

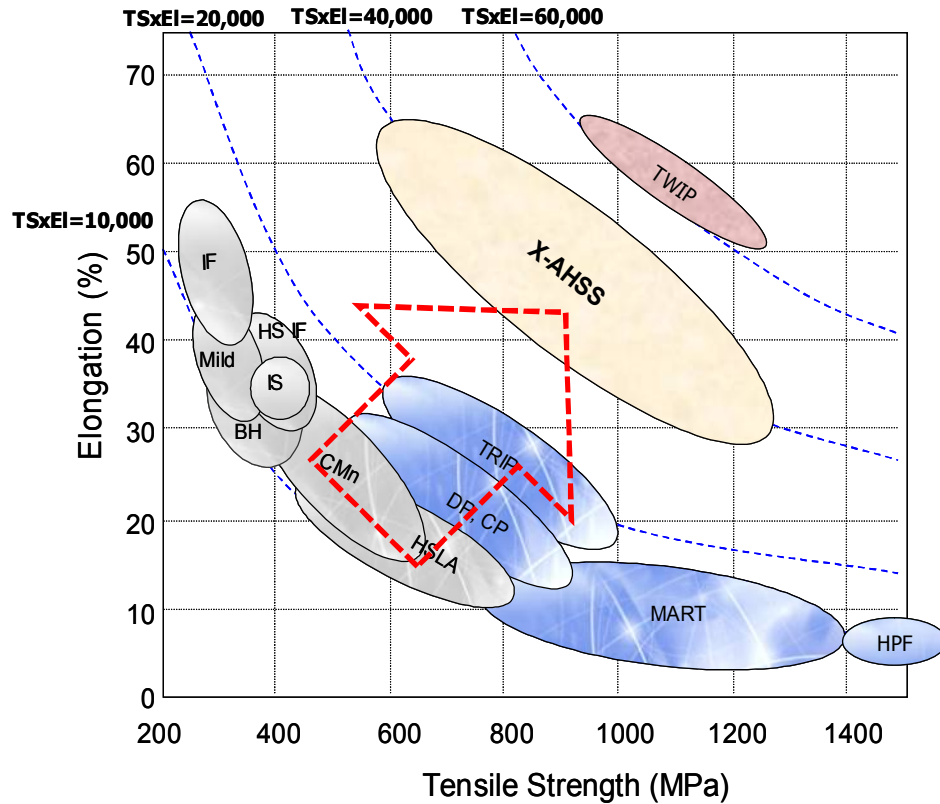
# 잔류오스테나이트를 포함하고 있는 강재의 레이저 용접부 파단특성

2016. 03. 30.

강민정, 한흥남, 김철희



# Recent trend for developing steels



H.N. Han et al. *Materials Science and Engineering A* 499 (2009) 462-468

차체 안정성 & 경량화

→ 우수한 충격흡수능 & 연신율

→ 다양한 합금첨가

→ 용접성 저하



## Weakness

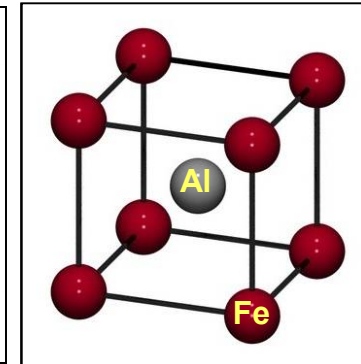
: 높은 비저항으로 인해 용접가능영역이 좁아짐

: 용접 중 가해지는 입열로 인한 금속의 상변태

# Density reduction by Al addition

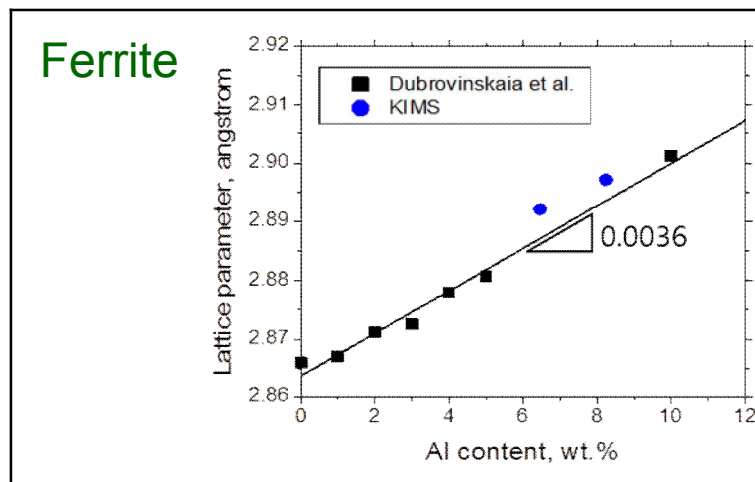
☉ Mass reduction (addition of substitutional light elements such as Al and Si)

Element	Fe	Al	Si
Atomic weight (g/mol)	55.8	27.0	28.1



☉ Volume expansion

❖ Lattice expansion by Al addition



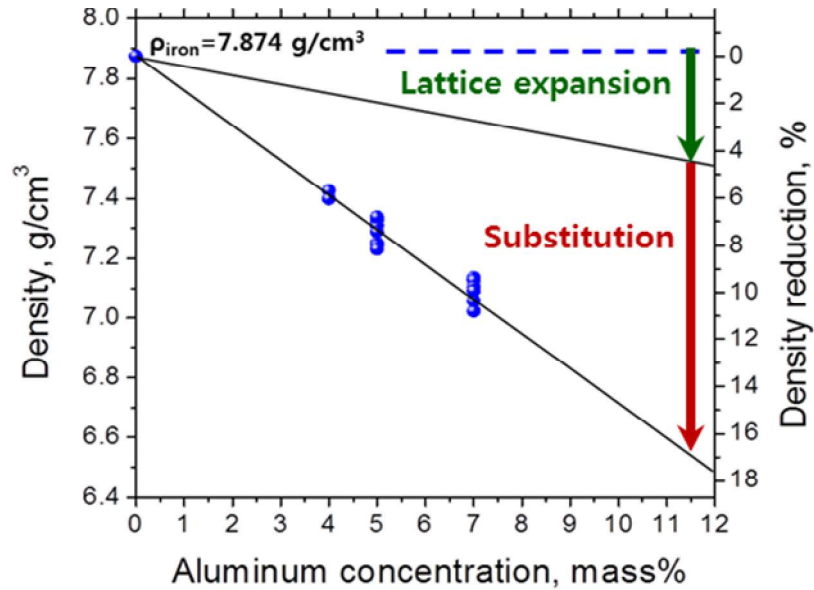
**Austenite**

$$\begin{aligned}
 a_{\gamma} (\text{\AA}) = & 3.5780 + 0.0330C + 0.00095Mn \\
 & - 0.0002Ni + 0.0006Cr + 0.0056Al \\
 & + 0.0220N - 0.0004Co + 0.0015Cu \\
 & + 0.0031Mo + 0.0051Nb + 0.0039Ti \\
 & + 0.0018V + 0.0018W \quad (\text{unit: wt.}\%)
 \end{aligned}$$

(D.J.Dyson and B.Holmes, J. Iron Steel Inst., 1970)

# Density reduction by Al addition

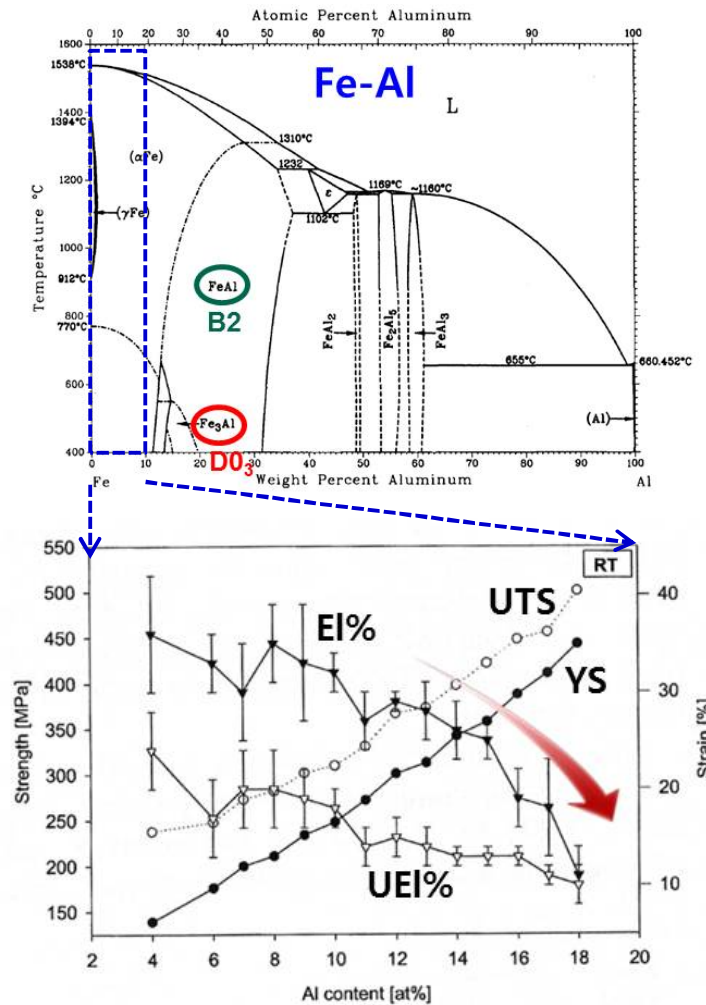
## Density reduction



- Substitution:  $\sim 1.0\%/wt.\%Al$
- Lattice expansion:  $\sim 0.5\%/wt.\%Al$

➔ Total density reduction:  
 $\sim 1.5\%/wt.\%Al$

## Fe-Al system



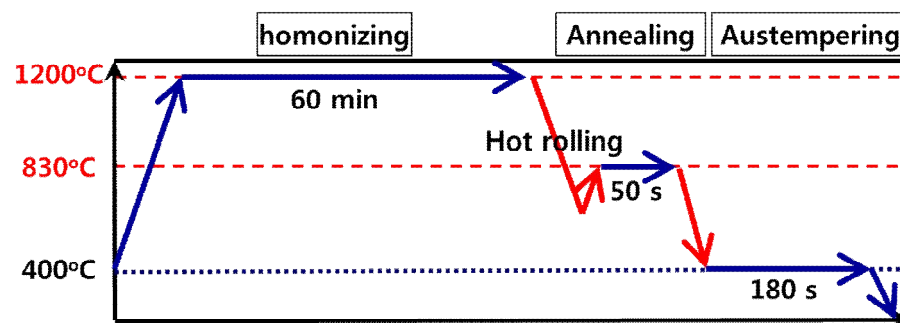
*J. Herrmann et al, Acta Materialia 51, 2003, 2847-2857*



