times 200\text{bars} = 40\text{kg}$$

over one bar of 200cm^2.

2.1 Test Preparation

Cross type tensile test is adapted from a common test used for wood product [1]. This test is not the most technically elaborate. However, with sufficient samples, it provides acceptable data for comparative glue evaluation. Figure 2 shows the setup for this test.

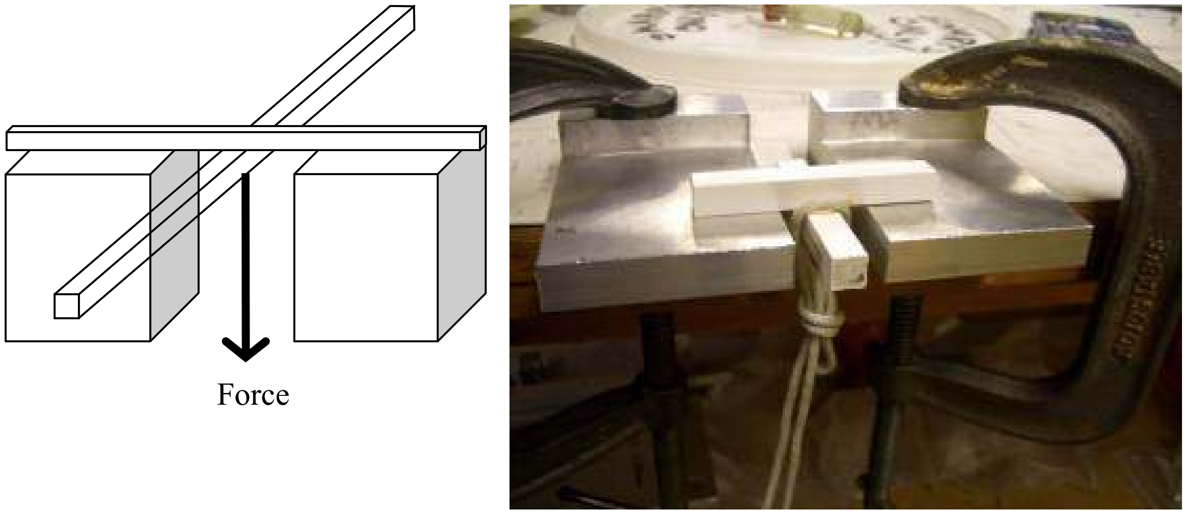


Figure 2: Cross-type Setup

Small specimens of length 7cm are glued orthogonally in the centre with $9.5 \times 9.5\ mm^2$ joint. The top bar is supported on both sides, and close to the glued region, to eliminate the weakening effect caused by bending. Load is applied in tension on the bottom piece until the glue joint fractures.

2.1.1 Surface Treatment

Prior to gluing, the surface is treated with cleaning solvent alconox or isopropyl, and/or sanding. The cleaning ensures removal of surface residue which would impede an optimum glue bond. The general procedure for cleaning is as follows: for cleaning with alconox, the surface is wiped with alconox damp paper. It is then rinsed with warm water followed by distilled water. As water often does not evaporate soon enough for application of glue, it is necessary to dry with Kim wipe accordingly. For cleaning with isopropyl, the surface is simply wiped with isopropyl damped Kim wipe. It air dries instantly. In addition, a few test samples are sanded with grid 180 sandpaper.

2.1.2 Epoxy Mixing

Epon/Versamid's mixing ratio is 1:1, whereas West System is mixed 5:1, resin/hardener, as suggested by the manufacturer. A thorough mixing for a small pot requires a constant stir for an extended period of time, typically a few minutes. Weld-on cement is ready out of the can.

2.1.3 Glue Application

Epoxies are applied in a thin film 1mm thick. After gluing, all epoxy that squeezes out of the joint must be removed before it cures.

2.1.4 Curing Conditions

Specimens were glued in the basement of Meson Hall where the temperature and humidity are not controlled, although recorded. The temperature and humidity range experienced are 7°C~23°C and 18~44%, respectively. The specimens stayed in the Meson Hall for 24 hours, and then were moved to the scintillator shop for subsequent curing. The scintillator shop is air-conditioned to 23°C, and its humidity is < 30%. All testing was done four days after gluing.

