Co-funded by the Erasmus+ Programme of the European Union

Project No. 601217-EPP-1-2018-1-BE-EPPKA2-SSA-B

CU 01: DED-ARC

Session 3.5 TIG-DED systems & Research

Prepared by: David Wimpenny

FOR SAM PILOT ATTENDEES AND TRAINERS ONLY

MM17,21

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TIG (GTAW) - DED

TIG welding offers significant benefits by decoupling heat input from wire feed rates

However limited commercial exploitation

This may, in part, be due to successful commercialisation PAW (Plasma Arc Welding) based systems and developments in MIG based DED systems

However, there is <u>significant activity</u> in TIG based DED particularly in academia

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Most of the recent publications on TIG-DED are from work in;

- China
- Indian
- Belgium

+

Some work in

- Brazil
- Germany

Very little elsewhere… ???

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But …to understand the origins of TIG-DED you have to go back over 50 years...

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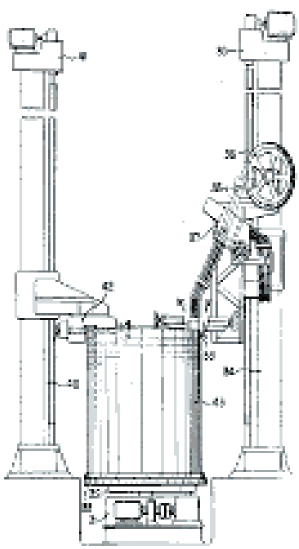
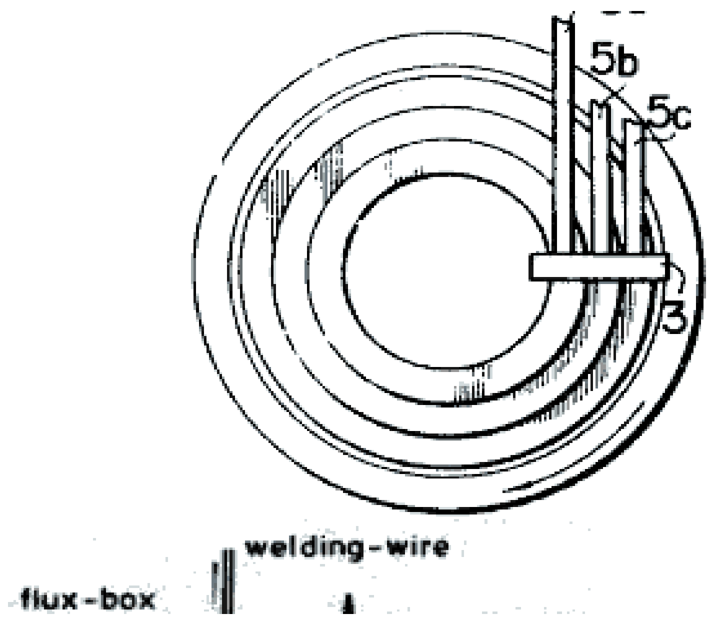
Cranfield UNIVERSITY

- 1971Ujiie (Mitsubishi) Pressure vessel fabrication using SAW, electroslag and TIG, also multiwire with **<u>different wires to give functionally graded walls</u>**





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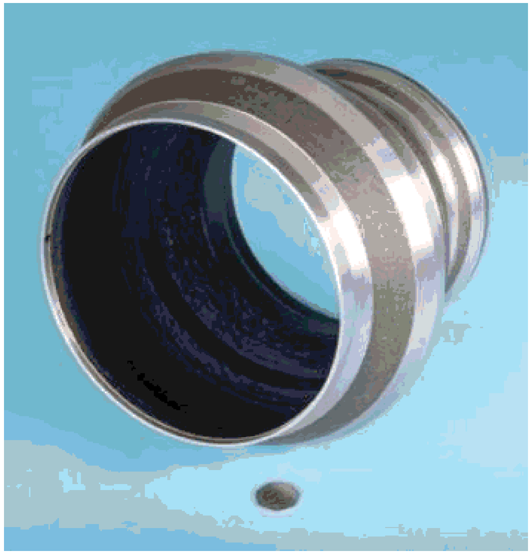
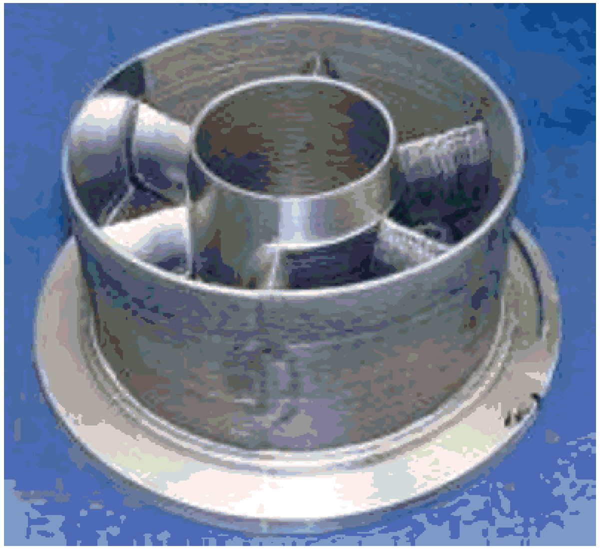
Metal Additive Layer Manufacture - History

Cranfield UNIVERSITY

- 1993 Prinz and Weiss **patent combined weld material build up with CNC milling** – called Shape Deposition Manufacturing (SDM)
- 1994-99 Cranfield University develop Shaped Metal Deposition (SMD) for Rolls Royce for engine casings, various processes and materials were assessed





www.cranfield.ac.uk

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(12) UK Patent Application (19) GB (11) 2 373 749 (13) A

(43) Date of A Publication 02.10.2002

(21) Application No 0107561.3

(22) Date of Filing 27.03.2001

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(51) INT CL^7
B23K 9/04

(52) UK CL (Edition T)
B3R RPB RSJ R131 R134 R135 R318 R51472 R81486

(56) Documents Cited

GB 2254816 A	GB 1269671 A
EP 0549398 A1	EP 0206080 A2
WO 2000/074887 A1	US 5250780 A
US 4595815 A	

(58) Field of Search
UK CL (Edition S) B3R RPA RPB RSH RSJ
INT CL^7 B23K 9/04 9/16 35/38
Online: WPI, EPODOC, JAPIO

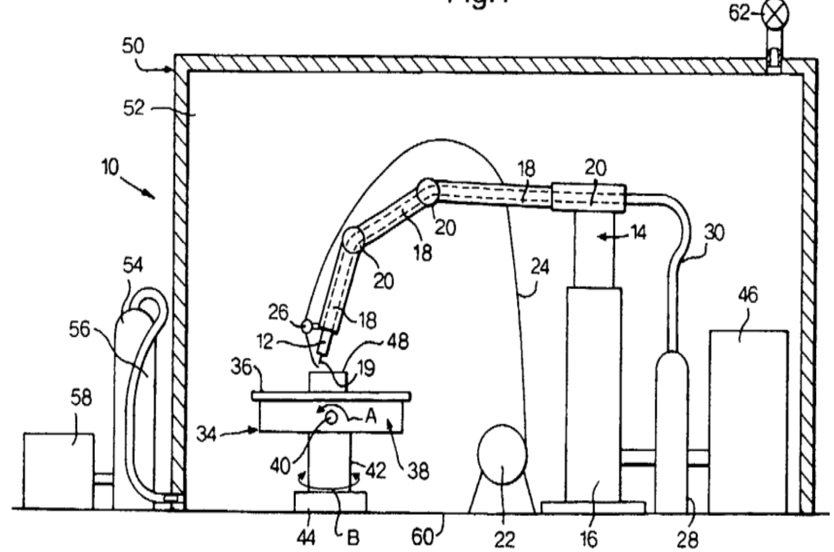
1. Apparatus for forming a body by deposition of a weld material, the apparatus comprising a welding head, support means for supporting the body, a supply of a welding material to be deposited on the support means by the welding head to form the body, means defining a chamber in which the support means and the welding head are arranged, and means for supplying to the chamber a gaseous medium to provide an atmosphere in the chamber which is substantially unreactive to the weld material.

2. Apparatus according to claim 1 wherein the welding head is mounted on manipulating means and also surrounds the manipulating means.

(54) Abstract Title
Apparatus and method for forming a body

(57) An apparatus 10 is disclosed for forming a body by deposition of weld material. The apparatus 10 comprises a welding head 12, support means 34 for supporting the body, and a supply 22 of a welding material to be deposited on the support means 34 by the welding head 12 to form a body. A chamber 52 is also provided which surrounds the support means 34 and the welding head 12, and the apparatus further includes means 54 for supplying to the chamber 52 a gas to provide an atmosphere in the chamber 52 which is substantially unreactive to the weld material. The gas may enter the chamber through a porous bed (64, figure 2).

Fig.1



Work on TIG (GTAW) –
DED at Rolls- Royce Plc dates back over 30 years

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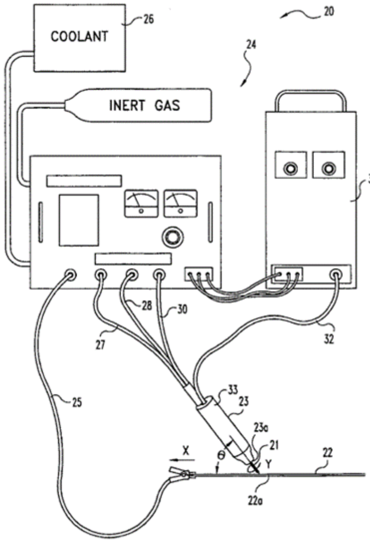
Also some <u>Allison Engine Company (USA) </u>had been undertaking trials on welding methods



In 1995 Allison Engine Company was purchased by Rolls-Royce Plc

The **Allison Engine Company** was an American aircraft engine manufacturer. Shortly after the death of James Allison in 1929 the company was purchased by the Fisher brothers. Fisher sold the company to General Motors, which owned it for most of its history. It was acquired by Rolls-Royce plc in 1995 to become the US subsidiary, Rolls-Royce North America.

Wikipedia

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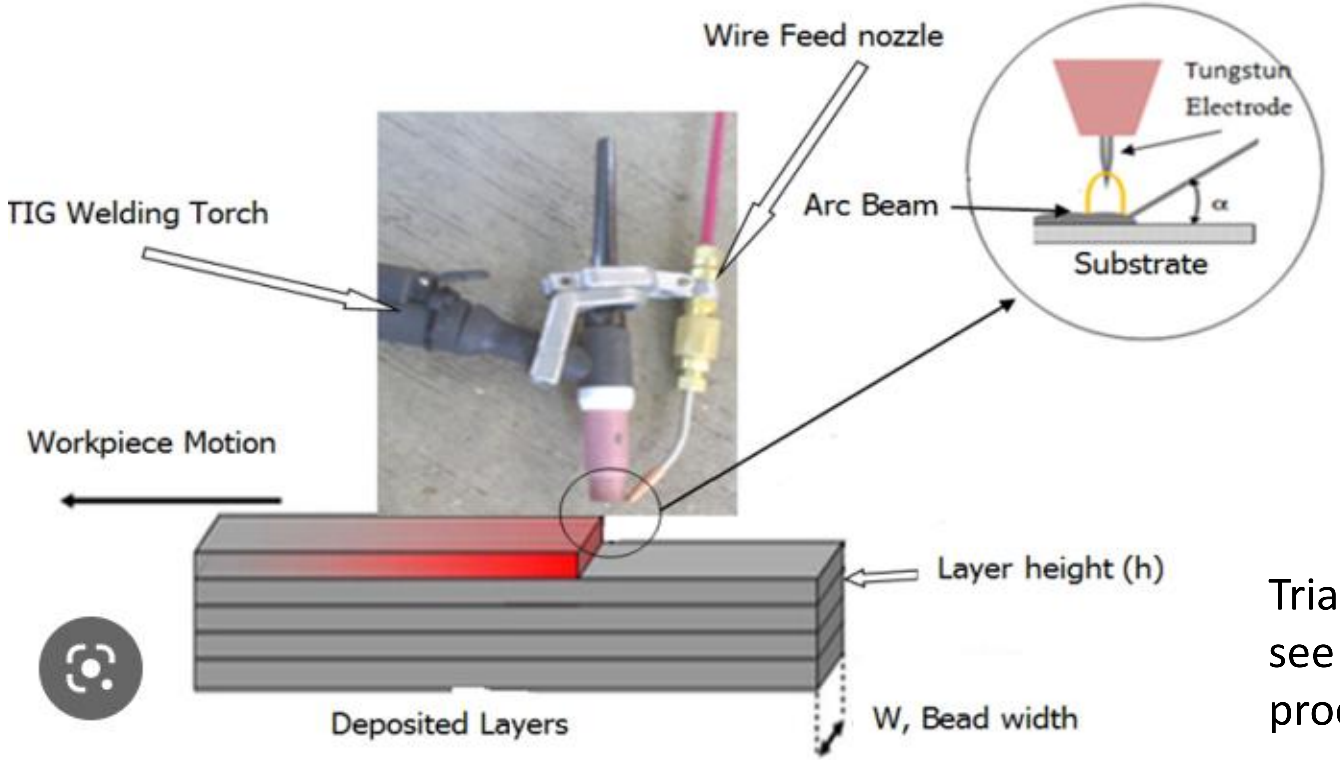
Shape Metal Deposition (SMD)

(SMD is often used now for many other DED processes)



