Graphene Enhanced Composites
A Comparative Study

COMPOSITES ONE®

Presented by:

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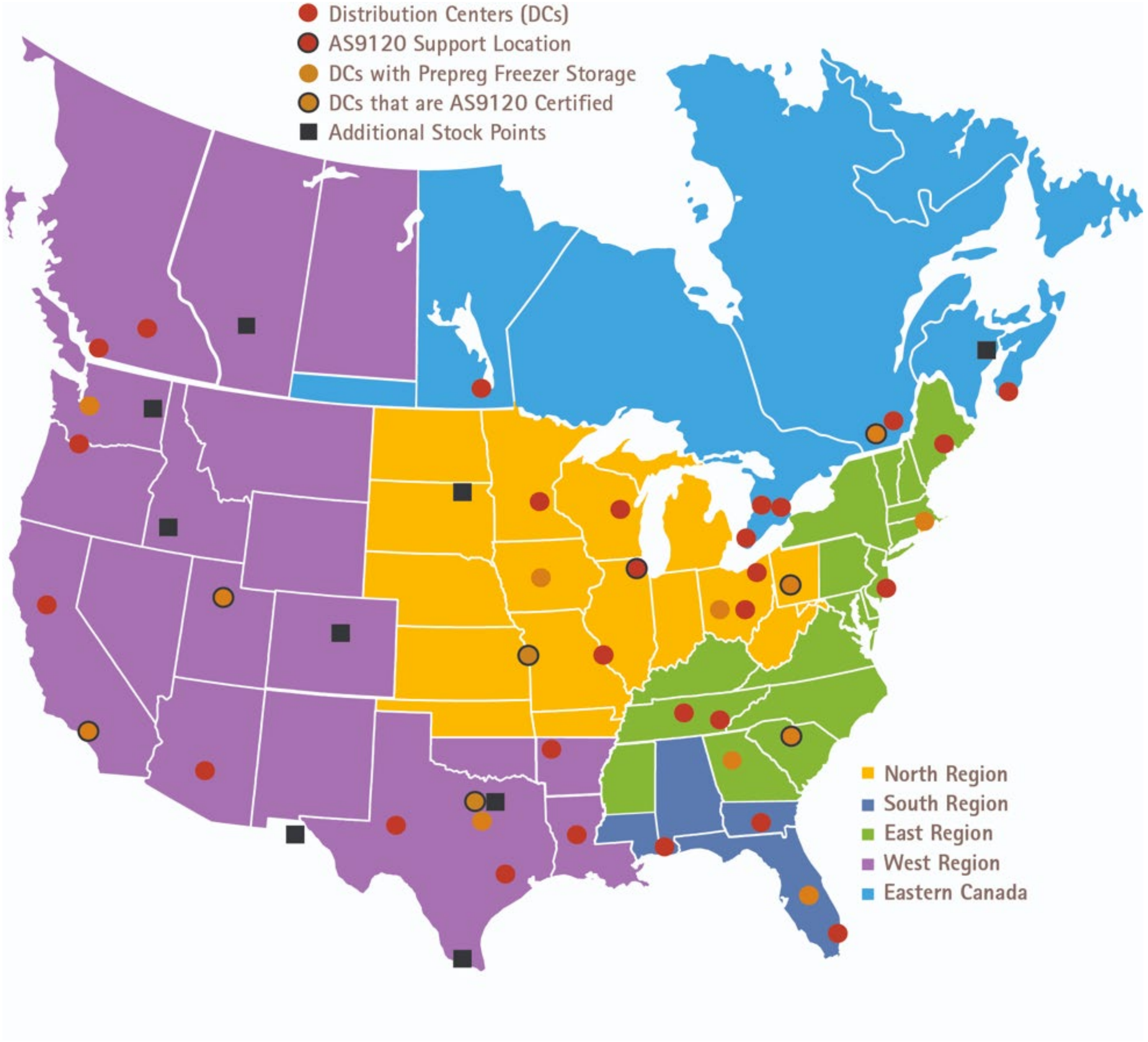
Composites One

Composites One Stocking Locations



<u>Freezer Locations</u>

***Lenexa, KS (AS9120)**

Bristol, RI

***Rock Hill, SC (AS9120)**

Lawrence, GA

Lakeland, FL

Monessen, PA (AS9120)

Dayton, OH

Goshen, IN

Grimes, IA

***Salt Lake City, UT (AS9120)**

Arlington, WA

***Santa Fe Springs, CA (AS9120)**

***Tolleson, AZ (AS9120)**

Ft. Worth, TX (AS9120)