2.1.5 Loading of Samples

Samples are loaded approximately at an average rate of 0.8kg/min. Load is increased whenever no fracture is observed 60 seconds after previous loading. When the specimen breaks, the current load is recorded as the ultimate strength of the glue.

2.2 Discussion of gluing test

Table 1 presents data obtained from the cross-type tests:

Adhesive	Surface	Sanding (grid)	1	2	3	4	5	6	7	8	Average /Maximum Deviation (kg)	Standard Deviation
Epon/V.	N	N/A	6.73	9.56	9.1	9.56	16.9	13.24	11.94	7.58	**10.6±6.3**	3.316
Epon/V.	I	N/A	9.11	8.26	14.56	8.42	7.58	14.08	9.07	7.57	**9.8±4.7**	2.832
Epon/V.	A	N/A	6.73	9.11	8.26	8.42	7.58	7.42	6.73	6.73	**7.6±1.5**	0.901
Epon/V.	A	180	13.24	11.94	13.93	15.22	14.77	12.39	11.25	11.1	**13.0±2.2**	1.565
W.System	A	N/A	9.11	6.73	9.11	3.9	3.9	14.77	6.73	14.77	**8.6±6.1**	4.273
W.System	A	180	19.59	12.39	11.1	11.94	11.94	9.56	11.94	10.41	**12.4±7.2**	3.317
Weld-On 4807	A	N/A	46.62								**46.6**	N/A

Table 1: Cross bar test

N-None I-Isopropyl A-Alconox
Experimental Error = ±0.4kg

2.2.1 Solvent Cleaning

With respect to surface preparation, neither cleaning solvent significantly affects the strength of the Epon epoxy. In fact, no increase in strength is observed when the specimens were simply cleaned with isopropyl alcohol or Alconox. Despite that, it should be noted that Alconox cleaning at least produces consistent results. Concerns of long-term crazing on polystyrene by alcohol were raised as well.

2.2.2 Sanding

Sanding with abrasive, on the other hand, shows consistent strength improvement. For this particular test with grid 180 sandpaper, test data indicates that glue bond strength improves by at least 40% for West System, and 70% for the Epon case.

2.2.3 Adhesive Choice

Based on its adhesion principles (see glossary under solvent cementing), Weld-On 4807 should show superior bonding strength, which agrees with the data. One sample in fact shows that, with solvent cementing the glue joint does not constitute the weakest plane. Rather the fracture occurs first within the polystyrene. Figure 3 (a) compares the two modes of fracture. The working time for this solvent cement, however, is as short as a few minutes. In addition, it attacks the surface quite fast and fiercely. Styrene cement is therefore not an ideal candidate for gluing the full size FGD.

Figure 3: Epoxy and Cement Failure Modes
(a) Epoxy Failure – adhesion failure
(b) Polystyrene failure

At a glance, Epon and West System seem at par in terms of strength especially when errors are accounted for. Nevertheless, one should note that *all else being equal*, Epon's result is more consistent, which give rise to its lower standard deviation. Additionally, the special Epon/Versamid blend is known for its easy handling because little heat is generated upon mixing, which makes it easier to handle on a large job like this one. Although mixing two brands of epoxy is not a recommended practice, glue tests have shown that Epon/Versamid provides strength comparable to other epoxies, if not better.

3 More Gluing Tests

Although tests described in Section 2 are sufficient for the purpose of glue comparison, they are not enough to determine the actual load capability. Thus alternative testing methods have been devised to retrieve more information on the strength of the Epon epoxy bonds.

3.1 Shear

Not only tensile, but also shear strength of the glue will play an important role in the FGD. The criterion for lap shear strength is quantitatively almost identical to that of the tensile where the top bar is expected to hold a layer by itself. A similar test as above is adapted to find out the shear strength of a $1cm^2$ joint, shown here in Figure 4.

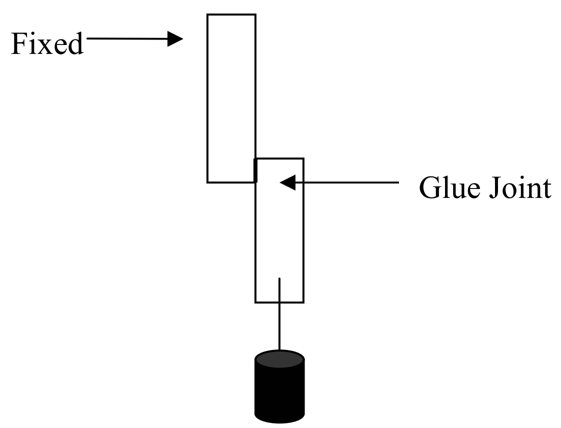


Figure 4: Lap Shear Test

Test procedure is similar to that of the cross-type test. The recorded load is however more a creep response than ultimate shear strength since fractures occurred a few days after the load was initially applied. Shear strength obtained is presented in Table 2.

