Study on optimum electron beam welding conditions

Takayuki Kubo (KEK)

Yasuo Ajima, Hitoshi Inoue, Takayuki Saeki, Kensei Umemori,
Yuichi Watanabe, Seiya Yamaguchi, Masashi Yamanaka,
KEK, 1-1 Oho, Tsukuba, Ibaraki 305-0801 Japan,
Tomohiko Nagata, ULVAC, Inc., 5-9-6 Tokodai, Tsukuba, Ibaraki, 300-2635, Japan

Introduction

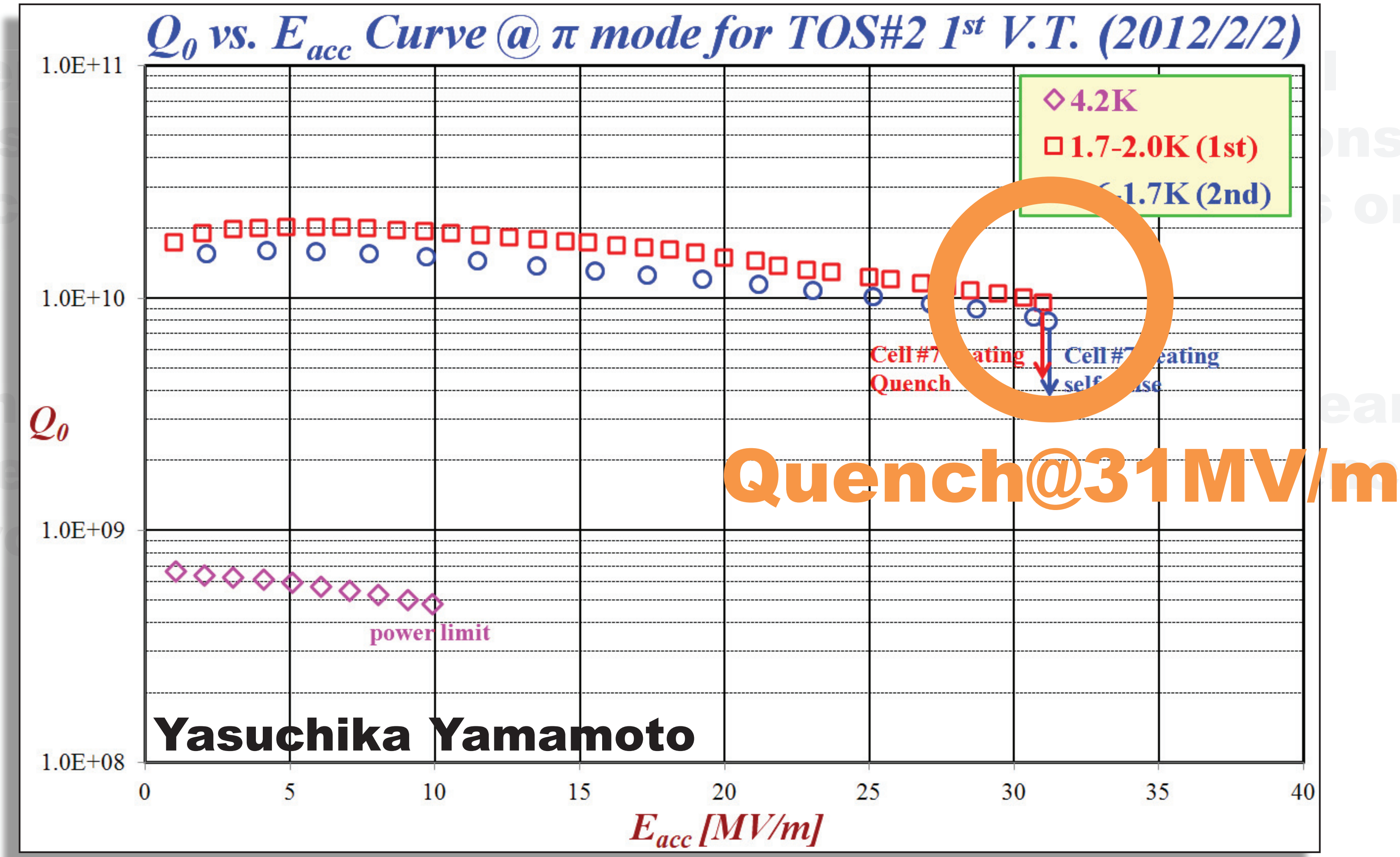
1. **Accelerating field of modern superconducting radiofrequency (SRF) cavities are often limited by quenches.**

2. **Quench locations can be identified by the temperature mapping and optical inspection system. According to these observations, poor weld is one of causes of quenches.**

3. **The above suggest that optimizing Electron beam welding (EBW) conditions might solve the quench problems.**

Introduction

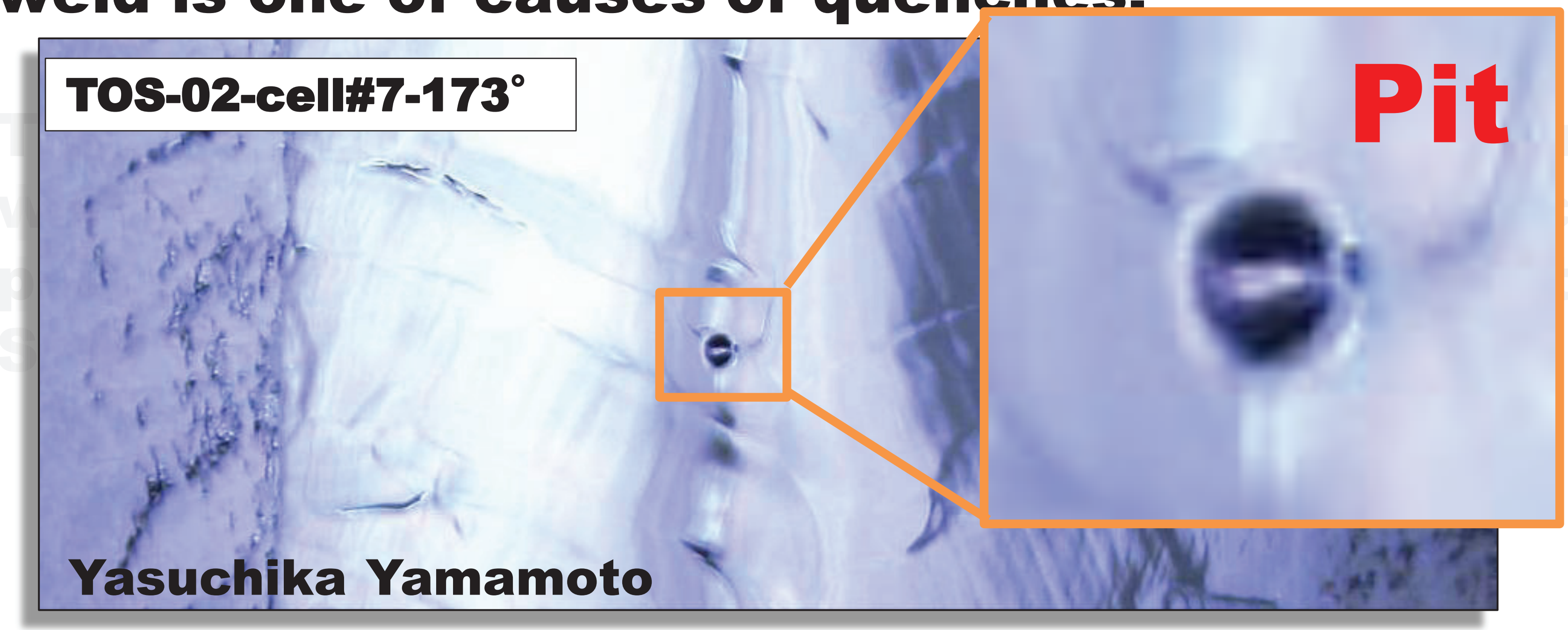
1. **Accelerating field of modern superconducting radiofrequency (SRF) cavities are often limited by quenches.**



Introduction

1. Accelerating field of modern superconducting radiofrequency (SRF) cavities are often limited by quenches.

2. Quench locations can be identified by the temperature mapping and optical inspection system. According to these observations, poor weld is one of causes of quenches.



Introduction

1. Accelerating field of modern superconducting radiofrequency (SRF) cavities are often limited by quenches.

TUP116

Quench field and Location in Vertical Tests at KEK-STF,

Yasuchika Yamamoto,

E. Kako, T. Shishido (KEK)

Introduction

1. Accelerating field of modern superconducting radiofrequency (SRF) cavities are often limited by quenches.

2. Quench locations can be identified by the temperature mapping and optical inspection system. According to these observations, poor weld is one of causes of quenches.

3. **The above suggest that optimizing Electron beam welding (EBW) conditions might solve the quench problems.**

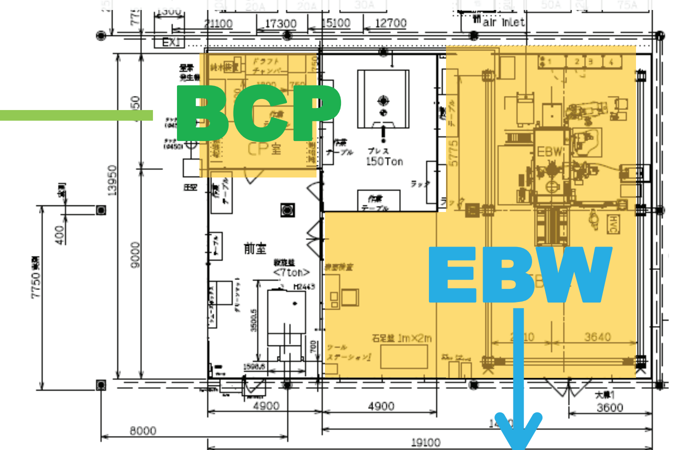
Outline

- Experiment and EBW parameters
- Typical geometries of weld beads
- Search for good parameter-regions
- Magnetic field enhancement at pits
- Summary and outlook

Experiments and parameters

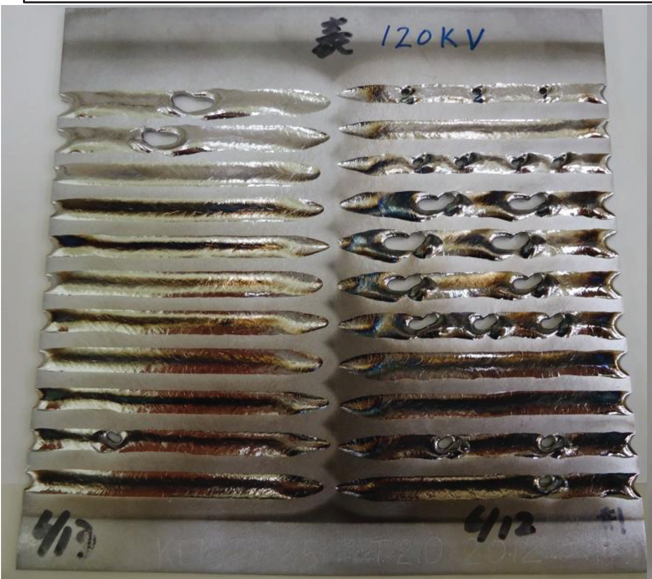
Experiment

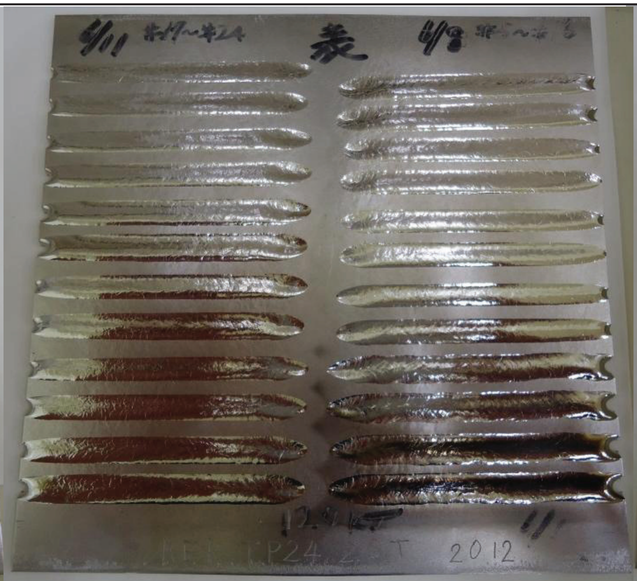
Cavity Fabrication Facility (CFF)

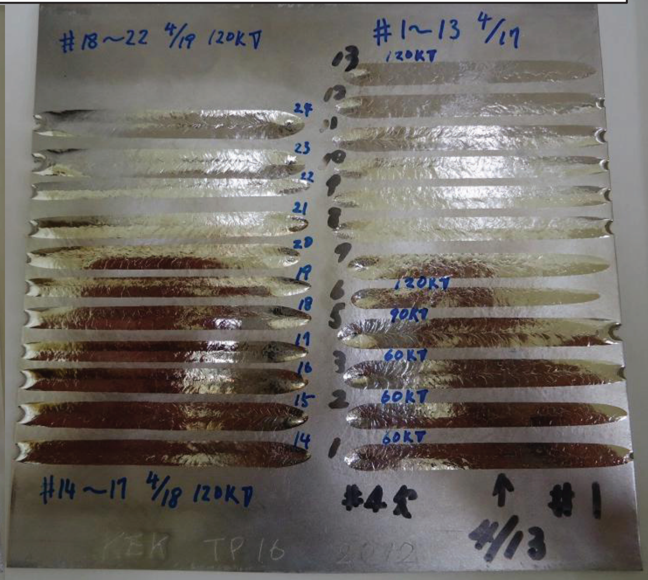


1. **Cut out Nb test-pieces (150mm × 150mm)**
2. **Pre-weld etchings (10–30µm) by 1:1:1 BCP solution.**
3. **EBW at the next room**

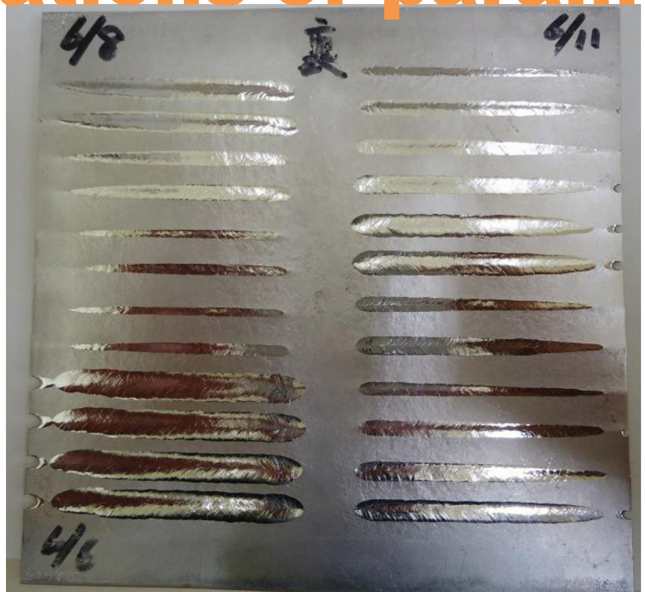
Experiment (cont.)







Examples of test pieces (heads↑ and tails↓).
Various combinations of parameters were tried



EBW parameters

1. Combinations of generator position and welding direction
2. Accelerating voltage, V_a (kV)
3. Beam current, I_b (mA)
4. Welding speed, v (mm/s)
5. a_b-factor

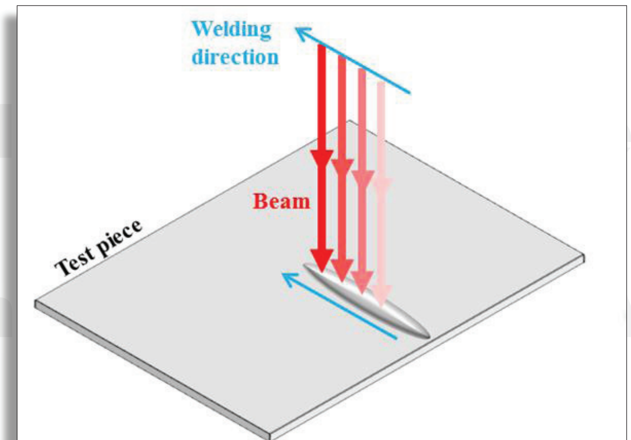
EBW parameters

1. **Combinations of generator position and welding direction**
2. **Accelerating voltage, V_a (kV)**
3. **Beam current, I_b (mA)**
4. **Welding speed, v (mm/s)**
5. **a_b-factor**

