Effects of temperature on quality of Al/Fe tube joints manufactured by magnetic pulse welding

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Outline

Introduction

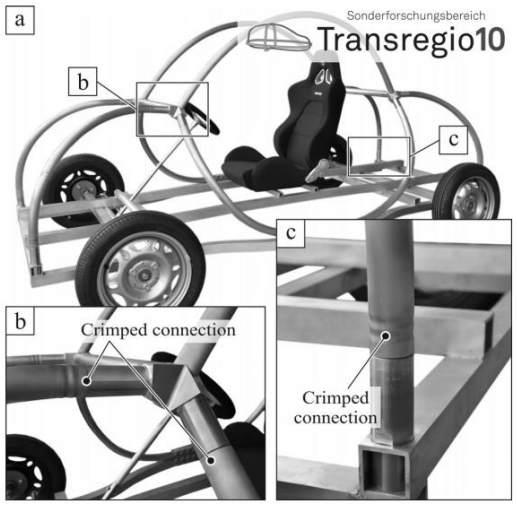
Weapon

Aerospace

Dissimilar metal joints

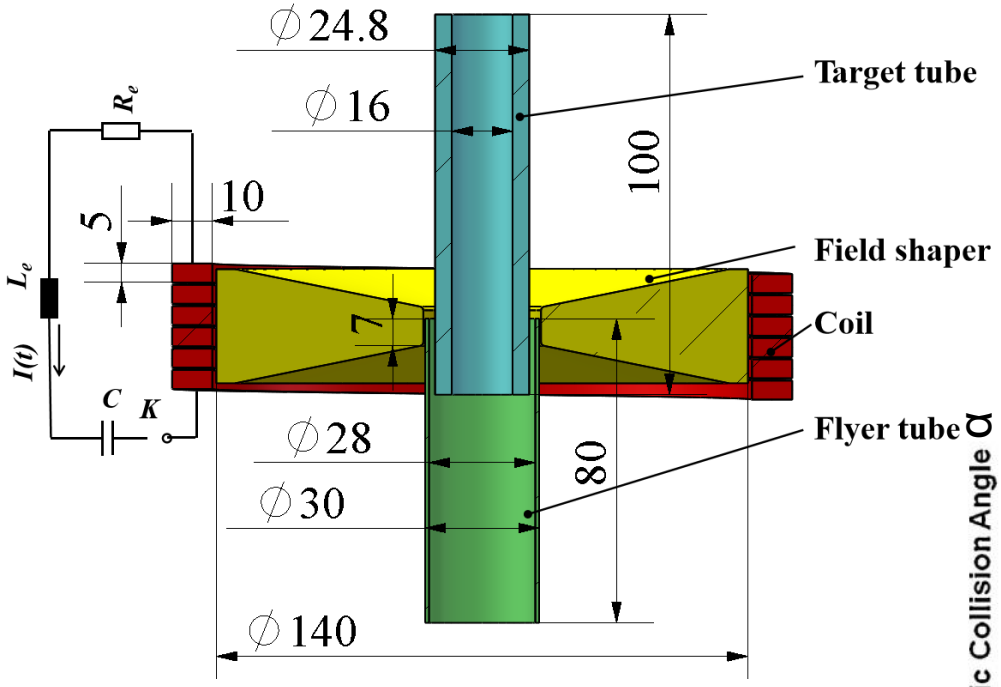
Vehicle

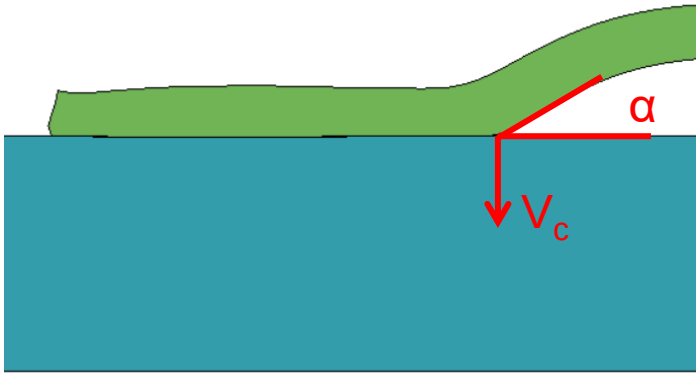
Appliances

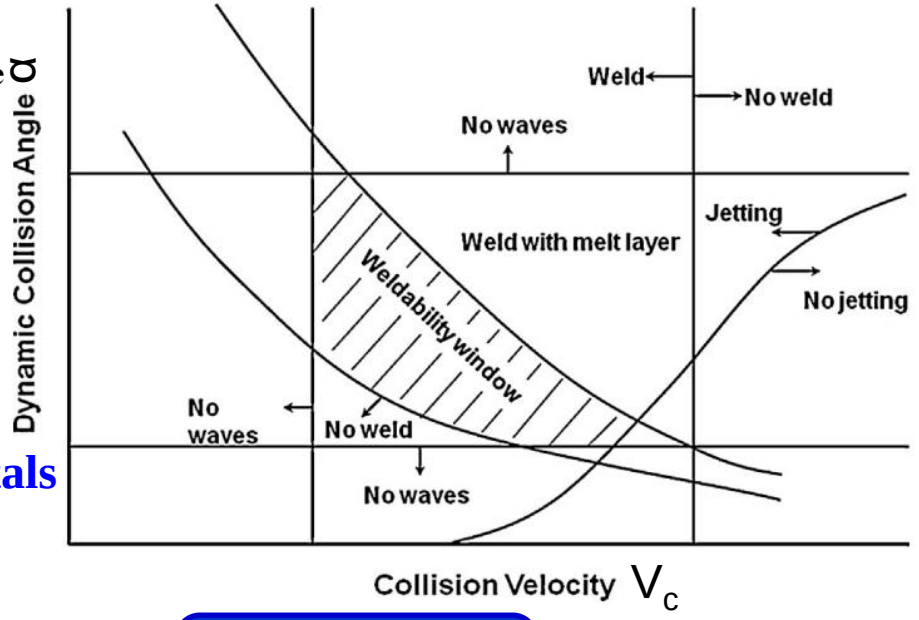


K. Faes. 2011; Christian Weddeling et al. 2015.

Procedure for Magnetic Pulse Welding





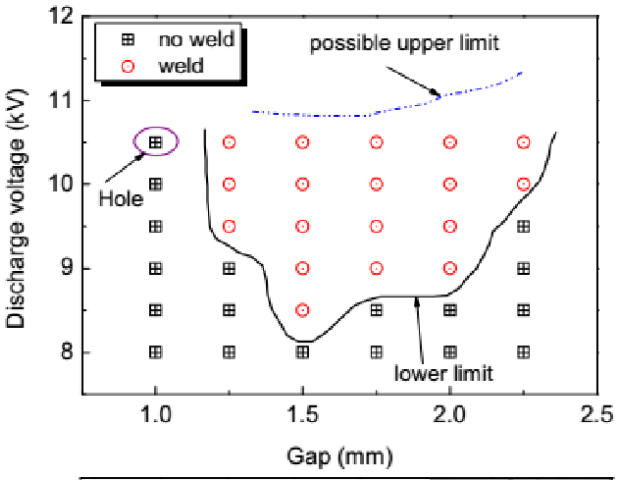


- **High efficiency**
- **Joints with a higher strength than base metals**
- **Flexible to weld geometry**

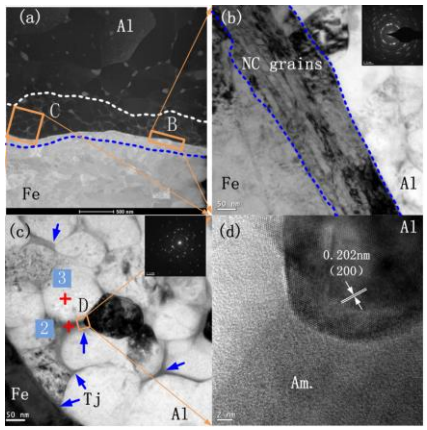
Electric Energy → **MPW System** → **Kinetic Energy** → **High Speed Oblique Impact** → **MPW Joints**

Akbari Mousavi et al. 2009

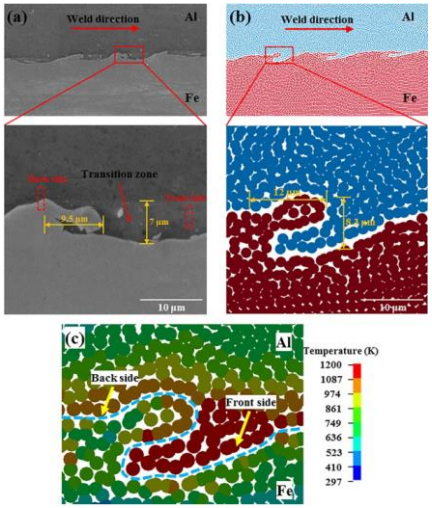
Current state of art



Weldability window

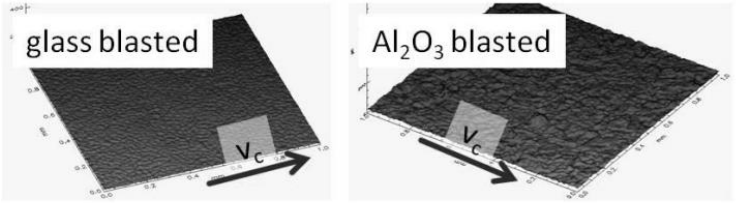


Interface microstructure

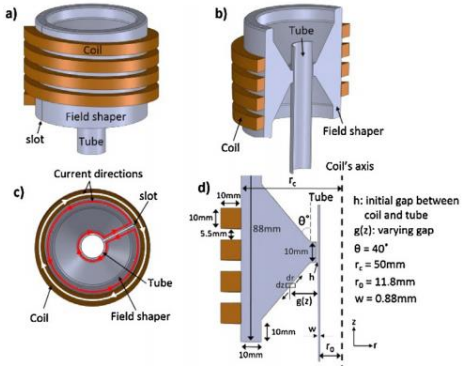


Numerical simulation

Al-Fe MPW



Improvement of joints quality



$$P_m = \int_0^w F dr = \frac{1}{2}\mu_m H_{gap}^2 \quad \cdots\cdots \quad (4)$$

$$H_z = \frac{i}{2\pi}\left[\frac{g(z)-r}{(g(z)-r)^2+z^2} + \frac{g(z)+r}{(g(z)+r)^2+z^2}\right] \quad \cdots\cdots \quad (5)$$

