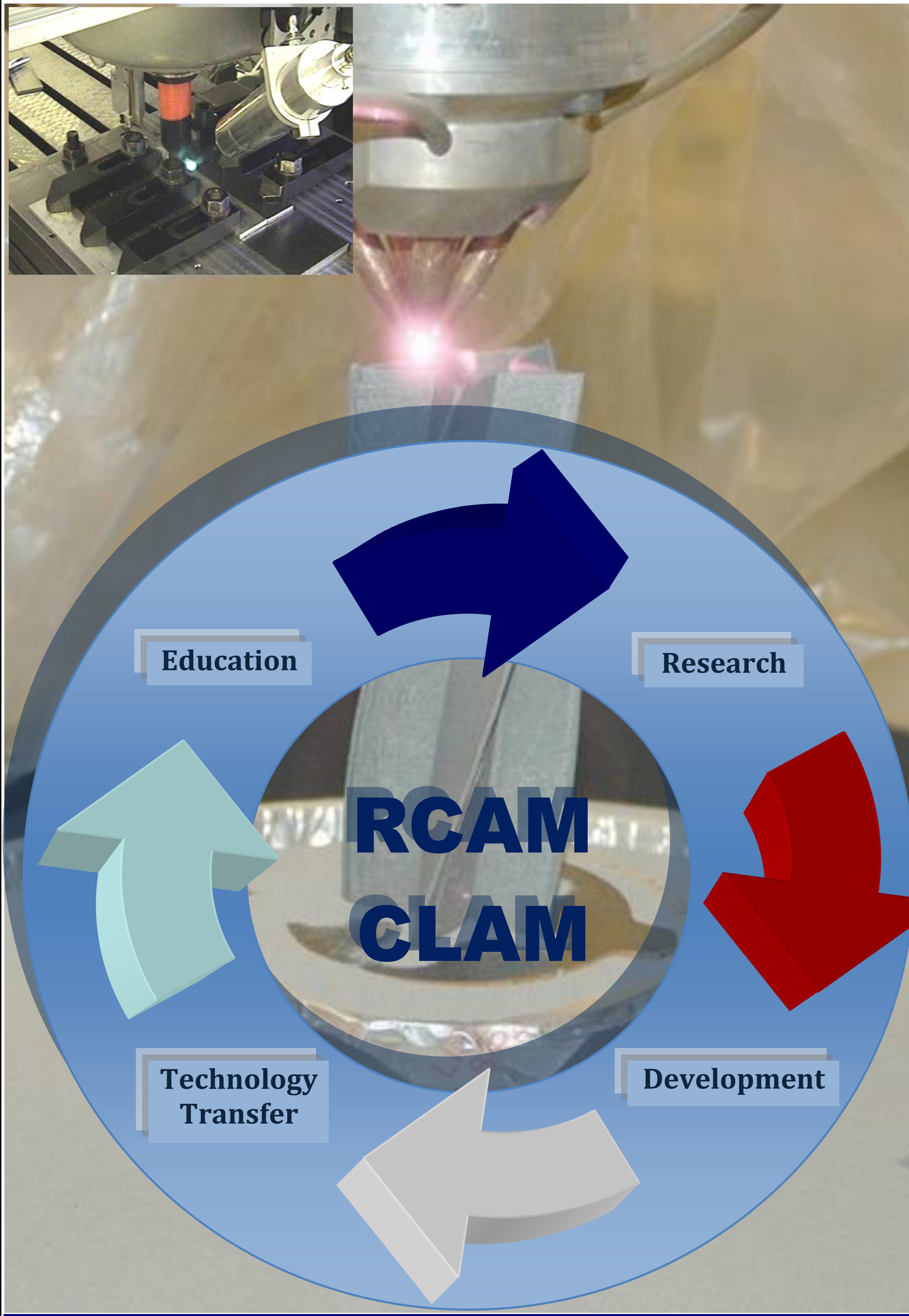
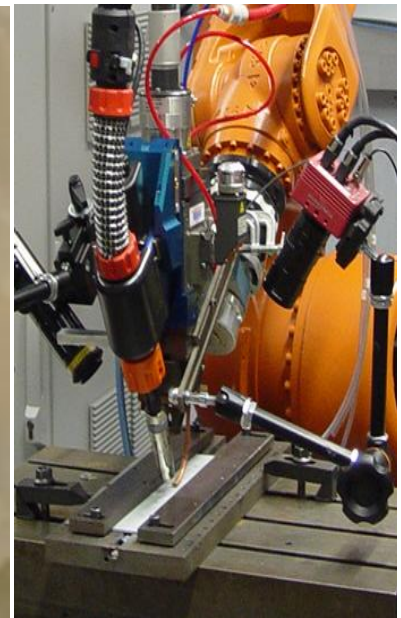
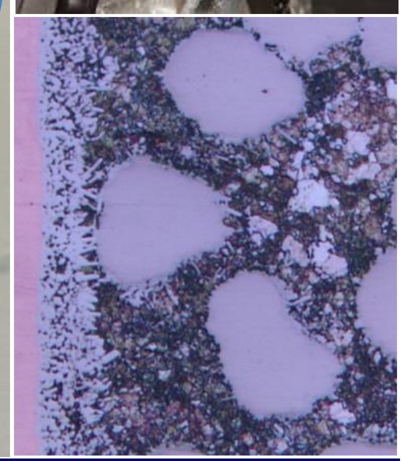
RESEARCH CENTER FOR ADVANCED MANUFACTURING & CENTER FOR LASER-AIDED MANUFACTURING







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Research Center for Advanced Manufacturing (RCAM) and Center for Laser Aided Manufacturing (CLAM) at Southern Methodist University

MISSION

To provide and apply university led R&D work, education, and training in advanced manufacturing.

RCAM

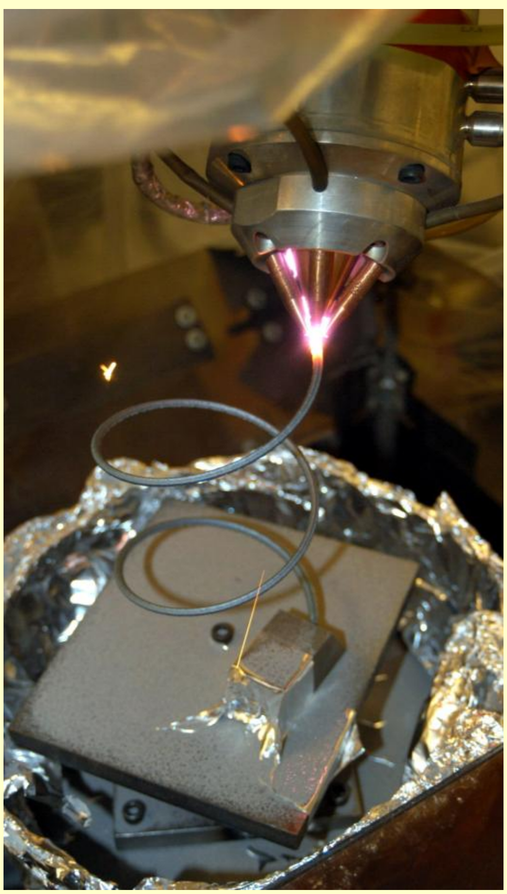
In order to respond to the industry's needs and to provide the conditions to educate undergraduate and graduate students in the area of manufacturing engineering, the Department of Mechanical Engineering and the School of Engineering established the Research Center for Advanced Manufacturing (RCAM) in September of 1999.

CLAM

In August of 2005, the National Science Foundation awarded SMU a grant to establish the Industry/University Cooperative Research Center (I/UCRC) for Lasers and Plasmas for Advanced Manufacturing. SMU is the fourth university site in the multi-institutional I/UCRC for Lasers and Plasmas for Advanced Manufacturing together with the University of Michigan, the University of Virginia and the University of Illinois at Urbana-Champaign.