# Classification of lightweight steel

Matrix phase	C (wt.%)	Mn (wt.%)	Al (wt.%)	Other (wt.%)	UTS (MPa)	EI (%)	Company	Year
Ferritic	< 0.03	0.03~0.2	5~9	-	300~500	20~30	MPIE	2002
	< 0.2	< 3.5	2.5~10	-	400~600	20~30	JFE	2007
	< 0.004	0.01~3	2~10	Si 0.01~7	400~500	20~30	NSC	2010
Austenitic & Multi-phase	0.02~0.04	15~25	3	Si 3	600~1,100	60~90	MPIE	2003
	0.8~1.2	10~30	8~12	-	700~900	60~80	NSC	2006
	0.5~2.0	18~35	8~12	(Si 3~6)	600~1,100	25~70	MPIE	2007
	0.3~0.4	3~4	5~6	Mn < Al	700~800	27~34	POSCO	2009
	0.15~0.5	6~12	5~6	Si 0.05~0.5	700~1,000	35~60	KIMS	2012
	0.8~0.9	15~17	8~10	Ni 4.9	1300~1500	20~35	GIFT	2015

## Heat treatment

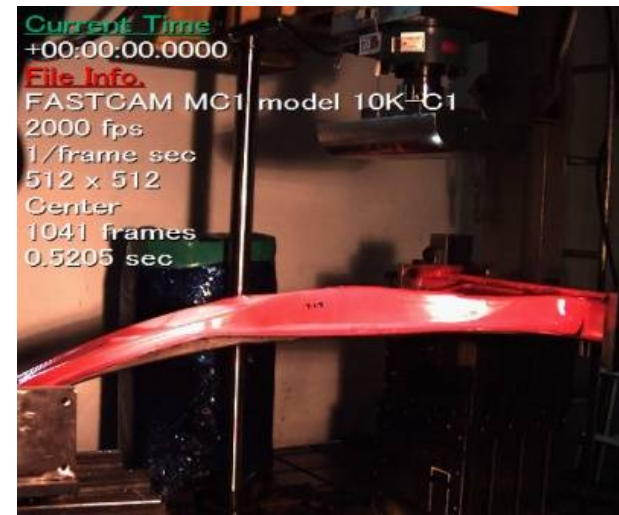


Ref.) Scripta Materialia 66 (2012) 519–522

✓ **Austempering**  
 → Retained austenite at room temp.

# Scope of study

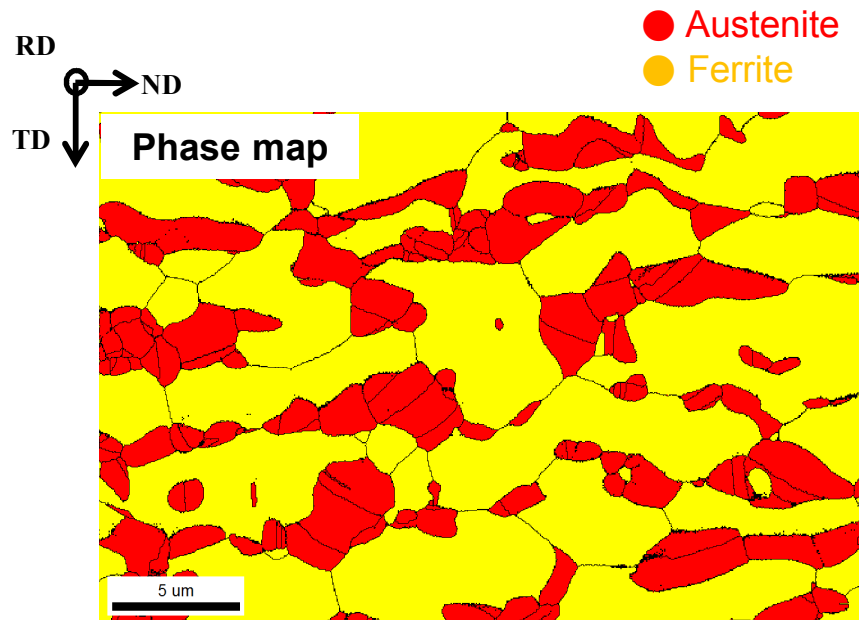
- ▶ 잔류오스테나이트를 포함하고 있는 강재를 대상으로 레이저 용접을 수행하고 기계적 물성 및 조직학적 거동을 확인



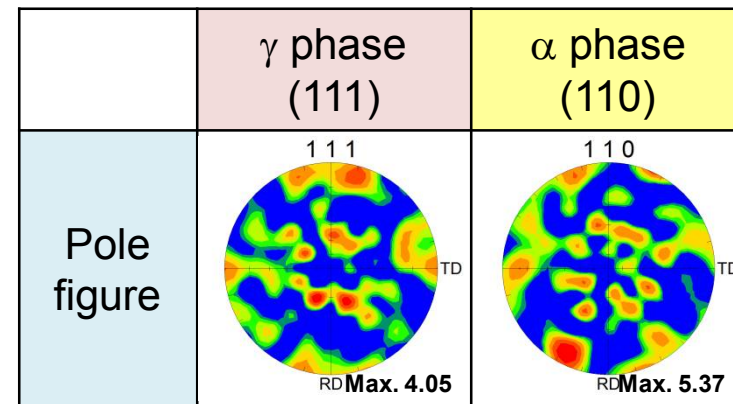
# Applied materials (Lightweight steel-LWS)

## ○ Properties of applied materials

	Chemical composition (Wt.%)							Mechanical properties (RD)		
	C	Mn	Al	W	Ti	Si	Fe	UTS (MPa)	YS (MPa)	E.L. (%)
<b>LWS 1</b>	0.33	<b>3.64</b>	<b>5.40</b>	0.16	0.027	-	Bal.	778	503	34%
<b>LWS 2</b>	0.34	<b>3.72</b>	<b>5.22</b>	-	-	0.11	Bal.	870	526	43%
<b>LWS 3</b>	0.33	<b>3.68</b>	<b>5.10</b>	-	-	0.08	Bal.			



오스테나이트와 페라이트의  
이상조직(Dual phase) 구성



Phase fraction (Austenite:Ferrite)	Grain size (μm, < 15°)	
	Austenite	Ferrite
33 : 67	1.75	5.02

# Experimental setup

## Equipment

- 4 kW Disk Yb:YAG laser
  - Fiber diameter: 200  $\mu\text{m}$
  - Beam diameter: 0.54 mm, 0.60 mm

## Welding condition

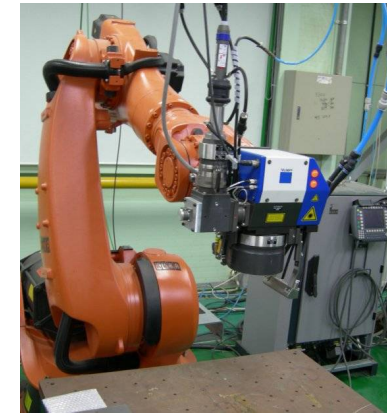
- Joint: bead on plate (150 X 240 X 1 mm)
- Focal position: 0 mm
- Shielding gas: None
- Variable: laser power, welding speed
- Full penetration

## Analysis method

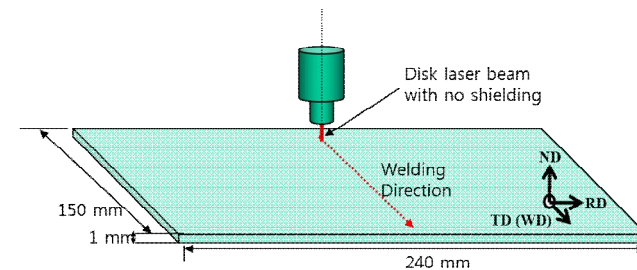
- Mechanical properties
  - : Tensile test, Vickers hardness test
- Morphology
  - : OM, SEM-EDS, EBSD, EPMA



[Disk Laser]

