Santos Vilaca da Silva, Pedro

Application of Friction Stir Welding and Allied Techniques to Aluminium

Published: 01/01/2014

Document Version
Publisher's PDF, also known as Version of record

Please cite the original version:
AGENDA

- Introduction to School of Engineering of Aalto University
- Fundaments of Friction Stir Welding (FSW)
- Industrial Application Samples of FSW
- Variants of FSW
- Innovations Based on Friction Stir Concept
- Applications and Developments of FSW at Aalto University
Aalto University - Where Science and Art meet Technology and Business

Created from the merger of 3 leading Finnish universities 1 January 2010:

☞ the Helsinki School of Economics (HSE), founded 1911
☞ the University of Art and Design Helsinki (TaiK), founded 1871
☞ the Helsinki University of Technology (TKK), founded 1849

Aalto University is a community of:
- 75,000 alumni
- 20,000 students
- 4,700 faculty & staff
- with 340 professors

Aalto University
6 Schools (with a Dean) and Respective Focus Areas

School of Engineering
- Arctic technology
- Mechanics and material technology
- Multidisciplinary energy technologies
- Sustainable built environment
- Systems design and production

School of Science
- Computing and modeling
- Materials physics
- Energy sciences
- ITC, software and media
- Neuroscience and technology
- Creating and transforming technology based entrepreneurship

School of Chemical Technology
- Sustainable use and processing of natural resources
- New materials
- Energy technologies

School of Electrical Engineering
- Energy
- Health and wellbeing
- Environment
- Information and communication technology
- Micro- and nanotechnology

School of Arts, Design and Architecture
- User driven design and art
- Art & design, science and business
- Heritage based forerunning
- Sense based skills and knowledge

School of Business
- Strategic management & marketing in the global context
- Microeconomics
- Behavioral finance & corporate governance
- Decision-making
Welding Technology

History

1888 Bare electrode
1904 SMAW
1930 SAW
1940 GTAW
1950 GMAW
1961 Electro-gas
1959 Electro-slag
1920 Thermite
1980 Sinergic
1970 FCAW
1990 CMT
... Nd-YAG
CO₂
Excimers
Diodes
Fiber
...

Classification

Welding Process Classification

1881 Coal electrode
1903 Oxifuel
1930 Electric Arc
1940 Thermal Treat.
1950 Brasing
1958 EBW

Fusion Welding
Includes partial fusion of Base Material, with /without application of pressure, with/without filler metal added to weld pool

Brazing and Soldering
No fusion of base material components which are joined by inserting melted filler metal in the overlap joint configuration

Solid State Welding
Joining is obtained by solid state joining mechanisms

Note: There are (many) others possible classifications.
**Welding Technology**

**Solid State Welding History**

- Iron and coal: 1855-60 (The Industrial revolution by William Bell Scott)

**Friction Stir Processing**

**Solid State Welding Classification**

- Mechanical Energy
  - Friction; Ultrasonic; Explosion; Diffusion

- Heat Energy
  - High-frequency; Flash; Stud (liquid joining interface)

- Cold Pressure
  - No-Weld
  - Recrystallization
  - Fusion
  - T[°C]
  - P [N/mm²]
Solid State Welding
Sample of Conventional Solutions

High-Frequency Welding
Stud Welding
Ultrasonic Welding

Third-Body Region Based Technologies

Friction Stir Based Technologies
Friction Stir Welding
Friction Stir Welding Variants

Friction Based Technologies
Friction Surfacing

Hybrid Joining Involving Friction (e.g. with: acoustic, electric arc, electrical resistance; laser beam)
Friction Brazing (third-body friction joining)

Friction Flow Drilling
Friction Cutting
Friction Stitch Welding
Friction Riveting

Orbital Friction Welding
Radial Friction Welding
Rotary Friction Welding Inertia and Continuous Drive
Friction Based Technology
Sample of Processes

Friction Welding
Internacional Patent
2/1956 (A.I. Chudikov)

Friction Extrusion
Friction Hydro Pillar
Friction Riveting

© TWI, England
© HGZ, Germany
Friction Based Technology
Sample of Processes

Friction Surfacing

FS Production of Functionally Graded Materials (FGM)

Friction Stir Welding Process
Fundaments and Parameters

FSW was patented by TWI, 1991, W. Thomas et al., UK
Friction Stir Welding Process
Inventor: Wayne Morris Thomas @ TWI (UK)

The responsible for the most significant development of welding technology in recent history


Last Patent (US 5,813592) assigned to TWI Expires: 29 September 2015

Friction Stir Welding Process
Fundaments - Typical Macrostructure
Friction Stir Welding Process
Fundamentals – Heat Input

\[ P_{\text{mech}}[W] = \left[ M[n\text{ rpm}] \times 2\pi \Omega[rps] + F[w] \times v[\text{mm/min}] \right] \times \frac{1000}{60} \]

\[ \eta_{\text{heat}} = \left( 1 - \frac{P_{\text{heat}}}{P_{\text{mech}}} \right) \times 100\% \]

\[ H[J/mm] = \frac{P_{\text{heat}}[W]}{v[\text{mm/min}]} \times 60 \]