Buffalo, NY

**Boeing Enterprise QA and BR&T Approved Composites Supplier Status*

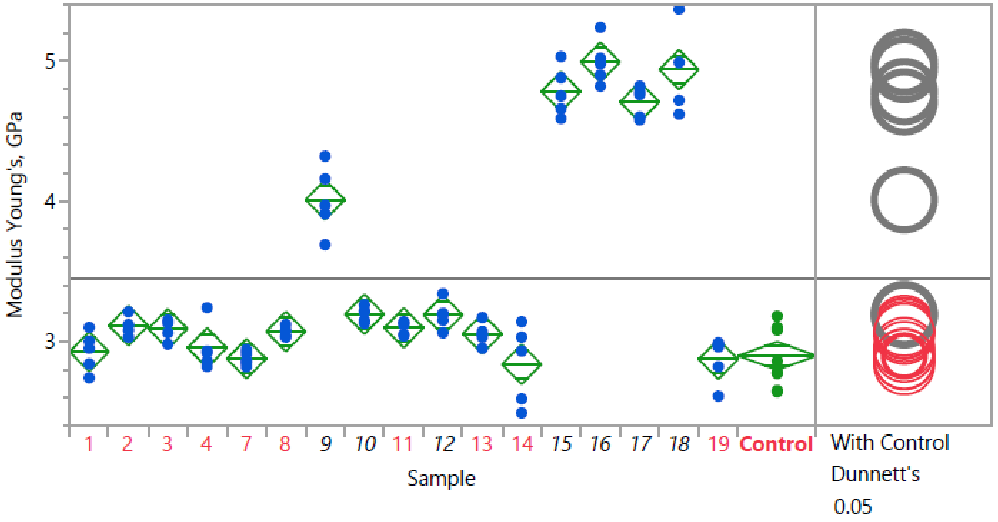
- The Graphene Council Project:
  - At the University of Maine
    - 15 samples of graphene enhanced epoxy slurry were dispersed and sent to the University of Maine
    - Samples were let down to 0.5 and 0.1% in epoxy resin
    - They were mixed using high-speed orbital mixer, and degassed under vacuum
    - A curative package was introduced
      - Used common amine ratio for all samples
      - We did not account for potential functionality on graphene itself
    - The samples were then mixed, poured onto molds at 140°F (60°C), and cured for 30 min
    - All samples were then subjected to a 3-hour post-cure at 320°F (160°C)
    - Samples were then cut from molded panels, subjected to flexural (Instron) and notched Izod testing
    - In general, performance varied, but we did see gains.
      - As much as ~35% gain to flexural strength
      - Up to ~75% gain in flexural modulus
      - Little or no damage to notched Izod values from embrittlement

