COTS Assemblies for Class-D Missions : Examples of Modifications to Improve Board-Level Reliability

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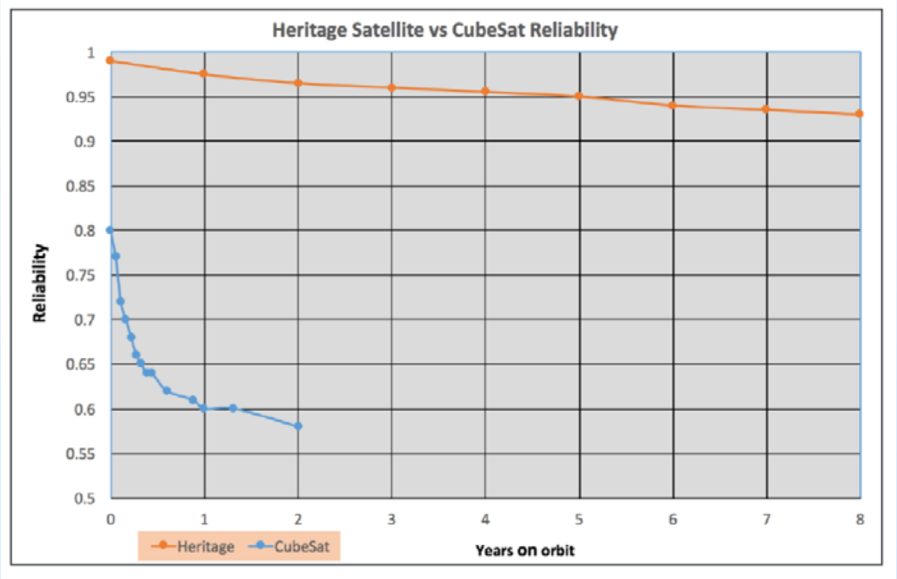
CubeSat/SmallSat

- **2018: 1200 spacecraft <200kg launched: NASA missions accounted for only 3%**[1]
- **NASA strategy is to be an early adopter or fast follower**
  - **Identify commercial capabilities and test in relevant environments to reduce risk for use on future missions**[1]
  - **15%-50% failure rate for technology demonstrations**[1]
- **Cubesat high immediate failure rate**[2]



Heritage and CubeSat Reliability Plotted on Same Curve[2]

