Superior Flux & Mfg. Co.

Direct Aluminum Soldering - IBSC 2018 Conference

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Outline

Introduction

Methods for Soldering to Aluminum

Heating for Soldering Aluminum

Cleaning Aluminum

Environmental Exposure

Strength of Soldered Joint

Conclusions

References

Introduction

- **Aluminum oxidizes with extreme rapidity; it is almost impossible to remove its ever-present oxide coating more rapidly than it reforms.**
- **Aluminum oxides are removed during soldering by aluminum cleaners and soldering fluxes.**

Introduction

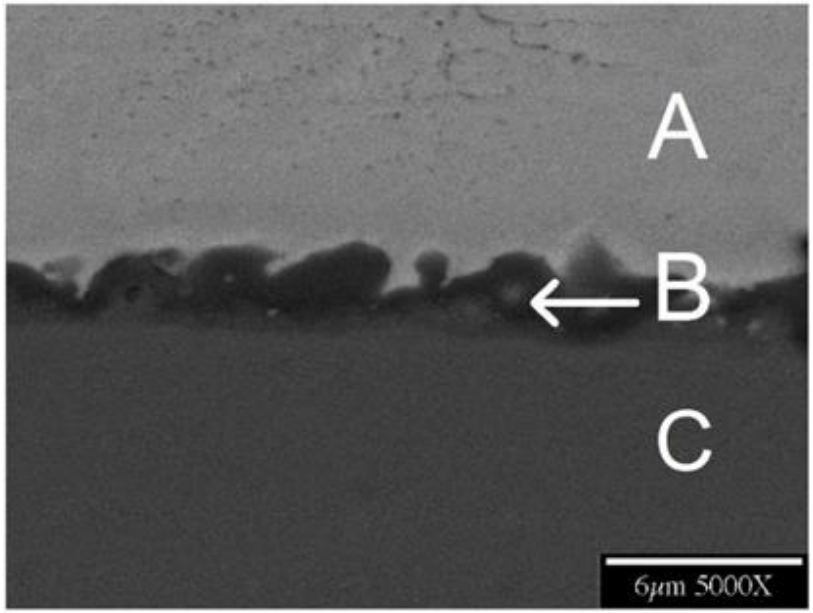
- Many elements are used to combine with aluminum to make different alloys.
- Silicon lowers the melting point and improves extrusion properties. Magnesium, zinc, and titanium are added to improve strength.
- The addition of these elements decreases the interaction with pure aluminum and can significantly reduce the solderability of those particular alloys, because of the inherent poor solderability of these elements.

Introduction

- In selecting a solder, the question is will it make a metallurgical bond with the aluminum?
- The common tin-based solders that have been found to properly bond to aluminum contain zinc, silver, and copper.
- Neither tin nor lead will alloy to aluminum as a solder, so a simple tin-lead solder should be avoided.
- The best solders include tin-silver, tin-copper-silver, tin-copper, and tin-bismuth-silver.

Introduction

- Properly soldering to aluminum means making an intermetallic bond between the solder alloy used and the aluminum surface.
- The intermetallic zone is a new compound that is neither solder nor aluminum



SEM photo of un-plated Aluminum Surface Soldered with 91/9 Tin-Zinc

Description:
A – 91/9 Tin-Zinc Solder
B – Zinc/Aluminum Intermetallic Zone
C – Aluminum Base Metal

