Ultrasonic Consolidation Applied to Spacecraft Structures

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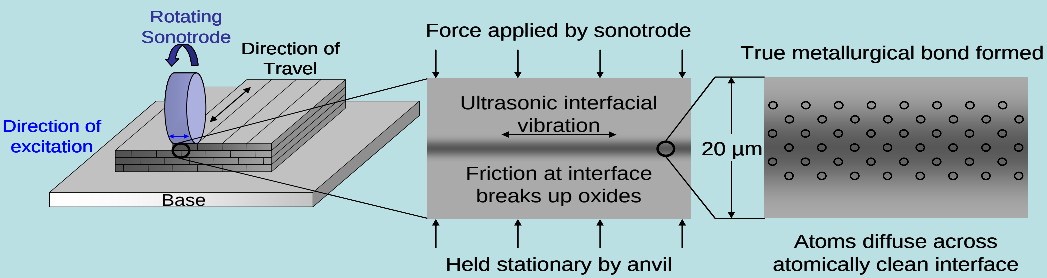
Ultrasonic Consolidation (UC)

Description of process

Ultrasonic Consolidation is a process that incorporates both additive and subtractive manufacturing techniques. The process welds a thin material to a support by running a sonotrode over the thin material while applying a force, rolling in one direction, and vibrating the sonotrode perpendicular to the roller motion at a specified frequency. This differential vibration causes plastic deformation at the interface, breaks up surface oxides and creates a true metallurgical bond. This is done layer by layer to produce parts in an additive manner. A CNC mill is also situated so that it can remove excess material to create the desired geometry, including internal features such as pockets, ribs, channels and embedded electronics.



Benefits of UC

- Internal Channels (Cooling Channels & Heat Pipes)
- Internal Support Structures (Honeycomb or Ribs)
- Built at Low Temperature (Room Temp to 300°F)
- Built Directly from CAD (Digital Reconfiguration)
- Embedded Components (Electronics, Wiring)
- Fiber Embedding (Metal Matrix Composites)

Additional Materials

Materials Capable of Being Ultrasonically Joined

(O'Brien, R.L., Welding Processes, Welding Handbook, Vol. 2, 8th Edition, American Welding Society, Miami, 783-812, 1991)

	Al	Be	Cu	Ge	Au	Fe	Mg	Mo	Ni	Pd	Pt	Si	Ag	Ta	Sn	Ti	W	Zr
Al Alloys	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Be Alloys		●	●			●										●		
Cu Alloys			●		●	●	●	●	●	●	●		●	●		●	●	●
Ge					●						●							
Au					●	●			●	●	●	●	●			●	●	●
Fe Alloys						●			●	●	●		●	●		●	●	●
Mg Alloys							●						●			●		
Mo alloys								●	●		●			●		●	●	●
Ni Alloys									●	●	●			●		●	●	
Pd										●			●	●				
Pt Alloys											●	●		●		●	●	
Si													●	●				
Ag Alloys													●	●				●
Ta Alloys														●		●	●	
Sn															●			
Ti Alloys																●	●	
W Alloys																	●	
Zr Alloys																		●

Materials Successfully Bonded to Al 3003 at USU

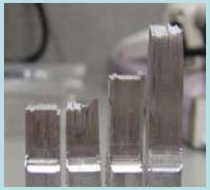
1. SST-(316, 347, & mesh)
2. Copper
3. Brass
4. Nickel –(201& 600)
5. AL 2024 T3
6. Metpreg® (pure Al with aluminum oxide fibers)

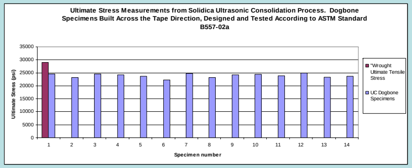
Properties of Al 3003 test specimens

Results from Tensile Test Specimen

(test samples built perpendicular to tape direction – low strength direction)