1. NASA SMALL SPACECRAFT STRATEGIC PLAN (08/09/2019)
2. SmallSat Reliability – DJ Sheldon (2017)

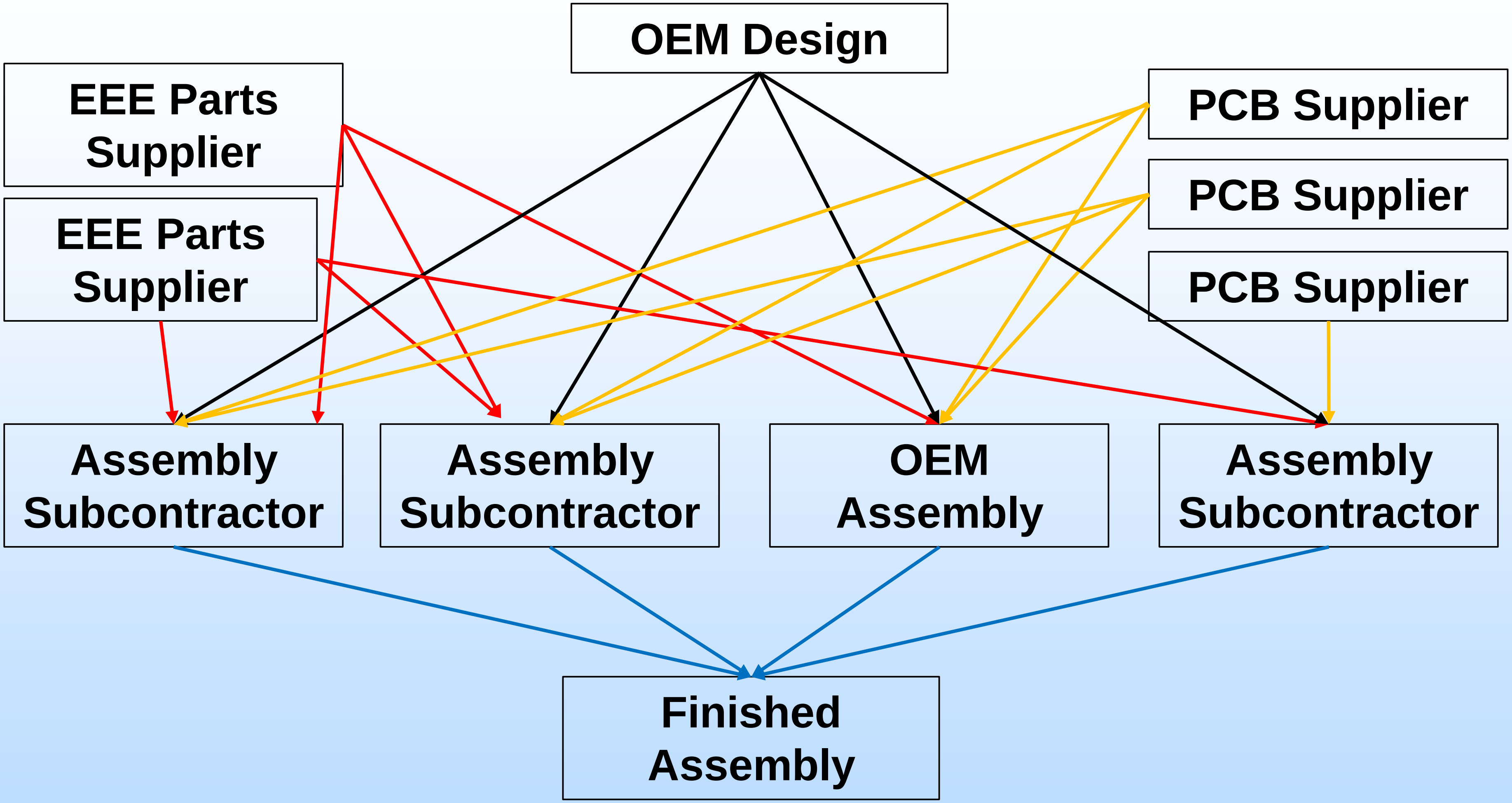
Mission Risk Classification

Characterization	Class A	Class B	Class C	Class D
Priority (Criticality to Agency Strategic Plan)	High priority	High priority	Medium priority	Low priority
National significance	Very high	High	Medium	Low to medium
Complexity	Very high to high	High to medium	Medium to low	Medium to low
Mission Lifetime (Primary Baseline Mission)	Long, > 5 years	Medium, 2-5 years	Short, < 2 years	Short, < 2 years
Cost	High	High to medium	Medium to low	Low
Launch Constraints	Critical	Medium	Few	Few to none
In-Flight Maintenance	N/A	Not feasible or difficult	Maybe feasible	May be feasible and planned
Alternative Research Opportunities or Re-flight Opportunities	No alternative or re-flight opportunities	Few or no alternative or re-flight opportunities	Some or few alternative or re-flight opportunities	Significant alternative or re-flight opportunities

Class D: Low Cost, Short Mission Life

Focus on reducing risk for early failure rather than maximizing life

Simplified COTS Assembly Flow



- Same product can have different parts, materials, and workmanship
- Complex mixture for finished assembly, may not have traceability
- Short product life cycles: Subcontractors are brought on and offline