EBW parameters

1. **Combinations of beam generator position and welding direction**

(a) V-H



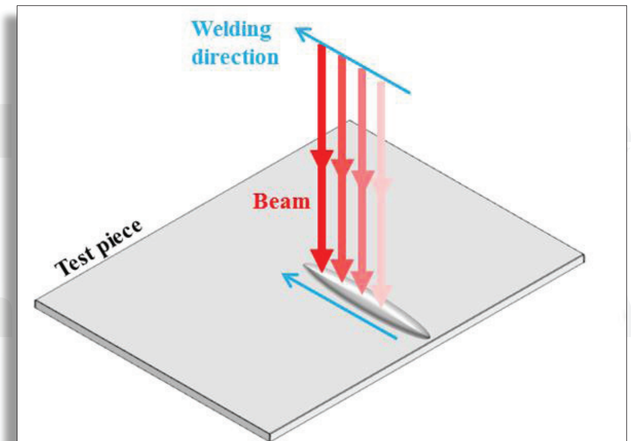
4. Welding speed, v (mm/s),

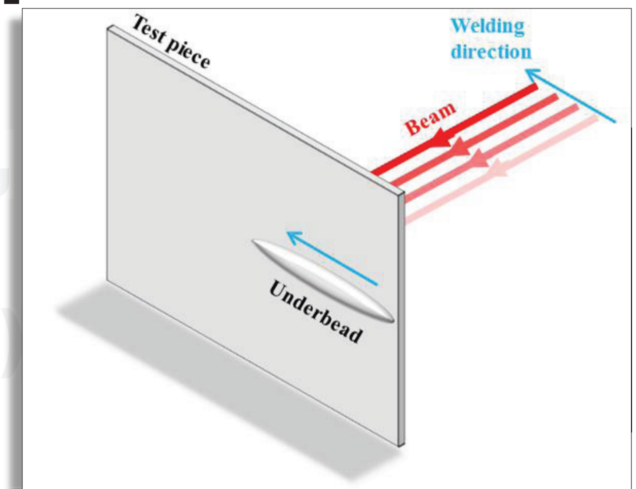
5. a_b-factor

EBW parameters

1. **Combinations of beam generator position and welding direction**

(a) V-H





(b) H-H

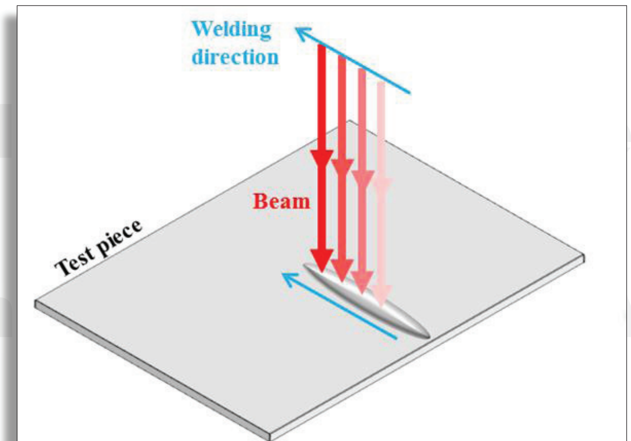
4. Welding speed, v (mm/s),

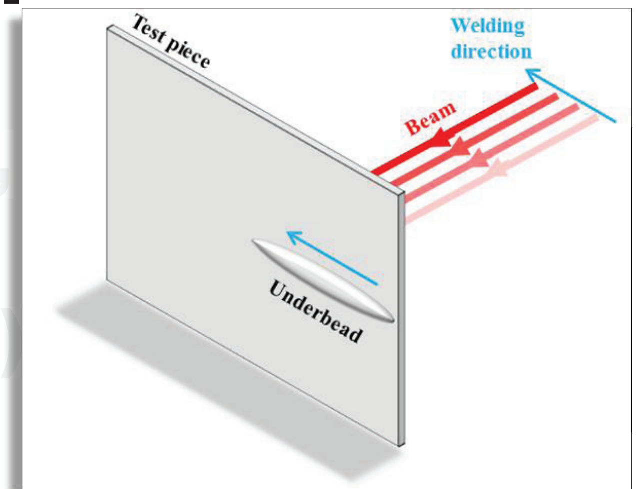
5. a_b-factor

EBW parameters

1. Combinations of beam generator position and welding direction

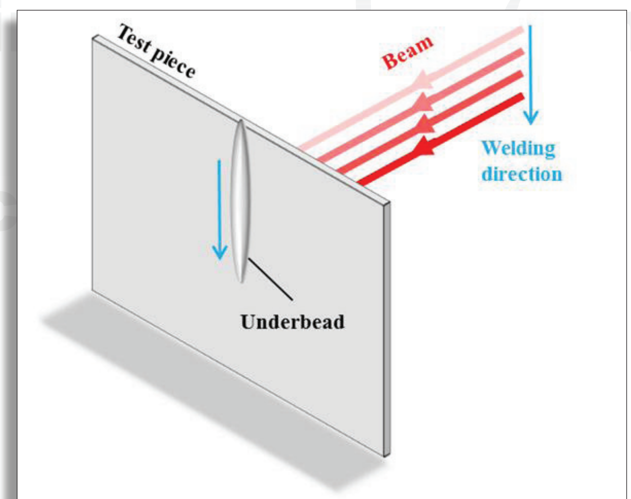
(a)
V-H





(b)
H-H

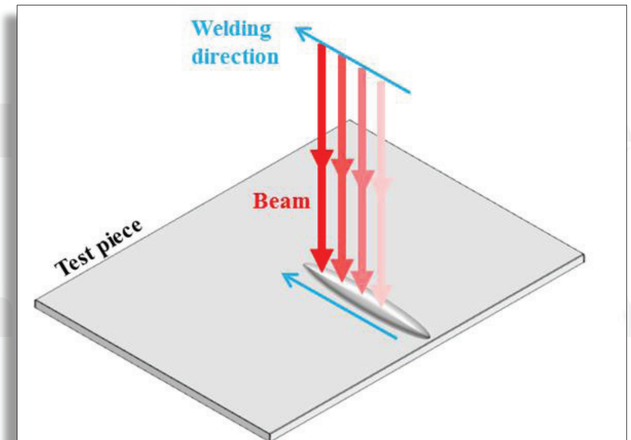
(c)
H-D



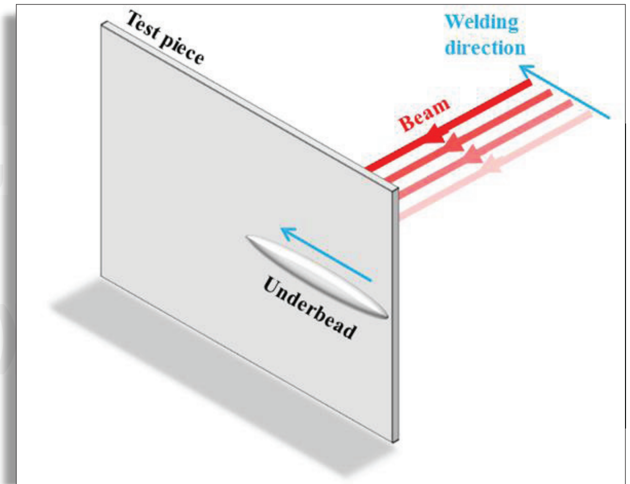
EBW parameters

1. Combinations of beam generator position and welding direction

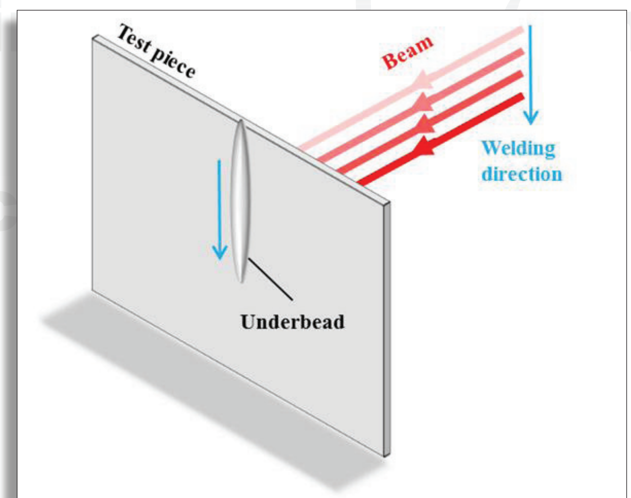
(a) V-H



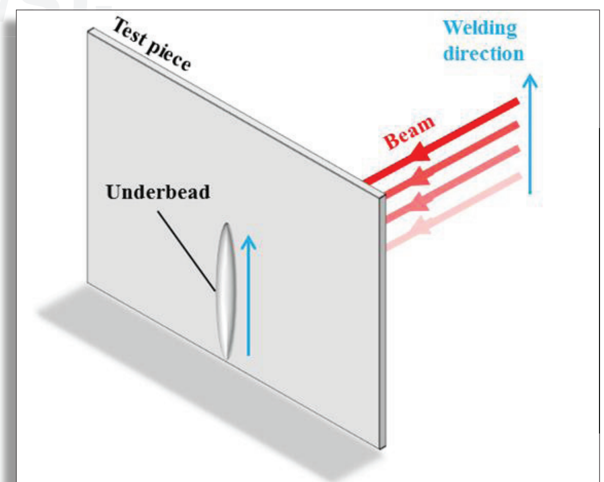
(b) H-H



(c) H-D



(d) H-U



EBW parameters

1. Combinations of beam generator position and welding direction,
2. Accelerating voltage, V_a (kV)
3. Beam current, I_b (mA)
4. Welding speed, v (mm/s)
5. a_b-factor

EBW parameters

1. Combinations of beam generator position and welding direction

2. Accelerating voltage, V_a (kV)

3. Beam current, I_b (mA)

Power

$V_a \times I_b$

4. Welding speed, v (mm/s)

5. a_b-factor

EBW parameters

1. Combinations of beam generator position and welding direction

2. Accelerating voltage, V_a (kV)

3. Beam current, I_b (mA)

4. Welding speed, v (mm/s)

Energy deposition per length $V_a I_b/v$

5. a_b-factor

EBW parameters

1. Combinations of beam generator position and welding direction
2. Accelerating voltage, V_a (kV)
3. Beam current, I_b (mA)
4. Welding speed, v (mm/s)
5. a_b-factor

EBW parameters

1.Combin
welding

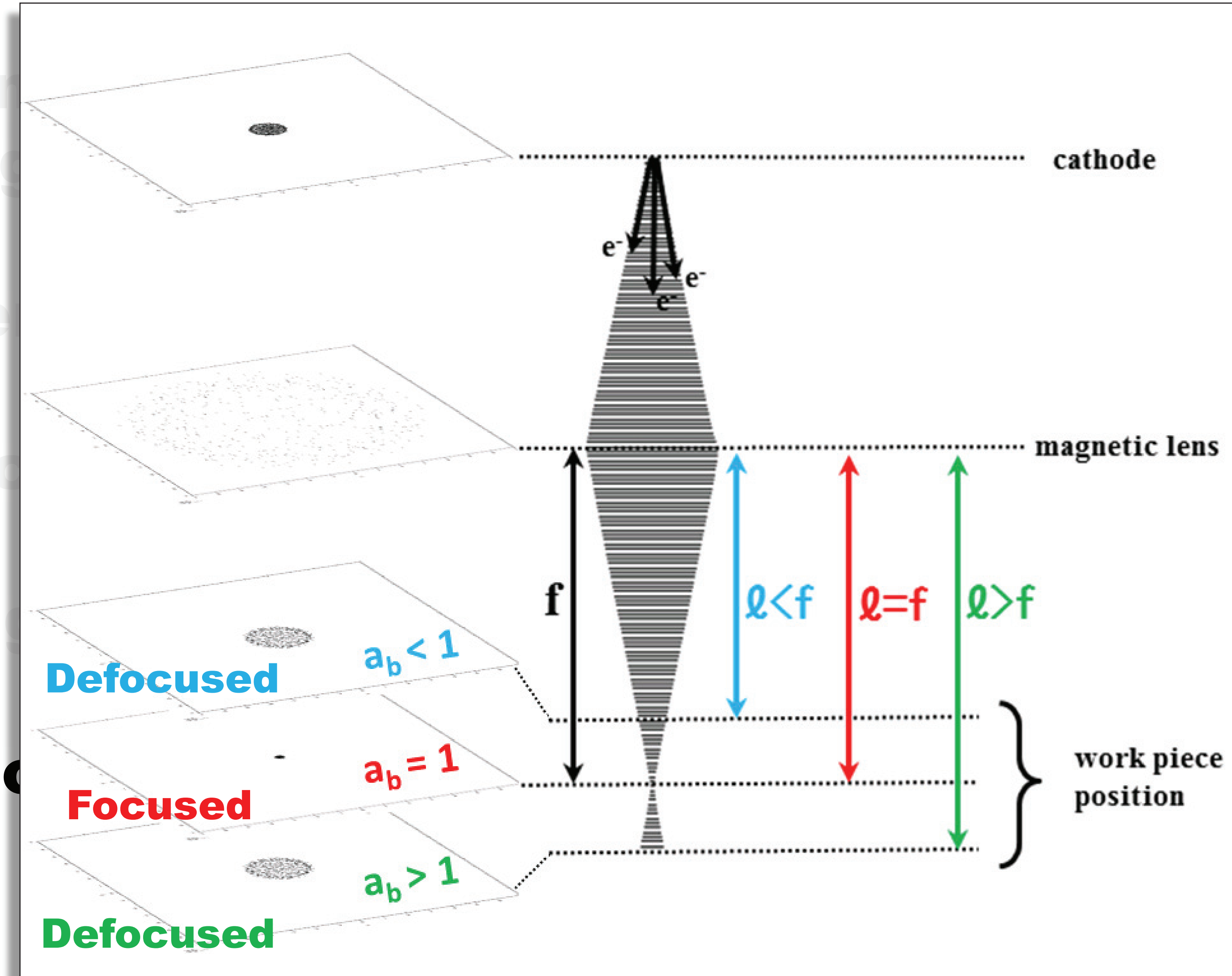
2.Accele

3.Beam c

4.Welding

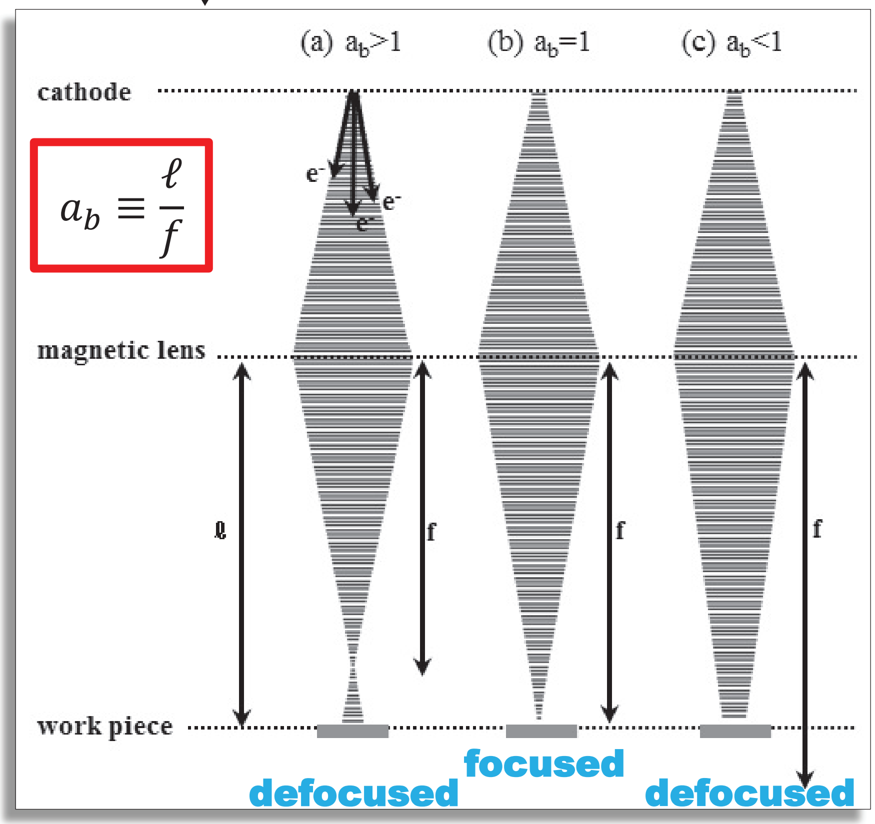
5.a_b-facto

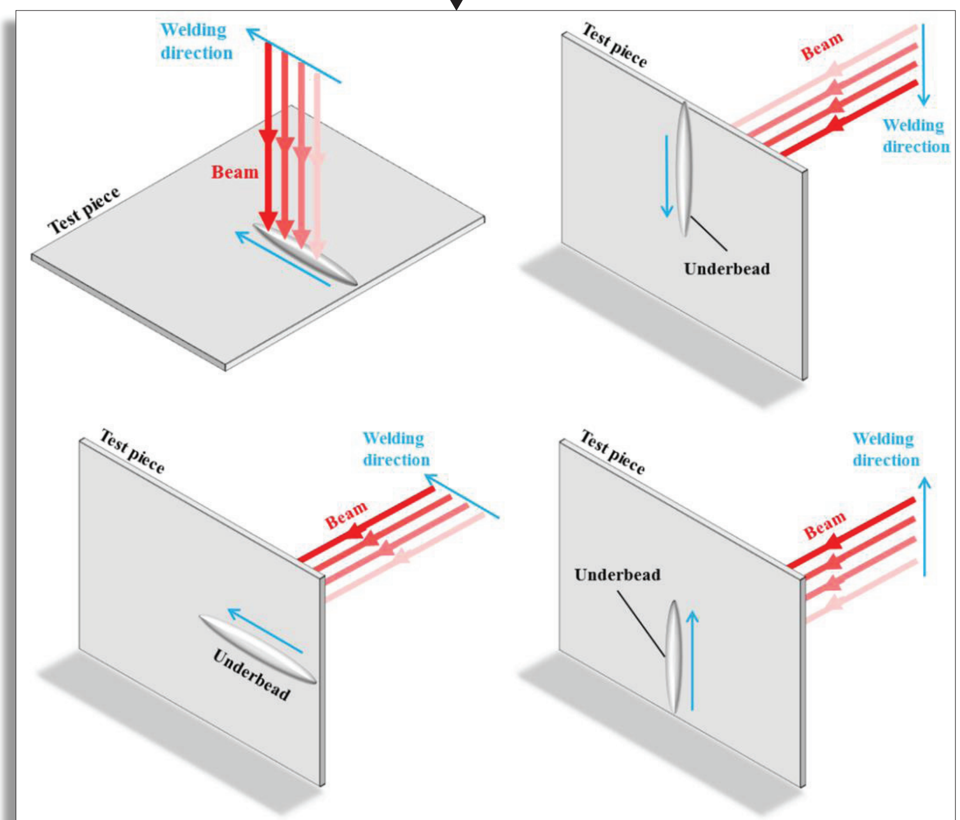
$$\boxed{a_b \equiv \frac{\ell}{f}}$$



EBW parameters

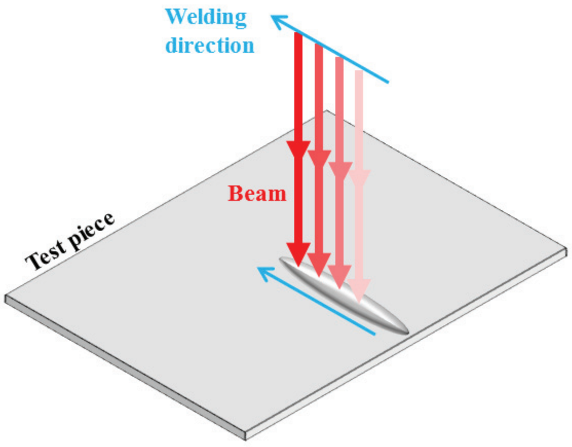
1. Combinations of generator and welding direction,
2. Accelerating voltage, V_a (kV),
3. Beam current, I_b (mA),
4. Welding speed, v (mm/s),
5. a_b-factor





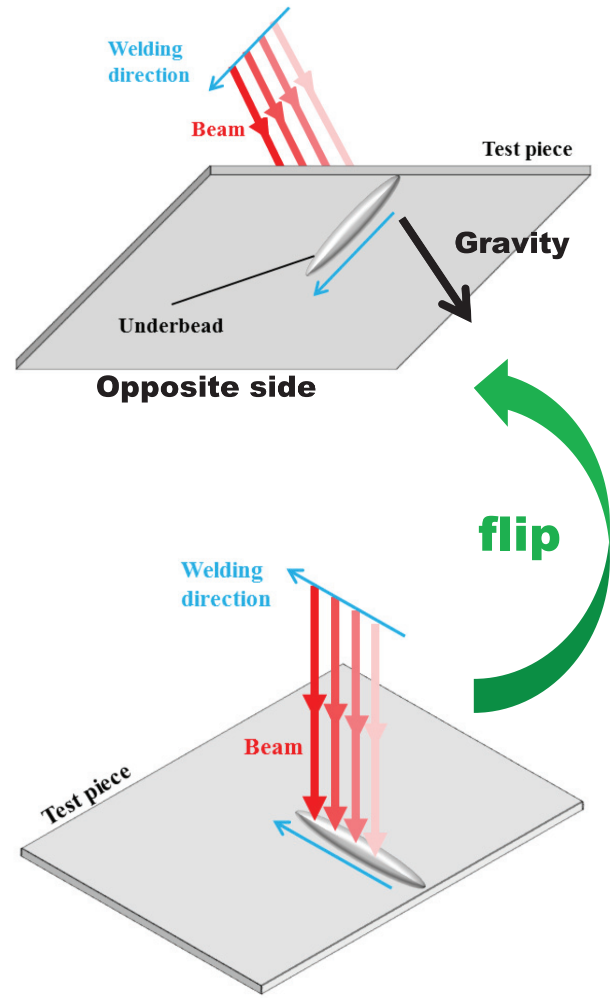
Typical geometries of weld beads

Underbead geometry (case (a): V-H)



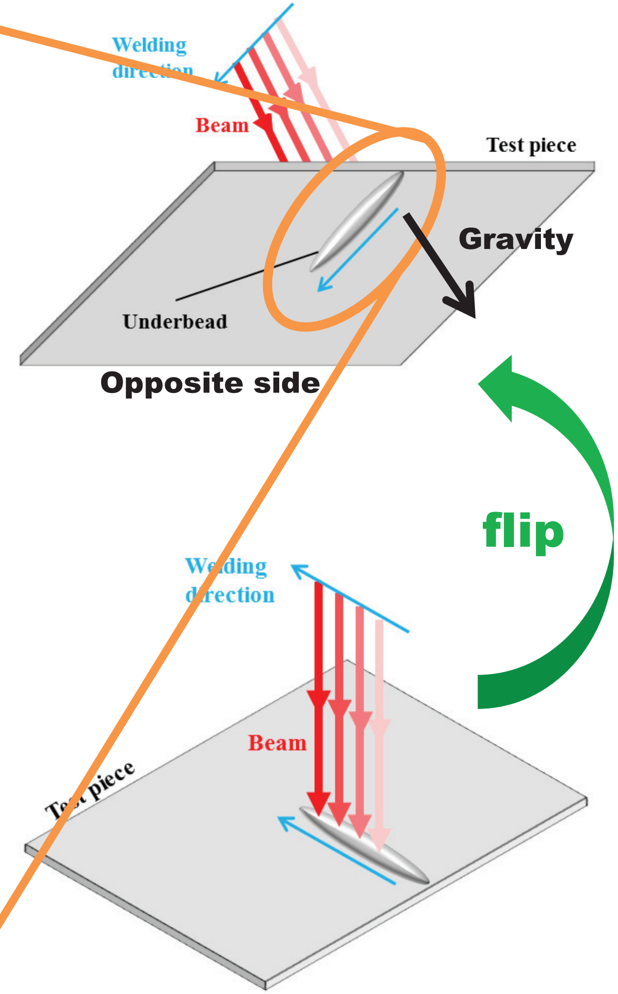
Case (a)
Vertical gun direction and
Horizontal welding direction.

Underbead geometry (case (a): V-H)



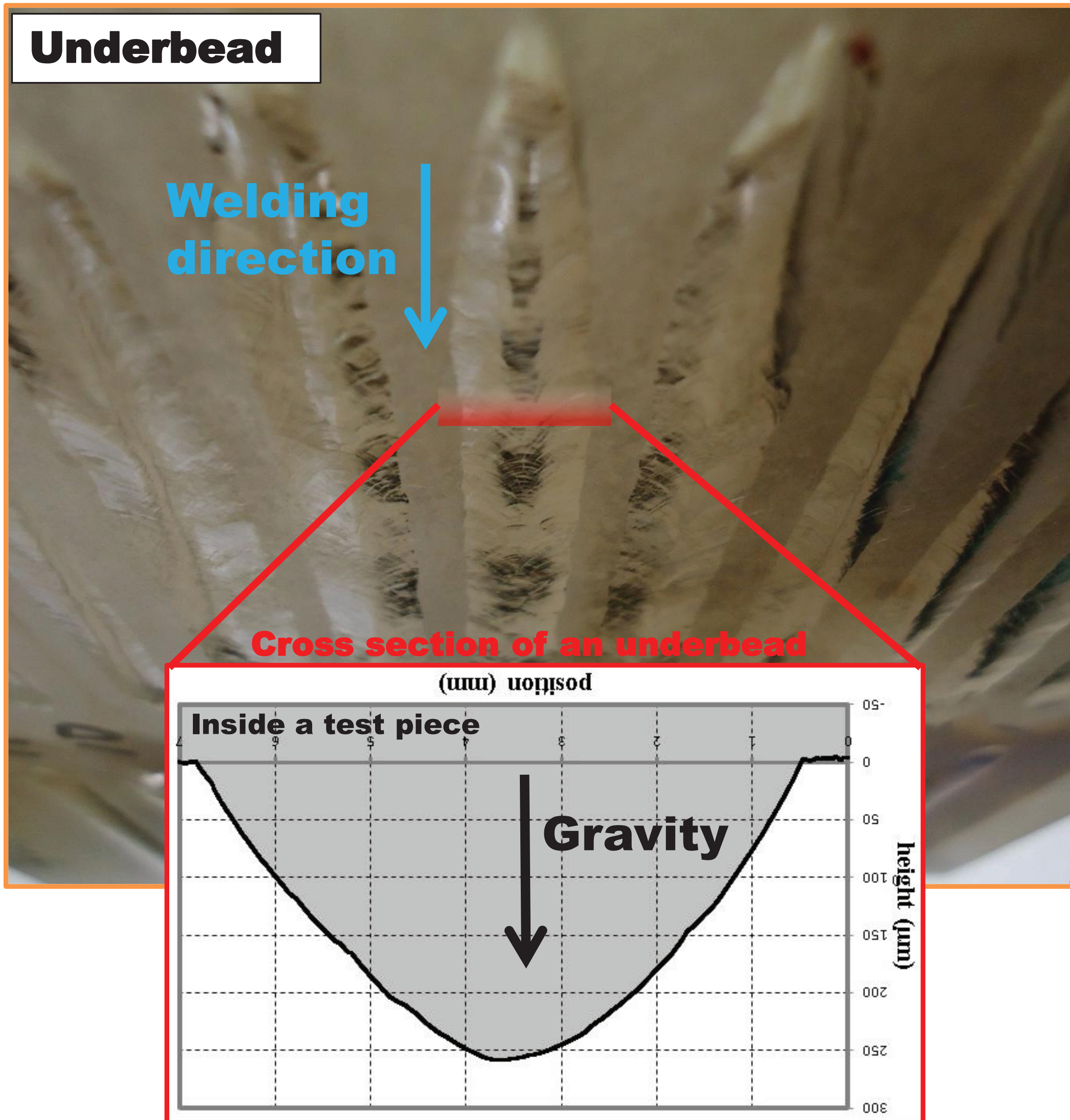
Case (a)
Vertical gun direction and
Horizontal welding direction.