Trials performed to see where this new process could be used

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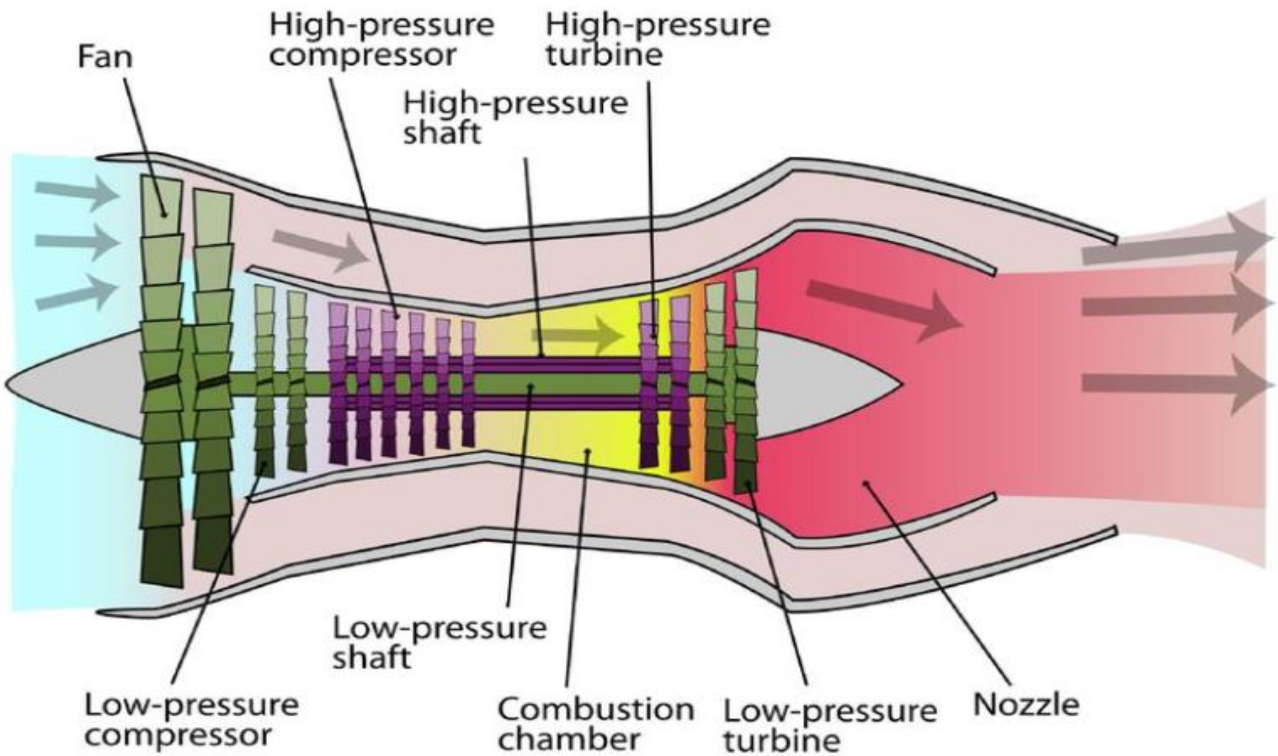
Aeroengine (gas turbine)



Prepared by Dr Diane Aston, IOM3

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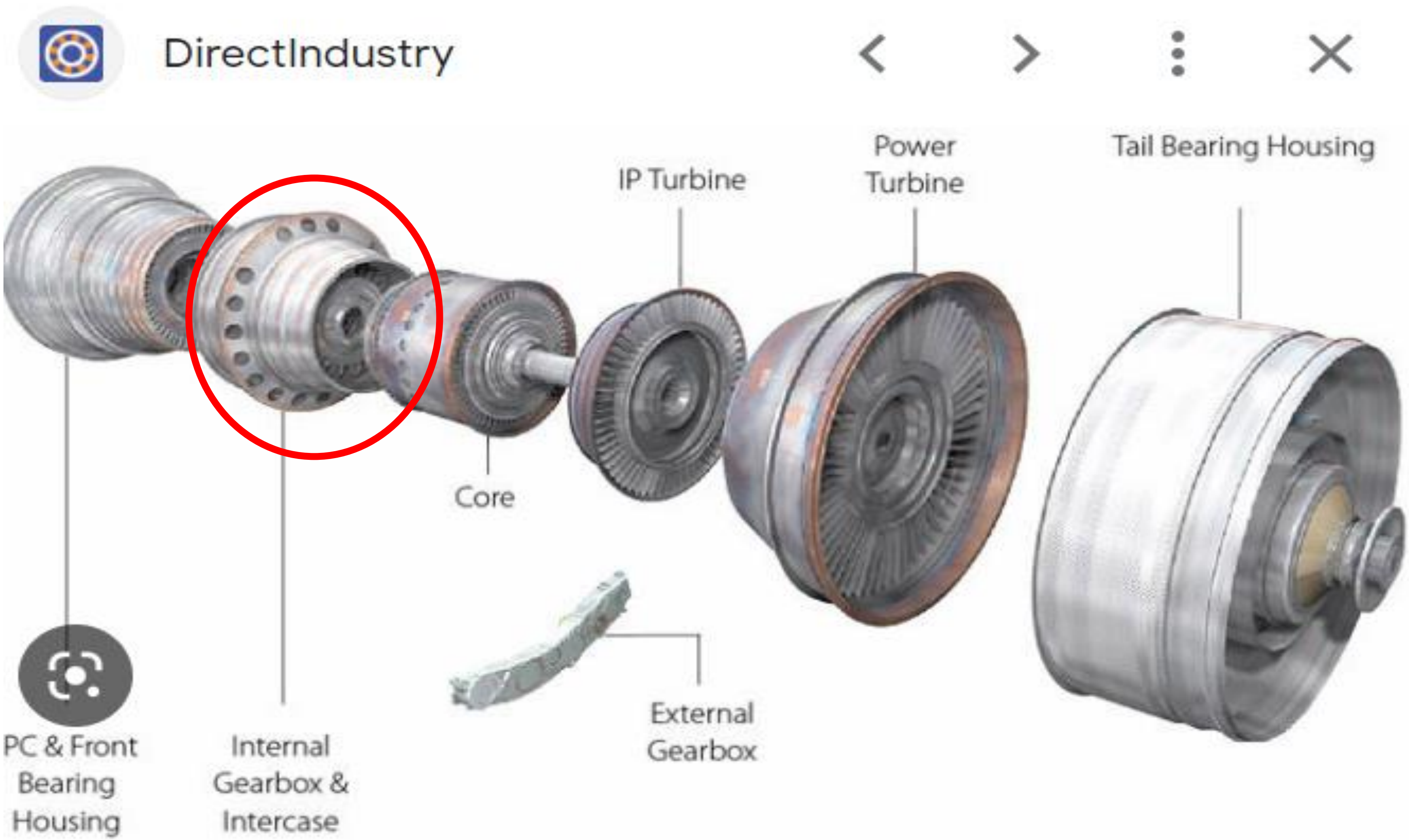
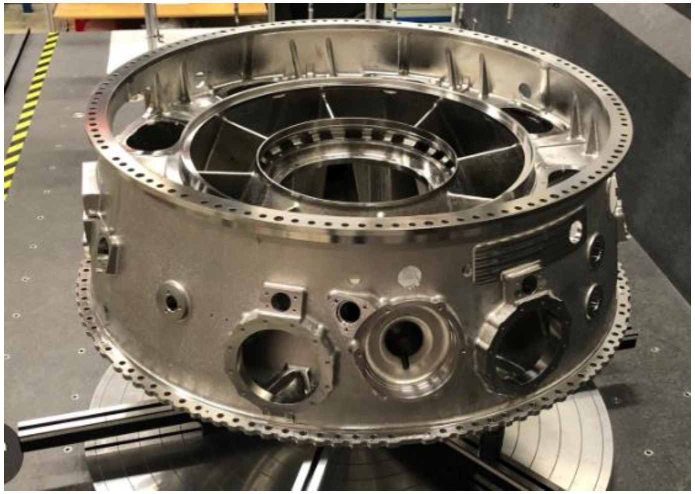

DirectIndustry
Power Turbine
Tail Bearing Housing
IP Turbine
Core
PC & Front Bearing Housing
Internal Gearbox & Intercase
External Gearbox

Intermediate Compressor Case (ICC) – “Intercase”

Structure between compressor cases, which carries the rotor gas loads to the engine casing and thrust mounts.



Modern ICC produced conventionally - courtesy of GKN

Cranfield University worked with Rolls-Royce to support the development of the SMD process for Intercase production but it was not adopted

Functional Jet engine component – concept and evaluation, Masters Thesis Lulea University of Technology, Fredrik Nytomt, Fred, 2002 Persson

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Hollow core fan blades

- Titanium blades made by super-plastic forming and diffusion bonding.
- Blades have a hollow, corrugated cross section.

Prepared by Dr Diane Aston, IOM3

SMD was used to deposit titanium at the base of early hollow core fan blades

Photo of Wide Chord Fan Blade Assembly on Trent 1000 Engine © 2008 Rolls-Royce Group plc

Process is no longer in use ?

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SMD unit moved to Sheffield University (AMRC)

“The SMD technology was initially developed by Rolls-Royce plc, but was not widely adopted for commercial production for several reasons.
The TIG welding process had to be manually controlled by a skilled technician, and there was little understanding of the material properties of the parts produced by such an innovative process.
Rolls-Royce licenced the technology to the University of Sheffield Advanced Manufacturing Research Centre with Boeing (AMRC)”

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EU Rapid Production of Large Aerospace Components – RAPOLAC Project (2011)

AMRC led 3 year international project to further develop shaped metal deposition (SMD) process

AMRC team worked with Università degli Studi di Catania, Sicily, to develop an automated control system. The AMRC team also focused on optimising the SMD process

Footprint Sheffield, the leading industrial partner in Rapolac, aims to adopt the technology in its own factory to help the company expand its markets and offer higher-value services …..project completed in 2011

Component made in the project by SMD

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That was over 10 years ago ……

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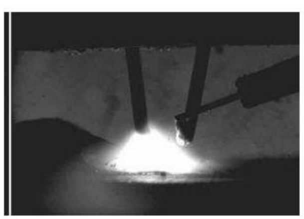
Work on TIG-DED (SMD) continued at Cranfield University

Methods of controlling deposition metal chemistry

Cranfield UNIVERSITY

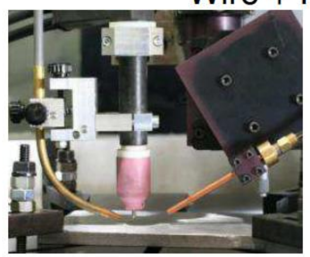
Multi wire approach

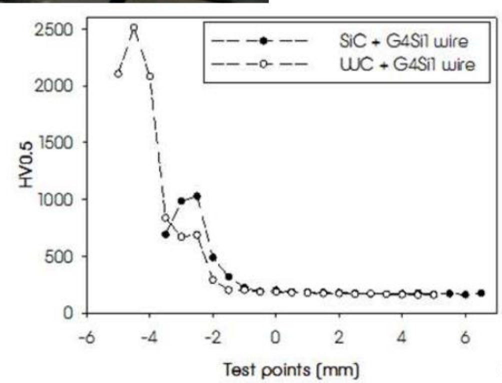
Aluminium hardness
1 wire Al6%Cu– 100HV
2 wire (Al4.5%Cu1.5%Mg) – 120HV



3 wire (Al8%Cu1.5%Mg – 140HV

Wire + Powder





WAAM – Latest results – mixed material systems Steel/bronze (CuSi3%) parts

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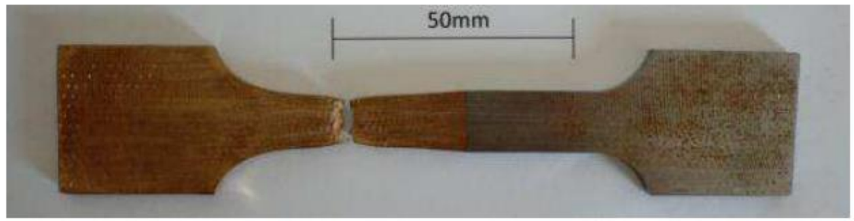
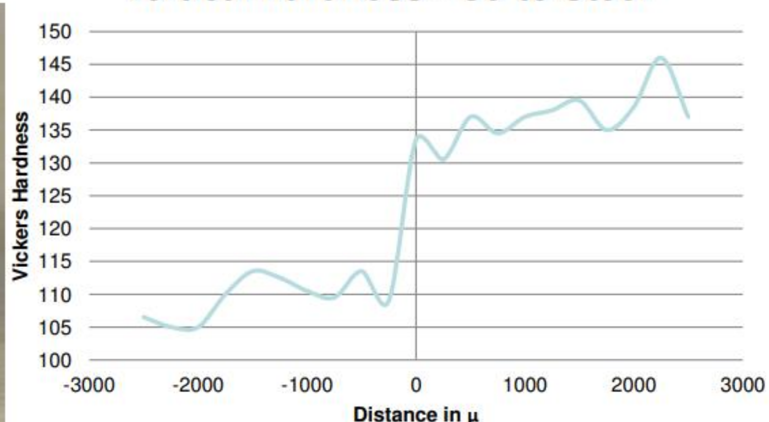


