Porosity in Thermite Welds

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What is Thermite Welding?

- **Thermite weld --** *A welding technique to utilize Aluminothermic reaction to join massive industrial components.*

- Aluminothermic reaction:

$$3FeO + 2Al = 3Fe + Al_2O_3 + 783\ KJ/mole$$

$$Fe_2O_3 + 2Al = 2Fe + Al_2O_3 + 759\ KJ/mole$$

$$3Fe_3O_4 + 8Al = 9Fe + 4Al_2O_3 + 3010\ KJ/mole$$

What is Thermite Welding?

- Equipment used for thermite rail welding:

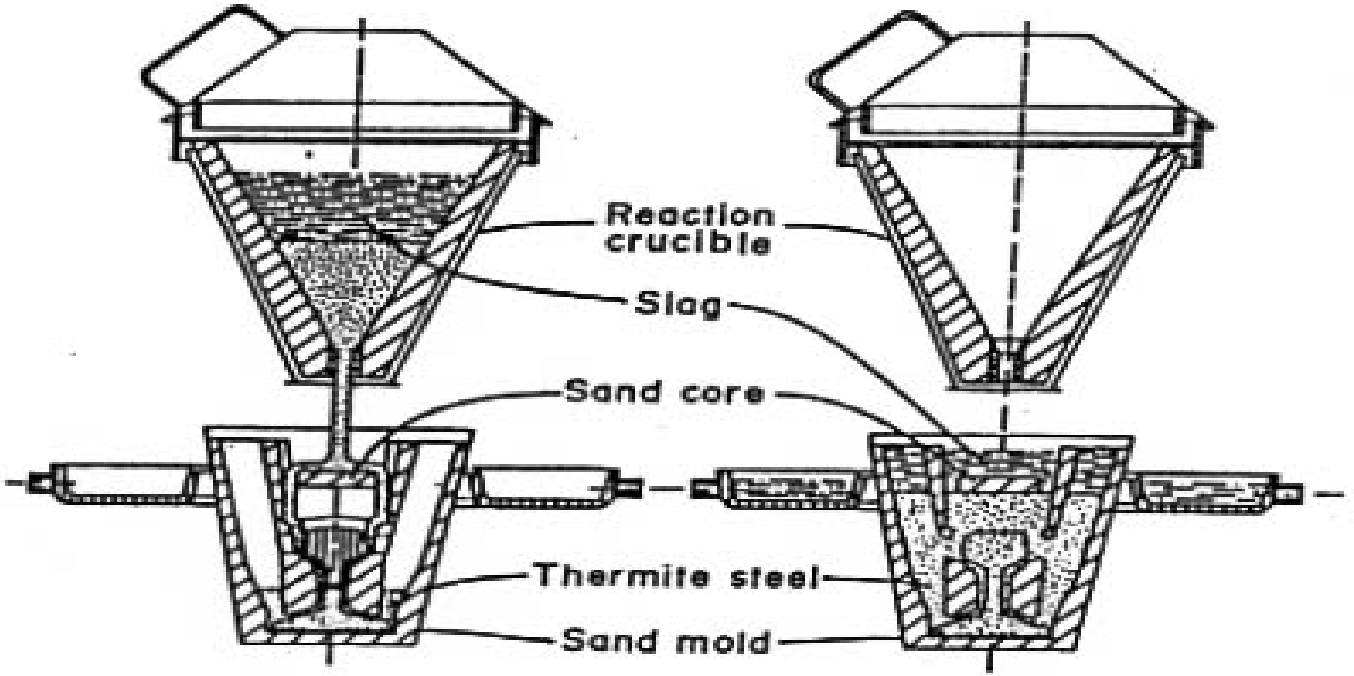
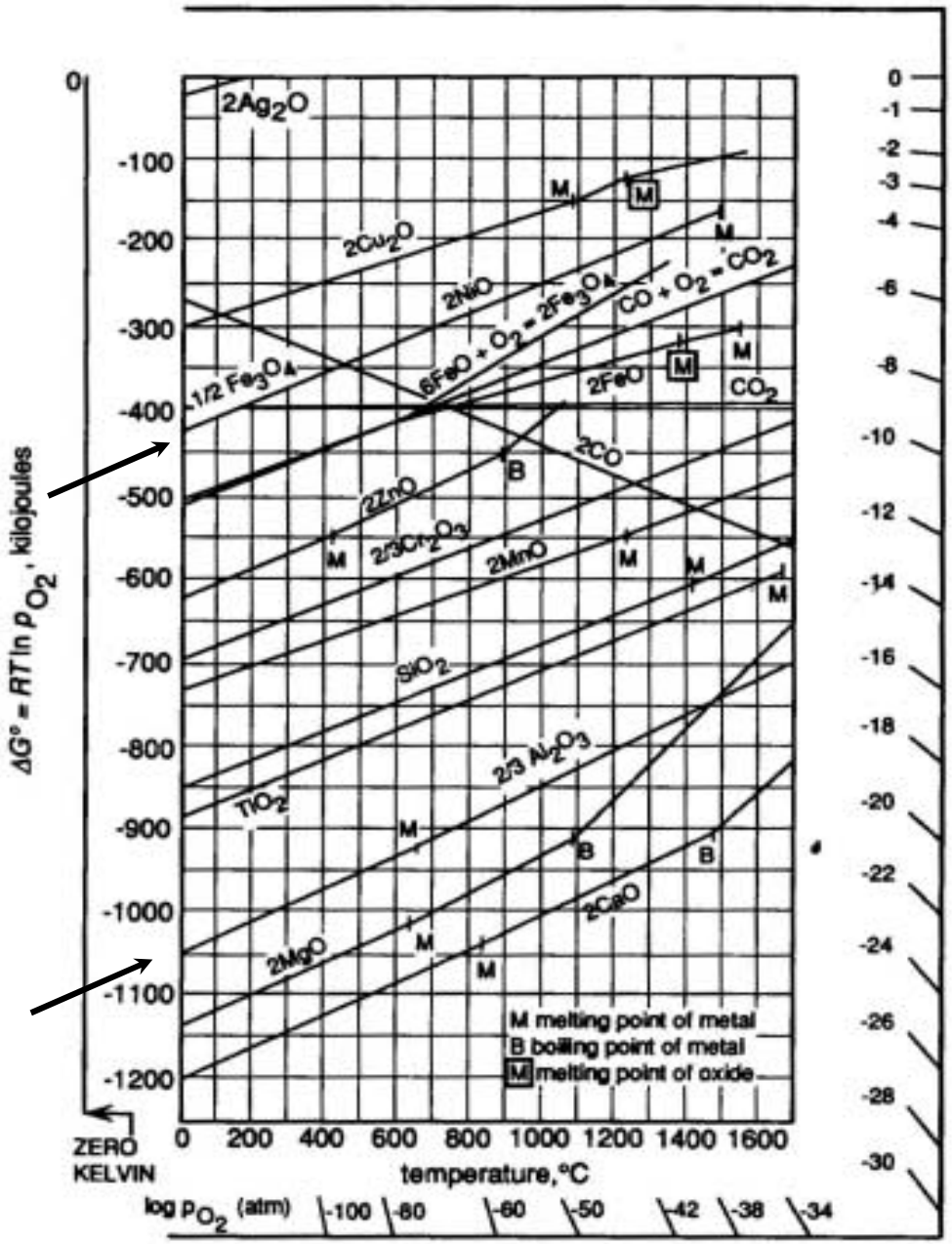