R&D AREAS

- **Rapid Manufacturing/Repair by Laser Cladding**
- **Electron Beam Direct Metal Deposition**
- **Friction Stir Welding**
- **High Power Lasers in Materials Processing**
- **Abrasive Water Jet Materials Processing**
- **Development of Lead-free Solders**
- **Paint Striping by Lasers**
- **Materials Characterization**
- **Process Automation**
- **Micromachining by Lasers**
- **Fusion Welding**
- **CAD/CAM/CAE**



EQUIPMENT

- TRUMPF 10 kW disk laser
- IPG fiber laser of 4 kW in power
- COHERENT direct diode laser of 8kW in power
- Spectra-Physics HIPPO Q-switched laser system with four harmonics wavelengths (1064, 532, 355, and 266 nm)
- NUVONYX direct diode laser of 2 kW in power
- NUVONYX fiber coupled diode laser of 1 kW in power
- LUMONIX Nd:YAG laser of 1 kW in power
- 3-axis CNC vertical machining center adapted for friction stir welding
- 5-axis CNC vertical machining center adapted for multi-fabrication process (combined additive and subtractive operations at the same setup for rapid manufacturing/repair)
- 5-axis CNC vertical machining center VF-4 adapted for high-speed machining
- 6-axis KUKA robot
- Two 6-axis MOTOMAN robots
- Two high-accuracy 4-axis CNC positioning systems for micro-machining
- Z Corp 3D color printer for rapid prototype
- Axila-portable coordinate measuring arm
- Abrasive waterjet cutting machine
- Well equipped Laboratories for R&D in welding, materials characterization, monitoring and control, and reverse engineering
- Well equipped machine shop

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SMU Center for Laser Aided Manufacturing

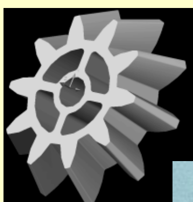
SMU Research Center for Advanced Manufacturing

Rapid Manufacturing/Repair MultiFab Platform

LYLE SCHOOL OF ENGINEERING

➢PROCESS DESCRIPTION

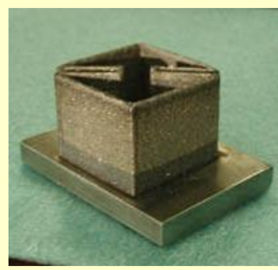
The SMU RCAM has developed an integrated platform for demonstrating/ expanding the concept of multi-fabrication (MultiFab) where additive operations based on laser cladding and the micro-plasma powder cladding are combined with high-speed multi-axis machining via integrated software to control the CNC based system. The MultiFab platform can be additionally configured with dimensional scan capability for reverse engineering, as well as for in-process and post-process inspection. Different engineering materials in the form of powders are used to manufacture components with variable compositions of Ni-alloys, tool steels, Ti-alloys, and metal-ceramic composites.



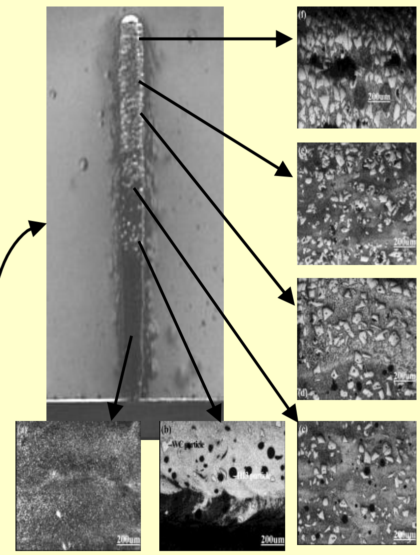
CAD model…

Actual Multifab part

Micro-Plasma Powder deposition

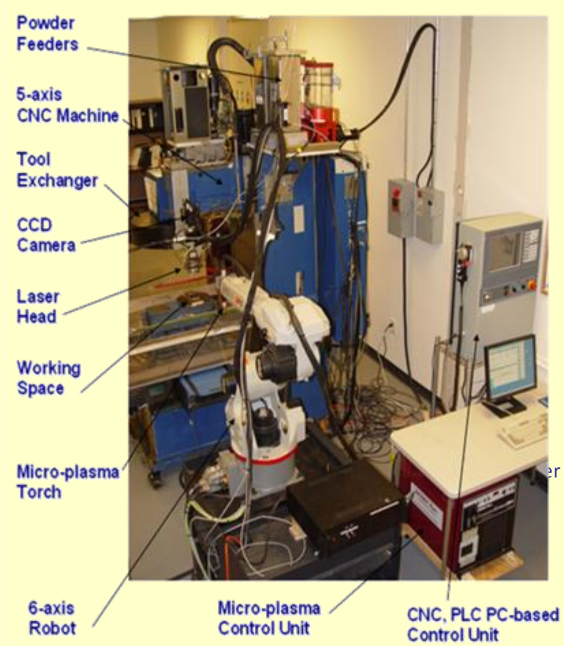


Functionally Graded Material (FGM) part



➢ADVANTAGES

- Repairing high-value components such as dies or molds minimizing cost and production downtime
- Manufacturing spare parts for legacy equipment "on-demand" from CAD files eliminating expensive inventory stock
- Producing components with Functionally Graded Material (FGM) compositions with properties unattainable by current manufacturing processes
- Create custom orthopedic implants or scaffolds using patient's image scans
- Improve surface resistance to heat, abrasion, corrosion, and erosion via laser cladding
- Synthesizing materials to achieve specific mechanical and physical properties



Multi-Fab Integrated Platform

➢RECENT PATENTS

- "System and Method for Controlling Welding Parameters in Welding-based Deposition Process", US Patent No. 6,940,037, issued on Sept. 6, 2005.
- "System and Method for Controlling the Size of the Molten Pool in Laser-based Additive Manufacturing", US Patent No. 6,995,334, issued on February 7, 2006.
- "System and Method for Fabrication or Repairing Part", US Patent No. 7,020,539, issued on March 28, 2006.
- "Powder Delivery System and Method", US Patent No. 7,045,738, issued on May 16, 2006.

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Joint Application Lab for High-Power Direct Diode Lasers

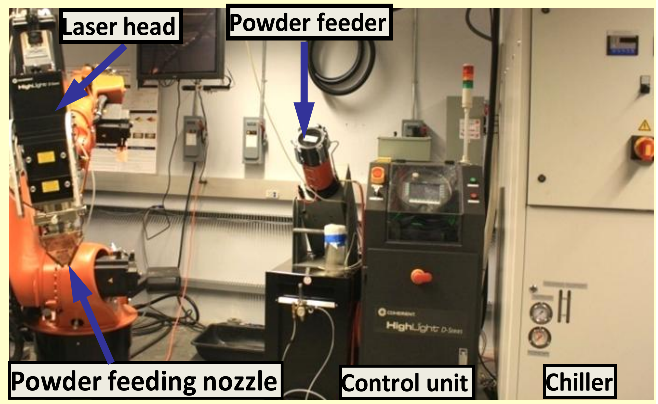
SMU | Center for Laser Aided Manufacturing

SMU | Research Center for Advanced Manufacturing

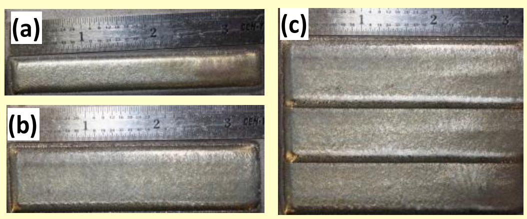
LYLE SCHOOL OF ENGINEERING

➢DESCRIPTION

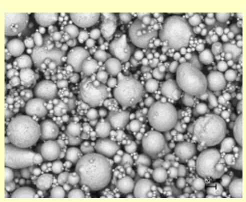
In October 2011, a Joint Application Lab for High-power Direct Diode Lasers has been established at CLAM as a joined effort among SMU, Coherent, Inc., the Army Research Laboratory and KUKA Robotics. Coherent equipped this Laboratory with its newest HighLight 8000D laser, with output power of 8 kW. This is the most powerful, energy-efficient industrial direct diode laser system currently available with free-space beam delivery. This type of laser is specifically developed to provide industry and research community with a cost-effective and controllable power source for heat treatment, cladding and welding in conduction mode.



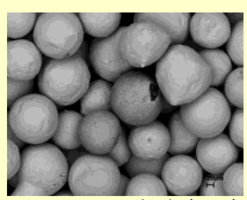
Coherent HighLight 8000D HPDL laser with 6-axis Kuka robot



Super stainless steel (Hoganas) coating on low alloy steel at a laser power of 4000 W, scanning speed of 7.5 mm/s and powder flow rate of 1.8 g/s
(a) single-pass with a beam size of 12 mm × 3 mm
(b) single-pass with a beam size of 24 mm × 3 mm
(c) multi-pass with a beam size of 24 mm × 3 mm



Nickel (Ni) powder



Tungsten carbide(WC) powder

Ni-55%WC (3 mm thick) on AISI 4140 steel at laser power = 3360 W, scanning speed =5 mm/s and powder flow rate = 0.74 g/s

Ni-55%WC composite coating (0.5 mm thick) on AISI 4140 steel at laser power = 3000 W , scanning speed =18 mm/s and powder flow rate = 0.66 g/s at preheating temperature =500°C

➢CHARACTERISTICS AND BENEFITS

- Low laser system cost
- Outstanding system electrical efficiency (~40% wall plug efficiency)
- Enhanced system thermal efficiency (high material absorption (975 nm wavelength), low dilution (4-7%), high quench rates)
- Metallurgical bond with very low porosity and low distortion
- Mobile and remote laser placement, (easy to integrate with a 6-axis robot)
- Specially designed co-axial cladding nozzle with a deposition rate of over 20 lb/hr and powder capture efficiency up to 93%
- Closed-loop control of heat input
- Variable line beam shapes from 1x3 mm to 1x36 mm and with beam width expansion from 1 mm to 12 mm
- High reliability, diode array MTBF – typically 20,000 hours
- Coating thickness from 0.4 mm (thin layer) to 4 mm (thick layer) at a scanning speed of 18 mm/s and 7 mm/s, respectively
- Ability to coat wide variety of materials including composite materials

➢ Industrial Applications

- Oil and gas
- Automotive
- Transportation
- Mining
- Energy sector

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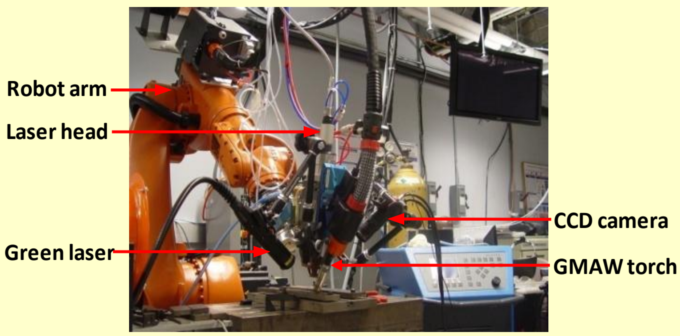
Hybrid Laser/ Arc Welding

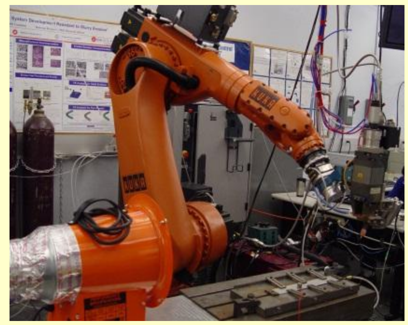
LYLE SCHOOL OF ENGINEERING

➢PROCESS DESCRIPTION

SMU's Center for Laser Aided Manufacturing (CLAM) has been developing a hybrid laser/arc technology which consists of a 4-kW fiber laser, a 6-axis KUKA robot, and one of the traditional GTAW, GMAW or micro-plasma welding systems. This technology leverages the individual strengths of the laser and arc welding processes in one platform.



