Joining Dissimilar Materials

Today's cutting edge devices often require a variety of materials to achieve optimal performance in operation. Systems and components are engineered utilizing the unique properties of multiple materials to meet end-product requirements. However challenges arise when components of differing materials must be joined. Unique material properties translate into dissimilar and sometimes incompatible behavior during the joining process, creating a need for specific bonding process solutions.

S-Bond Technologies has developed targeted joining solutions for the bonding of dissimilar materials. Patented S-Bond active solder alloys join a wide variety of materials, including aluminum, copper, stainless steel and refractory metals. S-Bond alloys also successfully bond metals to ceramics, such as aluminum oxide, aluminum nitride, and silicon carbide as well as other oxides, nitrides and carbides.

The Issue of Coefficient of Thermal Expansion (CTE) Mismatch

While S-Bond joining makes it possible to bond a wide range of materials, there are many variables that directly impact the ability to join components of dissimilar materials. The solution begins with compatible chemistry between the base materials and the filler metal, but it does not end there. The success of the bonding operation is also dependent on the size and geometry of the assembly.

This assertion is based solely on the mismatch in the Coefficient of Thermal Expansion (CTE) of the materials being joined. Materials expand at different rates depending on their composition (atomic elements), structure (atomic arrangement) and thermal properties. A material's volume will change based on the relationship between these factors. When derived to any linear dimension, the relationship of the increase of length per unit length per °C or °F can be established and expressed as the linear expansion relation below.

$$\alpha_V = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_p \quad \frac{\Delta L}{L} = \alpha_L \Delta T$$

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A table reflecting the CTE's of many common metals, ceramics and glasses is shown at right. As indicated in the table, material expansion rates vary widely. For example, with a linear CTE of 23 x 10^{-6} / °C, aluminum is one of the most expanding metals when heated. Alternatively, SiC, quartz and tungsten will each experience only very minimal expansion when heated.

When dissimilar materials must be bonded, this difference in expansion rates becomes a major design consideration. Many errors or miscalculations can occur when material volume changes at elevated bonding temperatures differ significantly within an assembly, that is when there is a large CTE mismatch.

Material	Linear coefficient, α, at 20 °C (10^{-6}/°C)
Aluminum	23
Brass	19
Carbon steel	10.8
Copper	17
Diamond	1
Glass	8.5
Glass, borosilicate	3.3
Gold	14
Invar	1.2
Iron	11.1
Lead	29
MACOR	9.3
Magnesium	26
Molybdenum	4.8
Nickel	13
Platinum	9
Quartz (fused)	0.59
Sapphire	5.3
Silicon Carbide	2.77
Silicon	3
Silver	18
Stainless steel	17.3
Tungsten	4.5

A Case in Point – Aluminum Bonding

To illustrate, consider applications which specify aluminum components bonded to components of another metal or ceramic. During the soldering or brazing operation, the components must be heated to a bonding temperature in the range of 200°C – 550°C. The aluminum components will experience a much greater expansion at bonding temperature than the other components, and thus a much greater contraction upon cooling. If not accounted for in the design of the assembly, failure will result.

