

9th International Symposium on Friction Stir Welding 2012

**Huntsville, Alabama, USA
15-17 May 2012**

ISBN: 978-1-62276-608-6

Printed from e-media with permission by:

Curran Associates, Inc.
57 Morehouse Lane
Red Hook, NY 12571



Some format issues inherent in the e-media version may also appear in this print version.

Copyright© (2012) by TWI Ltd.
All rights reserved.

Printed by Curran Associates, Inc. (2013)

For permission requests, please contact TWI Ltd.
at the address below.

TWI Ltd.
Granita Park Great Abington
Cambridge CB21 6AL UK

Phone: 441 223 891 162
Fax: 441 223 892 794

library@twi.co.uk

Additional copies of this publication are available from:

Curran Associates, Inc.
57 Morehouse Lane
Red Hook, NY 12571 USA
Phone: 845-758-0400
Fax: 845-758-2634
Email: curran@proceedings.com
Web: www.proceedings.com

TABLE OF CONTENTS

PLENARY

A Study on the Economic Incentives of Welding Steel Pipelines Using Friction Stir Welding	1
<i>A. Kumar, A. Wasson, D.P. Fairchild, M.L. Macia</i>	
The Evolution of Friction Stir Welding Theory at Marshall Space Flight Center	10
<i>Arthur C. Nunes Jr.</i>	

APPLICATIONS I

FSW in Automotive Mass Production – The New Mercedes SL	28
<i>Axel Meyer</i>	
Preparation of Friction Stir Welding of the Aluminum Alloy AA 2219 for Launcher Applications	39
<i>M. Kahnert, M. Mestek, I. Tessier, M. Okualla</i>	
Robotic Manufacturing of 5.5 Meter Cryogenic Fuel Tank Dome Assemblies for the NASA Ares I Rocket	47
<i>Ronald E. Jones</i>	
Development of FSW Process Parameters and Characterization for AA 2219 Propellant Tanks	48
<i>P. Srinivasa Rao, S. Ravishankar</i>	

INSPECTION

Generalized e-NDE Algorithm for Friction Stir Welding	66
<i>Enkhsaikhan Boldsaikhan, Dwight Burford</i>	
Early Detection of Volumetric Defects Using e-NDE during Friction Stir Welding	82
<i>Dwight Burford, Enkhsaikhan Boldsaikhan, Adam Wiley</i>	
Identification of Periodic Defects Due to Material Flow Variations in FSW Using Postweld Data Processing	100
<i>Haley Doude, Judy Schneider, Ben Ma, Jenny Du, Bryan Patton, Taylor Waters</i>	
SignaStir - Laser Ultrasound Testing of Friction Stir Welding	112
<i>Henrik Schmidt</i>	

WELD PERFORMANCE

Fatigue and Tensile Properties of Friction Stir Welds in AA6061-T6 and AA6082-T6 from Production Trials	121
<i>Jesus Mendoza, Sören Kahl</i>	
Thermal Management for Production of Very High Strength alloy 7050 Friction Stir Welds	137
<i>A.P. Reynolds, W. Tang</i>	
Analysis of Gray Line in Friction Stir Welding of 2024 Al Alloy	153
<i>Qiang Meng, Xiaojuan Guo, Xingmei Feng</i>	
Effect of Backing Plate Thermal Property on Friction Stir Welding of 25 MM Thick AA6061	165
<i>P. Upadhyay, A.P. Reynolds</i>	

FSW TOOLS

Application of Ni Base Dual Two-phase Intermetallic Alloy Tools for Joining SUS430 Plates	180
<i>Noboru Mochizuki, Takayuki Takasugi, Yasuyuki Kaneno, Sachio Oki, Tomotake Hirata</i>	
Past, Present, and Future Developments of Tungsten 25% Rhenium Tool Material for Friction Stir Welding of Steel and Hard Metals	191
<i>Todd Leonhardt, Brian Thompson</i>	
Material Properties Governing Wear of Co-based Alloy Tool During Friction Stir Welding of Steels	201
<i>Masahiro Miyake, Yutaka S. Sato, Hiroyuki Kokawa, Yoshikazu Takaku, Toshihiro Omori, Kiyohito Ishida, Shinya Imano, Seung Hwan C. Park, Satoshi Hirano</i>	
The Use of Novel Methods in Determining the Wear of Friction-Stir Tooling	209
<i>S. Dodds, A.H. Jones, S. Cater</i>	