Hybrid laser/GMA welding system at CLAM



Hybrid laser/GTA welding system at CLAM

➢ADVANTAGES

Deep penetration, high speed, narrow weld bead and HAZ, high quality welds, suppression of humping, reduction of porosities in the weld, possibility to add filler materials, good tolerance to joint fit-up

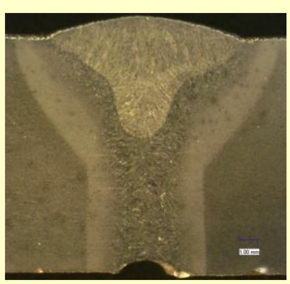
➢CLAM CAPABILITIES

- Welding of galvanized dual phase steel at gap-free overlap joint configuration
- Welding of mild steel, aluminum alloys, titanium alloys, stainless steels, and high strength steels
- Heat treatment via direct diode laser to restore mechanical properties of welded joint in high strength steels
- Monitoring of the welding process using acoustic emission, airborne sound, and machine vision systems
- Metallurgical analysis and mechanical testing of welded materials
- Numerical modeling of the welding process and heat treatment by diode laser

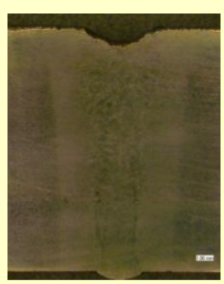
➢INDUSTRIAL APPLICATIONS

- Automotive industry
- Shipyard and marine industries
- Aerospace and aircraft Industries
- Heavy industries

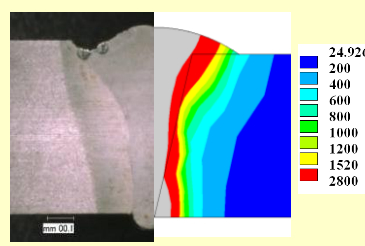
Laser weld



Hybrid laser-GMA weld



Laser with wire feeding



Comparison of experimental and numerical results of cross-sectional weld in Laser-GMA hybrid welding

➢RECENT PUBLICATIONS

- F. Kong, J. Ma, R. Kovacevic. Numerical and experimental study of thermally induced residual stresses in the hybrid laser-GMA welding process. The Journal of Materials Processing Technology. 2011, 211 (6): 1102-1111.
- W. Huang, R. Kovacevic. Development of a real-time laser-based machine vision system to monitor and control welding process, the International Journal of Advanced Manufacturing Technology, DOI:10.10071S00170-012-3902-0,2012.
- W. Huang, R. Kovacevic. A neutral network and multiple regression method for the characterization of the depth of weld penetration in laser welding based on acoustic signature, the Journal of Intelligent Manufacturing, 2011, 22 (2): 131-143.

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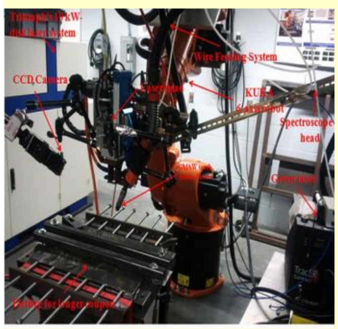
Hybrid Laser/Arc Welding of Dissimilar Materials

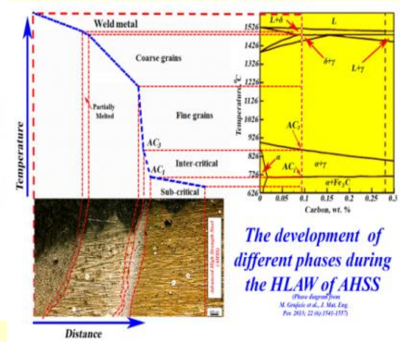
➢PROCESS DESCRIPTION

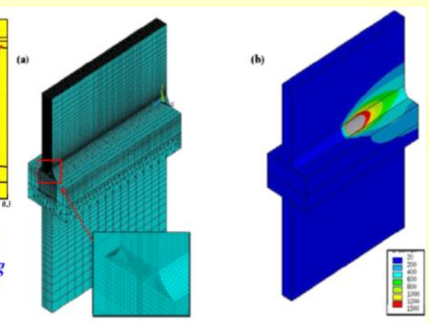
SMU's Center for Laser Aided Manufacturing (CLAM) has been developing combined welding techniques to join dissimilar materials. Based on the current state-of-the-art, it could be concluded that the welding of Advanced High Strength Steel (AHSS) to different aluminum alloys could be achieved only by using the Fe/Al structural transition inserts obtained by explosive cladding. Dynamic Materials Corp., Boulder, Co., provided one research team with TRICLAD® composite material that consist of ASTM 516 Grade 55/Aluminum 1050A/ Aluminum 5086 with thicknesses 19+9.5+6 mm, respectively. The shear strength of the TRICLAD® is typically 96 MPa and the tensile strength is typically 126 MPa. In order to provide a satisfactory load bearing structure and a large enough volume of heat sink a rule of "1:4" has been applied. The mechanical property of the explosively formed clad decreases substantially at the temperature above 300 ° C. One of the ways to keep the temperature at the interface of the TRICLAD® composite material below 300 ° C is the application of hybrid laser/arc welding (HLAW) process where the control of heat is possible by designing the welding procedure.



Experimental setup of the HLAW

The process parameters influencing the final properties of the HLAW of AHSS.

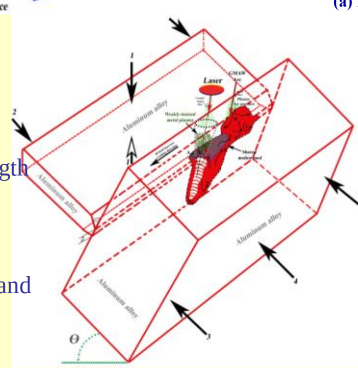




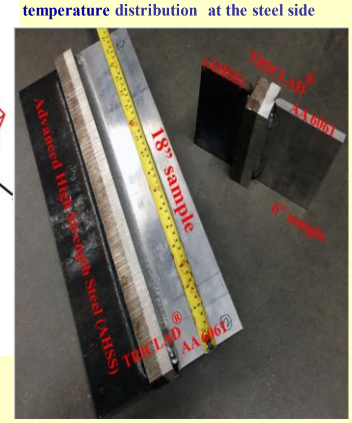
(a) Finite element model and meshing of T-joint, (b) temperature distribution at the steel side

➢CURRENT TOPICS OF RESEARCH

- Numerical investigation of hybrid laser arc welding of advanced high strength steels .
- Experimental and numerical analysis of the hybrid laser/arc welding of dissimilar materials using the TRICLAD in a T-joint configuration.
- Study of the laser welding of dissimilar materials assisted with a hot-wire and cold wire.
- On-line monitoring of the hybrid laser/arc welding of dissimilar alloys in different grooves configurations.



The mechanism of HLAW of aluminum alloys



An image from the welded coupon

➢RECENT PUBLICATIONS

- M. Mazar Atabaki, M. Nikodinovski, P. Chenier, J. Ma, M. Harooni, R. Kovacevic, Welding of aluminum alloys to steels: an overview, J. Manufacturing Science and Production (2014), 14(2): 59-78.
- M. Mazar Atabaki, M. Nikodinovski, P. Chenier, J. Ma, W. Liu, R. Kovacevic, Experimental and numerical investigations of hybrid laser arc welding of aluminum alloys in the thick T- joint configuration, J. Optics & Laser Technology (2014), 59 (7): 68-92.
- M. Mazar Atabaki, J. Ma, G. Yang, R. Kovacevic, Hybrid laser/arc welding of advanced high strength steel in different butt joint configurations, J. Materials & Design, 64 (2014), 573-587.
- W. Liu, J. Ma, G. Yang, R. Kovacevic, Hybrid laser-arc welding of advanced high-strength steel, Journal of Materials Processing and Technology, 214 (12), 2823–2833 (2014).