Yield 140 MPa, UTS 300 MPa, elongation 12%, failure in bronze

Vertical hardness - Cu to Steel



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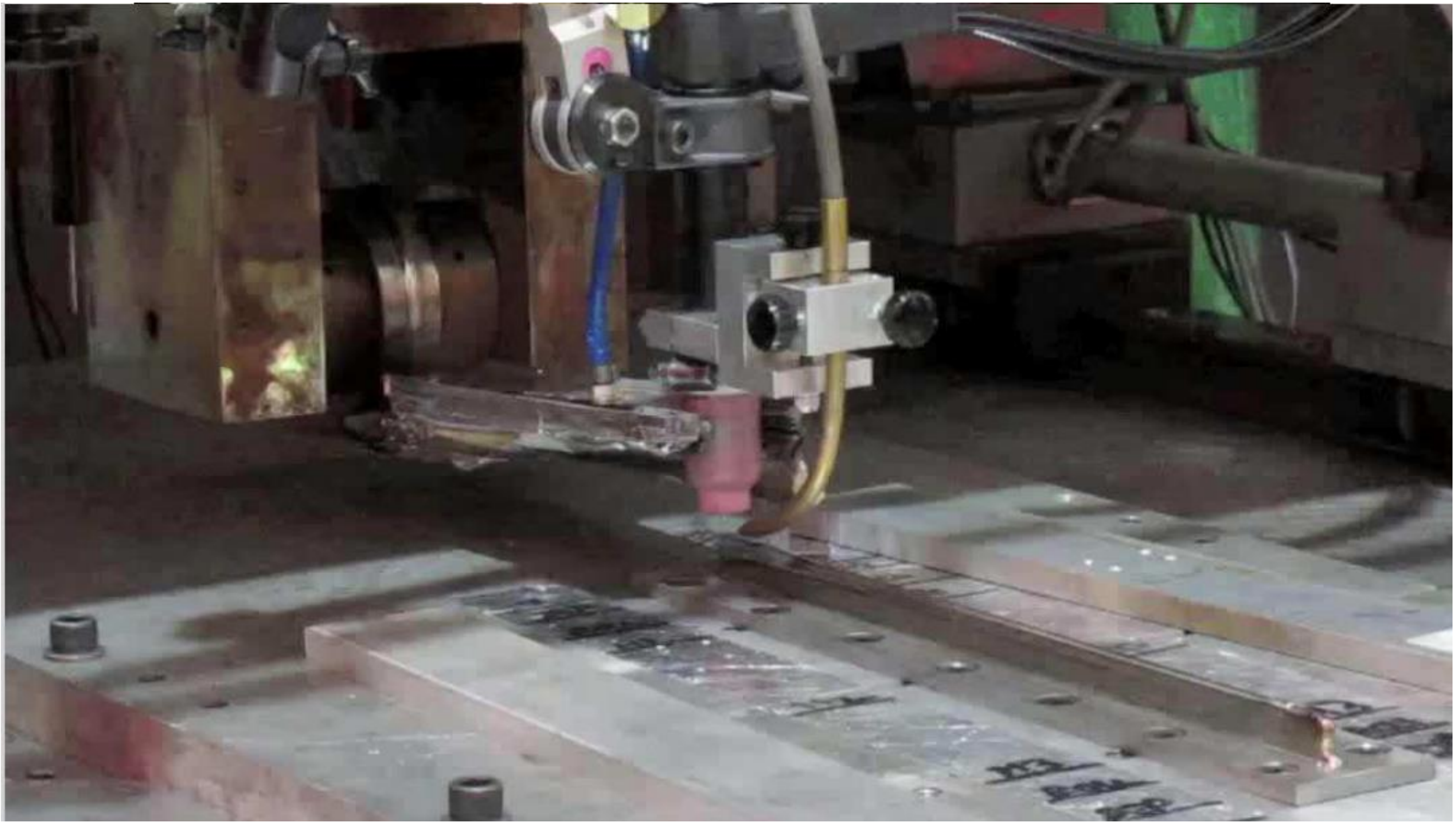
Initial Rolling Trials....



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Review paper which provides a good overview and <u>comparison of DED processes</u>

Advanced Powder Materials 1 (2022) 100054
KeAi CHINESE ROOTS GLOBAL IMPACT
Contents lists available at ScienceDirect
Advanced Powder Materials
journal homepage: www.keaipublishing.com/en/journals/advanced-powder-materials

A review on additive/subtractive hybrid manufacturing of directed energy deposition (DED) process

Mohammadreza Lalegani Dezaki [a], Ahmad Serjouei [a], Ali Zolfagharian [b], Mohammad Fotouhi [c], Mahmoud Moradi [d], M.K.A. Ariffin [e], Mahdi Bodaghi [a,*]

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[b] School of Engineering, Deakin University, Geelong, 3216, Australia
[c] Department of Materials, Mechanics, Management and Design (3MD), Delft University of Technology, Delft, the Netherlands
[d] School of Mechanical, Aerospace and Automotive Engineering, Faculty of Engineering, Environment and Computing, Coventry University, Coventry, CV1 2JH, UK
[e] Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, Serdang, 43400, Malaysia

Key findings for TIG;

- GTAW (TIG) is more stable than GMAW (MIG)
- GTAW (TIG) is normally used to repair dies
- Hot wire with voltage less than 5volts had little impact on residual stress of TIG
- Lower heat input led to defects
- High input led to rough surfaces and wider welds
- Overall difficult to control deposition accuracy

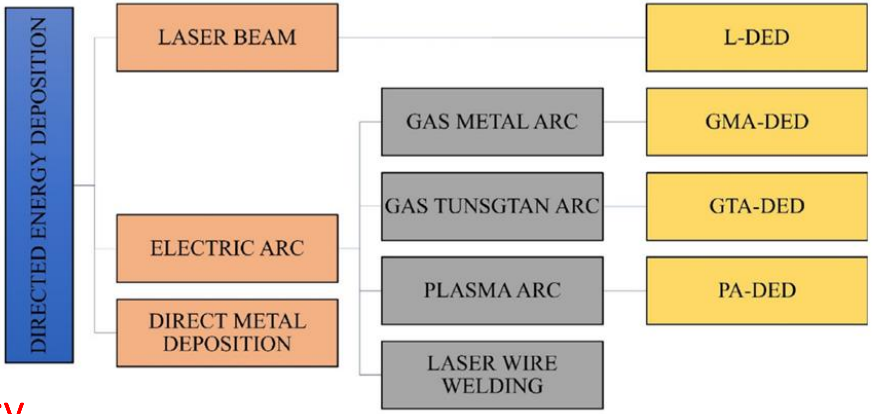

Fig. 3. Classification of DED process in 3D metal printing.

Optimization of wire feed for GTAW based additive manufacturing

Journal of Materials Processing Technology
Volume 243, May 2017, Pages 40-47

HaibinGeng, Jinglong Li, JiangtaoXiong, XinLin,Fusheng Zhang

State Key Laboratory of Solidification Processing,
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Xi’an 710072, PR China

Optimization of wire feed for GTAW based additive manufacturing – Background to study

- Benefit of TIG is heat input can be controlled independently of wire feed speed
- Cathode cleaning plays a crucial role during GTAW (TIG) DED for aluminium alloy removing oxide formed on layer surface, allowing molten metal to wet the substrate and maintain the stable arc.
- Discontinuous materials input and arc blow are exacerbated by thermal pinch effect of aluminium alloy leading to an uneven layer appearance.
- To obtain uniform layer size and appearance, heat input should be regulated during layer upon layer deposition to address heat accumulation effect.

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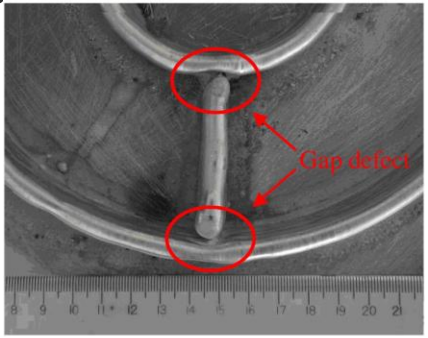
Optimization of wire feed for GTAW based additive manufacturing – Background to study

- TIG-DED suffers deposition accuracy problem, particularly at start position due to inaccuracy of wire feed, leading to defects, for example at cross or T intersections.



- Adjustment of wire feed position could eliminate this defect
- For DED-arc processes consistent welding conditions is key to part quality
- Adjustment of wire feed may introduce instability and surface appearance defects, such as humping and gouging.

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Optimization of wire feed for GTAW based additive manufacturing –Background to study

- Surface quality is determined by matching heat input and materials input
- A vision sensor can be used to monitor and control the arc length, and the height of deposited layer
- If not possible to adjust wire feed speed dynamically then adjust travel speed to match heat input to wire feed speed
- Without feedback control, the matched heat input to materials input can be obtained by process optimization based on stable materials input in manner of bridging transfer. Using this method, Wang et al. (2013) deposited two Ti-6Al–4V straight walls with 6.8 mm thick using TIG-DED and Baufeld et al. (2009) deposited cylindrical and rectangular parts,

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Optimization of wire feed for GTAW based additive manufacturing –Work undertaken

- Accuracy of start position in TIG-DED has not been studied previously
- Work focuses on start position correction and stable materials input (wire feed)
- To support this approach a mathematical model is developed to calculate the wire flying distance in arc zone, according which displacement compensation at the arc striking position could be set.

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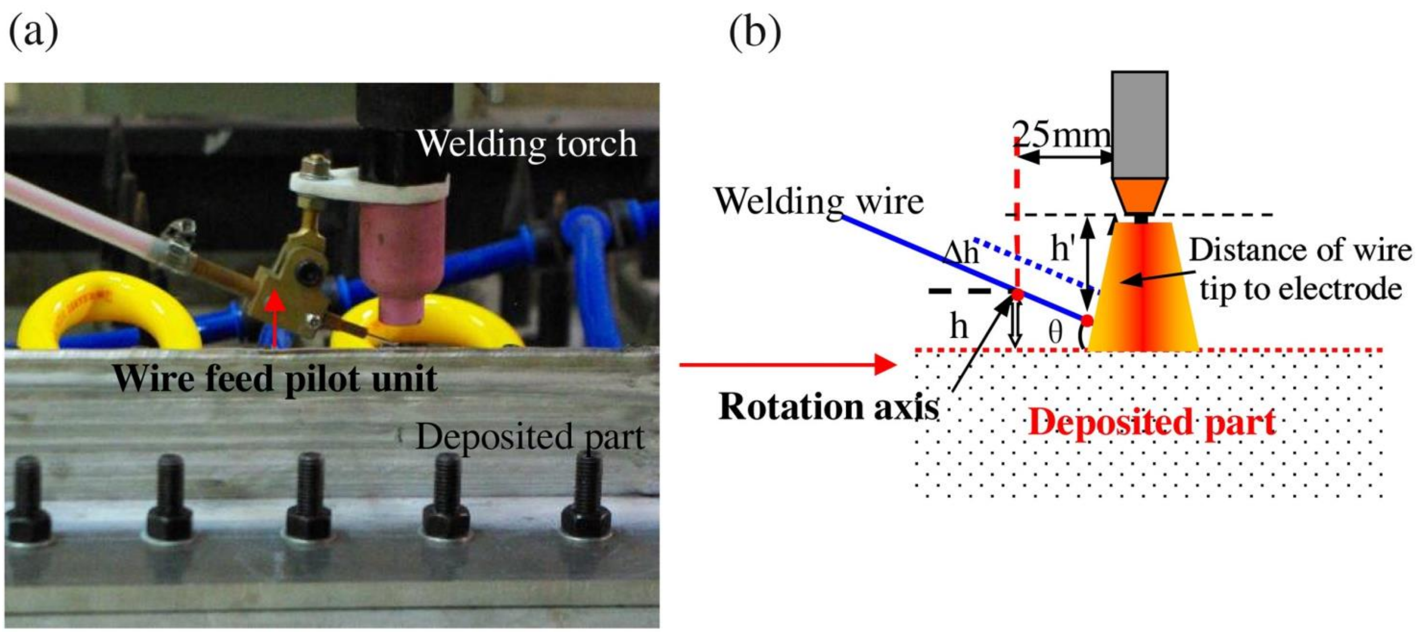
Experimental set-up

GTAW welding machine (EWM, Tetrix 521 Synergic AC/DC) with wire feeder was used for the experiment.



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Parameters

Wire:Φ1.2 mm aluminium alloy wire

Substrate: aluminium alloy 300 × 200 × 15 mm with water cooled back plate to remove heat

Wire feed direction: in front of the welding arc.

Gas shielding: Argon (99.99%)

Current: Rectangular pulse AC power mode - peak 160 A and background 100 A pulse frequency was set as 50 Hz.

Electrode: Φ3.2 mm tungsten

Wire feed: 2 m/min

Travel speed: 300 mm/min

Other parameters shown in table>

Table 1. Power supply parameters applied in this experiment.

Peak current time (s)	Duty ratio	Pulse frequency (Hz)	Down slop time (s)	Pre-flow time (s)	Post-flow time (s)	Gas flow (L/min)	Arc length (mm)
0.01	0.5	50	1.8	1.5	4	10	5

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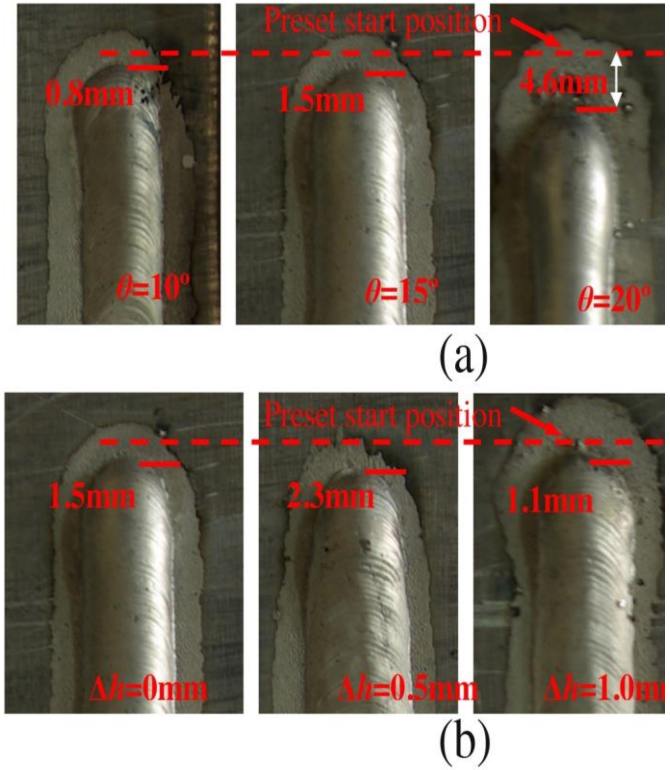
Optimization of wire feed for GTAW based additive manufacturing – Results