COTS Reliability

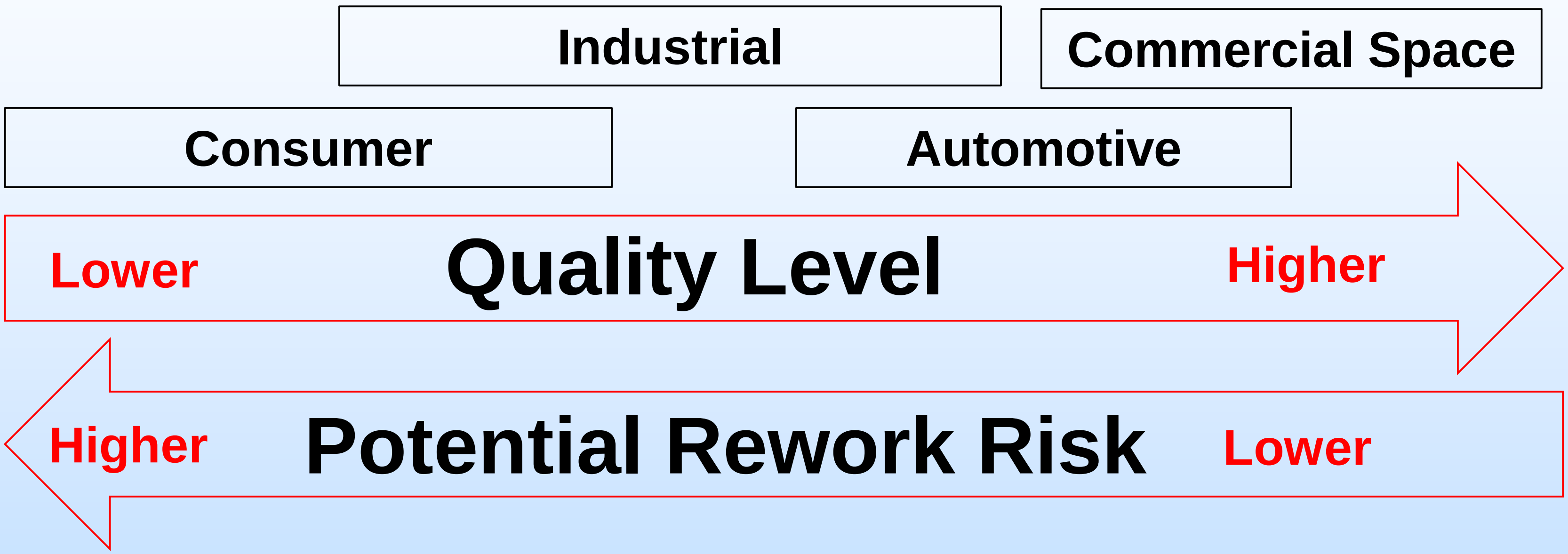
- Package reliability models for space are based on assumptions of workmanship standards
  - High level of control
  - Consistent state of hardware
- COTS assemblies
  - Little control
  - Many interacting variables to consider
- Cannot assume existing package qualification data covers all assemblies
  - Potentially different failure modes
- Package reliability alone is not sufficient to risk assess an assembly
- State of the hardware is equally important
  - The goal of rework, cleaning, underfills, and other ruggedization is to provide consistent, minimum level of quality

COTS Sensor Solder Joint

COTS BGA

Quality Risk

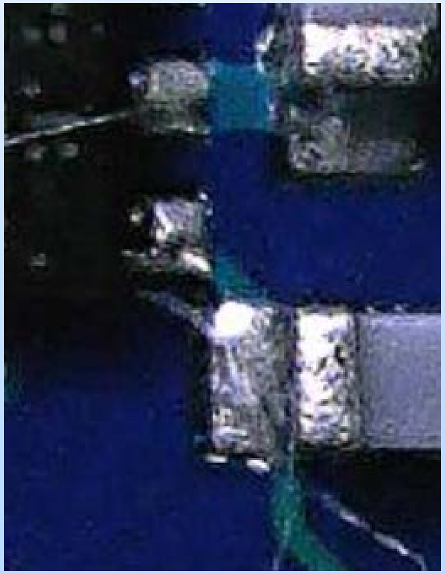
- COTS quality can vary significantly



- Engagement with commercial vendors to reduce risk
  - Build as engineering samples
  - Source inspection of inventory to choose best lots
- Higher upfront cost, reduce rework cost and schedule risk

