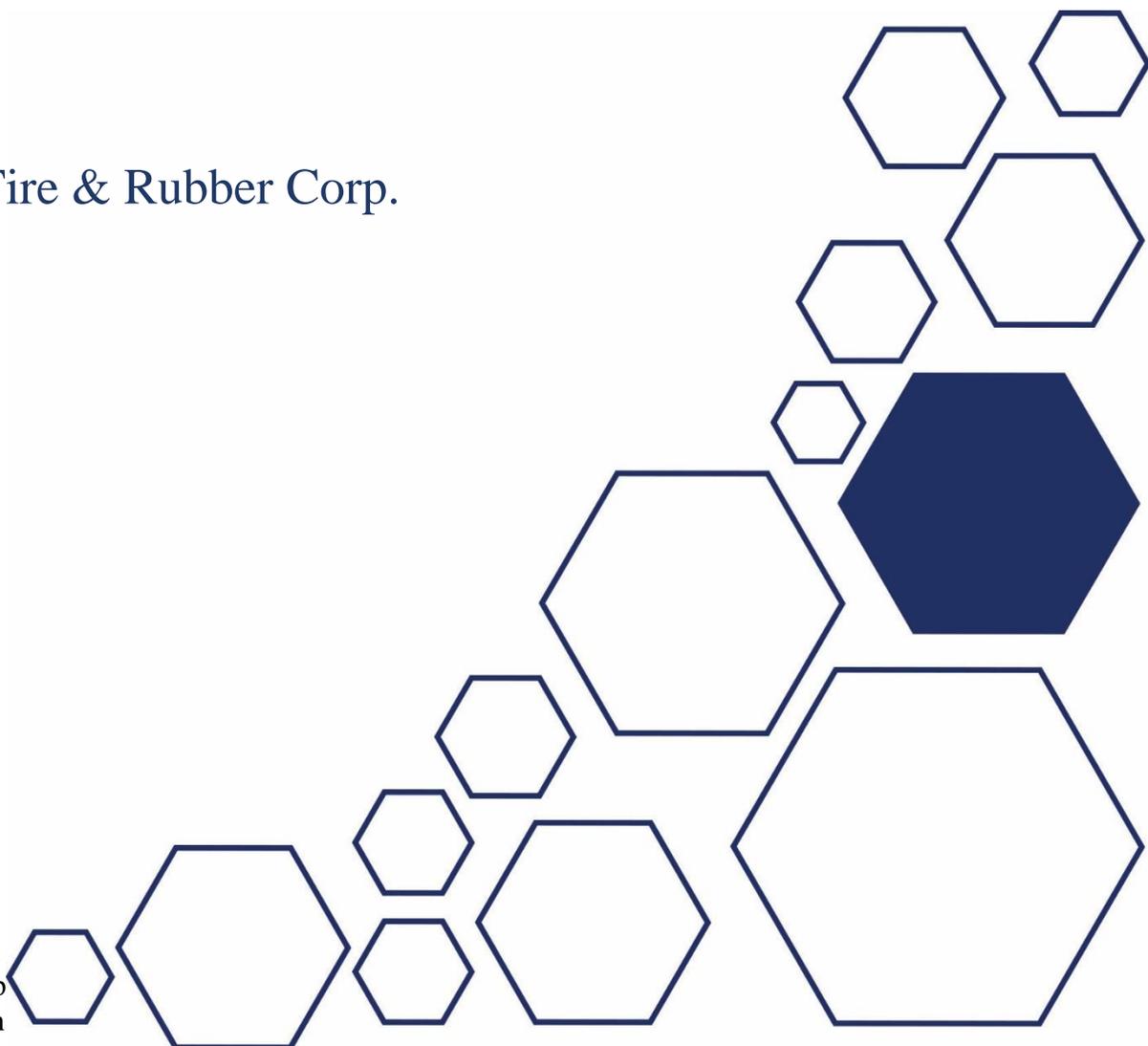


Performance Testing of Composite Connectors' Adhesive Bonds

6/22/2018

Superior Tire & Rubber Corp.

