

# Effects of Shielding Gas on Microstructure in Wire Arc Additive Manufactured Steel

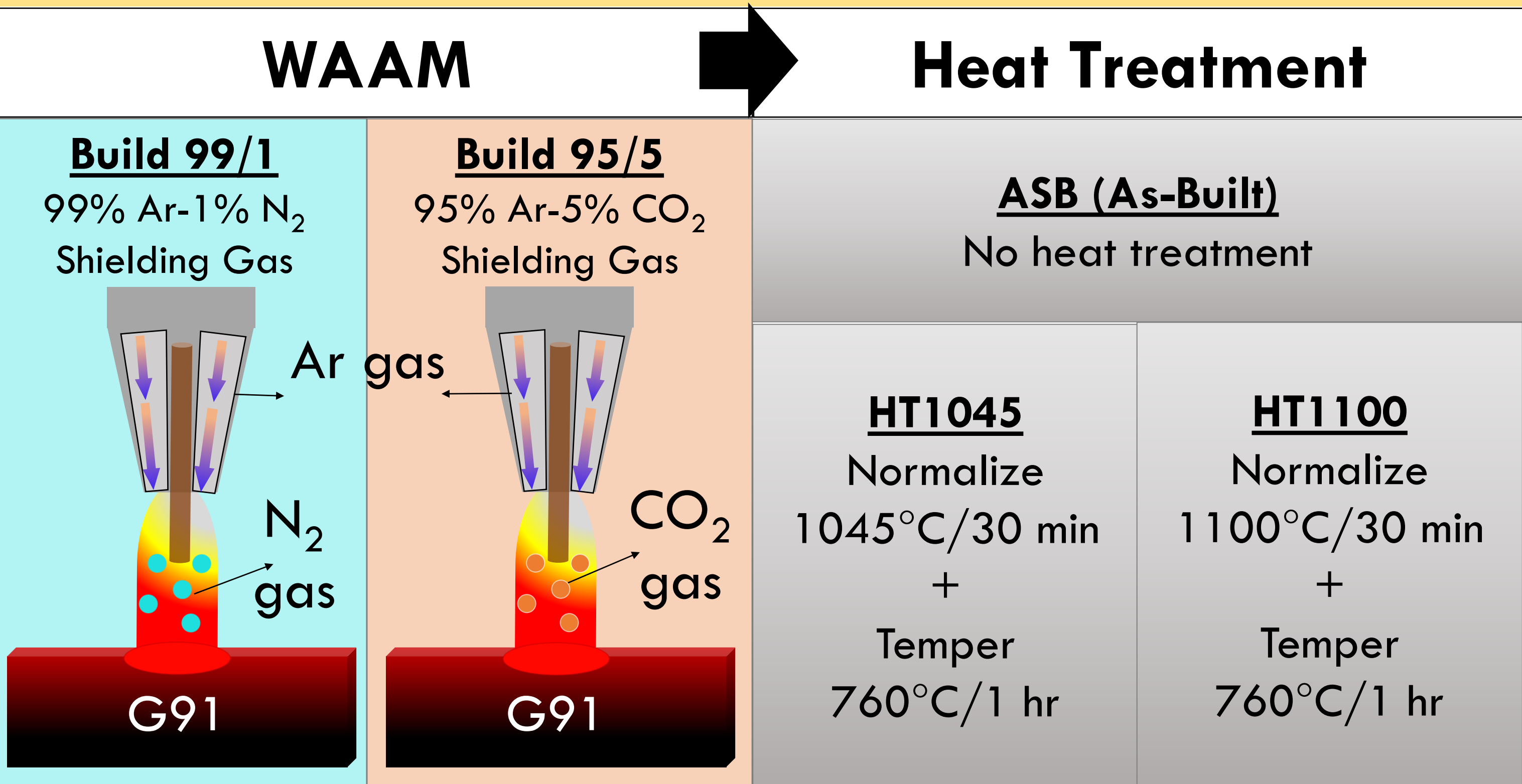
## Background

- Grade 91 (G91) is a 9 weight % Cr steel that derives its high-strength from a ferritic/martensitic structure and **MX (M=Nb,V/X=C,N) carbonitride precipitates**<sup>1</sup>
- Wire arc additive manufacturing (WAAM) is a promising technique to **fabricate G91 with an increased density of MX precipitates** for advanced nuclear reactor components<sup>2,3,4</sup>

## Objective

- Determine the **MX precipitation behavior** in G91 caused by using **CO<sub>2</sub>- and N<sub>2</sub>-containing shielding gases during WAAM**