Flexural Properties

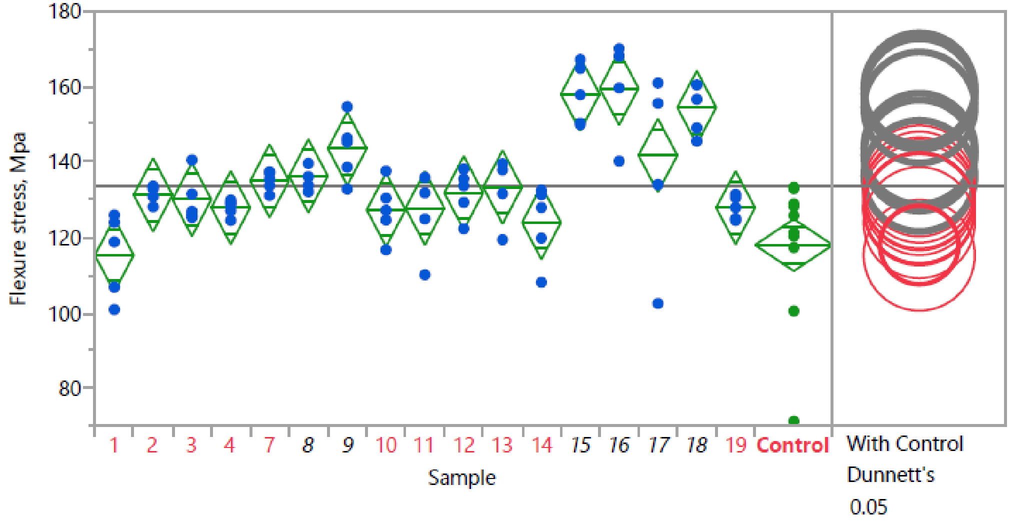
	Flexural Modulus (Gpa)						Flexural Strength (Mpa)						Flexural Strain (%)					
Conc. Wt %	0.1			0.5			0.1			0.5			0.1			0.5		
	% Change	Mean	Std Dev	**% Change**	Mean	Std Dev	**% Change**	Mean	Std Dev	**% Change**	Mean	Std Dev	**% Change**	Mean	Std Dev	**% Change**	Mean	Std Dev
Control	**0%**	2.90	0.199	**0%**	2.90	0.199	**0%**	118.0	18.98	**0%**	118.0	18.98	**0%**	4.93	1.036	**0%**	4.93	1.04
1	**1.0%**	2.93	0.140	**2.4%**	2.97	0.088	**-2.3%**	115.3	10.95	**5.0%**	123.9	4.06	**-10.3%**	4.42	0.653	**1.1%**	4.98	0.29
2	**7.4%**	3.11	0.066	**2.6%**	2.97	0.169	**11.3%**	131.3	2.15	**-8.7%**	107.7	11.96	**19.1%**	5.87	0.239	**-19.4%**	3.97	0.64
3	**6.7%**	3.09	0.070	**8.5%**	3.14	0.058	**10.2%**	130.0	6.33	**9.0%**	128.6	15.99	**16.1%**	5.72	0.835	**3.7%**	5.11	1.02
4	**2.0%**	2.95	0.166	**8.9%**	3.16	0.137	**8.4%**	127.9	2.15	**-2.0%**	115.7	13.57	**15.4%**	5.69	0.158	**-14.5%**	4.21	0.80
7	**-0.7%**	2.88	0.048	**2.9%**	2.98	0.158	**14.4%**	135.0	2.61	**7.4%**	126.7	4.37	**31.2%**	6.47	0.336	**-1.1%**	4.88	0.34
8	**6.0%**	3.07	0.036	**-0.2%**	2.89	0.222	**15.5%**	136.3	3.40	**-0.4%**	117.5	12.35	**30.2%**	6.42	0.478	**-2.0%**	4.83	1.05
9	**38.4%**	4.01	0.241	**0.2%**	2.90	0.149	**21.6%**	143.5	8.26	**9.5%**	129.1	8.85	**-13.2%**	4.28	0.592	**7.5%**	5.30	0.70
10	**10.3%**	3.19	0.053	**2.9%**	2.98	0.210	**7.9%**	127.3	7.67	**-16.5%**	98.5	4.08	**1.9%**	5.02	0.529	**-28.5%**	3.52	0.07
11	**6.9%**	3.10	0.047	**8.4%**	3.14	0.185	**8.3%**	127.7	10.85	**14.6%**	135.3	5.91	**11.5%**	5.49	0.981	**5.7%**	5.21	0.32
12	**10.0%**	3.19	0.101	**6.9%**	3.10	0.242	**11.7%**	131.8	6.19	**4.9%**	123.7	11.59	**16.5%**	5.74	0.694	**-4.6%**	4.70	0.60
13	**5.4%**	3.05	0.079	**8.5%**	3.14	0.174	**13.0%**	133.3	8.35	**13.1%**	133.4	4.27	**22.0%**	6.01	0.752	**8.2%**	5.33	0.33
14	**-2.1%**	2.84	0.282	**3.1%**	2.99	0.203	**5.0%**	123.9	10.14	**14.5%**	135.1	10.07	**18.5%**	5.84	0.968	**25.0%**	6.16	0.68
15	**65.1%**	4.78	0.176	**4.9%**	3.04	0.154	**33.9%**	158.0	7.99	**14.1%**	134.6	2.59	**-18.8%**	4.00	0.397	**22.5%**	6.04	0.35
16	**72.3%**	4.99	0.158	**4.5%**	3.03	0.192	**35.2%**	159.5	11.80	**12.1%**	132.2	4.22	**-22.0%**	3.85	0.566	**14.0%**	5.62	0.61
17	**62.5%**	4.71	0.110	**4.1%**	3.02	0.274	**20.1%**	141.7	24.24	**2.7%**	121.2	10.77	**-34.2%**	3.24	0.734	**-3.5%**	4.76	0.45
18	**70.5%**	4.94	0.292	**-2.5%**	2.82	0.289	**30.9%**	154.4	6.85	**-1.4%**	116.3	6.34	**-25.9%**	3.65	0.362	**0.0%**	4.93	0.60
19	**-0.9%**	2.87	0.162	**8.9%**	3.15	0.076	**8.4%**	127.9	3.12	**12.6%**	132.9	6.70	**13.5%**	5.59	0.168	**7.4%**	5.29	0.48

0.1% Loading

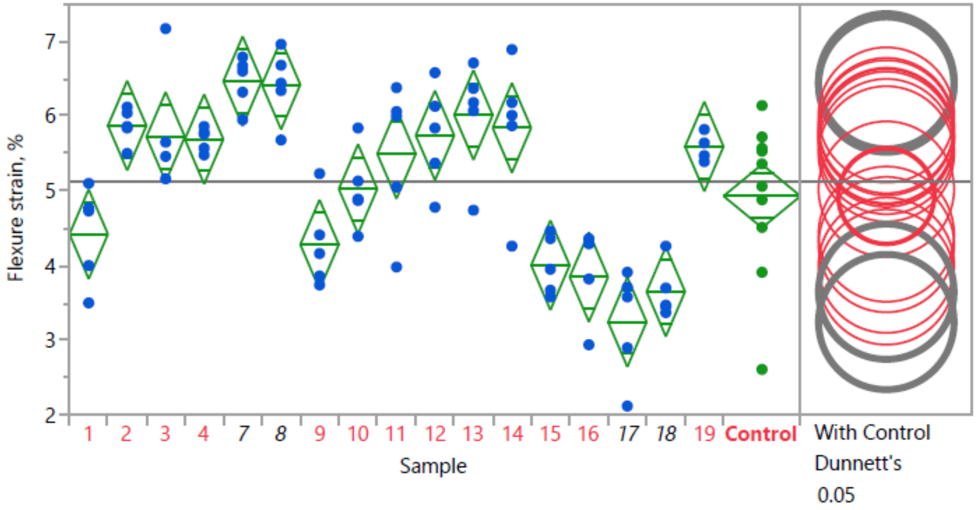
Oneway Analysis of Modulus Young's, GPa By Sample



