Trends in Joining of Aerospace Materials

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Outline of Presentation

✓ Why joining / welding ?
✓ What drives the selection of aerospace materials ?
✓ Why joining is difficult in aerospace materials ?
✓ What are the emerging joining technologies ?
✓ What appears to be the roadmap?
"Today, we can join/weld anything but a broken heart"
How Many Great Engineering Achievements of the 20th Century required Welding / Joining?

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Welding is indeed important for the Scientists and Engineers.
Better Understanding of Welding Science and Technology is key to National Growth.

- Critical enabling technologies in US manufacturing, construction and mining industries have resulted revenues of $3.1 trillion in FY2000 or 33% of US GDP.
- Welding related expenditures were more than $34.1 billion in FY2000 in the US.
- American Welding Science (AWS) meetings are attended by >50,000 delegates and majority of them are high school, undergraduate and postgraduate students.
- Weld Defects $\Rightarrow$ Catastrophic Failure $\Rightarrow$ loss of property and human life.

Ref.: American Welding Society (AWS)
Challenges for Aerospace Materials

Needs to be Larger

Airbus A380 > 850 seats

Boeing 787 > 15000 km

Requires to be Lighter
A Designer’s Approach to Choose Materials for Aerospace Parts/Components

Wing Span

Needs larger stiffness, $E$

Requires greater strength, $\sigma_y$

Needs higher toughness, $K_{1C}$

Needs to be lighter, $\rho$
Dominant Aerospace Materials

Nearly 70% of modern civilian aircraft structures is of aluminium alloys followed by titanium due to excellent strength to weight ratio and corrosion resistance.
Dominant Aerospace Materials

Different variants of electric arc welding facilitate more than 70% of the demand from the fabrication industries.

Out of several arc welding processes, gas tungsten arc welding (GTAW) process is used in aerospace as GTAW is suitable for aluminium alloys, can provide clean weld, and good weld aspect ratio (penetration to width).
Weld Pool in Fusion Arc Welding

Typical Weld Pools undergo strong convective current, high peak temperature and rapid thermal gradient.

The molten weld pool usually exhibits large width, small aspect ratio (penetration depth to width), and large heat affected zone.

Ref.: http://www2.matse.psu.edu/modeling/
Welds made with high intensity beams are characterized with exceptionally high rate of solidification and cooling.

Ref.: http://www2.matse.psu.edu/modeling/
Porosity in Aluminum Welds is the Major Challenge.

Aluminum exhibits 20% greater solubility of H2 in liquid state leading to gas entrapment and porosity in solidified weld.
High Distortion and Cracks are other Problems

- high coefficient of thermal expansion and volume shrinkage during solidification result in severely distorted weld joints or cracks during solidification.
Welding of Titanium Alloys is also challenging.

- Titanium starts reacting with O2, N2 and H2 above 260 C. The molten weld pool must be protected from atmospheric contamination till it cools below 470 C.

Welds contaminated with O2 are very brittle and hard. Usually, welding is carried out inside a chamber.
Friction Stir Welding – A Solid State Joining

Typical Tool Profiles

Weld Joint Profile
Many Problems of Fusion Welding are avoidable

Since workpiece does not melt, problems such as porosity, solidification cracks and thermal distortion are non-existent.

The harder the workpiece material, the stronger has to be the tool material.
Since the weld zone is contained inside, one route to realize the material flow in FSW process is via extensive computer simulations.

Phenomenological models can show how the weld will evolve as function of tool geometry, tool rotational speed, and welding speed.

Ref.: http://www2.matse.psu.edu/modeling/
Challenges of FSW Process – Bad Material Flow.

It is extremely important to identify appropriate combinations of tool geometry, tool rotational speed and welding speed to ensure proper material flow.

Challenges of FSW Process – Tool Failure

Because the tool experiences severe atmosphere of stress and temperature, commercial use of FSW for hard alloys still remains elusive.

Ref.: Arora et al., IJAMT, 2012
Fusion welding of Nickel based superalloys and Titanium alloys are difficult due to their high melting temperature and high reactivity at high temperature.

Friction Welding is by far the most efficient method for joining these materials in critical applications.
Laser Beam Welding of Al- and Ti-alloys is another attractive alternative

- The Laser Beam, produced by a solid state laser (YAG- Yttrium Aluminum Garnet Crystal) or a gas (CO2) laser, is focussed and directed through optical lens to achieve high power density.
- Laser Beam Welding can produce deep and narrow weld with minimum heat affected zone and distortion of final weld joint.
Laser Beam Welded Large Panel for Fuselage

Riveted Structure

- STRINGER PROFILE
- VARNISH (Primer and Top Coat)
- EDGE SEALING
- SURFACE SEALING
- SKIN SHEET

vis-à-vis

Laser Welded Integral Structure

- Welded
  (T-joint, Sheet/Stringer)
- Extruded
- T-joint
  (Clip/Sheet)
- Butt joint
  (Sheet/Sheet)

Laser Beam Welded Large Panel for Fuselage

Simultaneous welding from both sides minimize distortion in large spherical or cylindrical panels used for fuselage structure.

Electron Beam Welding in Aerospace

- Welding in a vacuum ensures no gas contamination.
- Provides deepest penetration irrespective of type of material or surface conditions.
- Proven track record and widely accepted for critical aerospace materials.

Ref.: www.ptreb.com
Electron Beam Welding in Aerospace

Critical aerospace components such as spiral bevel gear, and compressor rotors rotate at very high speeds under high loads and thus, need totally defect free welds. Electron beam welding is the only approved joining process.

Ref.: www.ptreb.com
Diffusion Bonding of Dissimilar Materials

A diffusion bond is formed between tangent surfaces when enough atoms or molecules migrate across the interfaces between them to create new metallurgical grains bridging the gap.

Usually, the process occurs at elevated pressure or temperature or a suitable combination of both.

The most suitable process for joining of materials of widely varying melting temperature (e.g. Ti and Steel).
FSW Everywhere

Super Liner Ogasawara
Ford GT
Falcon 9 Rocket
British Rail
Copper canister for nuclear waste.

http://en.wikipedia.org/wiki/Friction_stir_welding
FSW in Aerospace

- **Boeing**
  - Delta II and Delta IV expendable launch vehicles in 1999.
  - Space Shuttle external tank, for Ares I and for the Orion Crew Vehicle as well as Falcon 1 and Falcon 9 rockets at SpaceX.
  - C-17 Globemaster III and 747 Large Cargo Freighter

- **Eclipse Aviation**
  - Wings and fuselage panels of the Eclipse 500 – supplied 259 friction stir welded business jets.

- **Airbus**
  - Floor panels for A400M military aircraft

- **Embraer**
  - In Legacy 450 and 500 Jets

http://en.wikipedia.org/wiki/Friction_stir_welding
Possible Roadmap

- Friction Stir Welding (FSW) will be the key joining technology for aluminum and titanium alloys in aerospace fuselage structure. Currently, FSW is used more as a technology – a science based understanding is yet lacking.

- Laser Beam Welding (LBW) provides the highest welding speed, excellent penetration and weld aspect ratio second only to Electron Beam Welding (EBW). However, EBW requires a vacuum which is a limitation and justified for critical materials, components and complex joint configuration.

- Inertia friction welding of large structural engine components with axial symmetry remains as an indispensible technology.

- Diffusion bonding is the other key technology for joining of critical components especially in dissimilar materials.
Thank You for your kind attention

Please do not hesitate to contact in case you have any further query to amit@iitb.ac.in and feel free to visit www.me.iitb.ac.in/~amit.html