Process Control For Wire-Arc Additive Manufacturing

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Content

1 Concept of WAAM
2 Challenges to WAAM
3 Rolling Assisted Wire Feed Direct Deposition
4 Realisation of Multi-Sensor System
5 Conclusions
Concept of WAAM

- **WAAM** is an arc-based Additive Manufacturing technique.
- **WAAM** can build large part with low cost.
- **WAAM** can achieve high energy efficiency.

Schematic of WAAM process

WAAM depositing process
Concept of WAAM

Titanium Component production

The deposition coordinates are then transferred to the DMD production unit, realizing the production of the component.

Source: http://www.norsktitanium.com/
2 Challenges to WAAM

Distortion & Residual Stress are an challenges in WAAM

Shrinkage and uneven cooling rate are the main reasons for distortion and residual stress

Too many factors are involved in the WAAM process, such as welding voltage, welding current, feeding speed, ambient temperature, protecting gas flow rate, etc.

Still lack of systematic metrology method for WAAM

WAAM produced part tilts up due to the residual stress

Aeroplane near net-shape part
RAWFEED - Concept

- **ROLLING** every layer after it was deposited to improve the microstructure and the mechanical property of the material.

- This method has been proved to be effectively reduced 30% ~ 50% distortion.

Ref: Colegrove, P. a., *et al.* (2013). *Journal of Materials Processing*

Video Source: Cranfield University
3 RAWFEED - Demo
Real-time monitoring system to monitor:

- **Shape** to provide feedback for rolling system
- **Heat** to avoid excess heat input/output which may cause distortion
- **Oxygen level** to prevent part from oxidation
4 Multi-Sensor Framework – Aims

Factors monitored:
1 Oxygen Level  2 Gas Flow Rate  3 Current  4 Voltage  5 Temperature
6 Profile  7 Wire Feed Speed (WFS)  8 Welder Travel speed
Multi-Sensor Framework – System Topology

Dell Tower 7910 PC

Data Acquisition System

Infra-red Sensor → Temperature
Oxygen Sensor → Oxygen Level

Control Box

Voltage Sensor → Voltage
Current Sensor → Current
Wire Feed Speed Sensor → Wire feed Speed
Gas Flow Sensor → Gas Flow Rate

Profilometer → Profile

FANUC PLC Controller → Welder Traveling Speed
4 Realization of Multi-sensor System
Multi-Sensor System – Laser Scanner
4 Multi-Sensor System – Laser Scanner Result
Voltage Sensor

Voltage Sensor Result

Sampling Rate: 5Hz

Voltage Signal fluctuated within a small range. The reason is under investigation. It might be due to the continuous periodic metal wire melting and dropping.
The signal data distribution roughly conforms to the Normal Distribution, and the noise might be able to be eliminated by a Kalman Filter.
4 Average Height Variation along Y axis
4 Realization of the System – Structure

**Environment Monitoring Sub-system**
- Oxygen Concentration Sensor
- Shielding Gas Flow Sensor

**Heat Monitoring Sub-system**
- Infrared Sensor
- Arc Voltage/Current Sensor

**Bead Geometry Control Sub-system**
- Laser Profilometer
- Wire Feed Speed Sensor
- Torch Travelling Speed
5 Conclusions

- The main problems in the WAAM process have been analysed and a novel integrated monitoring solution proposed.

- A multi-sensor system has been built to monitor the WAAM process.

- The specified system shows that for a WAAM machine with an integrated rolling process to be monitored and controlled, a wide range of sensors needs to be configured and used.
Any Questions?