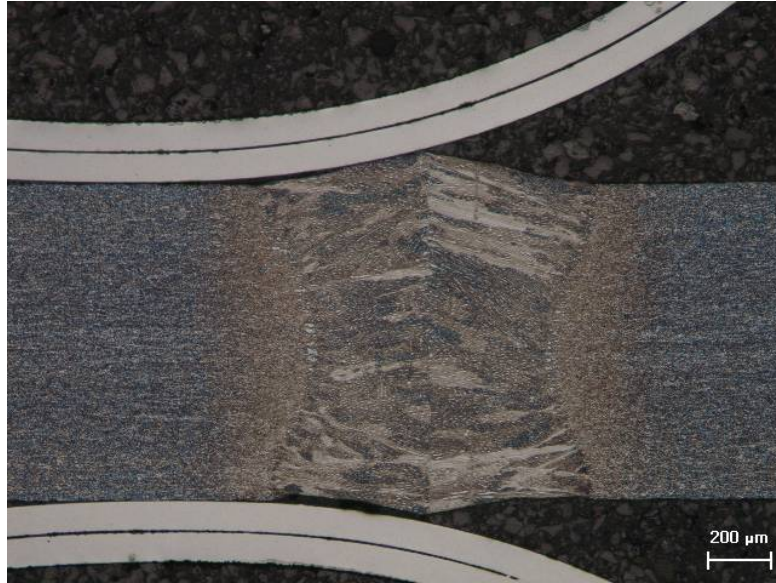


[6-axis robot]



[Schematic diagram of set up]

# Macro-sections



- 용융부에 **주조조직** 형성
- 열영향부** 형성 확인

## Welding condition

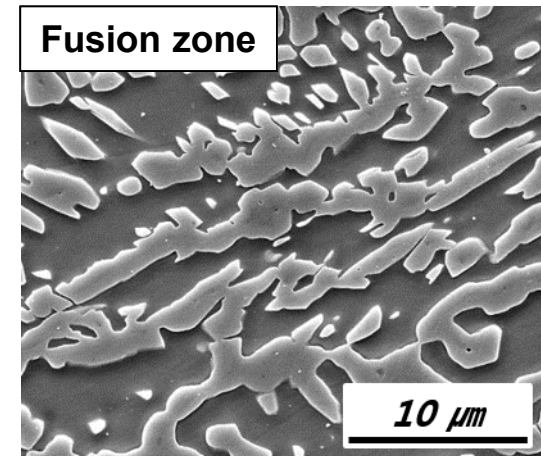
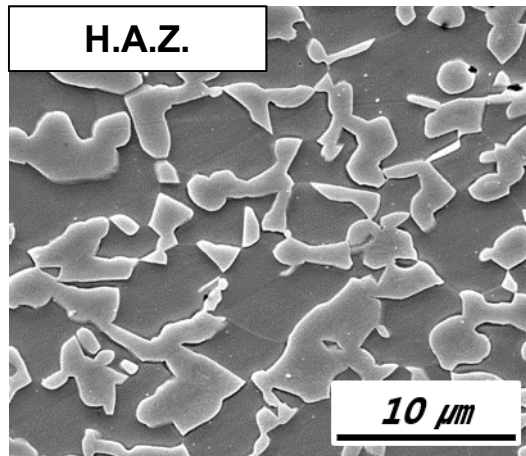
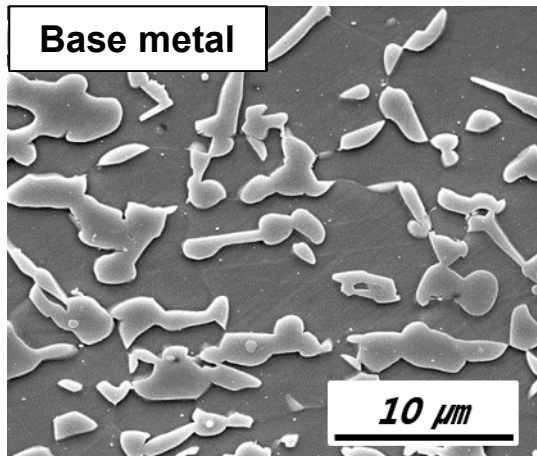
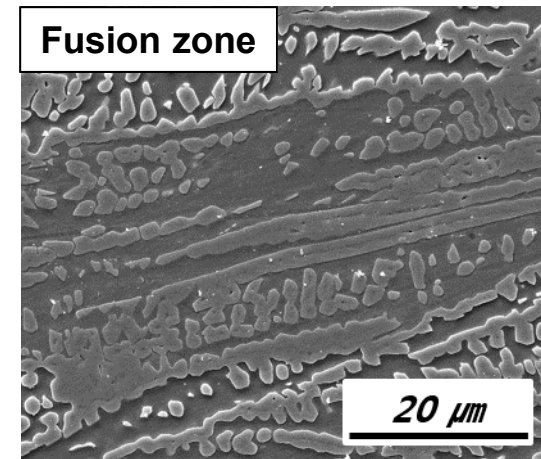
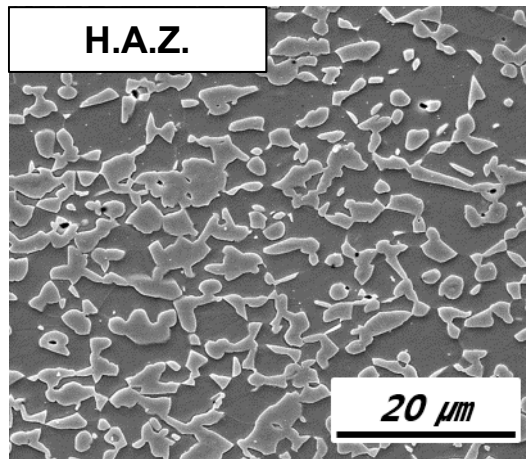
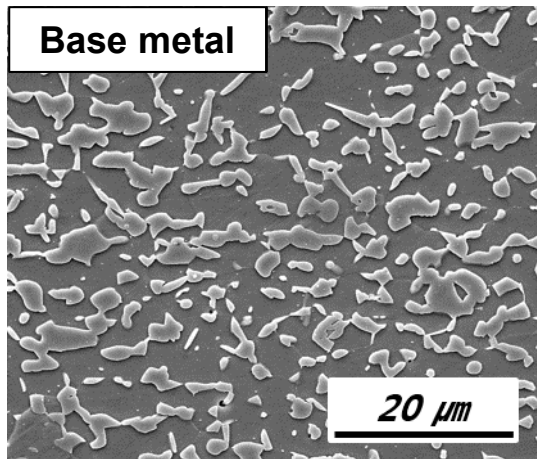
- 0.54 mm beam diameter
- 3 kW laser power
- 6 m/min welding speed





# Macro-sections

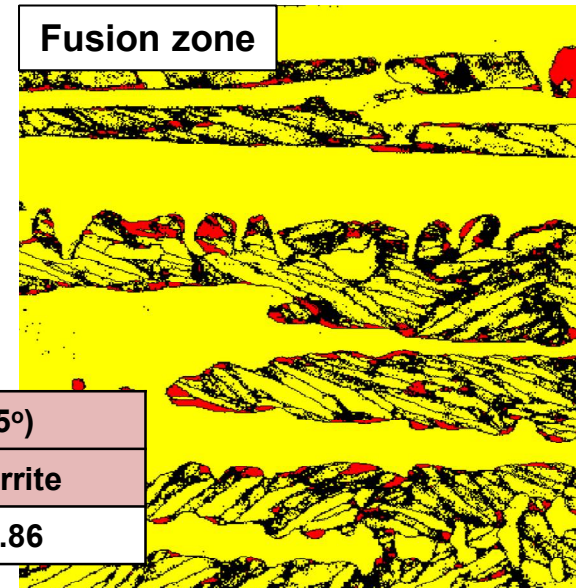
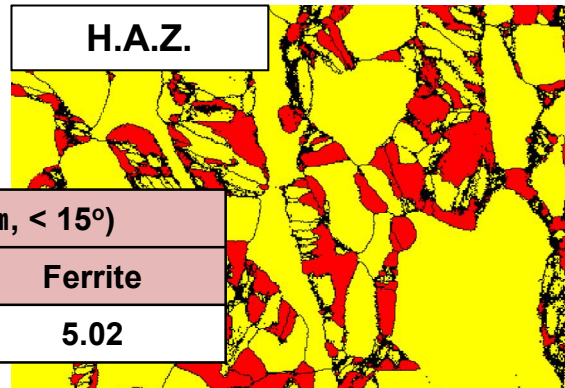
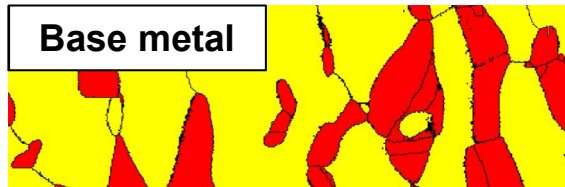
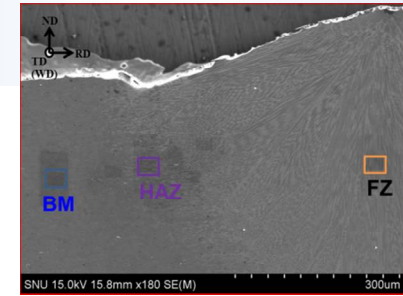
## ✓ SEM images of welds



# EBSD phase map

## ✓ Results of EBSD

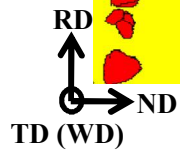
- Austenite ( $\gamma$ )
- Ferrite ( $\alpha/\alpha'$ )



Phase fraction (Austenite:Ferrite)	Grain size ( $\mu\text{m}$ , $< 15^\circ$ )	
	Austenite	Ferrite
33 : 67	1.75	5.02

Phase fraction (Austenite:Ferrite)	Grain size ( $\mu\text{m}$ , $< 15^\circ$ )	
	Austenite	Ferrite
20 : 80	1.07	4.86