Figure 2.3. Schematic Diagram of Thermite Welding Set Up [16]

Thermite Charges

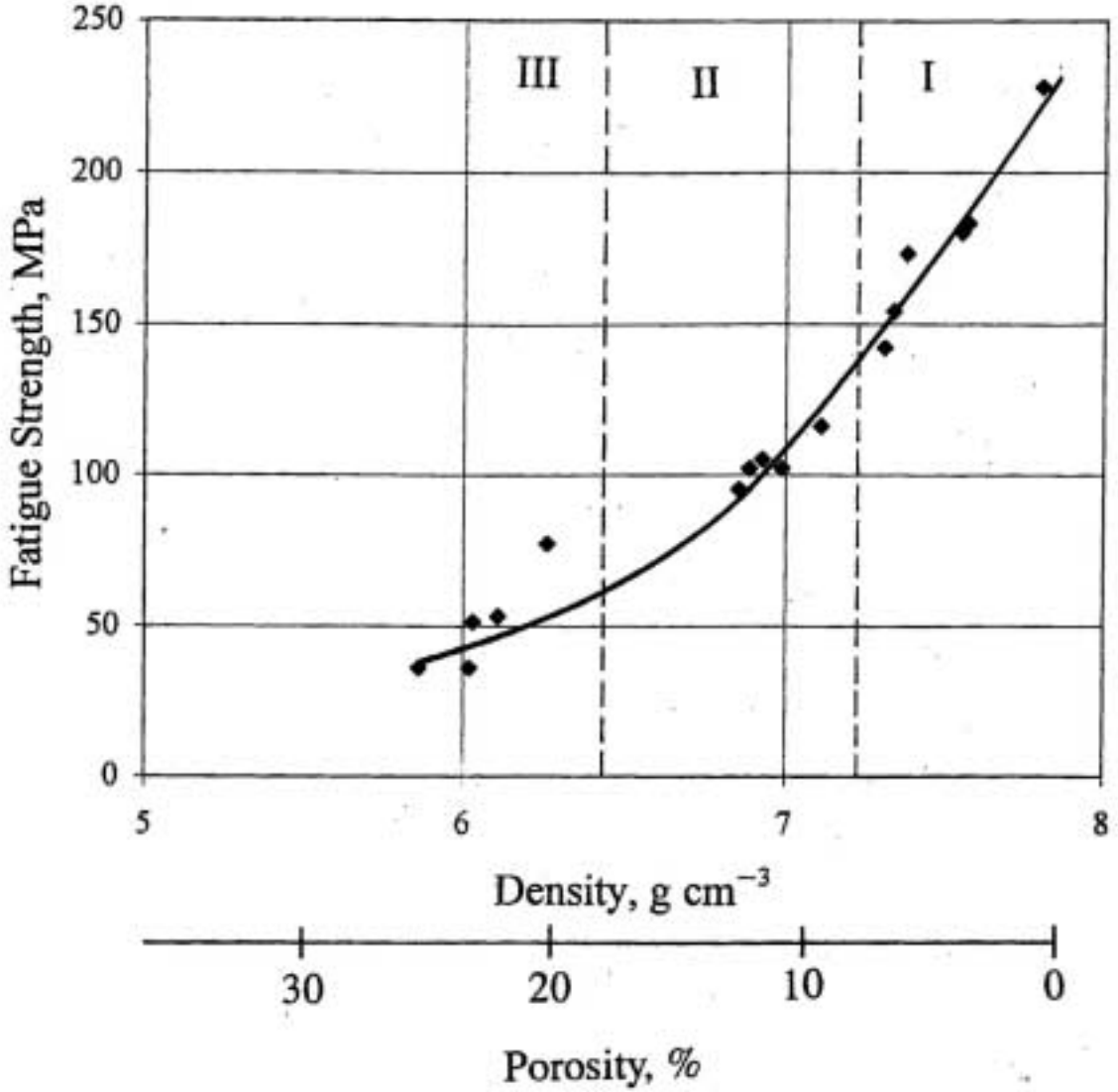
- Iron oxide particles
  - *with ferroalloy pellets*
- Aluminum powder
  - *10~15% in excess of stoichiometric amount*
  - *Size: 3-500μm*
- Additives
  - *help slag-metal separation*