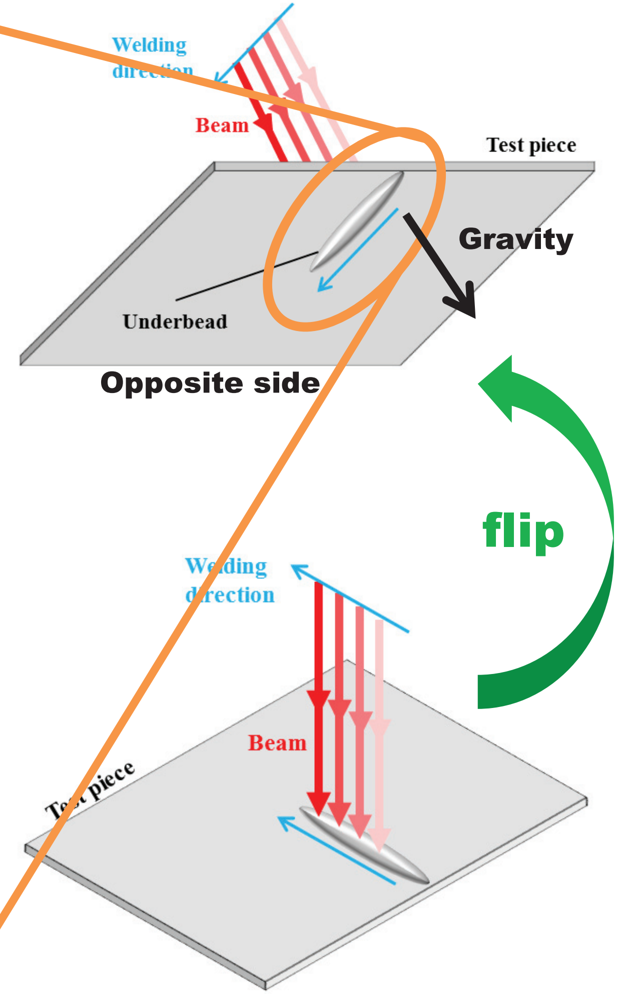
Underbead geometry (case (a): V-H)



Case (a)
Vertical gun direction and
Horizontal welding direction.

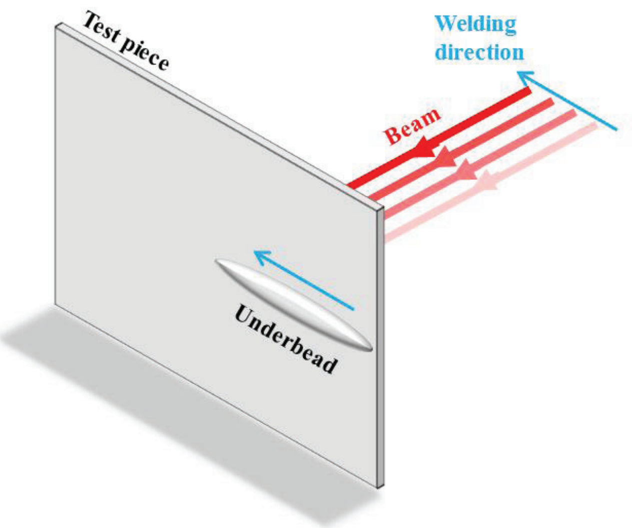
Underbead geometry (case (a): V-H)





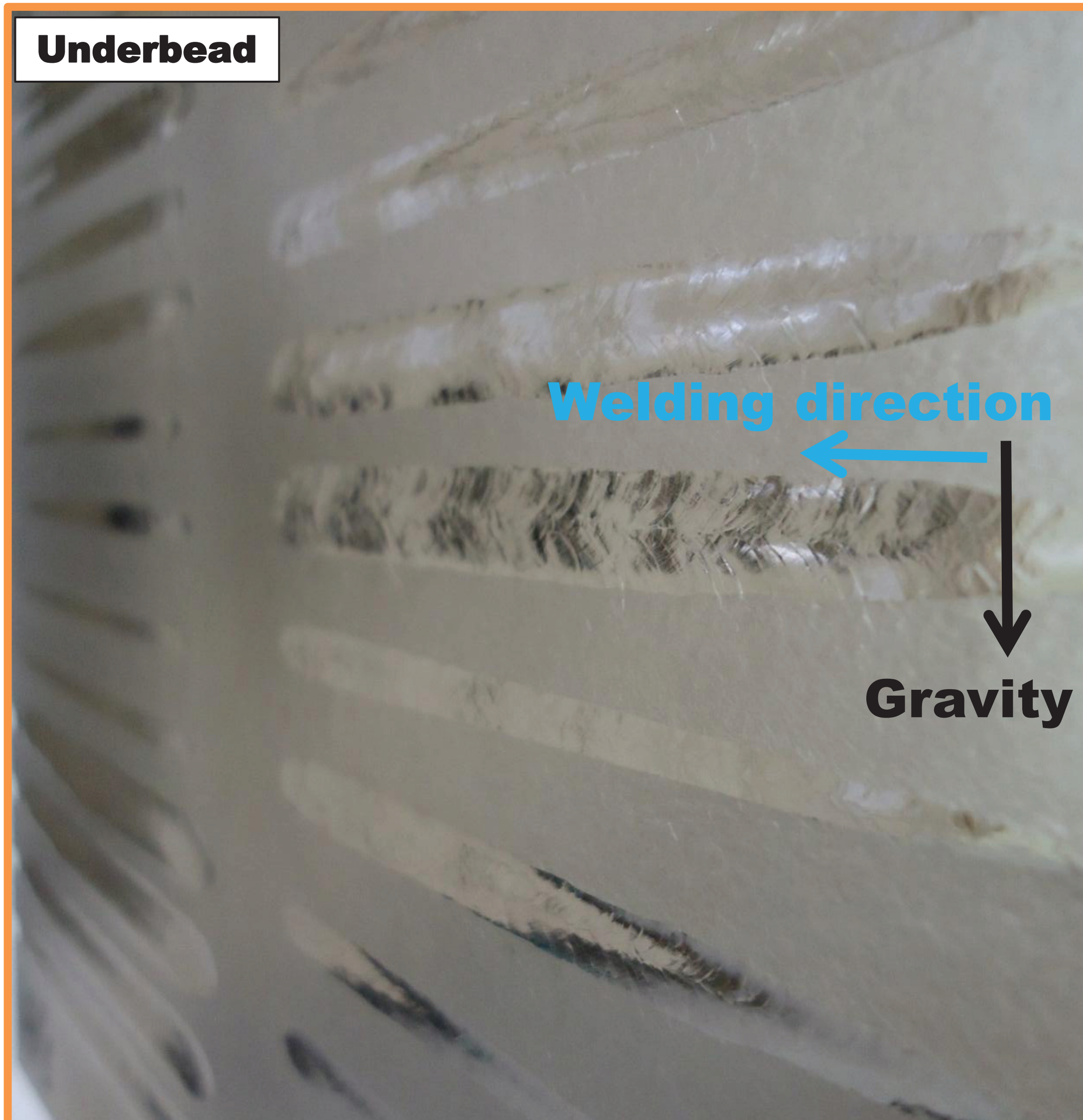
Case (a)
Vertical gun direction and
Horizontal welding direction.

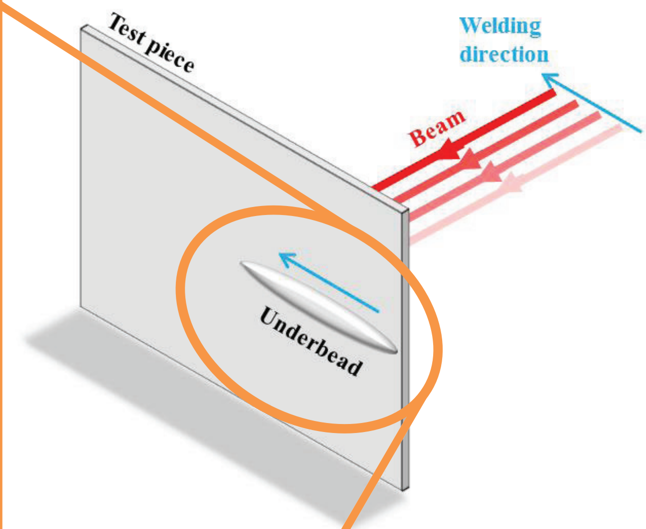
Underbead geometry (case (b): H-H)



Case (b)
Horizontal gun direction and
Horizontal welding direction.

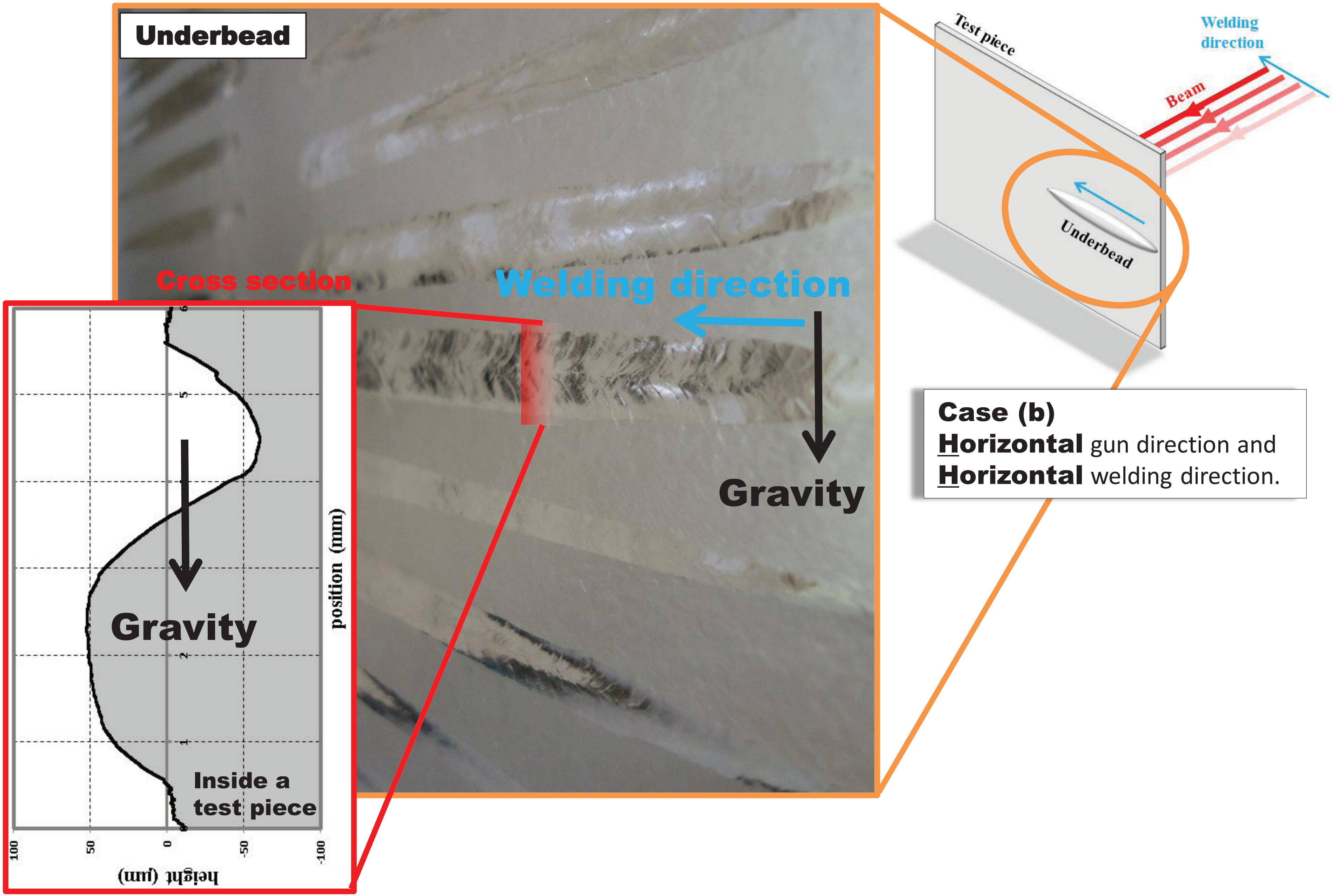
Underbead geometry (case (b): H-H)





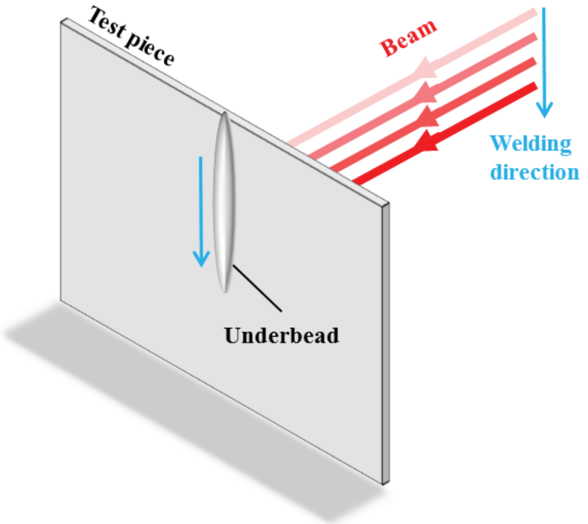
Case (b)
Horizontal gun direction and
Horizontal welding direction.

Underbead geometry (case (b): H-H)



Case (b)
Horizontal gun direction and
Horizontal welding direction.

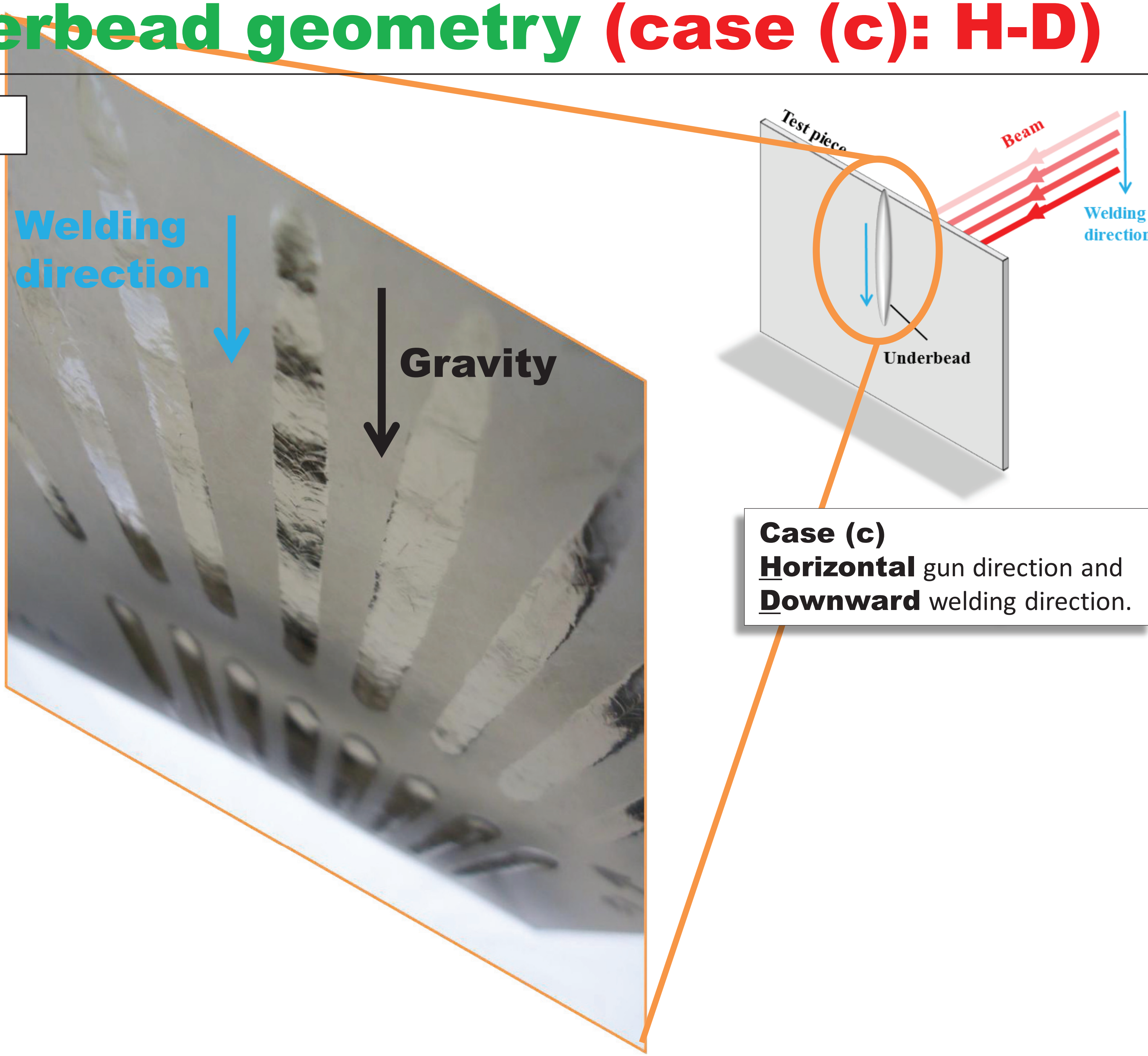
Underbead geometry (case (c): H-D)



Case (c)
Horizontal gun direction and
Downward welding direction.

Underbead geometry (case (c): H-D)

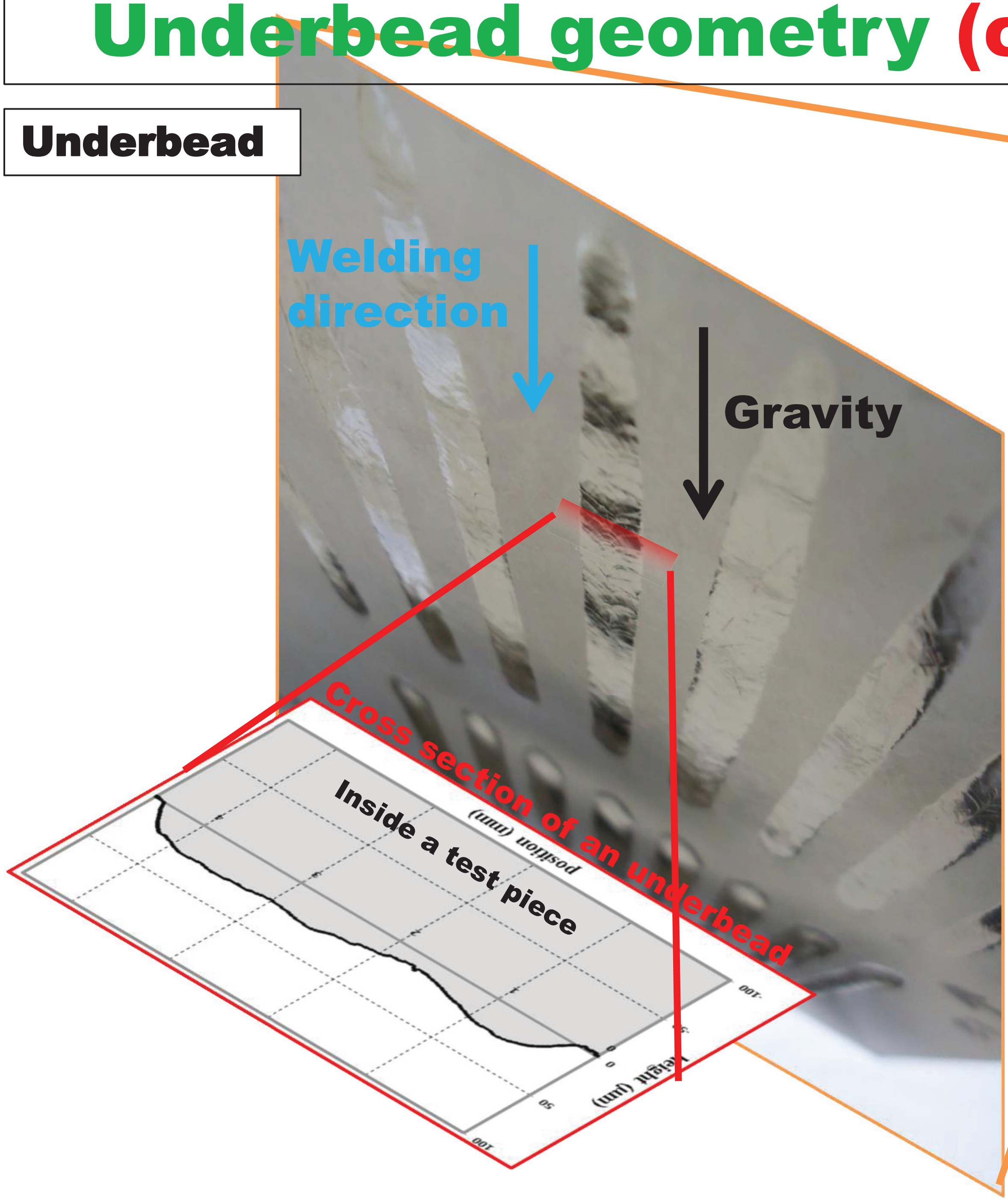
Underbead

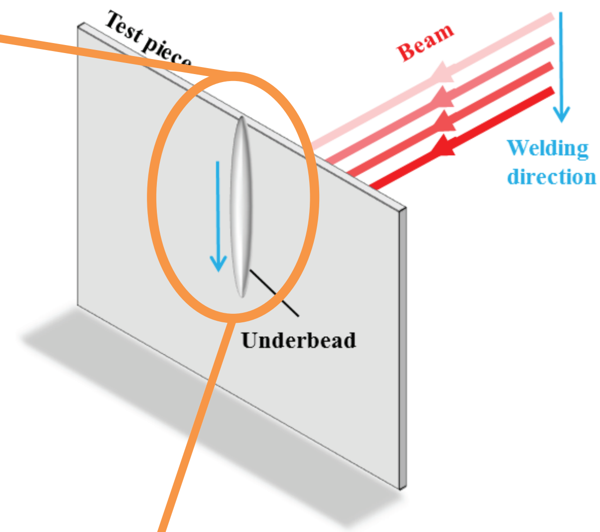


Case (c)
Horizontal gun direction and
Downward welding direction.

