

# マグネシウム合金のレーザー溶接

## —マグネシウム合金のレーザー溶接性に関する研究—

名古屋大学 工学研究科

沓名 宗春

黒川 聡昭

(現:三菱電機)

# 講演内容

- マグネシウム合金のレーザー溶接における  
溶融特性
- レーザ溶接における気孔発生機構
- レーザ溶接部の継手性能
- アダプティブミラーを用いたレーザー溶接

# マグネシウム合金のレーザ溶接における 溶融特性

表1 各種金属の物理的性質の比較

物性値	単位	温度範囲	マグネシウム Mg	アルミニウム Al	鉄 Fe
密度	Mg/m <sup>3</sup>	20℃	1.74	2.70	7.87
融点	℃	-	651	660	1536
沸点	℃	-	1107	2056	2735
表面張力	mN/m	融点	559	914	1872
比熱	J/kg·K	20℃	1022	900	444
熱容量	J/m <sup>3</sup> ·K	20℃	1778	2430	3494
熱膨張率	10 <sup>-6</sup> /K	20-100℃	26.1	23.9	12.2
熱伝導率	W/m·K	20℃	167	238	73.3
電気抵抗率	10 <sup>-8</sup> Ω·m	20℃	4.2	2.67	10.1
ヤング率	10 <sup>11</sup> Pa	20℃	0.443	0.757	1.90