- When wire feed angle is increased from 10° to 20°, start position shift increases from 0.8 mm to 4.6 mm.
- When vertical distance of melting wire tip to molten pool surface increased from 0 to 1.0 mm, start position shift increases from 1.5 mm to 2.4 mm and then decreases to 1.1 mm
- Optimised wire feed based on layer size precision and layer surface appearance.
- Wire fed at an 10° angle and vertical distance 3.8 mm gave smooth layers



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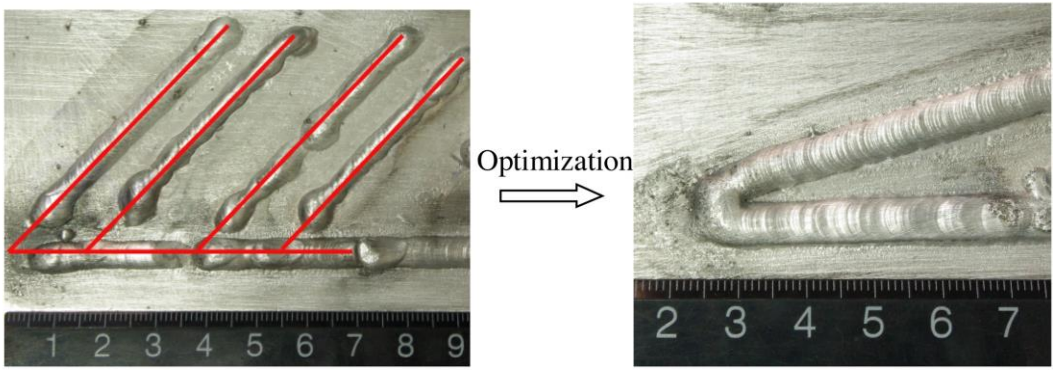
Findings

- Increasing wire feed angle from 10° to 20° shifts start position from 0.8 to 4.6mm
- Increasing vertical distance of wire tip to melt pool from 0 to 1.0 mm shifts start position from 1.5 to 2.4 mm initially (then decreases to 1.1 mm)
- By optimising wire feed considering both layer size precision and surface appearance. Wire feed at 10° and height 3.8 mm could gives a smooth layer appearance.
- When the vertical distance of melting wire tip to tungsten electrode is varied within 2 mm, the droplet landing position only changes by 0.4 mm thus allows translation or rotation movement.



(a) (b)

Optimization of wire feed for GTAW based additive manufacturing – Key references cited

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PAUSE for questions

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Volume 37, May 2022, Pages 103-109

Effect of build direction on the microstructure evolution and their mechanical properties using GTAW based wire arc additive manufacturing

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Department of Chemical and Materials Engineering, University of Alberta, Edmonton, Canada

School of Mechanical Sciences, Indian Institute of Technology, Bhubaneswar, Odisha 751013, India

Summary

In this study GTAW DED system was developed

Low-carbon alloy steel ER 70S-6 filler wire was used

Room temperature tensile test, hardness and Charpy toughness tests were undertaken on samples

Microstructure reveals a mostly homogeneous ferrite phase as a matrix and a small amount of pearlite phase at grain boundaries, except for the last build surface.

The grain size was found to be doubled from middle build to last build surfaces.

The tensile test results show isotropic tensile properties in both directions. The observed morphological features of the fractured surfaces in both directions were found to be in good agreement with their tensile test results, confirming a higher ductility across the build samples. Large scatter was observed in the hardness tests concerning the building direction

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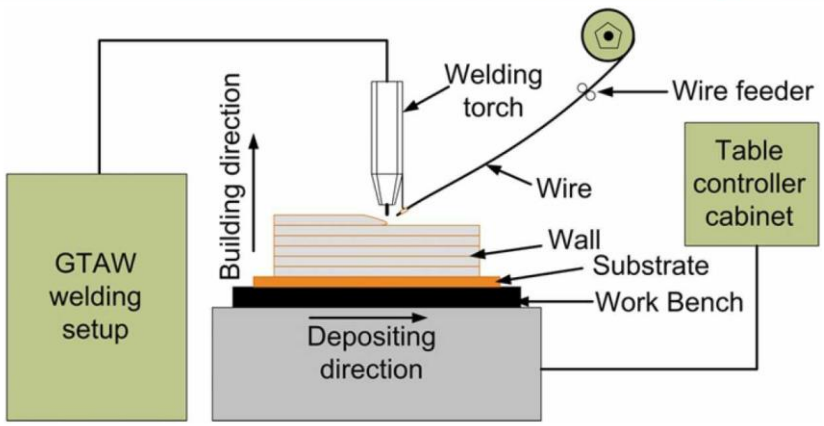
Experimental set-up



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Materials

Filler wire - low carbon steel (ER70S-6), 0.8 mm diameter

Table 1. Chemical composition of filler wire.

Element	C	Mn	S	Ni	V	Cr	Cu	Si	P	Mo
wt%	0.1	1.6	0.03	0.12	0.02	0.15	0.5	0.96	0.025	0.13

Table 2. Mechanical properties of filler wire.

Filler wire	Density (Kg/m^3)	Yield strength (MPa)	UTS (MPa)
AWS ER70S-6	7833	420	500–640

Substate - machined mild steel plate 200 × 200 × 10 mm

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GTAW Process Parameters

Table 3. Process parameters of experiments.

Current (Amp)	Travel speed (mm/min)	Gas flow rate (l/min)	Wire-speed (mm/min)
95	80	10	800

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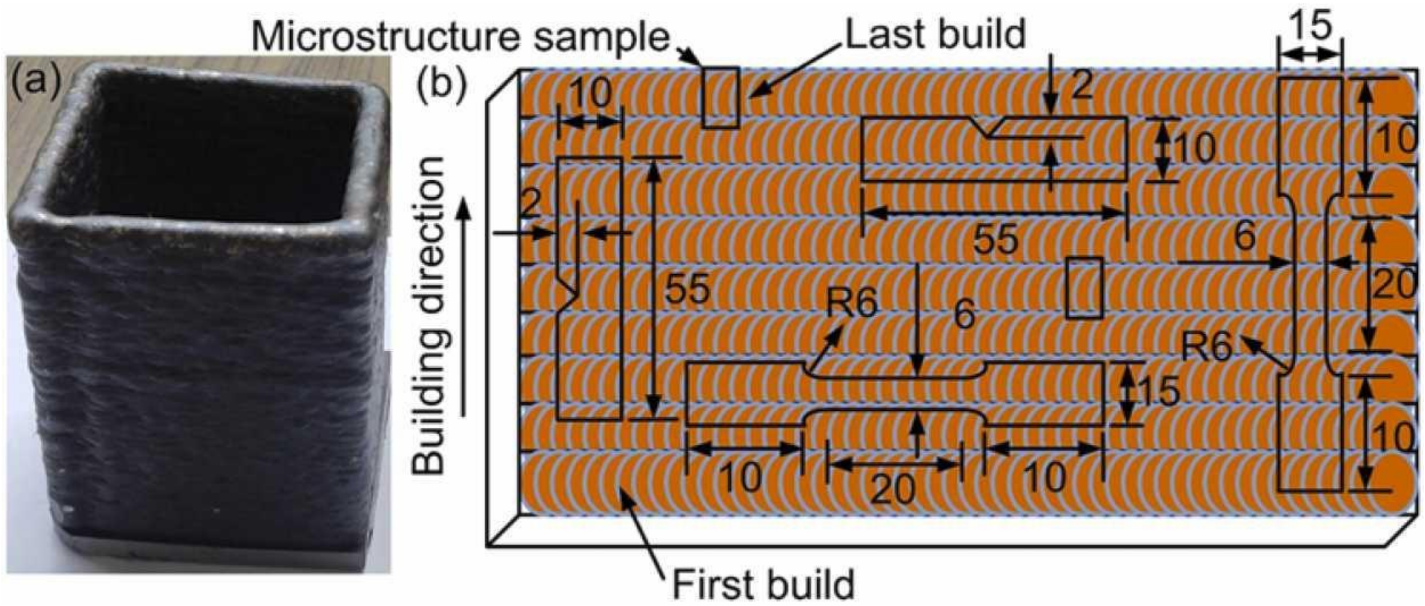
Samples generated



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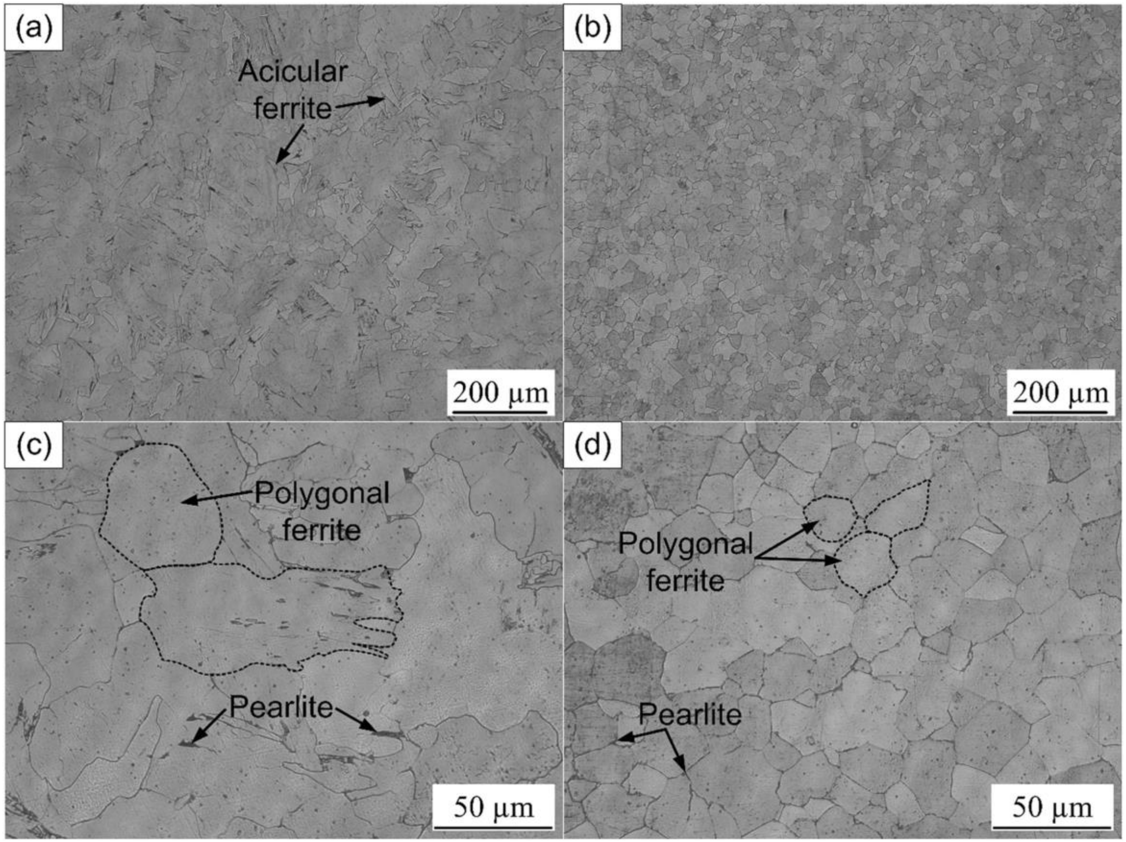

Fig. 4. Optical micrographs of the printed WAAM ER70S-6 alloy, (a) and (c) last build at different magnifications; (b) and (d) middle build at different magnifications

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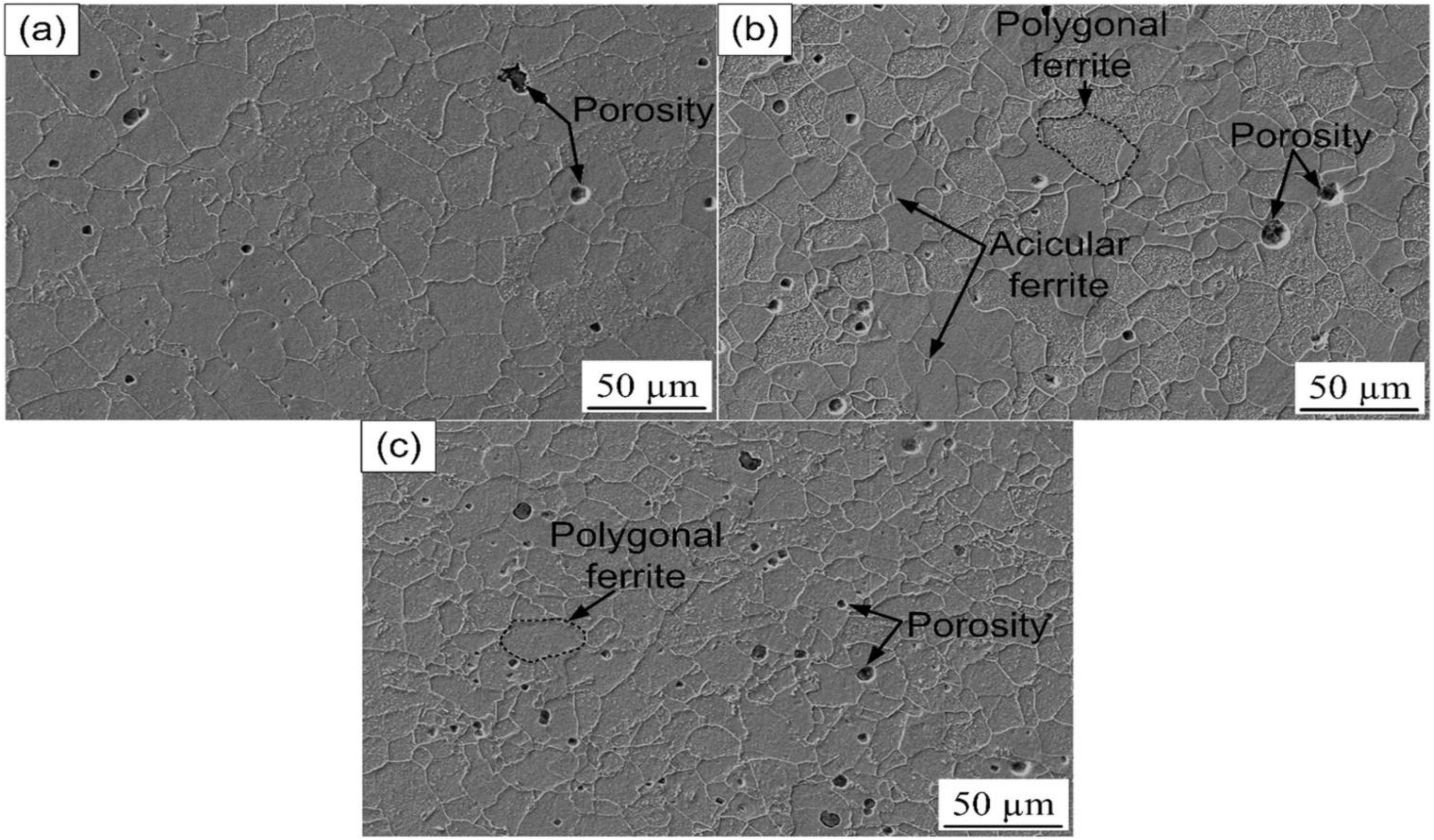

Fig. 5. Scanning electron micrographs of the printed WAAM ER70S-6 alloy, (a) last build, (b) middle build and (c) first build.