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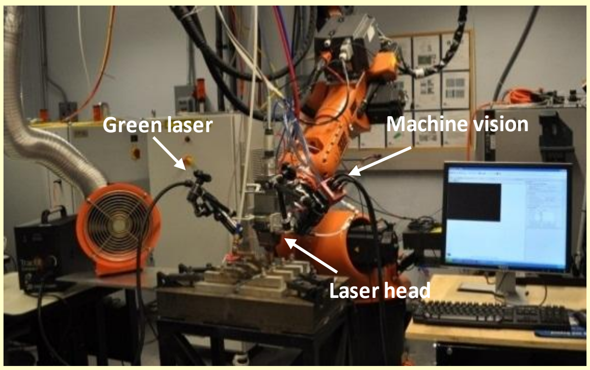
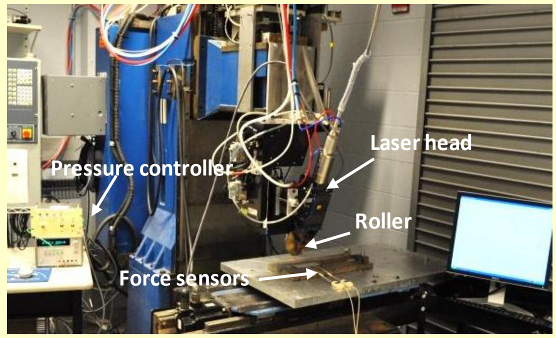
Laser Welding of Galvanized Steels

➢PROCESS DESCRIPTION

SMU's Center for Laser Aided Manufacturing (CLAM) has been in development and evaluation of a hybrid laser/arc technology which consists of a 4-kW fiber laser, a 6-axis KUKA robot, a CNC and a pressure wheel systems. This technology can successfully weld galvanized steels in a zero gap lap joint configuration.





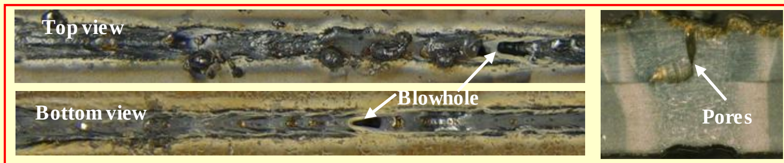
Laser welding with pressure wheel system at CLAM

➢ADVANTAGES

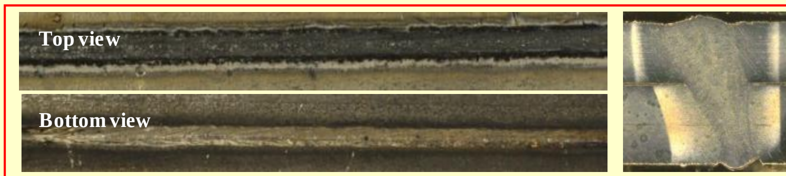
Sound lap-jointed galvanized steel, deep penetration, high speed, narrow weld bead and HAZ, high mechanical properties of welds, suppression of humping, reduction in porosity

➢CLAM CAPABILITIES

- Mitigation of zinc vapor in welding of galvanized high-strength dual-phase steels in a zero gap lap joint configuration by applying:
  - low power low speed laser welding
  - two-pass laser beam welding
  - a controlled compressive load at the interface
  - hybrid laser/GTAW
- Monitoring of the welding process using acoustic emission, airborne sound, spectroscopy and machine vision system
- Metallurgical analysis and mechanical testing of welds
- Numerical modeling of the welding process



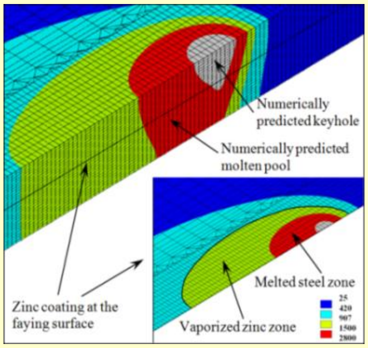
Common defects in laser welding of galvanized steel in lap-joint configuration



High quality galvanized steel joint achieved by laser welding with controlled compressive load

➢INDUSTRIAL APPLICATIONS

- Automotive industry



Numerical simulation of vaporized zinc area at the overlapped interface during laser welding of galvanized steels

➢RECENT PRESENTATIONS

•J. Ma, F.Kong, R. Kovacevic, Finite-Element Thermal Analysis of Laser Welding of Galvanized High-Strength Steel in a Zero-gap Lap Joint Configuration and its Experimental Verification, Materials and Design (2012) Volume: 36, Pages 348–358

• S. Yang, B. Carlson, and R. Kovacevic, Laser Welding of High-Strength Galvanized Steels in a Gap-Free Lap Joint Configuration under Different Shielding Conditions, Welding Journal (2011) Volume: 90, Pages 8-18

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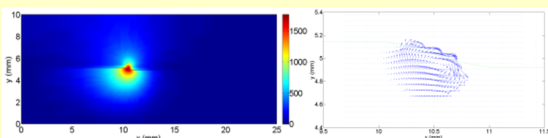
Numerical Simulation of Heat-Based Processes

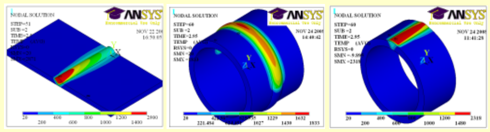
LYLE SCHOOL OF ENGINEERING

➢PROCESS DESCRIPTION

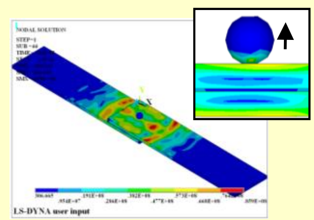
SMU's Center for Laser Aided Manufacturing (CLAM) has been developing numerical simulation of heat and mass transfer in different material processing techniques (cladding, heat treatment and welding), as well as of the erosion of surface impacted by solid particles mixed with liquid. These simulation techniques provide the end-user with the optimized process parameter windows using only a limited number of experiments.



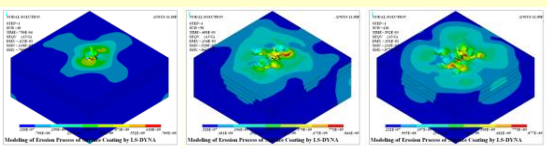
Temperature distribution (left) and fluid flow (right) in the molten pool of laser multilayered cladding



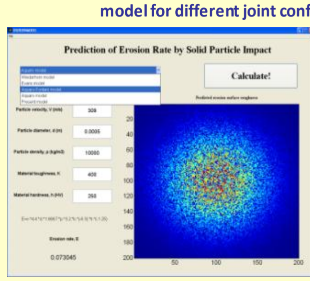
Temperature field of submerged arc welding predicted by FE model for different joint configurations



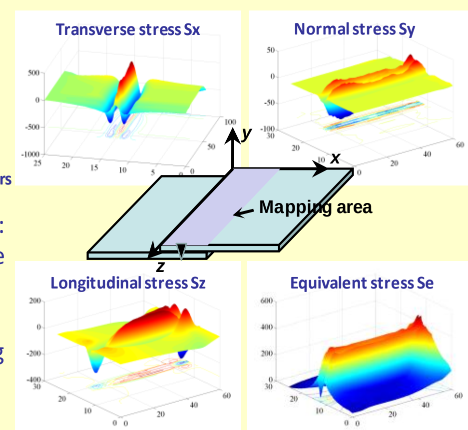
The contours of equivalent stress of adhesively bonded joint under solid particle impact



Sequential contours of equivalent stress distribution at the eroded surface impacted by continuous solid particles mixed with liquid



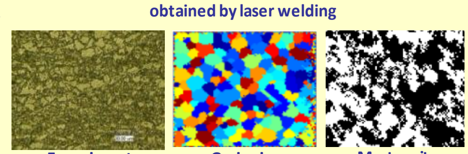
Development of a user friendly interface for parameters optimization in the erosion process



FE modeling of residual stresses at the top surface of a lap joint obtained by laser welding

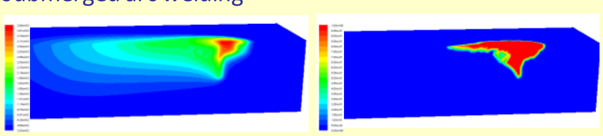
➢CURRENT TOPICS OF RESEARCH

- Modeling of heat transfer and fluid flow in laser-based manufacturing processes: welding, hybrid laser/arc welding, heat treatment, cladding, paint stripping, surface texturing, micro-welding, micro-drilling, micro-cutting
- Modeling of microstructure evolution in laser-based manufacturing processes
- Prediction of residual stresses and the level of distortion in laser-based manufacturing processes
- Dynamic analysis of adhesively boned joints under impact load
- Fatigue life prediction of laser welds
- Thermal implicit-to-explicit modeling of roller hemming of aluminum sheets with laser preheating
- Explicit modeling of erosion process of surface impacted by solid particles
- Numerical simulation of heat transfer and the level of residual stresses in the submerged arc welding

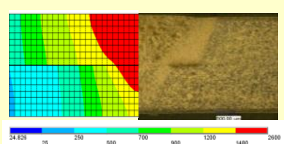


Experiment | Grain size | Martensite

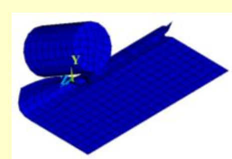
Experimental and numerical results of the microstructure in the HAZ in direct diode laser heat treatment of DP980 steel



Temperature (left) and liquid fraction (right) distribution in the weld pool obtained by hybrid laser-GTA welding with 2 mm stand-off distance from laser to arc



Comparison of the cross-section profiles of weld beads obtained by simulation and by hybrid laser-GTA welding



Deformation of roller hemmed aluminum sheet predicted by using LS-DYNA

➢RECENT PUBLICATIONS

•Fanrong Kong, Radovan Kovacevic. Modeling of heat transfer and fluid flow in the laser multilayered cladding process. Metallurgical and Materials Transactions B, 2010, 41(6): 1310-1320.

