# Development of Wire + Arc Additive Manufacture for offshore structure

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## Introduction

**The increase in wind power generation and size of wind turbine components has resulted in the need for optimization of the structural materials and manufacturing process used in their fabrication. To build larger, more powerful and lighter wind turbines to be used in the offshore, lighter materials that will give better fracture toughness and strength properties will be needed. The use of modern HSLA steel for the wind industry will allow for the reduction in weight and cost of some specially made components. The cost saving from installation and reduced inspection times as a result of damage tolerance material (HSLA steels) usage is enormous. Wire + Arc Additive Manufacture (WAAM) generally adopts an arc welding power source, wire as feedstock and a robot to manipulate the torch and deposit metallic bespoke components layer by layer. It offers benefits through logistical simplicity and reduction of material wastage when compared to the conventional subtractive process. Contrary to the powder-based additive process, WAAM has the potential for building large scale components. The cold metal transfer (CMT) process, which maintains a stable liquid metal transfer behaviour during deposition process was used.**

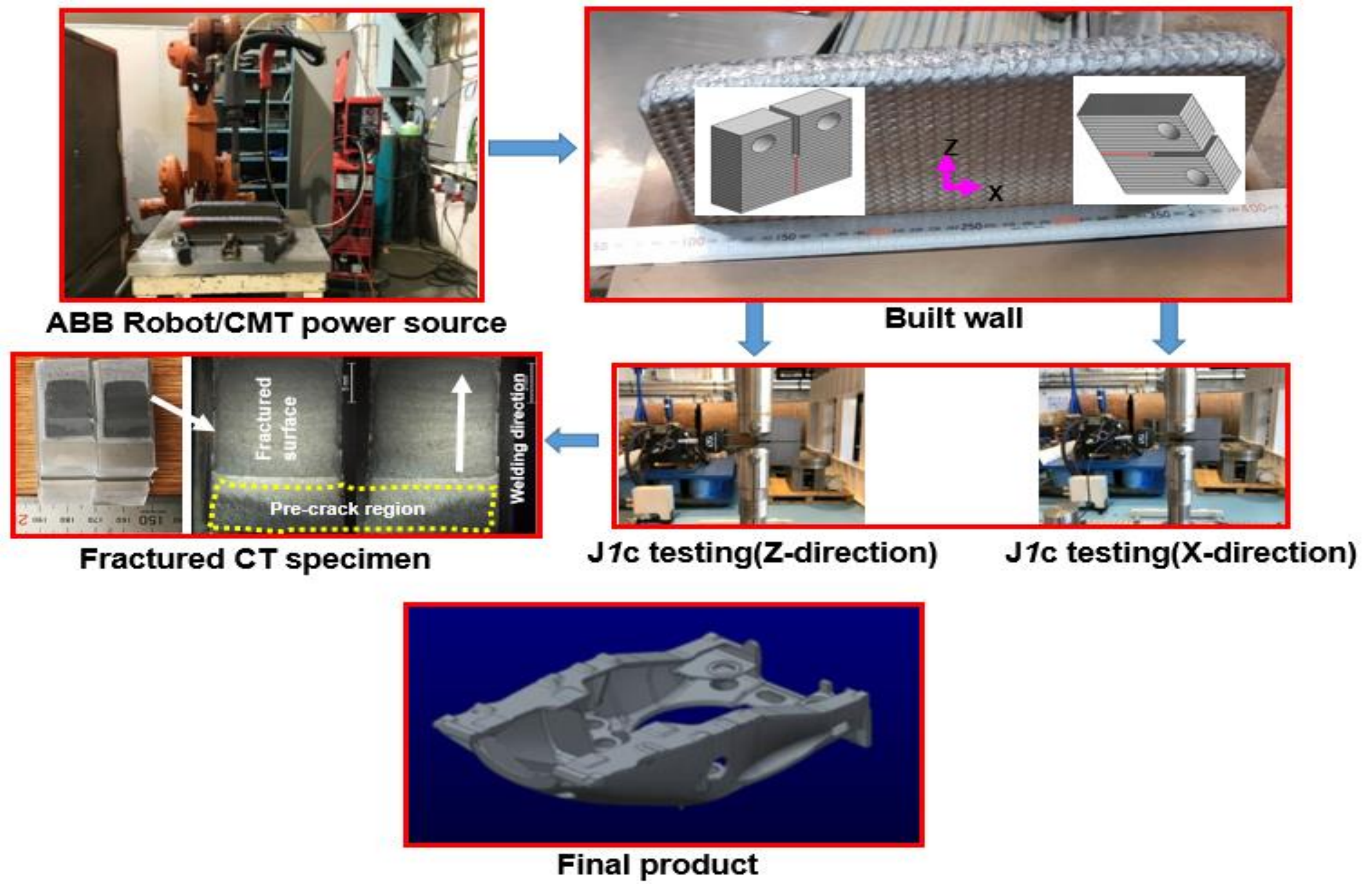
## Research Aims

**To study crack microstructural interaction in WAAM produced structural steel parts and how it can be modified to improve its properties.**

## Methodology

**The WAAM process was carried out with cold metal transfer (CMT) process using the oscillatory strategy with an ABB robot to manipulate the torch**

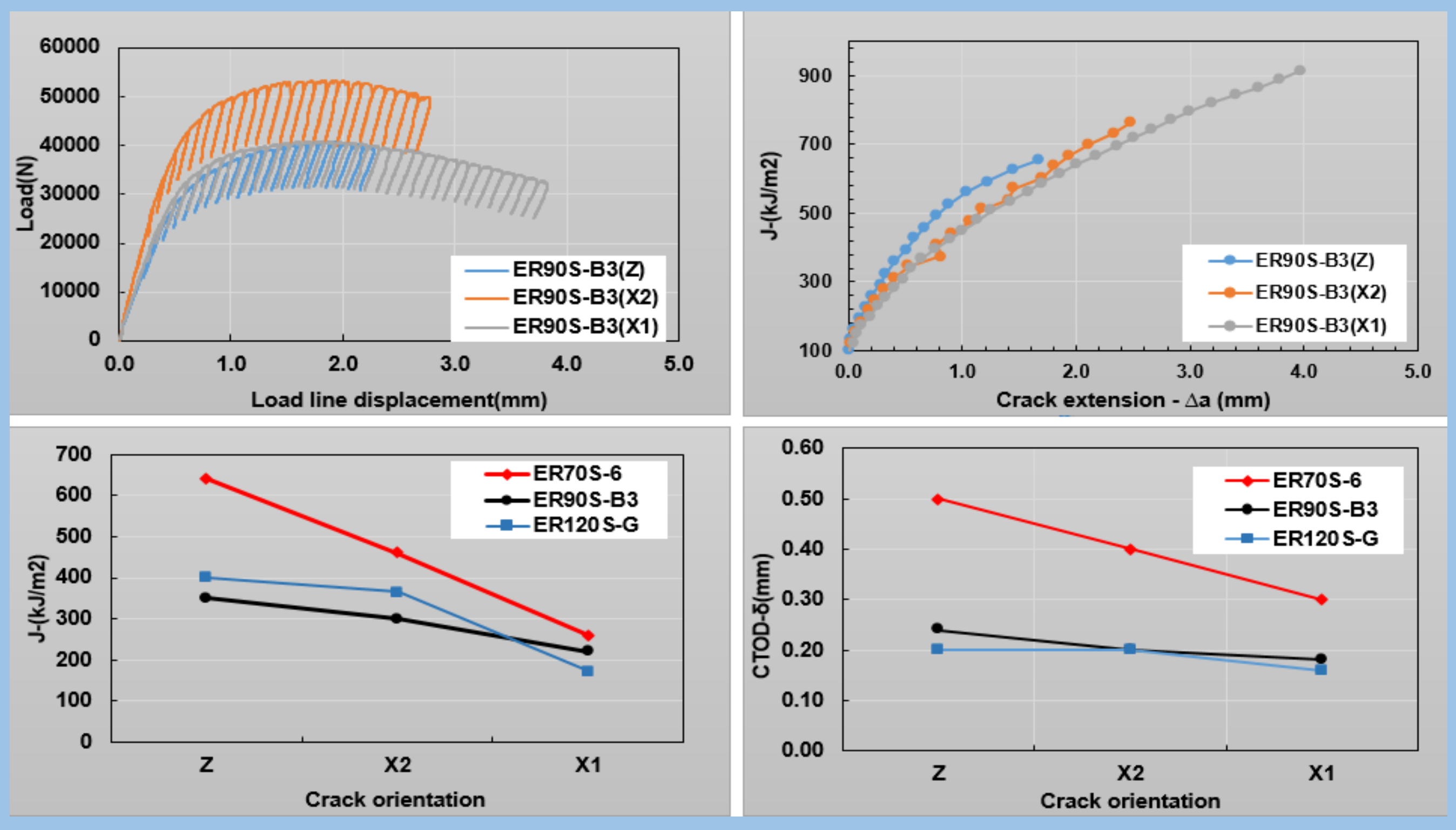
- **Process constant**
- **Gas flow: 25 l/min**
- **Wire feed speed: 83.33mm/sec**
- **Cooling time: 60 secs**
- **Travel speed: 6.67mm/sec**
- **Wire diameter: 1.2mm**
- **Layer height: 3.5mm**
- **Heat input: 0.313kJ/mm**
- **Shielding gas: Ar + 20%$C_{O2}$, Ar+ 2%$O_2$**