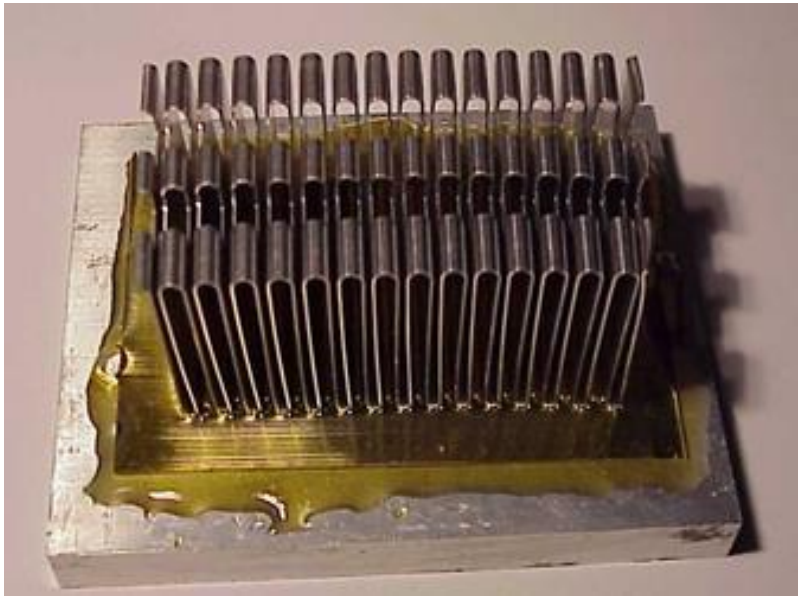
Methods for Soldering to Aluminum

Liquid flux and solder

- **Liquid flux - a mixture of organic amines and inorganic fluoroborate salts and typically has the consistency of honey, whose color may range from amber to deep brown.**
- **Other chemicals such as alcohols are sometimes added to modify the viscosity.**
- **Organic flux formulations are designed for temperatures of 177°C to 316°C / 350°F to 600°F.**

Methods for Soldering to Aluminum

Liquid flux and solder



Liquid flux applied to surface between two aluminum parts with a solder foil present.

After heating on a hot plate the solder has flowed and has connected the aluminum parts.

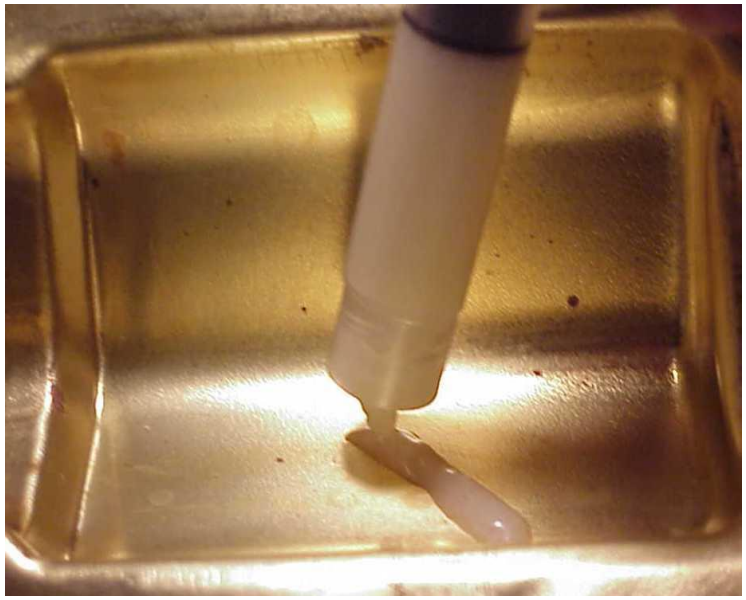
Methods for Soldering to Aluminum

Paste flux and solder

- **When chemical binders are added to the liquid flux, it transforms the state of the flux, making it a paste.**
- **The paste is readily dispensable by a needle, which allows for more accurate placement of the flux.**

Methods for Soldering to Aluminum

Paste flux and solder



Paste flux dispensed to metal surface.

Methods for Soldering to Aluminum

Flux-cored solder wire

- **When the organic flux formulation is further modified to have higher solids content it will be more viscous, instead of being liquid at room temperature.**
- **When this material is heated it will liquefy, which allows it to be injected into a solder core. Once the wire is cooled, the flux core becomes hard, which allows the wire to be used as a flux-cored solder wire.**