### マグネシウム合金の特徴

比重が1.7と構造用金属材料で最も小さい。

振動吸収性に優れている。

電磁波吸収性に優れている。

寸法安定性に優れている。

### レーザー溶接の特徴

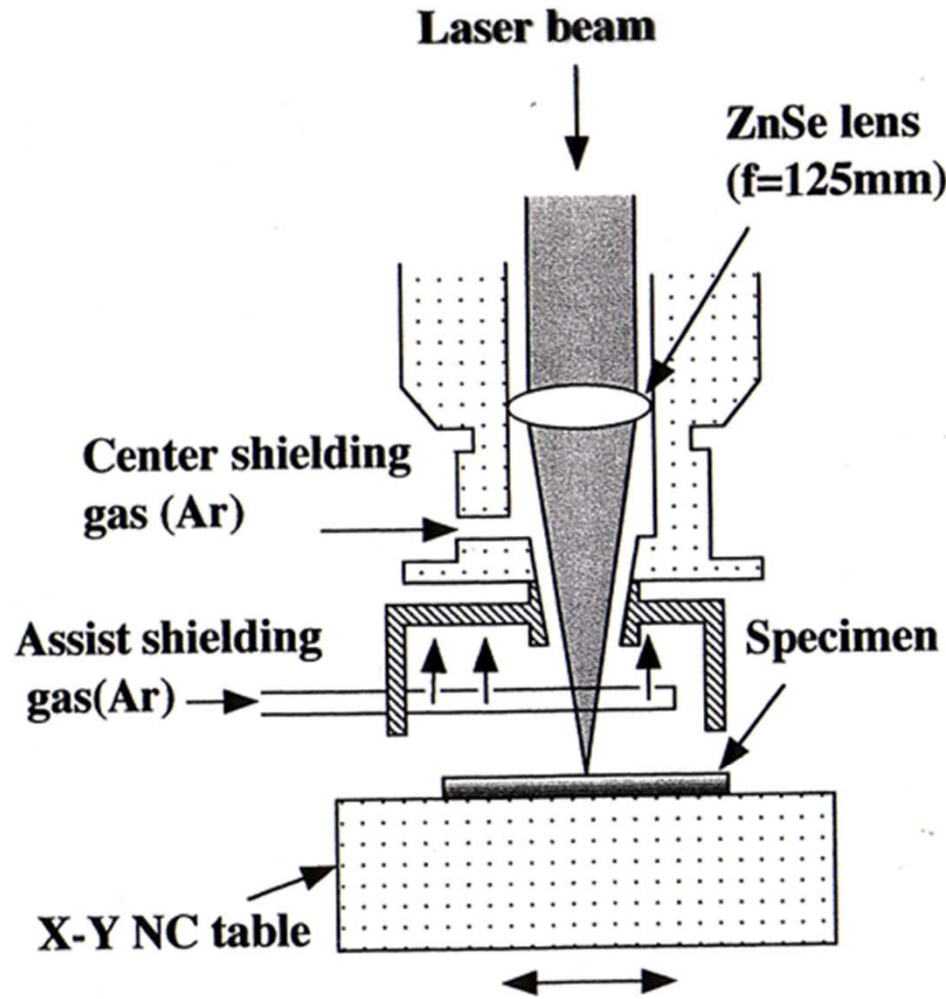
高エネルギー密度により、深溶込みを得られる。

非接触で溶接が可能である。

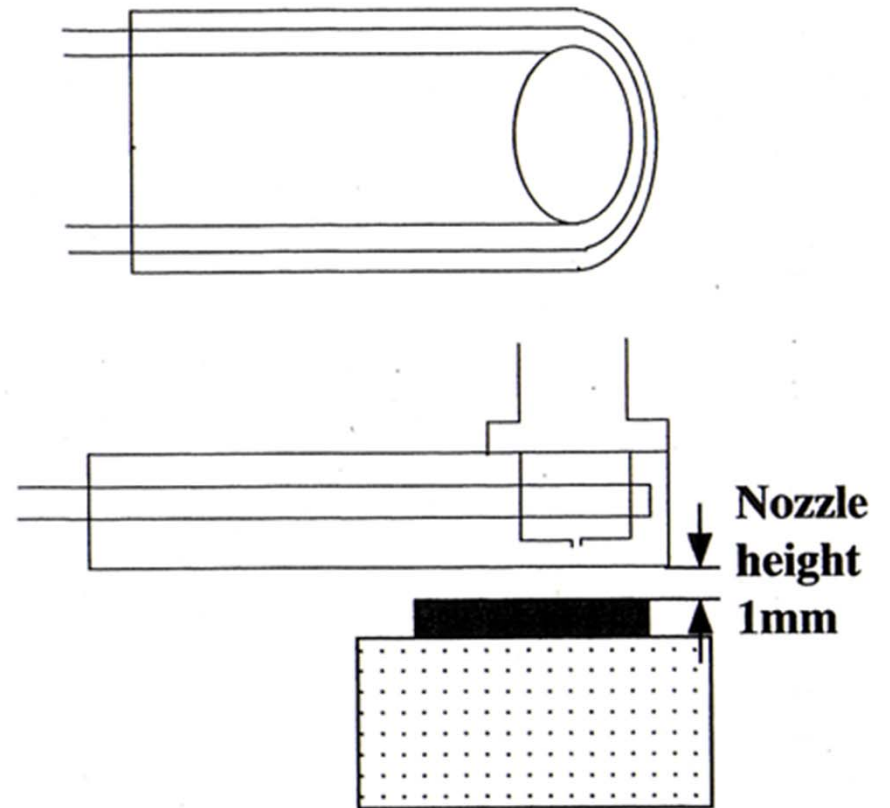
微細で精密な加工が可能である。

小入熱で溶接変形が少ない

# レーザー溶接実験概要



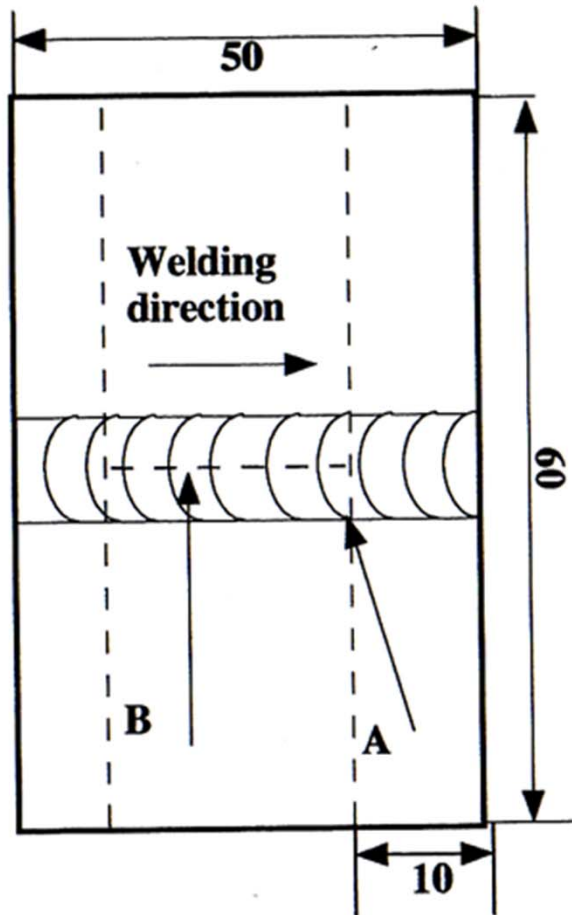