VARIANTS I

Development of an All-in-One Exit Hole Elimination Technique for Thin Section Aluminum	225
<i>Brian Thompson, Jeff Root, Richard George, Mike Eff, Saurabh Sedha</i>	
The Role of Joint Interface on Tensile-Shear Fracture Strength of Friction Stir Lap Diffusion Al-to-Steel Welds	235
<i>Z.W. Chen, S. Yazdani, G. Littlefair</i>	
Friction Stir Welding at TWI: Information Available for Public Release	241
<i>Dick Andrews</i>	
A Feasibility Study for Stationary Shoulder Self-reacting Pin Tool Welding	257
<i>Toshiyuki Suda, Yasuhiro Sakamoto, Tomonori Miyamichi, Tetsuro Sato</i>	

MODELLING I

Challenges in Thermomechanical Modelling of Friction Stir Welding	267
<i>Henrik Schmidt</i>	
Tool-Workpiece Interface Temperature Measurement and Improved Closed-loop Control in Friction Stir Welding	284
<i>Axel Fehrenbacher, Neil A. Duffie, Nicola J. Ferrier, Michael R. Zinn, Frank E. Pfefferkorn</i>	
Model-based Process Monitoring in Friction Stir Welding	300
<i>Alicia A. Gonzalez-Rodriguez, George Panoutsos, Kirsten Sinclair, Mahdi Mahfouf, Kathryn Beamish</i>	
Influence of Friction Stir Weld Tool Geometry and Runout on Magnitude and Form of In-process Weld Forces	317
<i>M.S. Brendel, J.A. Schneider</i>	

PROCESS I

Control of Temperature, Power Input and Tool Depth During FSW of Copper Canisters	328
<i>Lars Cederqvist, Olof Garpinger, Isak Nielsen</i>	
Development and Implementation of a Robust Temperature Control Algorithm	335
<i>Kenneth A. Ross, Carl D. Sorensen</i>	
Relationship Between Joining Parameter and Tool Tip Temperature During Spot FSW	353
<i>Takeshi Shinoda, Yohei Katsuragi, Kazuki Tani</i>	
Process Regimes in FSW. Monitoring and Consequences for Quick Parameter Set Up	362
<i>A. Echeverria, E. Aldanondo, P. Alvarez, E. Arruti</i>	

FSP

Engineered Surface Layers in Ni-base Alloys using Additive Friction Stir Processing	376
<i>J. Rodelas, J. Lippold</i>	
Friction Stir Welding of High-Workability Titanium Alloy	387
<i>Kenta Kitamura, Hidetoshi Fujii, Yoshiaki Morisada, Atsushi Ogawa</i>	
Fabrication of Locally Reinforced Al 6061/SiCp Metal Matrix Composite Using Friction Stir Process	392
<i>Chih-Wei Huang, Jong-Ning Aoh, Jyun-Syong Lin</i>	
Modification of Cold-Work Tool Steel by Combination of Laser Cladding and Friction Stir Processing	393
<i>Toru Nagaoka, Hiroyuki Watanabe, Masao Fukusumi</i>	

APPLICATION II

Aircrafts Structural Parts Demonstrators Manufactured Using Friction Stir Welding	395
<i>I. Bordesoules, A. Bigot, C.Hantrais, T. Odièvre, J. Laye</i>	
Friction Stir Welded Rib One	409
<i>François Marie, Franck Batalla</i>	
Damage Tolerance Assessment of Friction Pull Plug Welds	416
<i>Preston McGill, Jonathan Burkholder</i>	
Application Study of Refill FSSW on Aerospace Industry	423
<i>Hideki Okada, Kenichi Kamimuki, Mitsuo Fujimoto</i>	