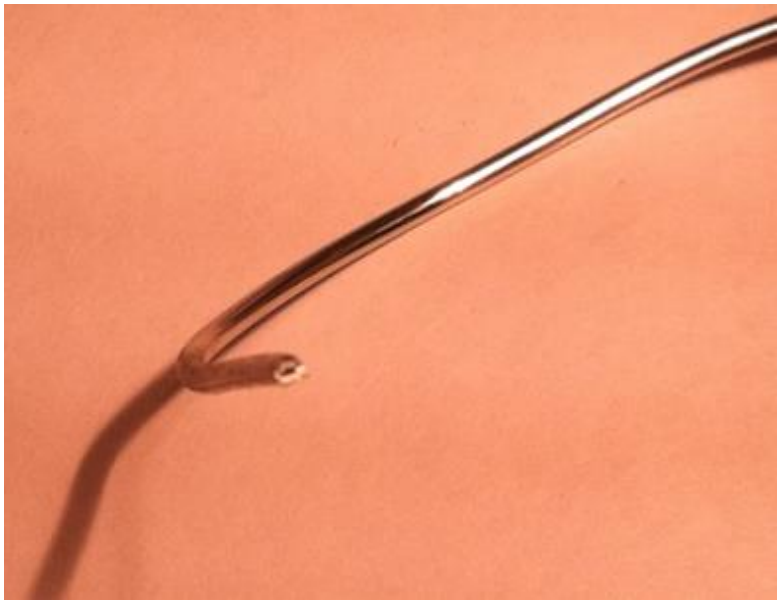
Methods for Soldering to Aluminum

Flux-cored solder wire

- **The chemistry of this modified flux solid is activated for soldering aluminum at the 280°C to 380°C / 536°F to 716°F.**
- **The flux-cored aluminum wire solder is different than typical flux-cored wire solder for copper, in that the aluminum itself must be heated to the activation temperature before melting the core wire solder on the hot surface.**

Methods for Soldering to Aluminum

Flux-cored solder wire



Wire solder with aluminum core flux in the center of wire.

Soldering aluminum to aluminum with wire solder containing core flux.