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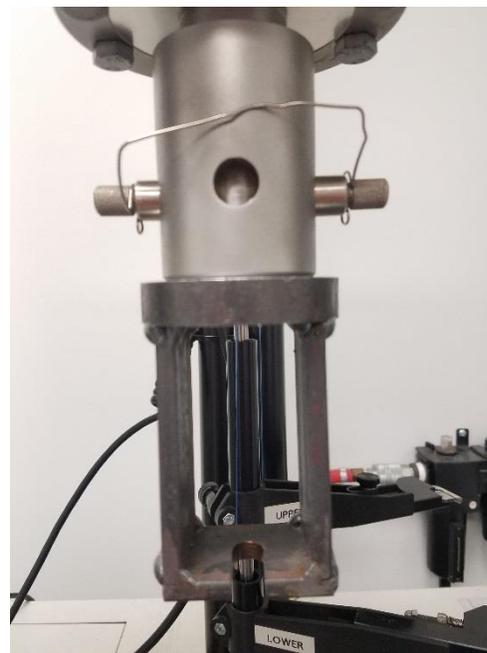
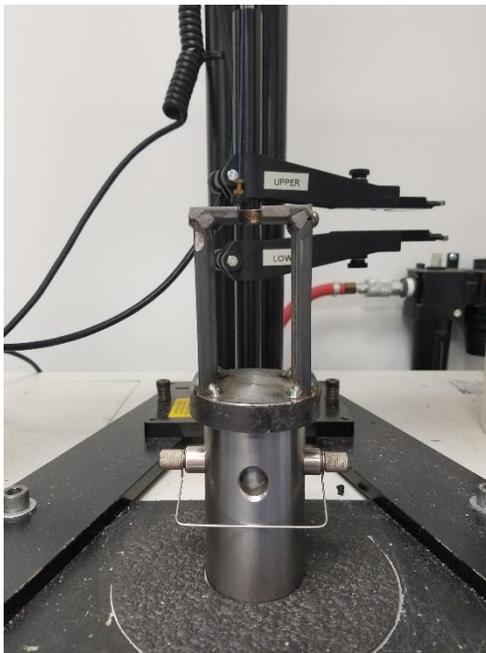


Introduction

This report details the testing of adhesive used to connect 3D printed connectors to carbon fiber tubes, provided by Pat Conarro of Composite Connectors. Adhesive types included:

- Loctite 5 min. epoxy – dry bonded
- Loctite 5 min. epoxy with nano tubes – dry bonded
- Gorilla Glue original – wet bonded
- Gorilla Glue 3% nano tubes – wet bonded

These assemblies were tested using Superior Tire and Rubber's (STR) Instron and STR-made jigs.



Images of STR-made jig attached to the Instron

Test Parameters

Three or four assemblies (depending on how many were provided) of each adhesive type were tested on STR's Instron to reveal how much load and tensile strength it took for the adhesive bond to break. The connector and carbon fiber tube assemblies were placed in STR-made jigs, which were connected to the Instron. A modified tensile program was written for the Instron that applied force in attempt to pull the assemblies apart. This program measured the percent elongation,

maximum load, extension at maximum load, tensile strength, and failure mode. Failure modes included:

- Adhesive failure – Adhesive bond between carbon fiber tube and connector breaks, causing the connectors to become loose or fall off
- Break at tube – Carbon fiber tube cracks or breaks
- Break at connector – 3D printed connector cracks or breaks
- Delamination break – 3D printed connector separates into layers