Visual Inspection

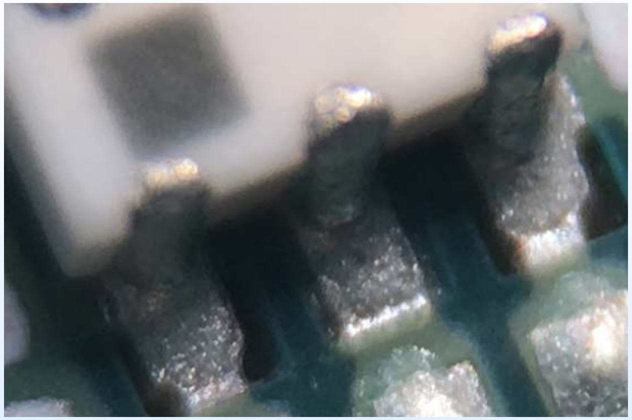
- **Although not intended to meet J-STD-001FS class 3 standards, inspect class D hardware to this level**
  - **Collect notes on all anomalies, only formally document non-conformances to mission requirements**
  - **Minimal effort, useful for troubleshooting**
- **QA training on Pb & Pb-free solder differences**
  - **Pb-free solder will be more grainy**
  - **Shrinkage lines vs disturbed solder**
  - **Cold solder is more common for Pb-free; higher melting point and “pasty range,“ may pass less strict inspection**



Grainy Pb-free Solder Joints

Solder Joint Rework

- New procedures and tools may be needed
  - Pb-free requires higher soldering temperatures
  - Higher densities
  - Different pad designs
- Rework and inspect to meet mission requirements



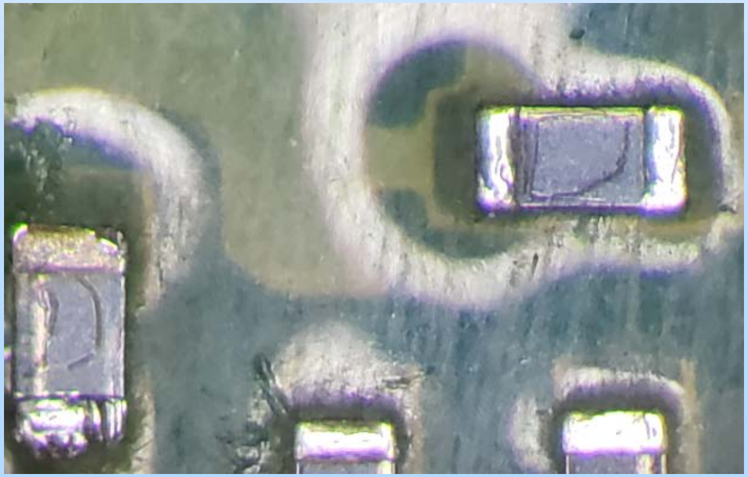
Insufficient solder

- Use Sn63 where possible

If Pb-free solder wire or paste will be used, it is critical to have procedures to prevent accidental mixing

Cleaning

- Removal of solder balls/powder – conductive
- Other FOD – mix of conductive/non-conductive
- Flux residues
  - Can cause de-wetting of conformal coats
  - No-clean generally low risk
  - Water soluble, or RA flux residue pose risk for corrosion, dendrites
- Some EEE parts may be incompatible with cleaning chemicals
  - Attack thermal adhesives, degrade epoxies, become entrapped and cause latent failure
  - Highest risk are non-hermetic parts



