SMT Power Wire Connector Insights – What You Might Wish You Had Known

The point of this article is to inform customers about aspects of SMT (Surface Mount Technology) parts, particularly from a mechanical engineering point of view, where some of the mechanics of SMT soldered parts may not be well understood.

When using the horizontal screw tear off peeling SMT mode 100% inspection of production is required.

Generally, in vertical screw twisting mode SMT, much higher torques are achievable, and the tighter distribution curves may enable a customer to sample torque test each lot, versus test every single part for a secure attachment, if the customer data supports that in the given application.

If you are thinking about using Surface Mount Wire Technology (SMT/SMD) Wire Connectors on your new High Current PCB project, here are some mechanical engineering insights to help make good choices.

Rule #1 – do everything you can to use a THT wire connector (Through Hole Technology with one or more soldered-through the PCB bus legs) since you will save yourself some potential headaches associated with Surface Mounted components.

THT mounted connectors tend to be intrinsically rugged mechanically, and electrically, for a long life and reliable performance. Screw torque on IHI's THT PCB connectors is resisted by stiff conductive legs or staples using mainly favorable compressive stresses with less reliance on shearing, tearing, and peeling stresses.

THT wire connectors can be used on IMS metal core aluminum backed Double Sided PCB
https://lugsdirect.com/PDF%20Documents/tht-high-power-wire-connector-with-bottom-cooled-ims-metal-core-pcb.pdf

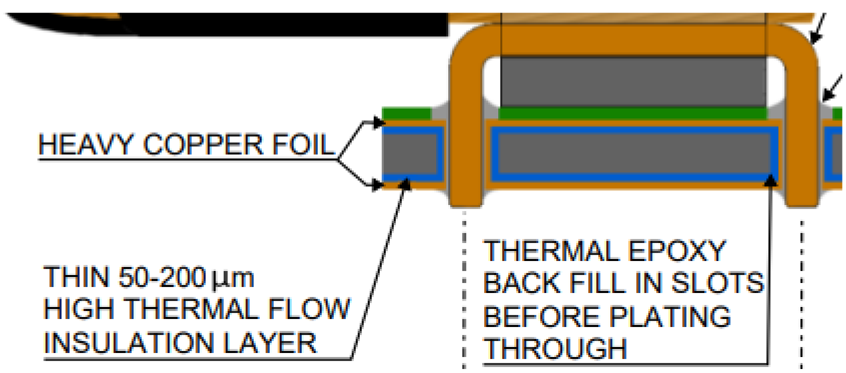


Figure 1. ***Dual layer IMS metal core with relieved metal and epoxy back fill, plated through slots creates optimum sharing of current and heat flow with excellent mechanical properties for a sturdy wire connector***

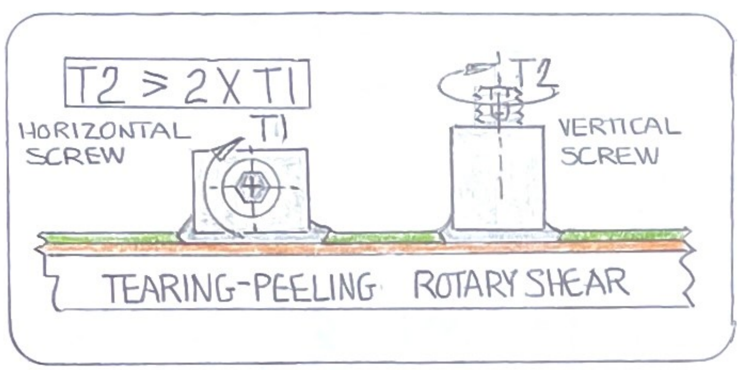
Rule #2 – Look long and hard at the best way to handle both current and mechanical demands of a wire connector on a PCB as well as long term heat flow.