1cm shear	Cleaning	Sanding	1	2	3	4	5	Average(kg)
Epon	Alconox	N/A	10.0	10.6	10.6	10.5	16.23	**11.6**

Table 2: Lap Shear Strength of 1 cm^2

Note that sample 5 was tested significantly later than the other four. Its unusual strength could have been due to statistical maximum or to the fact Epon continued to cure and set.

3.2 Tensile test with Custom-made Clamps

To model more closely the actual load condition, clamps with straight flat edges are made. They are seen in Figure 5.

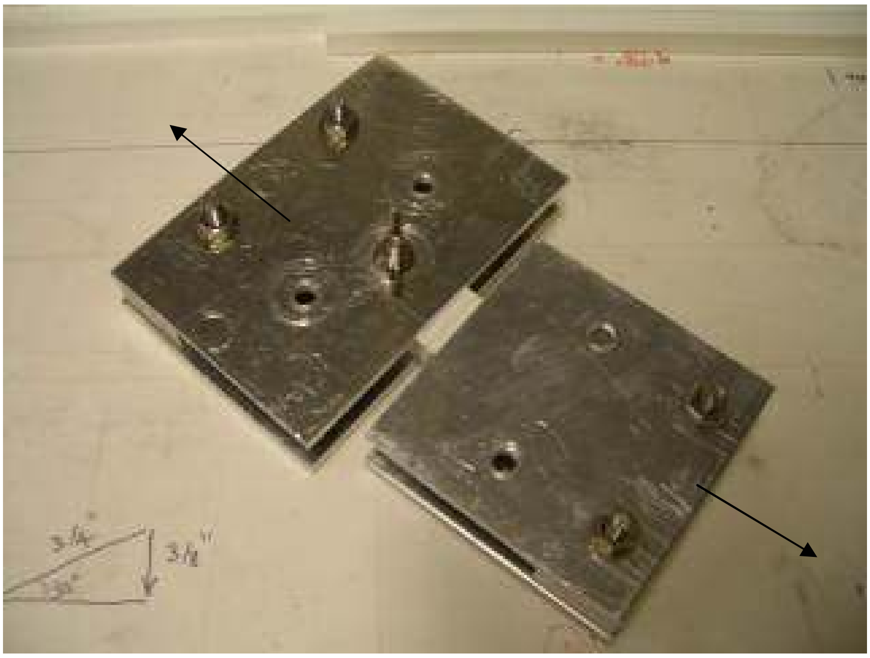


Figure 5: Clamp Test

3.2.1 Test Setup

This test is similar to the cross-type in that it is also a destructive test. The goal of the test is to break the specimens and to record the maximum stress taken by the glue joints before they fail. Setup is shown in Figure 5. Test specimens of same length are glued along each other. One clamp is fixed while the other is subject to parallel pulls, the direction of which is indicated in the arrows of Figure 5. It is imperative that the edge is straight so that the clamp makes even contacts across the bar. Any epoxy residue must be removed from the surface of the specimen. At the time this document is prepared, only data for 2cm pieces have been successfully obtained.

3.2.2 Discussion

2cm	Cleaning	Sanding	1	2	3	4	Average
Epon	Alconox	N/A	18.05	17.52	20.88	15.22	17.92

Table 3: 2cm tensile strength

Data is presented in Table 3 for the 2cm glue specimen. The data implies that glue load applicable is proportional to the surface area of the glue joint. This is to be verified however due to the low sample size. To successfully identify the relationship, tests should be conducted for specimen of larger sizes with the same loading condition, i.e., constant load across the bar.

4 Prototyping

The previous tests were aimed at investigating which glues would be suitable for joining the scintillator bars. However, it was suggested that instead of simply testing individual joints, building a full-size FGD module might be a more practical solution because of its simple geometry. Thus, various fraction-size mockups FGD's have been built. They are not only useful in determining the mechanical strength but also suitable for discovering other issues that surround FGD, for example, electronics integration and cross-talk measurements. Most importantly, gluing issues can be resolved and experience gained.