(a) CO<sub>2</sub> laser system



(b) Tail shielding gas nozzle



# 供試材



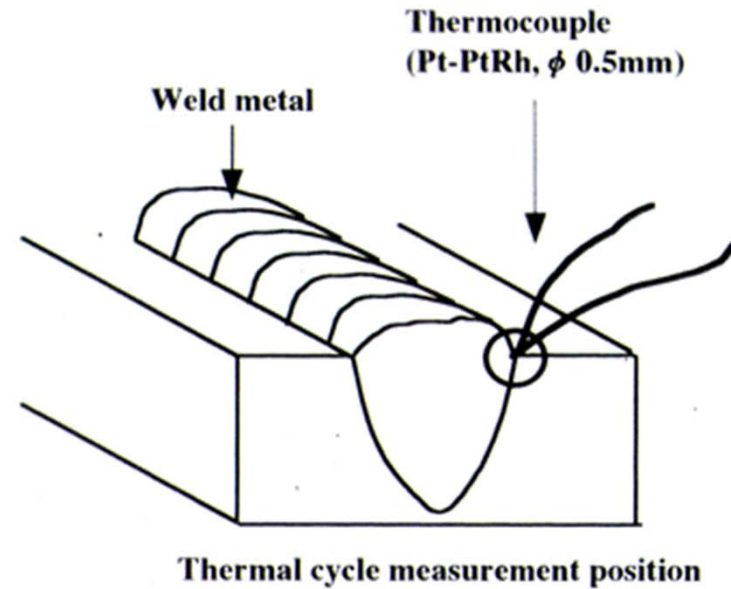
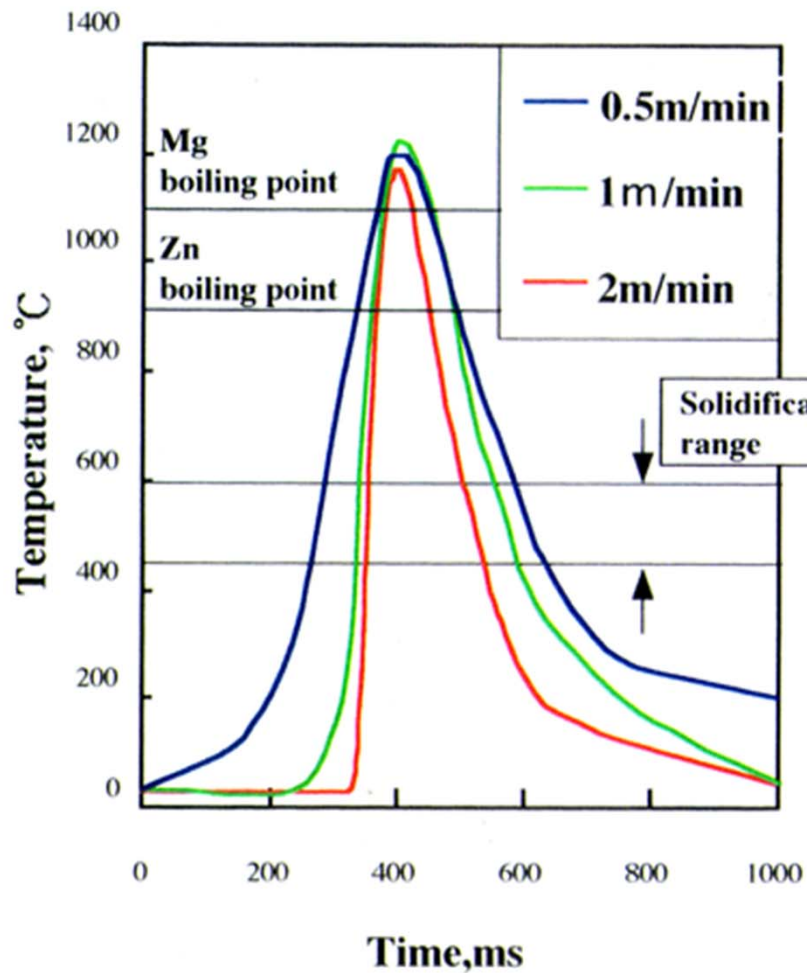
(a) Specimen size

Table Chemical composition of Mg alloys

Material	Type	Element(wt%)		
		Al	Zn	Mn
