

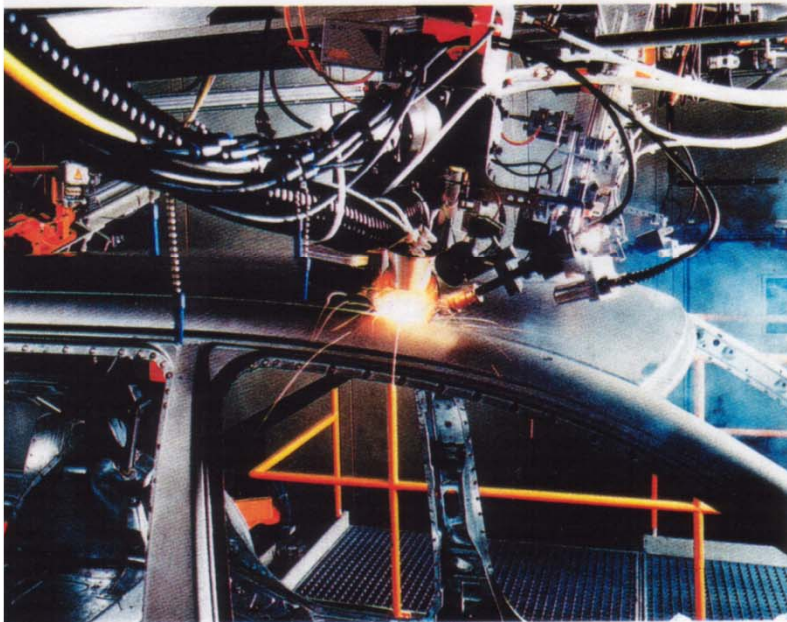
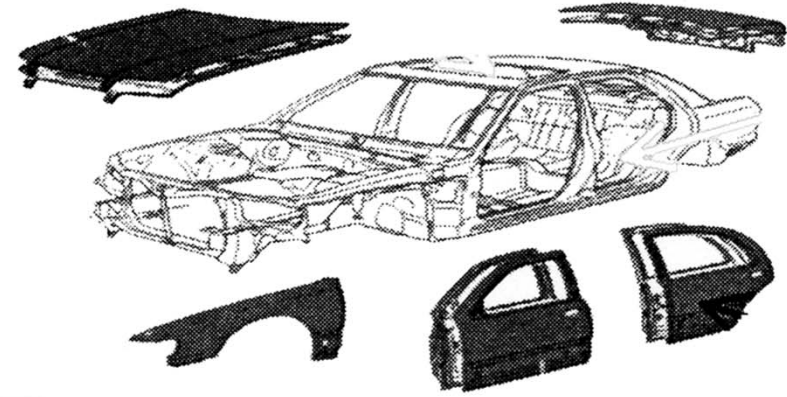
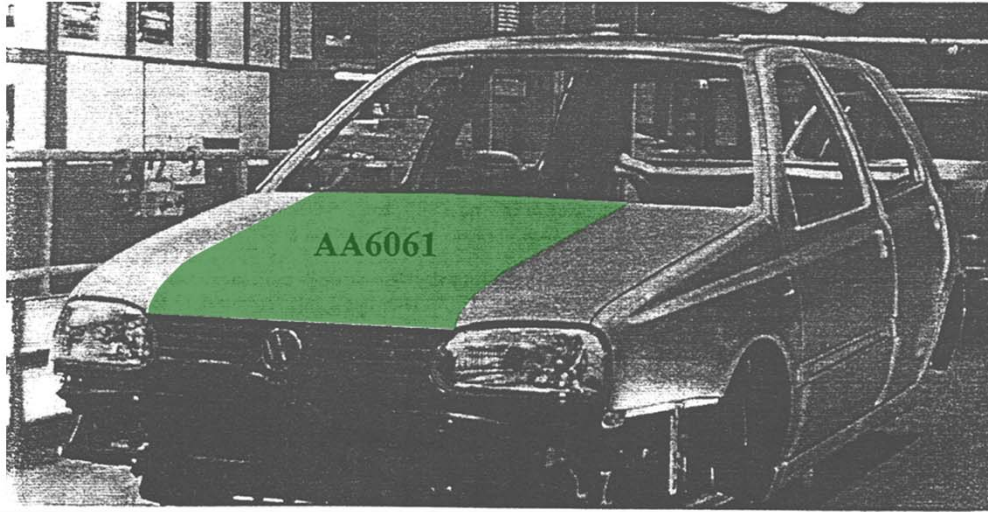
*IWJC-Korea 2017*  
*April 12<sup>th</sup> , 2017, Gyeongju*

# **Laser Roll Welding of Dissimilar Metal Joints**

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# 1. Introduction

## Needs for multi material structures



Materials:  
Max. size:  
Height :  
Sheet thickness :  
Corrugated sheet thickness:  
Angle of corrugated sheets :

Structural steel, stainless steel, aluminium, zinc coated steel  
17 m x 4 m  
40 – 500 mm  
0,7 – 6,0 mm  
0,7 – 3,0 mm  
40-60 °

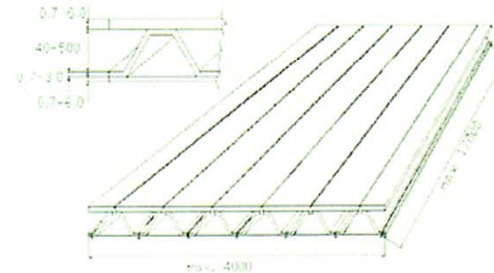


Figure 10. Dimensions of all steel welded sandwich panel.