VARIANTS II

Friction Stir Welding of Thin Aluminum Using Fixed Gap Bobbin Tools	434
<i>Kevin J. Colligan, Alan K. O'Donnell, James W. Shevock, Mark T. Smitherman, Gabriel J. Hostetter</i>	
Effect of Material Flow by Double-Sided Friction Stir Welding on Weld Structure and Mechanical Properties of Magnesium Alloy	451
<i>Juan Chen, Hidetoshi Fujii, Yufeng Sun, Yoshiaki Morisada, Katsuyoshi Kondoh</i>	
The Concept of Electrically-Assisted Friction Stir Welding and Application to Processing of Various Metals	457
<i>W. Ferrando, D. Lammlein, M. Posada, A. Floyd</i>	

METALLURGY

Influence of Welding Parameters and Preheating Temperature on Abnormal Grain Growth After Post-weld Heat Treatment in Friction Stir Welding of 5083 Al Alloys	473
<i>François Nadeau, Daniel Larouche, Patrick Gougeon</i>	
Mitigating Abnormal Grain Growth for Friction Stir Welded Al-Li 2195 Spun Formed Domes	490
<i>Po-Shou Chen, Carolyn Russell</i>	
EBSD Study of Recrystallization in Friction-stirred Superaustenitic Stainless Steel	508
<i>S. Mironov, Y.S. Sato, H. Kokawa</i>	

NICKEL ALLOYS

Friction Stir Processing of Ni-base Alloys	519
<i>J.R. Rule, J.C. Lippold</i>	
Microstructure and Mechanical Properties of Friction Stir Processed Cast Alloy 718	536
<i>Bharat K. Jasthi, Edward Y. Chen, William J. Arbegast, Brahmanandam Kaligotla, Michael West, Christian A. Widener, Stanley M. Howard</i>	
Dissimilar Lap Joint Low Carbon Steel to Alloy 625 by Friction Stir Welding	543
<i>J. Rodríguez, A.J. Ramirez</i>	

MODELLING II

Three-dimensional Visualization of Material Flow in FSW by X-ray Radiography	553
<i>Y. Morisada, H. Fujii, Y. Kawahito, K. Nakata, M. Tanaka</i>	
Coupled Thermo-mechanical Analysis for Frictional Stir Welding Processes	559
<i>Narges Dialami, Michele Chiumenti, Miguel Cervera, Carlos Agelet de Saracibar</i>	
Predicting Grain Size Distribution in Friction Stir Welded 6061 Aluminum Alloy	580
<i>M. Nourani, A.S. Milani, S. Yannacopoulos, C. Yan</i>	

PROCESS II

Influence of Side-Tilt Angle on Process Forces and Lap Joint Strength in Robotic Friction Stir Welding	589
<i>Jeroen De Backer, Lars Cederqvist, Mikael Soron</i>	
Tool Path Control and Effort During FSW in PKM Machine Using ICAM Approach	596
<i>Arun Prasath Manogaran, Guillaume Racineux, Jean-yves Hascoet</i>	
An Automated Path Planning and Programming System With Real-Time Adaptive Control for Friction Stir Processing of Cast Surfaces	605
<i>Christopher B. Smith, Kenneth Schroeder, Axel Fehrenbacher</i>	
Friction Stir Welding of 3D-structures and Flexible Components	617
<i>A. Grimm, G. Goebel, E. Beyer</i>	
Optimization of FSW Clamping Systems by Utilizing Numerical and Experimental Approaches	629
<i>S. Schulze, G. Goebel, U. Fuessel, E. Beyer</i>	

FSSW

Abrasion Circle Friction Spot Welding for Rapid FSSW Al to Steel Automotive Sheet	640
<i>Y.C. Chen, P.B. Prangnell</i>	