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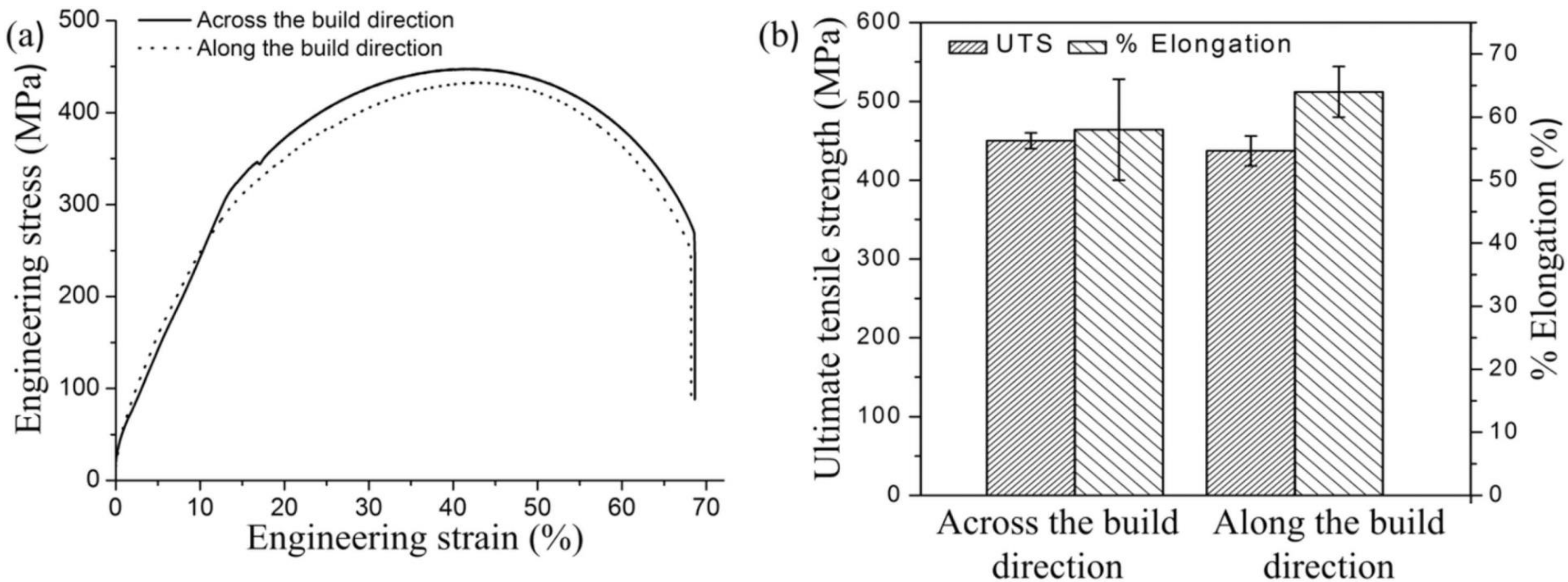
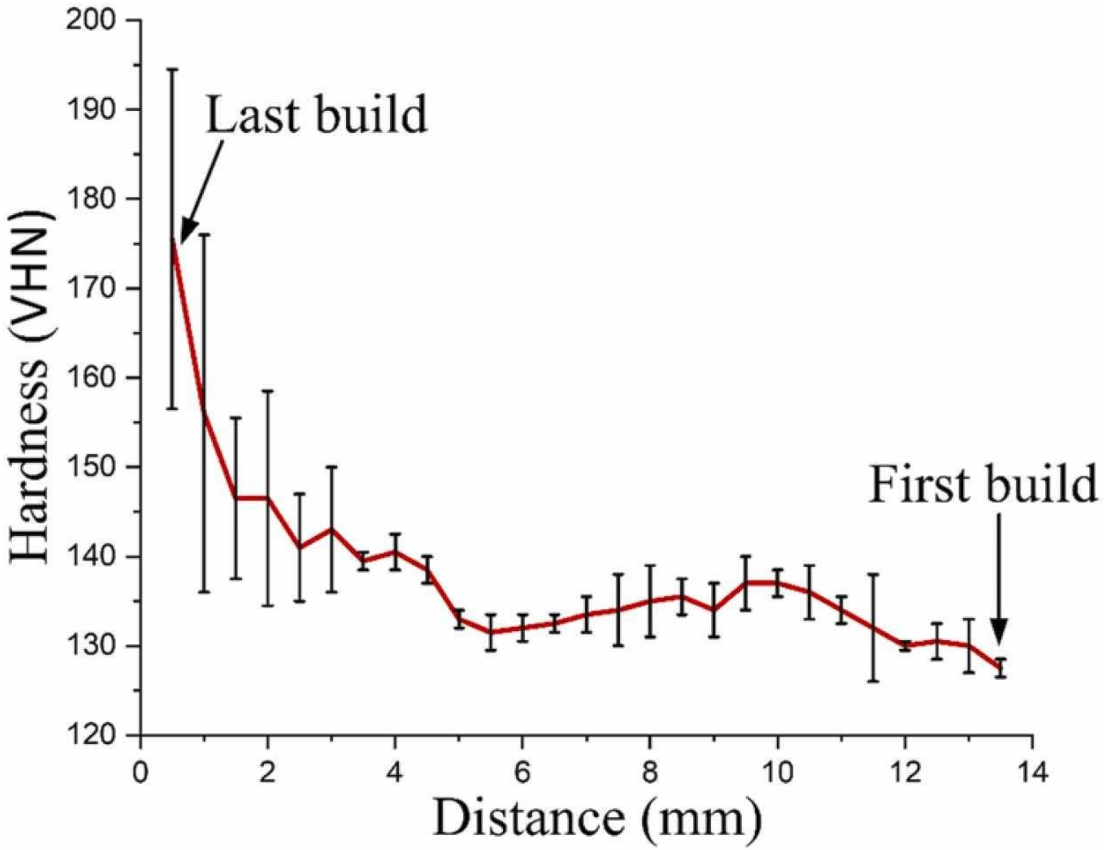
Mechanical Properties



Microhardness



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Findings

- Microstructure of middle and final layers is quite different (for example grain size)
- Big difference in Vicker's microhardness between last and middle layers
- Middle region has post-heating effect during deposition of subsequent layers whereas the final layers experience a faster cooling rate.

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PAUSE for questions

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Titanium aluminide (TiAl) is a high performance intermetallic material offering lightweight, high temperature capability

Intermetallic compound composed of definite proportions of two or more elemental metals, rather than continuously variable proportions (as in solid solutions).
https://www.britannica.com/science/intermetallic-compound

GE are using TiAl for aeroengines parts

But very difficult material to process

PBF-EB is slow and high scrap level

GE Aviation invests in widespread rollout of GE Additive Arcam EBM technology to support GE9X blade production

Thursday - June 20, 2019

production of titanium aluminide (TiAl) low-pressure turbine blades for the GE9X engine….roughly half the weight of traditional nickel-alloy turbine blades.

[GE Aviation invests in widespread rollout of GE Additive Arcam EBM technology to support GE9X blade production | GE Additive]()

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Highlights

- Two-wire TOP-TIG additive manufacturing of titanium aluminide alloys was proposed.
- The Al wire was fed in TOP-TIG welding mode but the Ti6Al4V wire was fed in conventional TIG welding mode.
- The main microstructure of the as-fabricated component is α_2/γ lamellae.
- The different Al content results in the different content and distribution of the γ and α_2 phase.
- 50 at.% Al content provides better mechanical properties.

ELSEVIER

Additive Manufacturing

Volume 35, October 2020, 101344

Wire arc additive manufacturing of titanium aluminide alloys using two-wire TOP-TIG welding: Processing, microstructures, and mechanical properties

Xiaoyu Cai, Bolun Dong, Xianlai Yin, Sanbao Lin, Chenglei Fan, Chunli Yang

DED-arc is being explored by a leading government research facility in China (State Key Laboratory of Advanced welding and joining , Harbin)

TiAl by TIG-DED

- To process TiAl you need two wires (Ti and Al) which are feed at the correct rate to ensure correct composition and microstructure
- Different melting point of Ti and Al
- This is very difficult to achieve using conventional TIG
- Interpass temperature needs to be carefully controlled to stabilise deposition characteristics and maintain cooling rate
- Properties are highly anisotropic (in plane UTS is higher than cross plane) - post heat treatment can reduce this problem
- Research in China in this fields dates back 10 years

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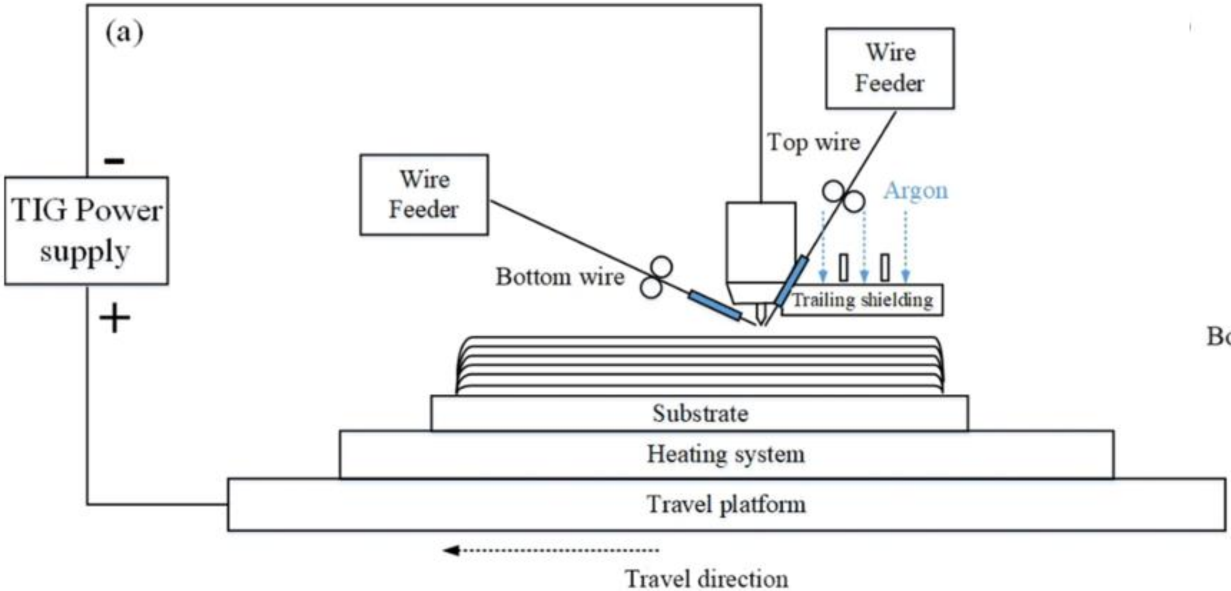
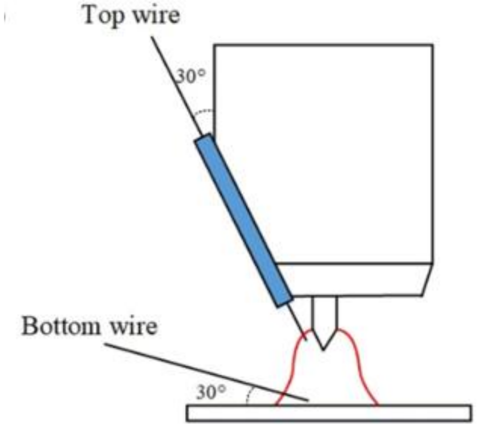
TOP-TIG

- Angle between electrode and wire is 20°-30° (standard TIG is 60°-75°).
- Enables wire melting rate to be adjusted
- Using top wire and bottom wire feed melting rate can be controlled





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Co-funded by the Erasmus+ Programme of the European Union

Wire and electrode composition

Table 1

Chemical compositions of the wires and electrode.

Materials	Composition (wt.%)							
Ti6Al4V	Ti	Al	V	Fe	Si	C	N	H
	Bal.	5.5~6.8	3.5~4.5	≤0.30	≤0.15	≤0.10	≤0.05	≤0.015
ER1100	Al	Cu	Si	Zn	Fe	Mn		
	Bal.	≤0.002	≤0.030	≤0.013	≤0.180	≤0.003		
Wce-20	W	CeO	SiO_2	Fe_2O_3	Mo	CaO		
	Bal.	2.0	0.06	0.02	0.01	0.01		

Pure aluminium
Titanium alloy Ti64

What is the electrode ?