Image of carbon fiber rod and connector assembly

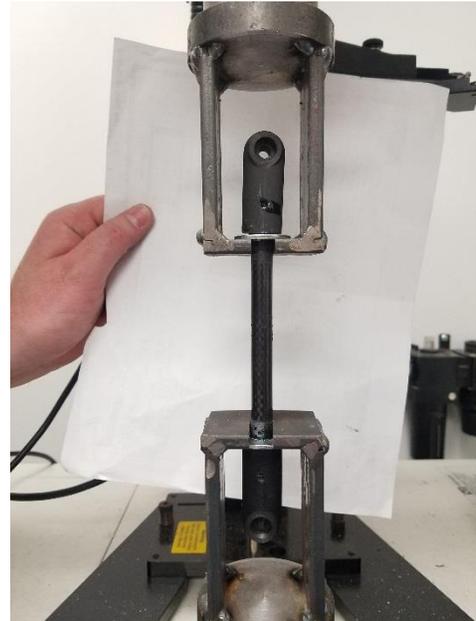


Image of assembly in jig

Results

The results of each test are summarized in the table below. See detailed results in the appendix.

Table 1: Adhesive Bond Test Results

	Elongation (%)	Maximum Load (lbf)	Extension at Maximum Load (in)	Tensile Strength (psi)
Loctite 5 min epoxy – dry bonded	238	686	0.31	15667
Loctite 5 min epoxy w/ nano tubes – dry bonded	202	730	0.27	16643
Gorilla Glue original – wet bonded	2	211	0.12	4814
Gorilla Glue 3% nano tubes – wet bonded	2	383	0.10	8728

In all cases, the maximum load broke the adhesive bond present but the connectors remained on the carbon fiber assemblies. However, they were loose enough to be removed by hand. The below images show samples of each adhesive type after testing.



Loctite 5 min epoxy



Loctite 5 min nano tubes



Gorilla Glue original



Gorilla Glue 3% nano tubes

Obstacles and Discrepancies

Some obstacles became apparent as the testing took place. One of the most prevalent problems noticed was that the starting extensions recorded by the Instron differ from each other (see below graphs). This is due to the washers not being flat in the jig and the Instron not resetting the gauge length like it was programmed to. Something else that contributed to this was excess adhesive on the assembly. This hindered the washer from sitting flat against the connector. Excess adhesive was removed as much as possible, but still was a problem.

There were also discrepancies noticed between each batch of adhesive types. Some adhesive types has three specimens provided, others four. Furthermore, the types of connectors differed between each batch and sometimes even within a batch. There were also incongruities with the adhesive types provided. Some were wet bonded and some dry bonded. These variances created an uncontrolled experiment, meaning there was more than one variable (instead of the adhesive being the only difference between each assembly). While these inconsistencies may not be large, they still have the potential to skew results and are worth noting.

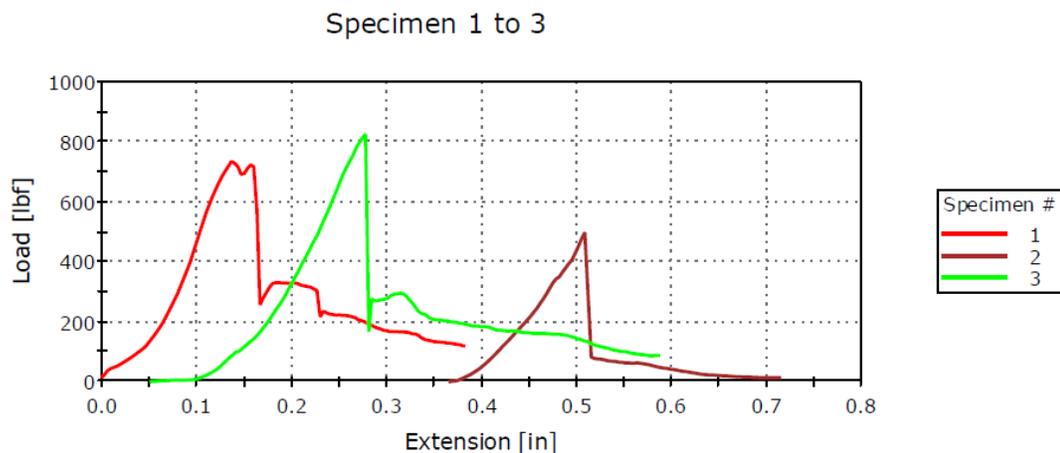
Conclusion

The testing of the given assemblies of carbon fiber tubes and 3D printed connectors used STR's Instron and jigs. The adhesive types tested included two types of Loctite and Gorilla Glue. Upon examining the data collected, it can be concluded that the Loctite is the stronger adhesive of the two.