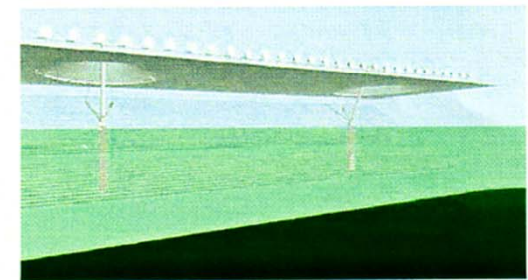
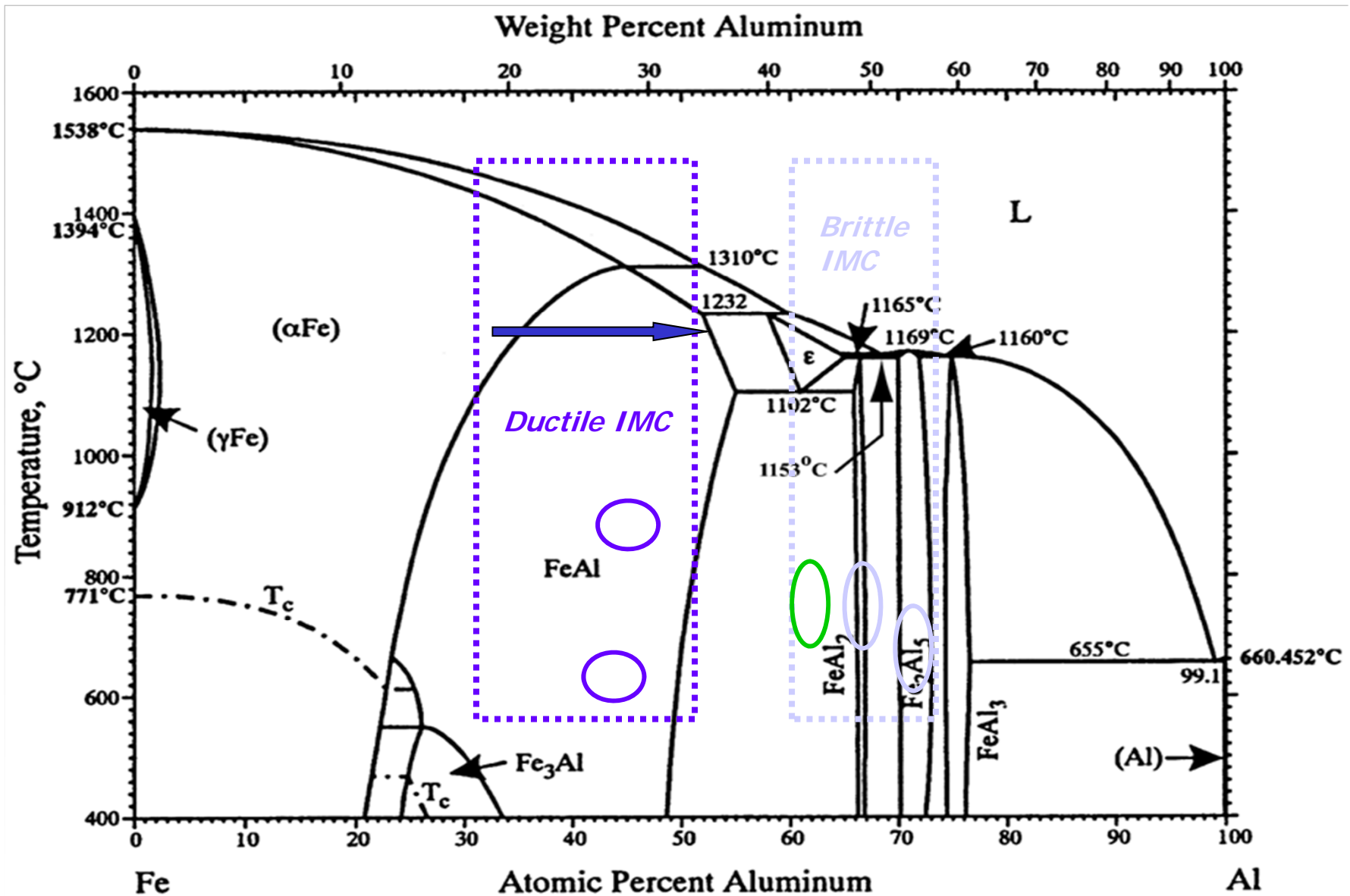
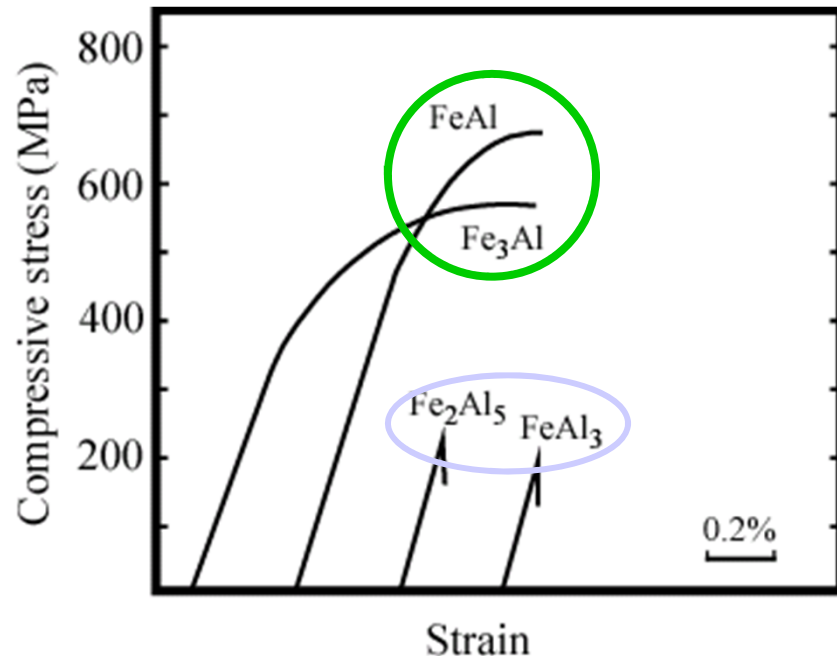


Figure 11. Example of future application of steel sandwich panels.

# Fe - Al equilibrium phase diagram



# Mechanical Properties of Intermetallic Compounds in Fe-Al series



Hardness and fracture toughness \*

Intermetallic compound	Vickers Hardness	$K_{IC}$ , MPa.m <sup>1/2</sup>
FeAl <sub>3</sub>	892	2.15
Fe <sub>2</sub> Al <sub>5</sub>	1013	2.3
FeAl	470	--
Fe <sub>3</sub> Al	330	--

\* M. Yasuyama and K. Ogawa, JJWS, 1996

Flow curves under compressive loading \*

(Yasuyama et al

- ❖ **Fe-rich IMC are ductile**
- ❖ **Al-rich IMC are brittle**
- ❖ Therefore, if amount of **Fe-rich ductile IMC** in interface layer is **increased** at the expense of Al-rich brittle IMC, the **joint strength may improve**.

# Mutual Diffusion Coefficient

$$D_{\text{Fe in Al}} = 1.2 \cdot 10^{-5} \text{ m}^2/\text{s}$$

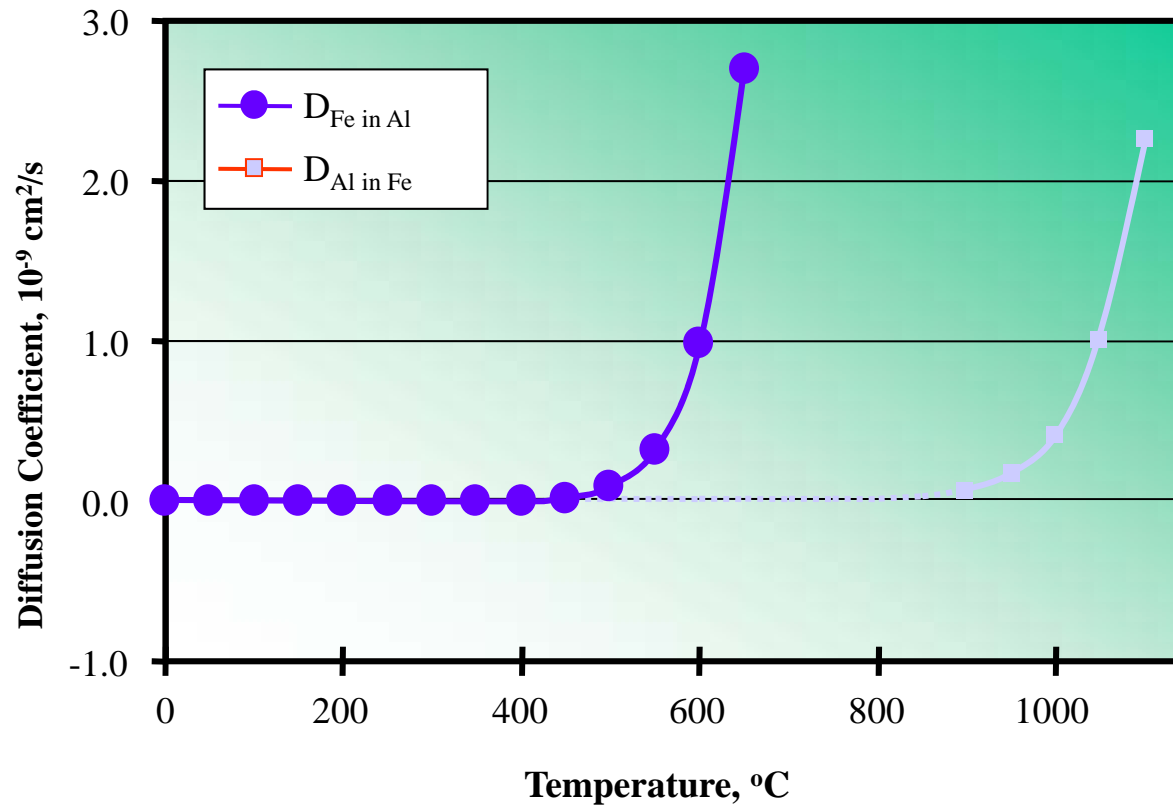
$$E_{\text{Fe in Al}} = 135,000 \text{ J/mol}$$