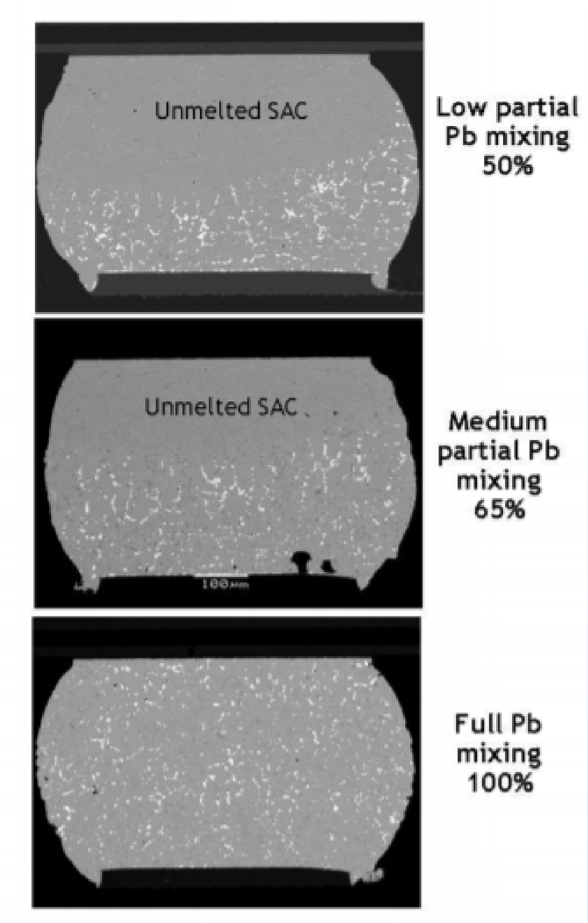
Conformal Coat Dewetting

Staking

- Required for some parts to meet shock & vibe requirements
  - Determine parts by analysis – May be cost prohibitive for class D
  - Package database or general guidelines – Lower cost
    - Heavy, few solder joints, high z-dimension, etc.
- Stake based on 8739.1 requirements

BGA Assembly

- Pb-free BGA with SnPb solder
  - Extended time above 210C to promote full solder mixing
    - Mixed literature on reliability improvement, but easier state to achieve consistently
  - BGA reballing
    - Widely provided service, but can extend lead times



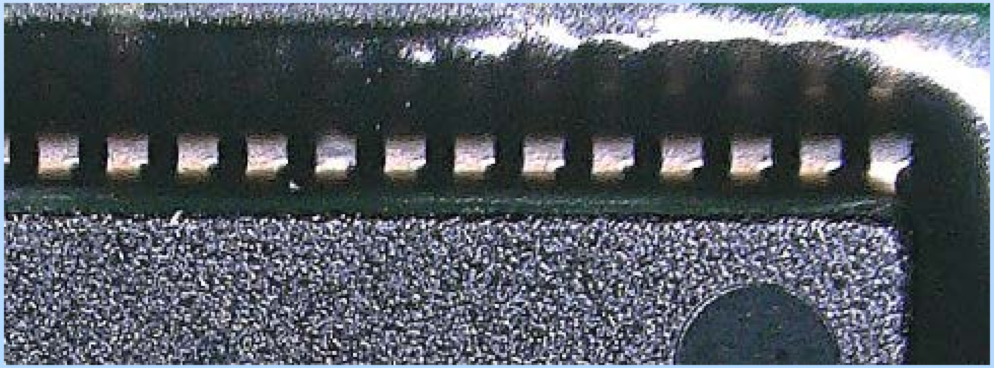
Pb-Free BGA Memory
No Mixing, No Self-Alignment

"<u>The Effect of Pb Mixing Levels on Solder Joint Reliability and Failure Mode of Backward Compatible, High Density Ball Grid Array Assemblies</u>"
Richard Coyle, Raiyo Aspandiar, Vasu Vasudevan, Steve Tisdale, Iulia Muntele, Richard Popowich, Debra Fleming, and Peter Read