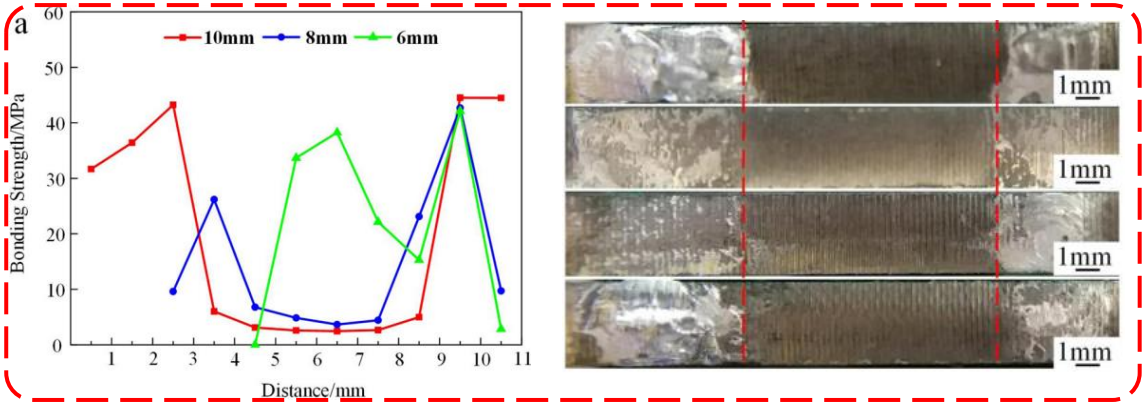
$$H_{gap} = \sum H_z \quad \cdots\cdots \quad (12)$$

Analytical model

Haiping Yu et al. 2017; M. Geyer et al. 2016; Zhisong Fan et al. 2016; Brad Kinsey et al. 2017; Huihui Geng, et al. 2019

Effective bonding length and Reliability

- Dynamic collision parameters
- Severe plastic deformation
- Transient thermal cycle

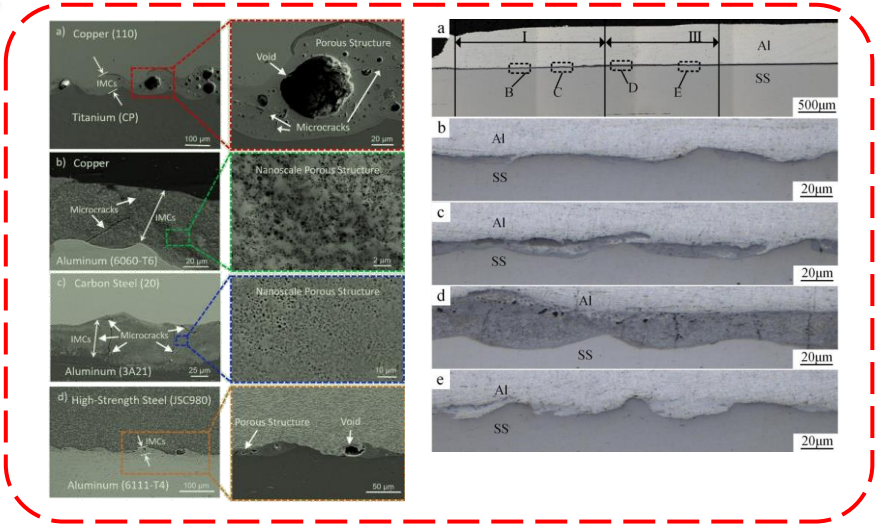


Axial mechanical properties and interface morphology

Uneven properties along axial direction

Micro defects

- **Low safety and reliability in service**
- **Small proportion of effective bonding length and then increasing weight of joint**

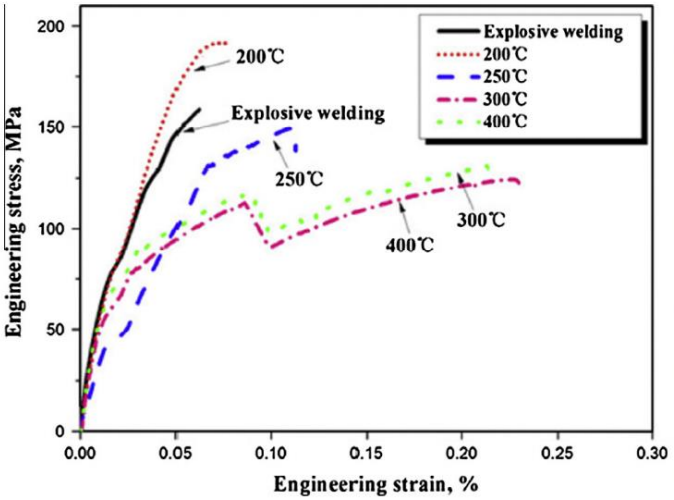


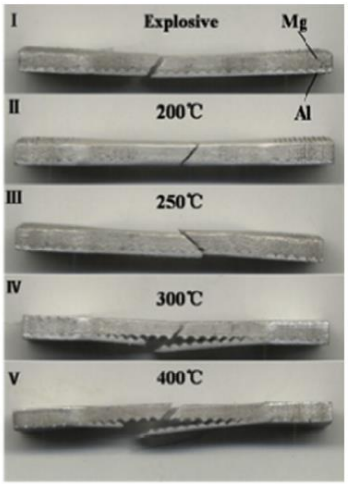
Micro defects and inhomogeneous interface structure

Zhenyang Lu,et al. 2019;

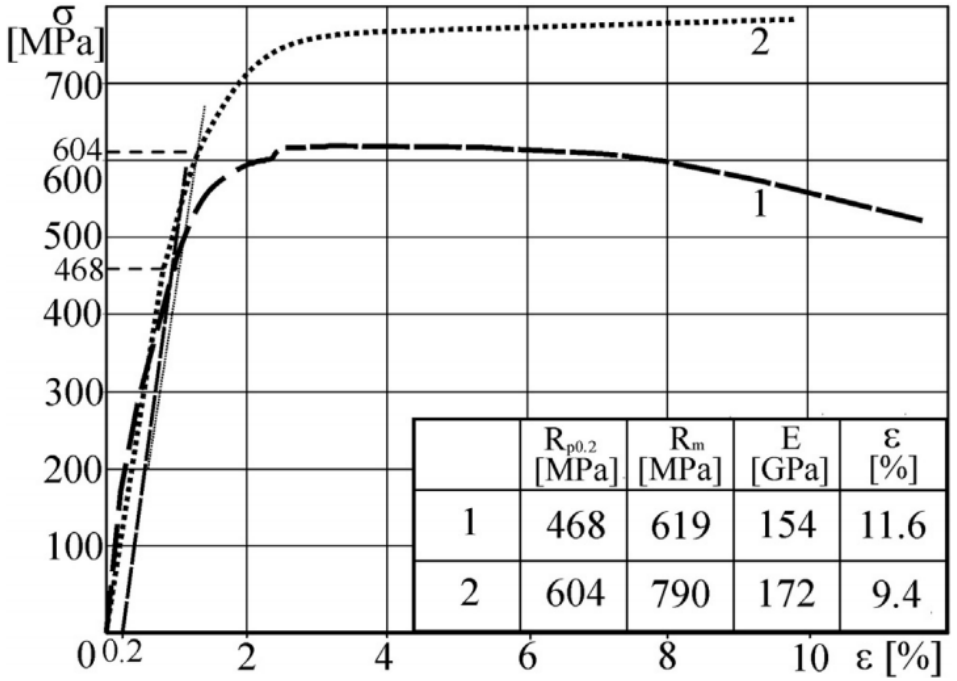
Post weld heat treatment——PWHT

Tensile strength of the Al/Mg EXW composite plates increased first and then dramatically decreased upon increasing the annealing temperature due to the diffusion of elements as well as the formation of intermetallic compounds.