Applications of a Flat Spot Friction Stir Welding Technique for Aluminium Alloys and Mild Steel Sheets	649
<i>Yufeng Sun, Hidetoshi Fujii, N. Takaki, Y. Okitsu</i>	
Friction Stir Spot Welding Between Dissimilar Light Metals	658
<i>Toshiaki Yasui, Hiroki Tahara, Takaaki Suzuki, Masami Tsubaki, Masahiro Fukumoto, Naoki Kawamoto, Hideo Furusawa, Takeshi Shinoda, Youhei Katsuragi</i>	
Material Flow Phenomena in Friction Stir Spot Welding (FSSW) of Butt Joints	664
<i>Egoitz Aldanondo, Ekaitz Arruti, Garazi Auzmendi, Alberto Echeverria, Pedro Alvarez</i>	

FSW STEEL

Approaches to Consistently Achieve Full Penetration in Pipeline Steel Welds Using Friction Stir Welding	674
<i>M. Mahoney, S. Sanderson, Z. Feng, R. Steel, S. Packer, P. Higgins</i>	
Thick Section Friction Stir Welding of Steel	692
<i>Russell Steel, Jeremy Peterson, Sam Sanderson, Paul Higgins, Scott M. Packer</i>	
Friction Stir Welding of P91 Steel with an Improved W-Re Tool Material for Nuclear Applications	700
<i>M. Kolluri, N.V. Luzginova, E.W. Schuring, W. Kyffin, J. Martin</i>	
Mechanical Properties of Dissimilar 4142 and S7 Tool Steel Friction Stir Welds	717
<i>Timothy D. Johnson, Todd R. Curtis, Eric East, Bharat K. Jasthi, Christian A. Widener, Matthew Carriker, Michael K. West</i>	

NON FERROUS

Analysis of Friction Stir Welded AA5454/AZ91-Joints	722
<i>Ottmar Klag, Guntram Wagner, Dietmar Eifler</i>	
Effects of the Relative Mechanical Strengths at High Temperature in Dissimilar Friction Stir Welds of 2014 to 6061 Aluminum Alloys	729
<i>Caroline Jonckheere, Bruno de Meester, Anne Denquin, Aude Simar</i>	
Interest of Friction Stir Processing for the Development of Graded Oxide Dispersion Strengthened Cu Based Materials	739
<i>M.-N. Avettand-Fènoël, A. Simar, R. Shabadi, R. Taillard, B. de Meester</i>	
Copper/Brass Laminates Bonded by Friction Stir Welding as Method to Study Material Flow	751
<i>I.F. Vutabwarova, A.H. Jones, C. O'dubghaill, S. Cater</i>	

APPLICATIONS III

Friction Stir Welding of Thick Section Aluminum for Military Vehicle Applications	768
<i>Brian Thompson, Kevin Doherty, Craig Niese, Mike Eff, Tim Stotler, Zak Pramann, John Seaman, Roger Spencer, Perry White</i>	
Application of FSW and FSSW on Advanced Automotive Structural Applications	781
<i>Arne Roos, Jan Carstensen, Jorge F. dos Santos</i>	
Application of Friction Stir Welding in Rolling Stock Manufacture Industry in China	782
<i>Guohong Luan, Chunlin Dong, Guang Li, Weibing Wang</i>	
Development of Cold Plate by Friction Stir Welding	792
<i>Nobushiro Seo, Hisashi Hori, Harumichi Hino</i>	

HIGH TEMPERATURE FSW

The Influence of Fast Diffusers in Friction Stir Welding of Titanium Alloys	800
<i>J. Wolk, R.K. Everett, S. Szpara, C. Scheck, M. Zupan</i>	
Friction Stir Processing of Ti-6Al-4V for Grain Size Reduction in Fusion Welds and Base Metals	808
<i>J.J. Livingston, J.M. Rodelas, J.C. Lippold</i>	
Friction Stir Processing of Martensitic Stainless Steel: An Alternative to Quench & Tempering Treatment for Cutting Tools?	816
<i>Daniel Gesto, David Verdera, Marcos González, Iago de Labra, Ana I. Álvarez, Gloria Pena</i>	
Microstructural and Mechanical Properties of Friction Stir Welded Cu-Cr-Zr Alloy	828
<i>Kaushal Jha, R.N. Singh, K. Bhanumurthy, G.K. Dey, K.N. Mahule</i>	