Problems associated with Thermite welds

- Low tensile ductility
  - *Rails*: 14% reduction area.
  - *Thermite welds*: 1~3% reduction area.
- Low impact toughness
  - *Rails*: ~ 6 J Charpy V-notch.
  - *Thermite welds*: 1.5~2.8 J Charpy V-notch.
- Coarse grain, dendrite microstructure.
- Inclusion and porosity
  - *Develop internal fatigue cracks, and offer easy crack propagation path.*
  - *Pores are much more serious defects.*

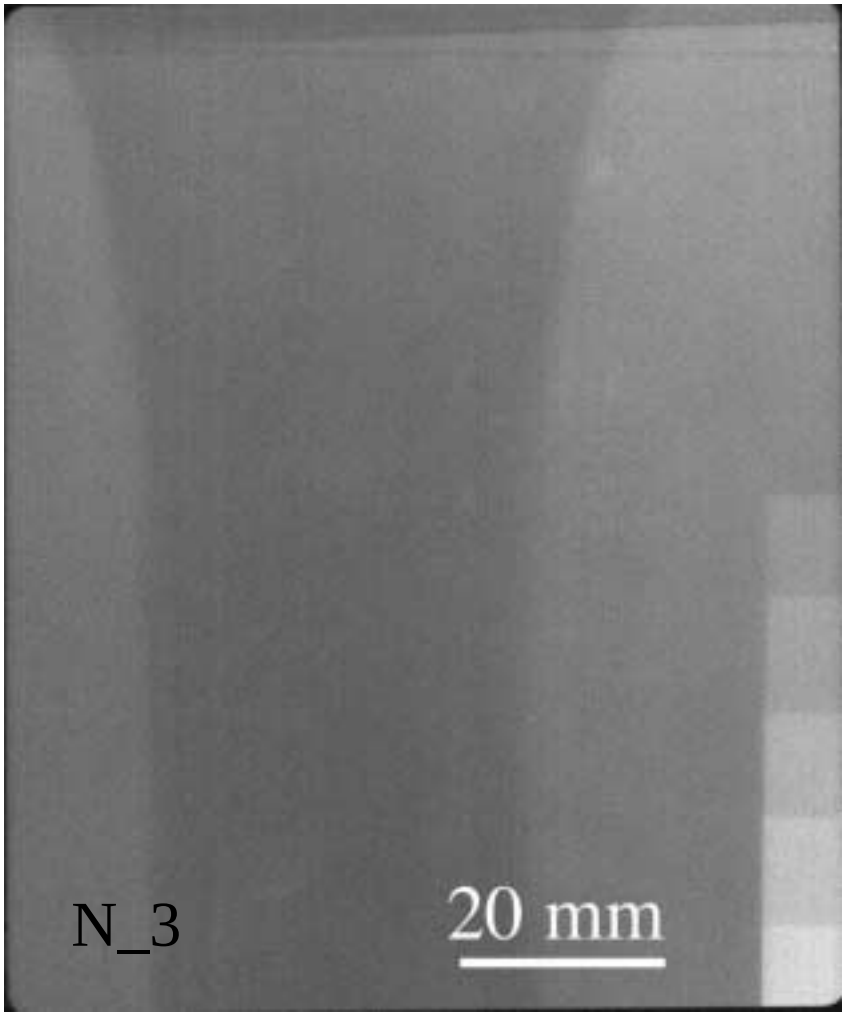
Porosity and fatigue strength



Source of porosity in thermite welds

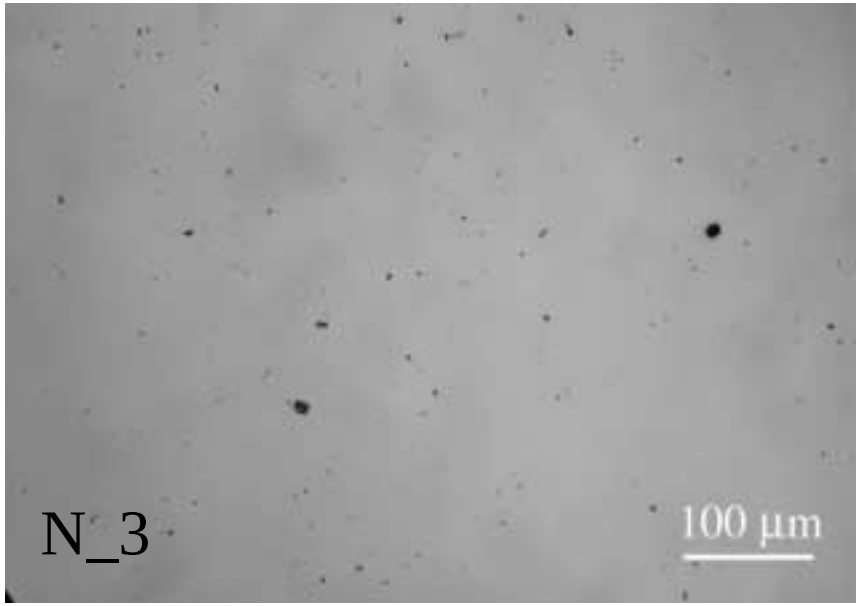
- Dissolved gases in molten metal.
  - *Due to small solubility of gas element in solid metal.*
  - *Form tiny, distributed gas pores in welds.*
  - *Weakly depends on solidification pattern.*
- Gas pores
  - *Trapped gas during pouring.*
  - *Chemical reaction products (eg. CO, CH_4)*
  - *Relatively large pores.*
  - *Depends on solidification condition and impurity.*
- Shrinkage pores
  - *Volume contraction during solidification.*
  - *Very large pores, or pore cluster.*
  - *Strongly depends on solidification condition.*