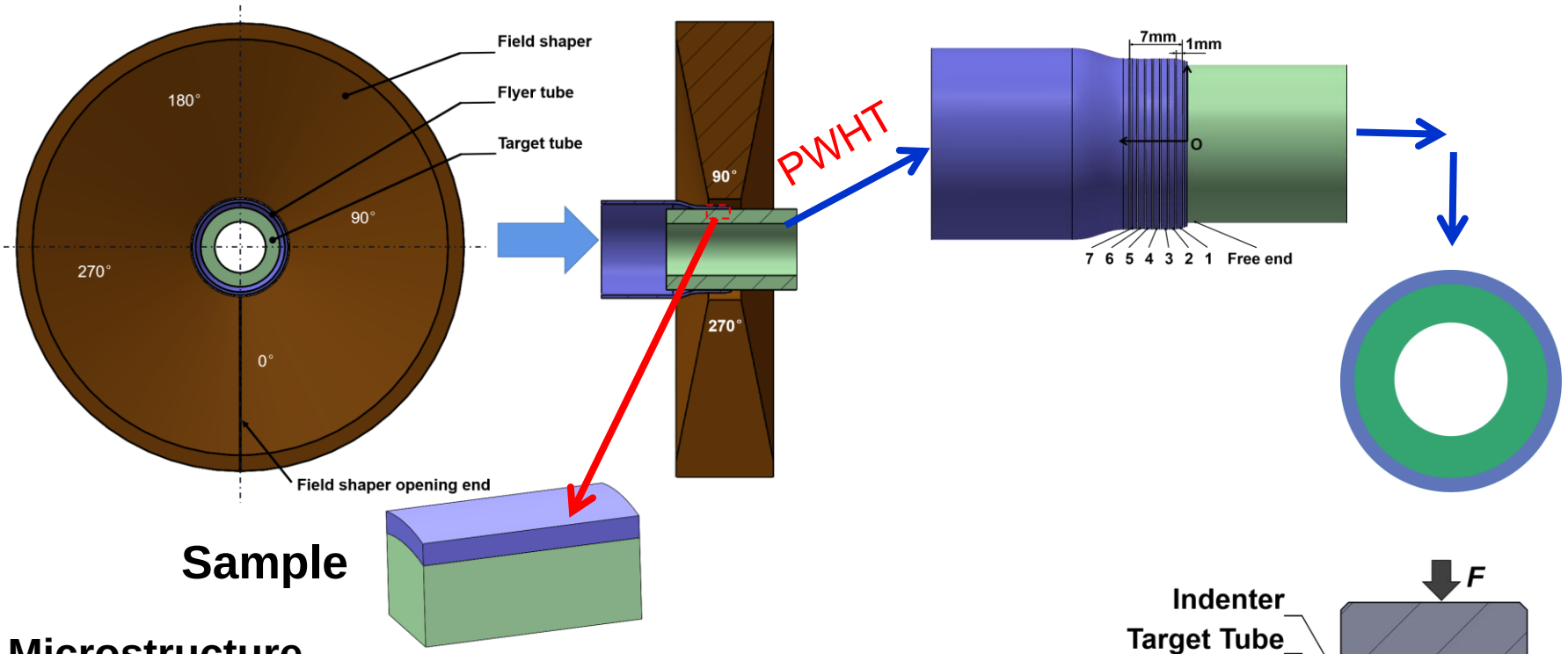
Low cycle fatigue properties of the AA2519/Ti6Al4V EXW composites were improved due to the release of residual stress and the removal of micro voids through PWHT.



	$R_{p0.2}$ [MPa]	R_m [MPa]	E [GPa]	ε [%]
1	468	619	154	11.6
2	604	790	172	9.4

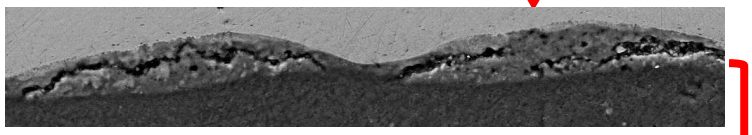
Nan Zhang et al. 2015; Ireneusz Szachogluchowicz et al. 201

Methodology——Roadmap

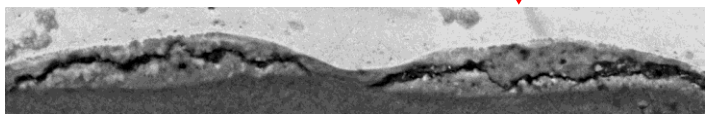


Sample

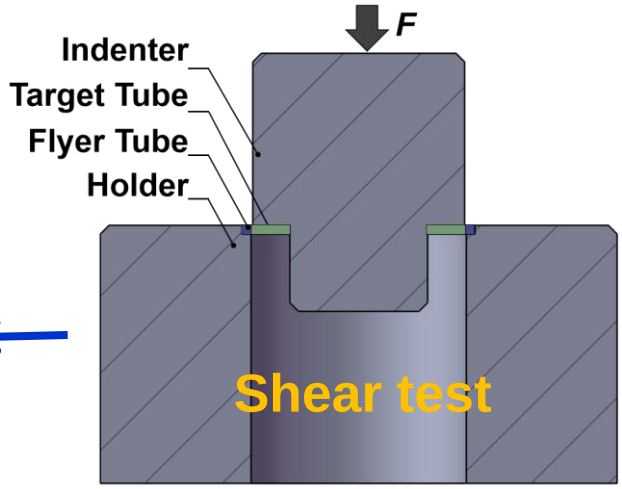
Microstructure



PWHT



Shear strength



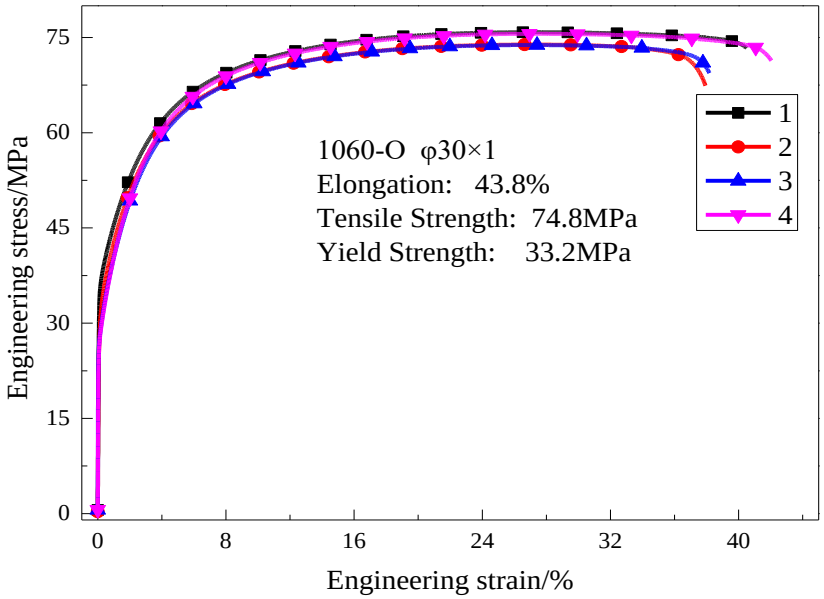
Methodology——Materials

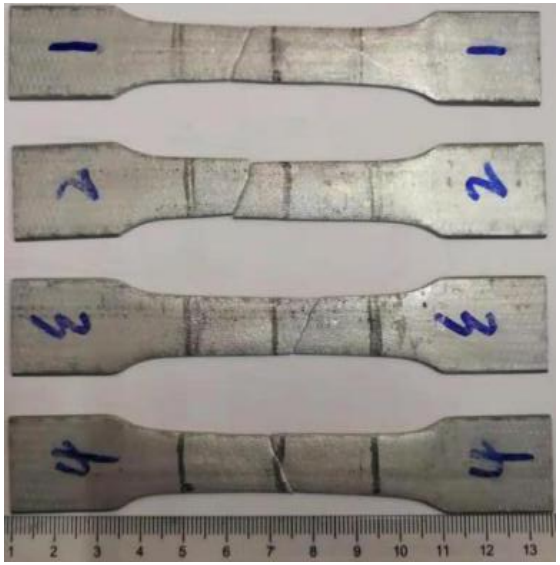
Materials Specification

Name	Materials	Length/mm	Outer Diameter/mm	Wall Thickness/mm
Flyer tube	AA1060-O	80	30	1
Target tube	20#Steel	120	26	5

Mechanical Properties

Materials	ρ /kg·m-3	σb/MPa	σs/MPa	ε(%)	E/GPa
AA1060-O	2700	74.8	33.2	43.8	69
20#Steel	7850	536	310	25	207

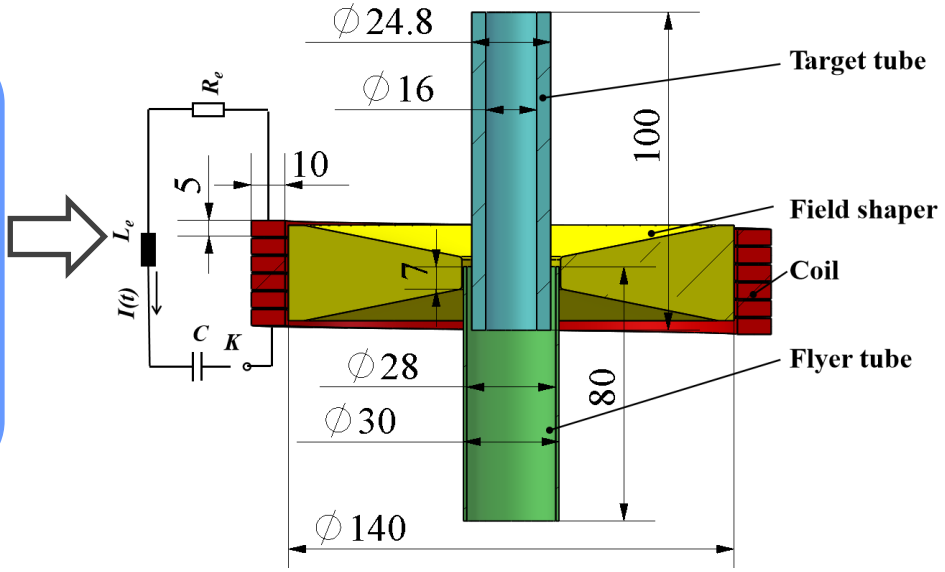




Samples after tensile tests

Methodology——Post weld heat treatment

As-welds are obtained under condition that discharge voltage is 12.5 kV, radial gap is 1.6 mm, and relative overlap length is 7 mm.