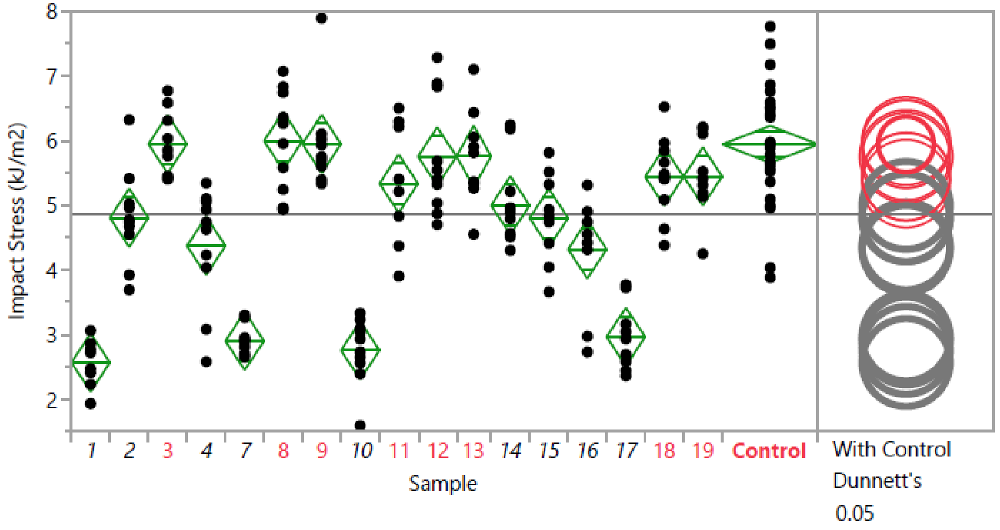
Oneway Analysis of Flexure stress, Mpa By Sample



Oneway Analysis of Flexure strain, % By Sample



Oneway Analysis of Impact Stress (kJ/m2) By Sample



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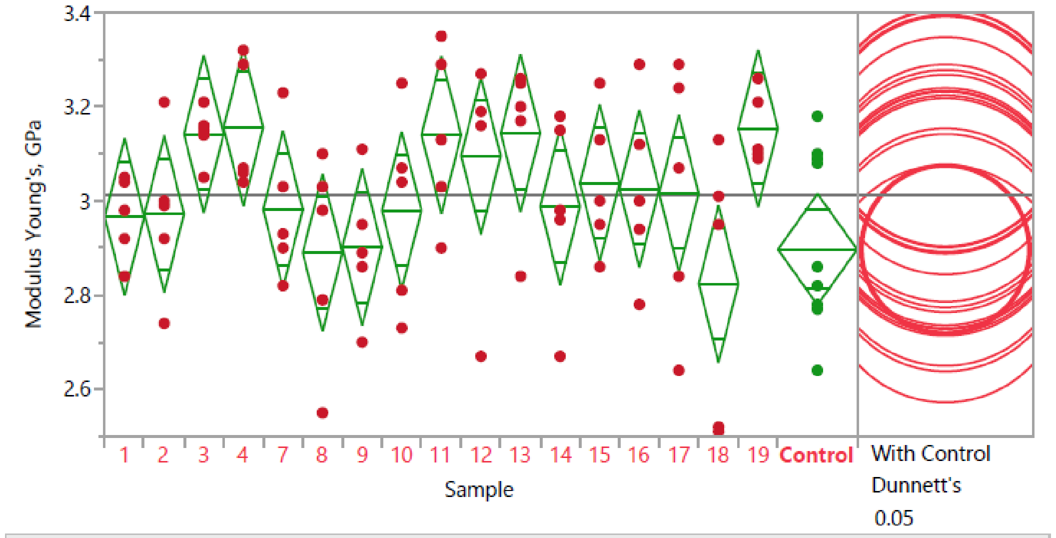
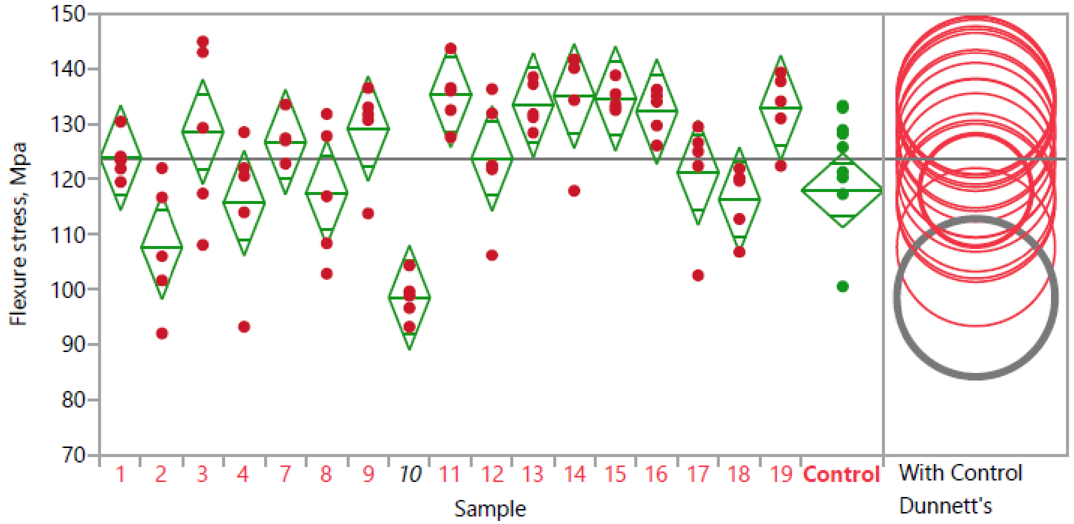
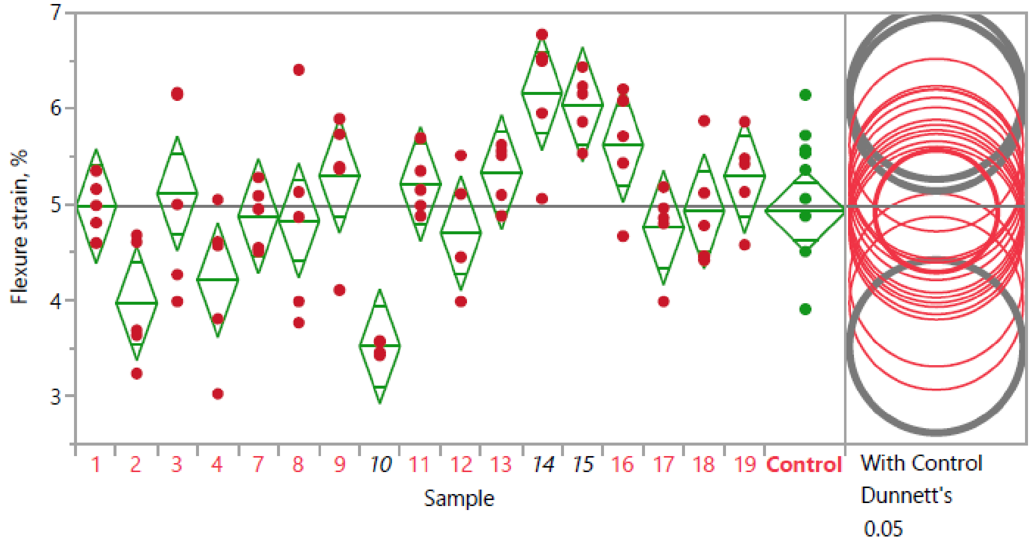
Oneway Analysis of Modulus Young's, GPa By Sample