•S. Santhanakrishnan, Fanrong Kong, and Radovan Kovacevic. An experimentally-based thermo-kinetic hardening model for high power direct diode laser cladding. Journal of Materials Processing Technology. 2011, 211 (7): 1247-1259.

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CENTER FOR LASER AIDED MANUFACTURING
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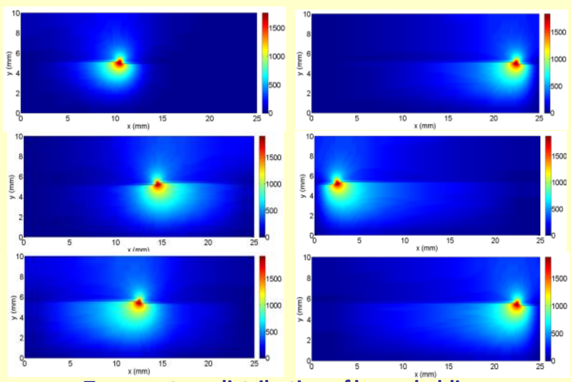
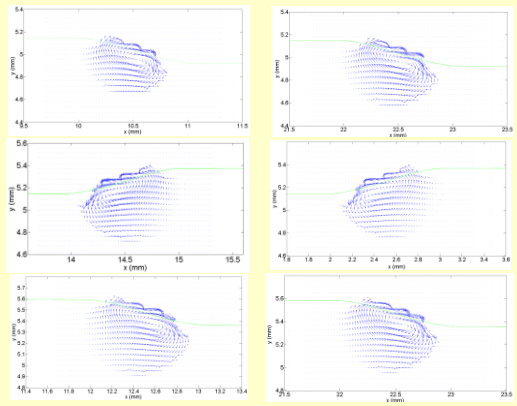
Modeling of Laser Cladding

➢PROCESS DESCRIPTION

SMU's Center for Laser Aided Manufacturing (CLAM) has been developing numerical simulation models for heat and mass transfer processes in the laser material processing, cladding, heat treatment and welding, as well as the erosion model of coated surface impacted by solid particles. These simulation techniques provide the end-user with the optimized process parameter windows using only a limited number of experiments.



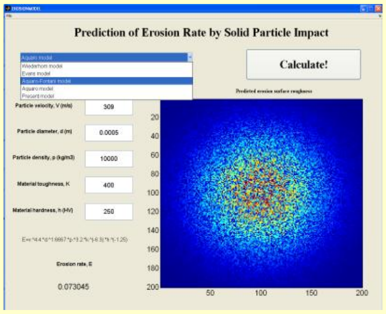
Temperature distribution of laser cladding



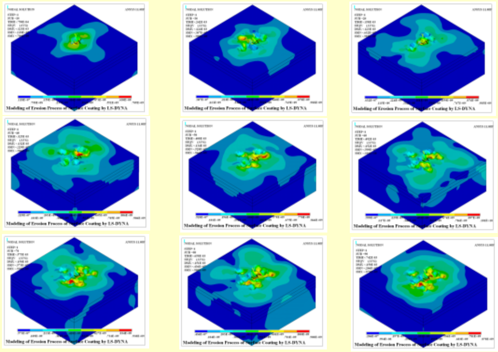
Fluid flow in the molten pool of laser cladding

➢CLAM CAPABILITIES

- Heat management of laser cladding as well as laser direct deposition manufacturing
- Fluid flow and surface evolution track of the molten pool in the laser cladding process
- Solute diffusion due to the convection of liquid phase in the molten pool in the laser cladding of surface coating
- Residual stress prediction and metallurgical analysis of clad materials
- Grain growth prediction in the solidified clad zone by using Finite Element-Monte Carlo (FE-MC) model
- Erosion model of surface coatings by solid particles impact
- Development of user friendly interface for parameters optimization in laser cladding and for simulating the erosion process by impacting the laser coated surface



Development of a user friendly interface for parameters optimization in the erosion process



Simulation of erosion process of surface coatings by solid particle impact

➢RECENT PUBLICATIONS

•Fanrong Kong, Radovan Kovacevic. Modeling of heat transfer and fluid flow in the laser multilayered cladding process. Metallurgical and Materials Transactions B, 2010, 41(6): 1310-1320.

•S. Santhanakrishnan, Fanrong Kong, and Radovan Kovacevic. An experimentally-based thermo-kinetic hardening model for high power direct diode laser cladding. Journal of Materials Processing Technology. 2011, 211 (7): 1247-1259.

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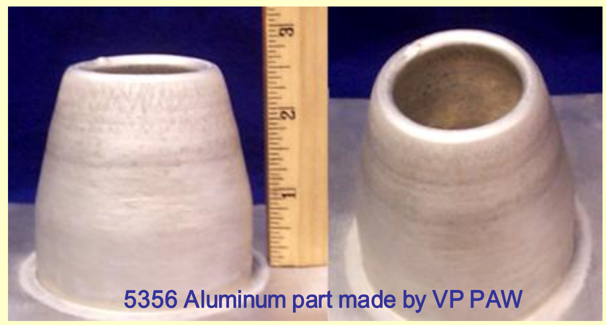
Rapid Manufacturing/Repair of Aluminum Alloy Parts

LYLE SCHOOL OF ENGINEERING

➢PROCESS DESCRIPTION

- Rapid manufacturing/repair techniques have been under development at SMU's RCAM using Variable Polarity Plasma Arc Welding (VPGPAW) for depositing layer by layer of aluminum alloys. The controllable shape and duration of the current pulse guarantees low dilution and high quality buildup formation.
- The system components consist of a precision five-axis CNC, the VPGTAW power source, sensing control units, wire feeder and a host computer with a custom software interface to coordinate communications.

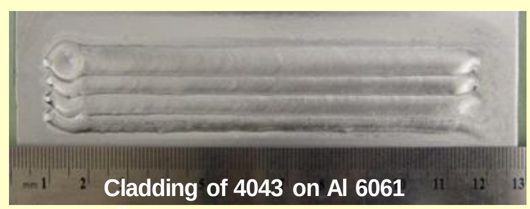
Variable Polarity Plasma Arc Welding Machine incorporated with a multi-axis CNC positioning system



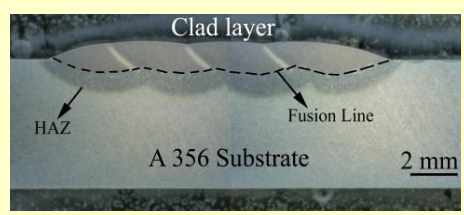
5356 Aluminum part made by VP PAW

➢INDUSTRIAL APPLICATIONS

- Rapid manufacturing of high-quality functional parts made of aluminum alloys.
- Repair of aluminum parts (e.g. undersized cast and machined parts) with low dilution.



Cladding of 4043 on Al 6061 alloy



Low depth of penetration of the clad

➢RCAM's CAPABILITIES

- Rapid Manufacturing of functional aluminum parts.
- Cladding on wrought and cast aluminum alloys with excellent metallurgical bonding, low depth of penetration, and good mechanical properties.
- Characterization of material properties.
- In-line sensing and monitoring of the process by spectroscopy, acoustic emission, and machine vision.
- Numerical simulations of material flow, heat transfer, and residual stress.

➢SELECTED PUBLICATIONS

- H. Wang and R. Kovacevic, "Rapid Prototyping Based on Variable Polarity Gas Tungsten Arc Welding for Aluminum Alloys", *Proc. Inst. Mech. Engrs.*, Part B: *Journal of Engineering Manufacture, Vol.215,* 2001, pp.1519-1527
- J. Ouyang, H.Wang, R. Kovacevic, "Rapid Prototyping of 5356-Aluminum Alloy Based on Variable Polarity Gas Tungsten Arc Welding", *Journal of Materials and Manufacturing processes*, 17(1), 2002, pp. 103-124

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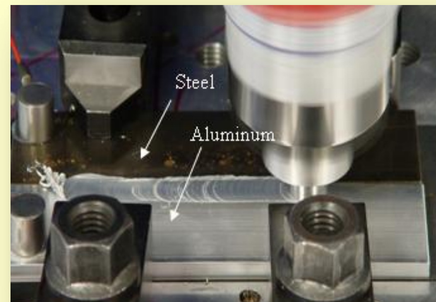
Friction Stir Welding

LYLE SCHOOL OF ENGINEERING



FSW of 1018 St to 6061 Al

➢PROCESS DESCRIPTION

Friction stir welding (FSW) is a solid-state joining process invented by TWI, UK in 1991. In this process:

- A rotating tool is inserted in the material which traverses along the joint.
- The rotary motion of the tool generates heat which creates a soft and plasticized region around the pin and the shoulders.
- A durable weld is produced by extrusion and forging of the plasticized material from the leading side to the trailing side of the moving.