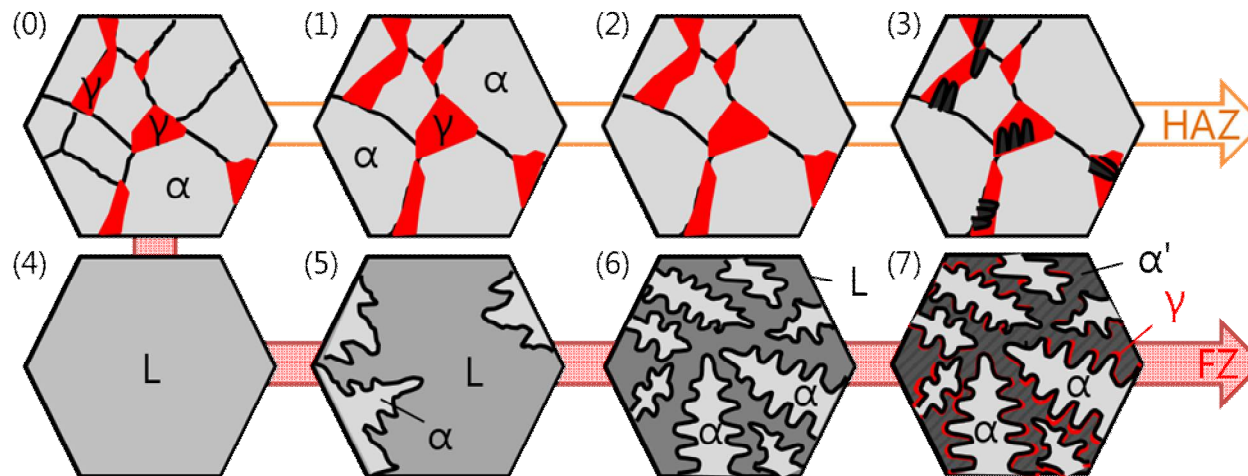
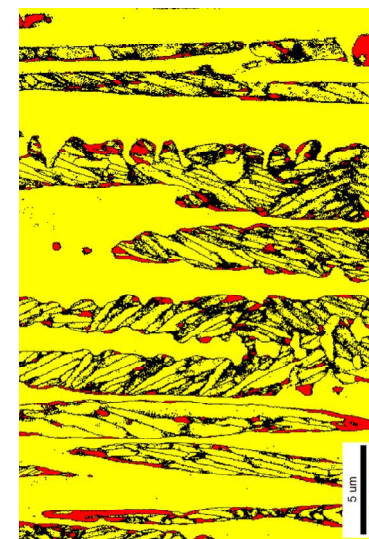
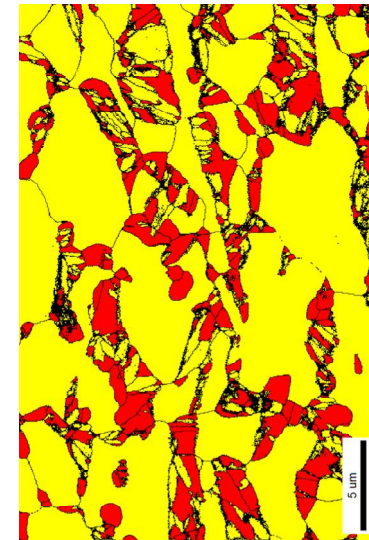
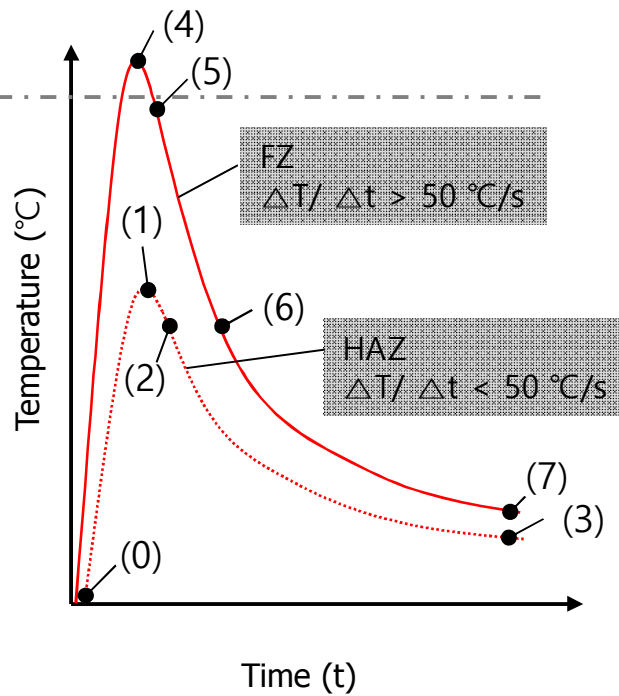
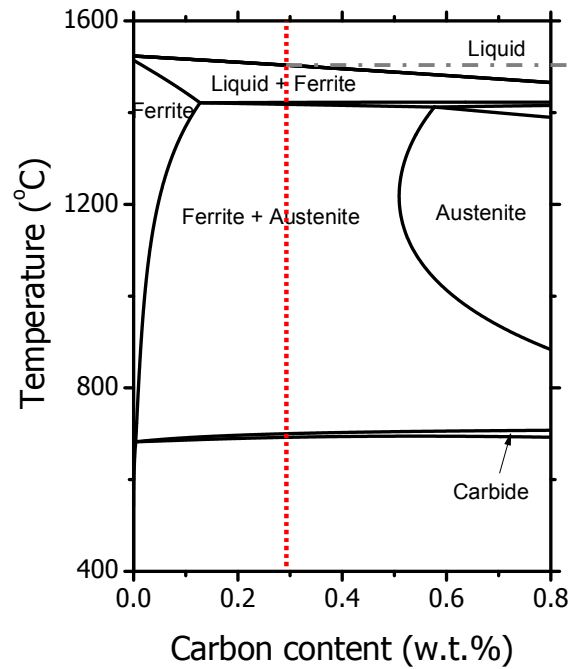
Phase fraction (Austenite:Ferrite)	Grain size ( $\mu\text{m}$ , $< 15^\circ$ )	
	Austenite	Ferrite
5 : 95	0.68	6.13



용접부에서 오스테나이트의 상분을 감소. 11

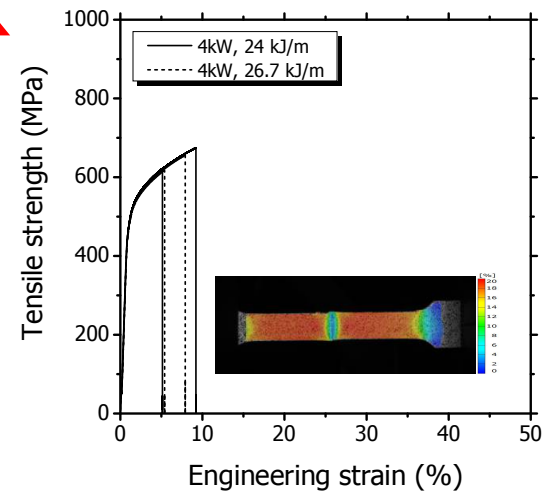
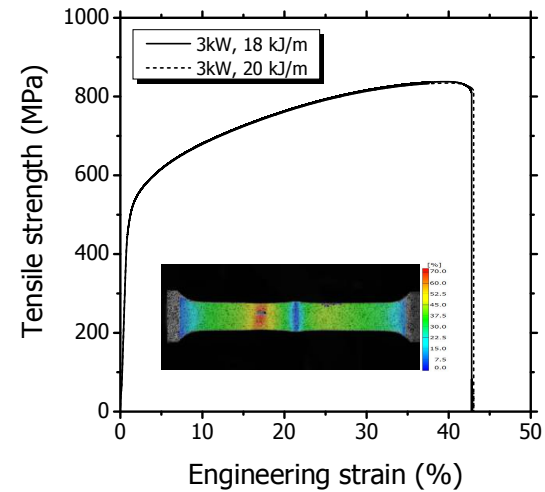
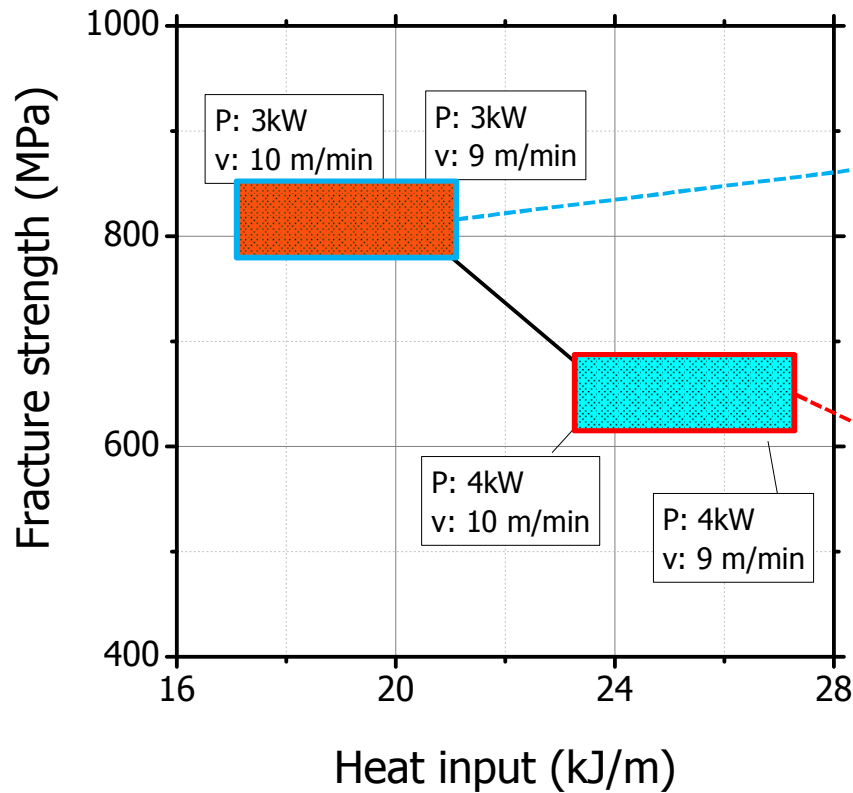