"A chain is only as strong as its weakest link"

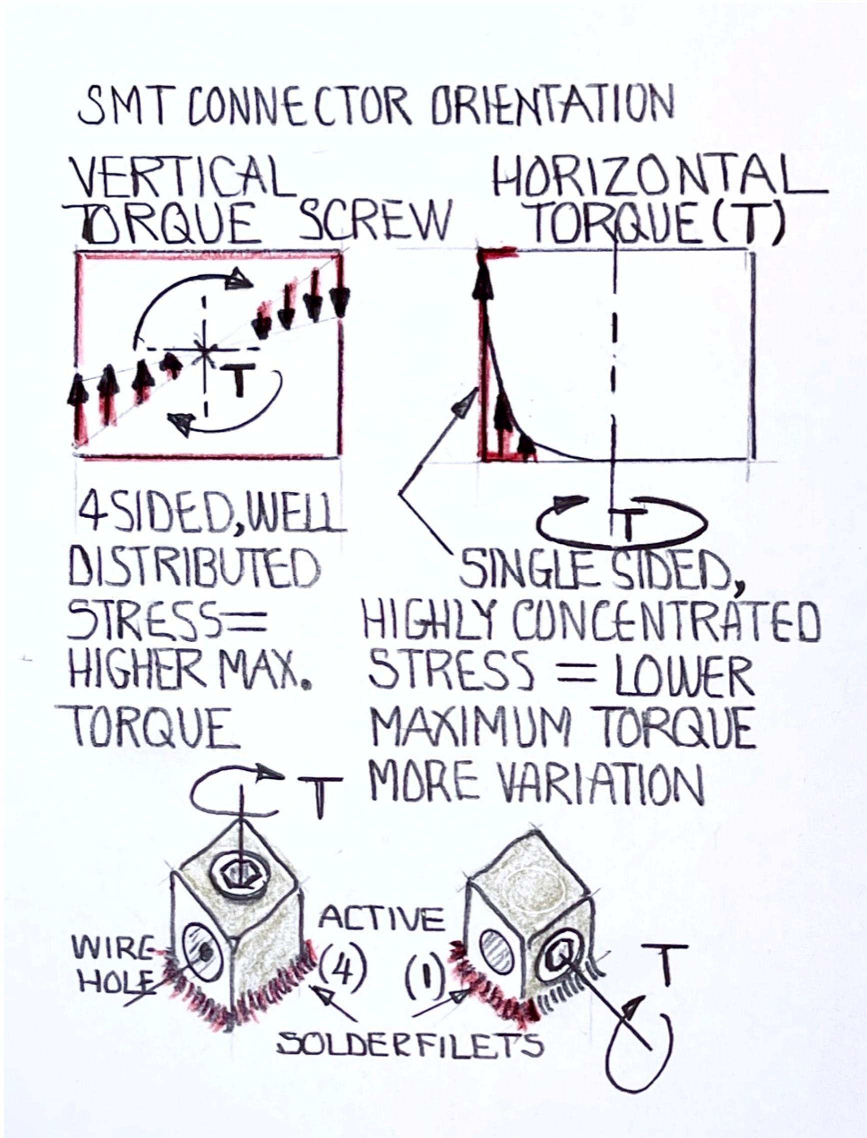
Rule #3 – If you must use SMT then let's be fully aware; look at the caveats and minimize them.

1. **Limit the size and power for SMT connectors. Use moderate temperature rises. SMT connectors are more limited on maximum wire size and maximum current, whereas THT connectors go all the way to the largest wires and highest currents used on PCB. THT designs are more scalable than SMT designs as current increases.**
   These size limits are based on differential CTE (Coefficient of Thermal Expansion) and fatigue life of the SMT solder joint, as well as limited mechanical strength for clamping and holding large wires.
   Very high temperatures and high cycles are harder on SMT soldered parts then THT ones.
2. **Consider <u>upsizing</u> the SMT lug – so you might use an AWG 6-14 lug for a # 10 wire if in horizontal screw torsion.**
3. **SMT connectors can be better suited to factory wiring (in house) than field wiring (end users).**
   Factory wiring can control the applied forces and torques and monitor and audit the actual outcomes of the SMT process and wire termination activity.
4. **Single "face and trace" contact of SMT wire connectors does not help to pass current (or heat) into the underside of the PCB as efficiently as a through bus THT part.**
   Of course, with metal core substrates IMS, this can be moderated for heat flow, though not for current flow which, unless double sided, IMS is used is limited to the top foil(s).
   The elimination of multiple trace layers and Single Sided PCB is a backward step for sharing current density distribution.
   Higher resistance current in limited foil paths create more I^2*R watts of wasted heat.
   SMT focusses all of the connector-to-foil power transmission as well as the mechanical strength to a single interface surface of low strength materials.
5. **Orientation of SMT connector screw = <u>vertical</u> = good. Use the optimum orientation for the maximum strength of the soldered joint which heavily <u>favors a vertical axis wire binding screw</u>**

   A rule of thumb is that the vertical torsional shear strength will be 2 times or more of the horizontal axis tearing / peeling separation strength for the same parts and soldered face size.
   This 2X + tends to bring the strength of the SMT joint in the decent range needed for tightening screws on larger wires but can fall short of targets in horizontal screw torque modes.