AZ13	cast	1.05	3.4	0.005
AZ31	wrought	2.5~3.5	0.7~1.3	0.1~0.3
AZ61	wrought	5.5~6.5	0.7~1.3	0.1~0.3
AZ91	cast	8.5~9.5	0.7~1.3	0.1~0.3

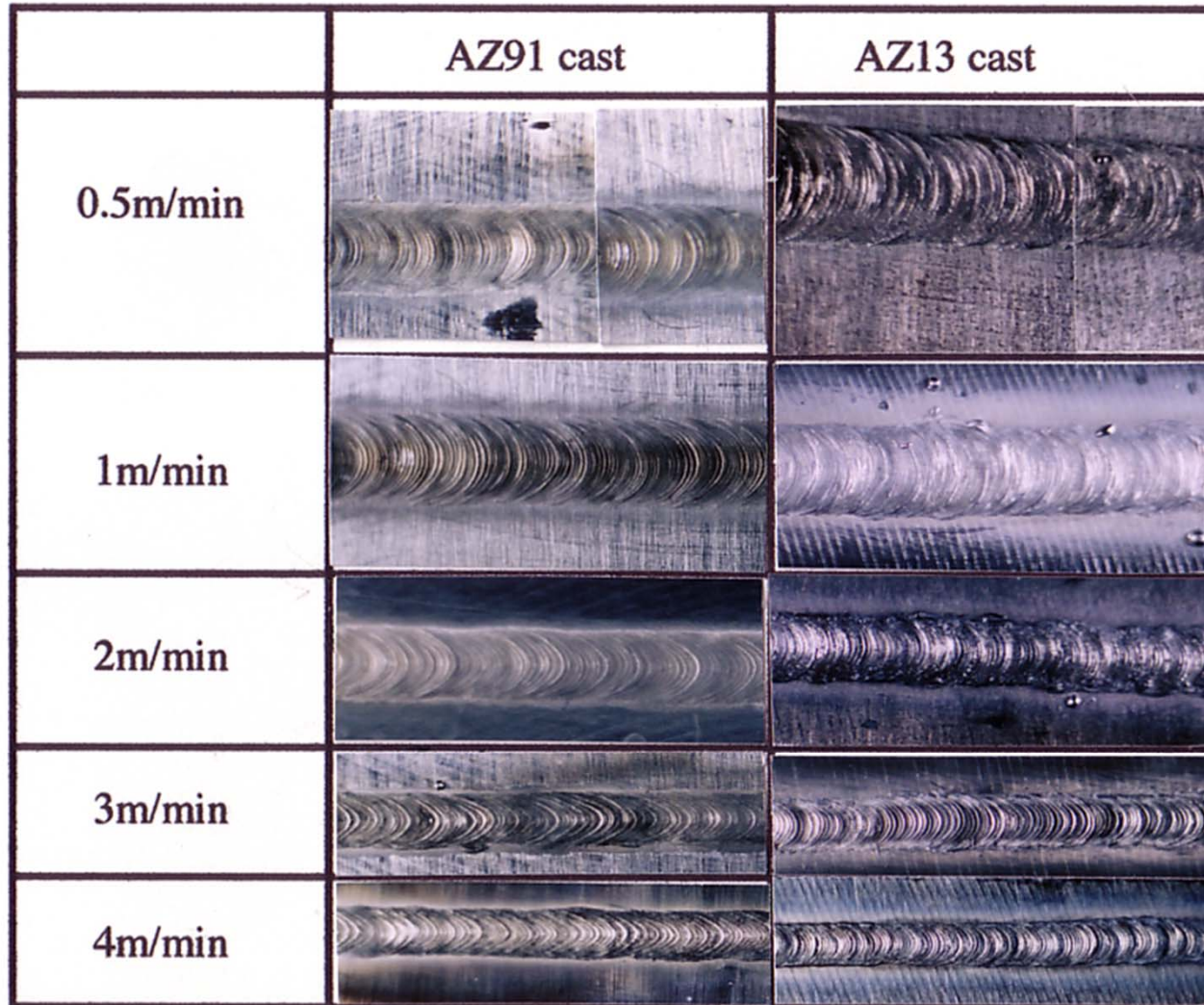
Fig Shape of laser welded specimen for analysis  
(Cross section A , longitudinal section B for analysis )