Friction Stir Welding Process
Fundamentals – Tool Geometry

Shoulders
Probes
Friction Stir Welding Process
Fundaments – 3D Material Flow

Friction Stir Welding Process
Fundaments – Standards

ISO EN DIN 25239 (03/2012) Friction Stir Welding - Aluminium

Part 1: Vocabulary
Part 2: Design of weld joints
Part 3: Qualification of welding operators
Part 4: Specification and qualification of welding procedures
Part 5: Quality and inspection requirements

AWS D17.3 / D17.3M:2010
Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications
Friction Stir Welding Process
Fundaments – **Advantages** versus **Disadvantages**

- Welds materials whose structure and properties would be degraded by fusion welding
- Minimal distortion + Low residual stress levels compared to fusion welding processes
- Environmentally friendly + Safe: No fumes + No radiation + High energy efficiency
- Easy repeatability + good control: suitable for automation and robotization
- Good mechanical properties: No cracks + No porosity
- No consumables for aluminium alloys
- Joint can be produced from one side and in all positions
- Minimal edge preparation required
- Not influenced by magnetic forces

- Backing anvil required (except bobbin stir tools)
- Keyhole at the end of each weld (except when a tool with a retractable probe is used)
- Workpiece requires rigid clamping (except when the Twin-stir™ variant is used)
- Application not as flexible as certain fusion welding processes

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**Industrial Application Samples of FSW**
Shipbuilding Industry

- First vessel (catamaran) in history made from FSW panels was built by Fjellstrand AS in 1996
- The panels were made by Marine Aluminium. This kick started the industrialization of FSW process
- Panels with total FSW length of 110km from 1996 to 1999
Industrial Application Samples of FSW
Aeronautic Industry

- Eclipse Aviation @ USA
- Wing
- Fuselage

Industrial Application Samples of FSW
Aerospace Industry

- Boeing Co @ USA
- FSW facility dedicated for the production of the fuel tanks of Delta IV
Industrial Application Samples of FSW
Aerospace Industry

New FSW for Space Launch System:

Vertical Assembly Center (VAC)
(NASA’s Michoud Assembly Facility New Orleans)

61 m Tall x 8.4 m Diameter

Cryogenic liquid hydrogen and liquid oxygen that will feed the vehicle’s RS-25 engine

Industrial Application Samples of FSW
Automotive Industry

Tailored Blanks joined by FSW and subsequently formed

Ford GT: FSW of tunnel to Al frame to form housing of transmission system and fuel tank

FSW of Tailor Welded Blanks using dissimilar thickness Al sheets – TWI research study

FSW of cast Al hub to wrought Al rim section
Produced by Fundo Wheels for Volvo XC90

Friction Stir Welds
Industrial Application Samples of FSW

Railway Industry

A-Train concept from Hitachi, Ltd @ Japan for rolling stock based on FSW

Features:
- Self-supported module
- Mounting rail fastening by bolts
- Reduced number of parts
- No adjustment work required
- Easier refitfest and maintenance

Informatics Industry

Apple 21.5 and 27-inch iMac 2012 @ USA

Apple slims down iMac 40% with 'friction-stir welding' & ditching the disc drive

By Daniel Eran Dilger

Apple’s new iMac updates the company’s flagship Macintosh into a faster, faster and — in particular — thinner version of itself.
Industrial Application Samples of FSW
FSW (kitkahitsaus) in Finland

- Equipment delivered to KMT Oy (PROMECO-Kankaanpää) in 12.2003
- Modular LEGIO 5UT (6m x 0.5m x 0.3m)
- Applied e.g. electromechanical components

- Jori Oy (South Ostrobothnia) designed and built their own automatic FSW machine in 2004
- Table 14m long for FSW of Al alloy tanks mostly for powder

Industrial Application Samples of FSW
Architecture Application

- Nobel Peace Centre @ Oslo, Norway

Canopy by David Adjaye that serves as gateway between Oslo City Hall where the Peace Prize Ceremony takes place and the Nobel Peace Center
Friction Stir Welding Based Innovations

- Com-stir™ Welding
- Stationary Shoulder FSW
- Skew-stir™ Welding
- Twin-stir™ Welding
- Re-stir™ Welding
- Bobbin Tool Stir Welding
- Dual-rotation FSW

Friction Stir Based Innovations

- Friction Stir Processing
- Friction Stir Channeling
- Friction Stir Microforming
- Near-Net Shaped Manufacture by FSW
- Friction Stir Self Embossing and In-Process Forming
- Friction (Stir) Spot Welding
FSW @ Aalto University
Different Joints and Materials

Overlap

Thick Al alloy

Mg Alloy

Dissimilar Mg-Al

Cu

Thin Al alloy

Dissimilar Al-Cu

Polyamide

Dissimilar thickness

FSW of tailored blanks welded by FSW

Thank You / Kiitos / Tack

Aalto University
School of Engineering
Department of Engineering Design
and Production
Materials Joining and NDT

29th October 2014
Turku, Finland