<u>Figure 2.</u> Vertical screw orientation increases torque shear greatly over horizontal screw axis.
This works well since the soldered interface is in rotary shear which is strong.
Essentially all of the solder at the periphery of the interface is collectively resisting shearing and quite high numbers are possible.



<u>Figure 3.</u> Illustration of the stress levels on the SMT joint between <u>vertical</u> (favorable) and <u>horizontal</u> wire screw torque axis (less favorable)

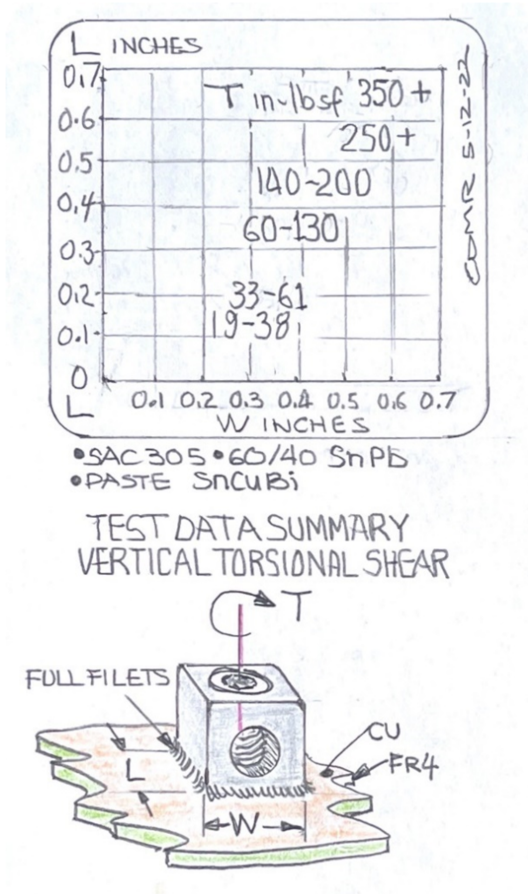


Figure 4. ***Scatter graph of typical range for the more favorable <u>vertical</u> <u>torsional shear strength</u> with full filets for different sizes of the soldered face. Parts with full filets properly soldered tend to have very useful torque numbers enabling larger wires at higher torques to be tightened without compromising the SMT joint.***

6. **Orientation of SMT connector screw = <u>horizontal</u> = not nearly so good. If you use a <u>horizontal wire binding screw</u>, only the solder along one edge of one side of the soldered interface is active in retainment. This creates a complex mix of peeling stresses, crack propagation, and minimal active area of the soldered interface contributing to the tensile retention strength.**

   In other words, the type of stress is not shear stress that acts on a large known fixed area but a type of peeling stress, or tear off stress, which reduces the torque to failure by a factor of 2 or much more and introduces indeterminate stress concentrations avalanche crack propagation.

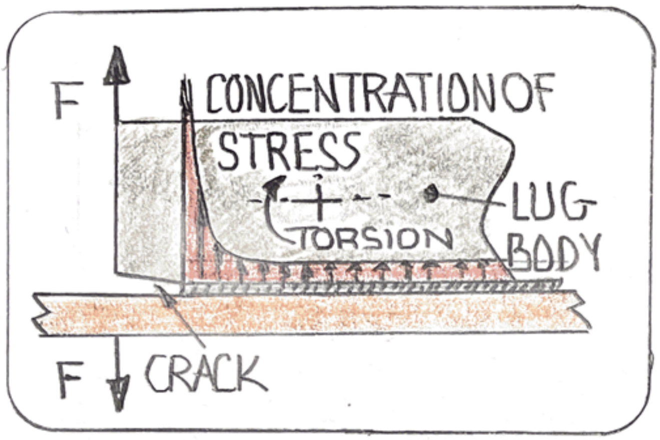


Figure 5. ***Stress concentrations at the lateral peel-tear edge locations creates lower tear off torque.***