Underbead geometry (case (c): H-D)

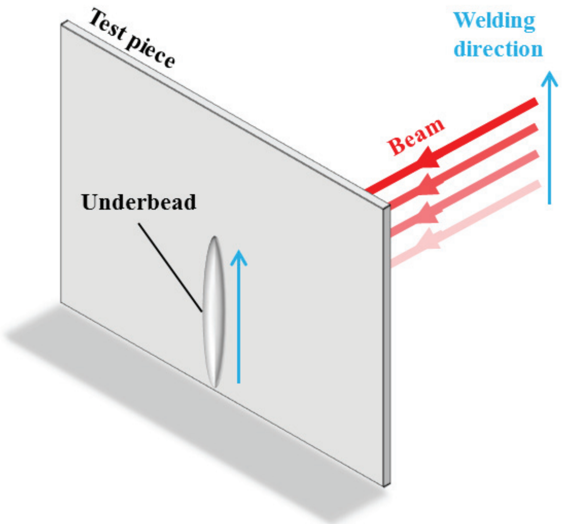
Underbead





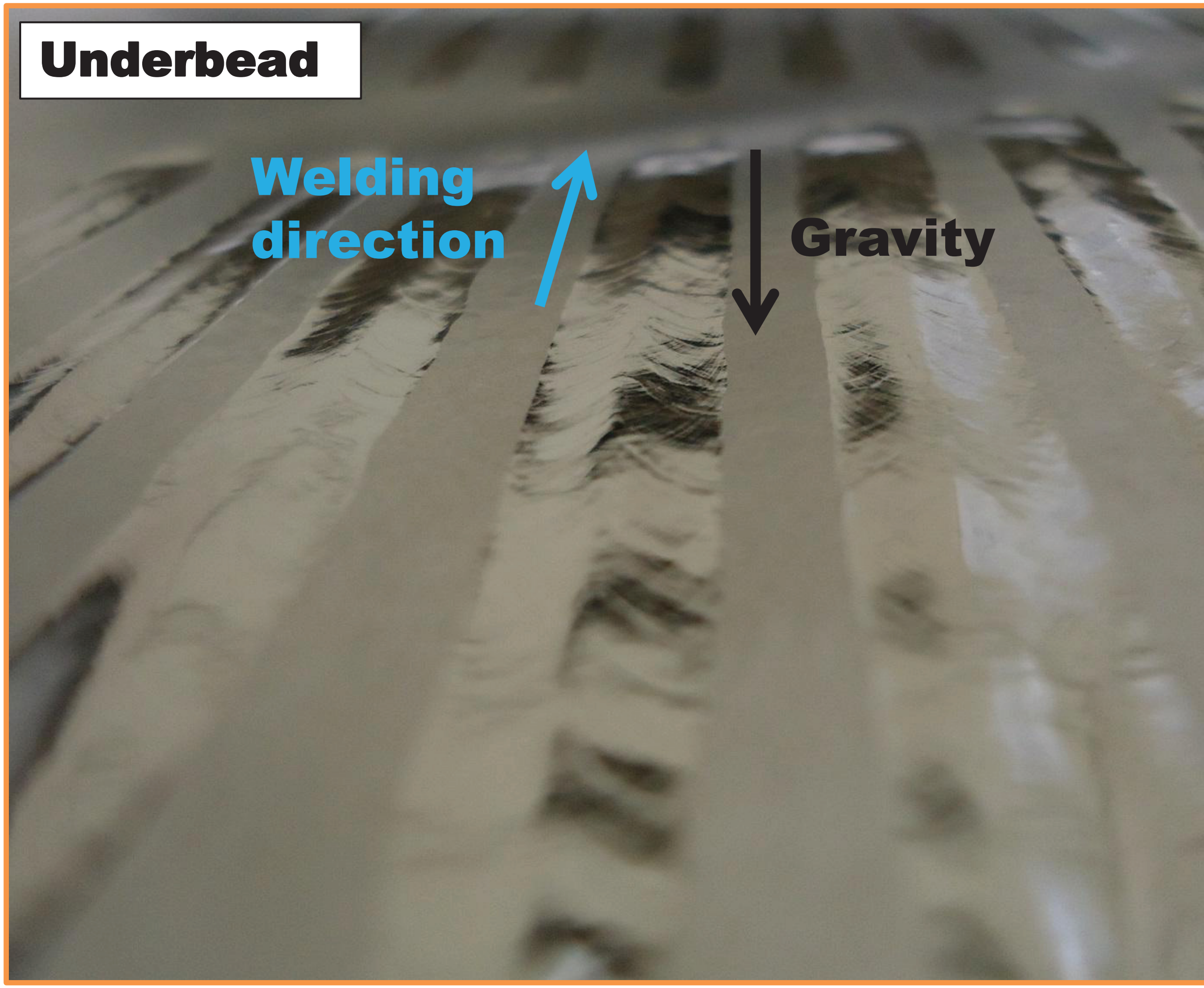
Case (c)
Horizontal gun direction and
Downward welding direction.

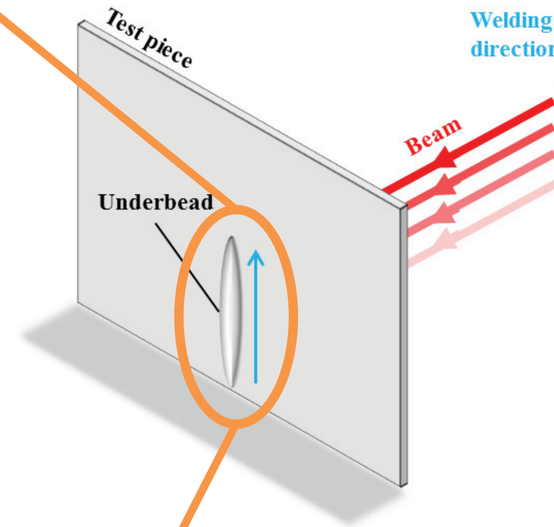
Underbead geometry (case (d): H-U)



Case (d)
Horizontal gun direction and
Upward welding direction.

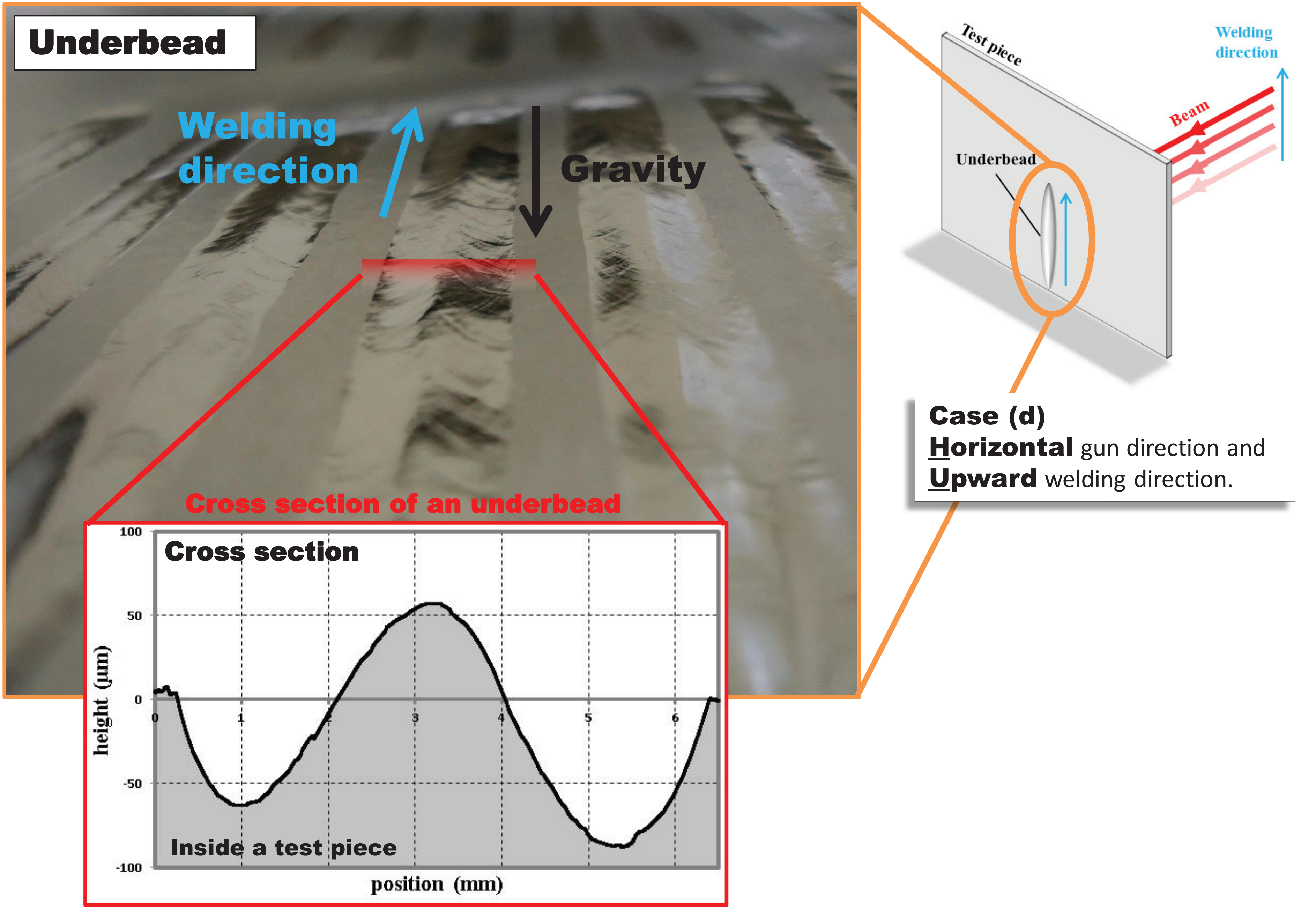
Underbead geometry (case (d): H-U)



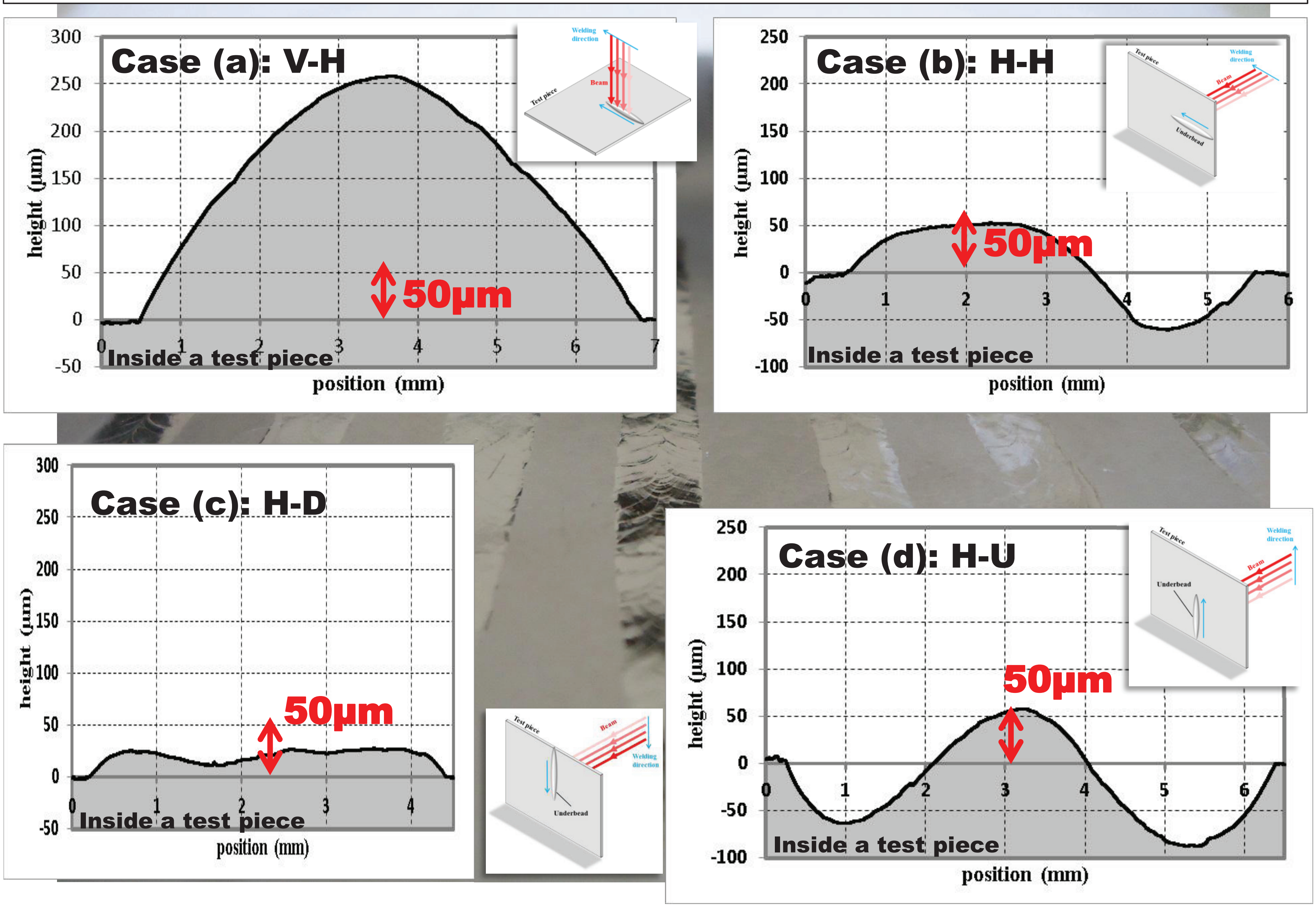


Case (d)
<u>H</u>orizontal gun direction and
<u>U</u>pward welding direction.

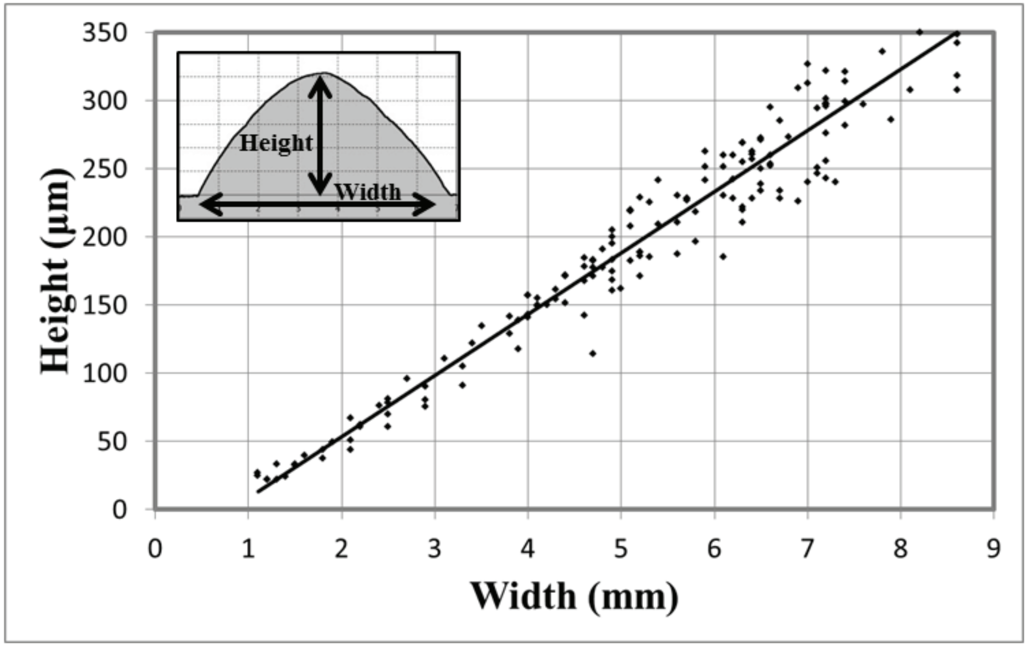
Underbead geometry (case (d): H-U)