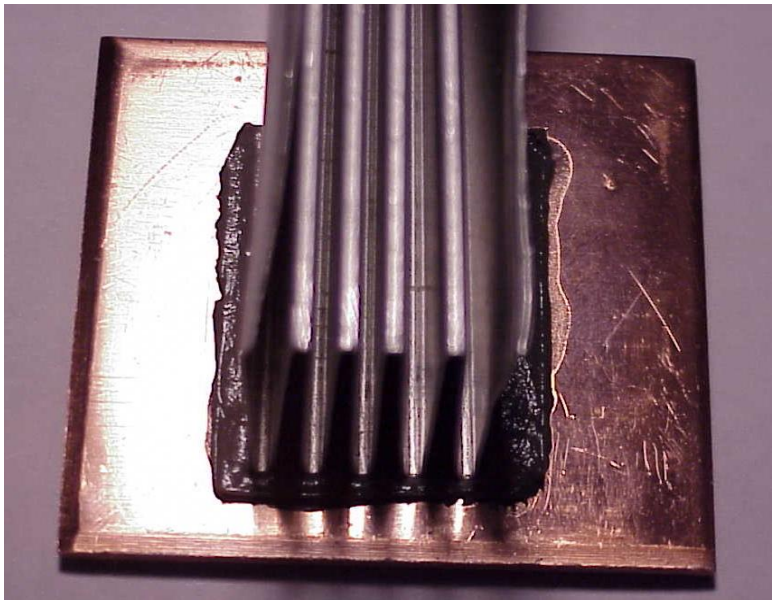
Methods for Soldering to Aluminum

Solderpaste

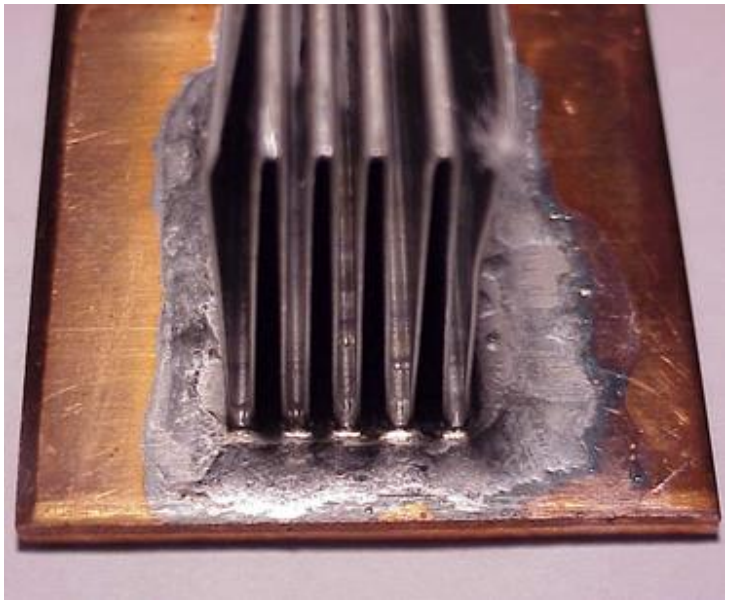
- **The organic type of aluminum flux can be converted to a solderpaste, by incorporating solder powder and binders. The same temperature limitations, 180°C to 316°C / 350°F to 600°F, apply to most versions of this solderpaste.**
- **A high-temperature solderpaste has been developed having activating temperatures in the range of 280°C to 380°C / 536°F to 716°F.**

Methods for Soldering to Aluminum

Solderpaste



Aluminum fin placed on solderpaste dispensed on copper.



After solder reflow fins are soldered to copper.

Heating for Soldering Aluminum

Hotplate

- **Can be thermostatically controlled electric devices, non-controlled electric units, and even metal plates set over gas jets.**
- **Parts to be soldered are cleaned, fluxed and positioned on the hotplate. The solder may be preplaced or face-fed.**
- **As heat is applied the solder melts and flows through the joints, then the part is removed from the hotplate.**

Heating for Soldering Aluminum

Convection Oven

- **Furnace soldering lends itself to both small-lot and high volume production.**
- **Parts too large or massive to be evenly heated by other means may be soldered with minimum distortion in a furnace.**
- **A furnace is also useful for soldering complex and intricate parts with joints that cannot be easily heated after assembly by other techniques.**

Heating for Soldering Aluminum

Convection Oven

- **Solder reflow via conveyor belt oven is a proven and widely used procedure for consistent reliable soldering.**
- **Furnace soldering is excellent for long solder joints, producing highly controlled solder fillets, neater joints and more efficient use of solder.**

Heating for Soldering Aluminum

Induction

- **Joints are soldered by bringing the metal to solder reflow temperatures by high-frequency electrical current induced heating of the soldering parts.**
- **Heating is localized, fast and generally accomplished in a few seconds.**
- **Soldering by induction is an extremely accurate and repeatable operation, which can be automated.**

Heating for Soldering Aluminum

Resistance

- **Heat is created by passing a current through the metal being heated.**
- **An intense heat can be rapidly developed directly within the joint area and in a tightly controlled manner which minimize the potential for thermal damage to materials.**
- **This makes resistance soldering comparable to flame soldering in some situations but without warming a wider area.**

Heating for Soldering Aluminum

Torch

- **It is low in cost, portable, and suited to production work as well as single assemblies and repairs.**
- **Its flame is hot enough to be used readily with all solders, and its output can be varied to accommodate small and large assemblies..**
- **Will ignite chemicals used to make low-temp fluxes, solder pastes, and cored-wire solder; torch heat should be used only to heat these metal surfaces.**

Heating for Soldering Aluminum

Soldering Iron

- **May be heated electrically or by a gas flame. However, the weight of the "copper head" and its temperature is most important.**
- **It must be large enough and hot enough to bring the joint and much of the adjoining metal up to soldering temperature in a fairly short time.**
- **Generally, are used only with low temperature soft solders and on relatively low mass materials.**

Cleaning Aluminum

Aggressive Cleaners

- **These can be either caustic or strong acid solutions.**
- **Cleaning in theses systems is always followed by multiple water rinses to stop the activity of the strong cleaner on the aluminum.**
- **Such cleaning solutions are dangerous to handle and the raw chemicals used to make them are extremely hazardous.**