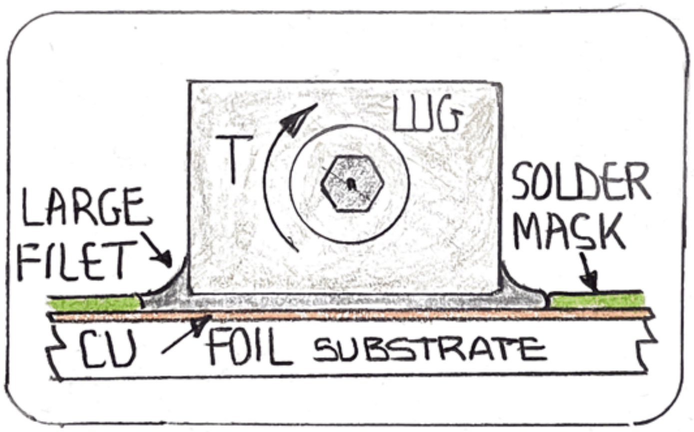


Figure 6. ***Use solder mask dam to add a large filet radius to the lateral side subject to peel-tear stresses. Large filets are essential for best screw torque performance of both horizontal and vertical SMT wire connector orientation.***

With reflow solder paste processes, pre-fluxing the sides of the connector may be needed to assist with full wetting strength and an optimal wet-up height of the full filet radius which acts as a stress crack blocker and stress spreader in front of a boundary which presents crack-like edges of a multilayer sandwich stack.

Filets are required by IPC standards and do offer a large boost in mechanical performance for both vertical and horizontal twist modes.

Filets tend to have less gas bubbles in them compared to the trapped flux gasses in the main interface layer.

The filets also act as an augmented length of the "torque arm" that increases favorable resistance to the applied separating torque.

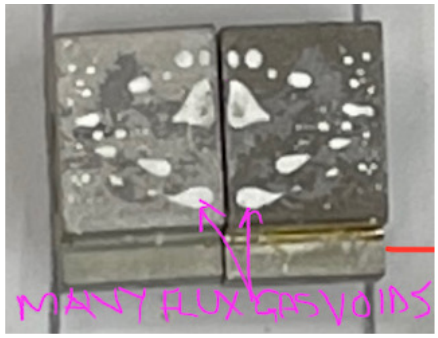


Figure 7. ***"Wet" low viscosity solder paste may have more flux gas voids. Voids nearer the outer edge can reduce torsion or tear of strength randomly. External filets tend to have less gas bubbles trapped due to increased ease of flux gas release.***

7. **Solder paste flux may not clean tin plating as effectively as it spreads up the sides of the connector. Fluxing effectiveness would be stronger under the connector, though traps more flux gas bubbles in a confined location.**

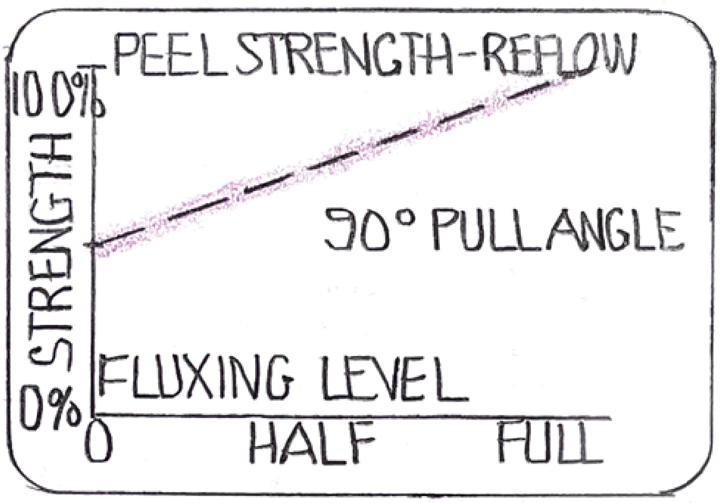


Figure 8. ***Peel strength of solder is directly affected by fluxing level of that surface. No fluxing can result in 50% or less peeling strength of solder or non-wetting. (4)***

8. **Peeling-tearing type of failure mode is much less predictable than rotary shear since it is a form of tearing along a single edge line, or at best, a thin linear minimal area zone in tension. It can easily behave in a crack propagation mode and is associated with much lower thin film peeling stress numbers that apply to the solder and plated layers.**
   Intermetallic diffused bonding layers also play an important role in plated and soldered metal interfaces with regard to peeling strength, but are hard to quantify on a given part due to variations at the subatomic quantum physics level.
   IHI has developed a process that enhances peeling bonding strength of the solderable plating which reduces low fliers in the distribution curve.
   As a practical matter for higher stress SMT mounting configurations, especially horizontal screw axis only 100% testing of the final soldered bond can give the needed measure of proof that all is withing the customer desired standard.