Measurement of porosity content

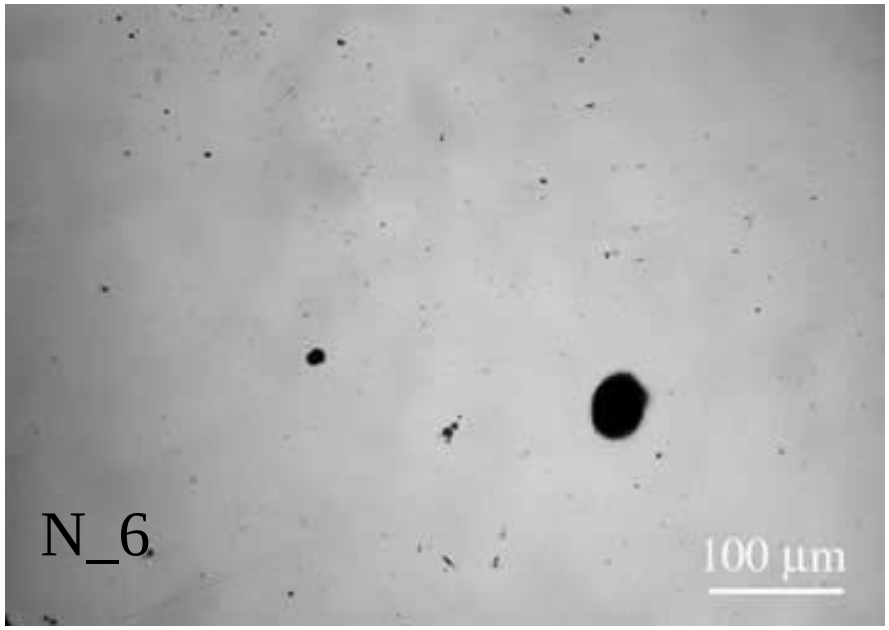


Radiographs of thermite welds

Measurement of porosity content



Optical measurement of Thermite welds



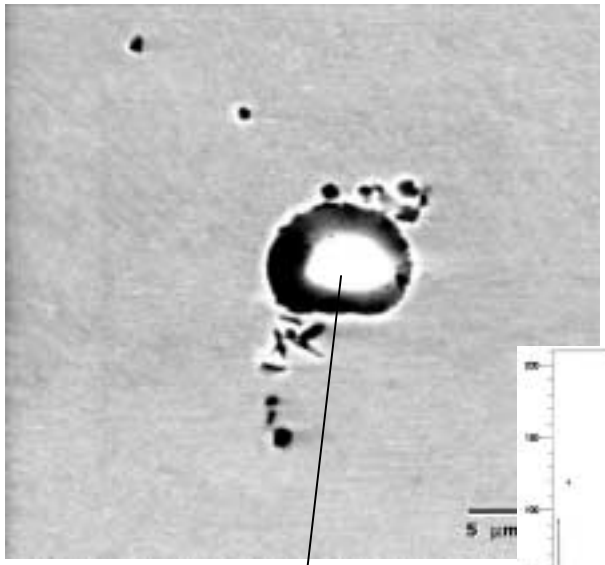
Measurement of porosity content

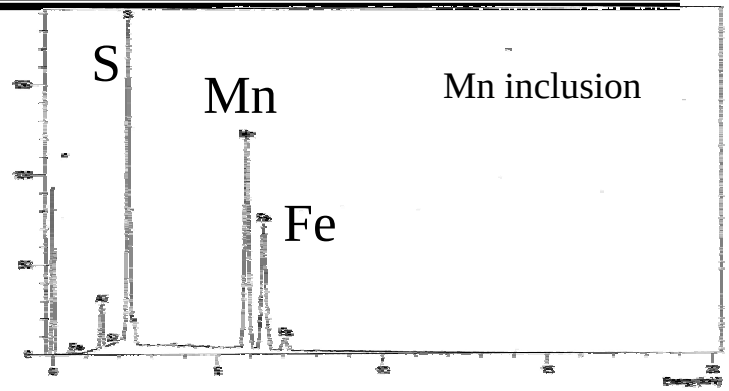
Table 1: Porosity content in thermite weld.

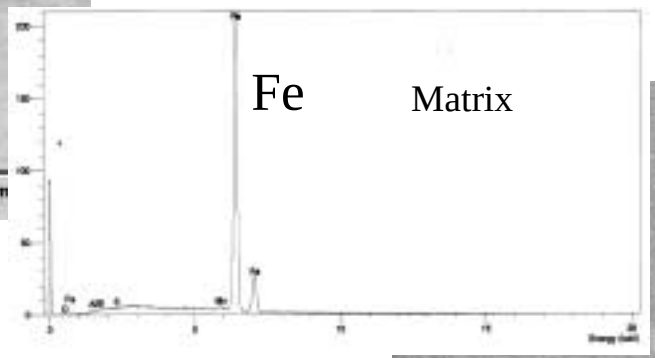
Sample Name		L_1	F_1	F_3	F_4	N_1	N_2	N_3	N_6	N_7	N_8
Porosity (vol.%)	**x-ray**	0.84	0.92	0.4	0.4	0.6	0.96	1.2	0.4	0.56	0.56
	optical	0.93	1.01	-	-	-	-	1.28	0.48	-	-

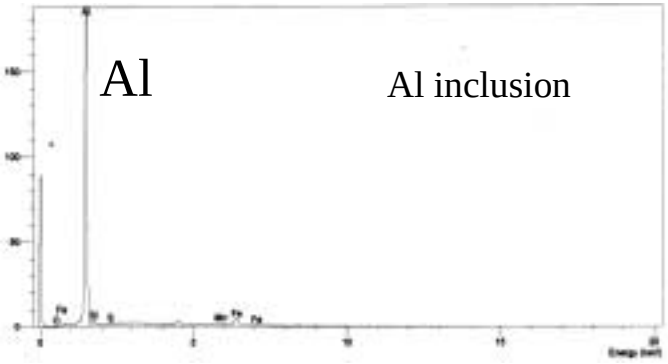
- There is a wide variation of porosity content in different welds.
- Porosity content measured by radiograph method is lower than that of optical measurement.