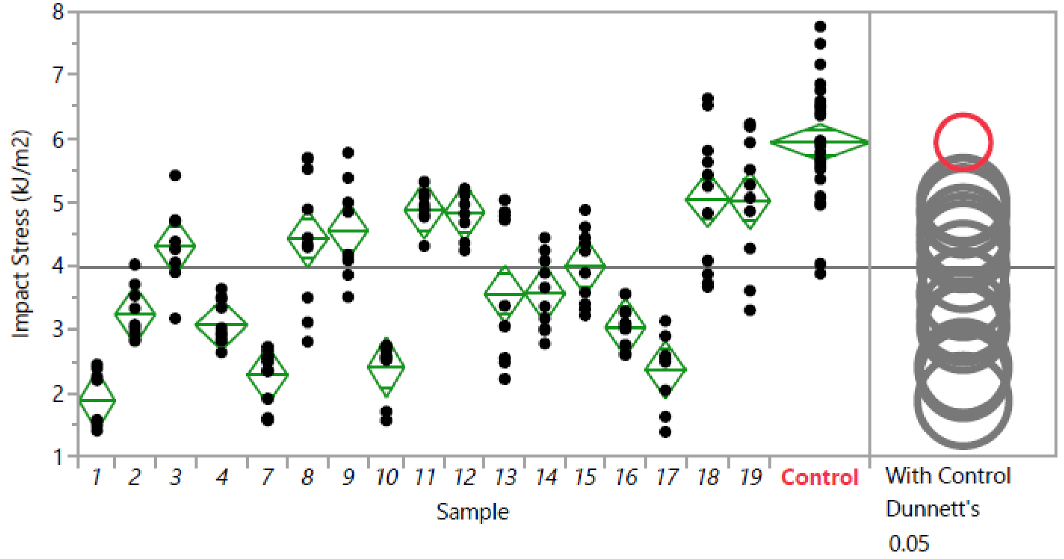
Oneway Analysis of Flexure stress, Mpa By Sample