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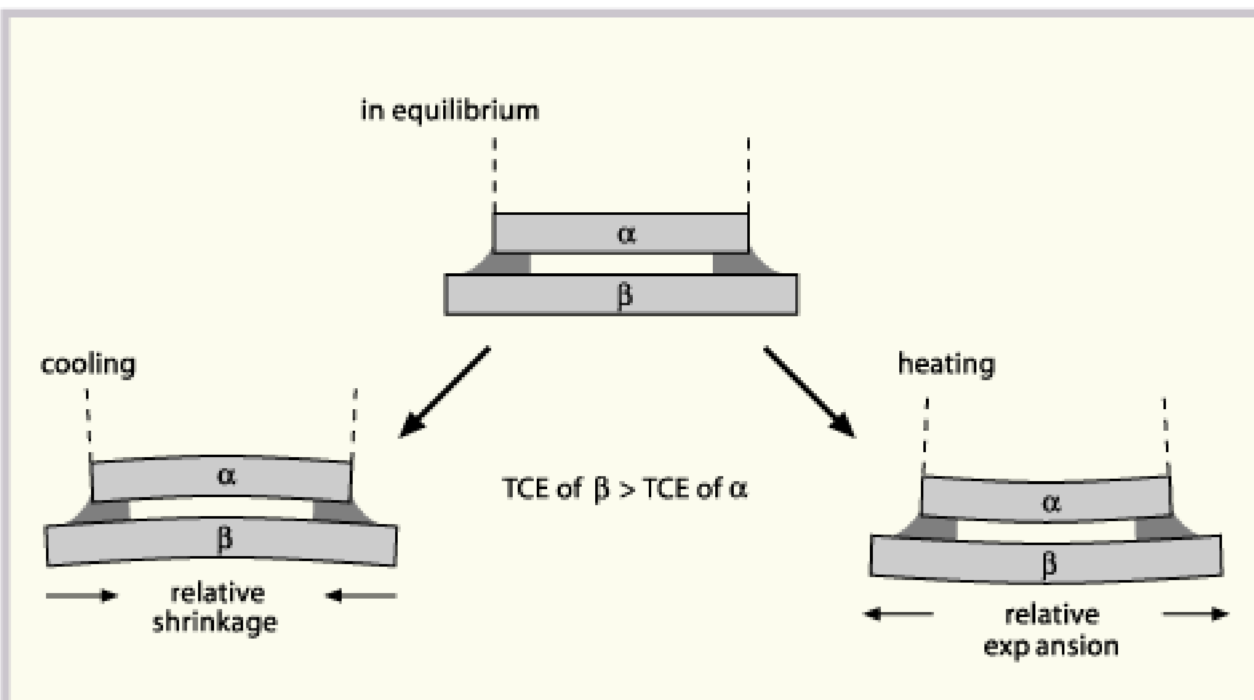
For example, when joining a 12” plate of aluminum to a 12” plate of carbon steel with S-Bond 220 active solder, the component parts require heating to 250 °C. Referring to the CTE values in the table above, the 12” plate of Al with a CTE of 23 ppm will grow by almost 0.060”. The 12” plate of steel, with a CTE of 10.8 ppm, will only grow by about half of that amount. Upon cooling, the aluminum will try to return to length, contracting 0.060”, while the steel will only contract by about 0.030”. This creates a strain difference and will result in the bending of the plates as seen in the figures below. If the accumulation of stress from the strain mismatch is great enough, fracture will initiate at the edges of the S-Bond solder joint where the stresses exceeded the tensile strength of the S-Bond.Furthermore, if a ceramic plate was used in place of the steel plate, the strain difference between the aluminum and ceramic upon cooling will deflect the ceramic plate enough to fracture it, if the design permits.



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Accommodating CTE Mismatch for Bonding Success

A distinct advantage offered by S-Bond joining is low process temperature. S-Bond is a soldering process, and as such, bonds at a lower temperature than brazing processes, which require heating assemblies to over 700°C. Lower bonding temperatures mean less thermal expansion during bonding.

Additionally, CTE mismatch in assembly designs can be addressed by some of the following techniques.

- Specifying materials with better matched CTEs (e.g. ceramic to Kovar®).

- Bonding components in multiple layers over a distance to accommodate CTE.

- Bonding smaller areas or components, or making a mosaic, breaking the larger CTE materials into smaller pieces.

- Stiffening a design to resist bowing - although joint fracture may still occur.

- Using lower temperature joining processes, such as exothermic materials that only heat the joint areas. A recent commercially developed nanofoil has been developed and can reheat and solder joints via a patented NanoBond® process.

To Learn More

S-Bond Technologies has been developing breakthrough materials and joining solutions for more than two decades. To learn more about joining dissimilar materials with S-Bond, go to www.S-Bond.com and explore our comprehensive knowledge base of application notes, white papers and videos prepared by our own engineers and materials professionals. You may contact us over the internet or directly at (215)631-7114.

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