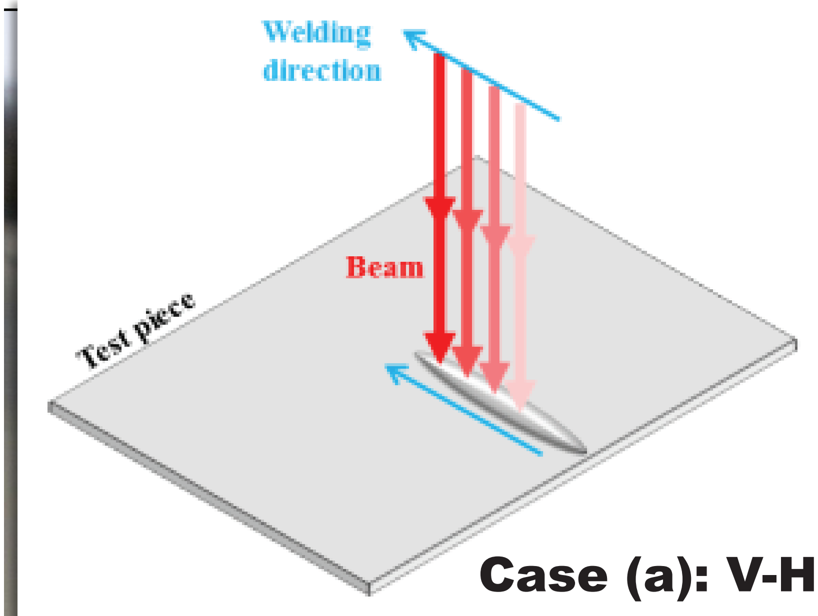


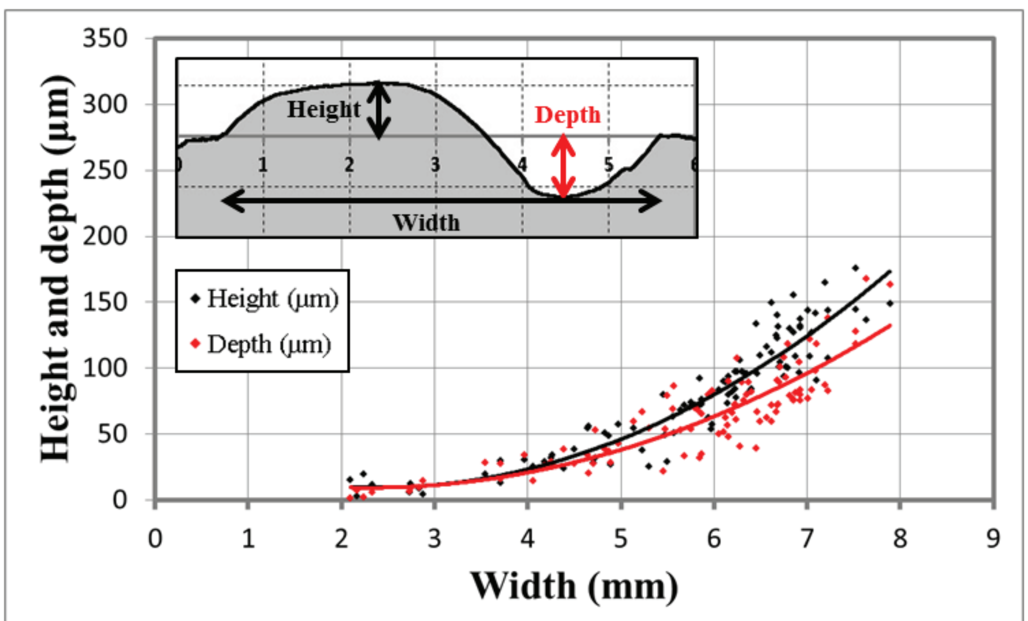
Underbead geometry

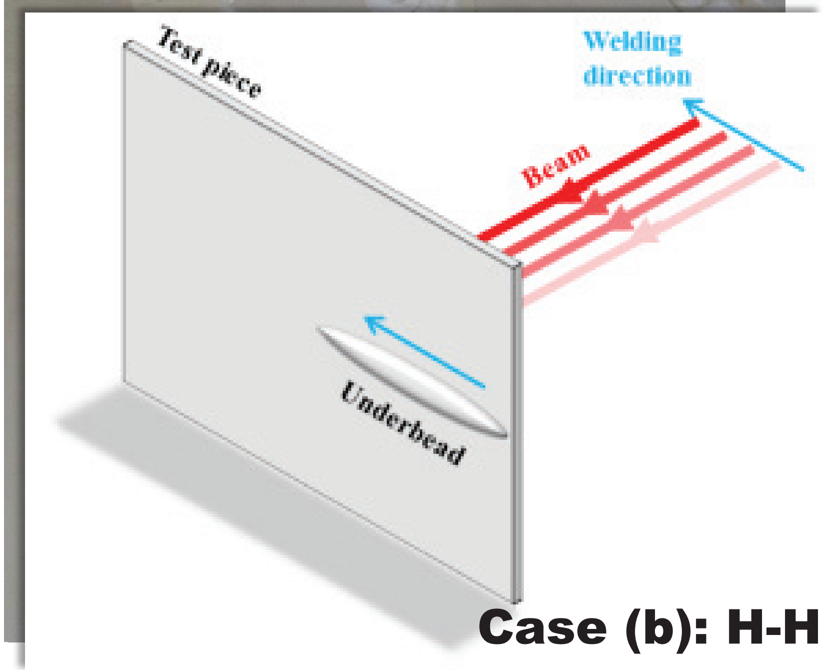


Underbead geometry



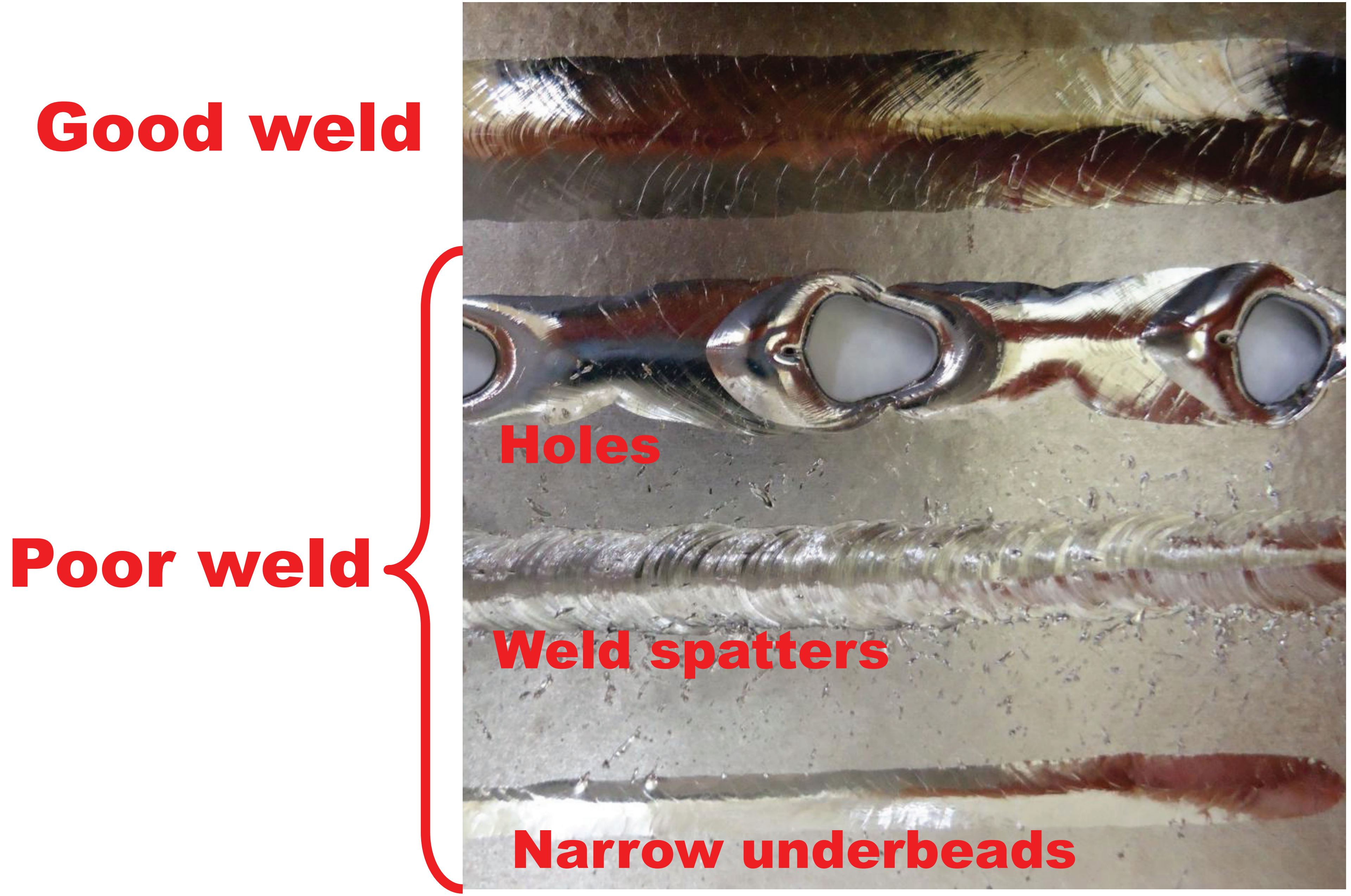




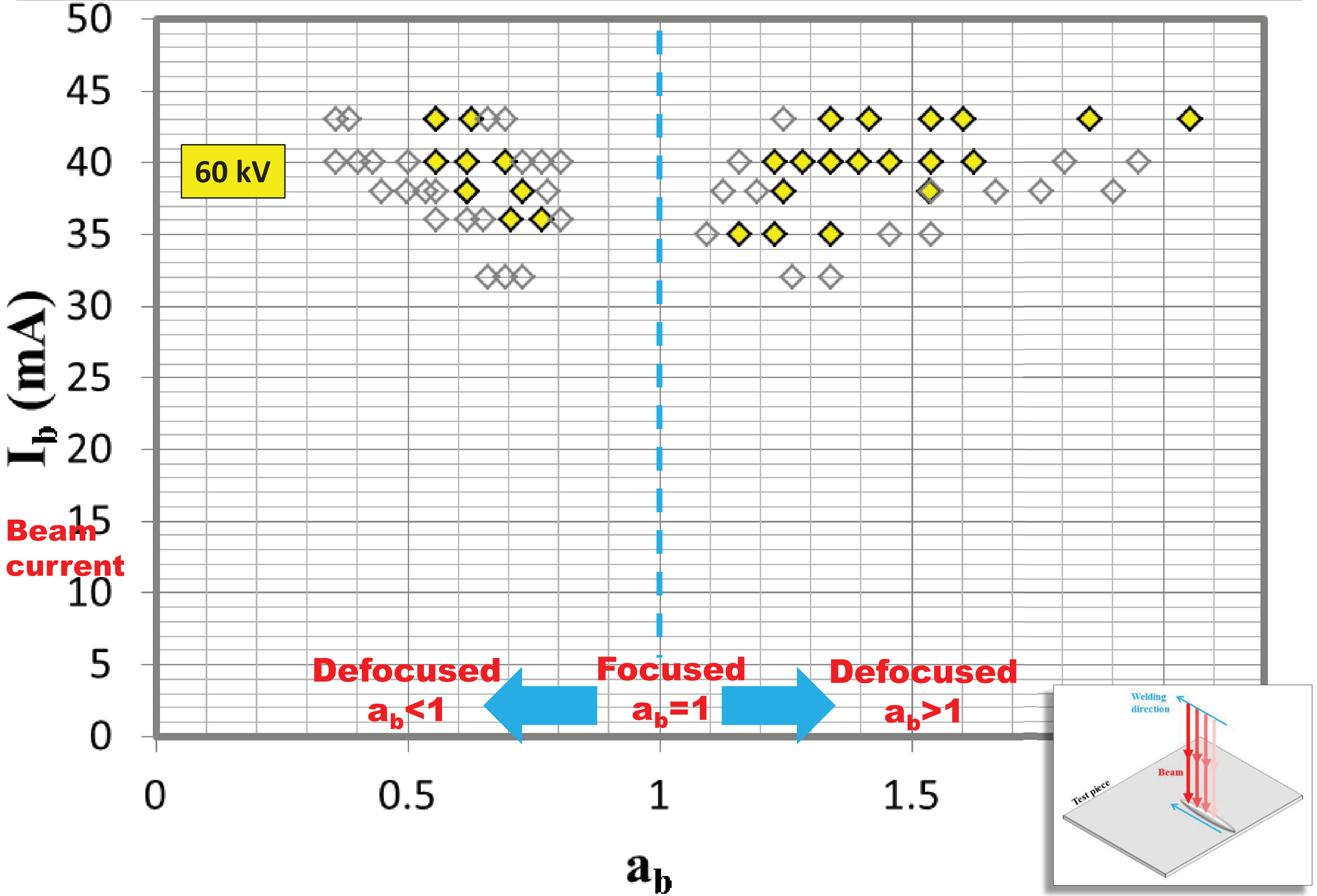


Search for good parameter-regions

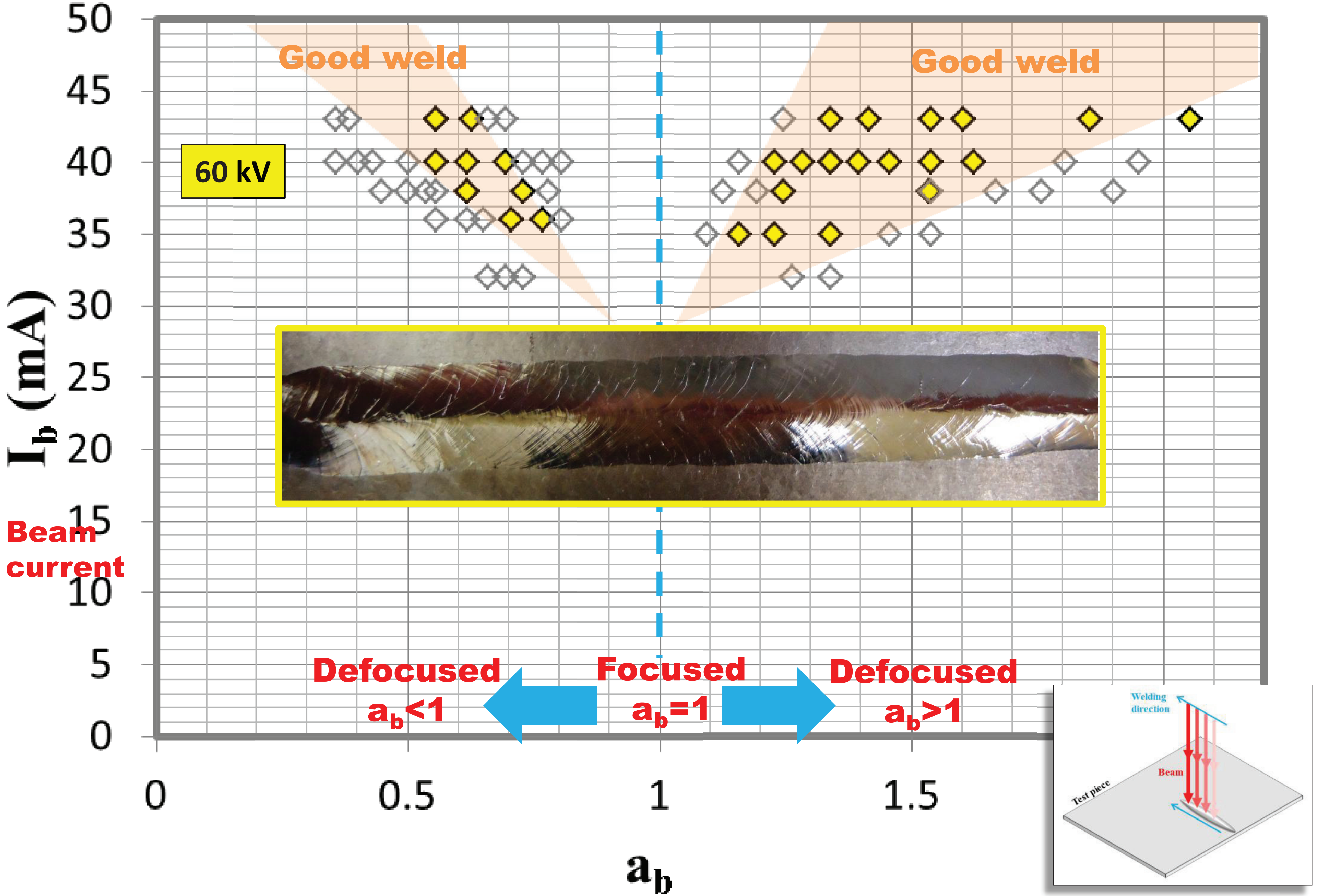
Examples of underbeads



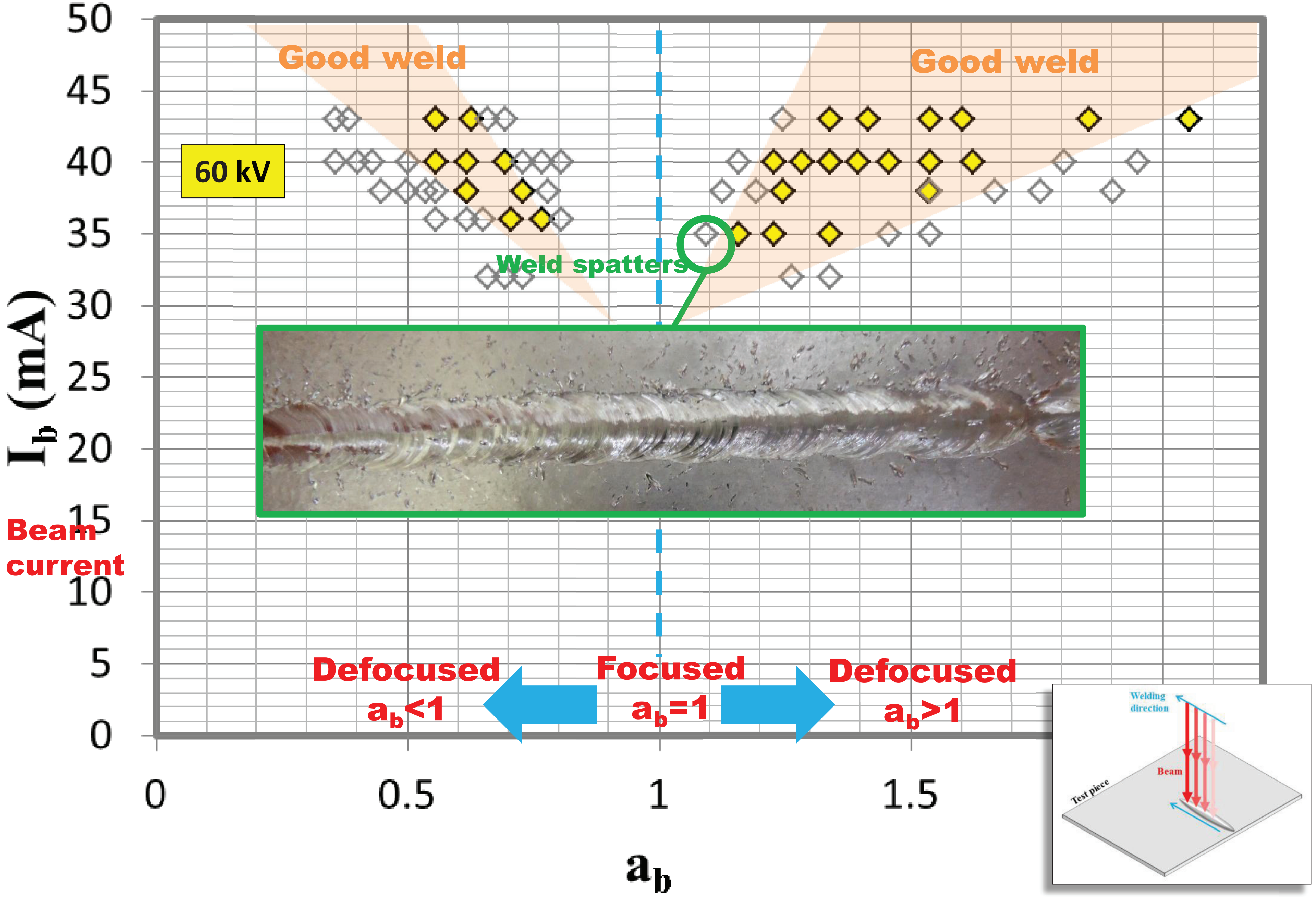
Good parameter-regions



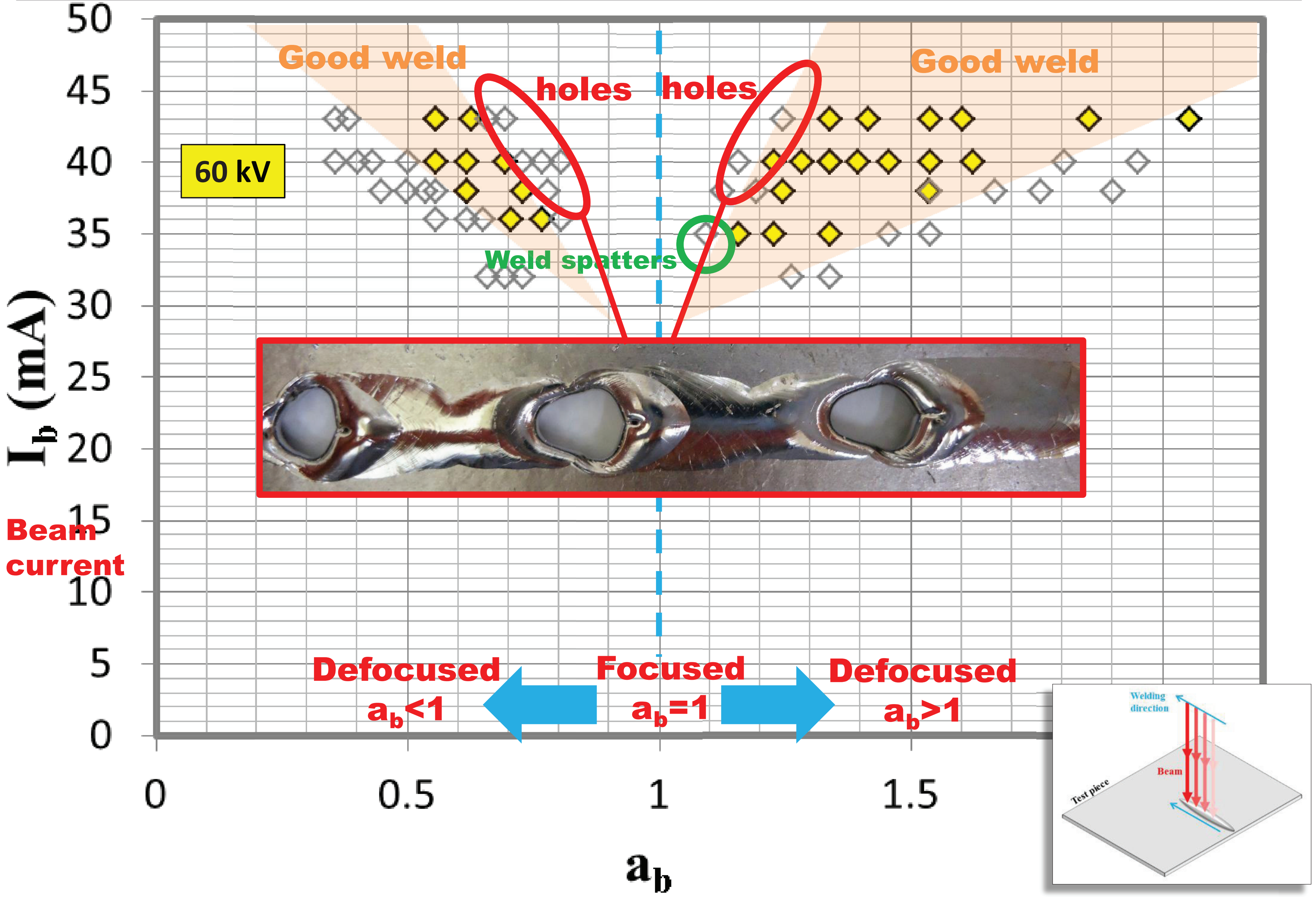
Good parameter-regions



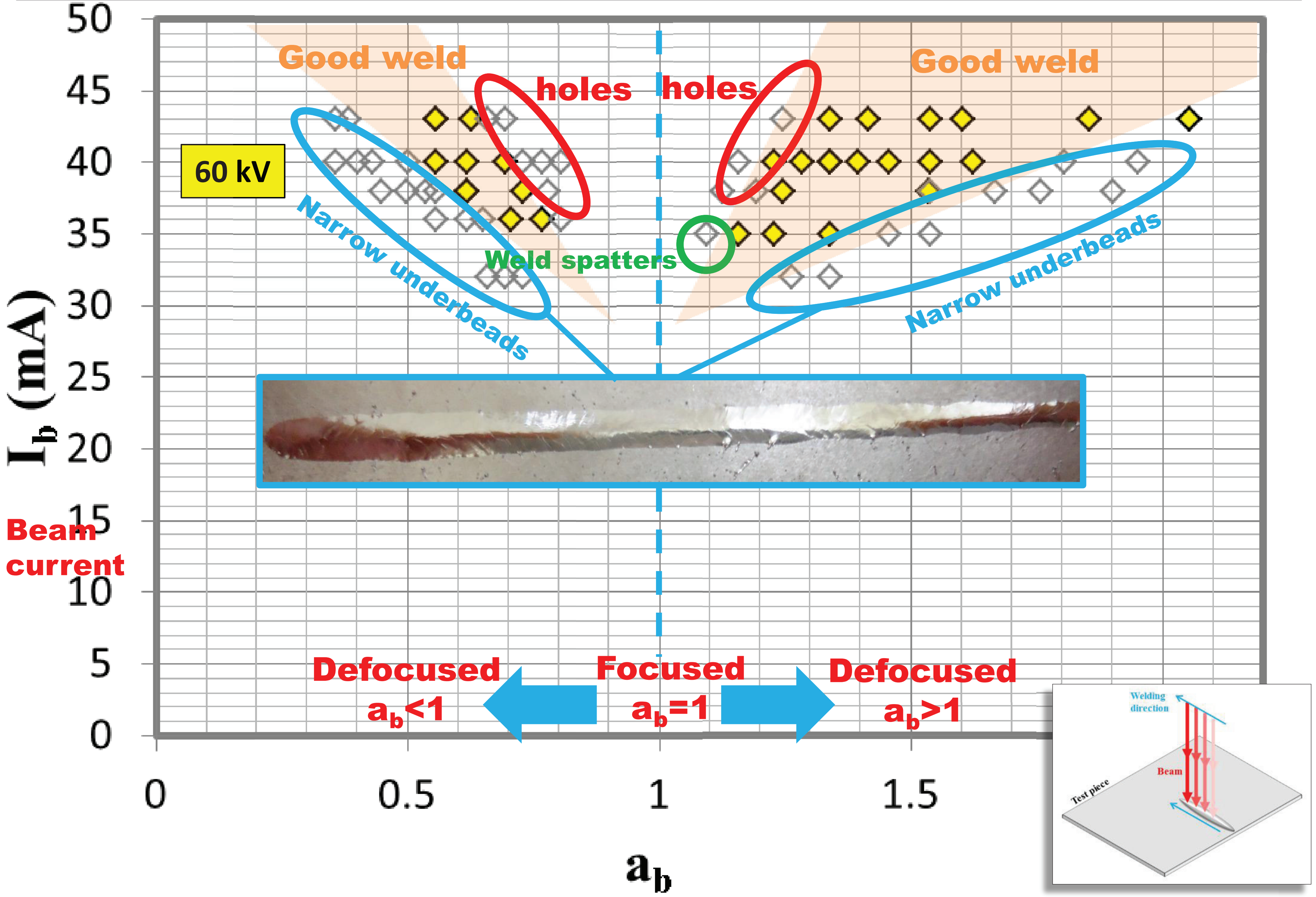
Good parameter-regions