Oneway Analysis of Flexure strain, % By Sample

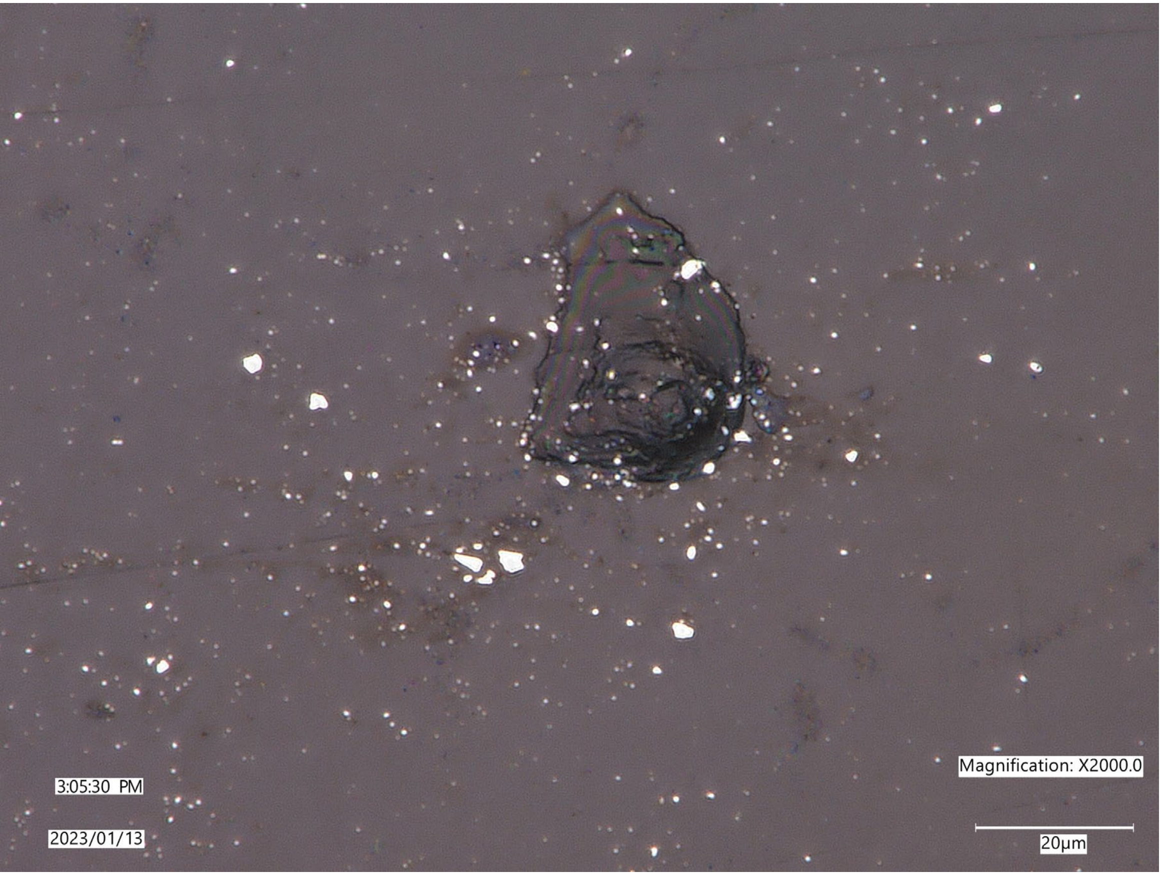


Oneway Analysis of Impact Stress (kJ/m2) By Sample

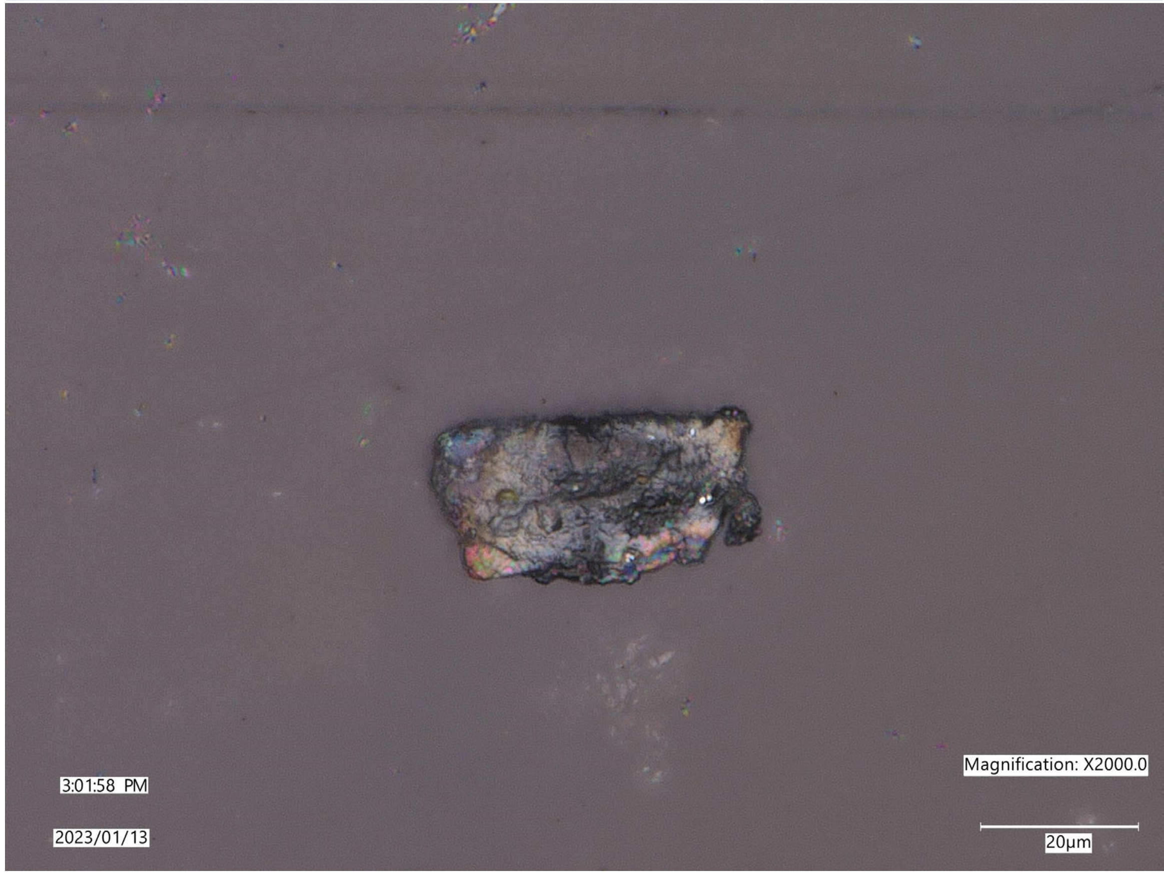


Graphene Agglomerations

Sample 18 – 0.1% Loading	