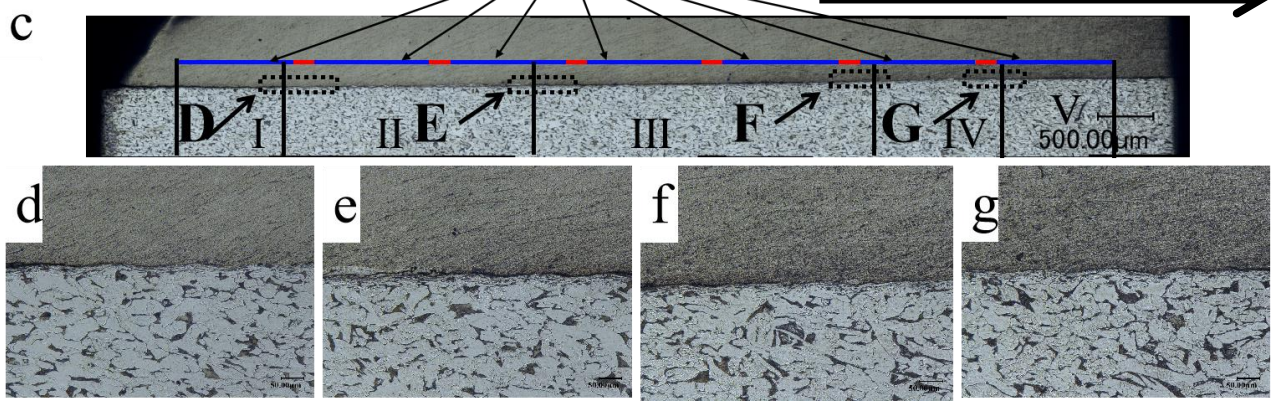
Scheme of PWHT

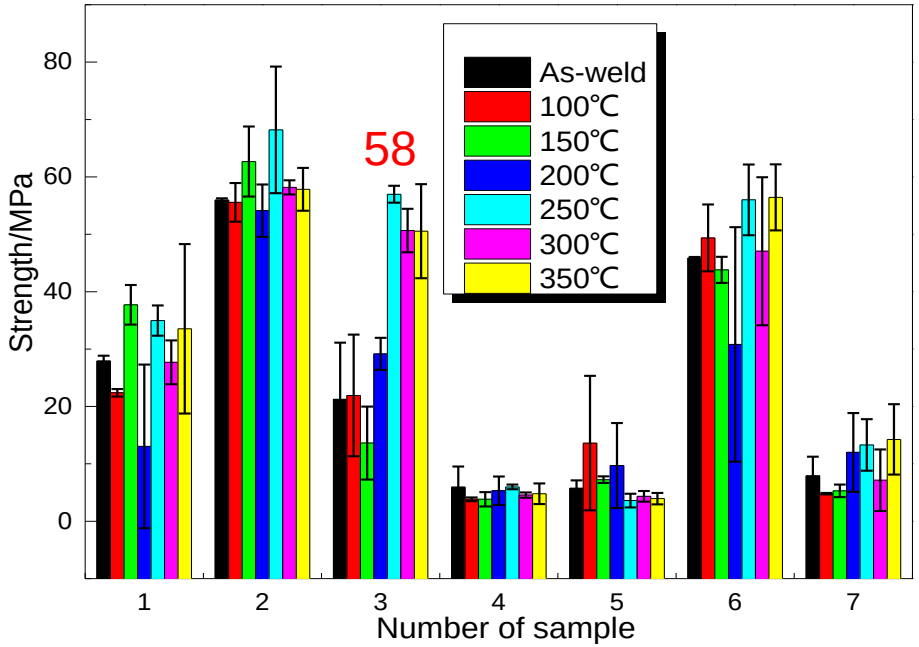
Equipment		Range of temperature: 100-350℃					
Rules	Temperature/℃	100	150	200	250	300	350
	Holding Time/h				1		

Distribution of local shear strength

Position of shear sample: 1 2 3 4 5 6 7 Welding direction

Interface morphology of as-weld





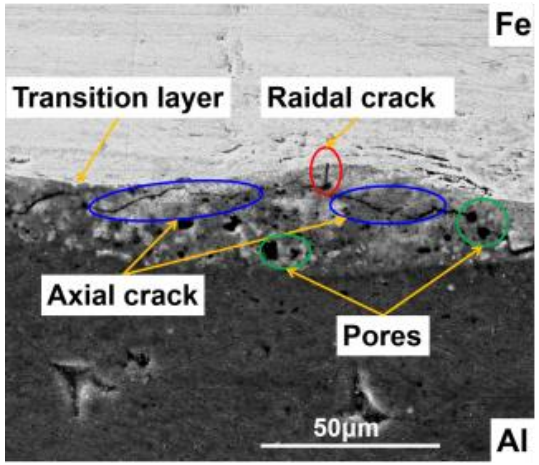
- ✓ **Sample 1, 4, 5 and 7-- non effective bonding zone cannot be strengthened by PWHT**
- ✓ **Sample 2 and 6--strong bonding zone cannot be also improved**
- ✓ **Sample 3-- weak bonding zone can be improved**

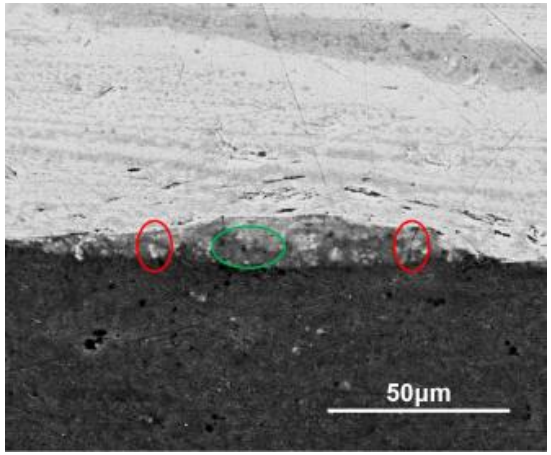
Distribution of local shear strength before and after PWHT

Transition zone microstructure

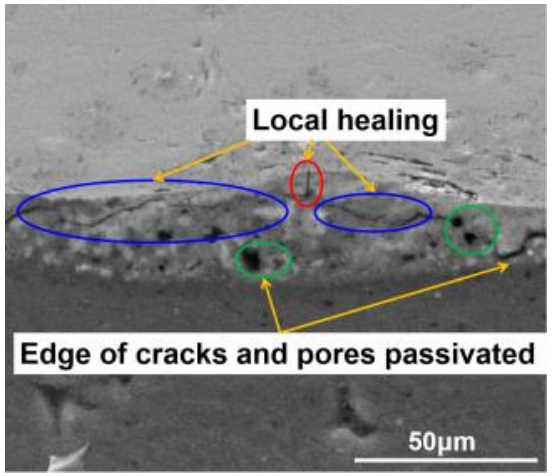
100℃

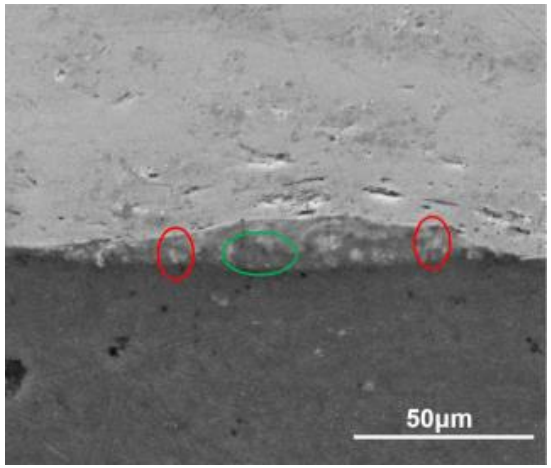
Before PWHT





After PWHT



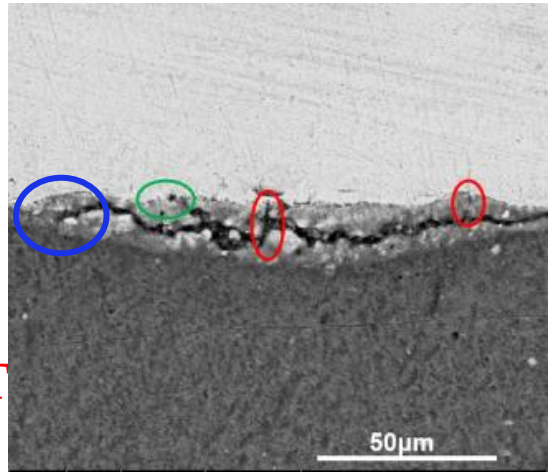


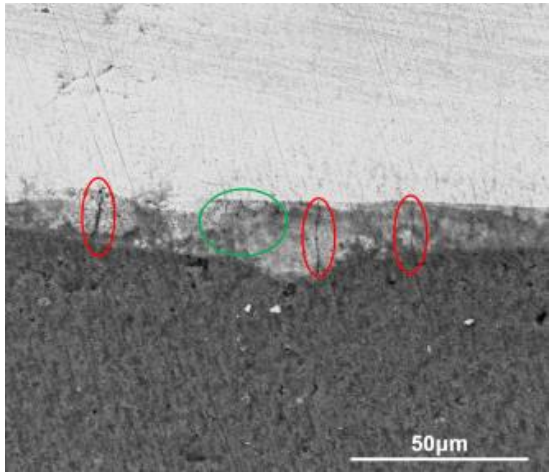
- ✓ **Micro pores tends to heal.**
- ✓ **Micro cracks also tends to be coalesced.**