4.1 Gluing x-y Layers: 7cm, 10cm, 20cm, and Half Size

A 7cm module, two 10cm modules, one 20cm module, and finally a half-size FGD are glued with Epon/Versamid epoxy. A nylon sheet and three layers of absorbent cloth (which remains unidentified) are placed below and above the working piece to absorb the glue that would otherwise stay on the surface. Figure 6 illustrates this layout.

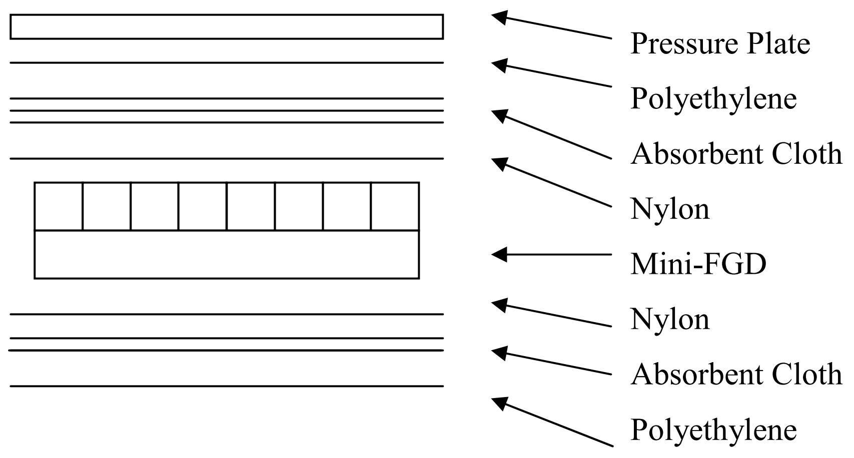


Figure 6: Prototype Gluing Layout

Due to short supply of the current absorbent cloth, when gluing the large prototype, one layer is substitued with 4oz. breather cloth which is puffier. Otherwise, the setups for the large prototype and the small ones are identical. Depicted in Figure 7 is the actual setup at the granite table at the basement of Meson Hall.

(a)

(b)

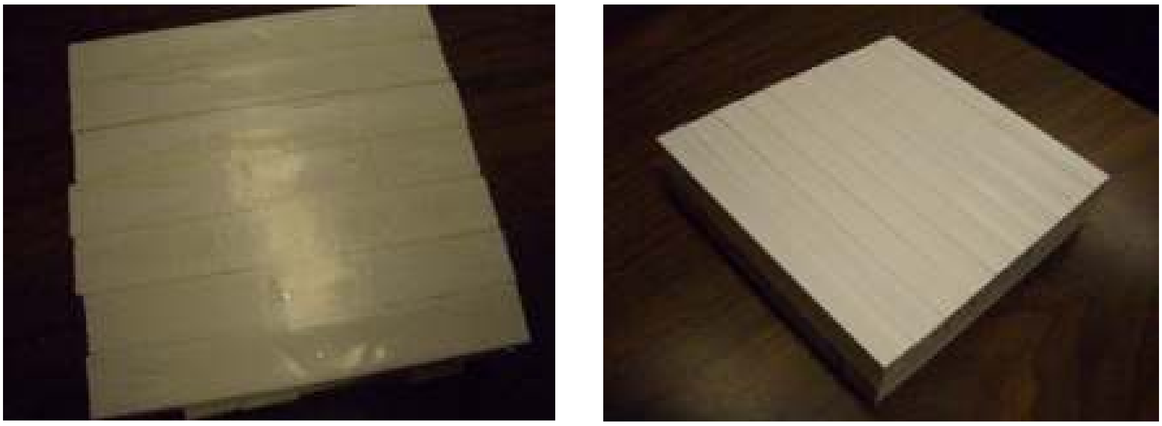
(c)

Figure 7: Half-Size Prototype Setup

(a) Lay the plastic and breather cloth
(b) Nylon and Jig sit on top of the cloth
(c) Dry Assembly of 192cm by 96cm

4.2 Discussion of Prototyping

The absorbent cloths work very well in sucking out excessive glue to provide clean final surface. This result is independent of the amount of glue placed in between. Figure 7 here shows the surface of the prototype with and without the absorbent cloth setup. Provided sufficient number of absorbing layers, glues can be easily sucked out. In this application, 2~3 layers are enough.