# Phase diagram



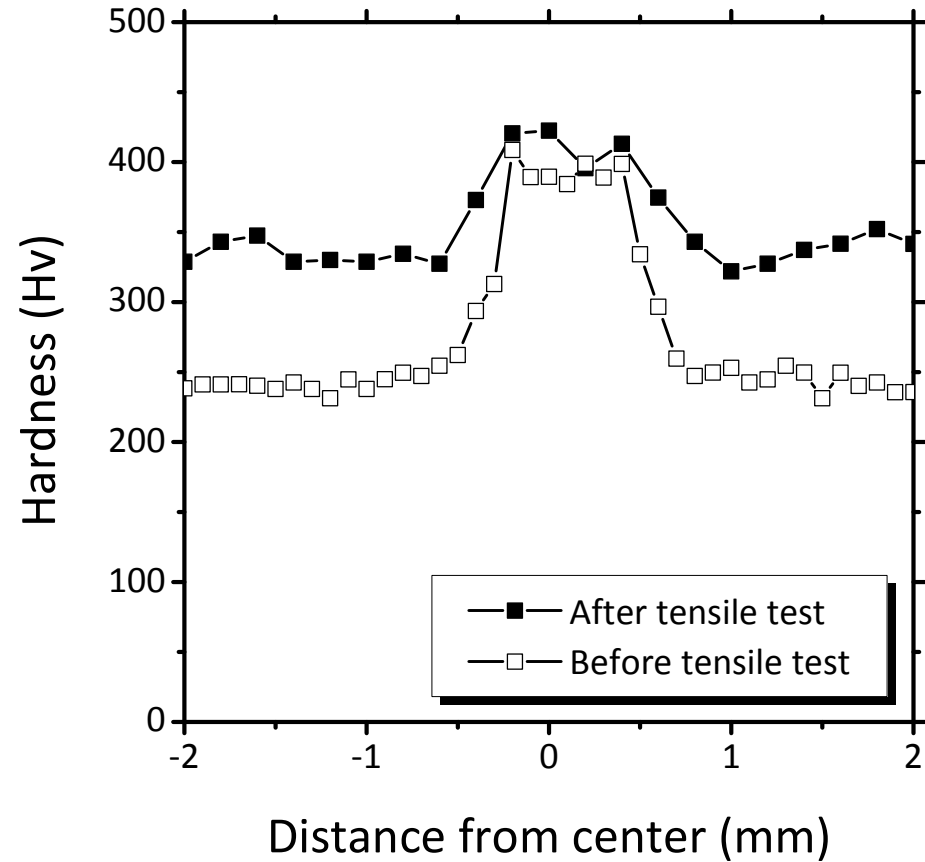
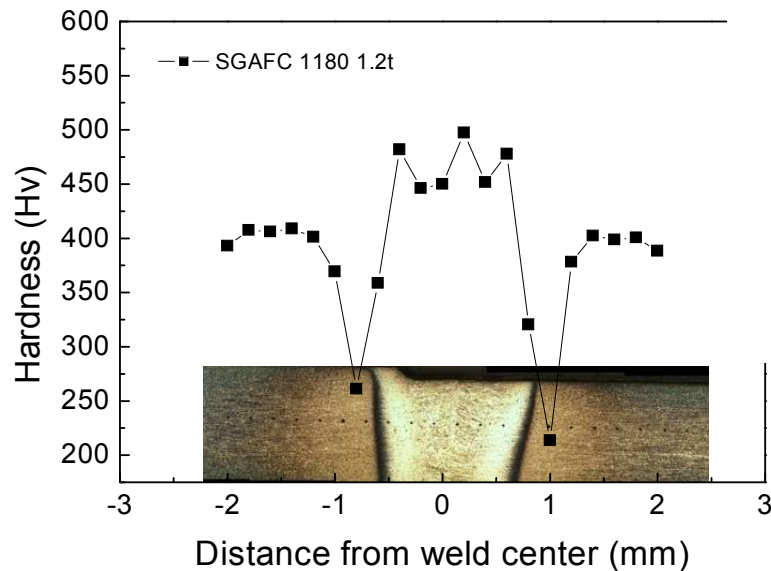
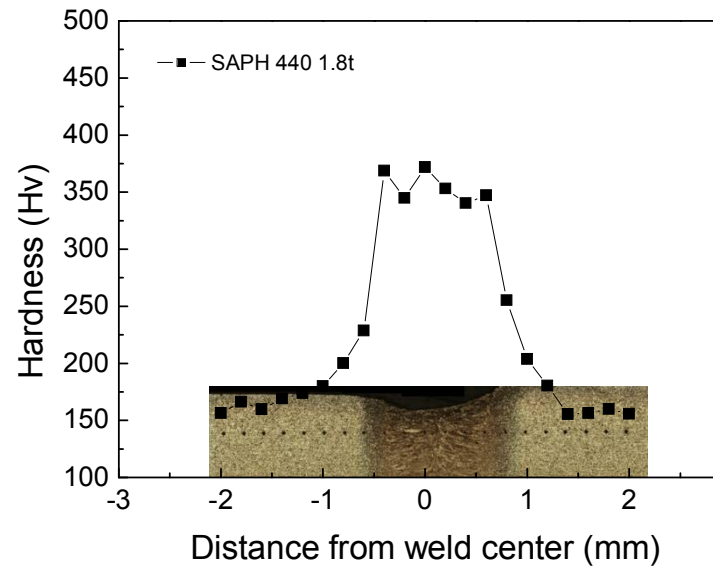


# Tensile test with various welding condition

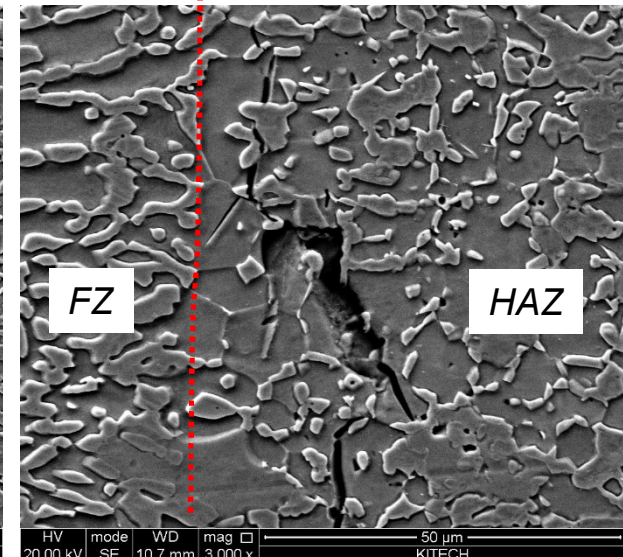
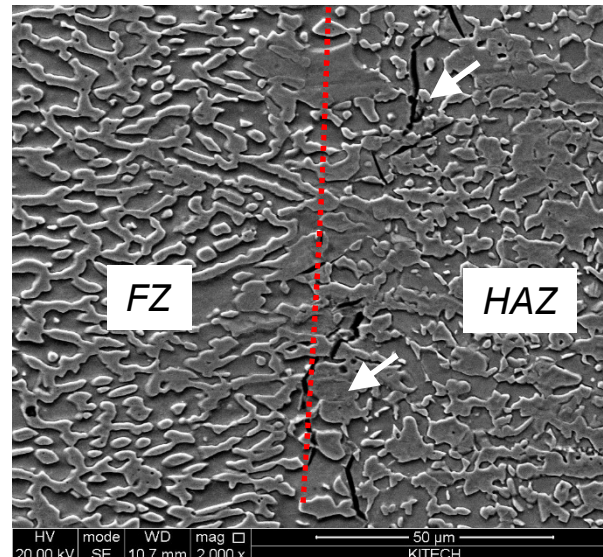
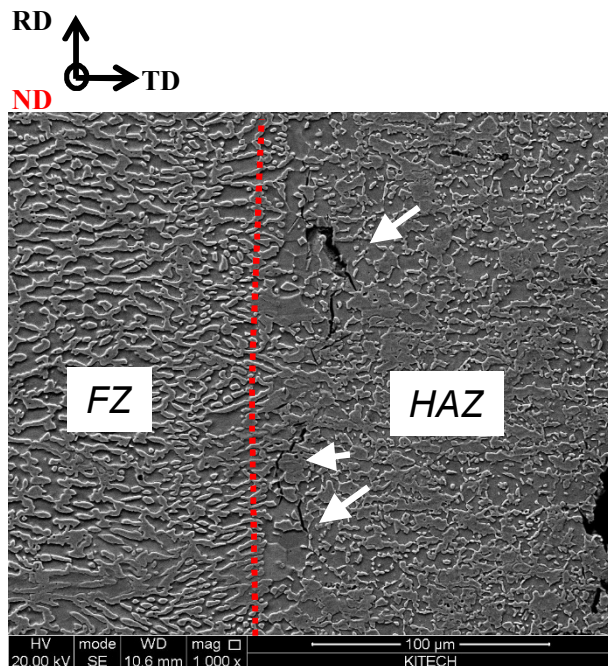
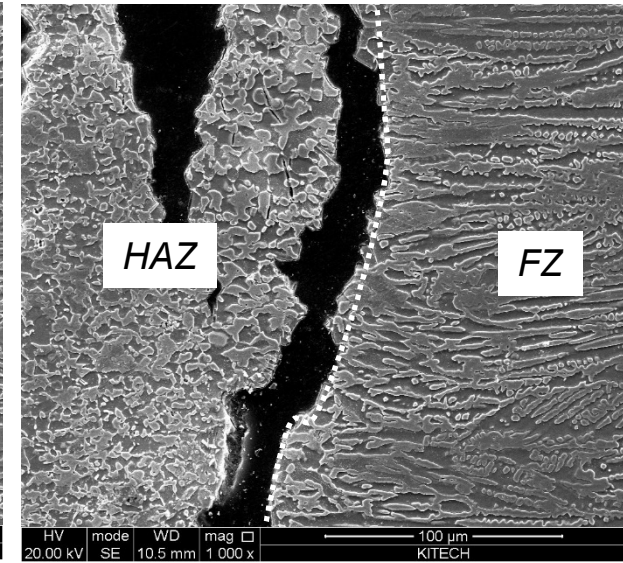
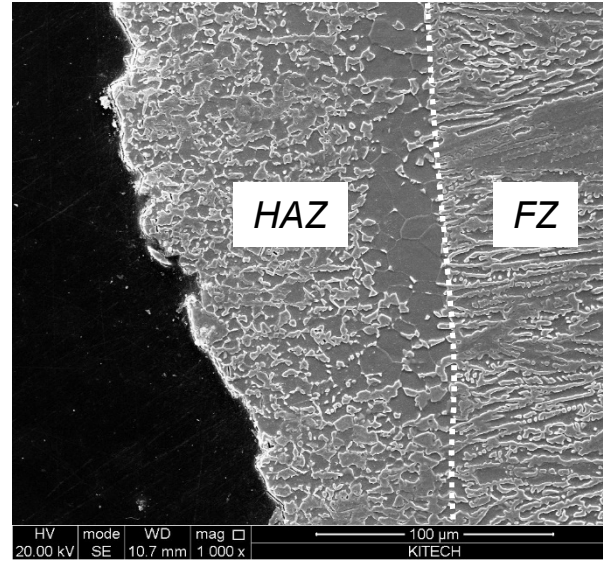
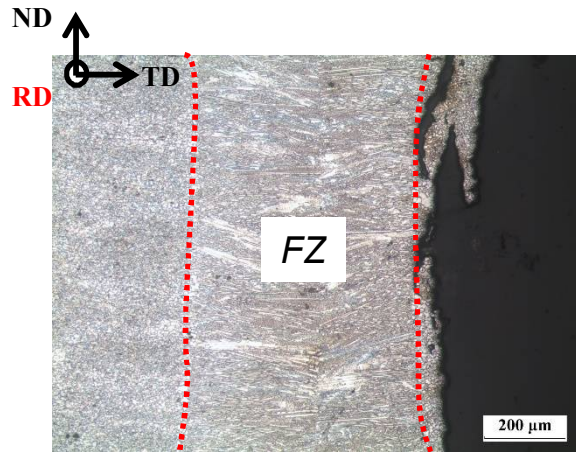