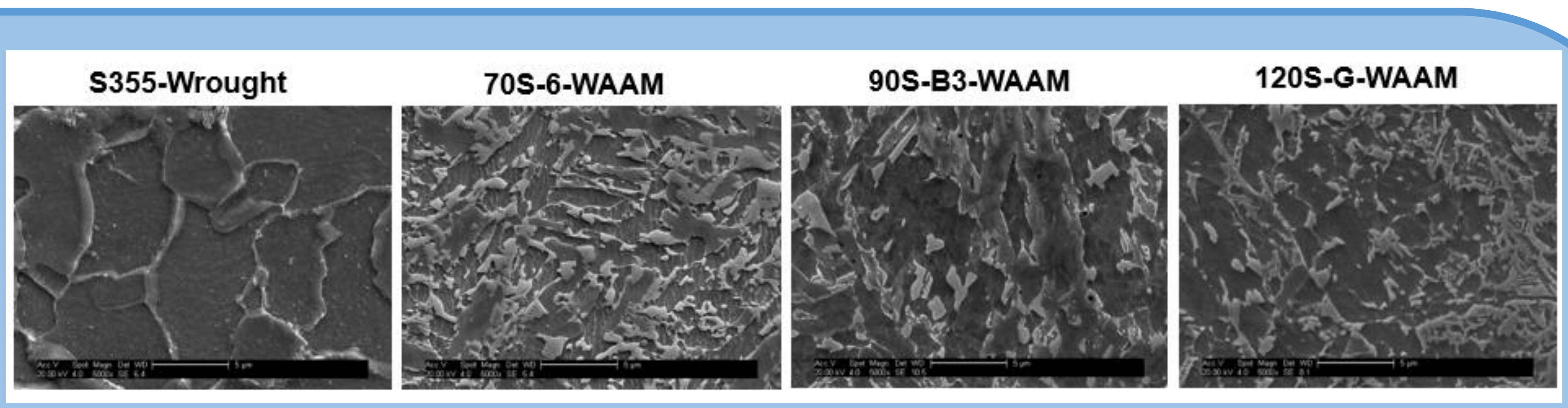


Fracture toughness was conducted according to ASTM E1820, *Standard Test Method for Measurement of Fracture* Toughness.