# 熱サイクル測定



Welding speed, m/min	Cooling rate, K/s (600~465°C)	Solidification time, s (600°C ~ 465°C)
0.5	$3.09 \times 10^3$	$4.37 \times 10^{-2}$
1.0	$3.55 \times 10^3$	$3.8 \times 10^{-2}$
2.0	$5.19 \times 10^3$	$2.66 \times 10^{-2}$

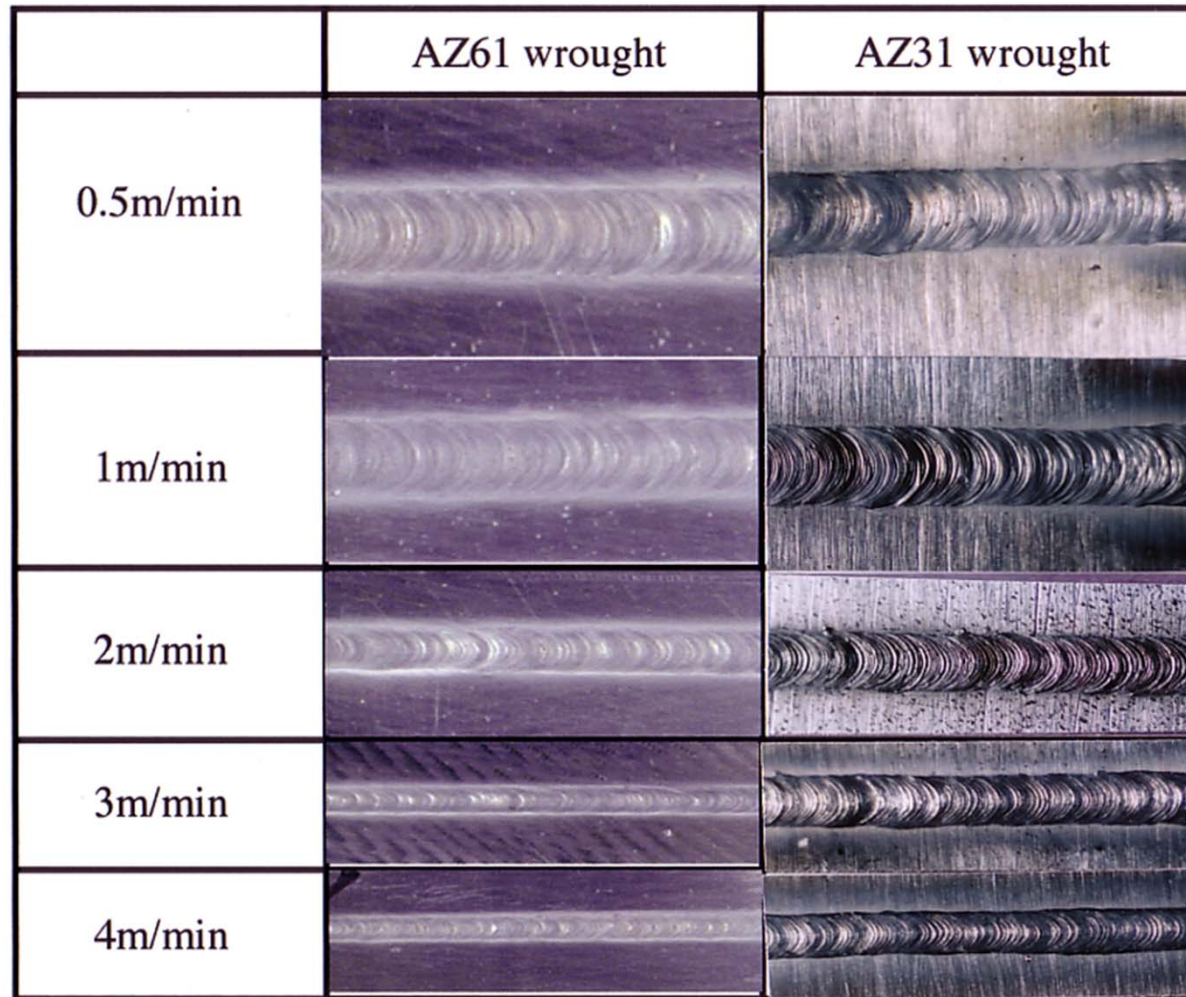
# レーザー溶接部のビード外観



2mm



# レーザー溶接部のビード外観



2mm



# ビードのマクロ断面写真

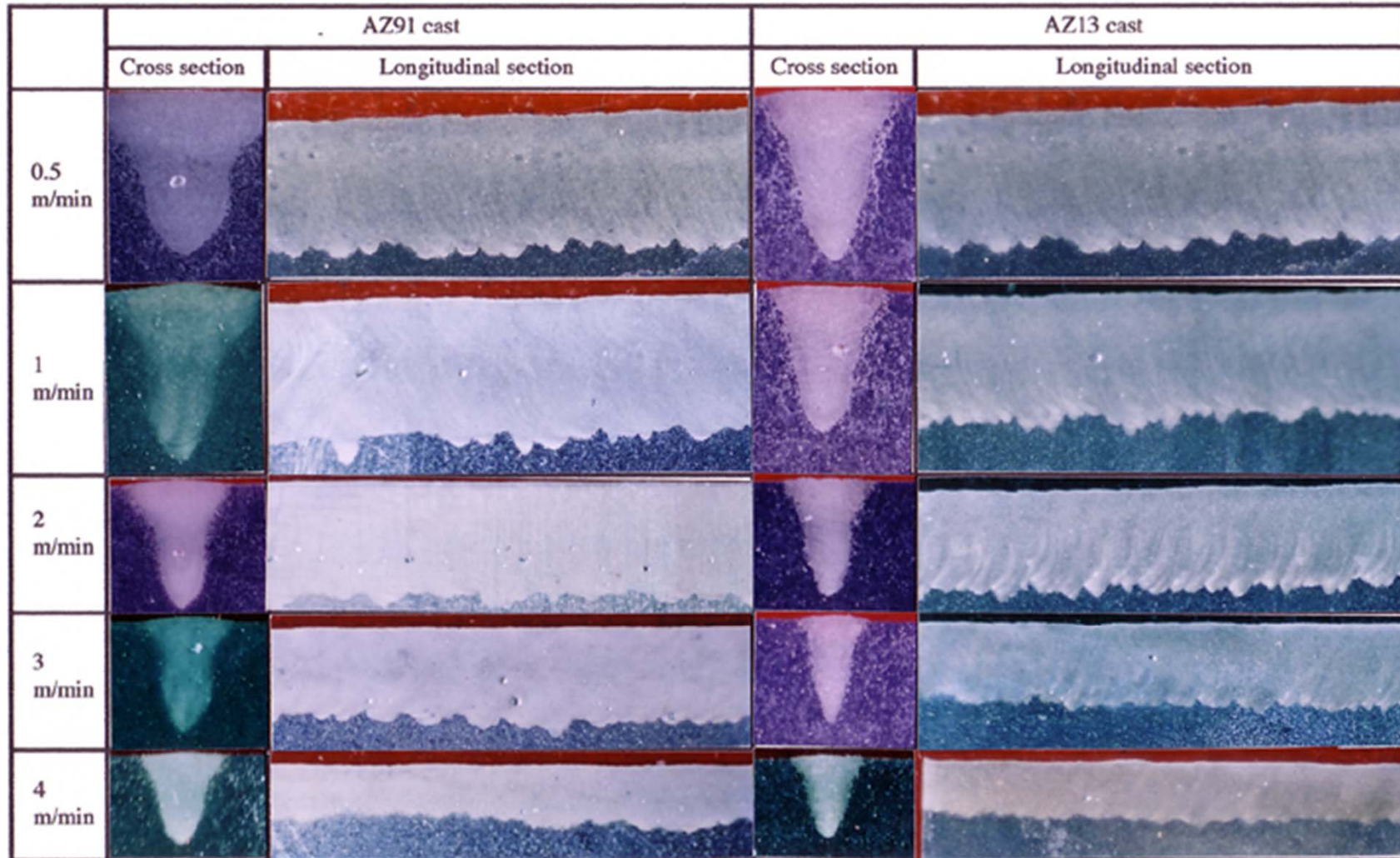
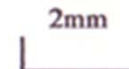