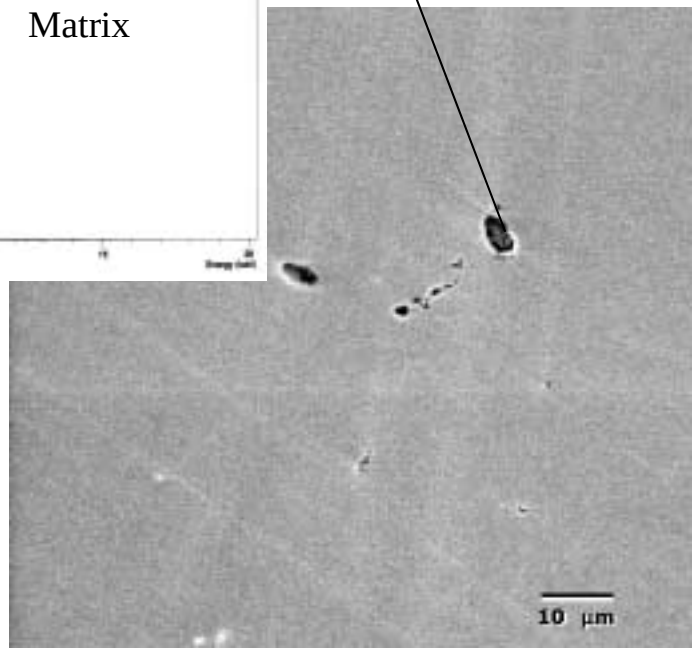
SEM observation





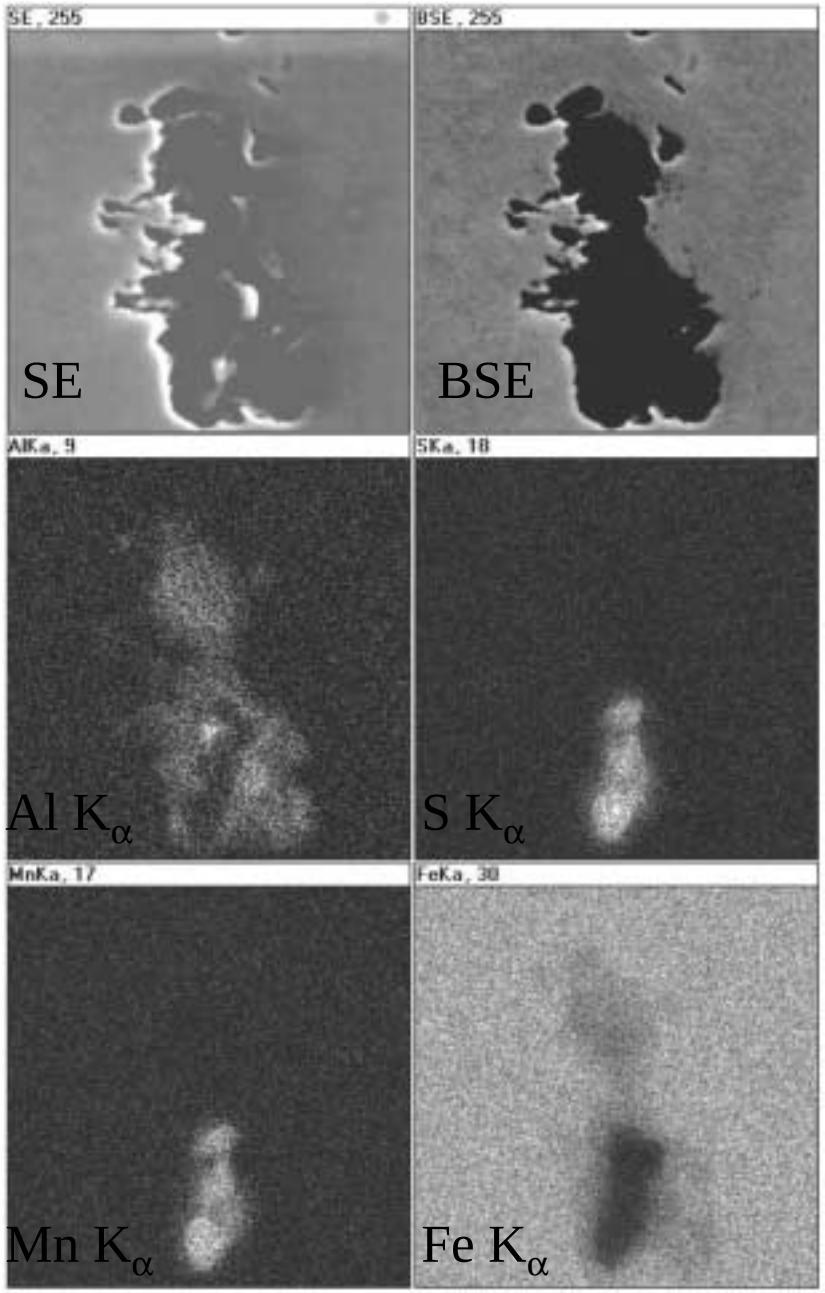




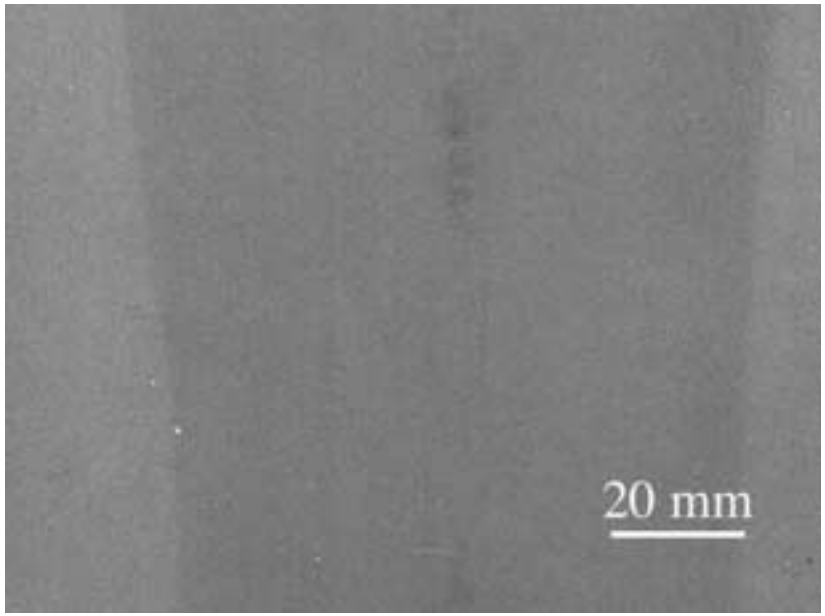


SEM observation

X-ray mapping of inclusions in welds

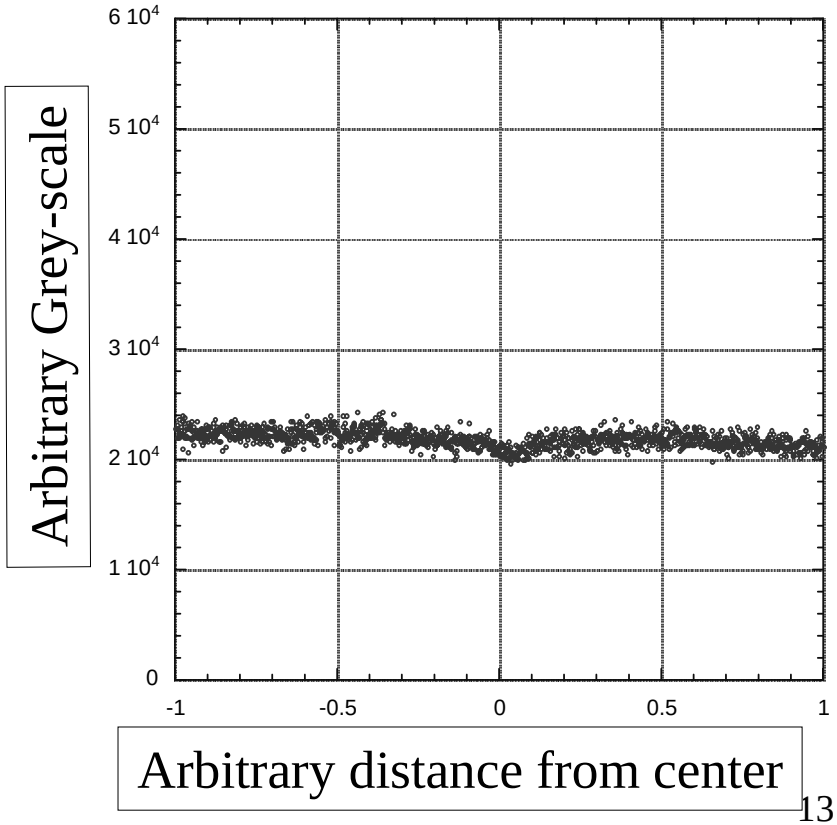


Porosity distribution

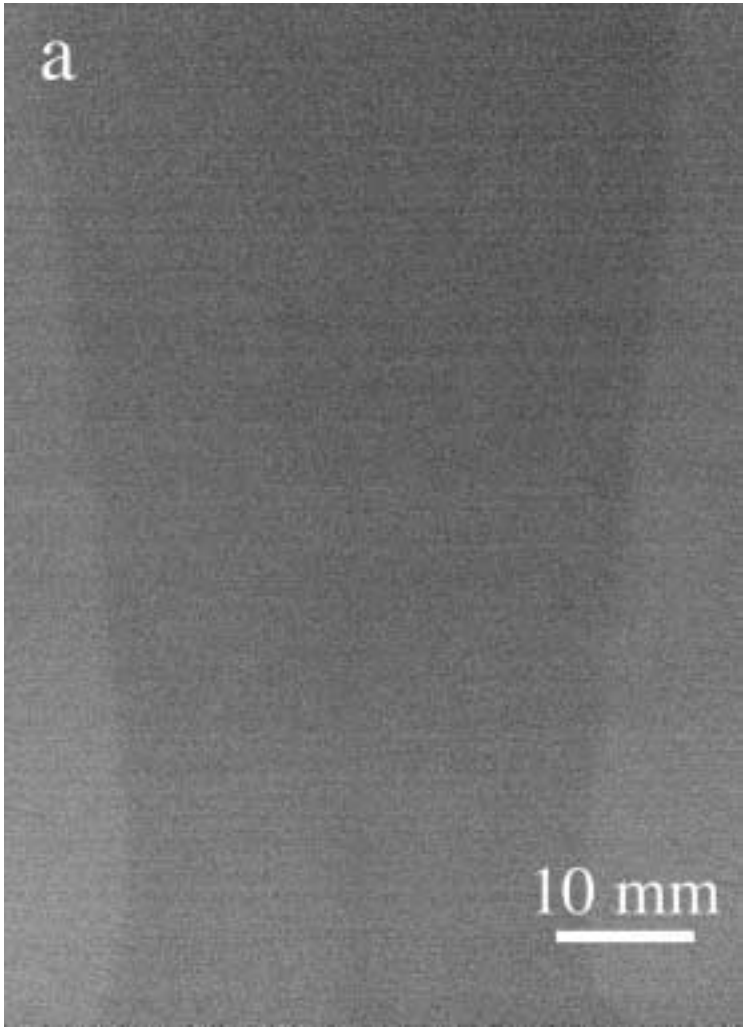


L_1

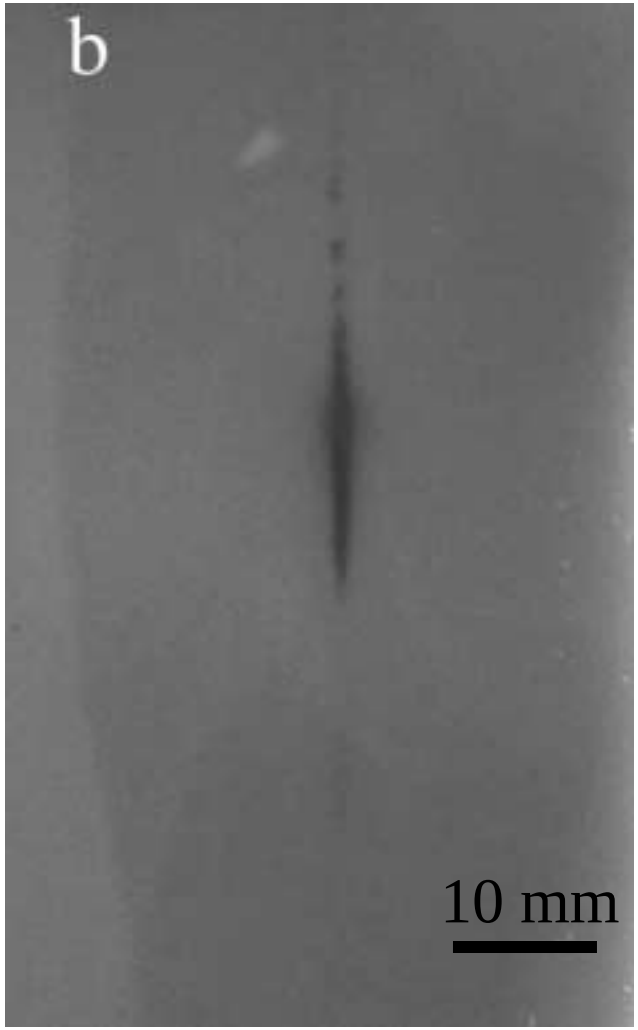