Cleaning Aluminum

Hot Water

- **This method is used with the chemistry of the organic “honey” flux.**
- **If the parts are immediately washed in hot water, the flux can generally be removed.**
- **However, the use of hot water will not effectively remove this type of flux residue if the residues are not immediately removed after soldering.**

Cleaning Aluminum

Non-hazardous cleaners

- **A new chemical cleaner has been developed, using citric acid chemistry, that is not like the strongly corrosive and hazardous cleaners**
- **This which works well on the organic "honey" type of soldering chemistry.**
- **This cleaner is nonhazardous and can be handled with much greater ease than the dangerous caustic or acidic cleaners and is safer to the environment.**

Cleaning Aluminum

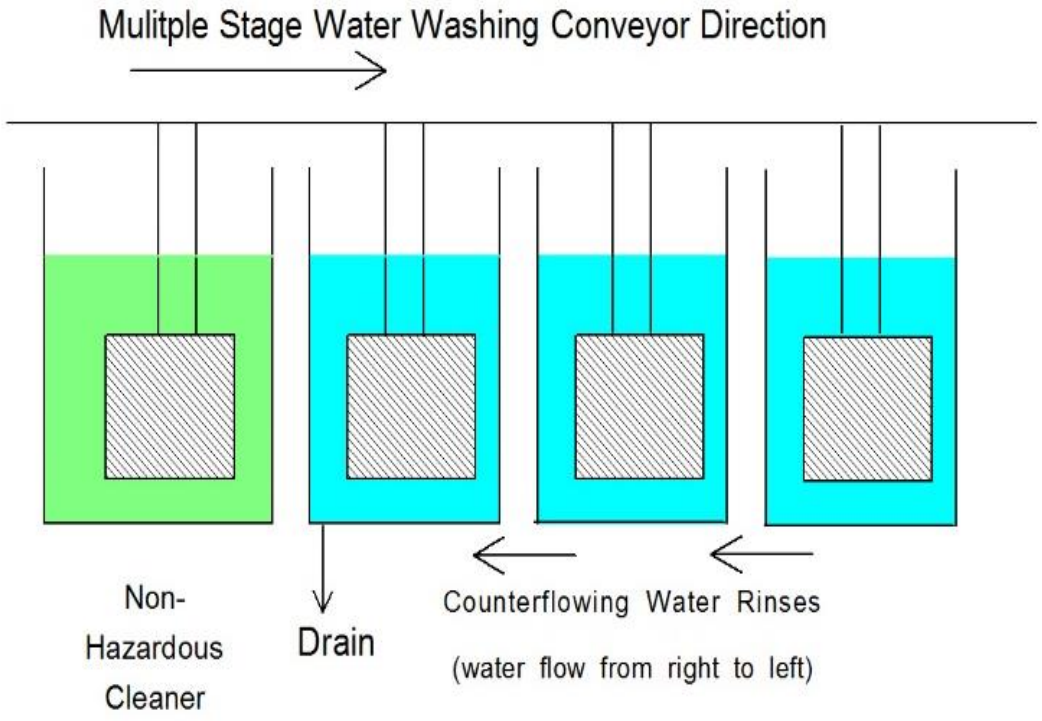
Non-hazardous cleaners

Nonhazardous cleaner removing oxides from aluminum.

The formation of small bubbles shows the reaction occurring.

Cleaning Aluminum

Non-hazardous cleaners



Cleaning schematic for multiple stage nonhazardous cleaner with counter-flowing water rinses to make the last tank of water as clean as possible.