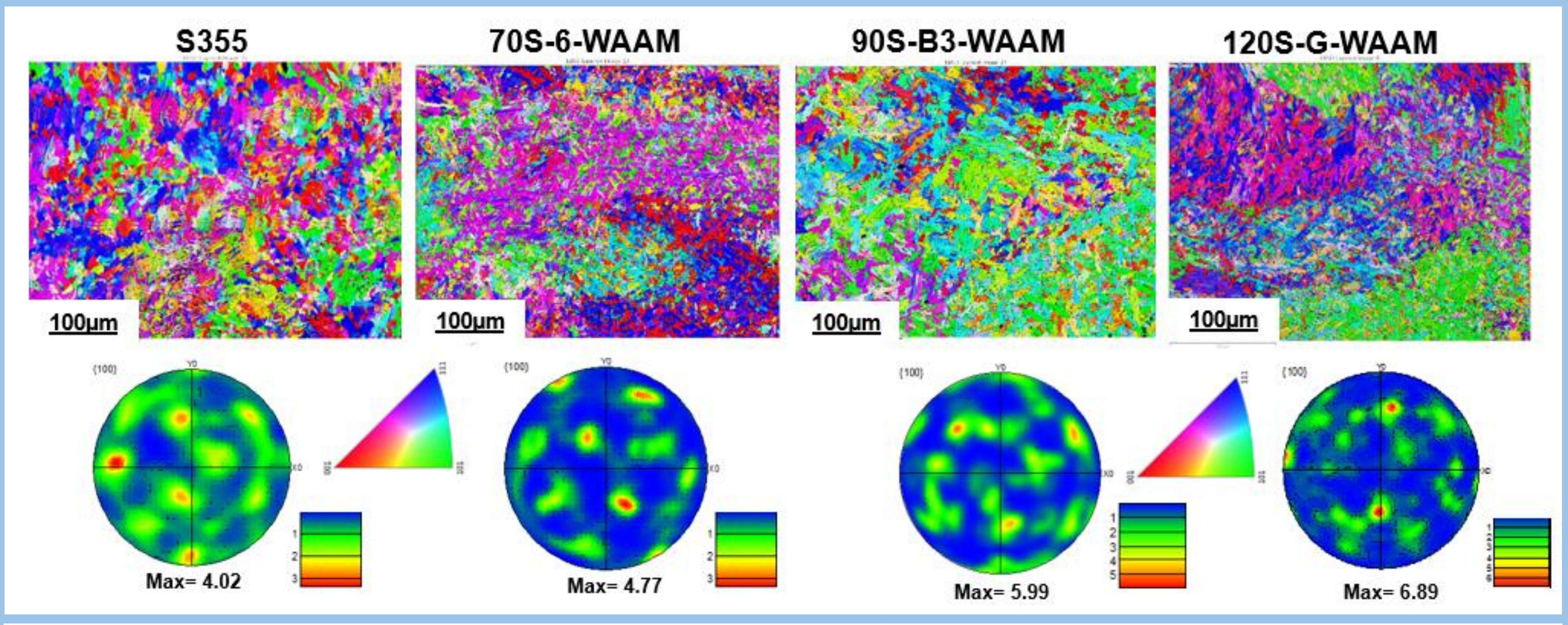
- **EPFM equations**
- J $= J_{el} + J_{pl}$
- $J_{(i)} = \frac{K_{(i)}{}^2(1-v^2)}{E} + J_{pl(i)}$
- $K_{(i)} = \frac{P_{(i)}}{\sqrt{B.Bn.}\sqrt{w}} . f(\frac{a}{w})$ (MPa√m)
- $\delta(CTOD) = \frac{J_i}{m\sigma_y}$
- m = $A_0 - A_1 * \left(\frac{\sigma_{YS}}{\sigma_{TS}}\right) + A_2 * \left(\frac{\sigma_{YS}}{\sigma_{TS}}\right)^2 - A_3 * \left(\frac{\sigma_{YS}}{\sigma_{TS}}\right)^3$

## Results





- Anisotropic martensitic and bainitic microstructure, both in random crystallographic texture and plate like morphology were obtained in 90S-B3 & 120S-G WAAM during the CMT WAAM process



| Wrought & WAAM steels | S355 | 70S-6 WAAM | 90S-B3 WAAM | 120S-G WAAM |
|---|---|---|---|---|
| Maximum grain size | 67 µm | 45 µm | 53 µm | 32 µm |

## Discussion

- **The result shows a very similar texture type and generally weak texture intensity within wrought and WAAM**
- **S355 and 70S-6 WAAM showed no significant preferential crystallographic direction, while 90S-B3 & 120S-G WAAM showed <101> crystallographic direction as the preferential orientation during solidification process**

## Conclusions

- **Anisotropic behaviour in the $J_{1c}$ & CTOD values were observed in both fracture orientation, fracture in the build direction posses higher toughness compared to the welding direction**
- **The obtained fracture toughness values and texture compares favourably with wrought steel of the same grade.**
- **The fracture toughness of WAAM steel structures is dependent on WAAM deposition parameters and alloy content of wires.**
- **The key strength of WAAM oscillatory strategy is that the deposition process can be controlled to obtain different thermal cycles to obtain different microstructure in a component .**

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