Appendix

All data collected can be found below. Note that copies of all data can be found by following the file path on the cover page.

Loctite 5 min. epoxy – dry bonded

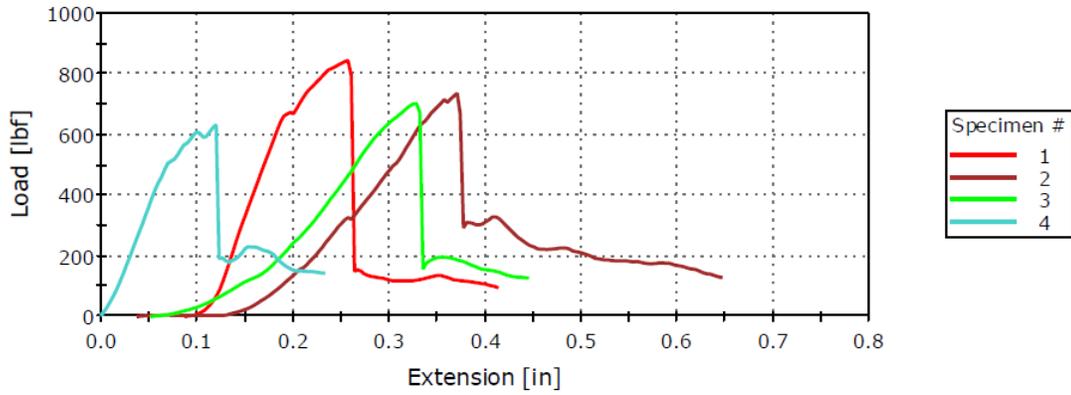


	Elongation [%]	Maximum Load [lbf]	Extension at Maximum Load [in]	Tensile Strength [psi]	Failure mode
1	233.81	735.32	0.137	16778.51	Adhesive Failure
2	239.55	499.48	0.508	11397.04	Adhesive Failure
3	240.35	825.02	0.278	18825.20	Adhesive Failure
Range	6.54	325.54	0.372	7428.15	
Mean	237.90	686.61	0.308	15666.92	
Standard deviation	3.567	168.149	0.188	3836.807	
Coefficient of variation	1.499	24.490	61.006	24.490	

Note the different starting extensions (explained in **Obstacles and Discrepancies**).