PLENARY

Material Flow During Tatsumaki Friction Stir Welding	836
<i>Seung Hwan C. Park, Satoshi Hirano, Shinichi Kaga, Mitsuru Onose, Noriaki Tominaga, Yasutsugu Yoshimura</i>	
Standards for Friction Stir Welding Aluminium	837
<i>David Bolser</i>	

POSTER SESSIONS

Numerical Simulation in Bobbin Tool FSW Process Development	844
<i>Jakob Hilgert, J.F. dos Santos, N. Huber</i>	
Effect of Tool Shoulder Geometry on the Axial Force and Mechanical Strength of FSSW Aerospace Alloys AA7075 and AA2024	845
<i>Avishwanath Iyer, Enkhsaikhan Boldsaikhan, Dwight Burford</i>	
Friction Stir Weld Development and Dynamic Crash Testing of a Bumper Crash Box Assembly Made from AA6082-T6 & AA6063-T6 Extrusions	846
<i>Jeff Buller, Alan Bruce Handyside, Farzad Baratzadeh, Blair Carlson, Enkhsaikhan Boldsaikhan, Dwight Burford</i>	
Development of Fine Grained Structure During Friction Stir Welding of a Duplex Stainless Steel	847
<i>Tohid Saeid, Amir Abdollah-zadeh, Firooz Kargar, Mostafa Jafarzadegan</i>	
Forge Force Reduction via Tool Design Variation	848
<i>Edward G. Cole, Nicola J. Ferrier, Michael R. Zinn, Neil A. Duffie, Frank E. Pfefferkorn</i>	
Material Flow in FSW Butt and Lap Welds and Its Implications	863
<i>Pedro Alvarez, Egoitz Aldanondo, Ekaitz Arruti, Alberto Echeverria</i>	
Effect of Base Material Properties on FSW Torque and Defects	865
<i>Carlos Leitão, David Verdera, Daniel Gesto, Dulce Rodrigues, Altino Loureiro</i>	
Microstructural and Mechanical Response Characterization of Friction Stir Welds in 6063 T4 Aluminum Alloy	867
<i>Murshid Imam, Vikranth Racherla, Kajal Biswas</i>	
Weld Zone Modeling of Friction Stir Welds	868
<i>Vikranth Racherla, Murshid Imam, Kajal Biswas</i>	
Investigation on the Joinability of Al 6061 Al-Alloy Plates with Friction Stir Welding	869
<i>Ilker Eker</i>	
Superplasticity in Friction Stir Processed Mg-RE Alloy	870
<i>Bolu Xiao, Qun Yang, Zong-Yi Ma, Chang-Cheng Guo, Zhuang-Zhi Tang</i>	
Building Phenomenological Based Semi-physical Models. Friction Stir Welding	872
<i>Elizabeth Hoyos, Diana Lopez, Hernán Álvarez</i>	
Effect of Welding Parameters on Microstructure and Mechanical Properties of Friction Stir Welded Precipitation-hardened Aluminum Alloys	873
<i>Zongyi Ma, Z. Zhang, B.I. Xiao</i>	
Analysis of Plastic Flow in FSW for Dissimilar Joint	875
<i>Gaku Yoshikawa, Fumikazu Miyasaka, Yoshinori Hirata, Yoshinori Katayama, Toshiaki Fuse</i>	
Characteristics of FSW Welds of Aluminum Alloys - Casted Elements with Rolled Elements	876
<i>Krzysztof Mroczka, Adam Pietras</i>	
Analysing the Challenge of Aluminium to Copper FSW	891
<i>I. Galvão, D. Verdera, D. Gesto, A. Loureiro, D.M. Rodrigues</i>	
Effect of Welding Speed Variation in Butt Joint by Friction Stir Welding Process on Microstructure and Mechanical Properties of 430 Ferritic Stainless Steel	908
<i>Shaghayegh Javadi, Ali Salemi, Amir Abdollahzadeh, Kargar Firooz</i>	
One-Dimensional Steady Shearing of Thermoviscoplastic Solids and Material Flow in Friction Stir Welding	909
<i>Zhigang Wei, Romesh Batra, Pingsha Dong, Fulun Yang</i>	
Welding Speed Limit in Friction Stir Welding of Titanium	911
<i>C. Nie, X. Pei, P. Dong, Z. Wei</i>	
Different Methods for Fatigue Assessment of Friction Stir Welded Joints	912
<i>Meysam Mahdavi Shahri, Rolf Sandström, Wojciech Osikowicz</i>	
Influence of Energy Induced from Processing Parameters on the Mechanical Properties of Friction Stir Welded Lap Joint of Aluminium to Coated Steel Sheet	913
<i>Hrishikesh Das, Sushovan Basak, Tapan Kumar Pal</i>	