for 20°C-642°C

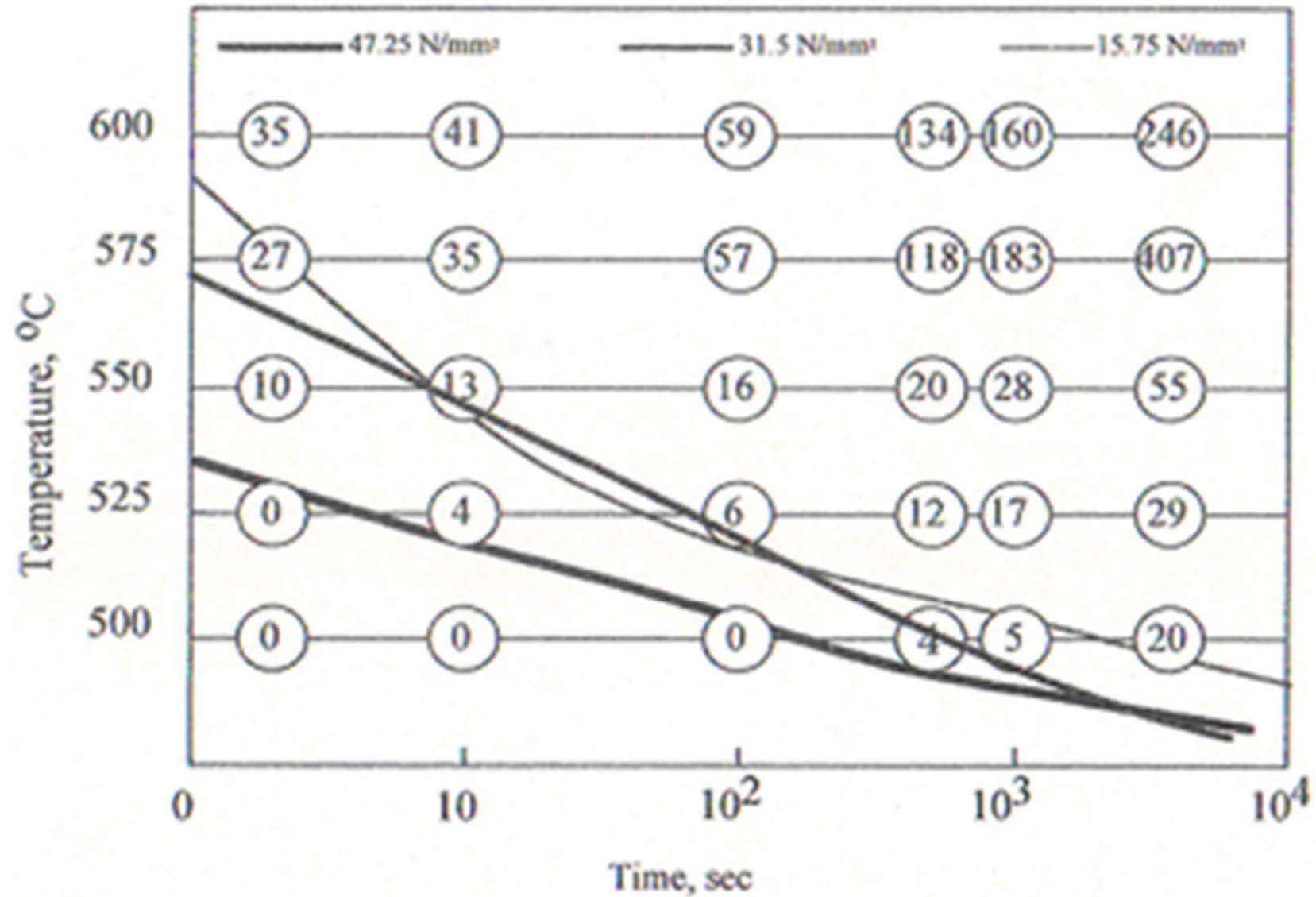
$$D_{\text{Al in Fe}} = 5.2 \cdot 10^{-4} \text{ m}^2/\text{s}$$