Transition zone microstructure

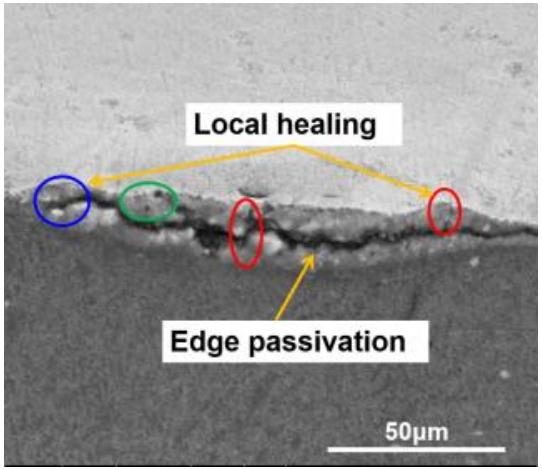
150℃

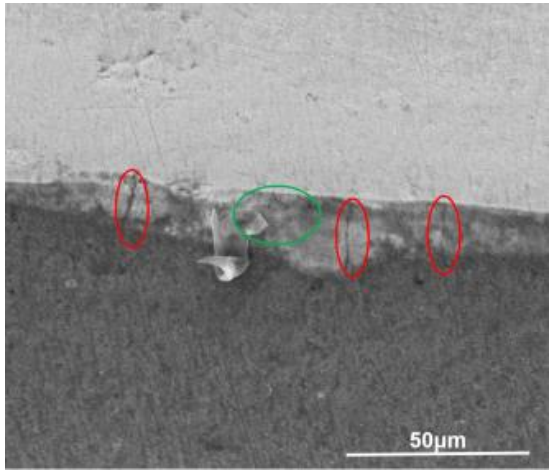
Before PWHT





After PWHT



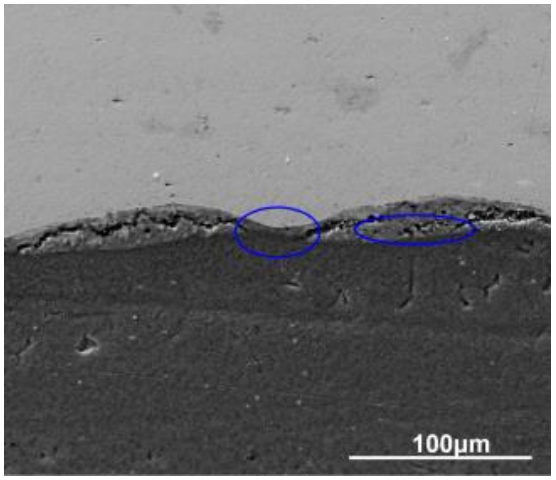


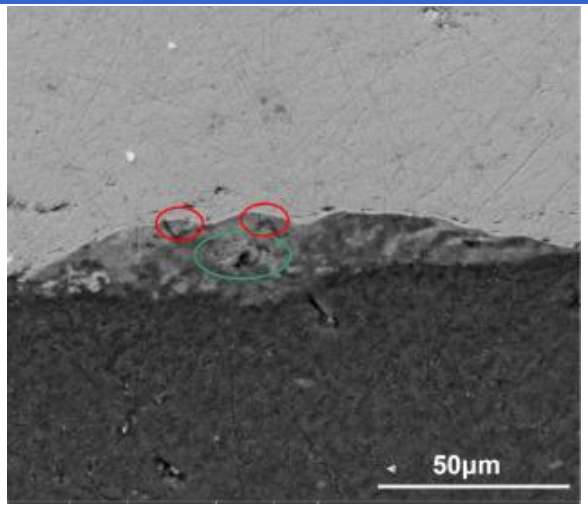
- ✓ **The small pores disappear and the larger become smaller.**
- ✓ **Micro cracks tends to be coalesced.**

Transition zone microstructure

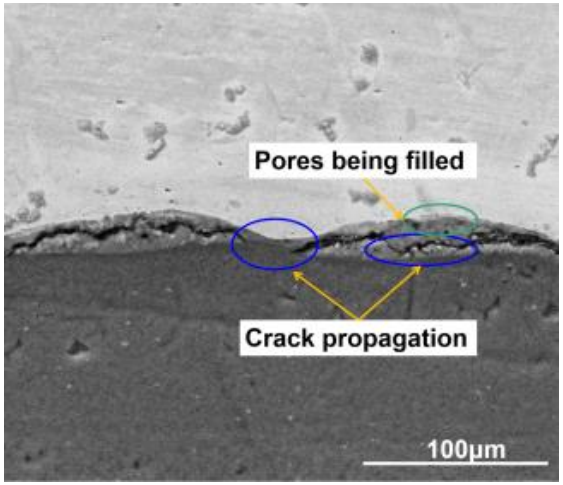
200℃

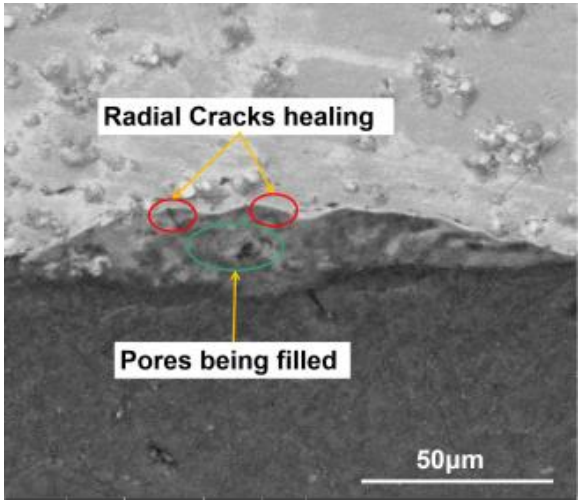
Before PWHT





After PWHT



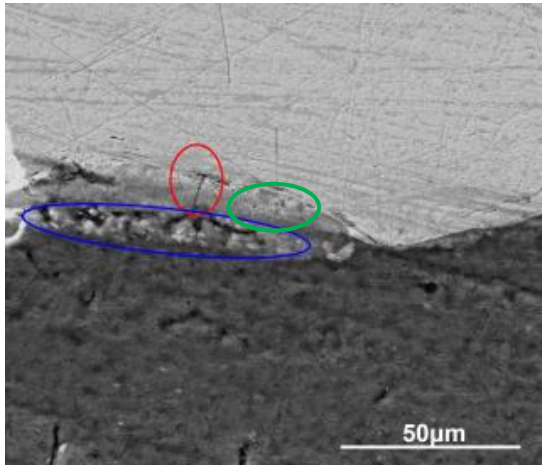


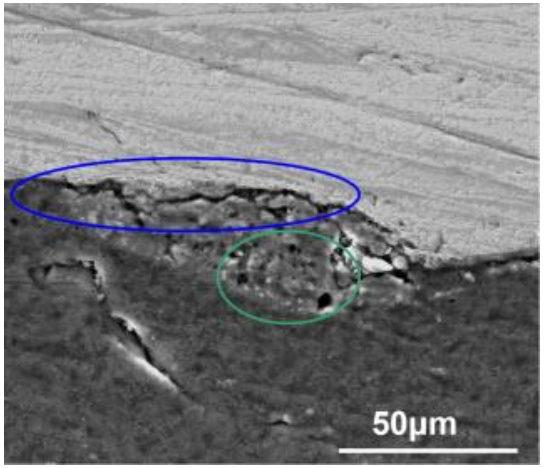
- ✓ **The small pores disappear and the larger pores become smaller.**
- ✓ **Radial micro cracks are locally coalesced.**
- ✓ **Axial micro cracks expand along the axial direction in the transition layer.**

Transition zone microstructure

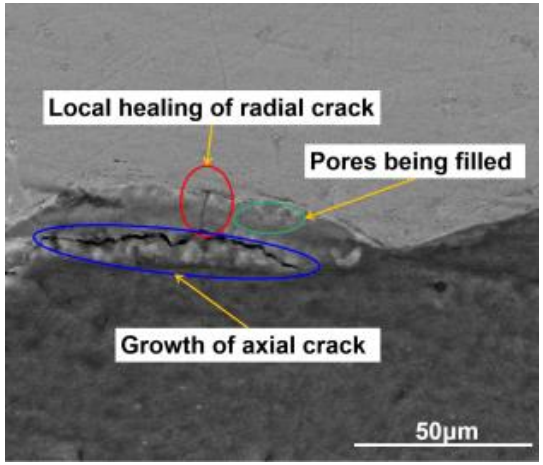
250℃

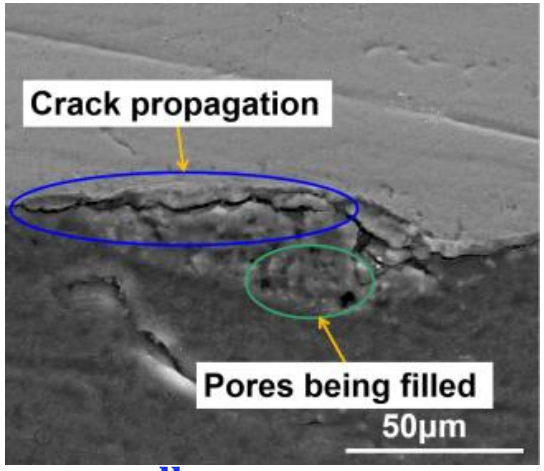
Before PWHT





After PWHT



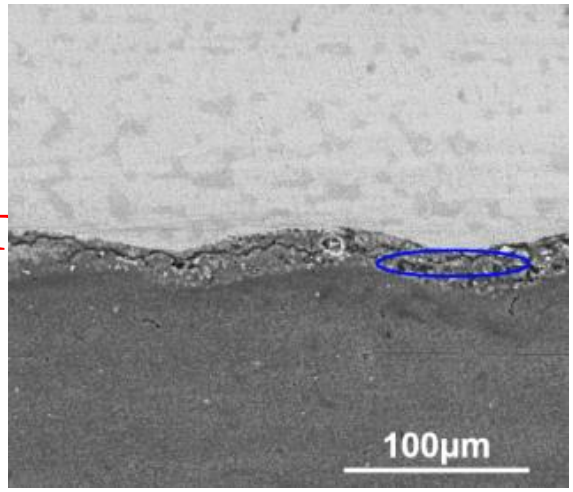


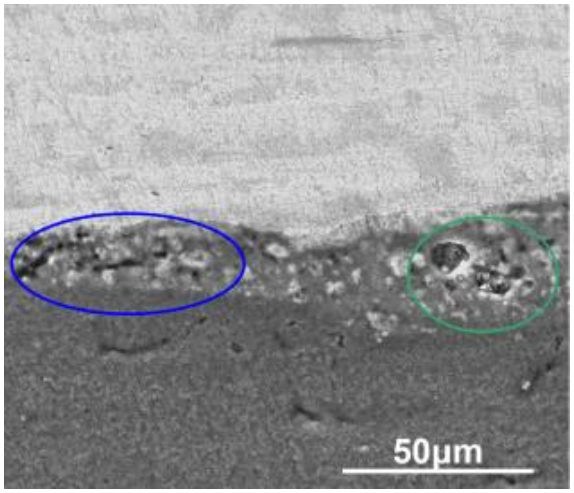
- ✓ **The small pores disappear and the larger pores become smaller.**
- ✓ **Radial micro cracks are locally coalesced.**
- ✓ **Axial micro cracks coalesce with micro pores around cracks and expand in the transition layer.**