Crack Growth Testing Under a Biaxial Cyclic Load	914
<i>Valentin Richter-Trummer, Philip Irving, Xiang Zhang, Marco Pacchione, Marcelo Beltrão, Jorge Fernandez dos Santos</i>	
Friction Stir Welding and Submerged Friction Stir Welding of Al alloy to Mg Alloy	915
<i>Mohammad Ammar Mofid, Amir Abdollahzadeh</i>	
Friction Stir Disc Welding	916
<i>M.M. Shrikman, N.M. Kashchuk</i>	
Effect of Material Flow Formation of Weld Interface between Aluminum and Steel by Friction Stirring	922
<i>M. Fukumoto, Y. Shimoda, M. Tsubaki, Toshiaki Yasui</i>	
Numerical and Experimental Comparison on the effect of Temperature Brass Plates (Cu Zn 30)	933
<i>Afshin Emamikhah, Ali Atefat, Bozarjemehr Ghasemi</i>	
Friction Stir Welding of AA 5052-H34 Thin Sheets of Different Thickness	935
<i>M. Dharamendara</i>	
The Effect of Paint Bake Treatment on the Properties of FSSWs in AA6111-T4 Automotive Sheet	936
<i>S.F. Liu, Y.C. Chen, D. Bakavos, P.B. Prangnell</i>	
Friction Stir Welding of Propellant Tanks for Indian Space Launch Vehicle Programme	944
<i>Tribikram Mohapatra</i>	
Friction Pull Plug Welding in Aluminum Alloys	946
<i>Shane A. Brooke, Vann Bradford</i>	
Friction Stir Welding of High-strength Aluminum Alloys (2xxx) for Subsequent Spinning Process (Preliminary Paper)	947
<i>Matthias Mestek, Sahin Sünger, Markus Kahnert, M.F. Zäh</i>	
Comparison of FSW and MIG Welding of Casting Aluminium Alloy AISI12	953
<i>Damjan Klobcar, Ladislav Kosec, Anton Smolej, Janez Tušek</i>	
Microstructure and Mechanical Properties of Friction Stir Welded Nickel Base Super Alloy Inconel 718	954
<i>M.M.Z. Ahmed, B.P. Wynne, J. Martin</i>	
The Effect of Welding Speed on the Tensile Properties of the Friction Stir Welds	955
<i>Sunao Tanaka</i>	
Microstructure and Mechanical Properties of Friction Stir Welded Joints in 7A60-T6 Super High-strength Aluminum Alloy	956
<i>Jihong Dong, Chunlin Dong, Qiang Meng, Guohong Luan</i>	
Friction Stir Welding of the Third Generation Al-Li Alloy C24S	963
<i>Chunlin Dong, Qiang Meng, Guohong Luan</i>	
Effect of Tool Geometry on Friction Stir Lap Welding of Magnesium Alloy to Aluminum Alloy	964
<i>J. Mohammadi, Y. Behnamian, H. Izadi, T. Saeid, A.H. Kokabi, A.P. Gerlich</i>	
Mechanical & Metallurgical Properties of Friction Stir Welded AA2198-T8 Joints	965
<i>Sarah Jurak, Enkhsaikhan Boldsaikhan, Dwight Burford</i>	
Application of Friction Stir Welding on the Large Aircraft Floor Structure	966
<i>Wang Yisong, Tong Jianhua, Li Congqing, Guohong Luan</i>	
Author Index	