Loctite 5 min. epoxy with nano tubes – dry bonded

Specimen 1 to 4

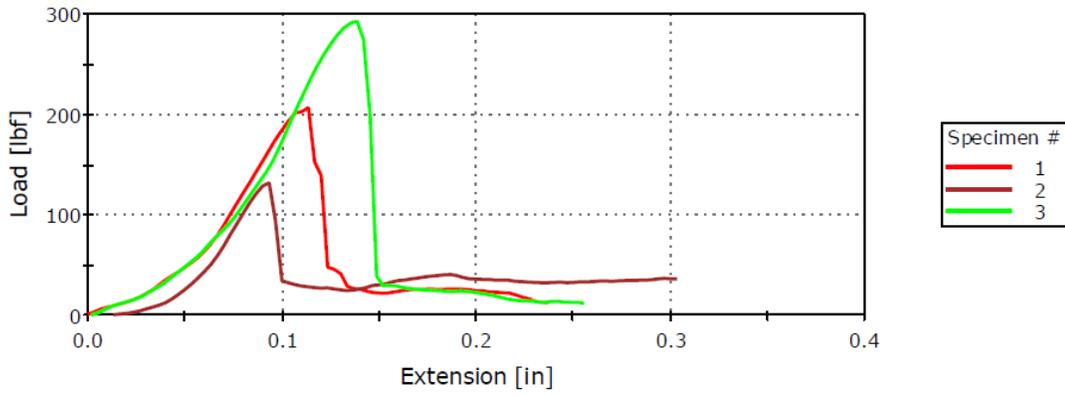


	Elongation [%]	Maximum Load [lbf]	Extension at Maximum Load [in]	Tensile Strength [psi]	Failure mode
1	175.88	844.10	0.257	19260.64	Adhesive Failure
2	201.50	737.13	0.371	16819.81	Adhesive Failure
3	204.97	703.11	0.329	16043.51	Adhesive Failure
4	226.28	633.21	0.120	14448.54	Adhesive Failure
Range	50.40	210.89	0.251	4812.10	
Mean	202.16	729.39	0.269	16643.13	
Standard deviation	20.662	87.863	0.110	2004.855	
Coefficient of variation	10.221	12.046	40.832	12.046	

Note the different starting extensions (explained in **Obstacles and Discrepancies**).

Gorilla Glue original – wet bonded

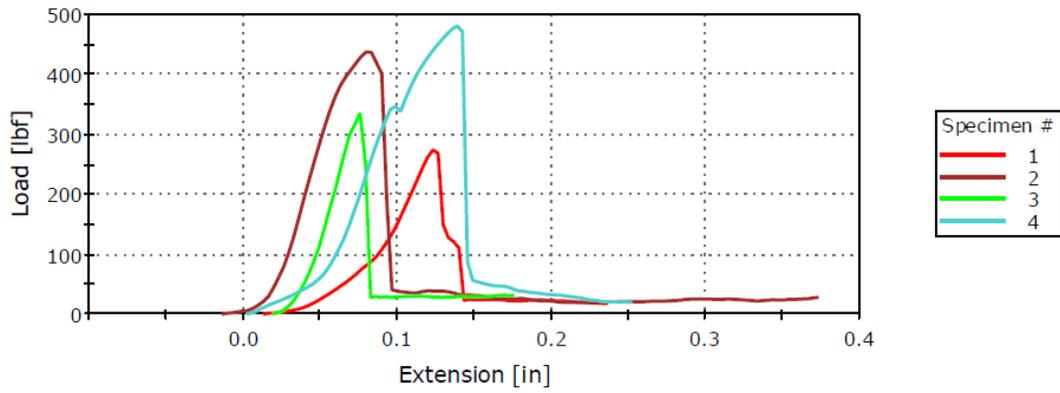
Specimen 1 to 3



	Elongation [%]	Maximum Load [lbf]	Extension at Maximum Load [in]	Tensile Strength [psi]	Failure mode
1	1.51	207.36	0.113	4731.48	Adhesive Failure
2	1.67	132.83	0.093	3030.81	Adhesive Failure
3	1.68	292.81	0.138	6681.34	Adhesive Failure
Range	0.17	159.99	0.045	3650.54	
Mean	1.62	211.00	0.115	4814.54	
Standard deviation	0.098	80.055	0.023	1826.685	
Coefficient of variation	6.019	37.941	19.717	37.941	

Gorilla Glue 3% nano tubes – wet bonded

Specimen 1 to 4



	Elongation [%]	Maximum Load [lbf]	Extension at Maximum Load [in]	Tensile Strength [psi]	Failure mode
1	1.71	274.70	0.123	6268.09	Adhesive Failure
2	2.01	437.75	0.080	9988.61	Adhesive Failure
3	2.10	336.43	0.076	7676.72	Adhesive Failure
4	2.19	481.18	0.139	10979.61	Adhesive Failure
Range	0.47	206.48	0.063	4711.52	
Mean	2.00	382.52	0.104	8728.26	
Standard deviation	0.205	94.047	0.031	2145.943	
Coefficient of variation	10.247	24.586	30.012	24.586	