Transition zone microstructure

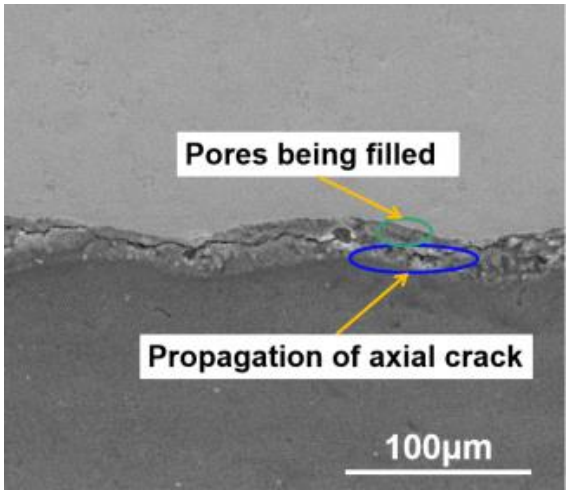
300℃

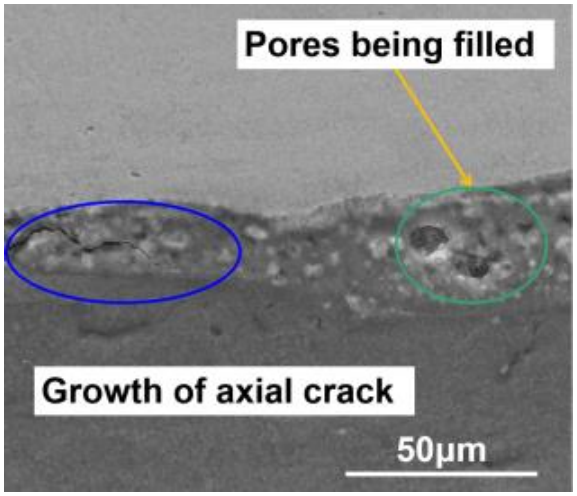
Before PWHT





After PWHT



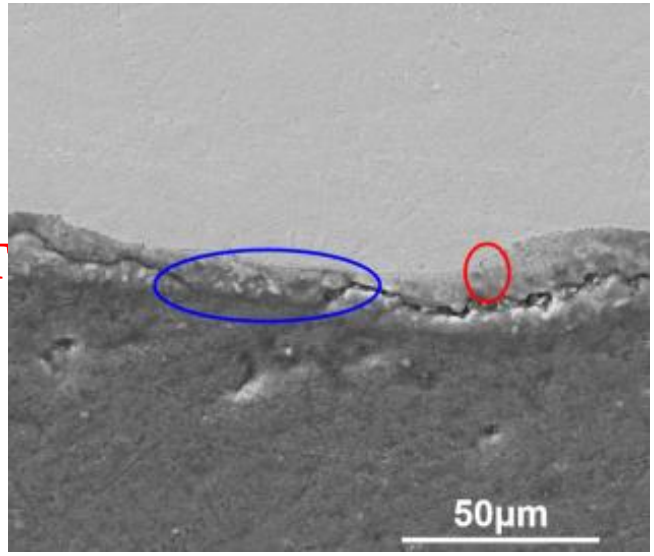


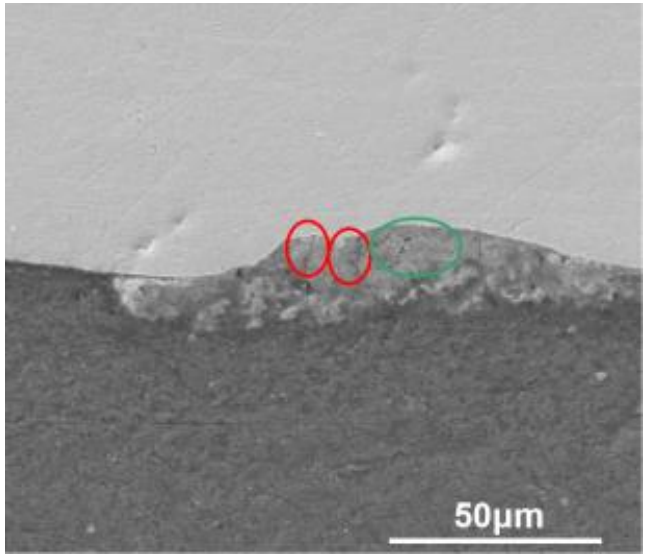
✓ **Evolution of microstructure is generally similar with that under 250℃ for 1h.**