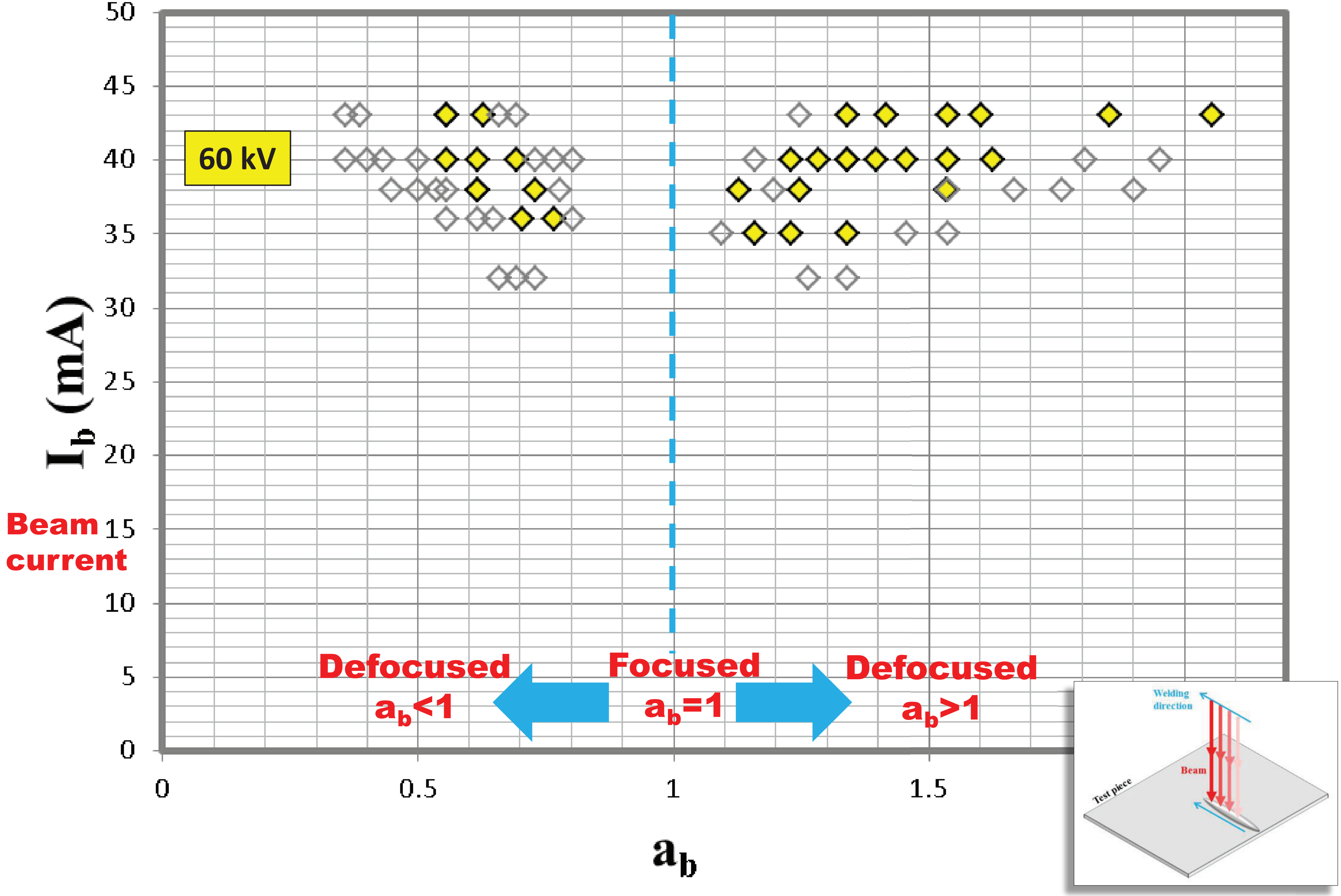
Good parameter-regions



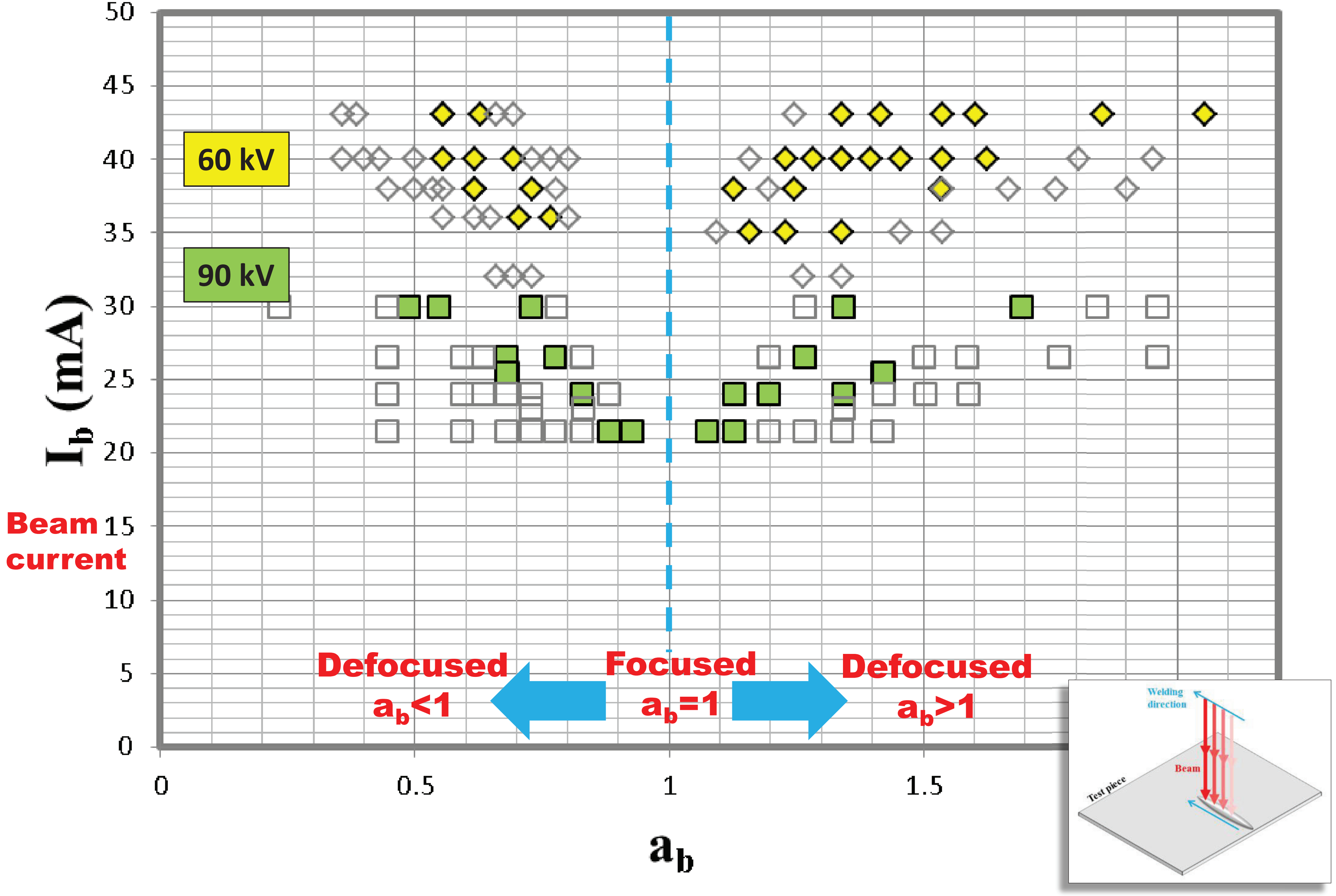
Good parameter-regions



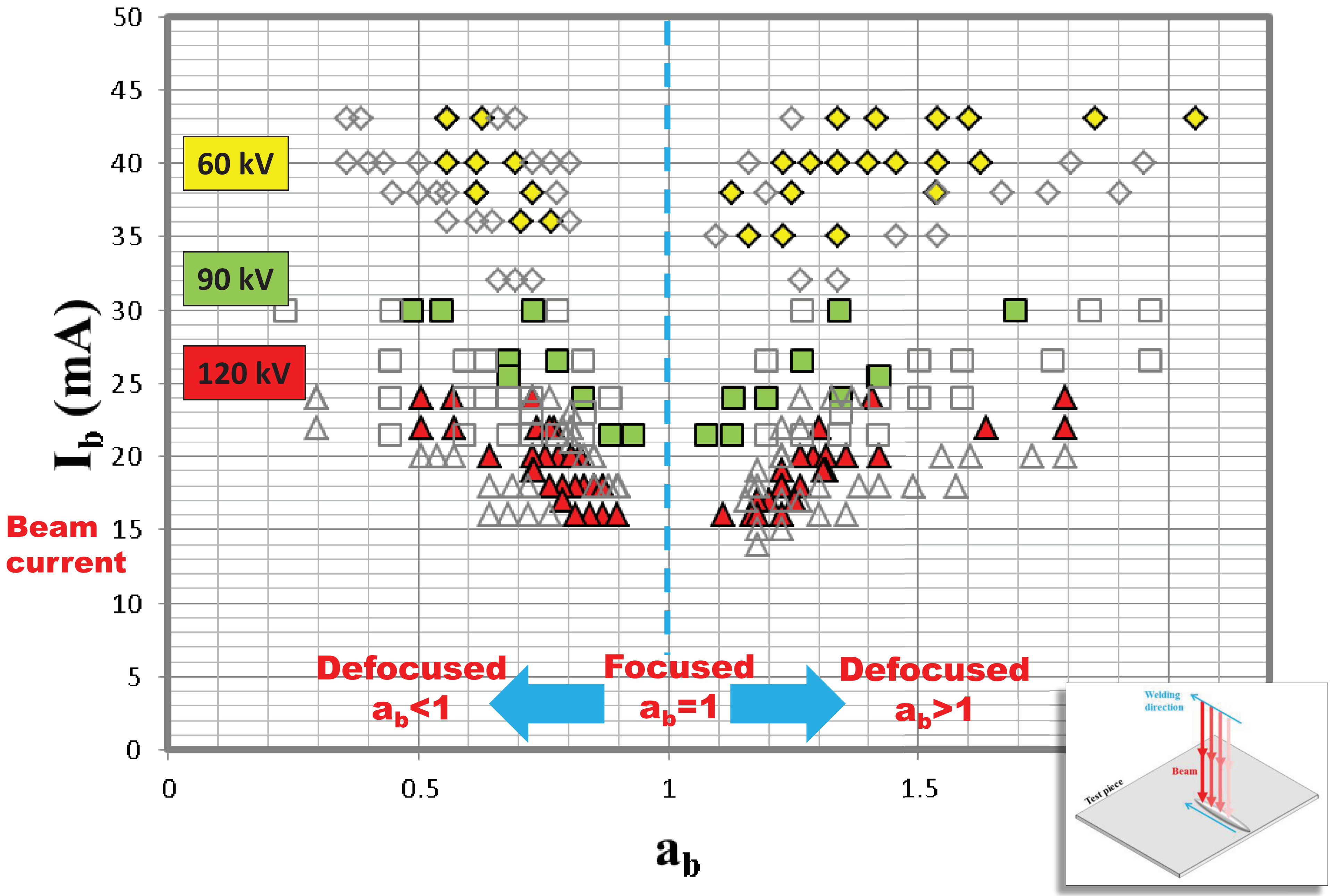
Good parameter-regions



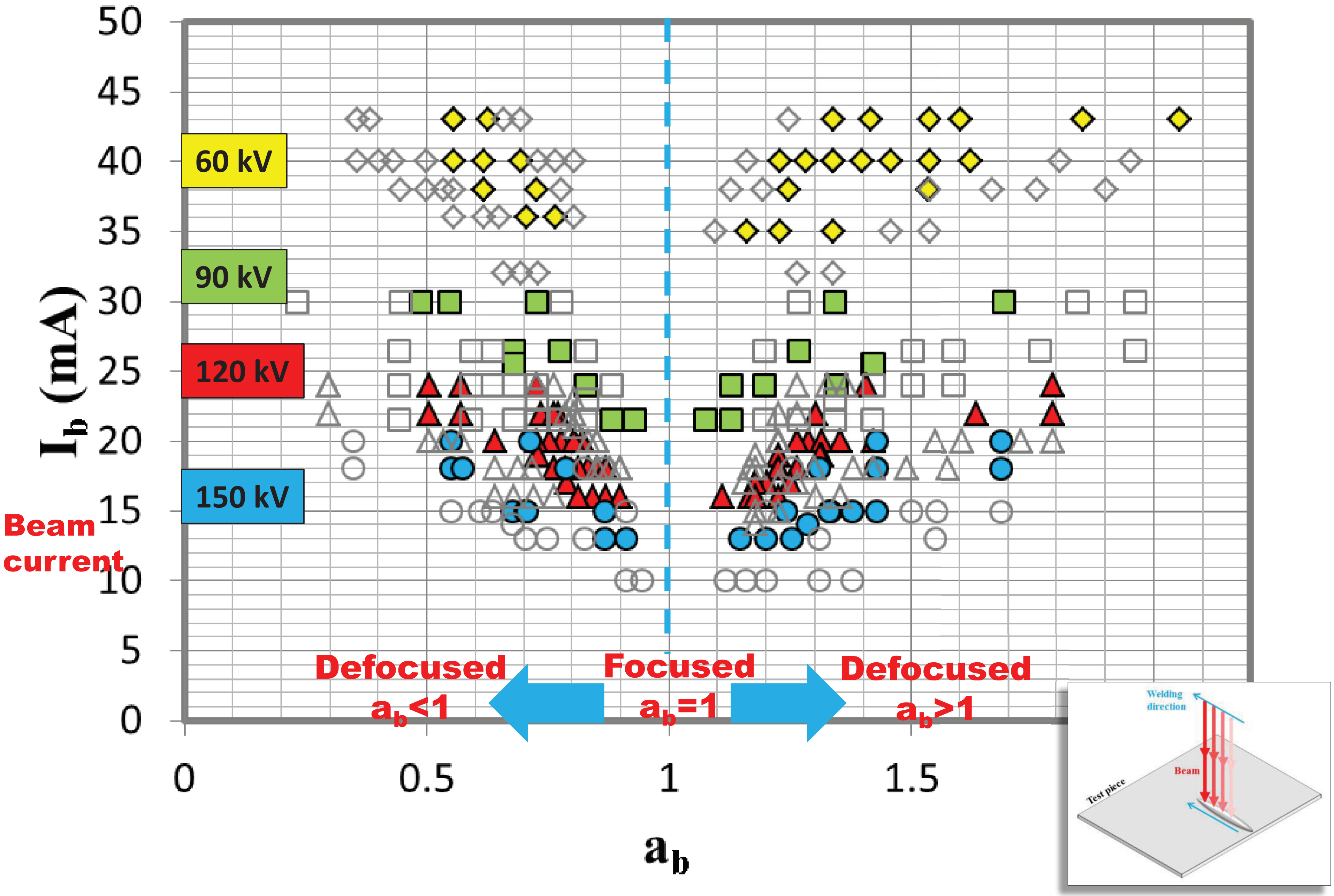
Good parameter-regions



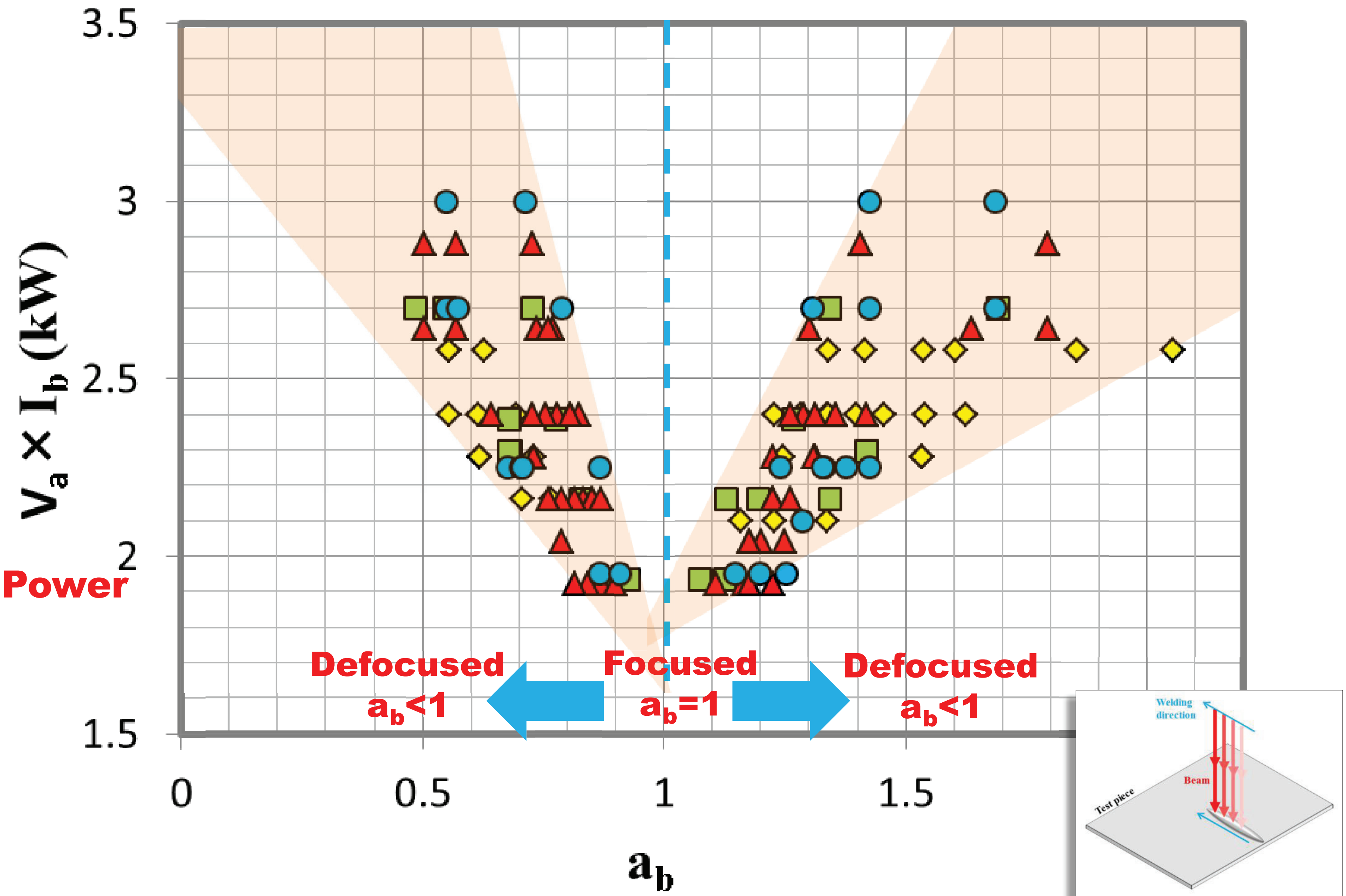
Good parameter-regions



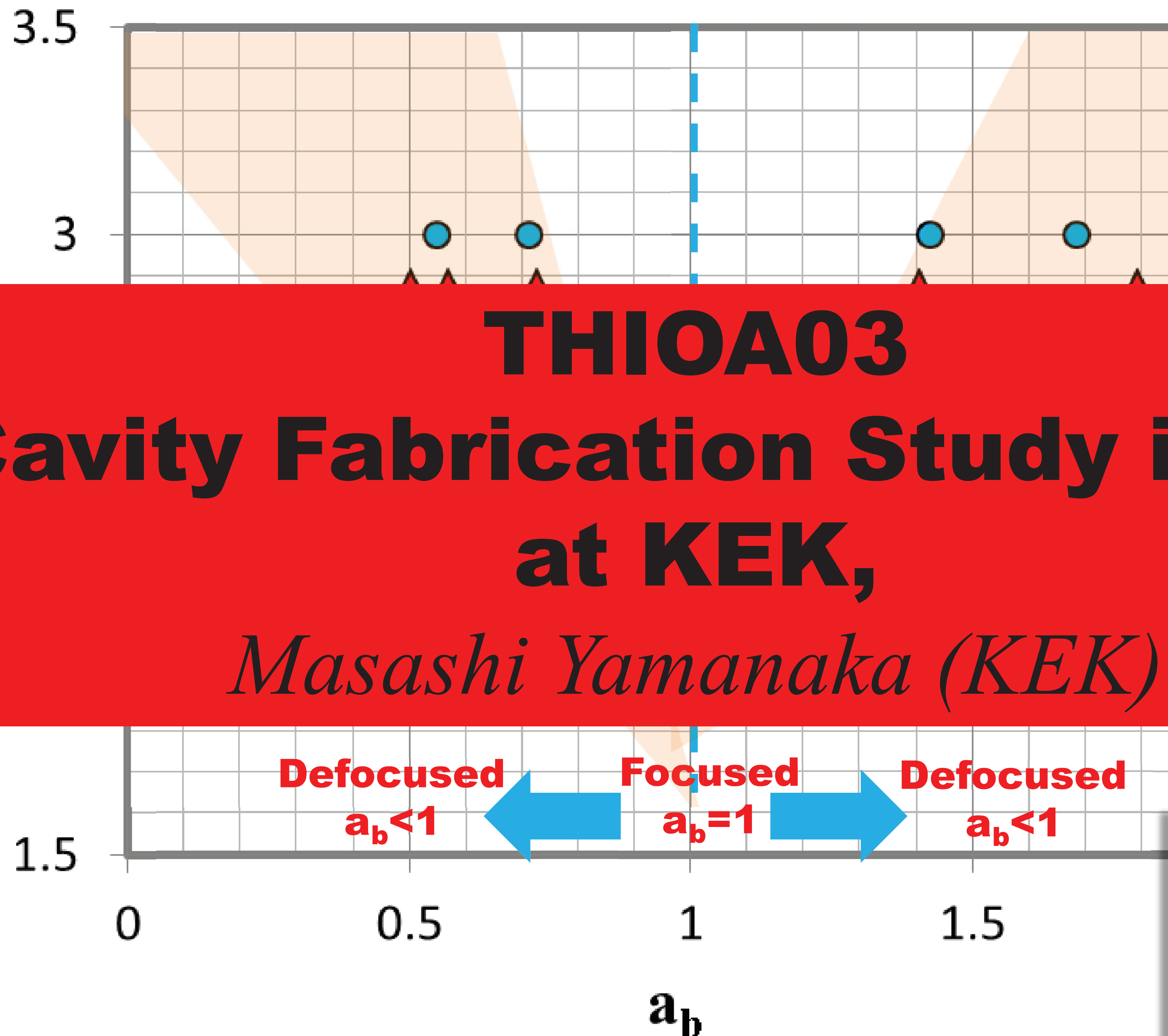
Good parameter-regions



Good parameter-regions

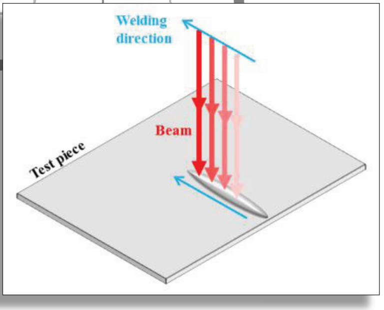


Good parameter-regions



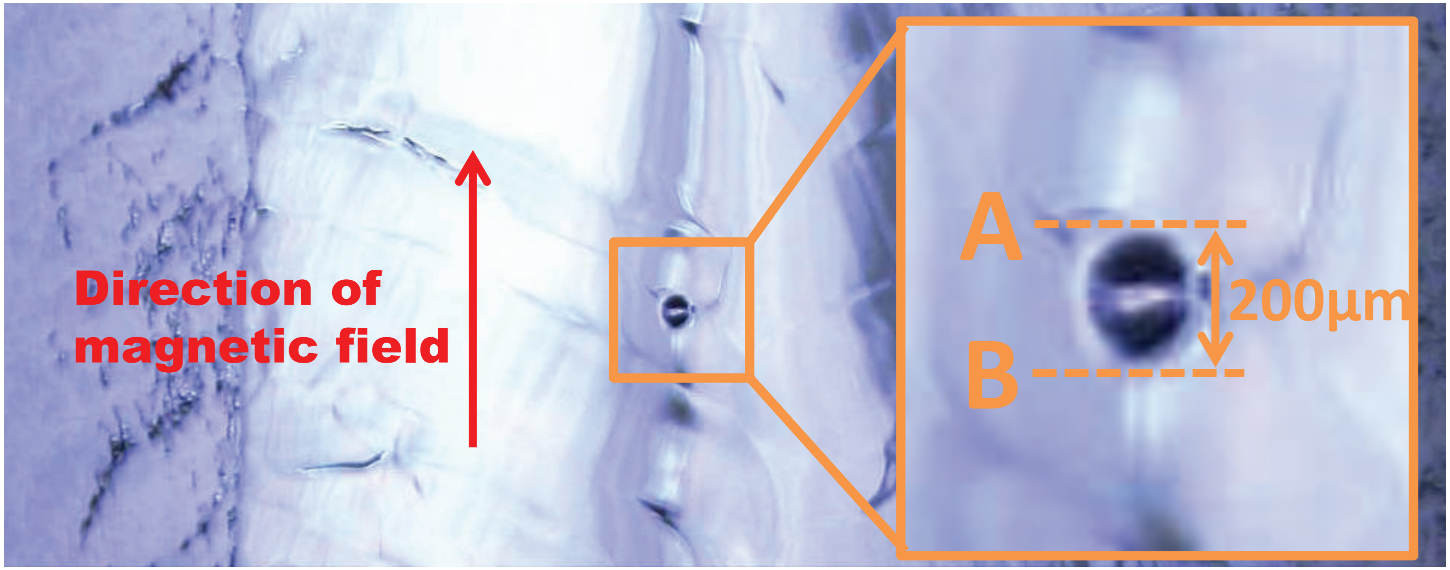
THIOA03
Cavity Fabrication Study in CFF at KEK,