Thorium
Lanthanum
Zirconium
cerium
Rare Earth Elements

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From Session 2.4

Ceriated

- Contain 1.8-2.0% cerium
- Performs best in DC welding at low current settings
- High current cause oxides to migrate to electrode tip thus reducing the benefits
- Can also be used in AC processes
- Excellent arc starts at low current
- Best used to weld carbon steel, stainless steel, nickel alloys, and titanium
- Applications - tube / pipe joining, thin sheet metal work, small and delicate parts.

https://www.thefabricator.com/thefabricator/article/arcwelding/guidelines-for-tungsten-electrode-and-color-types

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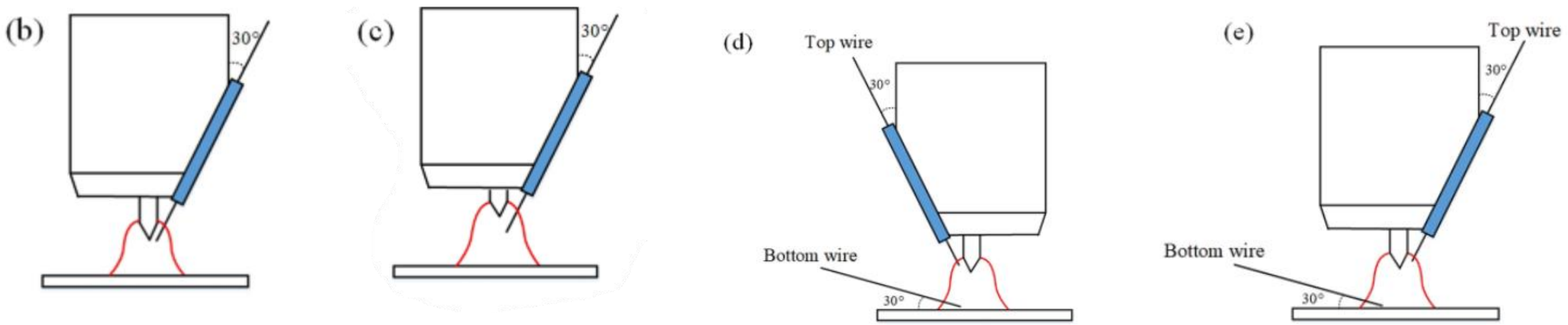
Methodology

- Study looked at different wire configurations / feed rates



(b) large extension length of electrode results in a short distance between electrode and wire; (c) small extension length of electrode results in a long distance between electrode and wire. (d) two wires are fed from the same side; (e) two wires are fed from different sides.

Table 2
Wire feeding speeds during the WAAM fabrication.

Parameter ID	Designed Al content	Al wire feeding speed	Ti6Al4V wire feeding speed
P1	48 at.%	481.6 mm/min	700 mm/min
P2	45 at.%	480 mm/min	800 mm/min
P3	50 at.%	600 mm/min	800 mm/min
P4	55 at.%	760 mm/min	800 mm/min

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Vertical walls (1 bead wide x n beads high) were generated using different set-ups

Mechanical property samples were taken from these walls and compared

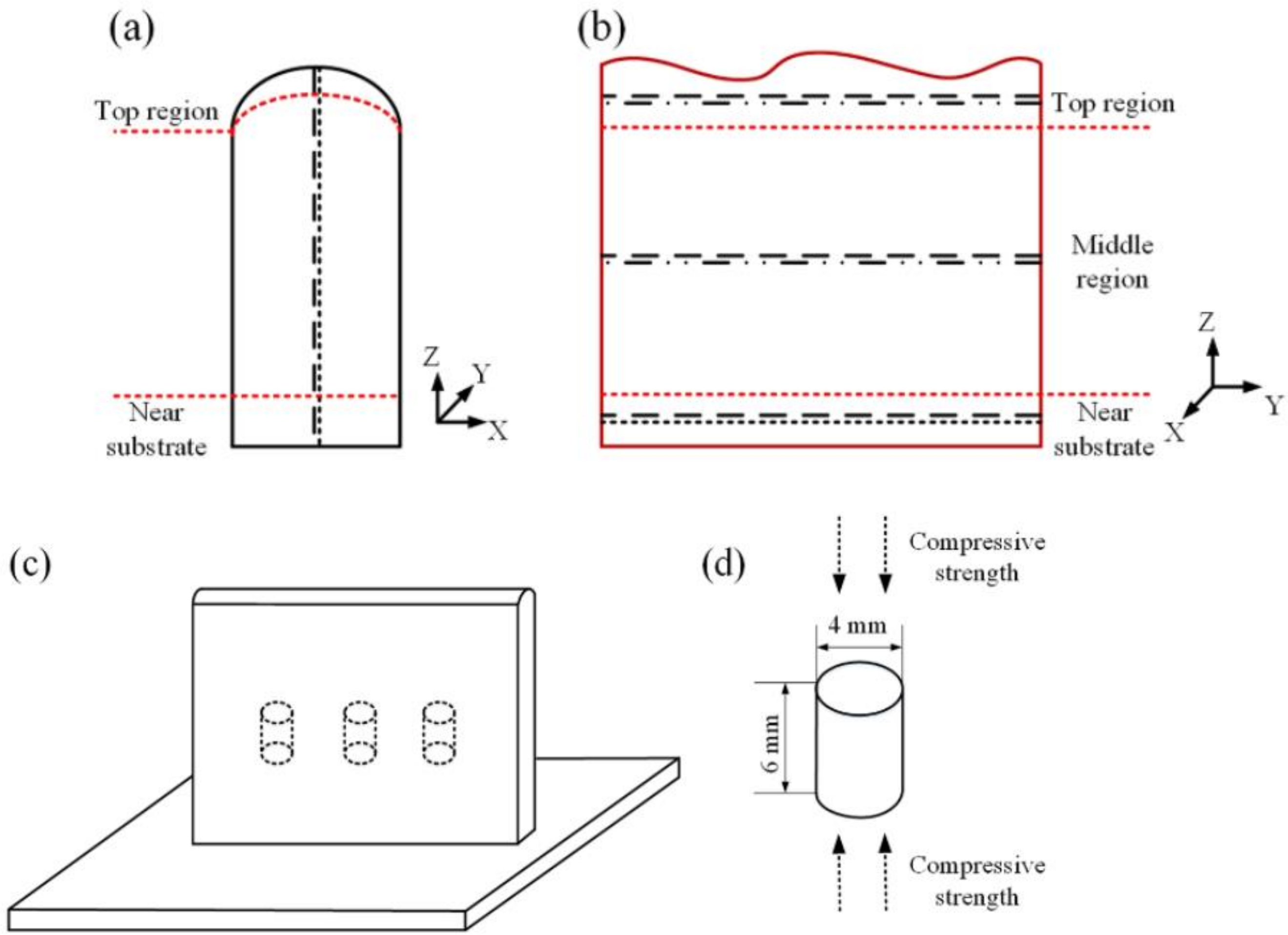


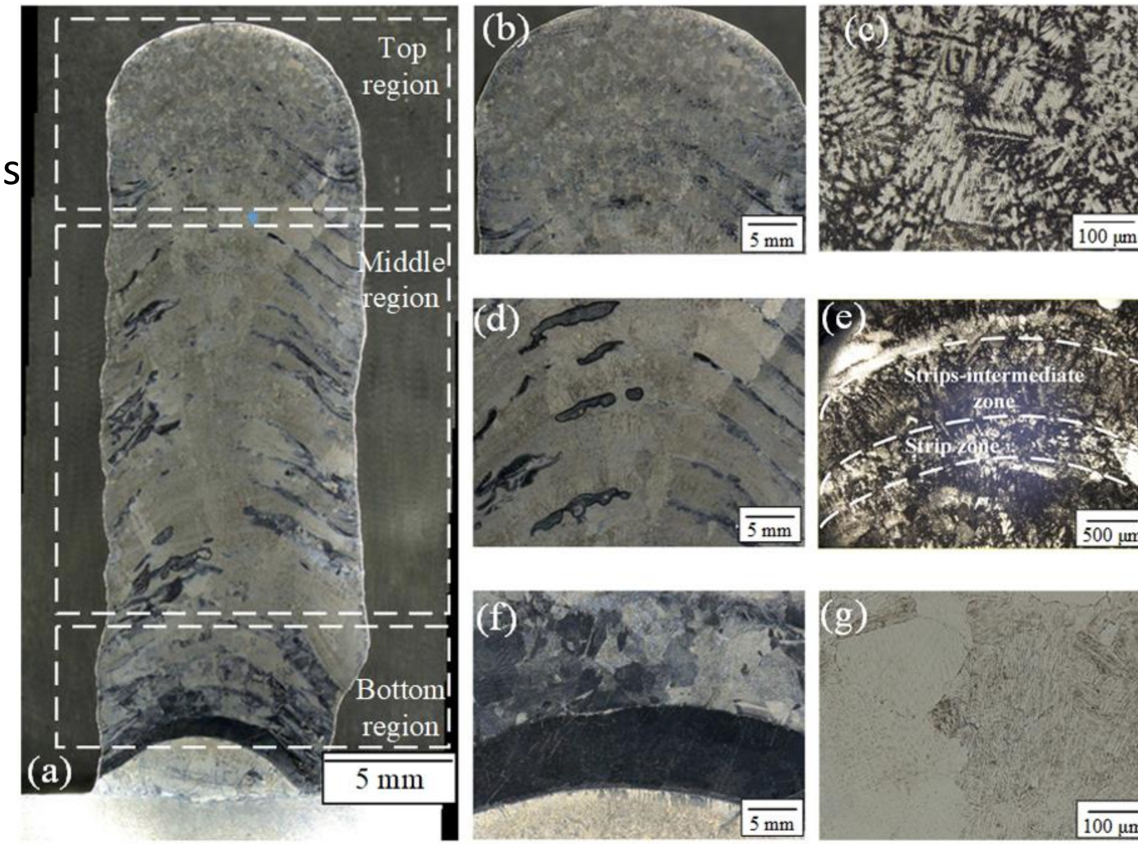
Fig. 2. Graphic diagrams of the mechanical properties testing: the locations of microhardness testing on the (a) x-z plane and (b) y-z plane; (c) the locations of the compression specimens; (d) dimensions of the compression specimens.

3 main regions:

Top - equiaxed primary dendrites (Fig. 7(c)).

Middle - significant banding

Bottom - affected by substrate



. Macro- and microstructure of TiAl alloys deposited by WAAM: (a) cross-section (x-z plane) morphology; (b) macro-and (c) microstructure in the top re

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Q- what is the travel direction ?
left to right >>
or
right to left <<

Q – why does the sample have this shape

Accumulation of heat as weld progresses

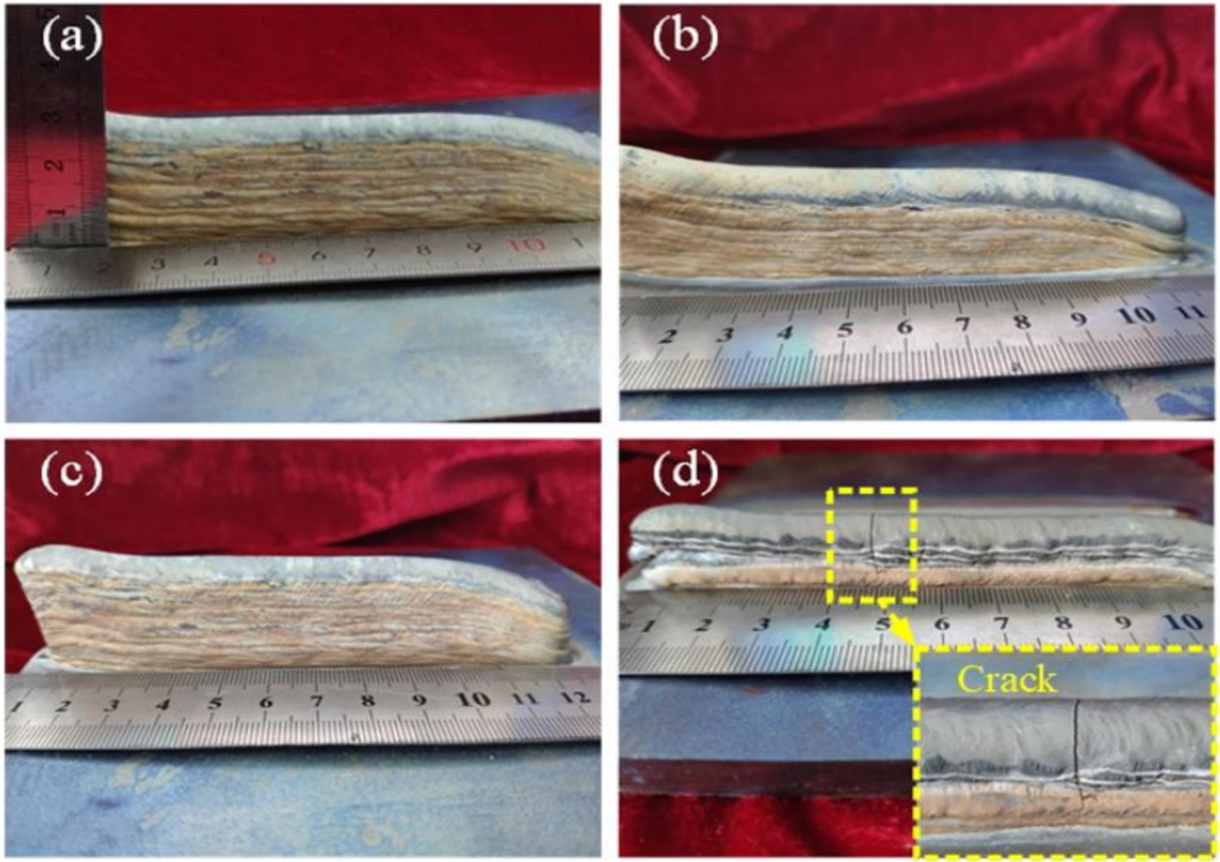

Fig. 6. Wall-shape components under different Al contents: (a) 48 at.%, (b) 45 at.%, (c) 50 at.%, and (d) 55 at. %

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Conclusions TOP-TIG paper

- TOP-TIG DED is a suitable method of producing TiAl
- Crack-free samples were produced
- Different wire feeding angles and the different feeding positions make the two wires melt synchronously in a broad range of wire feeding speeds.