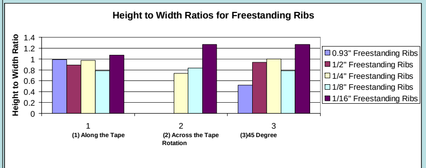
- Ultimate Tensile Strength averaged 24 ksi (165 MPa)
- Modulus of Elasticity as high as 54 ksi (37 GPa)





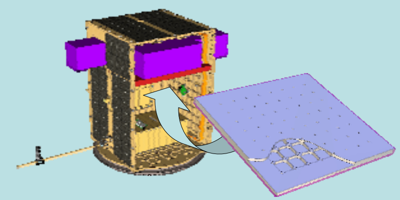
Machine Capabilities on Freestanding Structures

Maximum Height to Width Ratio approximately **1:1**



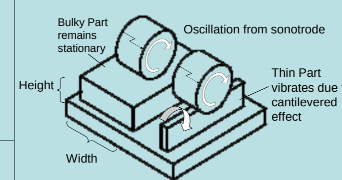
Structural Capabilities

Why Build a Structure Using Ultrasonic Consolidation?

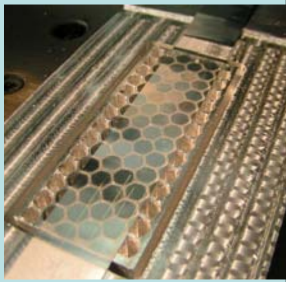


Since ultrasonic consolidation is an additive manufacturing technique, internal features such as honeycomb can be fabricated to yield a stiff and lightweight structure. During the build, a reinforced bolt pattern, wiring, sensors, thermal regulators, and other components can be embedded. Thus, a multifunctional panel is supported by an ultrasonically consolidated structure. The modular panels can then be assembled into a fully functional satellite.

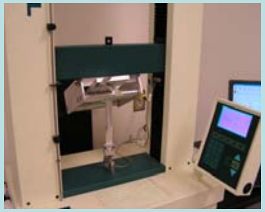
Can a Honeycomb-like Sandwich Structure be Built Using Ultrasonic Consolidation?



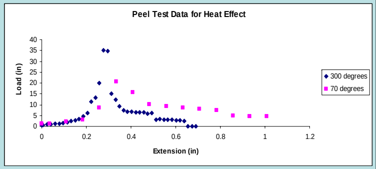
Ultrasonic consolidation presents many technical challenges for effective fabrication of light and stiff structures. For example, it is difficult to achieve a good bond when laying a tape on tall and thin ribs. A cantilever effects allows the ribs to vibrate. This impedes the differential vibration necessary to break up oxides on the surface of the tape and can create a very poor bond between aluminum layers. There are two ways to remedy this phenomena. The first is to design the rib configuration such that they are very stiff relative to the direction of oscillation from the sonotrode. The hexagon frequently used in honeycomb panels provides a rigid platform when rotated such that no rib section is parallel with the sonotrode rolling direction. The second method to achieve a better bond is to use a support material during ultrasonic consolidation. The support material prevents the ribs from vibrating and can be removed after the part is finished. Testing has shown that support material has a profound impact on the strength of the metallurgical bond.

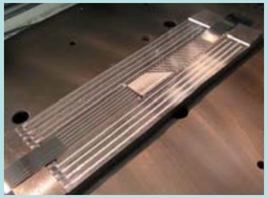


Developmental Testing



A peel test apparatus was constructed as a comparison method for different structural configurations. The Standard Test Method for Floating Roller Peel Resistance of Adhesives ASTM D3167-03a was followed. One effect studied was build temperature, which was investigated by peeling specimens which were consolidated at room temperature and 300° F. The results show that temperature has a profound effect on the bond strength. In the experiments with 3003 aluminum alloy, the 300° F specimens bonded almost twice as well as the room temperature specimens.





Thin rib tests were performed to determine the weldability of face materials to a rib pattern. These ribs were milled into a solid support plate rather than built up using UC. Ribs were milled at 0 and 45 degree orientations. The peel test was performed once a tape had been consolidated to the top and the results showed that a 45 degree orientation improves the bond strength.