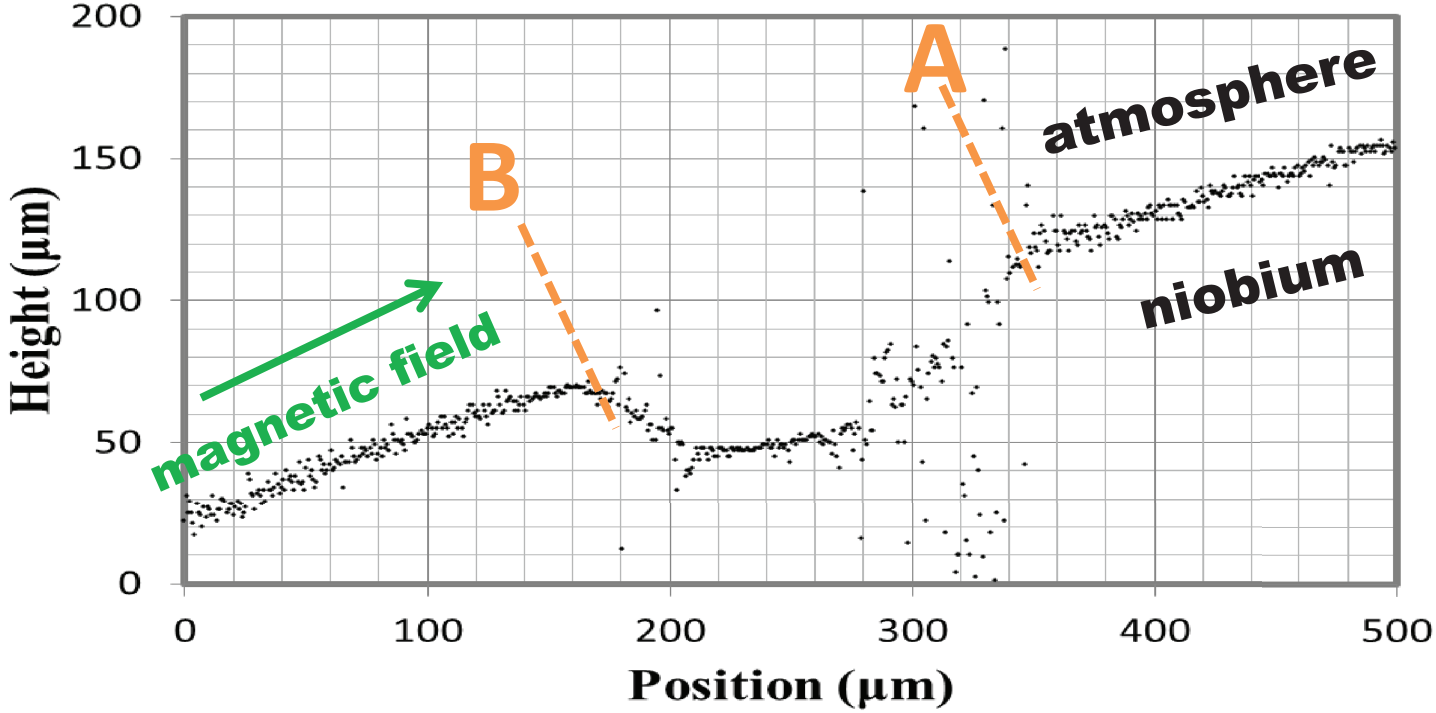
Masashi Yamanaka (KEK)



Discussions on pit

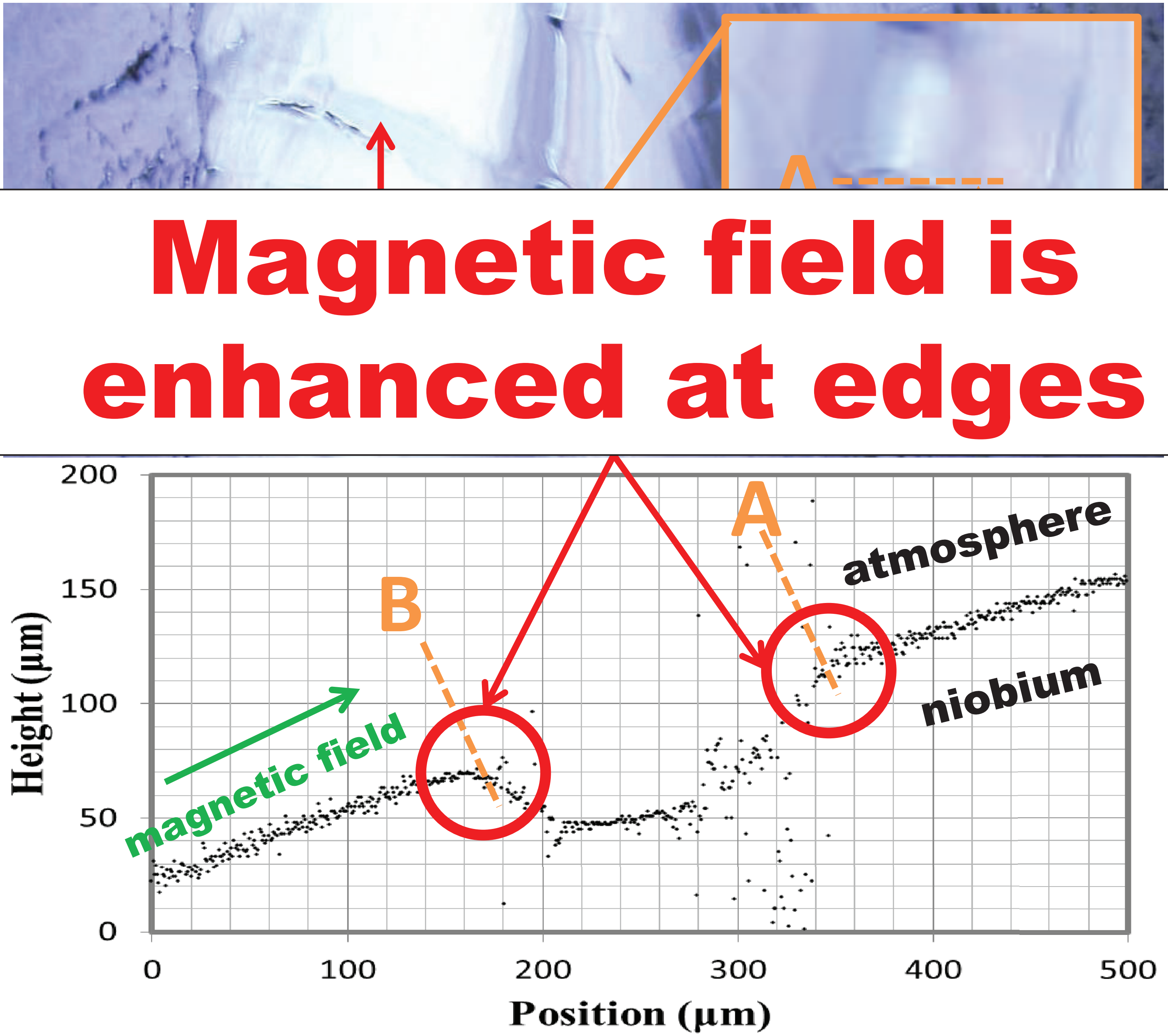
Magnetic field enhancement at pits



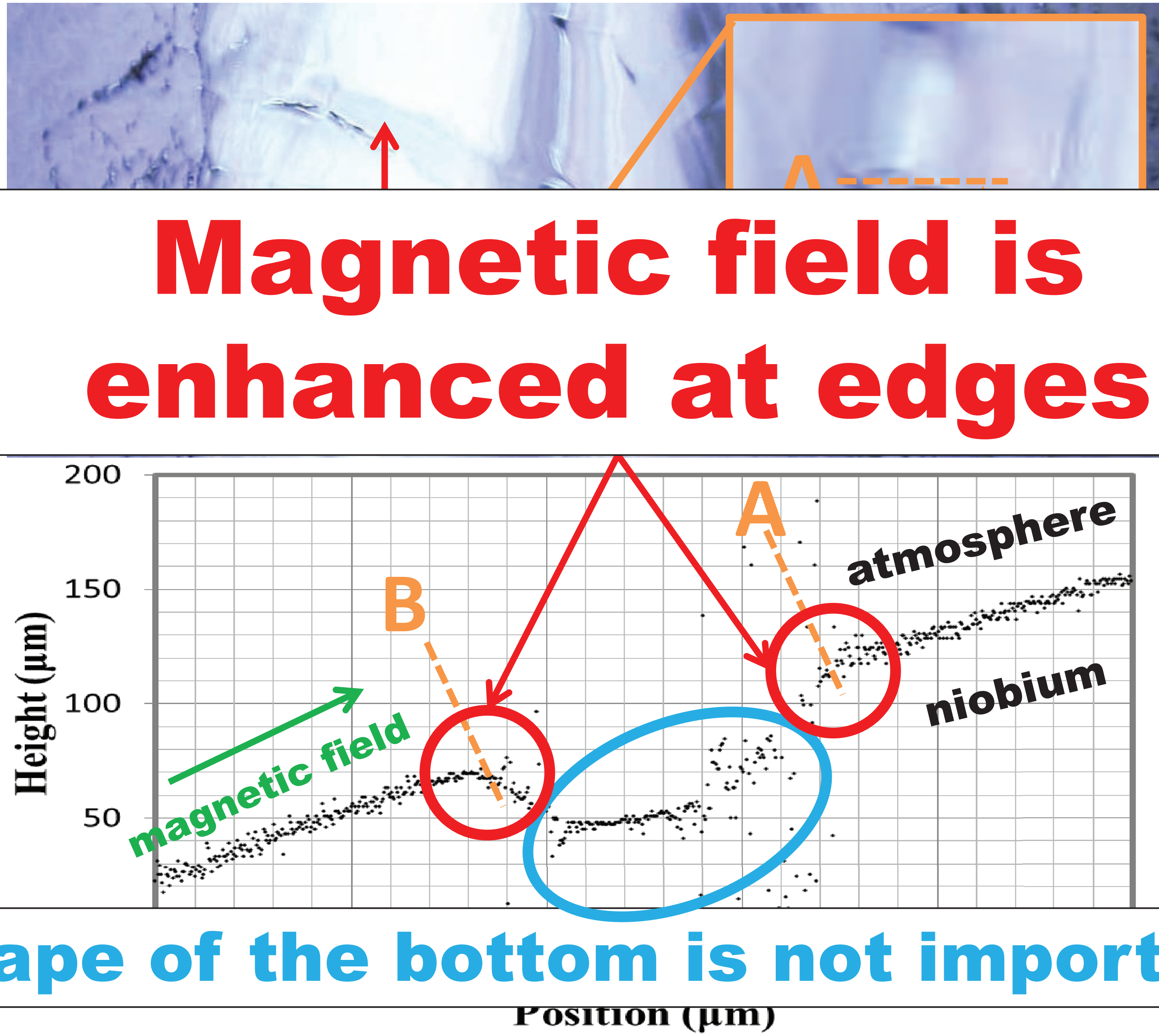


Magnetic field enhancement at pits

Magnetic field is enhanced at edges



Magnetic field enhancement at pits

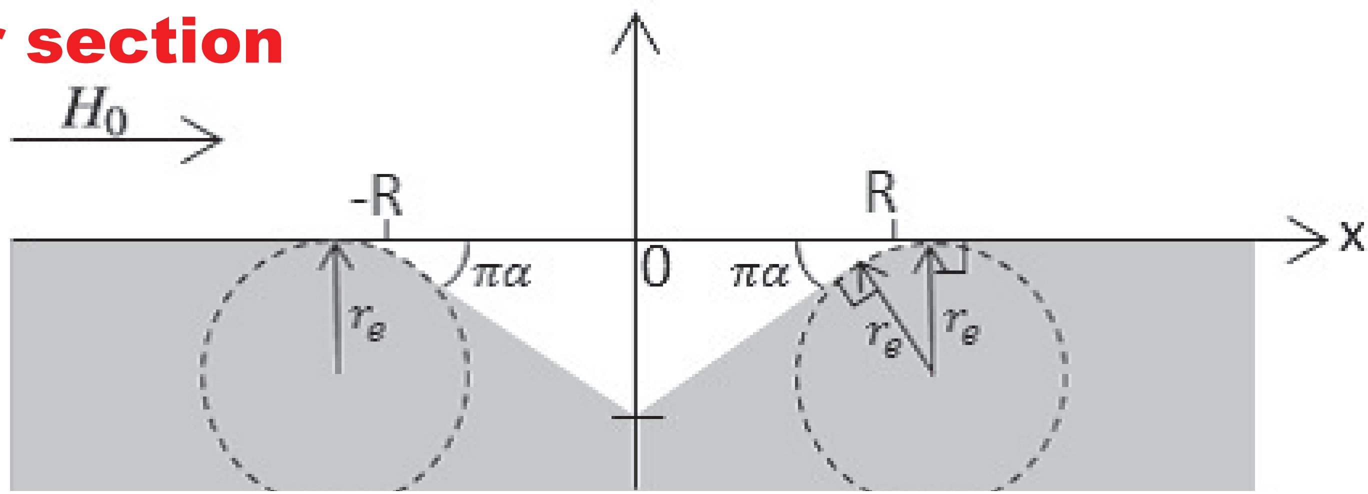


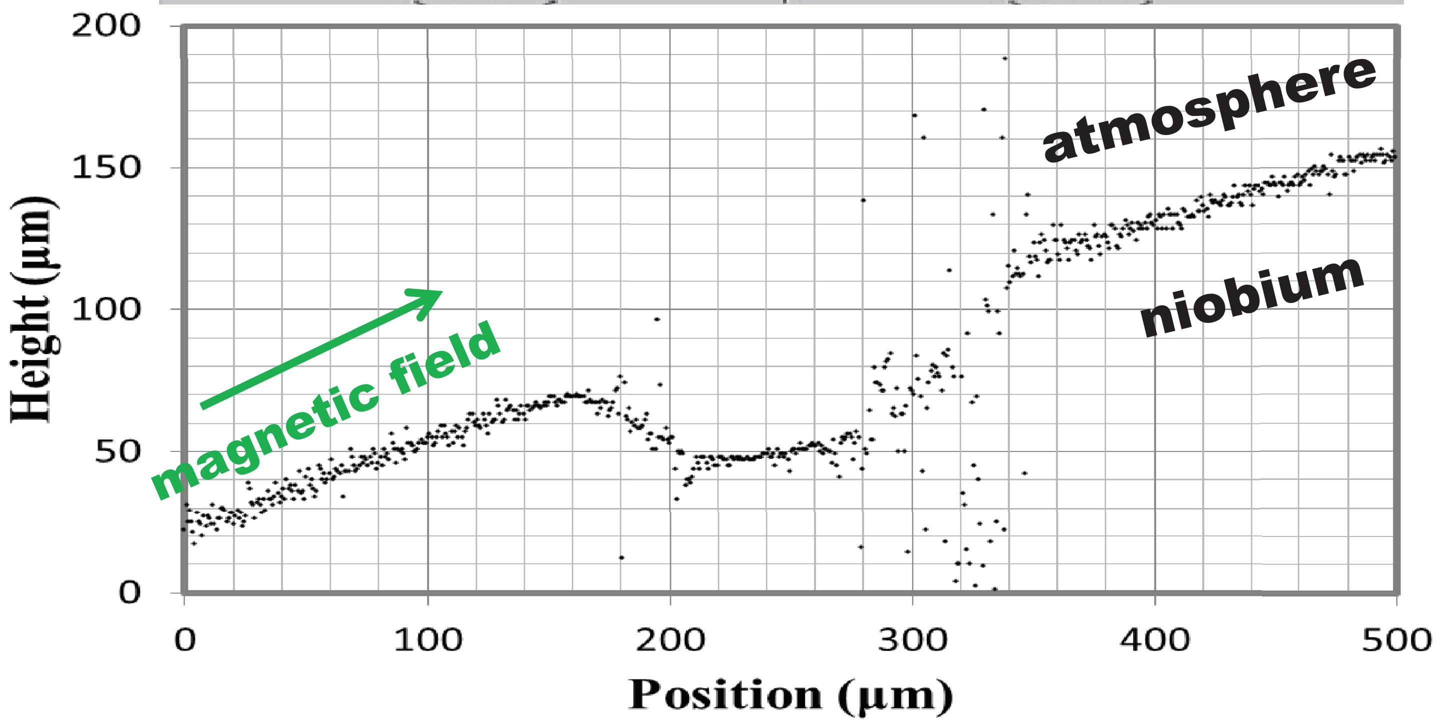
Magnetic field is enhanced at edges

Shape of the bottom is not important

Magnetic field enhancement at pits

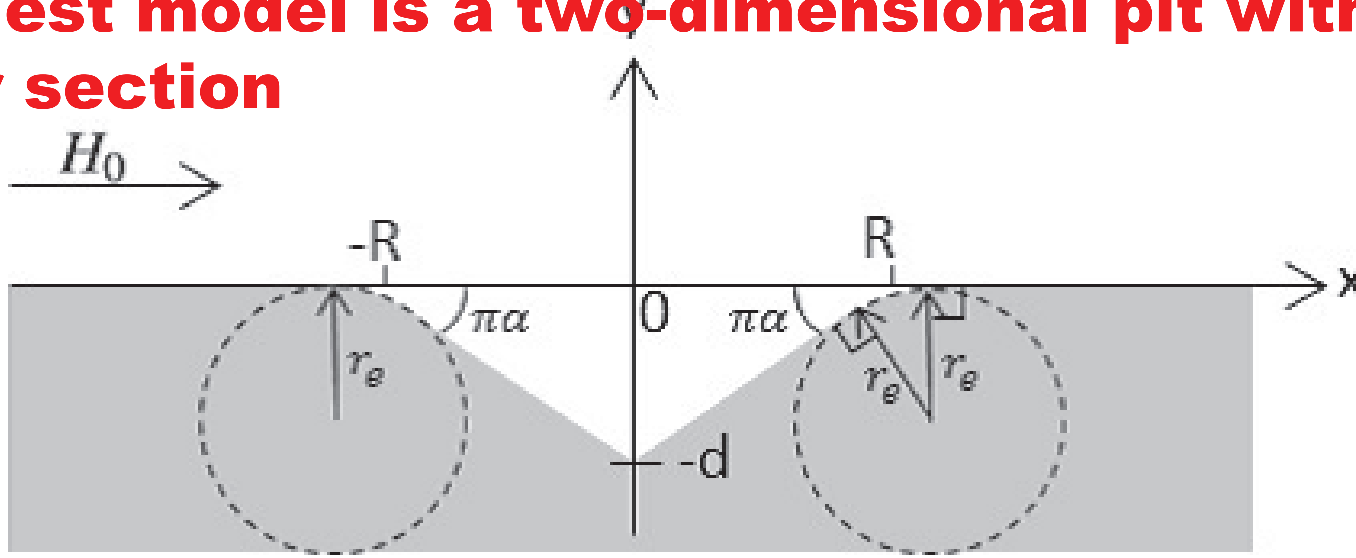
The simplest model is a two-dimensional pit with a triangular section