Transition zone microstructure

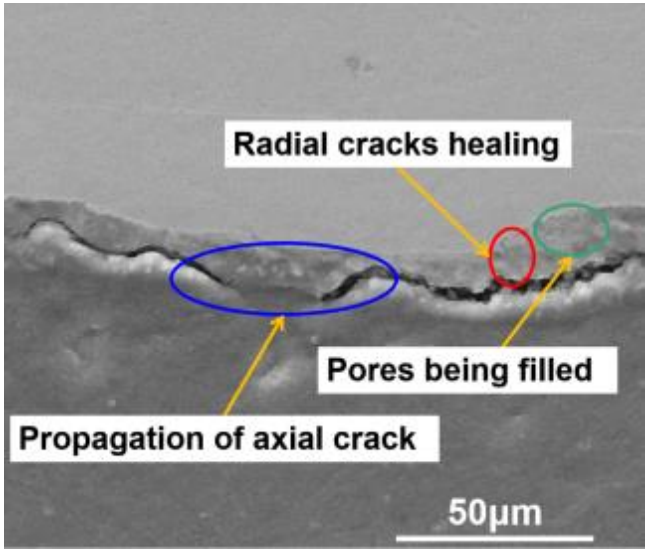
350℃

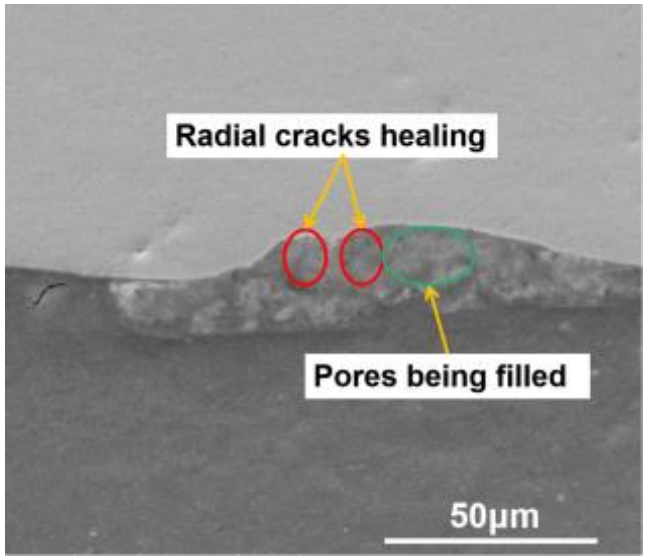
Before PWHT





After PWHT

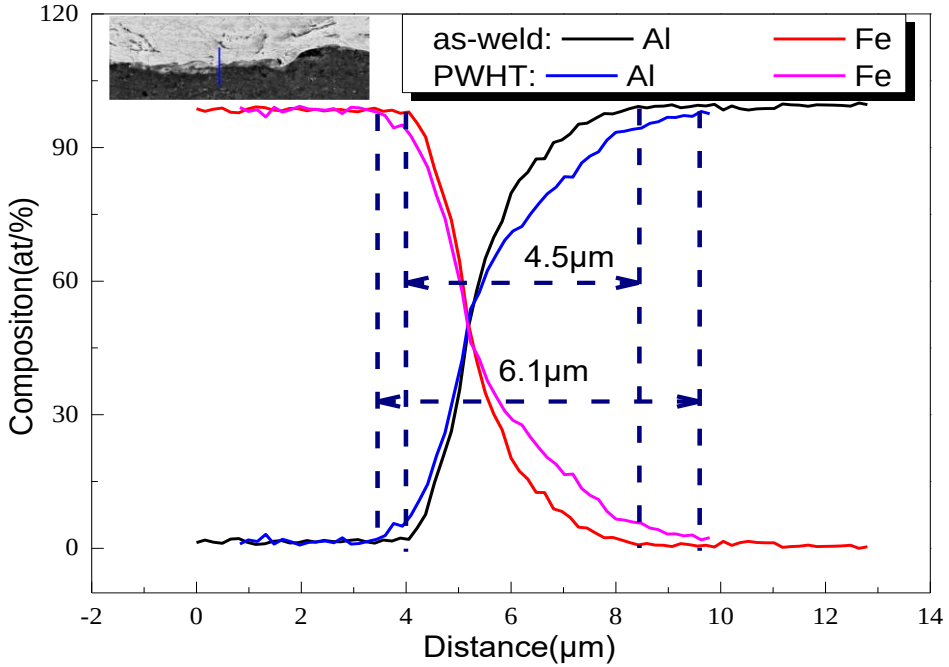




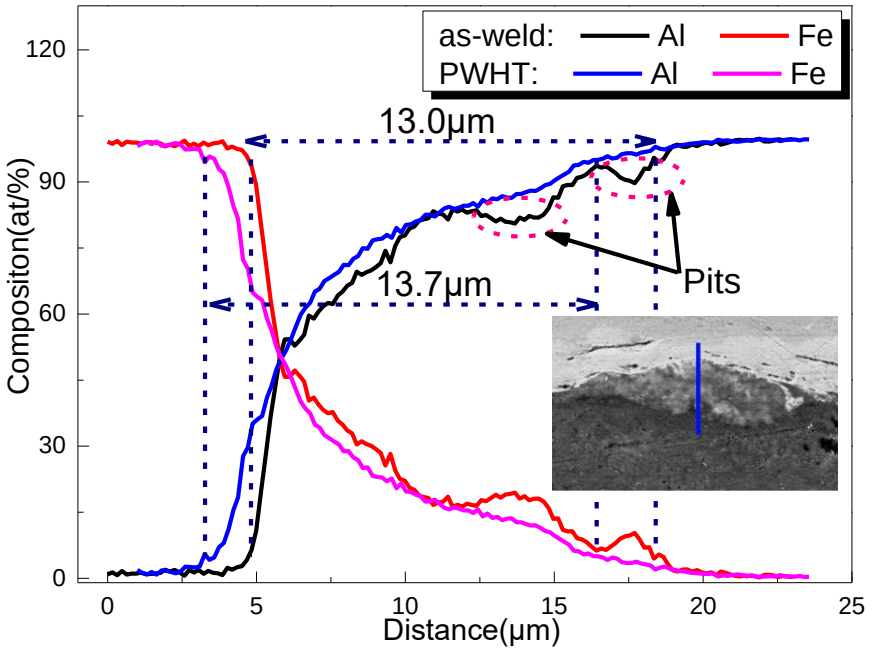
✓ **Changes of microstructure is generally same as that above 150℃ for 1h.**

Transition zone chemical compositions

Chemical compositions before and after PHWT at 100 ℃



Thin transition layer(Thickness≤10μm)

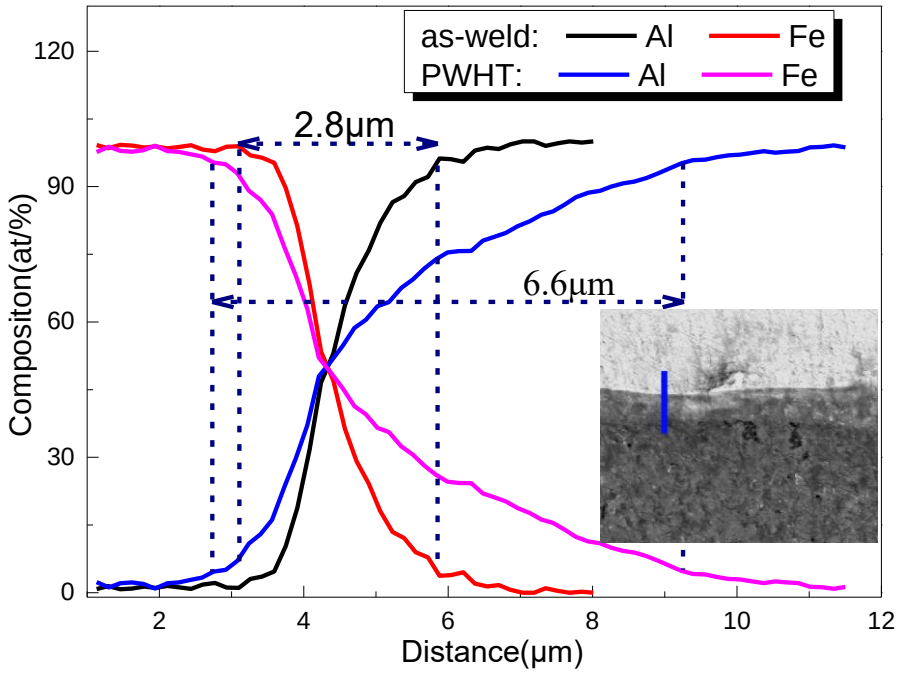


Thick transition layer(Thickness>10μm)

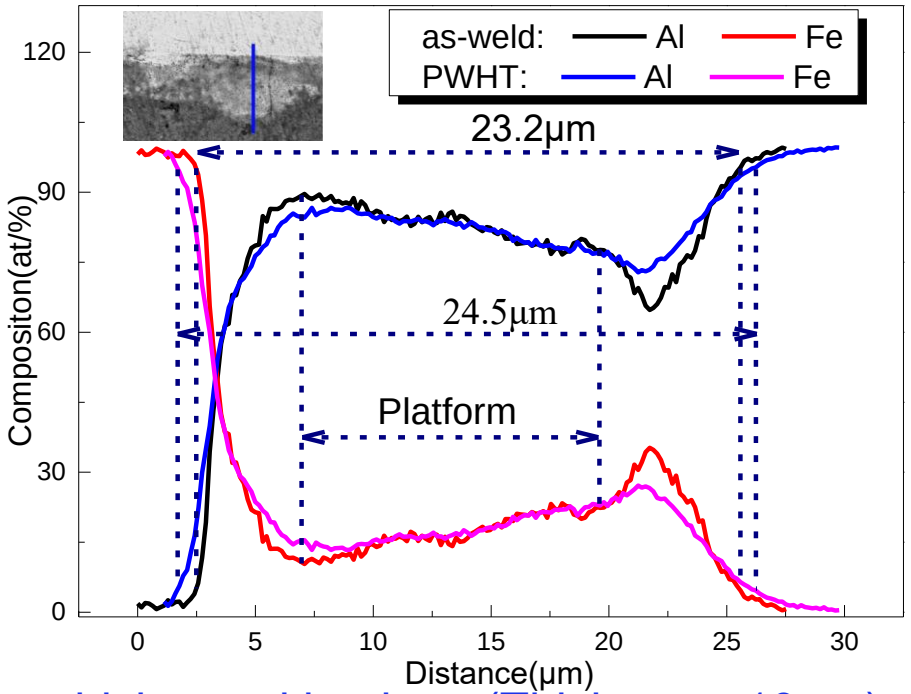
- ✓ **Transition layer thickness increases. (5~36%)**
- ✓ **Composition pits on the curve are filled.**
- ✓ **Curves become smoother.**

Transition zone chemical compositions

Chemical compositions before and after PHWT at 150 ℃



Thin transition layer(Thickness≤10μm)

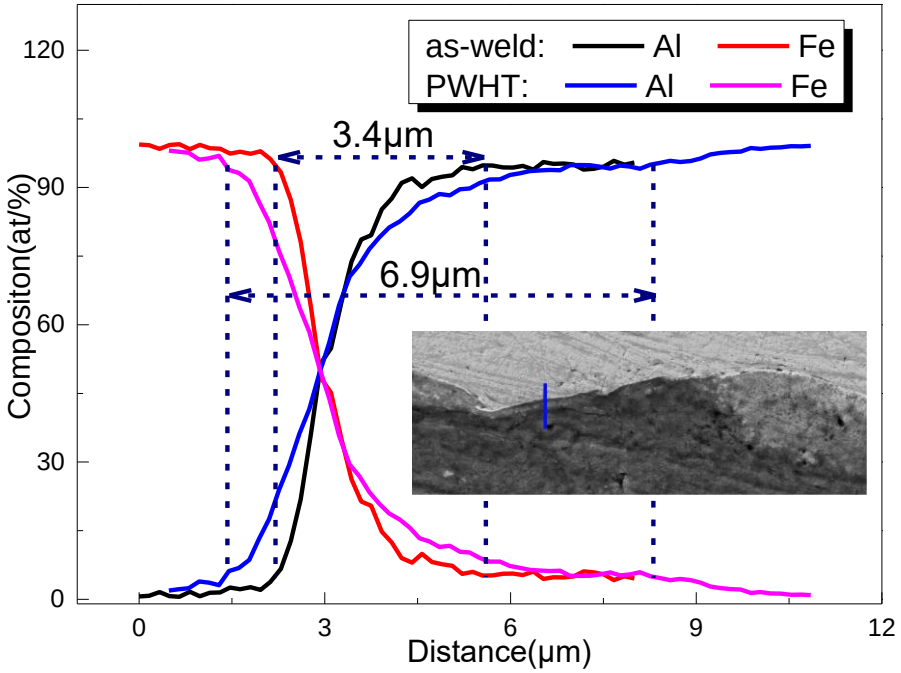


Thick transition layer(Thickness>10μm)

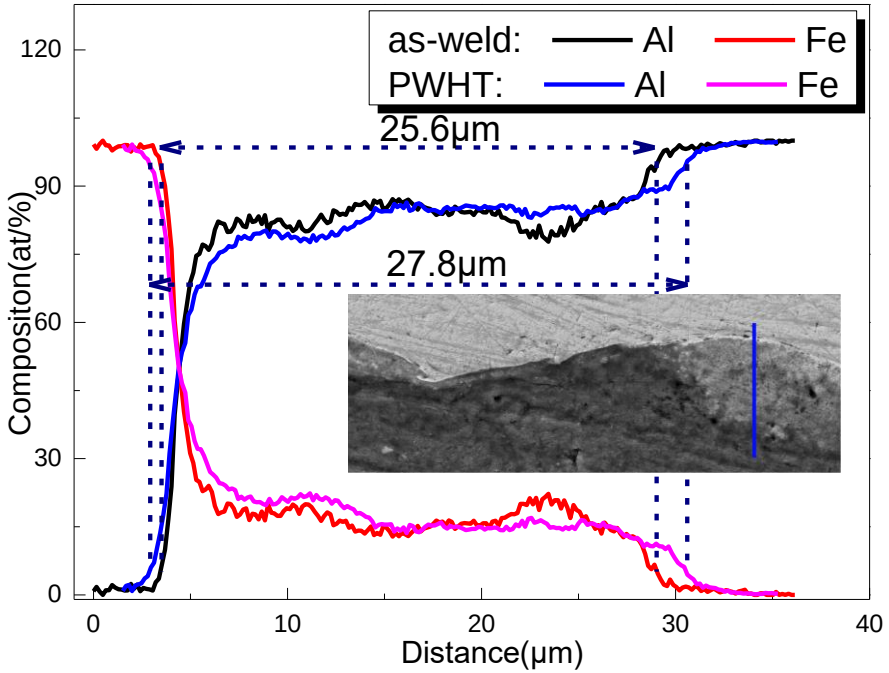
- ✓ **Transition layer thickness incresases. (6~136%)**
- ✓ **Some zones called " platform" with a constant Al-Fe ratio have no changes in their compositions.**