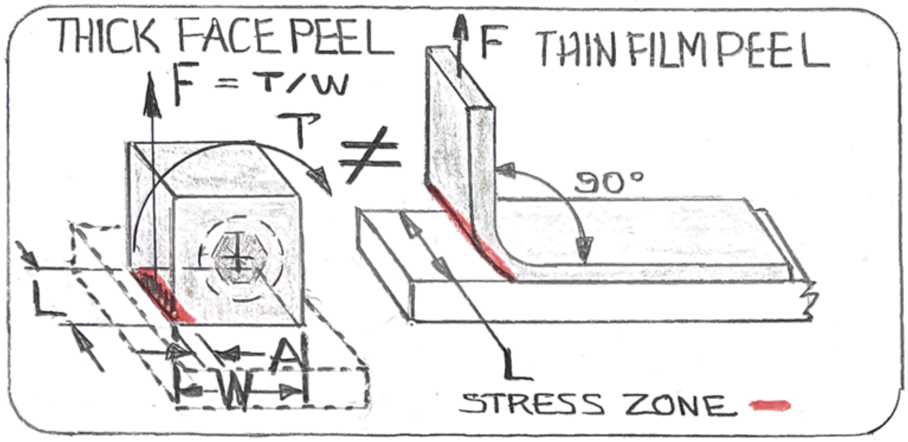


Figure 9. ***Thick objects do not behave as weakly as thin film peeling initially, but can become more so when separation (crack) starts.***

Testing indicates that some indeterminate tensile <u>area</u> = L*A (red zone) under the SMT connector "thick face", as well as the filet, is behaving like a favorable tensile stress zone, until it peels. As the crack moves inward the peak stresses rise, since the force F = Torque T / W width, F moves inward and becomes F= T/(W-A) and propagates the crack under load like in Figure 5.
The filet (if there is one) and the soldered bond along the lateral edge lines L, have the peak counter torque leverage initially, then falls rapidly.

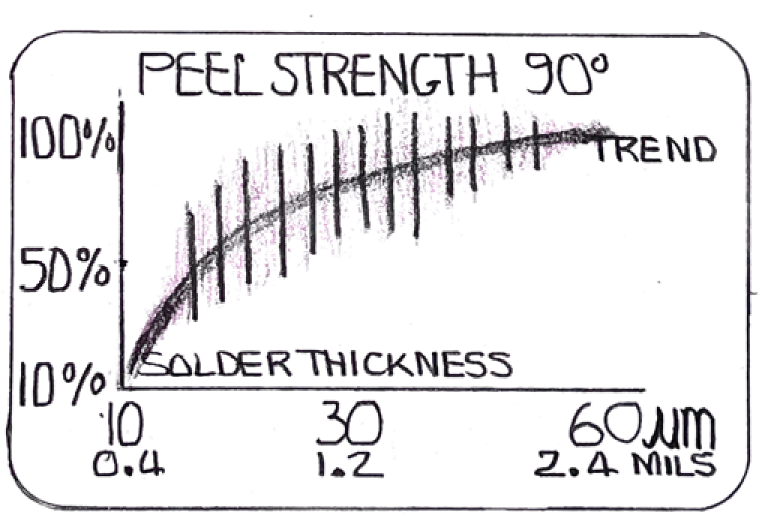


Figure 10. ***0.003" (80 micrometers) <u>minimum</u> solder thickness is a widely established number for strong solder joints. Excessive solder thickness reduces capillary penetration action and increases internal voids. (4)***