FSW Facilities in RCAM

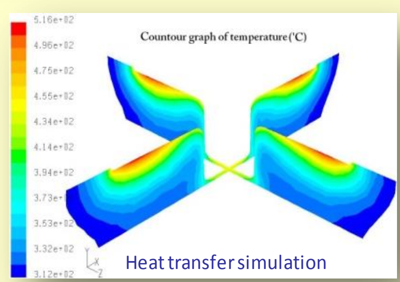
➢CURRENT INDUSTRIAL APPLICATIONS

- Automotive (Ford, Mazda, Audi, BMW, …) for engine and chassis cradles, wheel rims, truck bodies, fuel tanks, and motorcycle frames
- Aerospace (NASA, Eclipse Aviation, Lockheed Martin, …) for wings, cryogenics fuel tanks for space vehicles, aviation fuel tanks, external throw away tanks in military applications
- Ship building and marine industries for welding panels in docks, sides and floors, helicopter landing platforms, and marine structures
- Railway industry for welding tankers and wagons

➢RCAM's R&D ACTIVITIES

- FSW of similar and dissimilar aluminum alloys (1xxx to 7xxx series)
- FSW of dissimilar materials (Steel-Al, Cu-Al, Al-Ti, and other materials)
- FSW in different joint designs (Butt, edge-butt, and Lap)
- FSW in rapid manufacturing (e.g. abrasive water-jet cutting, FSW, and machining to produce complex products)
- Designing and manufacturing of the FSW tools for wear-resistive applications using laser-based direct metal deposition (LBDMD)
- Weld microstructural analysis and mechanical tests
- Sensing and monitoring of the process using load cells, thermo-couples, and acoustic emission sensors
- Numerical simulations (material flow, structural, and heat transfer analysis)


Hybrid manufacturing of complex parts



Heat transfer simulation

➢SELECTED PUBLICATIONS

- Chen, C. M., and Kovacevic, R., Joining of Al 6061 alloy to AISI 1018 steel by combined effects of fusion and solid state welding, *International Journal of Machine Tools & Manufacture*, Vol. 44(11), 2004, pp. 1205-1214.
- Soundararajan, V., Atharifar, H., and Kovacevic, R., Monitoring and processing the acoustic emission signals from the friction-stir-welding process, Journal of Engineering Manufacture, Vol. 220(10), 2006, pp. 1673-1685.
- Atharifar, H., Lin, D. and Kovacevic, R.,"Numerical Simulation and Experimental Investigations on the Loads Carried by the Tool During Friction Stir Welding", the Journal of Materials Engineering and Performance, Vol. 18(4), June 2009, pp. 339-350.
- Chen, C.M. and Kovacevic, R., "Parameteric Finite Element Analysis of Stress Evolution during Friction Stir Welding", the Proceedings of the Institution of Mechanical Engineers, Part B, Journal of Engineering Manufacture, Vol. 220, (2006) pp. 1359-1371.

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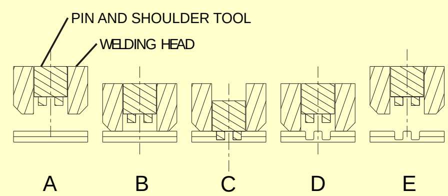
Friction Stir Spot Welding

LYLE SCHOOL OF ENGINEERING

➢PROCESS DESCRIPTION

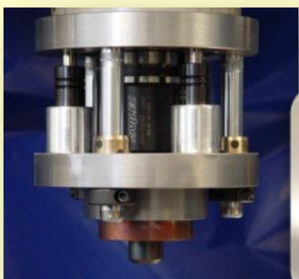
As a subsidiary process for FSW, friction stir spot welding (FSSW) is an alternative process to resistive spot welding (RSW) where the fusion of materials is replaced by solid-state joining. SMU-RCAM invented a new device for FSSW (see the patent app. below) characterized with the following functions:

- The FSSW welding head is placed above the area to be welded (position A).
- Rotation of the tool is initiated, and the welding head is brought into contact with the workpiece (position B).
- The tool with multiple pin is then pressed into the workpiece while the welding head is held in place (position C).
- The tool is then retracted (position D), and finally the welding head is moved away from the workpiece (position E).
- RCAM's invented welding head is capable to generate one weld-per-second.



Sequence of operations in FSSW

Typical FSSW weld with developed tool



RCAM FSSW welding head

Multiple-pin tool

➢R&D AREAS

- FSSW of similar and dissimilar aluminum alloys (1xxx to 7xxx series)
- FSSW of dissimilar materials (Steel-Al, Cu-Al, Al-Ti, and other materials)
- Weld microstructural analysis and mechanical tests
- Sensing and monitoring of the process using load cells, temperature, and acoustic emission sensors
- Numerical simulations (material flow, structural, and heat transfer analysis)

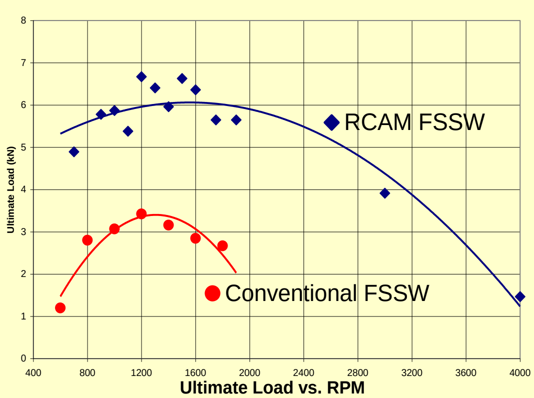
➢INDUSTRIAL APPLICATIONS

- Automotive (Ford, Mazda, Audi, BMW, …)
- Aerospace (NASA, Eclipse Aviation, …)
- Ship building and marine industries
- Railway industry

Weld from conventional tool

Weld from multiple-pin tool

Comparison indicates a greater volume of plastic flow around the proposed tool as compared to the conventional tool, as well as the absence of "pull-up" defects near the faying surfaces



Ultimate Load vs. RPM
For FSSW 10mm Spot, AA6022-T4, 1.9mm Thick (X2), 75mm/min

➢PUBLICATIONS

- Valant, M., Yarrapareddy, E., and Kovacevic, R., A novel tool design for friction stir spot welding, *ASM 7th International Conference on Trends in Welding Research,* Pine Mountain, GA., 2005.
- Valant, M., and Kovacevic, R., System and method for friction stir spot welding, US Patent Application No. 11/279,908, April 17, 2006.

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Laser Curing of Powder Coating with Closed Loop Control of Heat Input

➢PROCESS DESCRIPTION

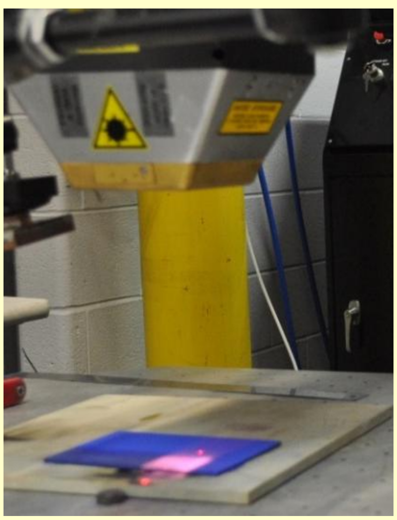
SMU's Center for Laser Aided Manufacturing (CLAM) in cooperation with Photo Fusion Technologies from Arlington, TX has been working on the closed-loop control system of localized laser curing of heat curable powder coatings. The objective of this research is to optimize the process parameters necessary for uniform curing of powder coatings over various substrates. The approach involves a closed loop control system of the heat input and modeling of heat transfer during powder coating as a function of the substrate heat sink conditions.