높은 입열이 가해지는 경우,  
낮은 강도 측정됨.  
→ Fusion line failure

# Hardness of commercial steels

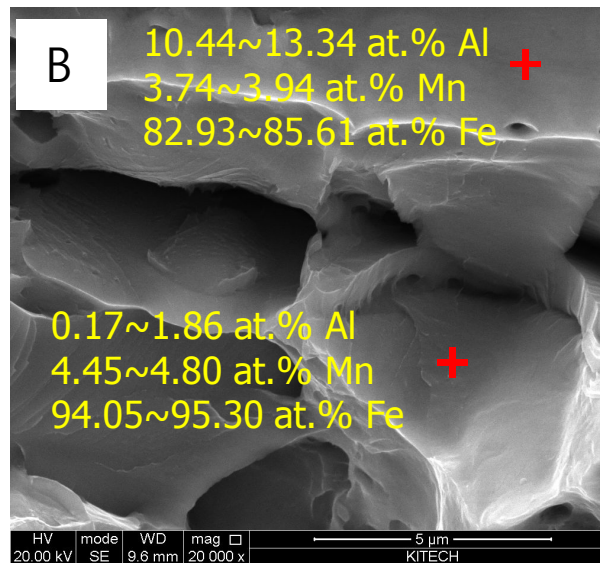
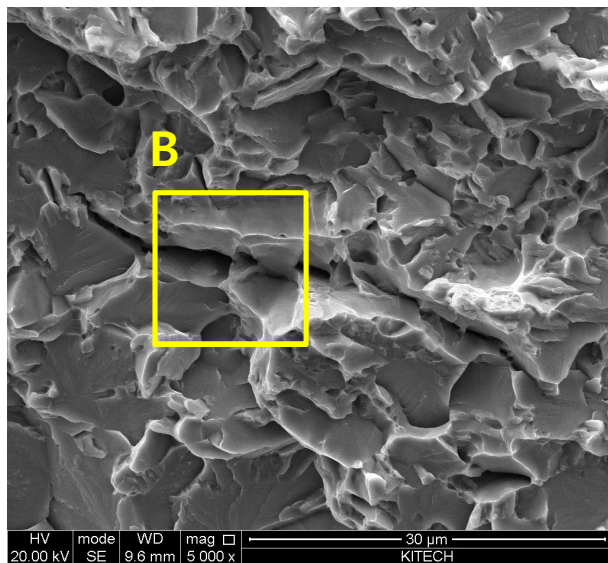
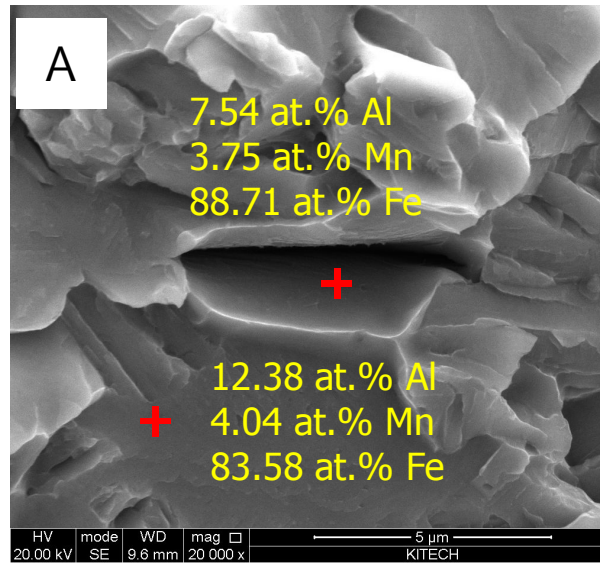
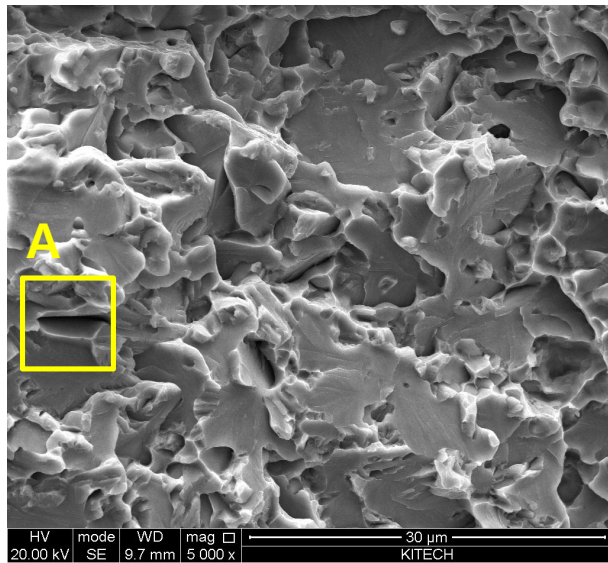