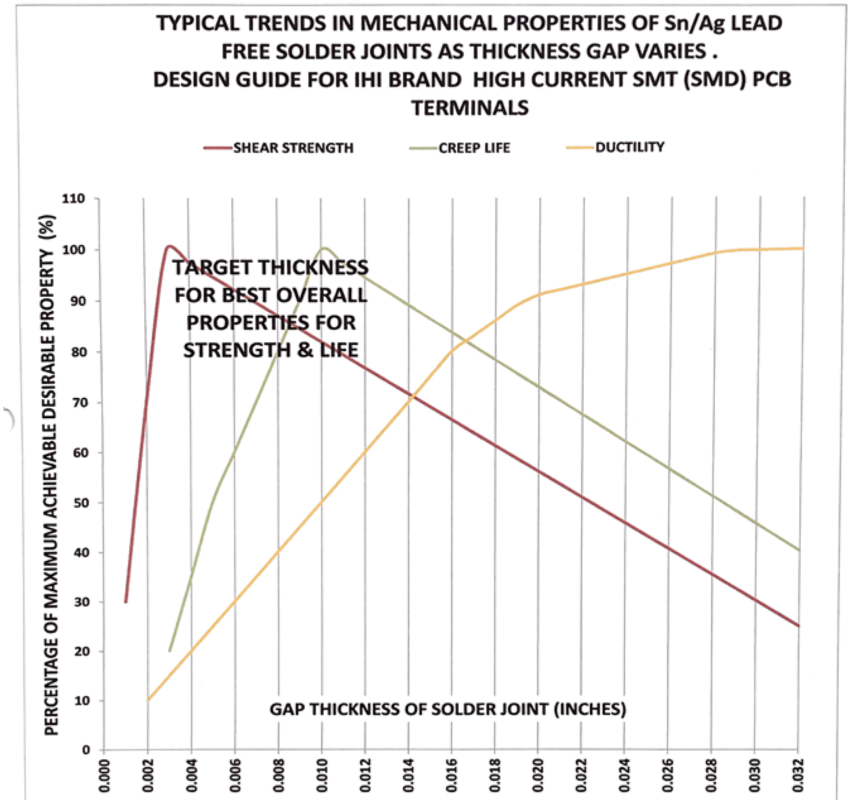


Figure 11. ***Optimum solder thickness for balancing strength and fatigue life of the soldered joint.***

https://lugsdirect.com/PDF%20Documents/Precautions-when-using-SMT.pdf

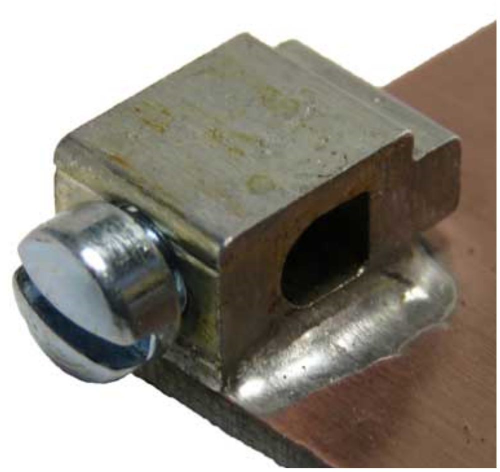


Figure 12. ***Shows a strong filet on the counterclockwise torque lateral edge line.***

Blooper alert, the Part in Figure 12 could be too close the edge of the PCB on the LHS. While there is a full filet both sides, the PCB foil could be the weakest link in “adhesive” thin film peeling mode which for PCB foil/FR4 is only 10 lbsf (pounds force) per inch of width using widely published numbers. After soldering, heat seasoning of adhesive copper foil / FR4 peel strength can be as low as 6-7 lbsf/inch. These things need to be settled in exhaustive testing in the particular end application after normal production processing.

Use of a hex socket screw can allow the part to move inboard having no large head to interfere or foul on the PCB.

Generally Agreed Peel Strength Numbers (1) (2) (3) (5)

FR4 and copper foils (epoxy adhesive)

Thin film peeling ……………………………..……. As made 1.5 N/mm, [10 lbsf/inch]

Thin film peeling ……………………………..……… After thermal stress of soldering 1-1.2 N/mm, [6-7 lbsf/inch

Solder (SnPbAg), nickel, and aluminum bonded surfaces

Thin film peeling ……………………………….. 5.7 N/mm, [32.6 lbf/inch] (5)

Solder and copper surfaces

Thin film peeling……………………………… 7 -8 N/mm, [40-45.7 lbsf/inch]

Thin film peeling ……………………………. 3.5-5.3 N/mm, [20-30 lbsf/inch

The thin film peeling mode is intrinsically weak.

It is also clear that inboard from the edges, the foil of PCB can act much stronger than its edge peeling mode.

Staying away of the outer edges of the PCB, is therefore wise.