Environmental Exposure

Exposure to Moisture

- **A major consideration in making any aluminum soldered connection is: “how viable is it”?**
- **Making a connection where the solder has appeared to flow on the aluminum is not sufficient to prove that the connection is truly sound.**
- **This may occur if proper conditions needed to make a viable solder joint have not been met.**

Environmental Exposure

Exposure to Moisture

- **If the wrong solder is used (no element availble to create the intermetallic bond to the aluminum) there will be no true soldered connection.**
- **If insufficient heat is used to create the joint, a cold joint will occur.**
- **Only a connection with a true intermetallic bond will survive the week-long humidity test (80-95% humidity at 40ºC / 104ºF).**

Environmental Exposure

Exposure to Salt

- **A major consideration for automotive and marine applications is the ability for soldered aluminum connection to withstand exposure to a salt environment.**
- **While not an issue for brazed connections, all tin-based conventional soft solder alloys used to solder aluminum failed to withstand long exposure to 2-10% salt solutions (one to three weeks' immersion at room temperature).**

Environmental Exposure

Exposure to Salt

- **Some of the proposed exotic protection schemes to prevent salt exposure such as coating the part after soldering or pre-tinning the aluminum before soldering, were either not practical and did not always protect the aluminum soldered connection.**

Environmental Exposure

Exposure to Salt

- **A new solder alloy, ALUSAC-35, based on tin-silver-copper, but having other proprietary elements added has proven that it can withstand the difficult room-temperature immersion test.**
- **Indeed, the ALUSAC-35 alloy also withstands the ASTM B117-16 salt fog test (the automotive industry elevated temperature salt environment test).**

Environmental Exposure

Exposure to Salt

- **The ASTM B117-16 test is done in an enclosed chamber with a solution of 2-10% salt water that is heated to 40ºC / 104ºF and is sprayed constantly on the soldered parts in the chamber for 24, 48, or 96 hours.**
- **The requirement is that the solder joint does not break apart under these conditions.**
- **The ALUSAC-35 alloy has a relatively high liquidus temperature; 341ºC / 646ºF.**