Grey-scale variation across sample



Porosity distribution and preheat

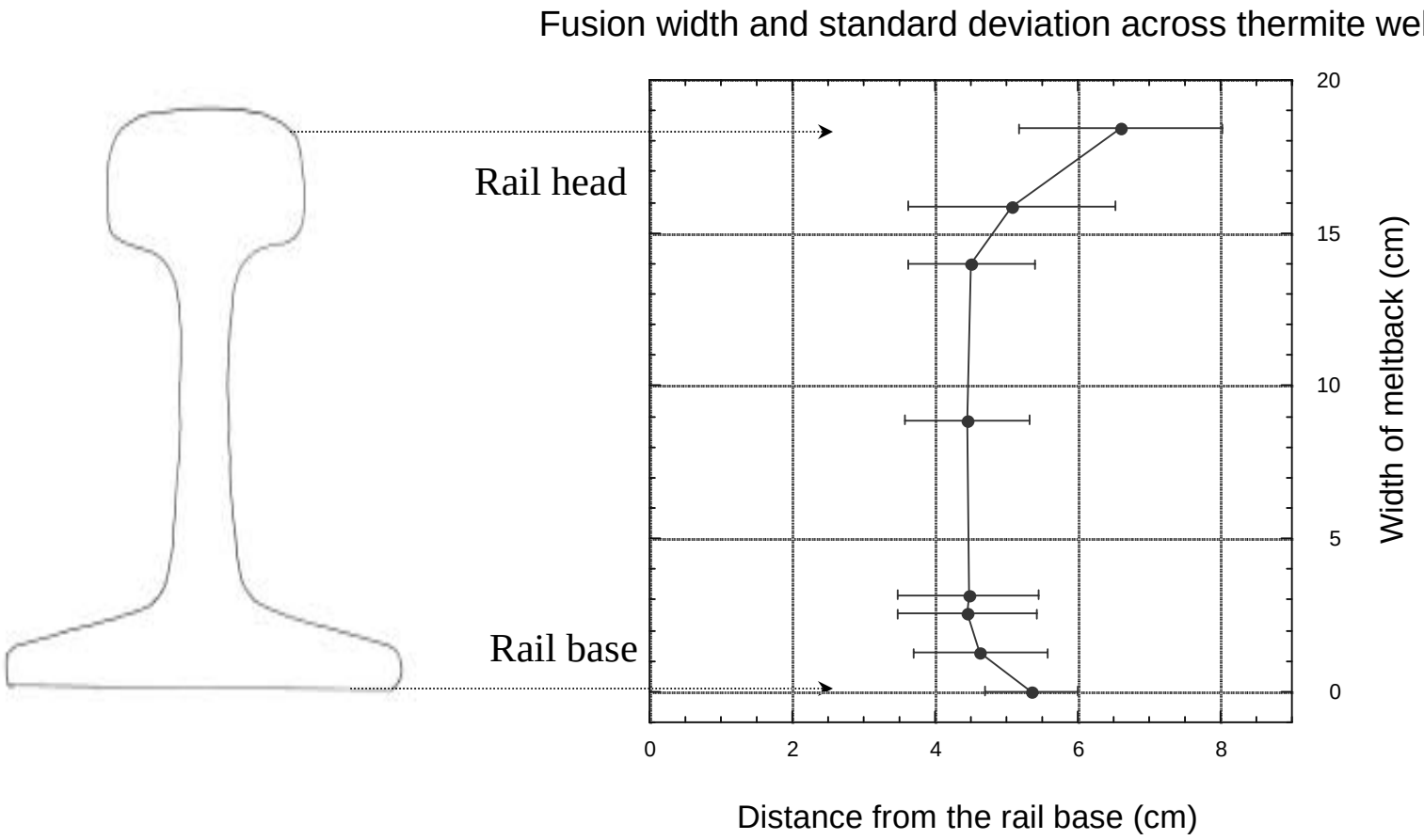


Long preheat (7 min)



Short preheat (2 min)

Width of melt-back

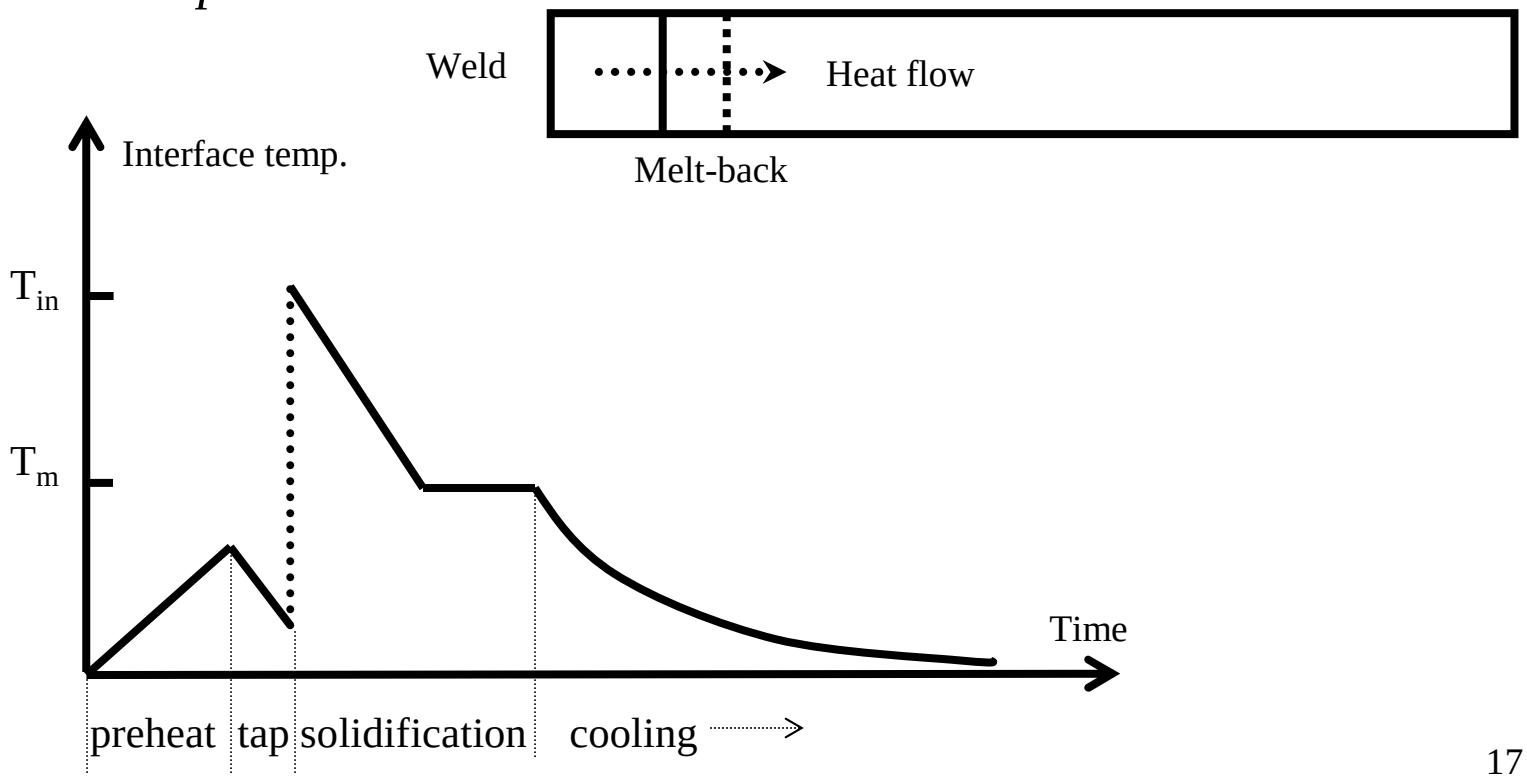


Summary

1. Porosity content in thermite welds is measured by radiography method. Because of the present of Al_2O_3, radiograph method underestimates the total porosity content.
2. There is a wide variation of porosity content in different welds.
3. Pores are very often associated with inclusions.
4. Porosity cluster is often observed along centerline of weld.
5. Preheat time can affect the formation centerline porosity cluster.

Future work

- Modeling the thermite welding process (2-D and 3-D).
  - *Effect of preheating: flame temperature + time.*
  - *Influence of tapping time.*
  - *Heat input: amount of thermite charges.*
  - *Ambient temperature.*



Future work

- Understand the key controlling factors for thermite welds, and what can be done to improve.

- Experimentally fabricate thermite weld in a well controlled environment and verify the theoretical study.