Magnetic field enhancement at pits

The simplest model is a two-dimensional pit with a triangular section



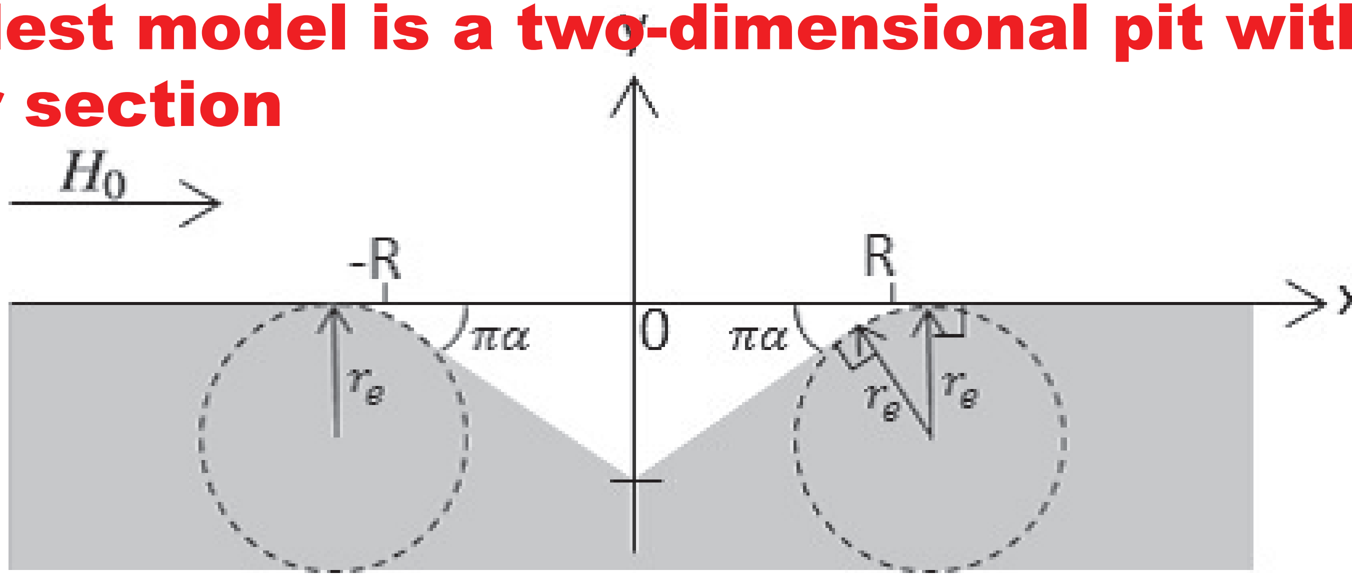
a slope angle α,

pit size R,

round edge radius r_e

Magnetic field enhancement at pits

The simplest model is a two-dimensional pit with a triangular section



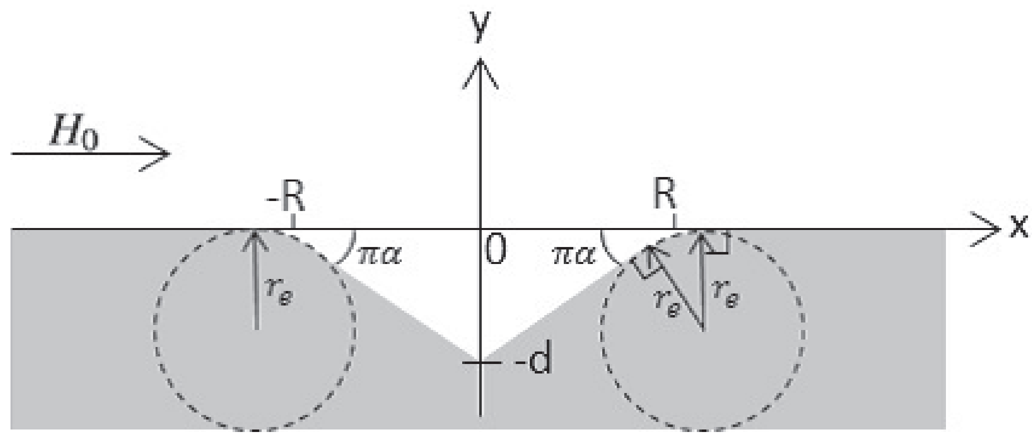
The magnetic field enhancement factor at the edges are given as a function of a slope angle α, pit size R, and round edge radius r_e:

$$\boxed{\beta^* = P(\alpha)\left(\frac{R}{r_e}\right)^{\frac{\alpha}{1+\alpha}}}$$

P(α) is given in Poster **TUP008**

Magnetic field enhancement at pits

$$\beta^* = P(\alpha)\left(\frac{R}{r_e}\right)^{\frac{\alpha}{1+\alpha}}$$



$$B_{\text{peak}}^{break\ down} \sim \frac{200\ \text{mT}}{\beta^*} = \frac{200\ \text{mT}}{P(\alpha)}\left(\frac{r_e}{R}\right)^{\frac{\alpha}{1+\alpha}}$$

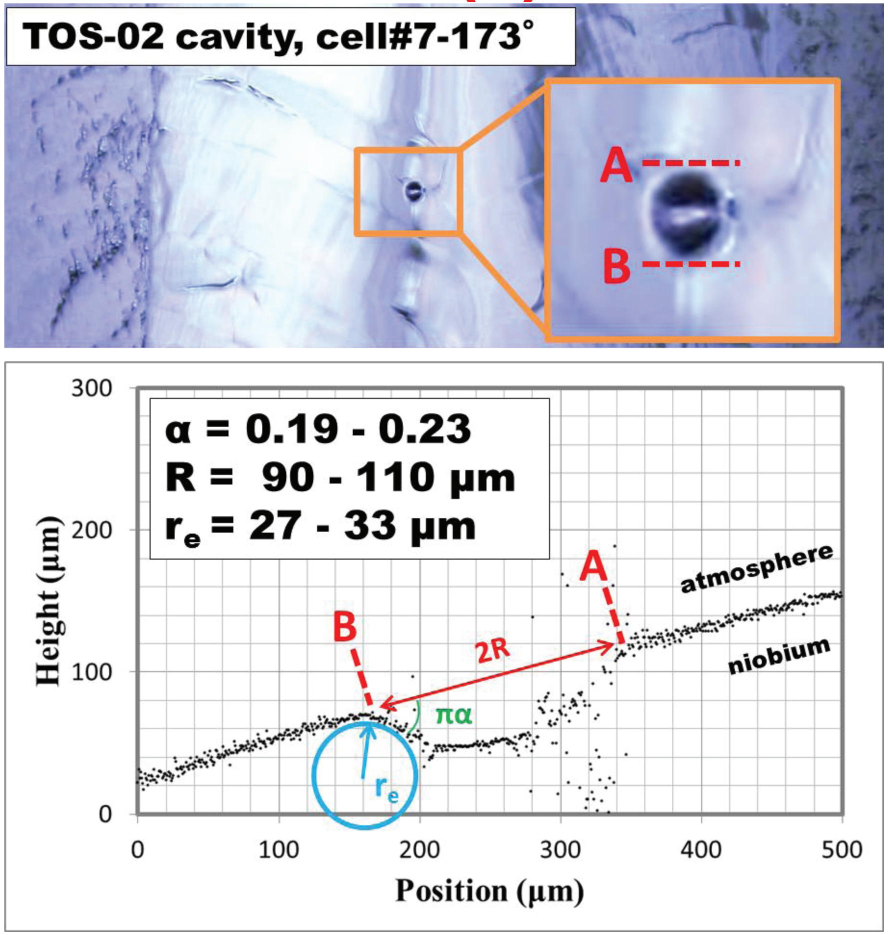
$$E_{\text{acc}}^{break\ dwon} = g^{-1} B_{break\ down} = g^{-1}\frac{200\ \text{mT}}{P(\alpha)}\left(\frac{r_e}{R}\right)^{\frac{\alpha}{1+\alpha}}$$

where g = B_{peak}/E_{acc} for a given cavity shape

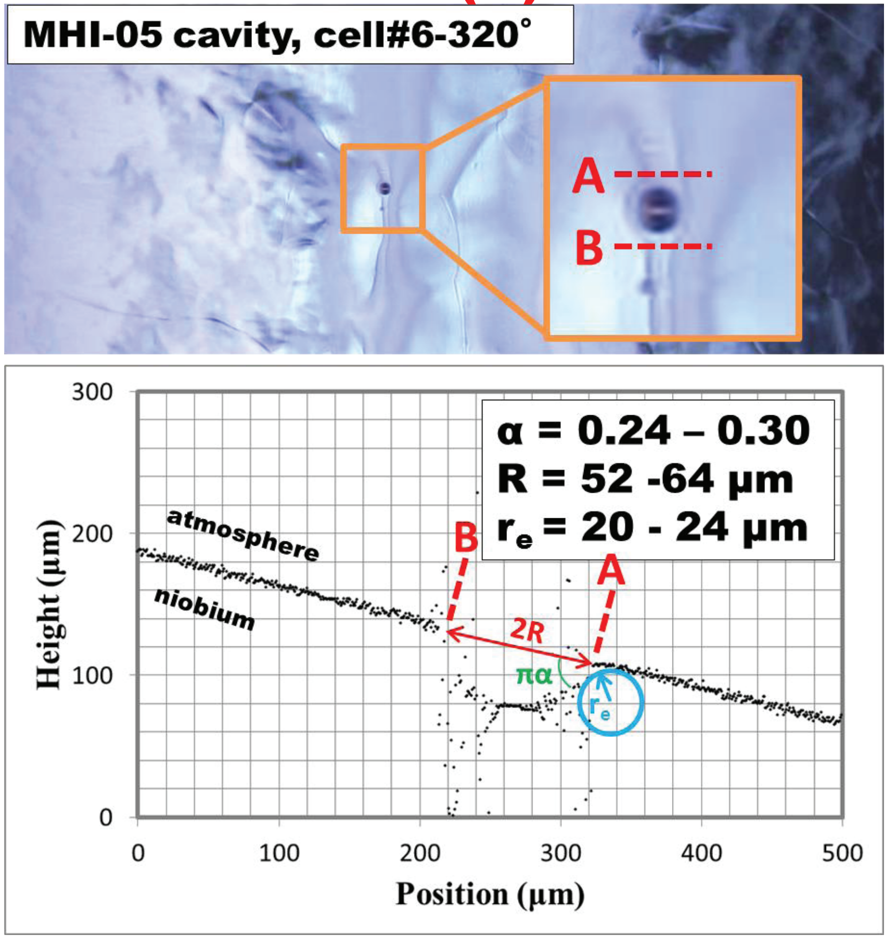
Comparisons with vertical test results

α, R, and r_e are measured from pit profiles

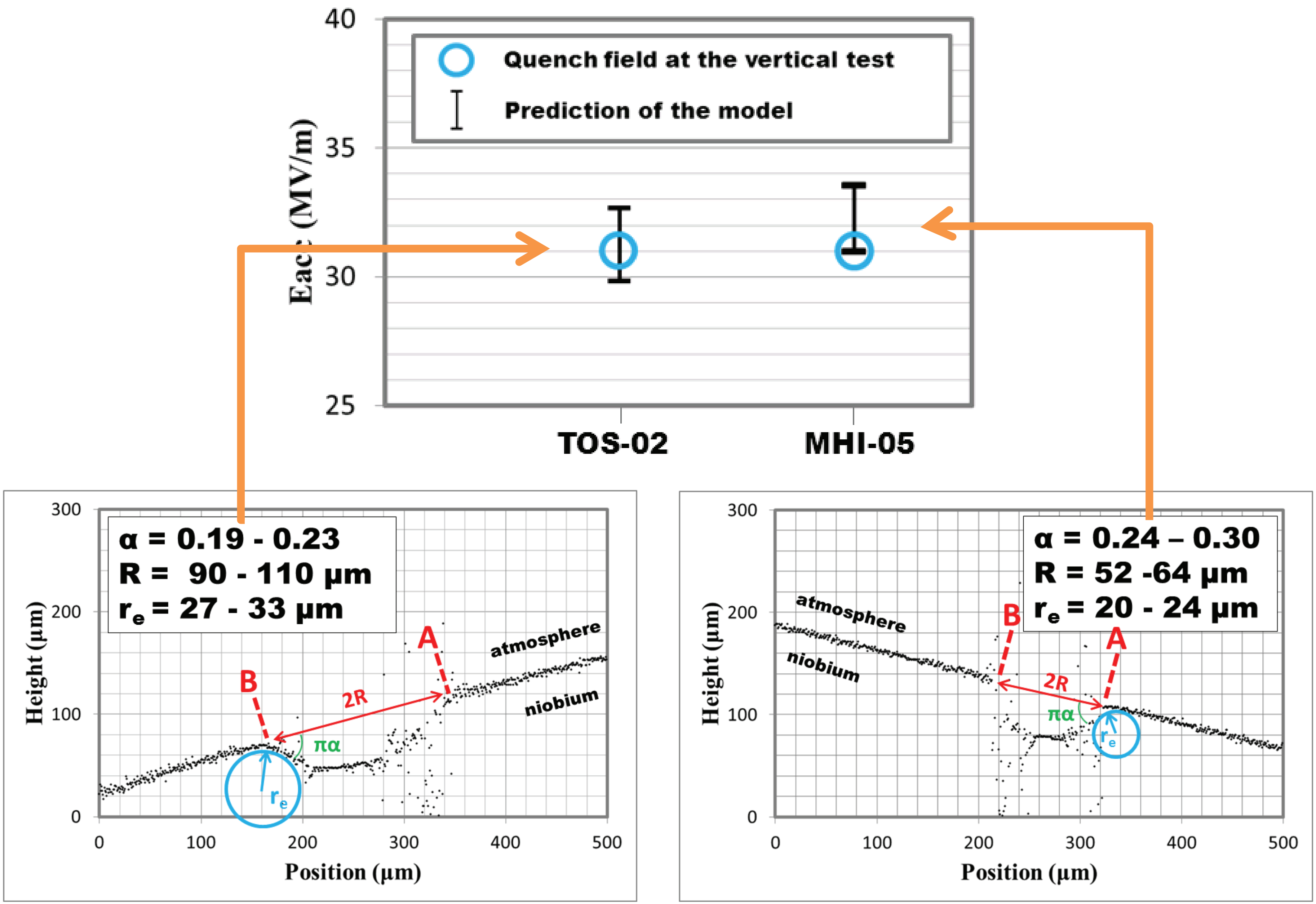
Pit (1)



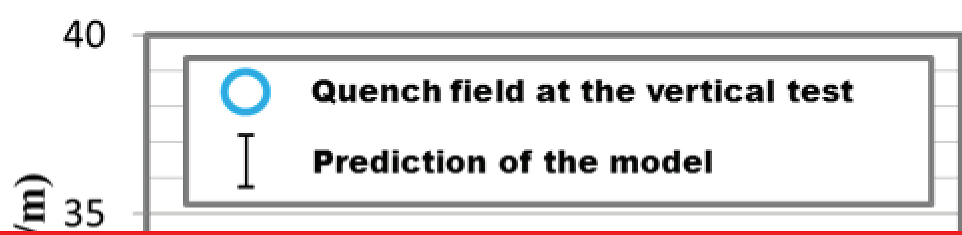
Pit (2)



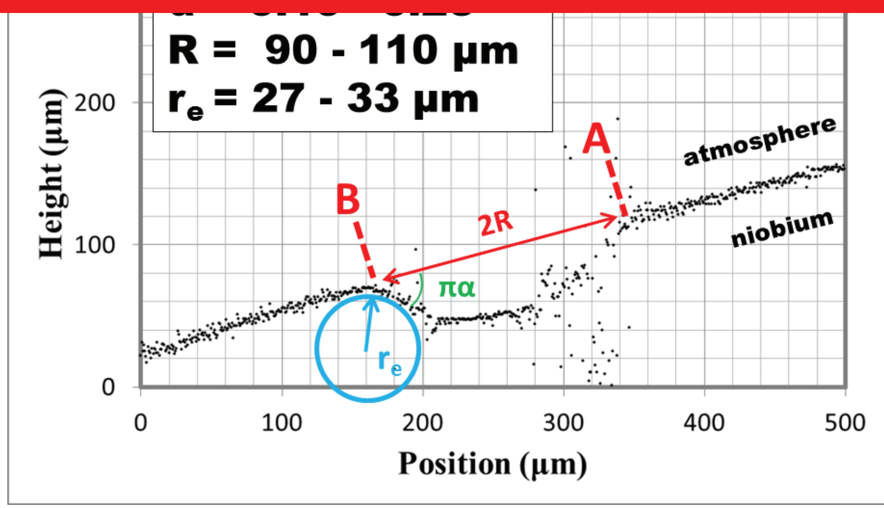
Comparisons with vertical test results

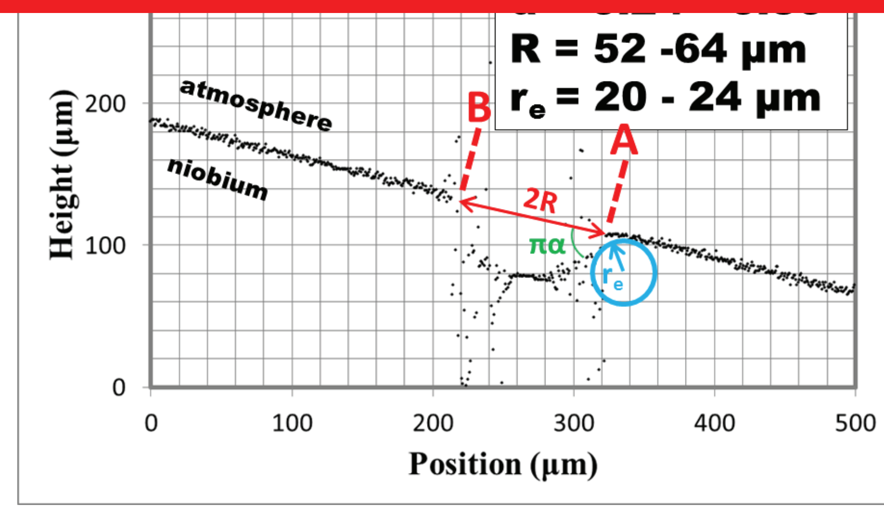


Comparisons with vertical test results



TUP008
Model of the magnetic field enhancement at pits,
Takayuki Kubo (KEK)





Summary

- We started a study on optimum EBW parameters.
- Beam generator position and welding direction dramatically affect a geometry of weld bead.
- Parameter regions for good welds were surveyed.
- Formula for a magnetic enhancement factor at pits was derived, which agree with experiments.

To accumulate statistics is a future work.

Backup

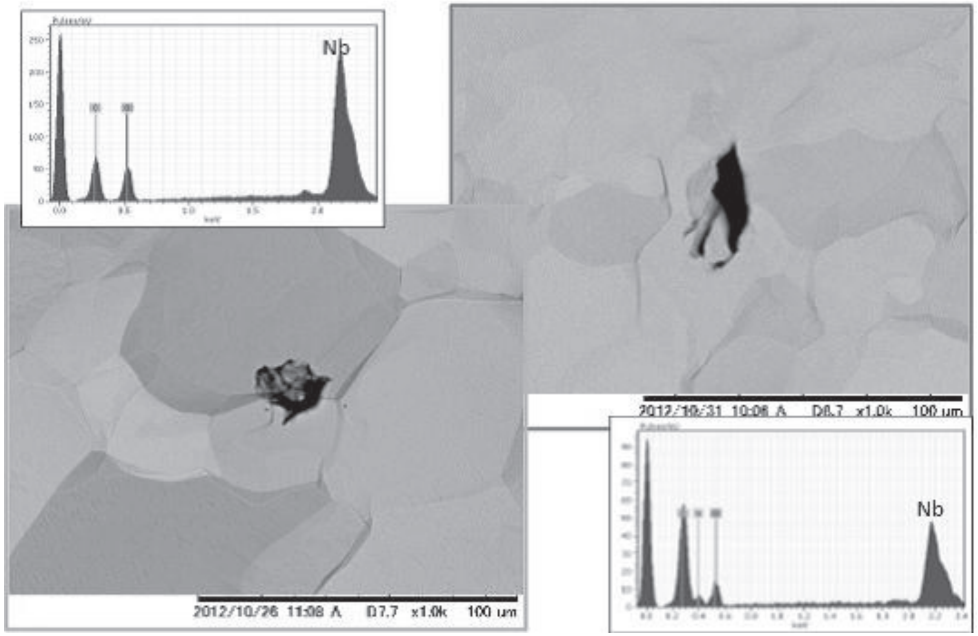


Figure 4: Examples of contaminants found after the BCP [3]. The contaminants include carbon and oxygen, or carbon, nitrogen and oxygen.

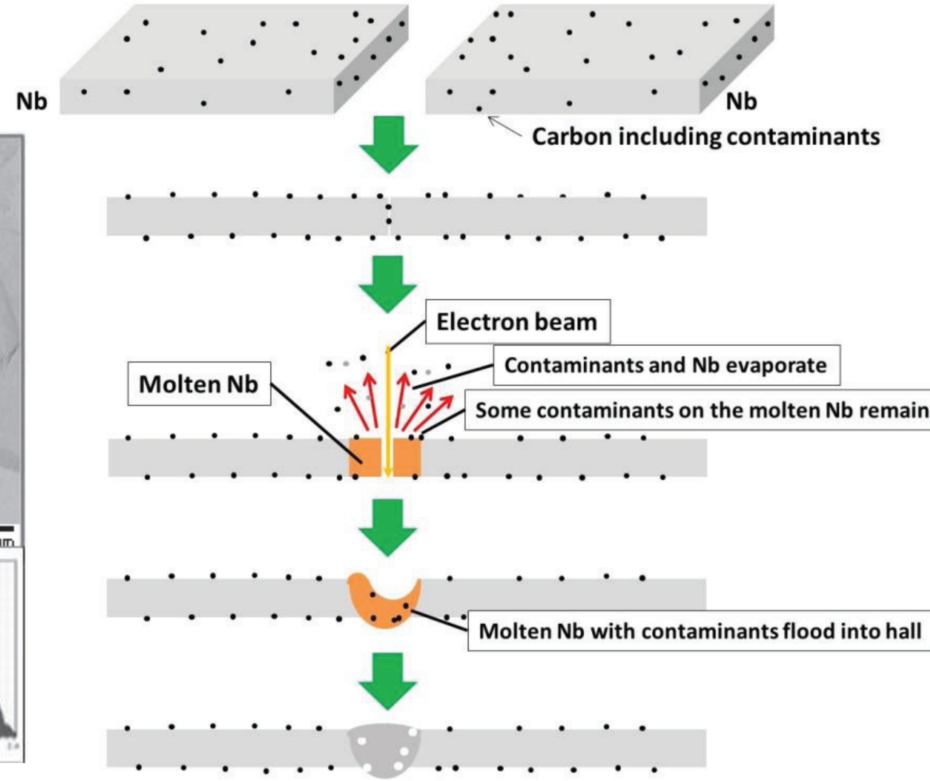


Figure 5: Schematic layouts of the speculated pit formation mechanism [3]. Contaminants involved in molten Nb cause a pit formation.