# Observation of failure specimen



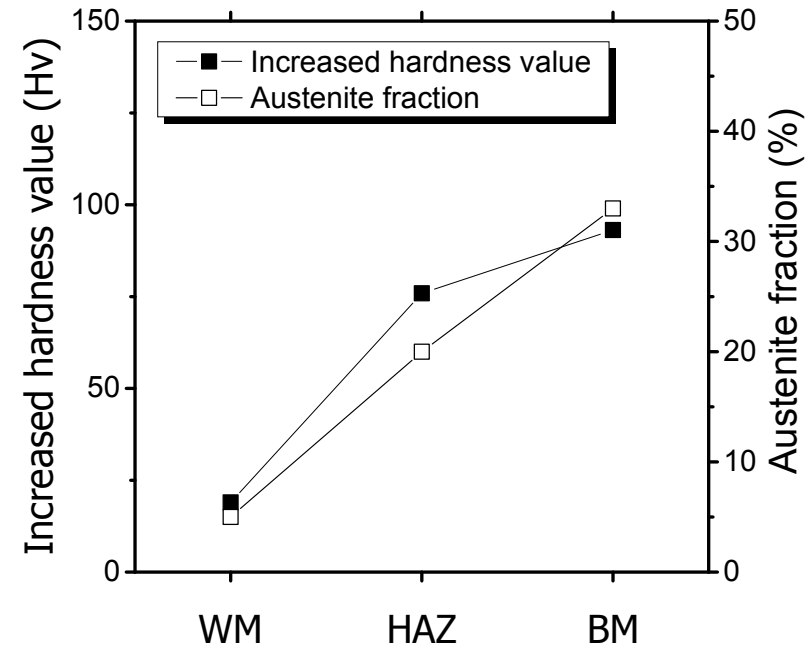
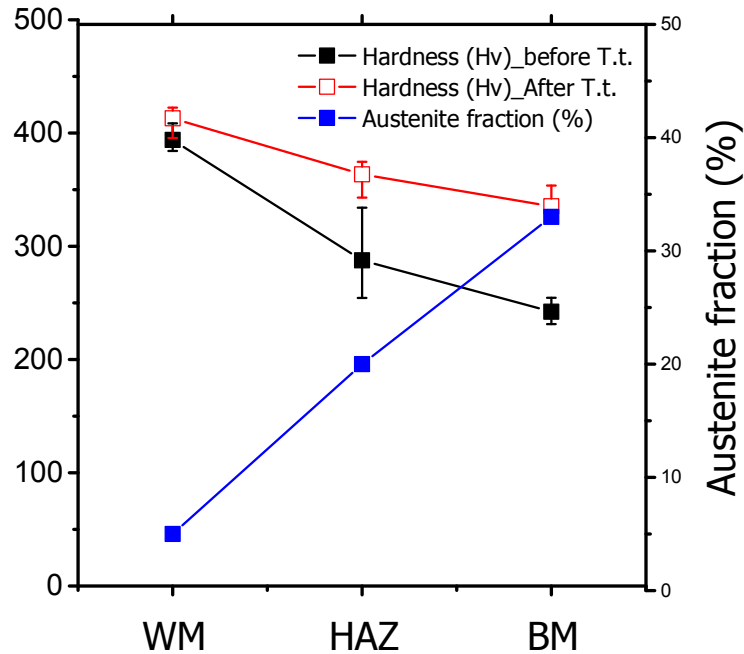


# Observation of failure specimen



균열부에서  
 낮은 Al 함량 측정  
 → 상간 경계면 취약  
 → 균열전파

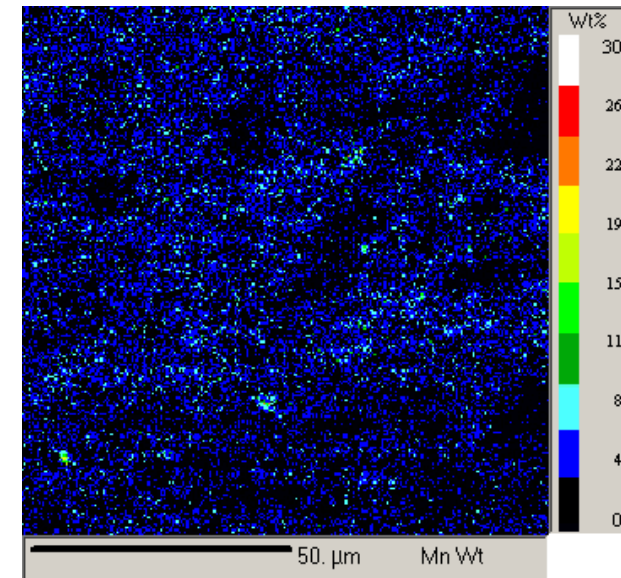
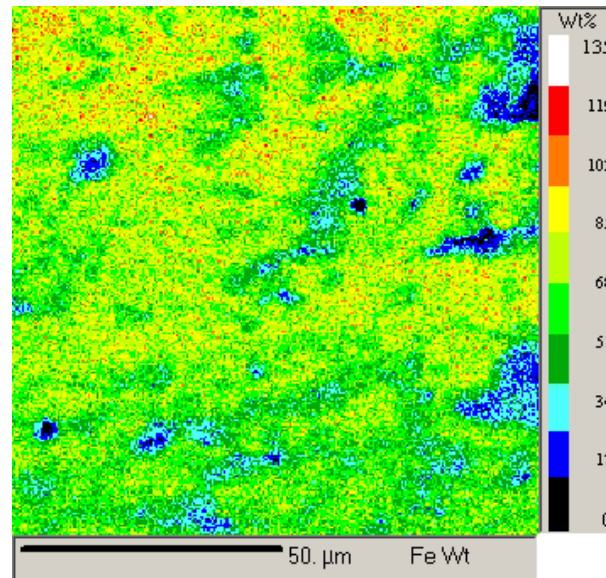
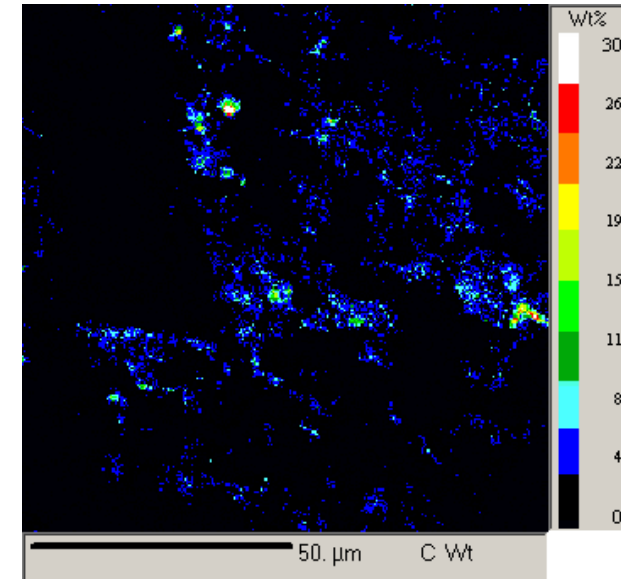
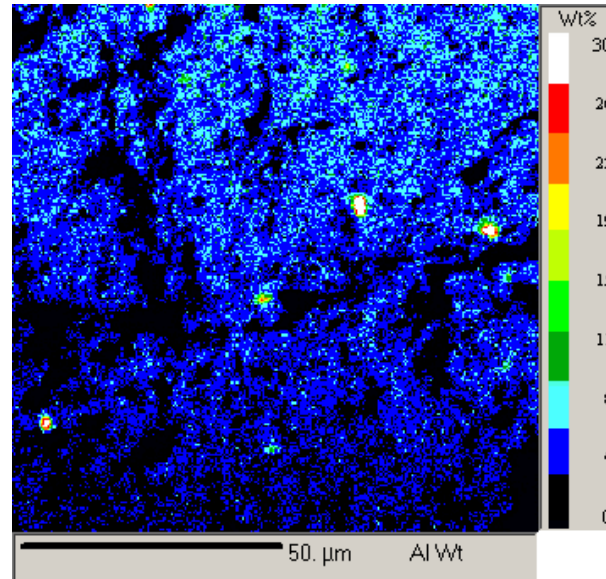
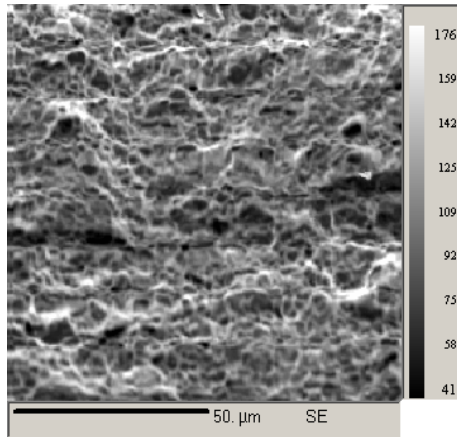
# Hardness and retained austenite fraction