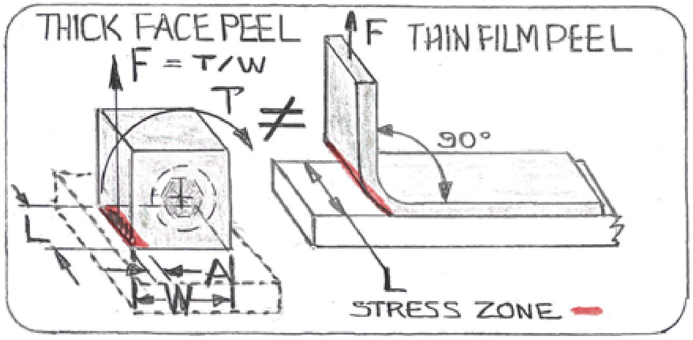
The low thin film peeling strength of plating is best accomplished by avoiding soldering connectors in the tearing – peeling orientation that generates tearing peeling stresses.

Avoid horizontal screw orientation or if used be ready to downrate the size of wire and so moderating the torque needed.

SMT connectors need to be 100% tested for adequate bonding strength since the number of variables are extensive and not all easily controlled.

Figure 13

Example calculations comparing some sample torque breakage numbers with those provided "thin film peeling" numbers from published sources.



THICK FACE PEELING Vs THIN FILM PEELING
Probable strength boost from tensile action of A*L
It is clear that while both modes share the same 90 degree tear off direction, the thicker blocky connector achieves much higher 'peel' strength numbers than is possible with thin films. Nevertheless the behavior of the thick face is somewhat bipolar with a very wide distribution curve. It is likely that the edge conditions along L and assisting zone A*L are subject to some of the same thin film peeling and crack propagation modes.

Tensile PSI <-- moderate estimate for solders
3000 lbsf/inch

B10-PCB EXAMPLE

In-lbsf	Inch	Inch	lbsf	F lbsf/inch L	Reference F lbsf/inch L	Reference F lbsf/inch L	L*A area assists Assumed A	Actual Breakage torque
T	W	L	F	P thick	P thin Sn/Ni/Al	P thin Cu/Sn	inches wide	Distribution typ Trend
5	0.34	0.39	14.7	38	33	42	0.013	
10	0.34	0.39	29.4	75	33	42	0.025	
15	0.34	0.39	44.1	113	33	42	0.038	
20	0.34	0.39	58.8	151	33	42	0.050	
25	0.34	0.39	73.5	189	33	42	0.063	
30	0.34	0.39	88.2	226	33	42	0.075	
35	0.34	0.39	102.9	264	33	42	0.088	
40	0.34	0.39	117.6	302	33	42	0.101	
50	0.34	0.39	147.1	377	33	42	0.126	

B6A-PCB EXAMPLE

In-lbsf	Inch	Inch	lbsf	F lbsf/inch L	F lbsf/inch L	F lbsf/inch L	Assumed A	Actual Breakage torque
T	W	L	F	P thick	P thin Sn/Ni/Al	P thin Cu/Sn	inches wide	Distribution typ Trend
5	0.34	0.42	14.7	35	33	42	0.012	
10	0.34	0.42	29.4	70	33	42	0.023	
15	0.34	0.42	44.1	105	33	42	0.035	
20	0.34	0.42	58.8	140	33	42	0.047	
30	0.34	0.42	88.2	210	33	42	0.070	
40	0.34	0.42	117.6	280	33	42	0.093	
50	0.34	0.42	147.1	350	33	42	0.117	
60	0.34	0.42	176.5	420	33	42	0.140	

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Supporting Test Data for SMT Vertical, SMT horizontal & THT Foot Mounted

The good news. In spite of challenges for SMT high current wire connectors, there is a strong test record. IHI has tested SMT connectors of the B4A-45 configuration with AWG 4 copper wire for <u>32,885</u> cycles current during 4 years between July 2015 and July 2019. The parts performed with no issues. The test was stopped to use the test equipment for other parts.

That is rather like doing the UL486 "500 cycle" stability test, <u>65 times in a row</u>, so quite the longevity test for SMT wire connection with a soldered face PCB attachment.

Testing was done with 30 minutes on, 30 minutes off, at 120-130 Amps. Both vertical screw and horizontal screw orientation were used. The parts are rated for 85A assuming a 75C CU7 NEC current rating.

