R & D Work in Additive Manufacturing at SMU

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“Everything in the factories of the future will be run by smarter software.”[1]

Additive Manufacturing at SMU

Fusion-based Techniques

– Laser-based Direct Metal Deposition \((US\ Patent\ no.\ 7,020,539)\)
– Electron Beam Melting®
– Gas Metal Arc Welding/Machining
– Micro-plasma Powder Cladding
– High-power Direct Diode Laser Cladding

Solid state-based Technique

– Friction Stir Welding
Patents Related to MultiFab Technology


Multi-Fabrication Manufacturing/Repair System (MultiFab)

MultiFab combines depositions by welding and laser cladding, multi-axis machining, and in-situ inspection into one highly integrated system based on a 6-axis robot and a 5-axis high speed CNC machining center, providing the next generation technology for rapid and precise net-shape manufacturing using metals and ceramics.
Prototype of Multi Fabrication (MultiFab) System

**LASER:**
- Finer geometrical features
- Smaller heat affected zone
- Less porosity
- Multiple material composition
- Better control of material properties

**WELDING:**
- Larger geometrical features
- Higher deposition rate
- Controlled heat input
- Controlled deposition rate

**MACHINING:**
- Complex geometrical features
- High dimensional accuracy
- High surface quality
Advantages of MultiFab Technology

- 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
- Improve surface resistance to heat, abrasion, corrosion, and erosion via laser cladding
- Synthesizing materials to achieve specific mechanical and physical properties
MultiFAB Presentation-Rapid Manufacturing
Laser-based Direct Metal Deposition

Click the screen to start the Movie
Close-up of MultiFab System

Machining of Sample Built by LBDMD

3D Sample Built by Laser-based Direct Metal Deposition (LBDMD)
Samples Built on MultiFab

Hollow Spiral

Gear

Slender Spiral
MultiFab CAM Software Solution

1. **CAD Files**
   - ProE/Solidworks

2. **CopyCAD/PowerSHAPE from Delcam**
   - CAD tool for Extracting geometric information

3. **PowerMILL from Delcam**
   - CAD tool for tool path generation

4. **MultiFabCAM**
   - Graphical User Interface
   - NC-Code
   - Post Processor

5. **PowerINSPECT from Delcam**
   - In-situ and post-fabrication Inspection

6. **Multi-Axis High speed Machining**

7. **KUKA Robot**
   - Tilt and Rotary Table
Information Flow in MultiFab

CAD Solid Model → Slicing & Path Planning → NC - Code → In-Process Sensing → Manufacturing → Finished Part
MultiFab as a Base for the Development of a “Mobile Part Hospital”
Schematic presentation of activities on MultiFab

Development of Rapid Manufacturing / Repair System - MultiFab

Software Development for CAD/CAM
- Path planning for additive/subtractive
- Multi-axis deposition planning
- Functionally Graded Material Design
- Repair

Process Additive/Subtractive
- Subtractive
- High-speed Multi-axis Machining
- Additive
- Laser Deposition
- Micro Plasma Powder Cladding
- Micro GTAW
- Controllable GMAW
- Hot Wire

Sensing / Control
- Powder Feeding
- Wire Feeding
- Molten Pool
- Power Source
- Position
- Scanning for Reverse Engineering
- Working environment

Numerical Simulation and Process Optimization
- Heat Transfer
- Fluid Flow
- Stress Evolution

Manufacturing / Repair of 3D Components of Monolithic and/or Functionally Graded Composition
A robotized laser-based direct metal deposition system

Click the above title to start the movie
Robotized Additive/subtractive system
A case on manufacturing of propeller

Click the above title to start the movie
1D FGM-Functionally Graded Material (H13+%WC)
Discretization and Material Field Overlap for FGM Model

Geometric model

Voxel model

Material field overlapped over Geometric model

Tool Path Generation Over a Slice

Maxel-volume plus material
3D Printed Tool for Friction Stir Welding with FGM Microstructure

H13 Vs WC composition

<table>
<thead>
<tr>
<th>Distance from tool axis</th>
<th>Material Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% WC</td>
</tr>
<tr>
<td></td>
<td>% H13</td>
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</tbody>
</table>

![Graph showing H13 Vs WC composition](image)

![Images of microstructure at various distances from the tool axis](image)

![3D printed tool image](image)

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SMU | CENTER FOR LASER AIDED MANUFACTURING

SMU | RESEARCH CENTER FOR ADVANCED MANUFACTURING
Development of powder flow rate sensor

1. Powder feeder

Advantages of new powder feeder:
- Powder delivery based on pressure difference
- Powder mass flow is linear function of the set-point input
- High resolution
- Repeatability
- Scalability
- Flow rate is controlled by controlling the speed of a servo motor

2. Flow rate sensor

Schematic of the flow rate sensor

Flow rate sensor
3. **Calibration**

Set motor voltage from 0 to 0.5 v with constant interval 0.05 v. Last several seconds at each motor voltage, collect the powder to get average powder flow rate (Fig. 1). During each collection process, average output voltage of the flow rate sensor was calculated (Fig. 2).

Good linear relationship when powder flow rate is less than 1.1 g/s.

4. **On-line sensing and control**

![Diagram of on-line sensing and control](image)
Development of Real-time Sensing and Control of the Molten Pool

1. Setup

Patent No. 6995334
Issued on Feb 7, 2006
2. Calibration of the infrared image of molten pool

Steps:
1. Capture video image of the molten pool (without powder);
2. Detect contour of the molten pool in video image;
3. Capture infrared images under same scanning conditions;
4. Overlap video and infrared images to get contour of the molten pool on an infrared image.

Coaxially acquired infrared image of the molten pool (laser power 1000 W, scanning speed 20 mm/s). Original image (left); overlapped result with grayscale threshold of 97 (right)
3. Molten pool in LBDM with closed-loop control

- Laser power: 400 W
- Scanning speed: 5 mm/s
- Powder flow rate: 0.45 g/s
4. Molten pool in LBDM with closed-loop control (PID)

Set pool size: 12000 pixels
Scanning speed: 5 mm/s
Powder flow rate: 0.45 g/s

Click the screen to start the Movie
5. Comparison between non-controlled and controlled molten pool in LBDMD

- **without control**
- **with control**

Horizontal cross section

Vertical cross section
Hybrid Rapid Manufacturing/Repair Based on Deposition by Welding and CNC Machining
• Goal is to keep the *droplet size* and *droplet transfer rate* within a certain range.

• A pulse period is divided into two periods:
  - growth period and
  - detachment period.
Metal Transfer Control in GMAW

Heat and mass transfer

Active metal transfer control

A-Metal transfer process with 100 A of average current.

B-Metal transfer process with 165 A of average current.

C-Welding current

D-Droplet tip coordinate.

Solid squares indicate the detachment.
Manufacturing Procedure in Building Part with 3D – Conformal Cooling/Heating Channels by GTADMD

CAD Model

Machining

Computer controlled Gas Tungsten Arc-based Direct Metal Deposition

Making cooling channel

Support Structure for cooling channel

Final part
Experimental Set-up for Micro-Plasma Powder Cladding (MPPC)
Samples Built by MPPC
Rapid manufacturing/repair techniques have been under development at SMU’s RCAM using Variable Polarity Gas Tungsten Arc Welding (VPGTAW) with 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.
Samples Built by VPGETAW

"Cylinder" shape part

"Cone" shape part

"Pipe reducer" shape part
Thank you