Strength of Soldered Joint

Simple Lap Joint Strength Testing

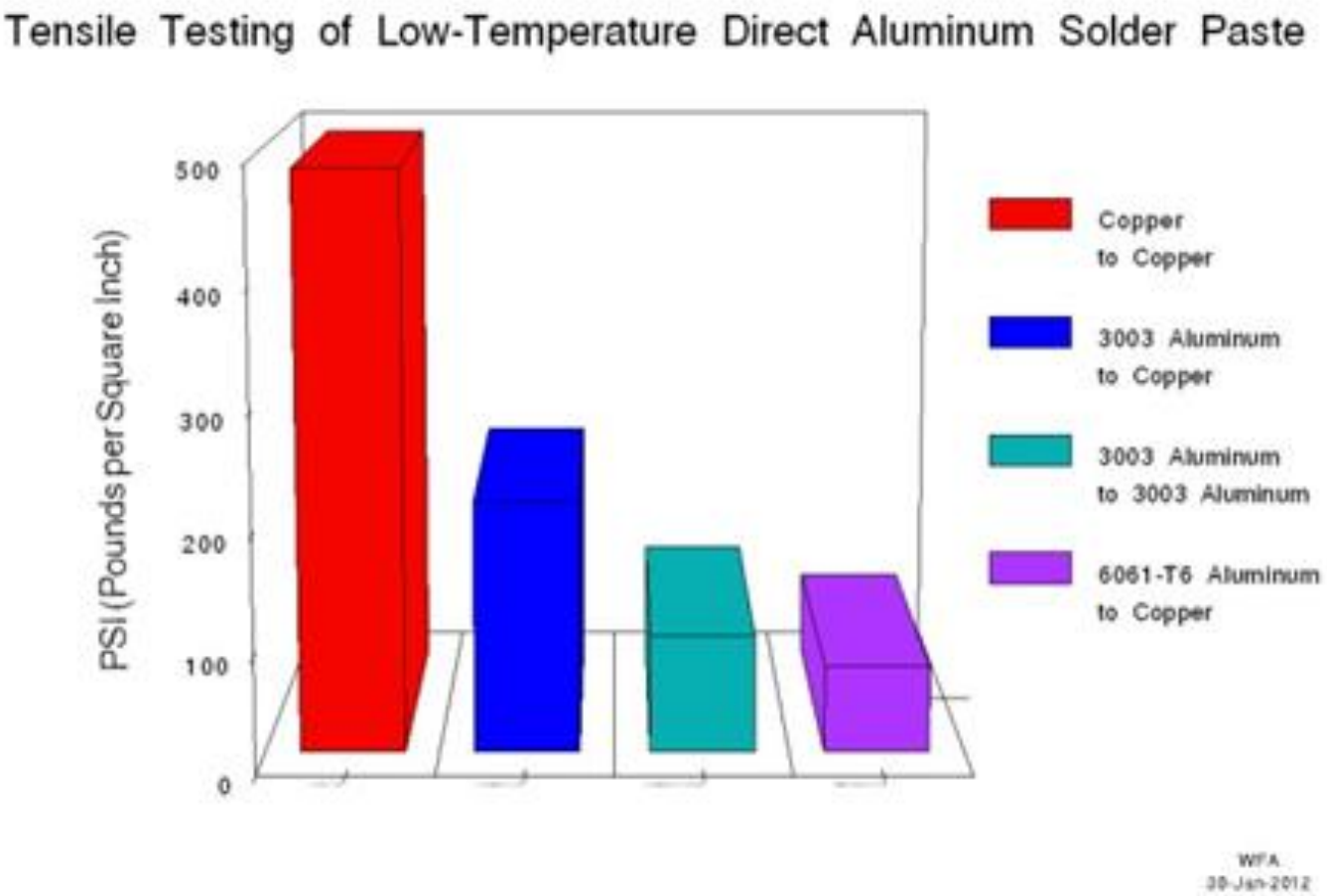
Copper to Copper Lap Joint

Aluminum to Aluminum Lap Joint

Copper to Aluminum Lap Joint

Strength of Soldered Joint

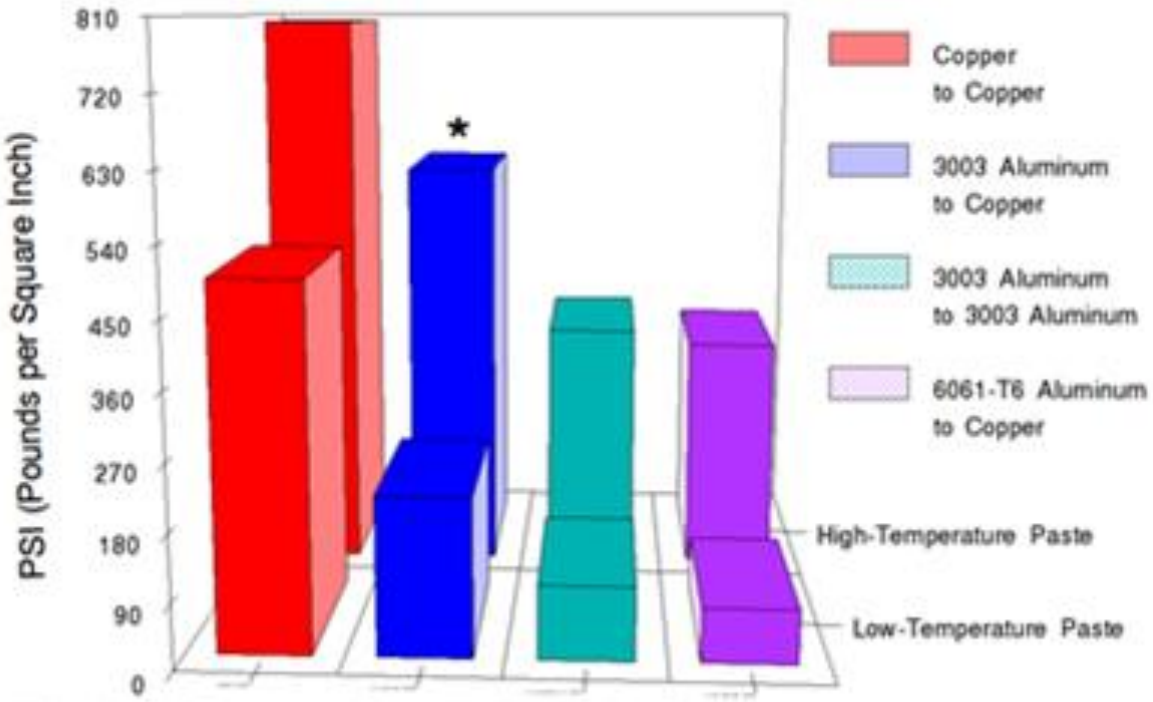
Simple Lap Joint Strength Testing



Strength of Soldered Joint

Simple Lap Joint Strength Testing

Tensile Testing of Low-Temperature Direct Aluminum Solder Paste
Compared to High-Temperature Direct Aluminum Soldering Paste