➢INDUSTRIAL APPLICATIONS

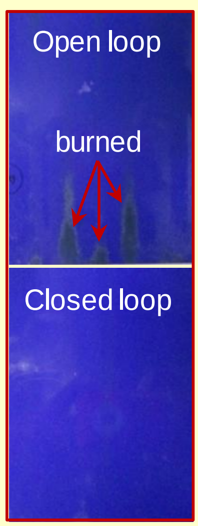
- Aerospace
- Aircraft (commercial and military)
- Pipeline system
- Shipyard and marine equipment
- Pulp and paper equipment
- Chemical storages

➢ ADVANTAGES

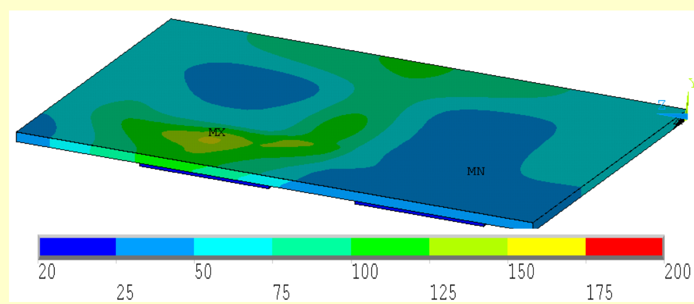
- Locally curing in-situ small patches
- Environmentally friendly
- Accurate control of heat input
- High efficiency and no limitations of workpiece dimensions
- Portable system



Defocused spot of direct Diode laser in curing thermoplastic powder



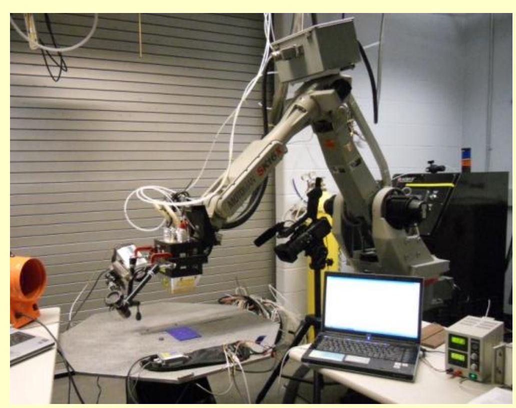
Laser cured coupons without and with closed loop control of heat input



Numerical simulation of heat transfer for powder curing on the substrate with different volumes of heat sinks

➢CLAM's CAPABILITIES

- Two robotized stations in operation, one equipped with a fiber coupled diode laser of 1 kW in power and the other one equipped with a direct diode laser of 2 kW in power.
- Microstructural and surface quality analysis with mechanical testing of coatings
- Real-time process monitoring via temperature and spectral analysis.
- Numerical simulations (heat transfer analysis).



Laser curing facilities at CLAM

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Paint Removal via Direct Diode Laser Ablation

LYLE SCHOOL OF ENGINEERING

➢PROCESS DESCRIPTION

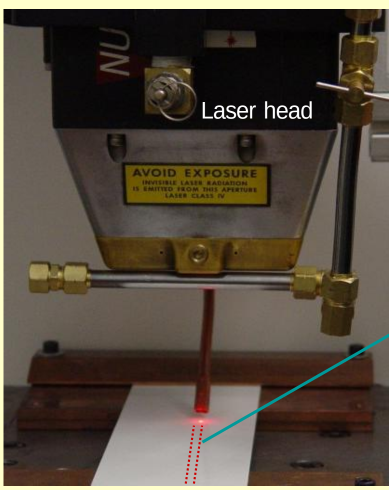
SMU's Center for Laser Aided Manufacturing (CLAM) has been studying the issues surrounding selective top coat paint removal via "on-the-fly" laser ablation. The objective of the research is to control removal of the surface layer by a heat input management while maintaining the functionality and original thickness of the underlying primer. This non-pyrolytic ablation technology has been successfully demonstrated on aluminum substrates. Carbon composite aircraft surfaces will also be studied as this minimally intrusive removal technique may prove an optimal solution.

➢INDUSTRIAL APPLICATIONS

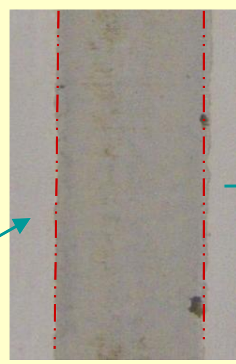
- Aerospace – Aircraft (commercial and military)
- Nuclear industry paint removal on contaminated surfaces
- Shipyard and marine industries
- Salvaged automotive parts
- Graffiti removal

➢ ADVANTAGES

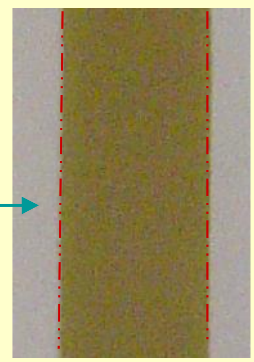
- Environmentally friendly
- Selective layer removal without damaging of primer
- Compatible with composite substrates (low heat input)
- Easily automated



Removal of white polyurethane paint from primer surface



Appearance of paint surface immediately after laser ablation



Appearance of the same surface after debris removal

➢RCAM's CAPABILITIES

- Two robotic paint removal stations in operation, one equipped with a fiber coupled diode laser of 1 kW in power and the second one with a direct diode laser of 2 kW in power.
- Microstructural analysis and mechanical testing of materials
- Real-time process monitoring via temperature, acoustic emission and spectral analysis.
- Numerical simulations (heat transfer analysis).

Robotically driven Direct Diode Laser platform

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Development of Lead-free Composite Solders Reinforced by Nanoparticles

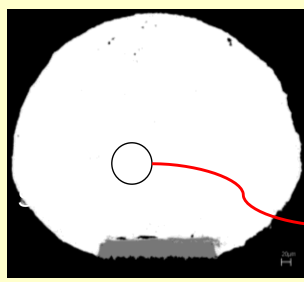
LYLE SCHOOL OF ENGINEERING

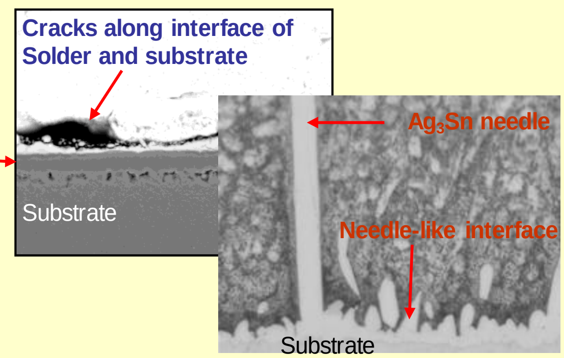
➢INTRODUCTION OF NEW COMPOSITE SOLDERS

SMU's Research Center for Advanced Manufacturing (RCAM) has developed improved composite lead-free solders derived from Sn-Ag and Sn-Ag-Cu systems and enhanced/ reinforced with nanoparticles of various materials as well as a technique to mitigate the tin whiskers growth. Investigation has shown that copper nanoparticles will reinforce the solder itself, but they fail to strengthen the interface between the solder and substrate. Nickel nanoparticles in solders will significantly improve the solder structure and strengthen both the solder and the solder/substrate interface. It is known that the multiple layering of Ni and Sn could prolong the appearance of tin whiskers.

➢AVANTAGES

- High strength and longer fatigue life
- Improved thermal reliability
- Mitigate the growth of tin whiskers





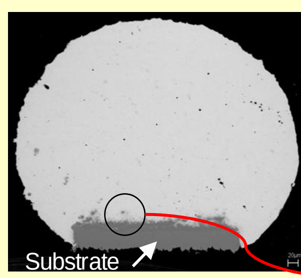
Commercially available Lead-free Solder "bumped"

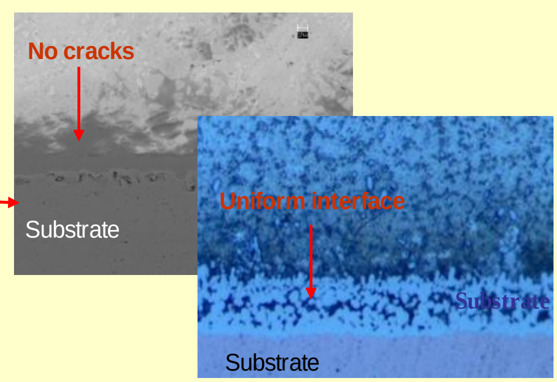
➢OUR CAPABILITIES

- Development of lead-free solders
- Modeling and testing solder systems
- Controlling the growth of tin whiskers

➢INDUSTRIAL APPLICATIONS

- Electronics packaging
- Surface mount technology
- Any critical electronic assembly





RCAM's composite solder enhanced with nanoparticles

➢RECENT PUBLICATIONS

- D.C. Lin, R. Kovacevic, et. al. (2007), An Investigation of the Influence of Nanoparticle Reinforcements on Microstructural Development in Lead Free Tin-Silver Solder. International Journal of Nanomanufacturing, Vol. 1, No. 3, 357-369.
- D.C. Lin, R. Kovacevic, et. al. (2006), Microstructural Development of a Rapidly Cooled Eutectic Sn-3.5% Ag Solder Reinforced with Copper Powder, Powder Technology. Vol.166, pp38-46.
- Dimitrovska, A. and Kovacevic, R., "Mitigation of Tin Whiskers Growth by Applying Multiple Ni/Sn Plating Prior to the Final Sn Finish", the Journal of Electronic Materials, Vol.38, No. 12, 2009, pp. 2516 – 2524.
- Dimitrovska, A. and Kovacevic, R., "The Effect of Micro-alloying of Tin Plating on Mitigation of Tin Whiskers Growth", IEEE, the Journal of Electronic Materials, Vol. 38, No. 12, 2008, pp. 2726-2734.

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SMU. CENTER FOR LASER AIDED MANUFACTURING

SMU. RESEARCH CENTER FOR ADVANCED MANUFACTURING

Application of Arc Surface Treatment in Adhesive Bonding

➢PROCESS DESCRIPTION

• SMU's Research Center for Advanced Manufacturing (RCAM) has been studying the effect of complex physical phenomenon of cathodic arcs in cleaning oxides layer from aluminum alloys surface before welding. It has been observed that the cathode spot generation on the surface of non-thermionic substrate such as aluminum, titanium, etc. can texture the surface. The experimental studies have shown that arc discharge can significantly increase the wettability of treated surfaces as well as the strength of the adhesive joint.