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PAUSE for questions

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Research Paper | Open Access | Published: 10 March 2020

Development of a novel TIG hot-wire process for wire and arc additive manufacturing

E. Spaniol, T. Ungethüm, M. Trautmann, K. Andrusch, M. Hertel & U. Füssel

Welding in the World **64**, 1329–1340 (2020) | Cite this article

•Technische Universität Dresden, 01069, Dresden, Germany

Hot wire technology

- Hot wire can be applied to a range of DED methods (arc and LB)
- Wire feed-stock is heated by resistance heating upstream of the arc
- This reduces the energy required in the arc to initiate melting

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What is GTAW hot wire welding ?

GTAW hot wire processes are characterised by a separate supply of energy and filler material making precise control the heat input possible.

Also possible to ignite the arc independently of filler material enabling stable, spatter-free starting process.

TIG hot wire processes are mainly used in the additive production of highly reactive materials such as high-alloyed steels as well as titanium and nickel-based alloys (Refs 22-30)

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Development of novel TIG –DED hot-wire process

Significant increase in melting performance with reduced heat input.

Upstream resistance heating of feed-stock wire between two contact points within the hot wire feeding system.

Torch, hot wire feeder and gas nozzle are designed in such a way that a constant bead geometry can be guaranteed regardless of travel direction.

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Challenges with hot wire TIG-DED

- Torch is set vertically with side hot wire feeding system.
- No rotationally symmetrical.
- Constant adjustment of hot wire feed required.
- For production of rotationally symmetric components problem can be solved using turn-tilt tables.
- TIG hot wire processes not yet reached roductivity of GMAW (MIG) of >8kg/h
- Preheating the wire does not provide enough energy input to keep the meltpool hot and smaller wires/ feed rate required

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Increasing productivity

- Drop separation and melting performance can be improved by additional mechanical oscillation of the hot wire.
- Further increase in the melting rate can be achieved by using two hot wire sources and torches. Depending on the current intensity, the melting rate can almost be doubled.

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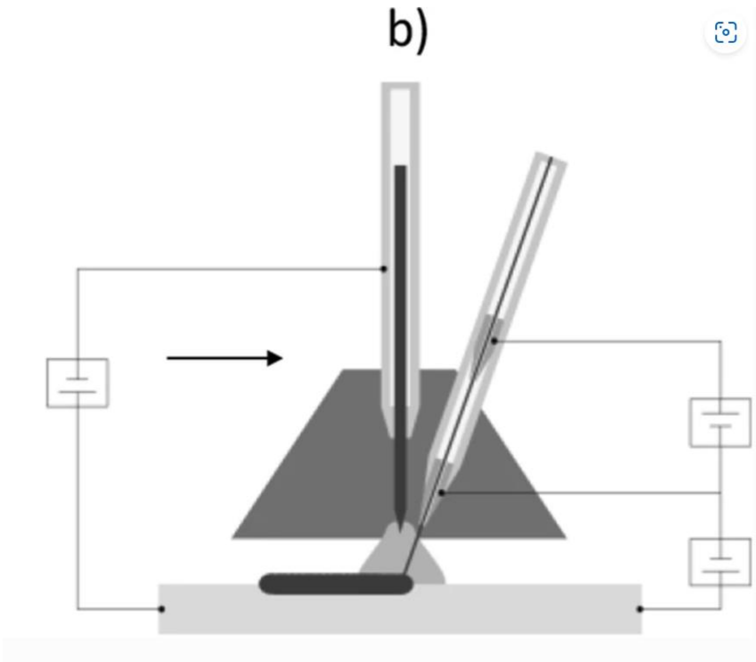
Configuration of new system

- TIG torch and hot wire built into common gas nozzle
- Allows wire feeding angles of up to 70° without torch inclination
- Rotationally symmetrical heat input is provided



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Process parameters

Fixed Parameters

- Base material: mild steel (S235JR)
- Filler wire material: mild steel (G3Si1)
- Filler wire diameter: 1.2 mm
- Travel speed: 0.3 m/ min
- Arc length: 6 mm

Process Variables

- TIG current
- Wire feeding rate
- Hot wire current

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Process Model

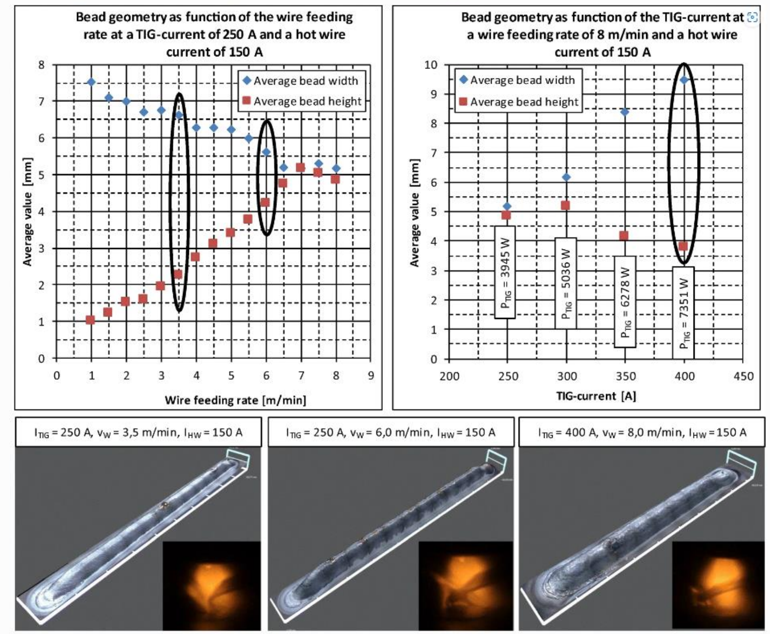
Developed to predict the effect of changing process variables

High feed rates lead to significant cooling and thus reduction in melt pool even at high hot wire voltages

This potential could lead to misfeed and process interruption

Higher TIG current would increase energy input but could lead to heat accumulation and a reduction in deposition accuracy, detrimental to process accuracy and microstructure

May be necessary to introduce pause in build to maintain interpass temperature



Bead geometry as a function of wire feeding rate and TIG current as well as process behaviour during cathode focussed GTAW hot wire welding

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Experimental Trials

Relationship between process parameters and bead geometry

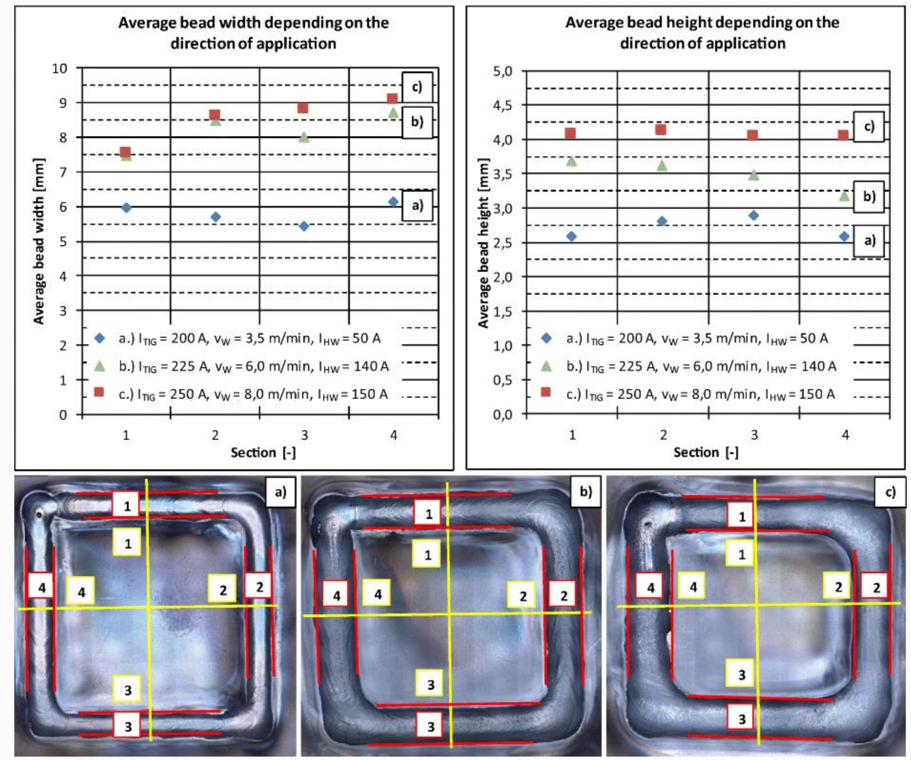
Square samples generated to assess direction independence.

Bead geometry was measured using 3D digital microscopy and evaluated as function of the direction of travel

Metallographic analysis performed to determine penetration and contact angle.

Aim to achieve low penetration, low degree of melting and low contact angles to avoid undercuts.

From: Development of a novel TIG hot-wire process for wire and arc additive manufacturing



Bead geometry as a function of the application direction with constant hot wire feeding during hot wire welding with indirect ohmic preheating (red lines

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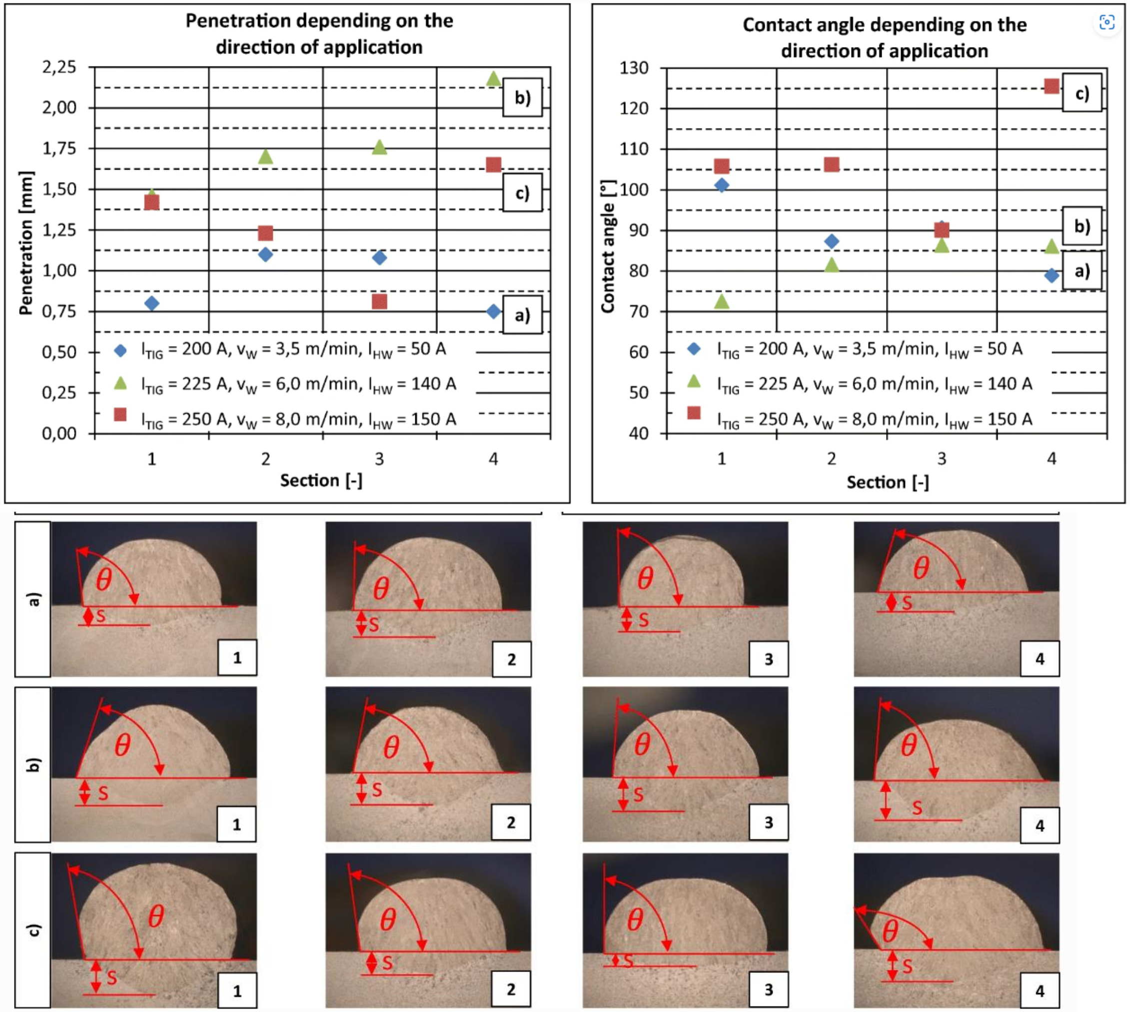
Results

From: Development of a novel TIG hot-wire process for wire and arc additive manufacturing



Penetration and contact angle as a function of the application direction with constant hot wire feeding during hot wire welding with indirect ohmic preheating along the cutting planes of Fig. 9

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Findings

- High productivity - wire feeding rates of up to 15 m/min
- Direction independence through high wire feeding angles up to 75° and hot wire feeding inside the gas nozzle
- Low penetration of the component but high contact angles through very low heat input

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PAUSE for Questions

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IOP Conf. Ser.: Mater. Sci. Eng. 26 012001

https://iopscience.iop.org/article/10.1088/1757-899X/26/1/012001/pdf

Manufacturing Ti-6Al-4V components by Shaped Metal Deposition: Microstructure and mechanical properties

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SMD set up

- TIG torch mounted on 6-axis Kuka robot linked to 2- axis table.
- Wire supplied cold wire feed into the chamber through an annular feed pipe via a motorized roller guide ensuring a constant wire feed speed.
- Ti-6Al-4V wire 1.2 mm diameter
- Setup is enclosed in airtight chamber filled with Argon (99.999% purity)
- Robot control performed by off-line program providing weld path information
- Process is controlled by operator observing through water-cooled vision system which allows real-time monitoring of the weld, particularly the size of the bead and the weld pool and their distance from the contact tip.