*With the High-Temperature Direct Aluminum Solder Paste
the 3003 Aluminum Broke Before the Solder Bond

WFA
29-Feb-2012

Strength of Soldered Joint

Aluminum to Copper

- **The copper to copper solder bond is stronger than any of the combinations. Not surprising, considering how easy copper is to solder and it's easy ability to make an intermetallic bond.**
- **With copper to aluminum this tends not to be as strong as copper to copper.**
- **When the tensile test is done, many times the break in the connection is actually in the body of the aluminum, not in the solder bond.**

Strength of Soldered Joint

Aluminum to Aluminum

- **This is always the weakest connection if all factors are equal.**
- **Aluminum is harder to solder than copper and two aluminum parts being soldered represents the hardest test.**
- **On the charts, alloy 3003 aluminum to copper is much stronger than 3003 aluminum to 3003 aluminum.**

Strength of Soldered Joint

Effect of Aluminum Alloy on Final Joint Strength

- **The aluminum alloy chosen is an extremely important factor in how strong a given soldered connection will be.**
- **3003 aluminum to copper bond is much stronger than the 6061 aluminum to copper bond.**
- **As a matter of fact, the 6061 aluminum to copper bond is slightly weaker than the 3003 aluminum to 3003 aluminum bond.**

Strength of Soldered Joint

Effect of Soldering Method on Final Joint Strength

- **By soldering technique, there is a difference in what chemistry is used, what solder alloy is used, and the soldering temperature employed.**
- **This shows the comparison of a low-temp direct aluminum solder paste to a high-temperature direct aluminum solder paste; different flux chemistry and solder alloy.**
- **These differences have a great effect on the strength of the solder bond achieved.**

Conclusions

- **Direct aluminum soldering eliminates the need to plate the aluminum before soldering.**
- **When soft soldering aluminum, it is important to consider the challenges of the tenacious aluminum oxide layer, the differences in aluminum alloys, and choosing the right solder alloy to properly bond to aluminum.**

Conclusions

- There are different techniques now available to soft solder aluminum, including liquid flux and solder, paste flux and solder, solder paste, and cored-wire solder.
- Similarly, there are many heating methods that will work on soldering aluminum.

Conclusions

- Once the soldering is completed, there are relatively simple and nonhazardous cleaning methods for removing flux residues.
- Soldered aluminum connections need to be evaluated for being truly complete after exposure to moisture.

Conclusions

- If an intermetallic bond has not been made between the solder and the aluminum, exposure to moisture will break the solder bond.
- Another major consideration is the relative strength of the soldered connection, especially compared to the copper to copper bond.

Conclusions

- **The copper to aluminum bond is stronger than aluminum to aluminum bond.**
- **The aluminum alloy used is a controlling factor in the ultimate strength of these connections.**
- **Finally, a new specialty solder, ALUSAC-35, has been developed that is capable of withstanding the ASTM B117-16 salt fog test.**

References

- Aluminum Soldering Handbook, 6th Edition, February 2017, The Aluminum Association, Edited by William Avery and Dr. Yehuda Baskin
- Haruka Nishino and Takuro Fukami, “An Innovative Approach to Soldering Aluminum with ALUSAC-35”, U.S. Tech, September 2017
- ASTM B117-16 “Standard Practice for Operating Salt Spray (Fog) Apparatus”, ASTM International
- William F. Avery, “Low-Temperature Direct Aluminum Soldering Paste”, IMAPS - 8th International Conference and Exhibition on Device Packaging, March 2012

End of Presentation

Thank you

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