.062" thick Double Sided FR4 with 3 Ounce/ Ft^2 copper with 8 square inches (roughly 2"x 4") of PCB per connector.

Results are expected to be similar for Sn/Pb Eutectic and SAC305 solders. Extensive Japanese studies showed these two solder types to have very similar mechanical and electrical properties, though SAC305 certainly takes much more heat input to achieve higher temperatures for proper wetting and has more contraction artifacts and surface finish frosting.

Typical heat rise was 40C-50C over ambient of 20C-25C for peak temperatures in the low seventies Celsius.

Free air cooled.

That is an impressive amount of elapsed time and cycles count and builds considerable confidence in these parts in SMT mode if working temperatures are moderate.

A similar test on the same THT monolithic PCB lug body, in "yin yang" pairs, with through wiring, foot to foot, using a simplified UL 500 cycle at 135A test has been running since July 2019 to current May 2022 so about <u>24,000</u> stable cycles or about 48 continuous "500 cycle" tests.

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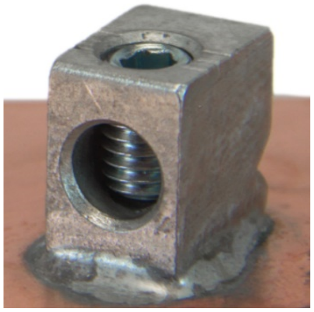
When using the horizontal screw tear off peeling SMT mode 100% inspection of production is required.

Generally, in vertical screw twisting mode SMT, much high torques are achievable and the tighter distribution curves can enable a customer choice to sample torque test each lot versus testing every part for a secure attachment if the statistics of that given application support that.

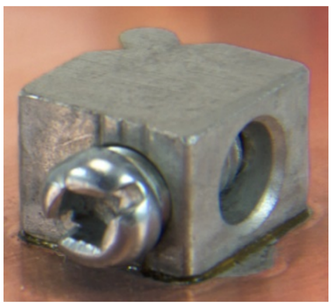


B6A-PCB-45(-HEX) SMT mode vertical screw axis AWG 6-14 65A 75C (0.34" wide)
B4A-PCB -45 SMT mode vertical screw axis AWG 4-14 85A 75C (.375" wide)

https://lugsdirect.com/B4A-PCB-45.html

https://lugsdirect.com/B6A-PCB-45.htm

For SMT connector for larger AWG 4, 6, 8 the IHI B6A-PCB-45 has shown itself to be sturdy both in the upright vertical axis SMT mode and in the horizontal SMT orientation where is gains significant area of contact on its side which improves the



B6A-PCB-45(-RS) SMT mode horizontal screw axis AWG 6-14 65A 75C (0.50" X 0.53" contact surface)
B4A-PCB -45 SMT mode horizontal screw axis AWG 4-14 85A 75C (0.50" X 0.53" contact surface)
https://lugsdirect.com/B4A-PCB-45.html

https://lugsdirect.com/B6A-PCB-45.htm

SMT parts screw torquing precautions

When torquing the wire binding screw to the proper amount for the size of wire, all SMT mounted versions must be protected against "prying" forces when driving the screw. Tearing detachment of the SMT soldered joint can occur due to its inherent weakness in some axes.

A universal jointed bit holder, universal joint coupling or universal "wobble" ended extension driver must always be used to apply pure rotational torque and no lateral prying torque moments.

SEE ALSO IHI GUIDE TO SMT COMPONENTS BEFORE USING SMT COMPONENTS IN DESIGNS

FOR FURTHER INFORMATION ON THE PROPER USE OF THIS PRODUCT IN SPECIFIC APPLICATIONS SEE

https://ihiconnectors.com/GuideToFlexFlexibleFineStrandedWireCableMechanicalLugsFAQ.html

https://ihiconnectors.com/Precautions-when-using-SMT.pdf

https://ihiconnectors.com/FAQ_SMT_SMD_High_CurrentPCB_Terminal_LugsSolderCreep.htm

https://ihiconnectors.com/NOTESonPCBFootPrintLayouts(SMT-SMD-Mode).pdf

https://ihiconnectors.com/High_Amp_Wide_Trace_PCB_Wire_Connection.html

https://ihiconnectors.com/Technical-Data-Installation.htm

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(5) Adhesion Improvement for Solder Interconnection of Wet Chemically Coated Aluminum Surfaces A. De Rose, et al