Magnification	2,000 X



Sample 10 – 0.1% Loading	
Magnification	2,000 X



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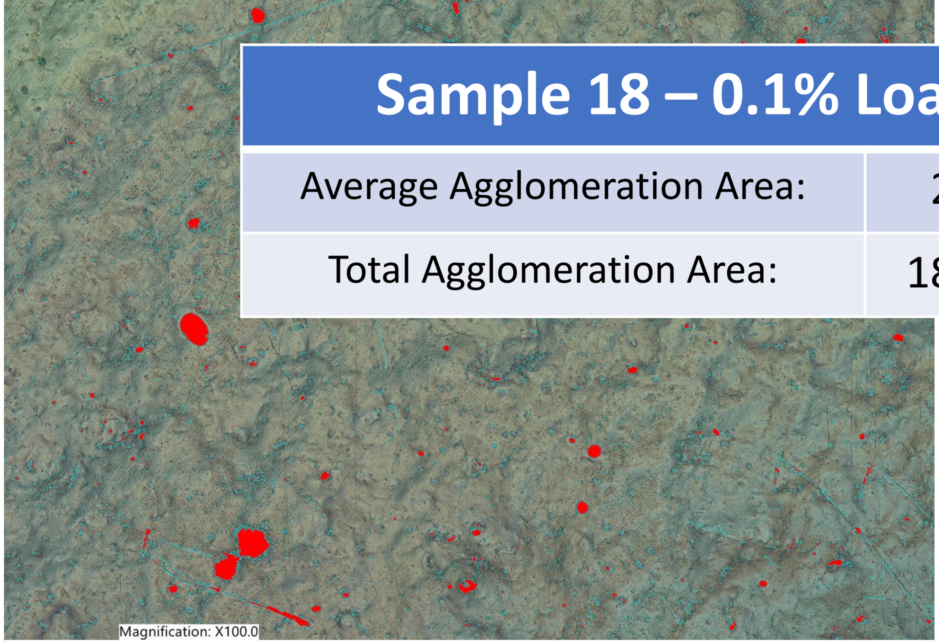
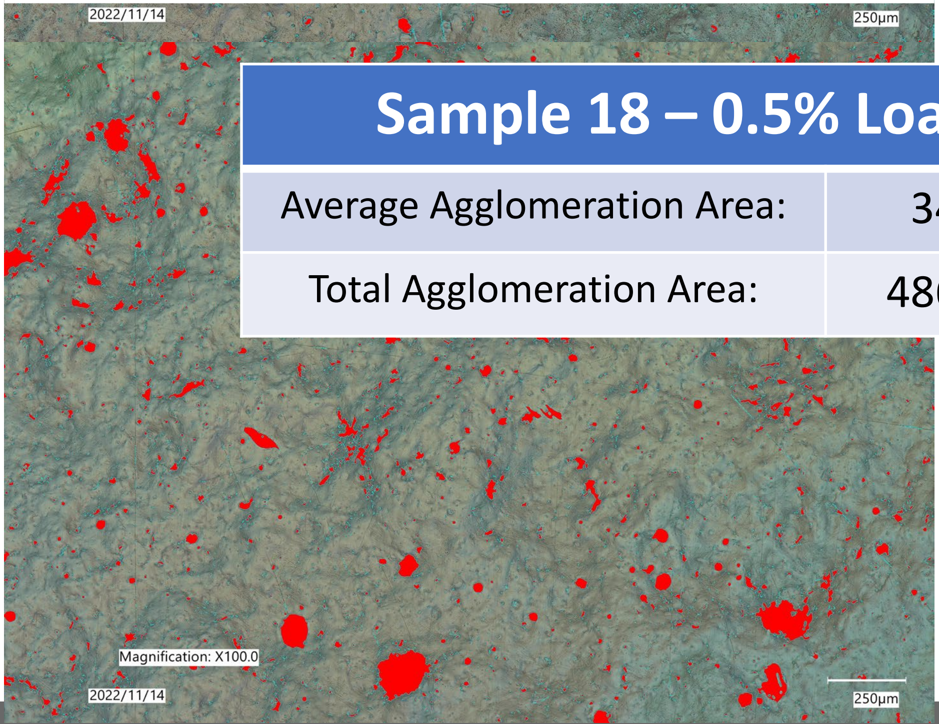