$$E_{\text{Al in Fe}} = 246,000 \text{ J/mol}$$

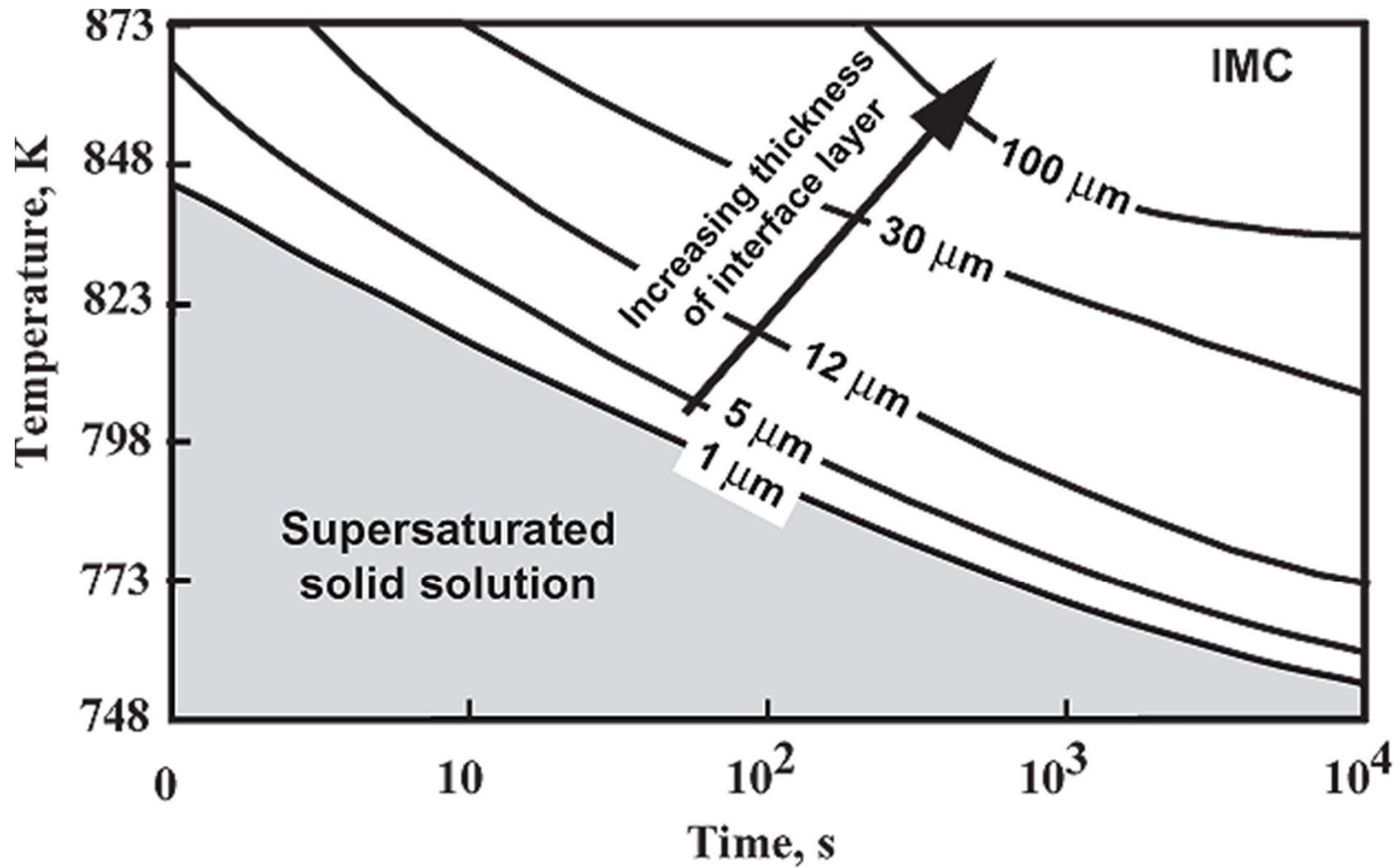
for 900°C-1100°C



# Growth of Intermetallic Compound



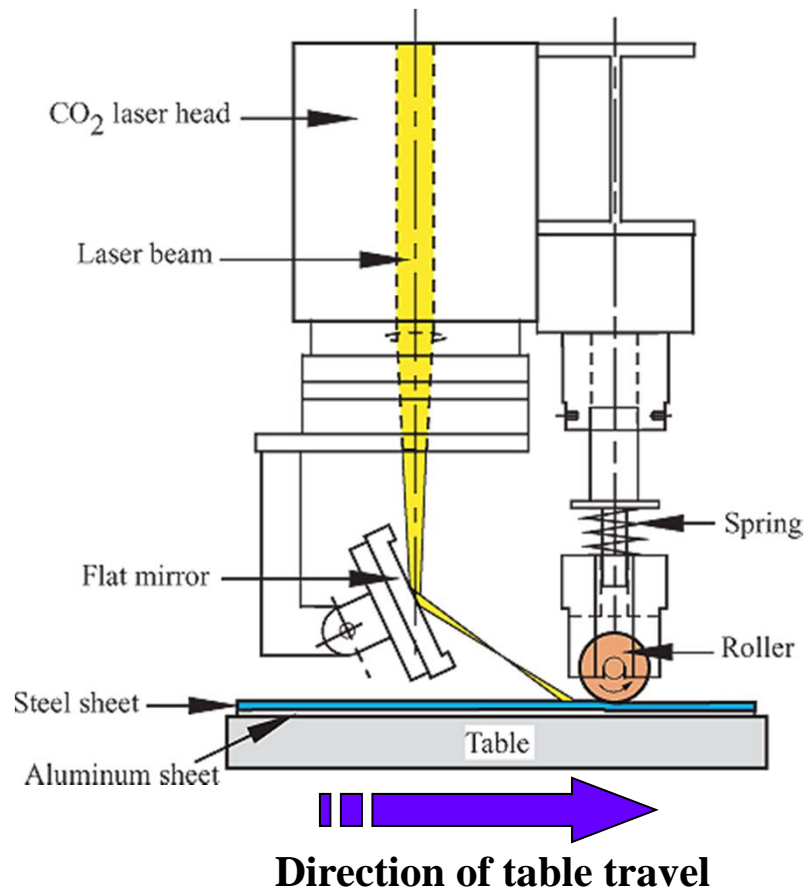
# Time-Temperature-Phase (TTP) Diagram



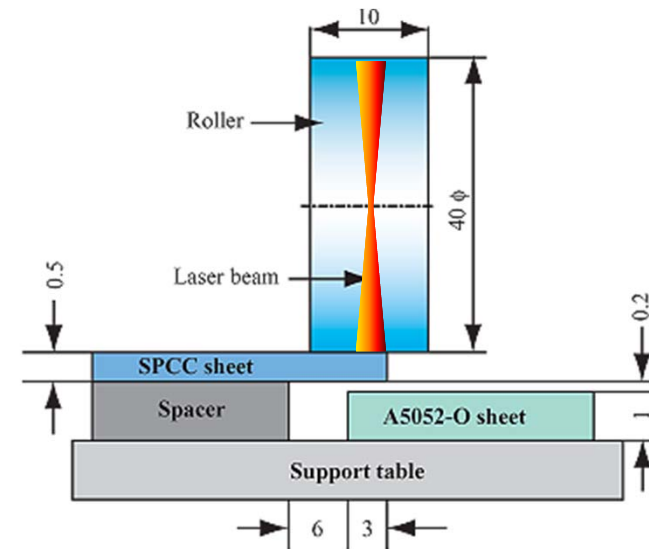
Pressure: 31.5 MPa

# 2. Laser Roll Welding for Fe-Al joint

2.4kW CO<sub>2</sub> laser with TEM 01\* mode



<b>Reflecting Mirror Angle</b>	<b>: 57.5°</b>
<b>Distance between Beam Spot center and Roller</b>	<b>: 17 mm</b>
<b>Beam Diameter</b>	<b>: 2.5 mm minor 3.5 mm major</b>
<b>Shielding Method</b>	<b>: Argon Gas shield</b>
<b>Insert material used</b>	<b>: Aluminium brazing flux, KAlF<sub>4</sub>:K<sub>2</sub>AlF<sub>6</sub>:H<sub>2</sub>O</b>

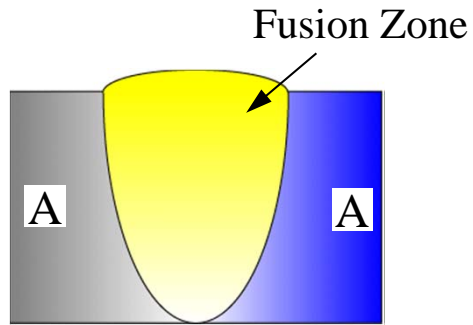


All dimensions are in mm.

**Details of Sheet Clamping**



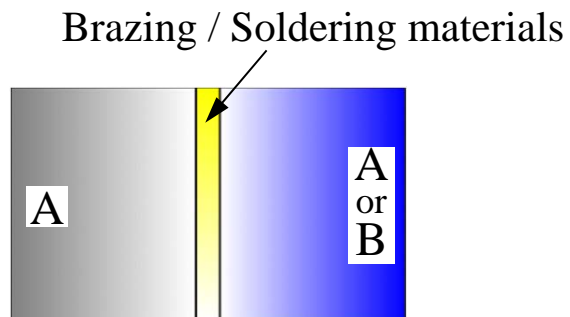
# Classification of Welding Processes



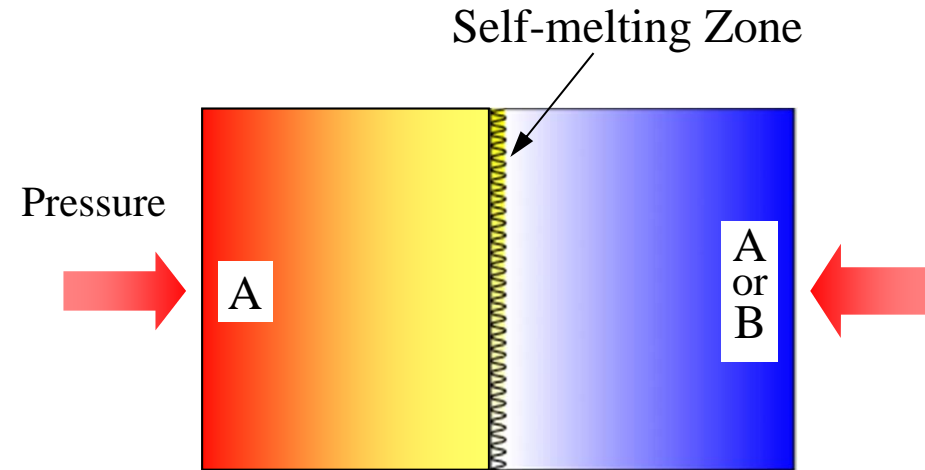
1. Fusion welding 融接



2. Solid-state welding 固相接合



3. Brazing ろう付



4. One side Melting Fusion Welding  
=Laser roll welding



# Process Features of LRW

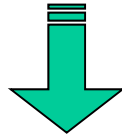
- 1) formations of ductile intermetallic compounds such as FeAl and Fe<sub>3</sub>Al or eutectic phase after self-melting in the interface layer;
- 2) keeping the intermetallic compound layer thickness less than 10 μm;
- 3) the idea of using a sharp intensified fast moving heat source to just cause wetting and diffusion for a very short period to form a metallic bond.
- 4) Heating is only one metal sheet by laser