Fig.2-8 Macro cross section of Mg alloys in laser welds





# ビードのマクロ断面写真

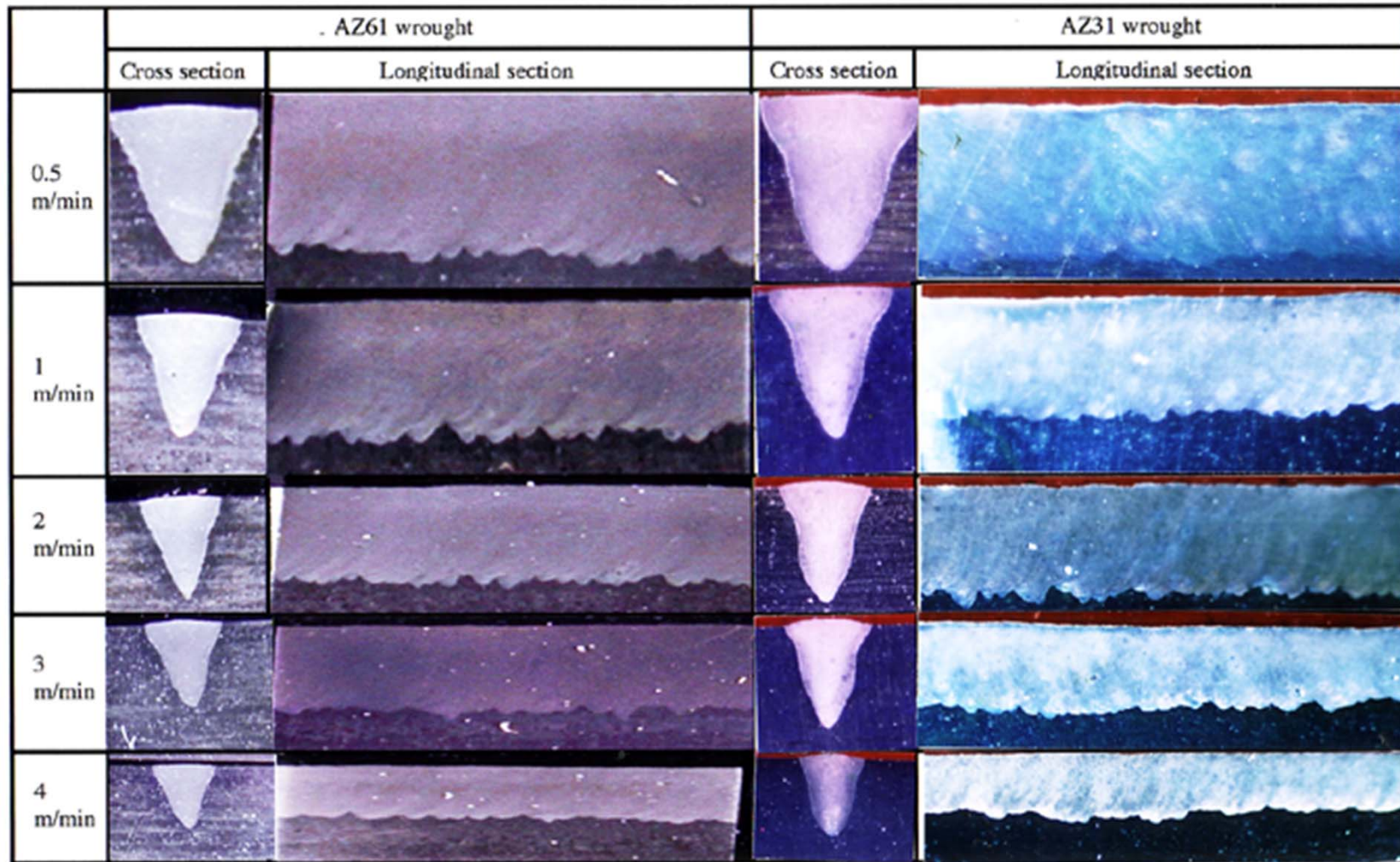
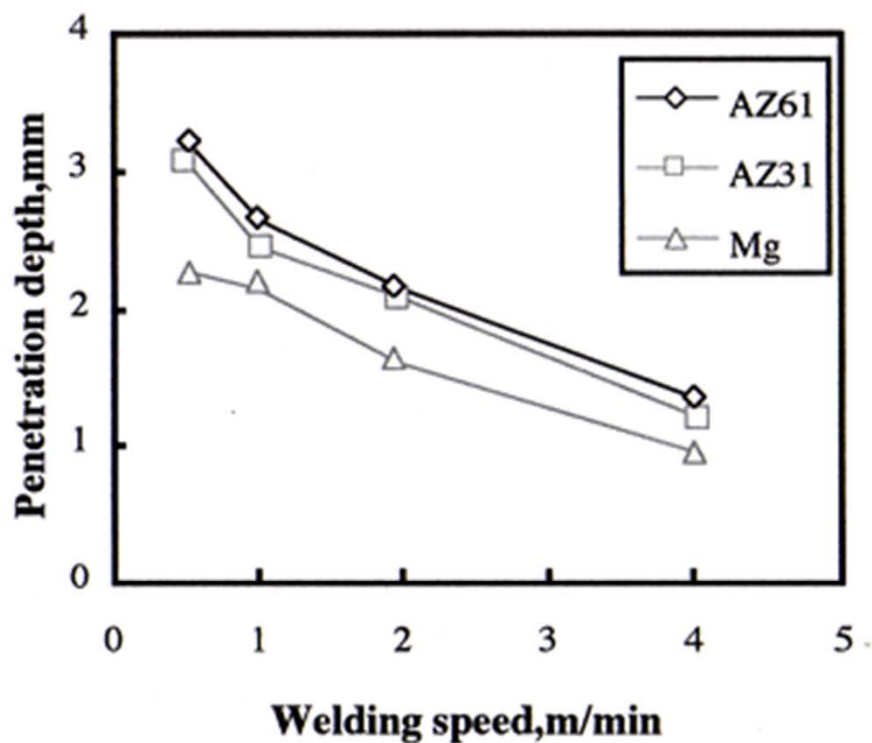