Transition zone chemical compositions

Chemical compositions before and after PHWT at 250 ℃



Thin transition layer(Thickness≤10μm)

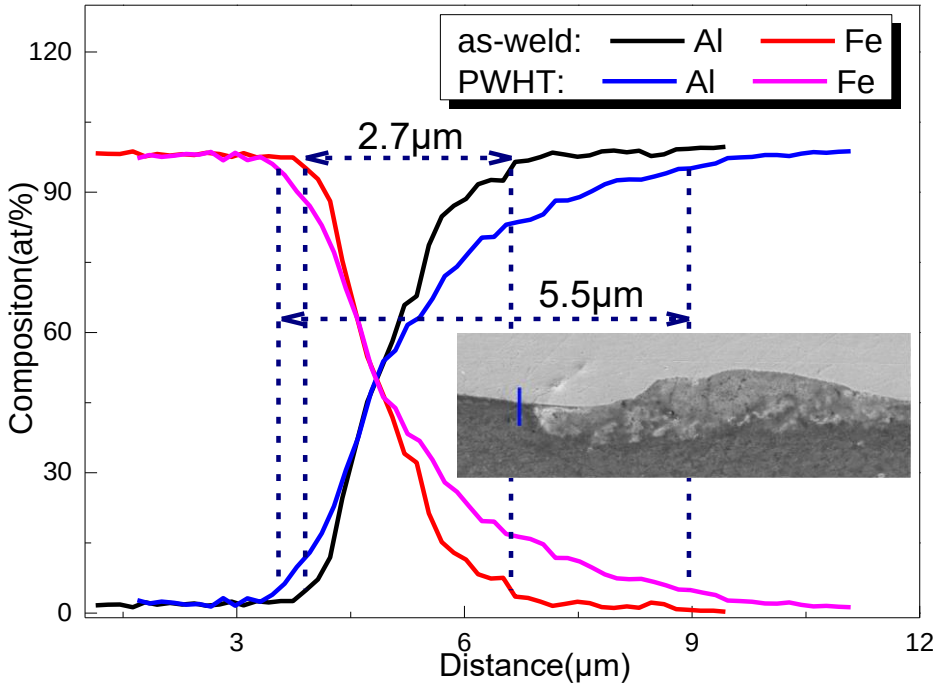


Thick transition layer(Thickness>10μm)

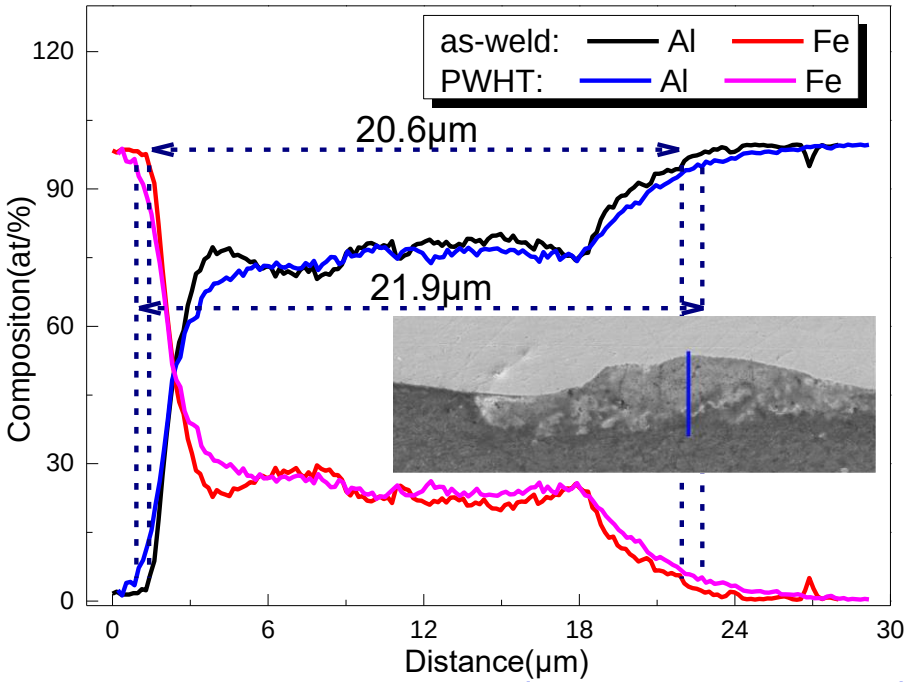
- ✓ **Transition layer thickness incresases. (9~103%)**
- ✓ **Compositions have no changes at local zones with a constant Al-Fe ratio.**
- ✓ **Composition pits on the curve are filled.**
- ✓ **Curves become smoother.**

Transition zone chemical compositions

Chemical compositions before and after PHWT at 350 ℃



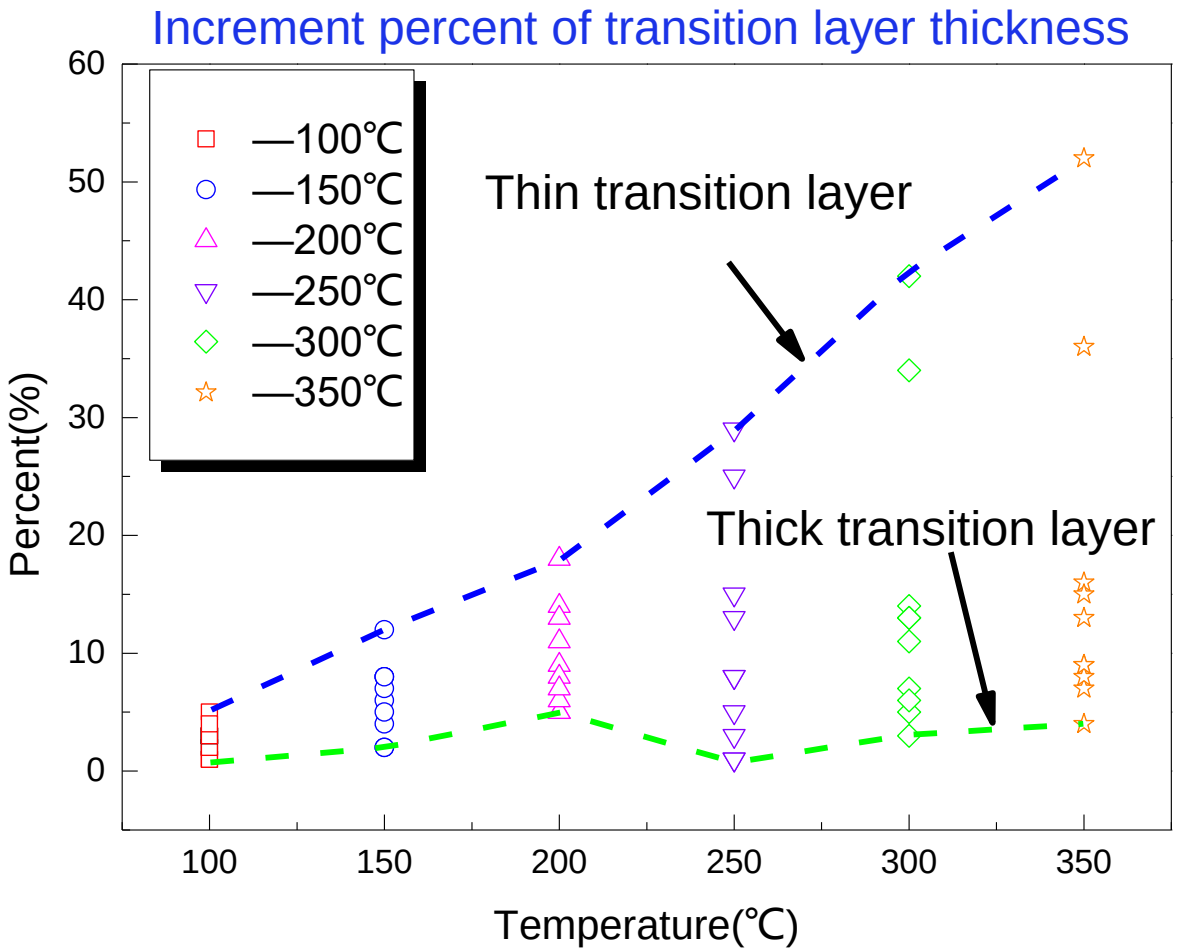
Thin transition layer(Thickness≤10μm)



Thick transition layer(Thickness>10μm)

- ✓ **Transition layer thickness incresases. (6~104%)**
- ✓ **Compositions have no changes at local zones with a constant Al-Fe ratio.**
- ✓ **Composition pits on the curve are filled.**
- ✓ **Curves become smoother.**

Transition zone chemical compositions



- ✓ **Transition layer thickness gradually goes up with the increasing temperature.**
- ✓ **Thin transition layer has a greater increment than the thick one.**

Conclusions

- Local shear strength of MPW joint can be improved at proper PWHT temperature. The shear strength at 3mm from the free end reached 58 MPa at 250 ℃.
- Radial cracks and micropores can be healed under 150 ℃. When the temperature exceeded 150 ℃, axial cracks propagated in the axial direction inside the transition layer.
- Chemical composition in the thick transition layer displayed a more uniform distribution.
- Thickness of the transition layer increased with the increasing PWHT temperature. The thickness increment of the thin transition layer was significantly greater than that of the thick one.

Thank You !