# **3. Laser Roll Welding of SPCC steel and Aluminum Alloys**

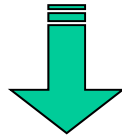
# Research Background

**Automobile industry aims at**

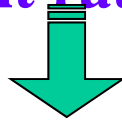
- **Improving fuel efficiency of vehicle**
- **Minimizing environmental pollution (CO2 Gas)**



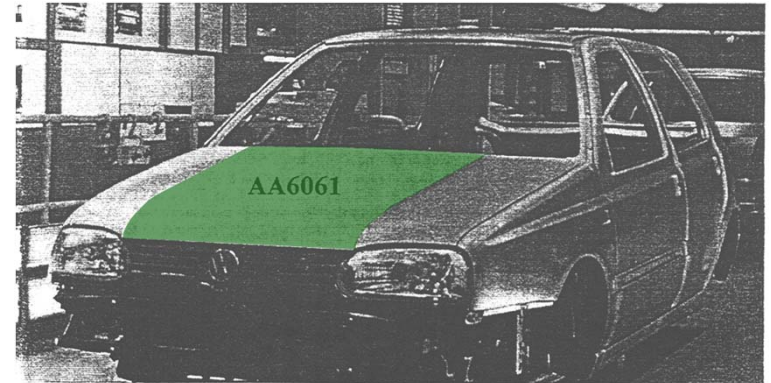
**One of the ways is  
to reduce vehicle weight by**



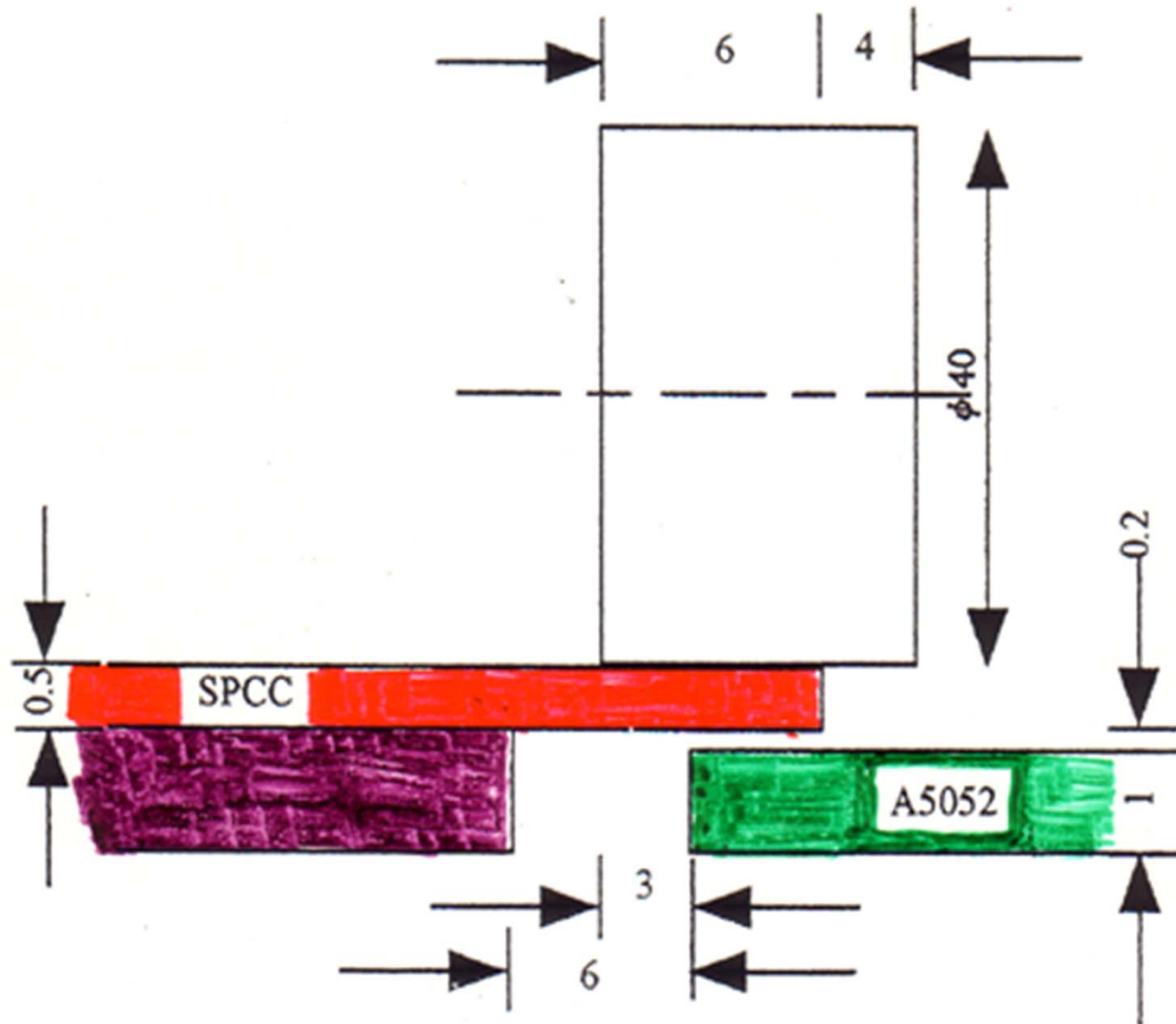
- **Use of high strength steels**
- **Amount of steel in the vehicle should be reduced by using aluminum alloys which have high strength-to-weight ratio**



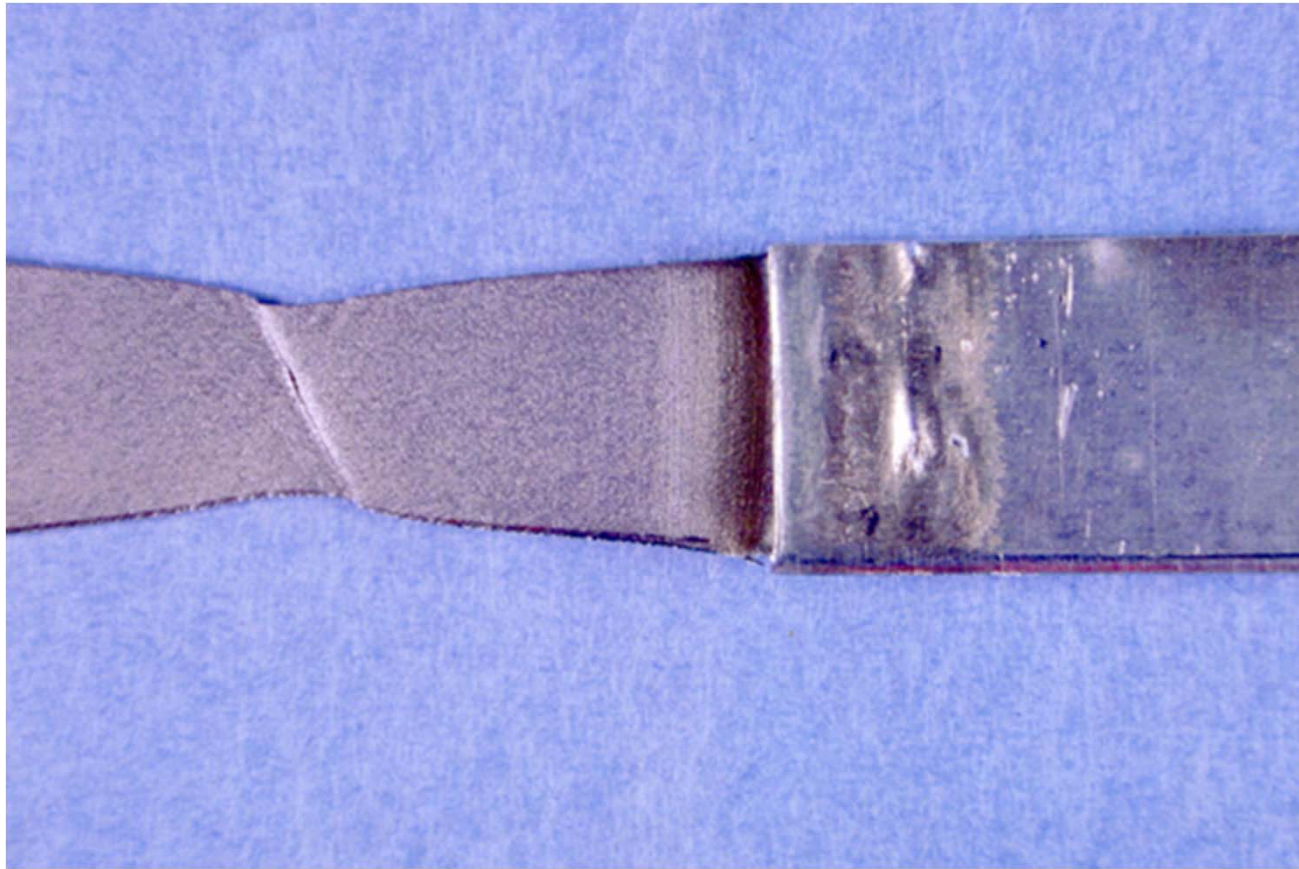
**For example, use of steel-aluminum hybrid structures.**