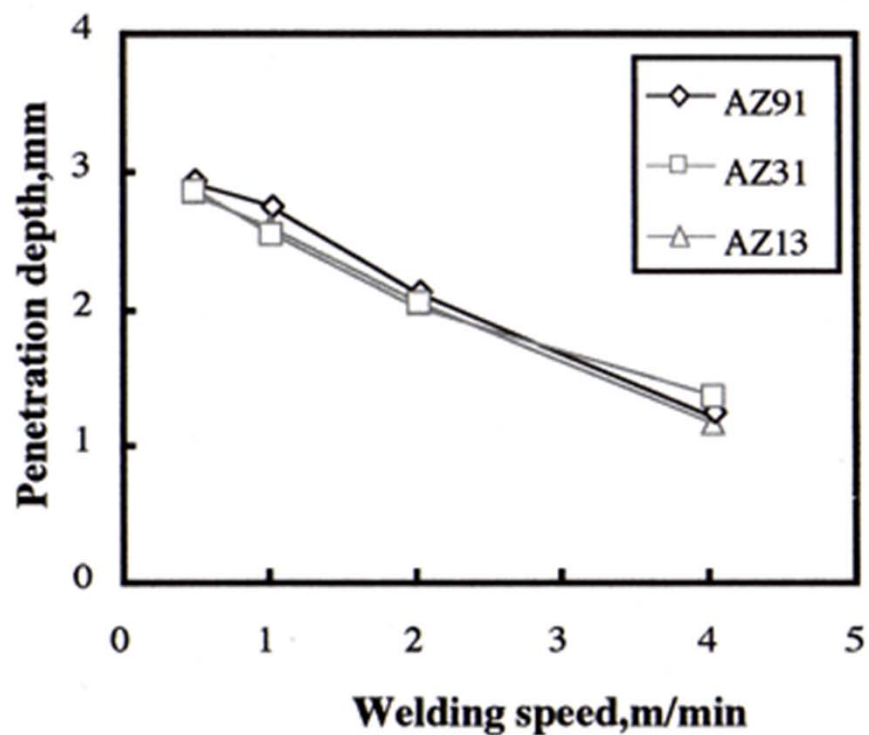
Fig.2-9 Macro cross section of Mg alloys in laser welds