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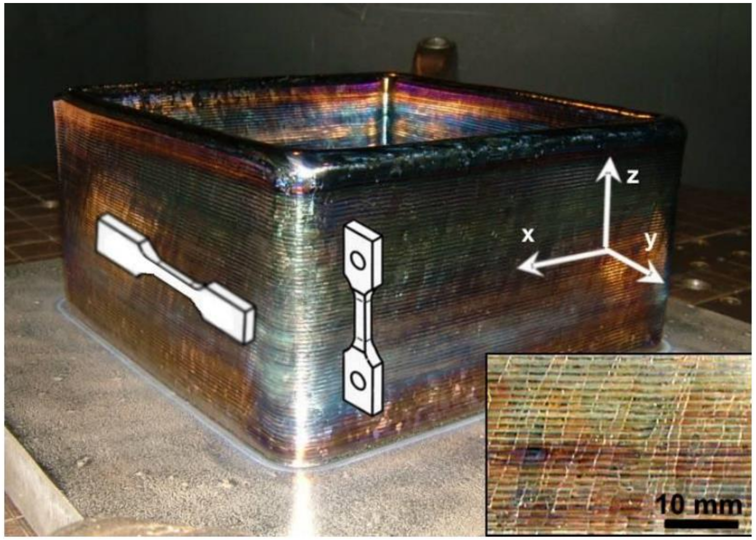
Components & Samples

- 4 square 150x150mm tubular components (A,B,C,D) were deposited using a single track and rotating the table
- Two different tensile specimens extracted from components

    35mm gauge length, 4 x 2mm section (X direction)

    10mm gauge length, 3 x 2mm section (Z direction)



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Mechanical Properties

Table 1 Deposition parameters, the resulting geometry and mechanical properties of four different SMD components.

	Deposition parameters			Geometry			Properties	
Component name	Current (A)	WFS (m/min)	travel speed (m/min)	Height (mm)	Wall width (mm)	Height of top region (mm)	µ-Vickers hardness (GPa)	Young´s modulus (GPa)
A	150	2.1	0.30	120	8.8	8.8	3.1	117
B	183	2.2	0.25	70	9.5	8.7	3.2	118
C	163	1.8	0.30	70	8.8	8.2	3.3	121
D	165	1.4	0.25	70	9.5	8.8	3.4	118

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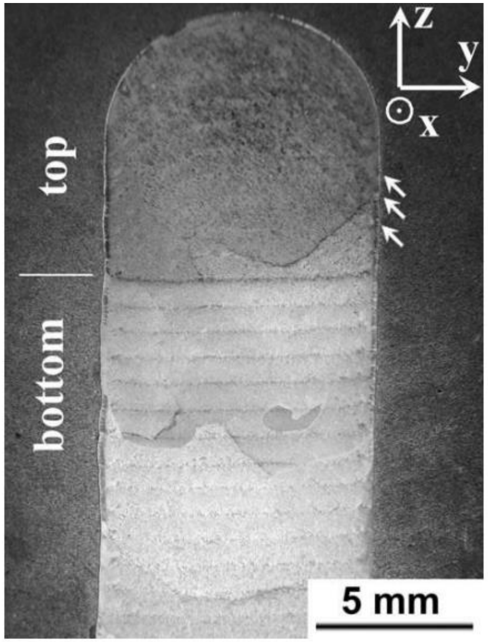
Observations

- Despite inert atmosphere surface of some components were discoloured indication oxidation
- No increase in bulk oxygen levels so just surface affect
- Etched cross sections (y-z planes)
  - Bottom - Banding parallel to base plate
  - Top - no banding



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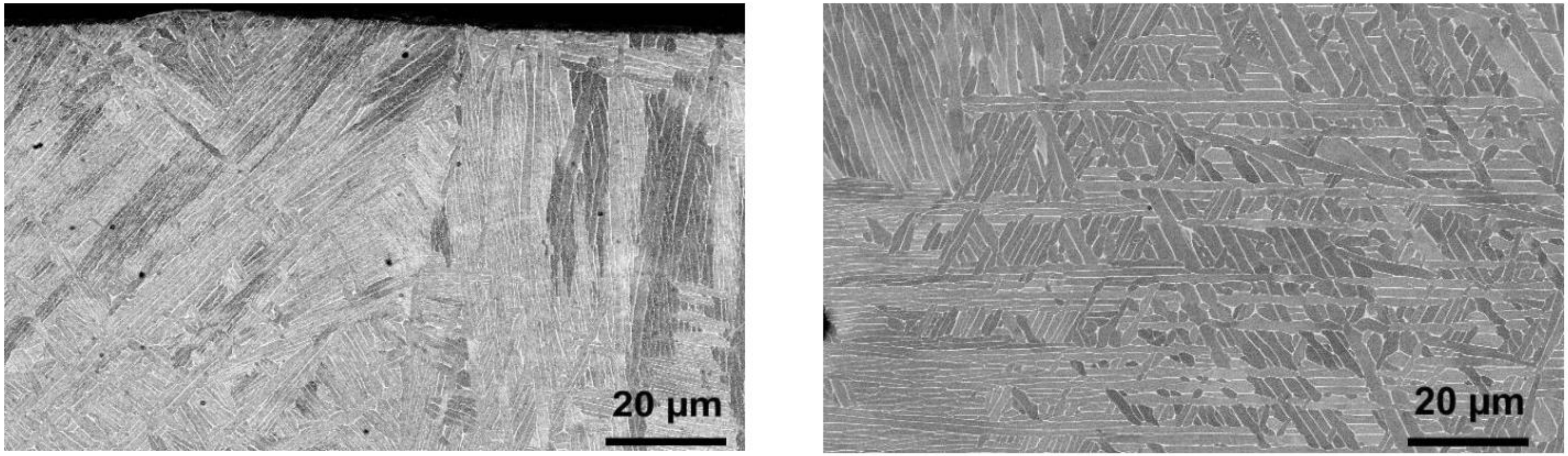
Microstructure

- Ti-6Al-4V exhibits a β phase field at high temperature and a α+β phase field at lower temperatures



a) b)

Figure 3. Microstructures of component A from the top (a) and the bottom region (b) (y-z plane).

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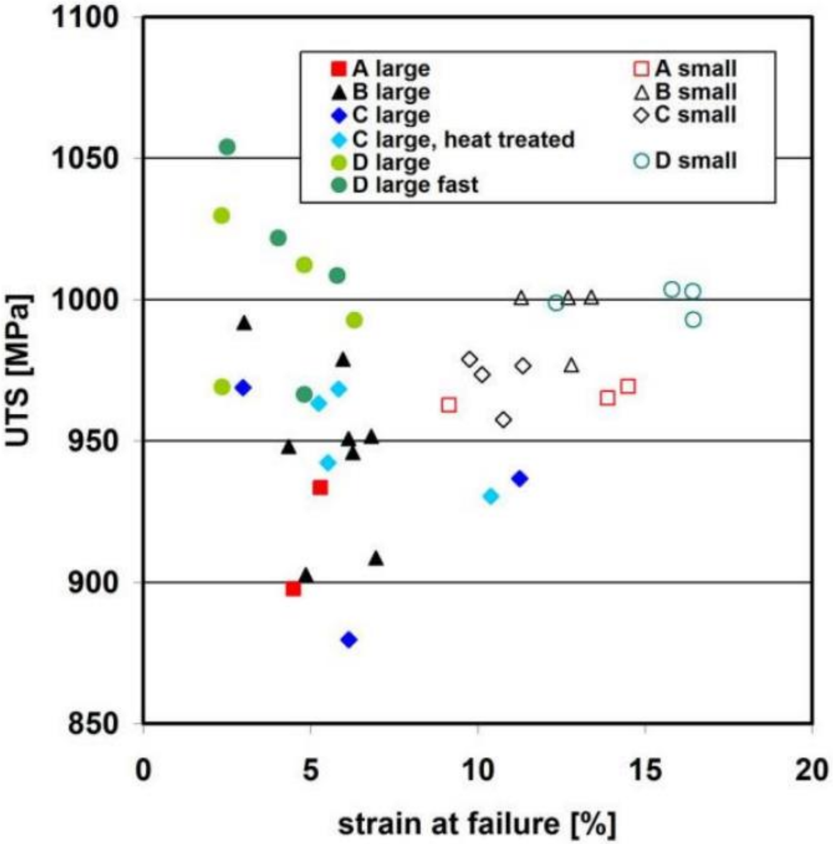
Significant scatter in results

Some evidence of pores



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Findings

- Mechanical properties are comparable to cast material
- Elongation to failure depends on build orientation
  - Parallel build plate ~ 5%
  - Perpendicular ~15%

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PAUSE for questions

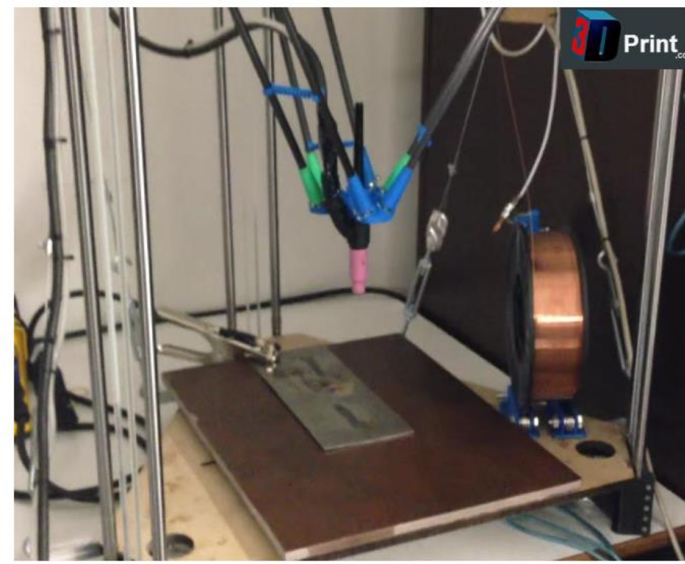
https://3dprint.com/4787/3d-metal-printer-600-euros/

French Man Has Developed a 3D Metal Printer for Just 600€: Capable of printing in steel, titanium and more

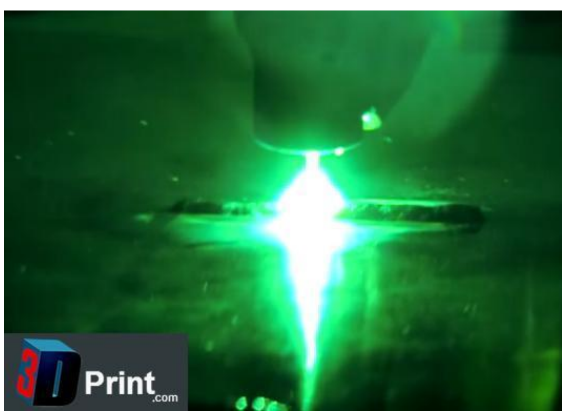
June 2, 2014 • by adlughmin • 3D Printers

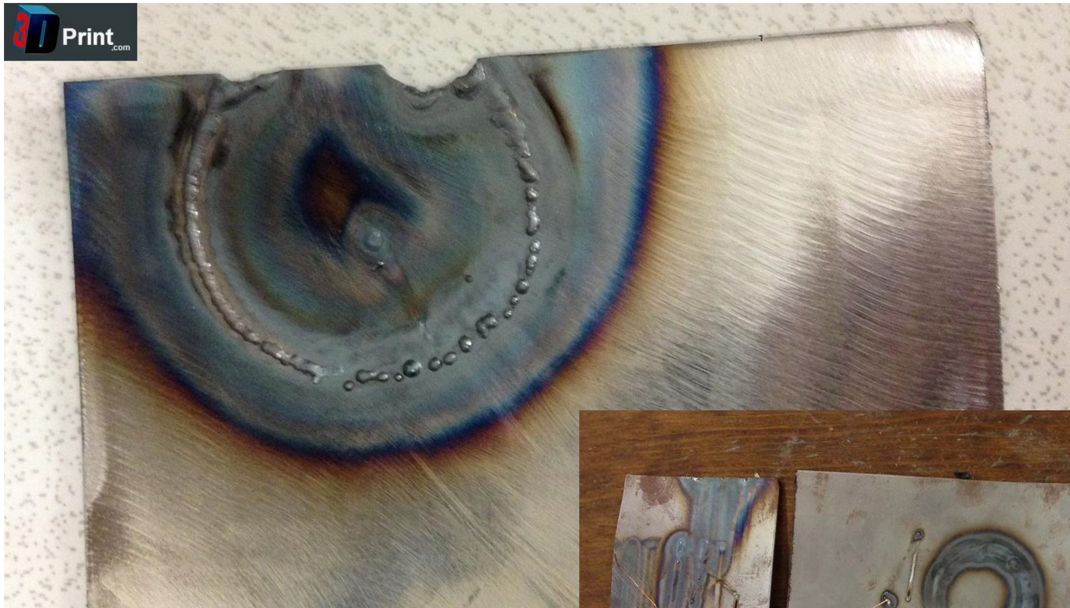
Site Sponsor

Jean-Michel Rogero, Toulouse, France and team at the Artilect Fablab in Toulouse are developing low cost “StrongPrint” TIG-DED unit



https://3dprint.com/wp-content/uploads/2014/06/strong-printing.jpg




Print


Print

Summary for TIG-DED session

- TIG does offer some advantages for DED
- Low cost hardware
- Compact systems
- Energy input is independent of wire feed rate
- TIG energy can be used for preheat/heating
- Potential for dynamic alloying using multiple wire feeds

But

Control of the wire feed position is critical

(PAW has the same issue but PAW systems are better developed in this respect)

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Thank you & Questions ?

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