# Set up of SPCC steel and A5052 Alloy



# Tensile test specimen



**SPCC base metal was broken**

# Erichsen Test Specimen



# Welding Condition of LRW

Laser Power	1.0 kW ~ 2.0kW
Travel Speed	1.0 ~ 3.2 m/min
Beam spot dia.	3mm ~ 5mm
Roll Pressure	100 ~ 202 MPa
Shielding Method	Argon Gas shielding
Insert Material used	Aluminium brazing flux,

**KAIF4:K2AlF6.H2O**



# 3.1 Experiment

## 1) Materials used

**SPCC steel for car body ; Thickness 0.7 and 1.0 mm**

**Size : 23mm x 200mm and 40mm x 200mm**

**Preparation: Polishing with Emery paper #120**

**Coating : Graphite coating**

**A6022 and A6K21 : Thickness 1.2 mm**

**Size : 23mm x 200mm and 40mm x 200mm**

**Preparation: Polishing with Emery paper #400**

**Coating : FL-7 flux for Al brazing**

## 2) Laser Facility used

**3kW Single mode Fiber laser (IPG)**



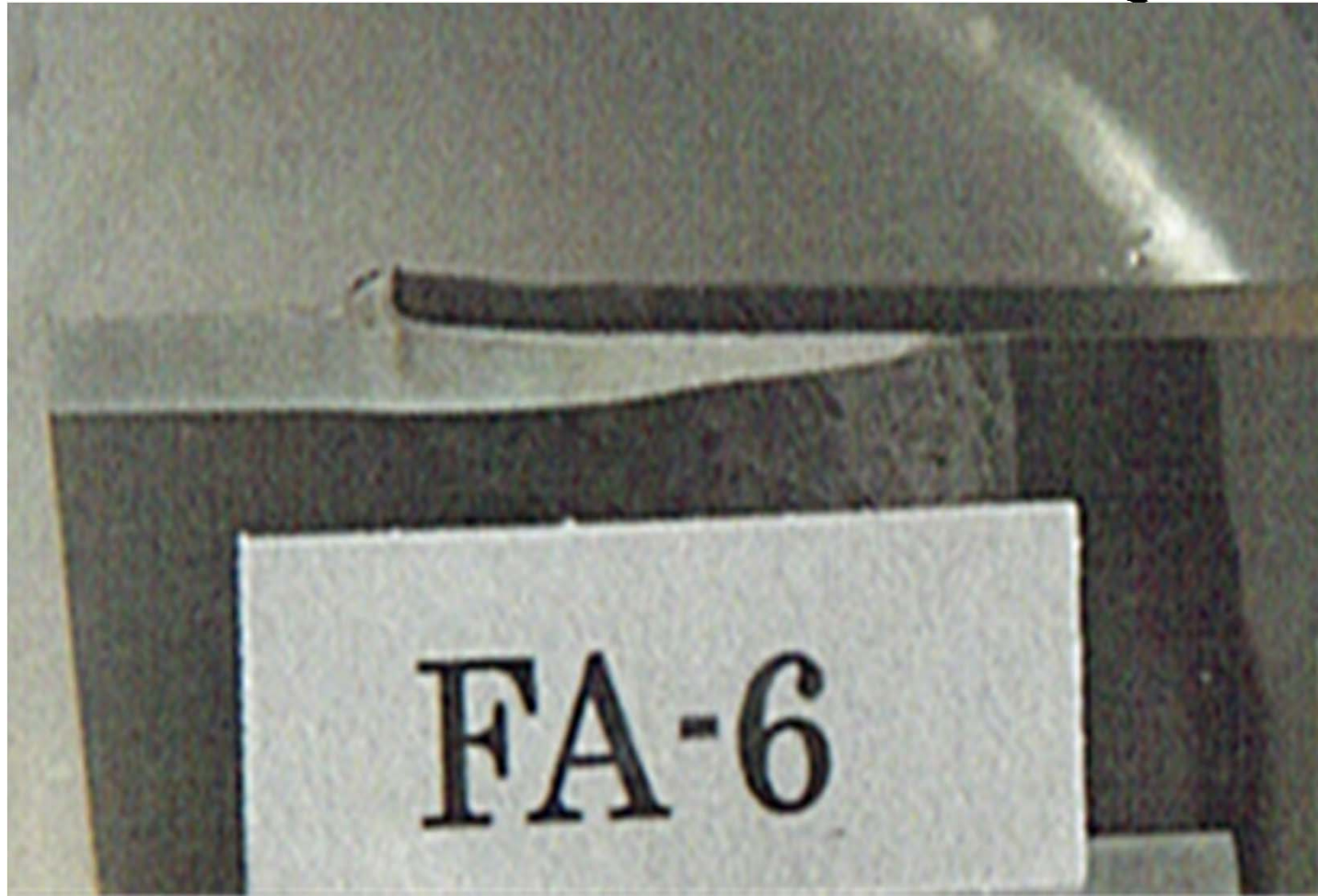
# Laser Roll Welding Machine



### 3) Welding condition

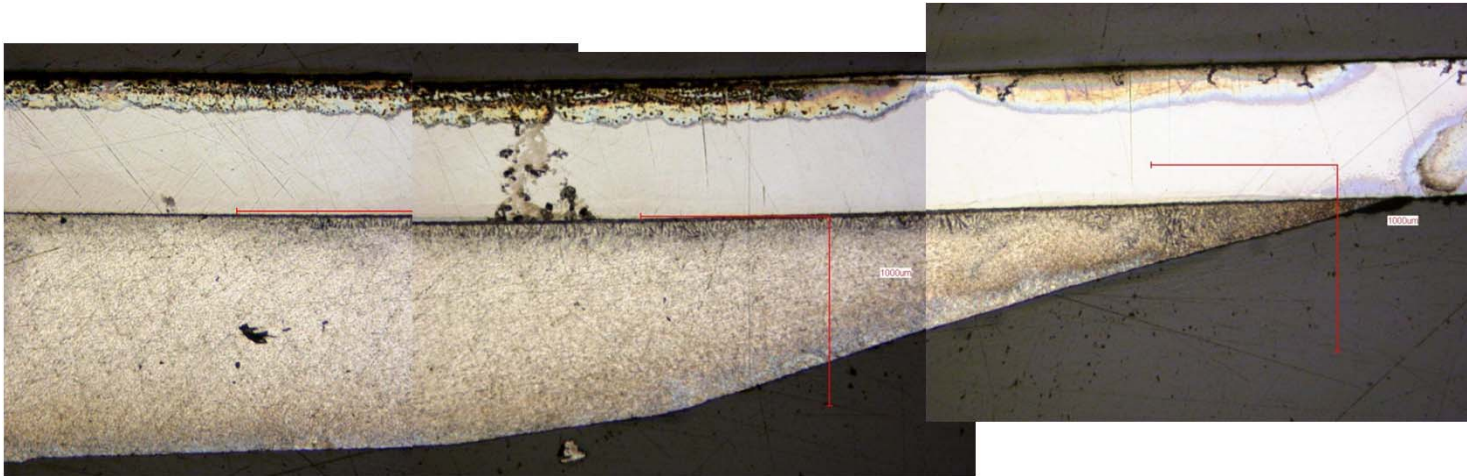
Specimen No.	Laser Power ( W )	Defocusing Distance D f ( mm )	Travel speed m m/sec	Loading ( N )	Shielding Gas and flow rate	Remarks
AT-1	2 2 0 0	1 6 5	1 5	1 0 0	A r 1 5 + 1 5	No Flux, Copper Backing
AT-2	2 2 0 0	1 6 5	2 0	1 0 0	A r 1 5 + 1 5	No Flux, Copper Backing
At-8	2 1 0 0	1 6 5	1 3	8 0 0	A r 1 5 + 1 5	With Flux, Copper Backing
AT-9	2 1 0 0	1 6 5	1 4	8 0 0	A r 1 5 + 1 5	With Flux, Copper Backing
AT-10	2 1 0 0	1 6 5	1 5	8 0 0	A r 1 5 + 1 5	With Flux, Copper Backing
AT-11	2 1 0 0	1 6 5	1 6	8 0 0	A r 1 5 + 1 5	With Flux, Copper Backing
AT-12	2 1 0 0	1 6 5	1 7	8 0 0	A r 1 5 + 1 5	With Flux, Copper Backing
AT-25	2 2 0 0	1 6 7	8	1 0 0	A r 1 5 + 1 5	With Flux, Copper Backing
AT-26	2 2 0 0	1 6 7	1 0	1 0 0	A r 1 5 + 1 5	With Flux, Copper Backing
AT-27	2 2 0 0	1 6 7	1 2	1 0 0	A r 1 5 + 1 5	With Flux, Copper Backing
AT-28	2 2 0 0	1 6 7	1 4	1 0 0	A r 1 5 + 1 5	With Flux, Copper Backing
FA-2	2 2 0 0	1 6 7	1 5	1 0 0	A r 1 5 + 1 5	With Flux, Copper Backing
FA-4	2 2 0 0	1 6 7	1 2	1 0 0	A r 1 5 + 1 5	With Flux, Steel Backing
FA-5	2 2 0 0	1 6 7	1 2	1 0 0	A r 1 5 + 1 5	With Flux, SUS Backing
FA-6	2 2 0 0	1 6 7	1 2	1 0 0	A r 1 5 + 1 5	With Flux, Alumi. Backing
AK-25	2 2 0 0	1 6 7	8	1 0 0	A r 1 5 + 1 5	With Flux, Alumi. Backing
AK-26	2 2 0 0	1 6 7	1 0	1 0 0	A r 1 5 + 1 5	With Flux, Alumi. Backing
AK-27	2 2 0 0	1 6 7	1 2	1 0 0	A r 1 5 + 1 5	With Flux, Alumi. Backing