Reference 에서는 ferrite가 변형을 하고,  
austenite는 변태를 한다고 언급

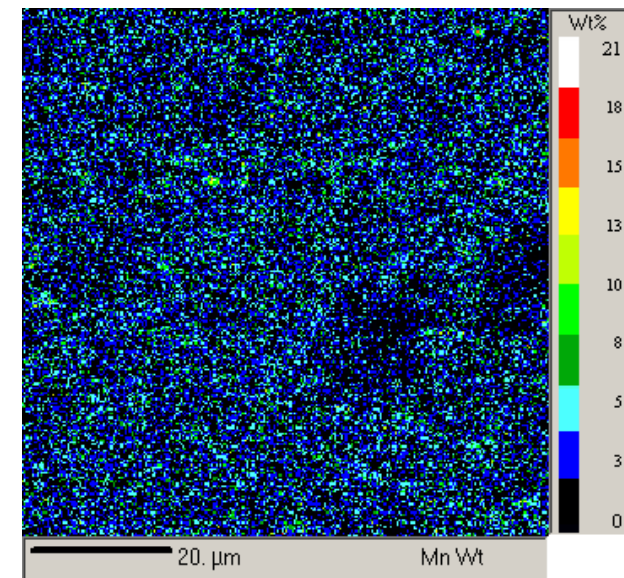
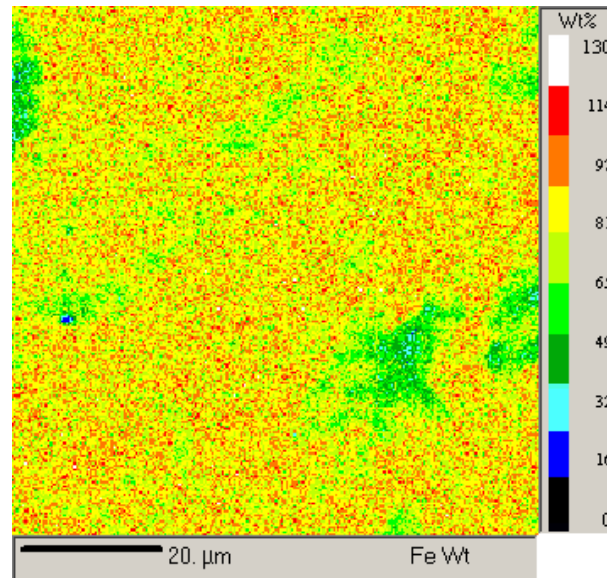
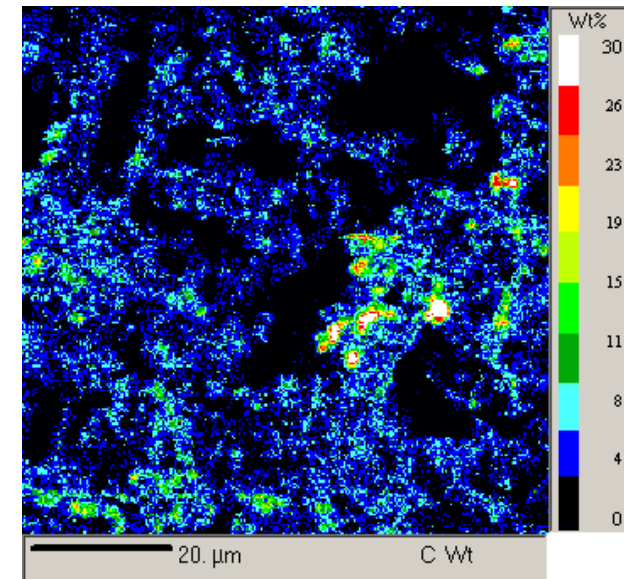
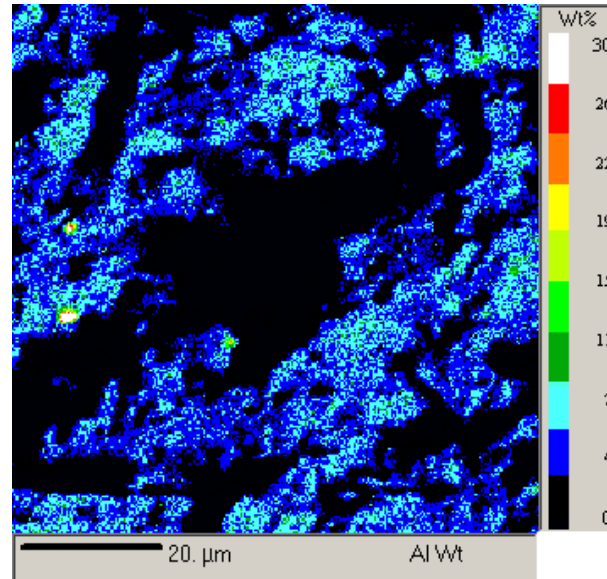
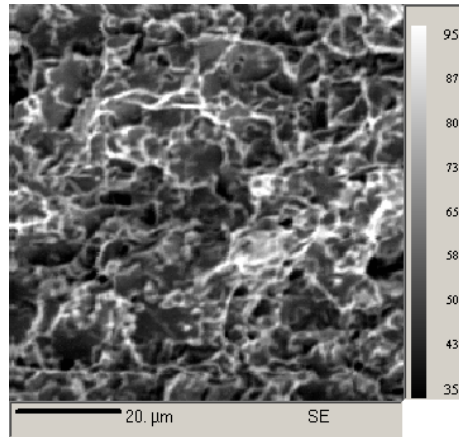
→ BM에서는 micro crack이 확인되지 않음.

# EPMA analysis of BM failure specimen





# EPMA analysis of FL failure specimen



# Summary and future work

## Summary

- ▶ 잔류오스테나이트를 포함하고 있는 강재를 대상으로 레이저 용접 수행.
  - 일부 조건에서 모재파단 발생.
  - 소재의 경도는 소성강화 거동으로 인해 인장시험 후 증가하며, 위치별로 변형율이 다르게 나타남.
  - 파단은 Al rich phase 주변에서 발생되어 입계를 따라 전파.

## Future works

- ▶ 공정최적화를 통해 안정적인 모재파단 조건 확보.
- ▶ 파단에 대한 원인 분석.

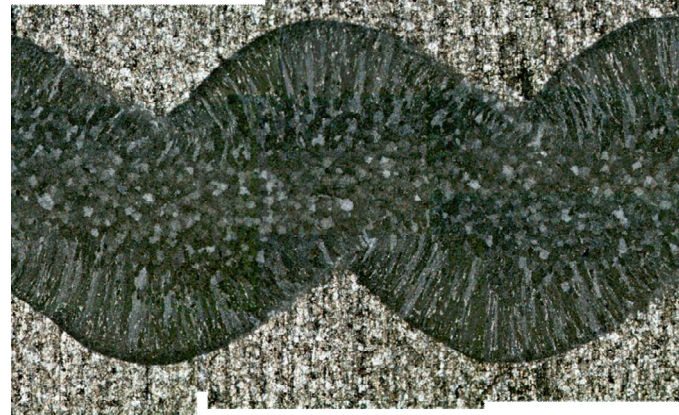
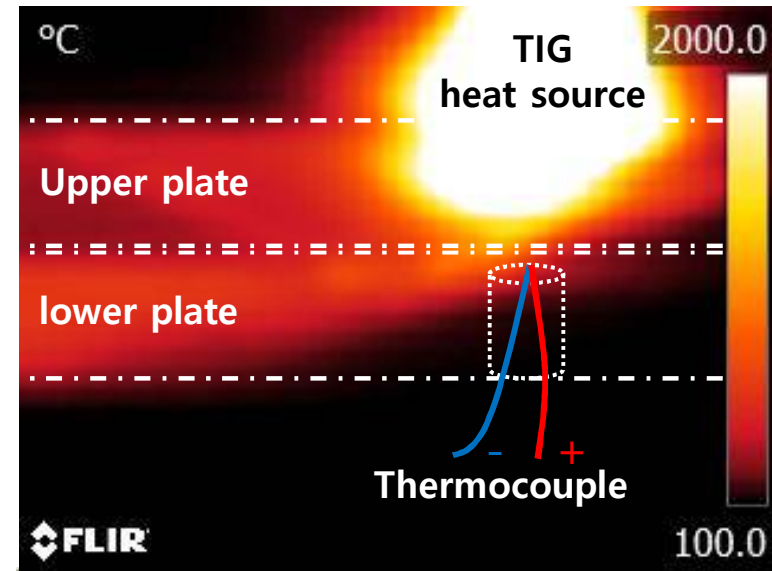




# Equipment

## Welder

- + ARC
  - MAG
  - MIG
  - TIG
  - SMAW
  
- + Laser
  - Disk laser (Nd:YAG)
  - Micro spot laser
  - Green laser
  
- + Spot
  - AC
  - DC
  - Delta spot
  
- + FSW





**THANK YOU FOR YOUR ATTENTION !**

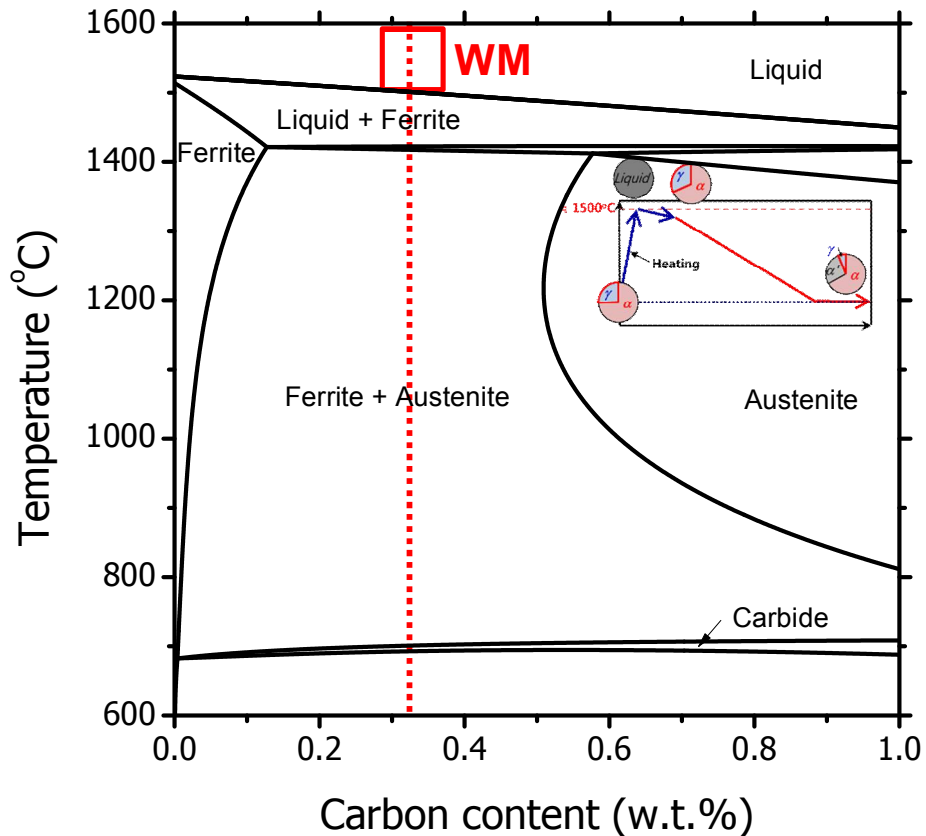


**KITECH** Korea Institute of Industrial Technology



# Phenomenon in welds

*Fe-C phase diagram*



상온에서 *austenite phase*가  
없는 조성이지만,

*Austempering*을 통해

*Retained austenite*를 형성시킴.

→ *Quenching (welding)*

→ *Martensite transformation*

# Phase transformation during tensile test