(a) (b)

Figure 8: Prototype Surface

(a) shows the epoxy covered surface, whereas (b) has clean surface

From the various prototyping, the result is shown here:

- Mass increases by 3% from the epoxy
- Width is increased by 0.3%, at no clamping pressure
- Thickness increases could vary, but is estimated at 0.15mm

By inspection, the fraction-size FGD is very strong thanks to reinforcement provided by the opposite perpendicular layer. Very empirical, non-systematic test is done by repeatedly dropping the 10cm module by 10 feet to the gravel ground, and the glue joints stay intact. Rather, the struck polystyrene shows visible deformation. Whether this strength statement still holds true is subject to further scrutiny by testing with bigger modules, which is just completed.
The following figures show the final result; Figure 9 is the scintillator surface, and Figure 10 shows the complete half-FGD in full view.

Figure 9: Finished Surface

Figure 10: Completed Half-Size Prototype

5 Conclusions/Recommendations

The following conclusions can be drawn based on test results presented in this document:

1. The final consensus on choice of glue and surface preparation is Epon/Versamid with alconox cleaning. This combination is shown to provide consistent and acceptable strength required for the FGD, based on the gluing tests. Sandpapering does enhance the gluing effectiveness; however it should be done to an extent not to thin out the TiO_2 coating. Additionally, Epon/Versamid has acceptable working time, with temperate mixing long enough for assembling the large-size modules..

2. Smaller mockups have shown that it is feasible to use Epon/Versamid epoxy to join the scintillator bars. The strength of an x-y module looks promising. Although epoxy is usually messy to work with, with the absorbent cloths in the right place, a clean-finished FGD with just the right amount of glue is possible.

As a half size FGD has been built, it is now possible to conduct tests on a larger scale. It will be useful to quickly determine the final support scheme of the FGD, and then to hang the prototype in its final orientation. Monitoring of the x-y width and the creep response of the glue will prove useful. Also worth doing is monitoring the FGD width since compressive stress resulted while the bars were pushed hard together in gluing. The result can be catastrophic if the stress is relieved or if the epoxy adhesion weakens over time.

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West System Inc., "*West System Epoxy User Manual*"
http://www.westsystem.com/webpages/userinfo/manual/index.htm

Appendix A: Data: Weight and Dimension change of glued X-Y modules

Prior	After						
Weight Measure(g)			Percent Increase				
83.7	86.5		3.345	%			
172.8	178.9		3.530	%		Average Percentage	
170.9	175.7		2.809	%		3.185	%
795.2	819.5		3.056	%			
Width (mm)		(X-Y)direction					
6	joints				Average per epoxy layer		
66.32	66.57		0.377	%	0.0417		
66.3	66.4		0.151	%	0.0167		
9	joints						
94.9	97.1		2.318	%	0.2444	XX(visible gap)	
95	95.3		0.316	%	0.0333		
9	joints						
95.02	95.25		0.242	%	0.0256		
94.93	95.24		0.327	%	0.0344		Average Percentage
94.95	95.14		0.200	%	0.0211		0.322%
94.97	95.44		0.495	%	0.0522		Average epoxy layer
94.94	95.34		0.421	%	0.0444		0.0334
94.96	95.25		0.305	%	0.0322		
20	joints						
199.39	199.92		0.266	%	0.0265		Projected (*195) Increase
199.47	200		0.266	%	0.0265		6.50
199.34	199.87		0.266	%	0.0265		
199.43	200.38		0.476	%	0.0475		
199.46	200.22		0.381	%	0.0380		
199.44	200.12		0.341	%	0.0340		
Height(thickness)		(Z)	direction				
1	joint						
18.97	19.1		0.685	%	0.1300		
18.97	19.04		0.369	%	0.0700		
18.95	18.94		-0.053		-0.0100	XX(bad)	
18.98	19.08		0.527	%	0.1000		
18.96	19.29		1.741	%	0.3300		Average thickness increase
18.95	19.21		1.372	%	0.2600		0.1683
18.95	19.07		0.633	%	0.1200		
18.96	19.37		2.162	%	0.4100		