# Cross section of Fe-Al joint



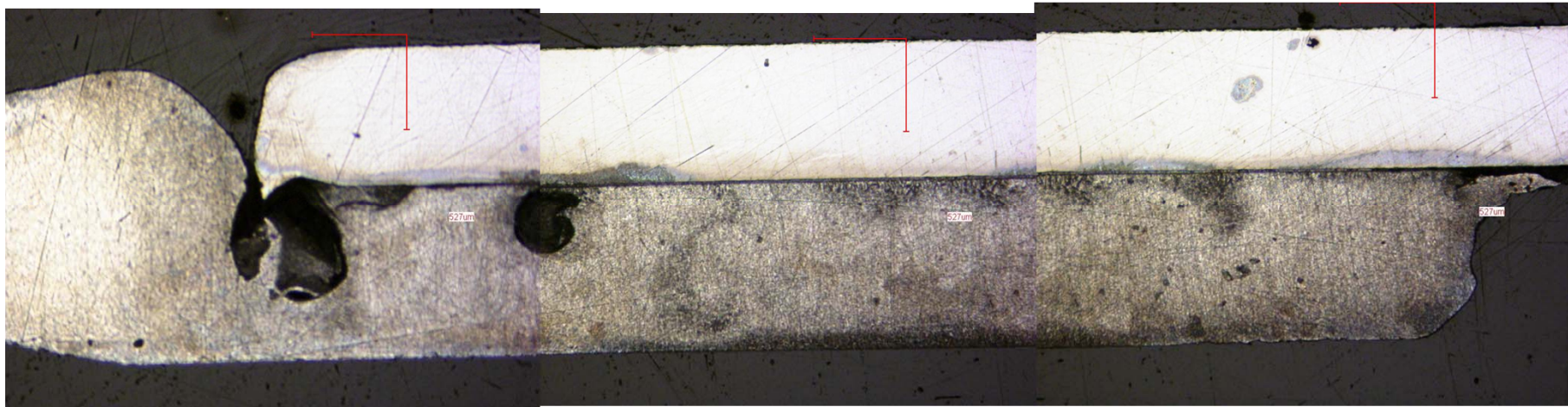
FA-6 : Aluminium Backing

# Cross section of Fe-Al joint



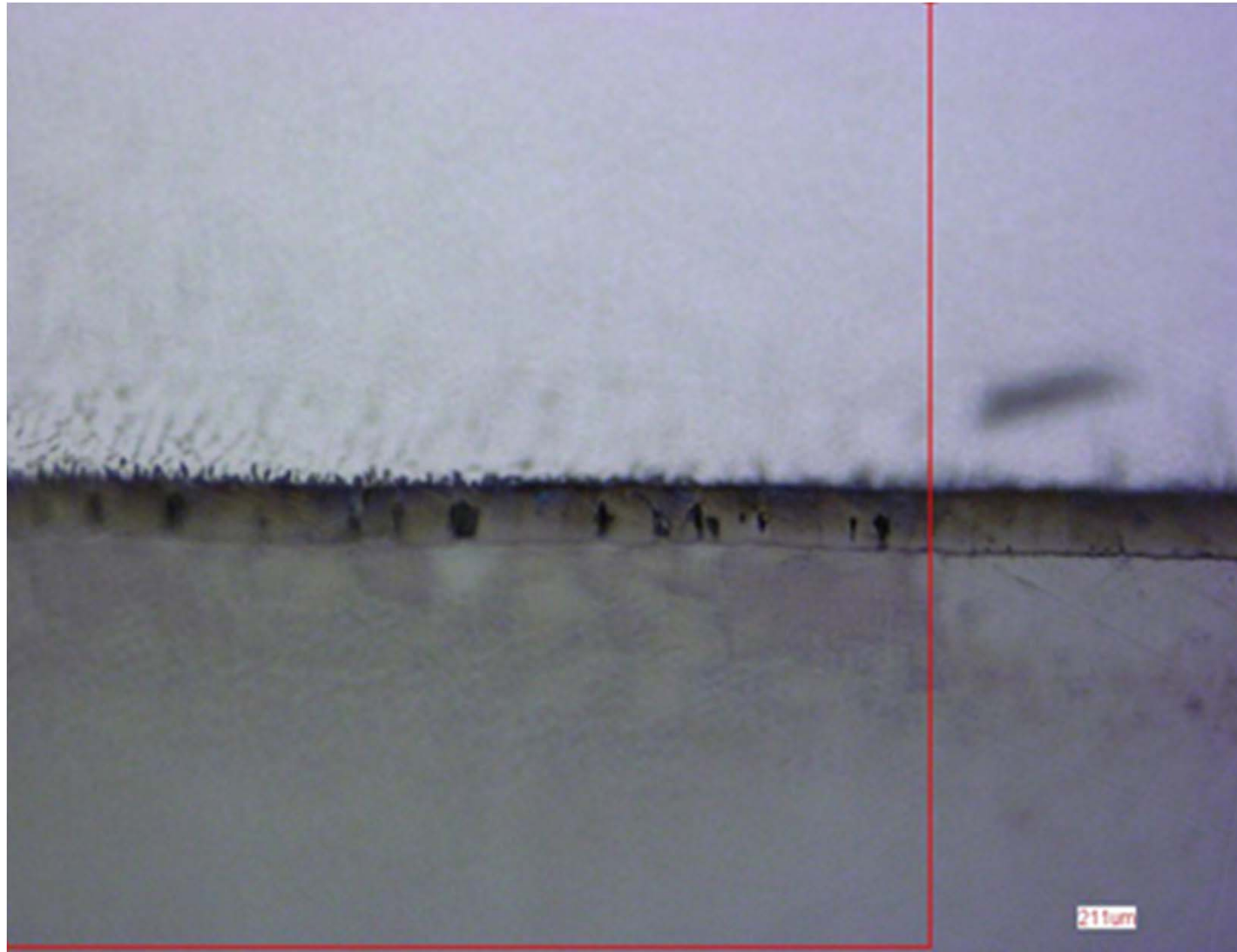
FA-2: Copper Backing

# Cross section of Fe–Al Joint



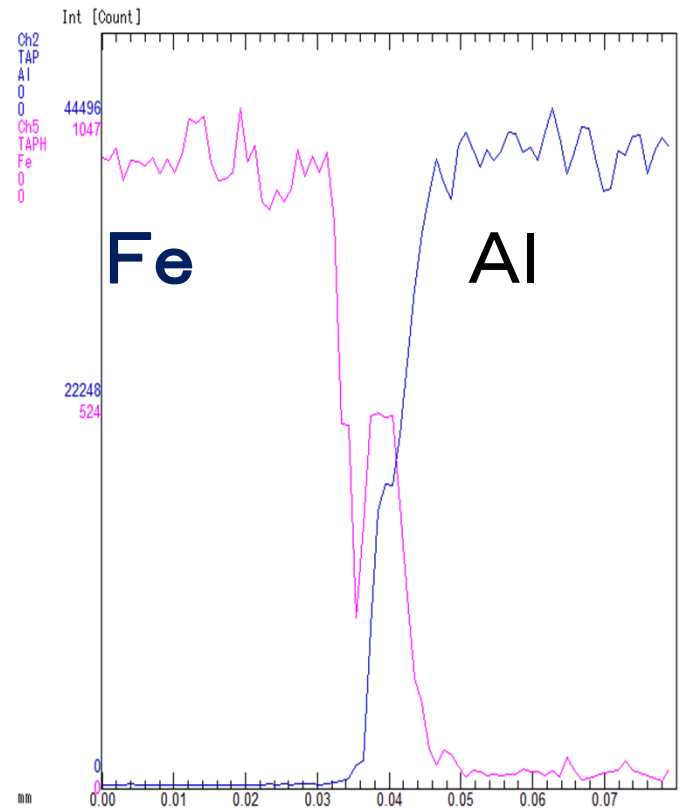
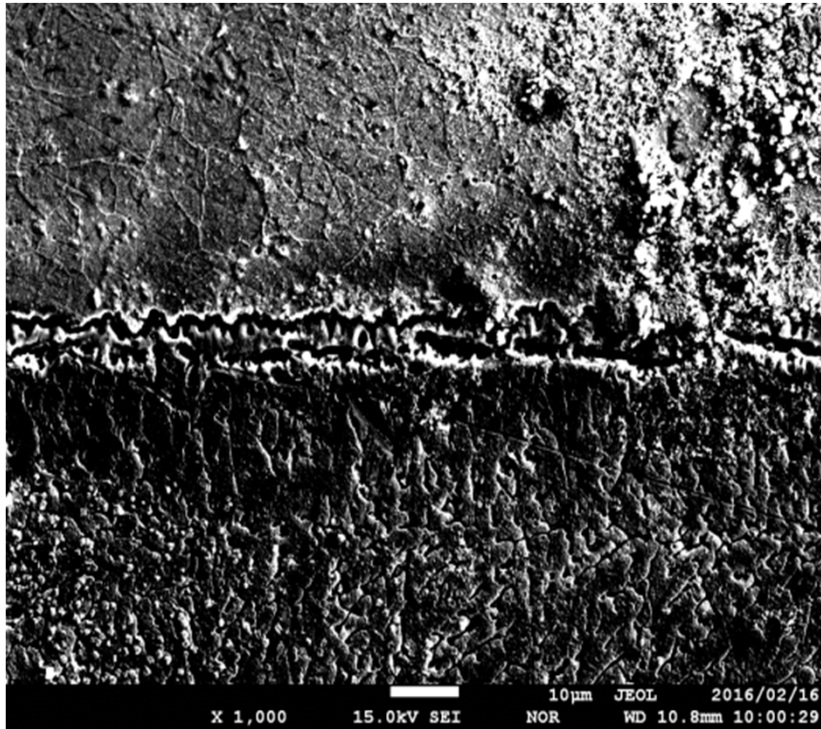
**FA-5: Stainless Steel Backing**

# Interface of joint FA-6





# Result of EPMA



保存パス : C:\Users\Guest\Desktop\ozaki  
プロジェクト : 20160216\_0004

2 16 10:17 2016  
ステージ スキャン  
加速電圧 15.0 kV  
照射電流 4.485e-008 A  
ビーム形状: SPOT  
ビーム径 (um) 0  
収集 (ms) 500.00  
ステージ番号 1  
X : 27.9250 mm  
Y : 22.4579 mm  
Z : 9.7430 mm  
方向 : 下方向  
点数 80  
間隔 1.01 um  
距離 80.00 um

Al WDS CH-2 TAP  
Ka 1 次線  
ピーク 90.6850 mm  
積算回数 1  
最大値 44496  
最小値 123  
平均値 20663.887  
A, B 値 0.0000, 0.0000  
Fe WDS CH-5 TAPH  
La 1 次線  
ピーク 180.9350 mm  
積算回数 1  
最大値 1047  
最小値 10  
平均値 470.487  
A, B 値 0.0000, 0.0000

# Re-za

Specimen No.	Laser Power (W)	Defocusing Distance D f (mm)	Travel speed mm/sec	Loading (N)	Tensile strength (MPa)	Remark
AT-25	2200	167	8	100	169	With Flux, Copper Backing
AT-26	2200	167	10	100	153	With Flux, Copper Backing
AT-27	2200	167	12	100	119	With Flux, Copper Backing
AT-28	2200	167	14	100	179	With Flux, Copper Backing
AK-25	2200	167	8	100	102	With Flux, Al Backing
AK-26	2200	167	10	100	168	With Flux, Al Backing
AK-27	2200	167	12	100	215	With Flux, Al Backing
FA-2	2200	167	15	100	330	With Flux, Copper Backing
FA-4	2200	167	12	100	126	With Flux, steel Backing
FA-5	2200	167	12	100	153	With Flux, SUS Backing
FA-6	2200	167	12	100	294	With Flux, Al Backing

# Tensile test specimen



**Copper Backing**



**Aluminium Backing**



**Stainless Steel Backing**

# Conclusion

- 1) It is suggested that intermetallic compound layer that is formed mainly is ductile FeAl . As the Backing material are Copper plate or Aluminum alloy.
- 2) The tensile strength of laser roll welded joint using copper backing is 330 Mpa. It was broken at Base metal of SPCC steel