Pb-Free BGA Memory
Complete Mixing, Self-Aligned

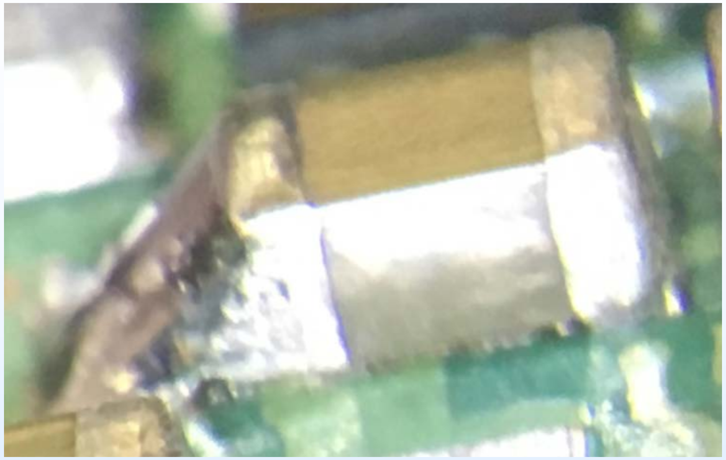
Underfills/Encapsulation

- TSOPs, BGA
  - Address CTE mismatch problems
  - Improve Pb-free shock & vibration performance
    - COTS box level assemblies not designed for space shock & vibration environments
  - Requirements are part and application specific
    - Datasheet properties may not always correlate to performance
- Underfill's cure temperature has to be compatible with parts and materials already on the assembly
- Compromises reworkability – hardware should be electrically tested



Encapsulated Leads

COTS Class D Example



- **MLCC with extended solder for bridging pads**
- **What is the reliability of this part?**
  - **Small part, solder appears to have wet the surfaces properly**
    - **On the face, shock, vibe, temp cycle low risk for most class D**
  - **Potential failure modes not typically considered in inspection**
    - **MLCC Thermal shock: Soldering iron likely contacted the part to achieve this solder joint; <u>low risk</u> for class D**
    - **Consumption of termination metal: Attachment to two copper pours, high heat, large solder volume, extended soldering time; <u>high risk</u>**
- **Solution: Replace part and wire pours at separate location**

Future Work

- **Examine BGA underfills to address shock & vibe concerns for Pb-free**

Summary

- **SmallSat/CubeSats have high "infant mortality" rates**
- **COTS have complex supply chain – hardware pedigree difficult or impossible to determine**
- **Engagement with vendors will reduce risk**
- **Visual inspection for COTS provides valuable information**
- **Assemblies may require one or more techniques to meet minimum quality to meet mission requirements**
- **Risk assessments must consider mission requirements and less traditional failure modes**

Backup

Data from Literature

	Temp cycle condition	Without Underfill	With Underfill	Data source
TSOP	0 to 100ºC	1st failure at 150 cyc	No failure until 3000 cyc	Alan Emerick et al, 1993
CSP	-40 to 125ºC	N_{63} ~ 3300	1 or no failure up to 5200 cyc, out of 180 samples.	Jing Liu et al, 2003
uBGA	-65 to 125ºC	4 of 10 failed by 800 cyc	No failure up to 4500 cyc	Jong-Min Kim et al, 2003
BGA	-40 to 125ºC	N_{63}~4690	N_{63}~5780	Haiyu Qi et al, 2009

Underfill Properties

Underfill	Tg (°C)	CTE (ppm/K)	Modulus	Cure time (min)	Reworkability	Outgassing
SUF1589-1	120	23/80	Bending / 13 GPa	80	No	Pass
UF3811	124	61/190	Storage / 2.45 GPa @25C	60	Yes	Pass
Loctite 3549	38	55/177	Storage / 2 GPa @22C	5	Yes	Fail
SMC-386GM	75	60	Flexural / 2.5 GPa	30	Yes	TBD
Loctite 3563	130	35/110	Tensile / 2.8 GPa	7	No	TBD
UF3800	69	52/188	Storage / 3.08 GPa @25C	8	Yes	TBD
UF3810	102	55/171	Storage / 2.99 GPa @25C	8	Yes	TBD
Loctite 3128	45	40/130	Tensile / 3.9 GPa	20	No	TBD