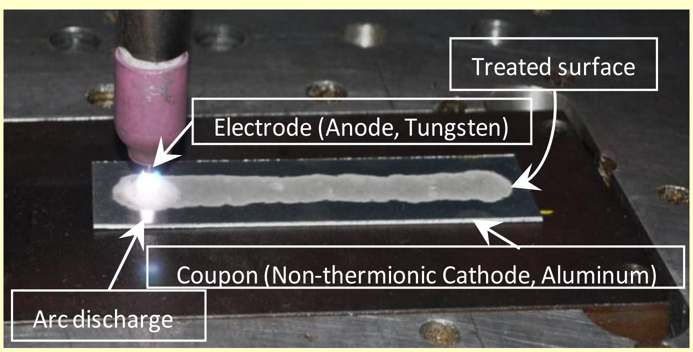
➢INDUSTRIAL APPLICATIONS

❑ Treating surface for:

- Welding of aluminum alloys
- Adhesive bonding and painting

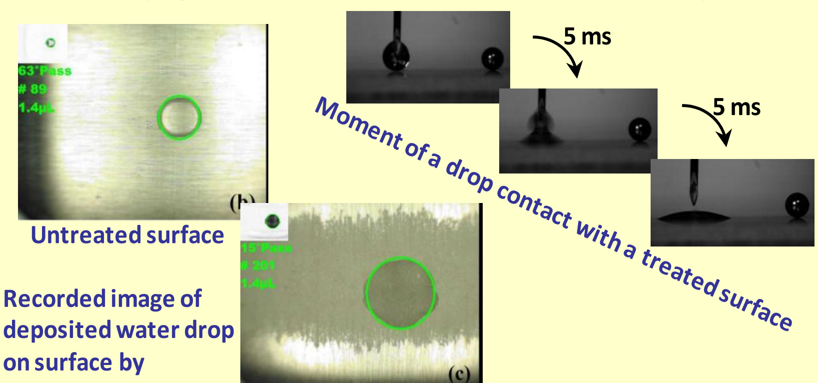
➢ADVANTAGES OF ARC SURFACE TREATMENT

- Environmentally friendly
- Rapid and single-step process
- Capability to treat 3D and/or complex geometry objects
- No damage to bulk material
- Easily automated
- Economic al



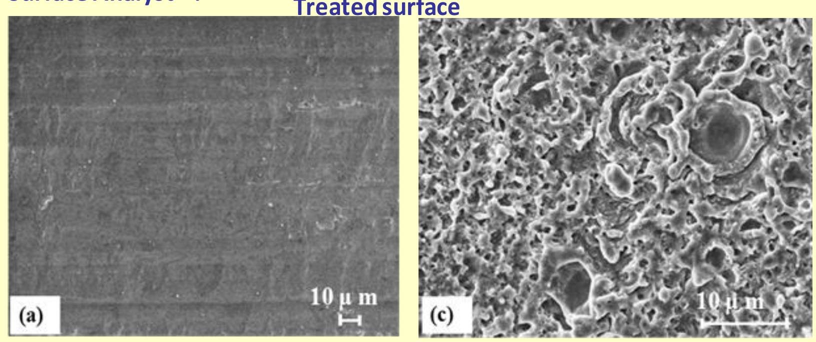
Principle of arc discharge treatment process based on formation of cathodic spots

Studying the effect of surface treatment on its wettability



Recorded image of deposited water drop on surface by Surface Analyst™:

Treated surface



SEM images of: (a) untreated coupon surface (b) treated coupon surface

➢RCAM's CAPABILITIES

- Performing adhesive bonding
- Surface characterization including optical profilometer, high accuracy vision system
- Microstructural analysis (access to SEM, EDS, etc.) and mechanical testing of materials (tensile testing, microhardness, etc.)
- Real-time process monitoring
- Numerical simulation

➢RECENT PUBLICATIONS:

- Sarrafi, R. and Kovacevic, R., "Cathodic Cleaning of Oxides from Aluminum Surface by Variable-Polarity Arc," Welding journal, 89 (2010):1-s-10-s
- Rouzbeh Sarrafi, Mehdi Asgharifar, and Radovan Kovacevic "Surface Texturing of Metals by Cathode Spots of Atmospheric Arc" ASME Conf. Proc. 2 (2011): 323-329
- Asgharifar, M., Kong, F., Carlson, B., Kovacevic, R., "Studying Effects of Arc Discharge Surface Texturing on Stress Distribution in Adhesively Bonded Joints by Using Finite Element Modeling" ASME Conf. Proc. 2 (2011): 1-7

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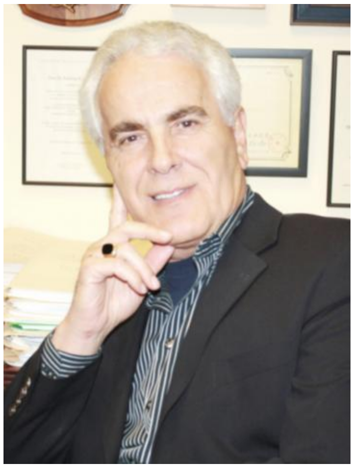
Radovan Kovacevic



Herman Brown Chair in Engineering

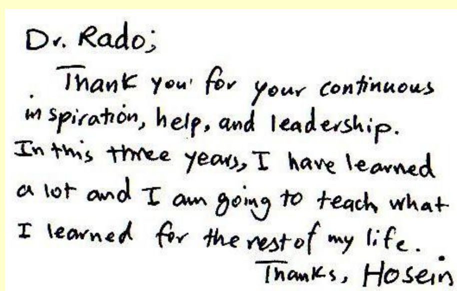
Professor of Mechanical Engineering

Director of Research Center for Advanced Manufacturing and Center for Laser-aided Manufacturing

Since August 1997, Dr. Radovan Kovacevic has been a Herman Brown Chair in Engineering and a Professor of the Mechanical Engineering at SMU. He has also been a founder and Director of the Research Center for Advanced Manufacturing since 1999 and a Director of the NSF Industry/University Cooperative Research Center for Lasers and Plasmas for Advanced Manufacturing (SMU's site) since 2005. Prior to joining SMU, Dr. Kovacevic was a faculty member at the University of Montenegro, former Yugoslavia, for fifteen years, at Syracuse University for four years, and at the University of Kentucky for six and a half years. His research interest is in materials processing by high-power lasers, abrasive water jet, and electron beam; hybrid laser/arc welding; friction stir welding; numerical simulation of heat transfer in fluid flow in different manufacturing processes; monitoring and control of different manufacturing processes; micro-machining by short-pulsed lasers; rapid manufacturing with reverse engineering; and design and manufacturing of bio-medical implants. Dr. Kovacevic is a Fellow of three prominent engineering societies: the American Welding Society (AWS); the American Society of Mechanical Engineers (ASME); and the Society of Manufacturing Engineers (SME). He was awarded the 2000 Taylor Research Medal by the Society of Manufacturing Engineers for his accomplishments in education and research related to manufacturing engineering. Additionally, he was a recipient of the Alexander von Humboldt Scholarship (Germany) for two years, Carl Duisberg Scholarship (Germany) for one year and the Fulbright Foundation Scholarship for one year. His work has been presented to the engineering community in over 580 technical papers, six books, seven U.S. patents and over 20 invention disclosures. Since 1987, his research activities have been financially supported by a number of state and federal agencies and the industry in excess of $20 million. Over 200 graduate students, visiting scholars, undergraduate interns, and high school teachers have worked in his laboratories since 1987. He graduated 32 Ph.D. candidates and his publications have been cited over 5700 times with the citation index h=38. More information on his research activities is available at www.lyle.smu.edu/rcam and www.lyle.smu.edu/clam.

The following statements are excellent testimonials of Dr. Kovacevic's accomplishments as a teacher, adviser, and researcher.

- Dr. Hosein Atharifar, an Assistant Professor at the Department of Industry and Technology of Millersville University of Pennsylvania, a former doctoral student of Dr. Kovacevic who graduated in May of 2008, wrote to Dr. Kovacevic the following note:



Dr. Rado;

Thank you for your continuous inspiration, help, and leadership. In this three years, I have learned a lot and I am going to teach what I learned for the rest of my life.

Thanks, Hosein

- On February 28, 2009, Dr. Jianming Qu, a Professor and Associate Chair in the School of Mechanical Engineering at Georgia Institute of Technology sent a thank you note to Dr. Kovacevic after his visit to SMU with the following content:

  "Dear Radovan,

  It was a great pleasure meeting you last week. I am extremely impressed by the quality and quantity of your research operation there. It is amazing that you single handedly developed such a large-scale research program within such a short period of time. I have visited many universities and met a lot of people in the manufacturing area. I rarely see an individual who has carried that much research.

  Thank you again and best wishes, Jianmin"

- Dr. Geoffrey Orsak, Dean of Lyle School of Engineering made the following statement in the article "SMU Graduate School Specializes in Green and Joining Technology", published in the Welding Journal, June 2010:

  "The RCAM and CLAM have brought a great deal of international visibility to the SMU Lyle School of Engineering. The quality and impact of the work conducted in these two aligned centers is simple spectacular".

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