## Methods



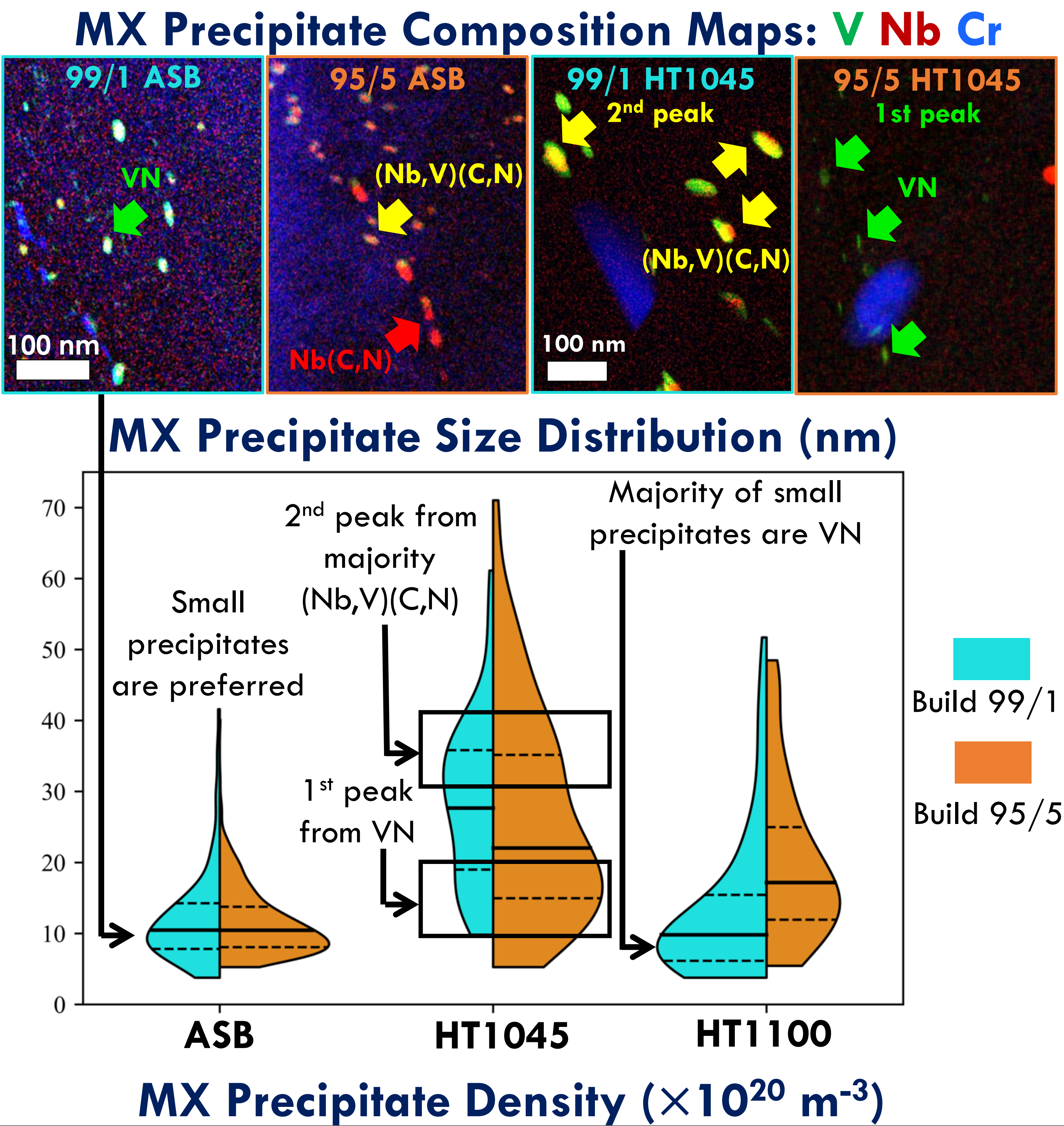
## Final Sample Matrix

Build 99/1		
ASB	HT1045	HT1100
Build 95/5		
ASB	HT1045	HT1100

## Results-Shielding Gas Effect on ASB Composition

	O (wt.%)	C (wt.%)	N (wt.%)	
Wire	0.008	0.08	0.04	Build 99/1: 62% increase in N Build 95/5: 16.25% increase in C
ASB 99/1	0.0178	0.072	0.0648	
ASB 95/5	0.0316	0.093	0.0386	

## Results-Shielding Gas Effect on MX Precipitation



ASB		HT1045		HT1100		Wrought G91 <sup>5</sup>
Build 99/1	Build 95/5	Build 99/1	Build 95/5	Build 99/1	Build 95/5	0.2
14±3	20±4	1.8±0.3	2.1±0.4	9.6±1.8	3.1±0.6	

## Discussion

### ASB

- 99/1: 3.8x more VN than 95/5
  - N<sub>2</sub> gas drove VN precipitation
- 95/5: 2.3x more (Nb,V)(C,N) than 99/1
  - CO<sub>2</sub> gas drove (Nb,V)(C,N) precipitation

### HT1045

- Nb-rich MX agglomerated and coarsened (2<sup>nd</sup> peak)
- V-rich MX dissolved and re-precipitated (1<sup>st</sup> peak)

### HT1100

- All MX dissolved during austenitization
- Higher N content of 99/1 caused **increased MX precipitate density** and **smaller precipitate sizes**

Wire arc AM increased beneficial precipitate number density by 1-2 orders of magnitude over traditional wrought steel

CO<sub>2</sub> and N<sub>2</sub> gas additions to an inert shielding gas during WAAM:

**Modified C and N content**  
**Affected carbonitride precipitation composition**

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