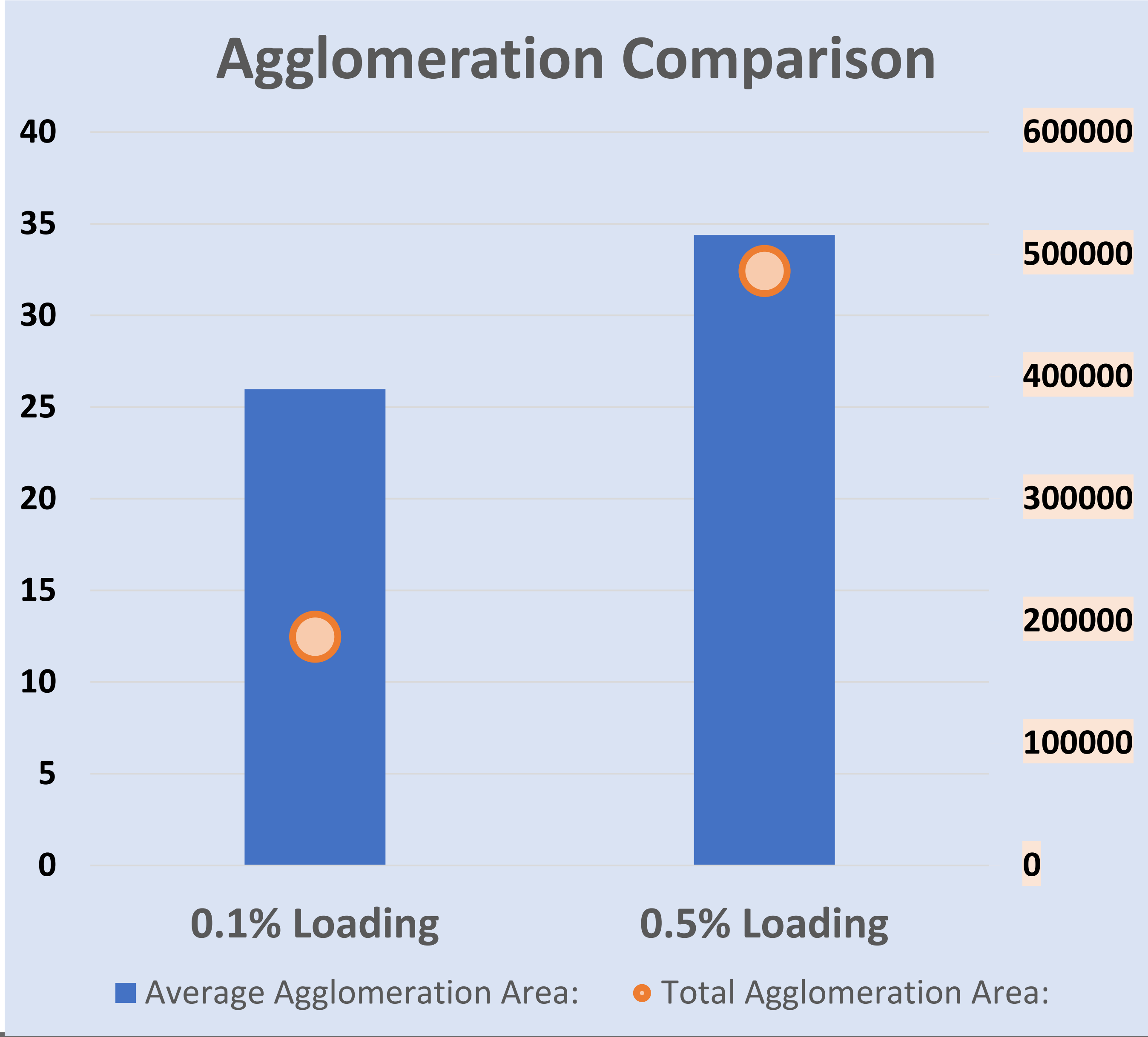
Sample 18 – 0.1% Loading

Average Agglomeration Area:	25.97 µm^2
Total Agglomeration Area:	187,215 µm^2



Sample 18 – 0.5% Loading

Average Agglomeration Area:	34.39 µm^2
Total Agglomeration Area:	486,543 µm^2



TESTING PROJECT SUMMARY

- Five samples of 0.1% loading significantly improved Flexural Modulus
  - An increase of 38% to 72%
  - Samples 9,15,16,17 & 18

- The same five samples significantly improved Flexural Strength
  - An increase of 20% to 35%

- Two of the five samples had negligible detriment to impact toughness

- This was a blind study with no optimization made for any functionalization

- In general, the 0.1% loading provided better results

Proposed Next Steps:

- Allow testing of additional graphene producers (at manufacturer's expense) through the Graphene Council.
  - Test at 0.1% loading for comparison to original data.

- Publish findings in peer-reviewed periodical.

- Identify optimum percolation threshold for specific grades.
  - This may vary from grade to grade and system to system.
  - Investigate other loadings for optimization.

- Conduct trials in fiber-reinforced systems.
  - How do these enhancements affect laminate properties?

Why is this important?

- Stronger, better material.
    - For example: reduced plies/lighter part.

- Cost effective solution:
    - Extremely low load factor = minimum impact to cost.
    - Able to source from multiple sources.

- Drop-in solution.
    - No change to existing process.

VIBRANTZ TECHNOLOGIES™ The Graphene Council COMPOSITES ONE®

Questions?

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