# 溶込み深さの変化

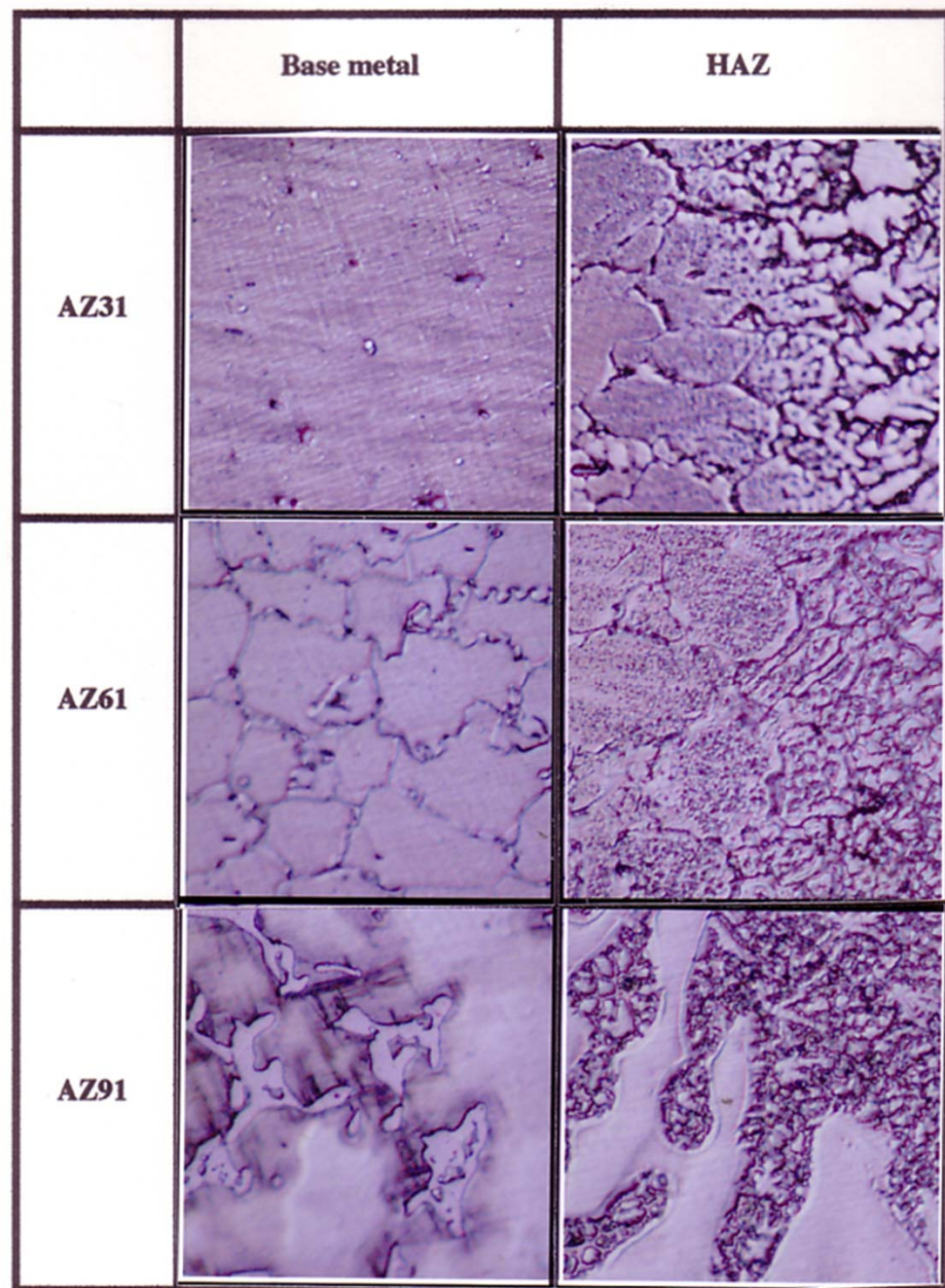


(a) Wrought Alloys



(b) Cast Alloys



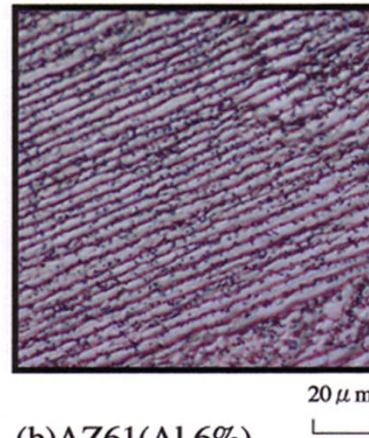


100  $\mu$  m

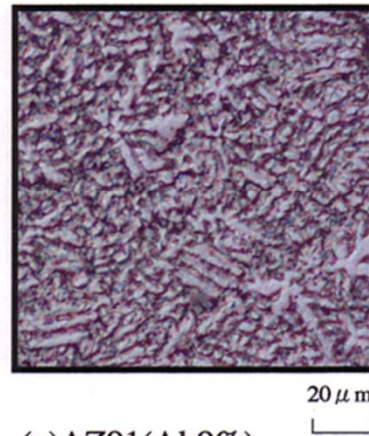


溶質元素の増加とともに  
セル状からデンドライト状  
に移行

(a)AZ31(Al 3%)



(b)AZ61(Al 6%)



(c)AZ91(Al 9%)

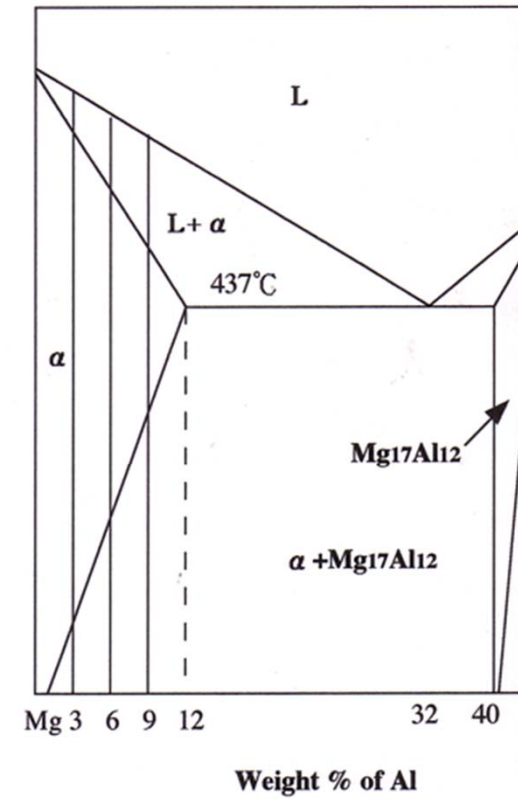
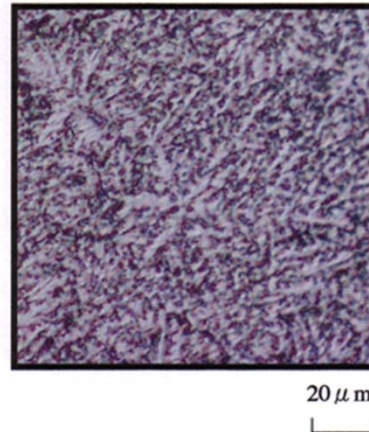
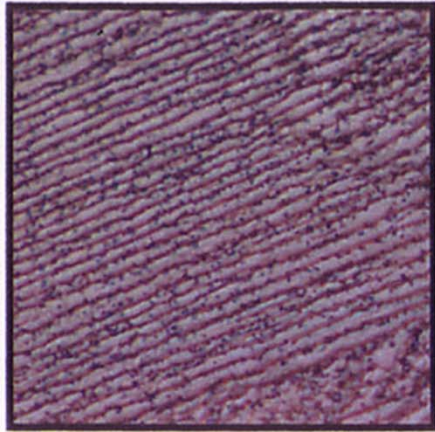


Fig.Mg-Al phase diagram

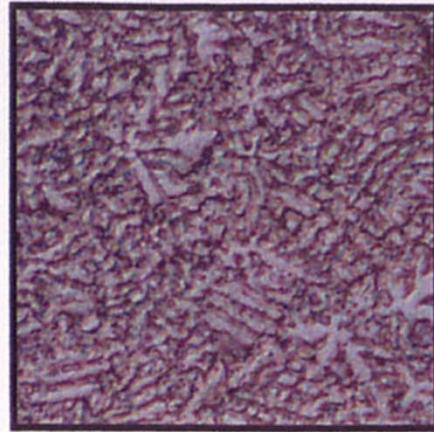


(a) AZ31 (Al 3%)



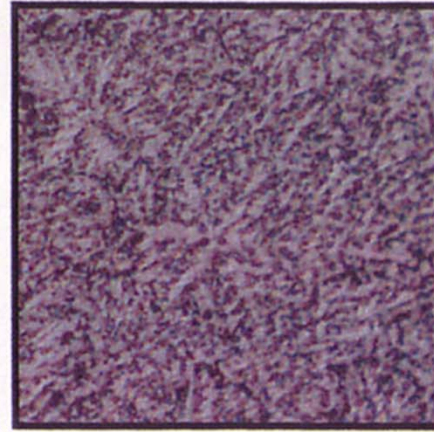
20  $\mu$  m

(b) AZ61 (Al 6%)

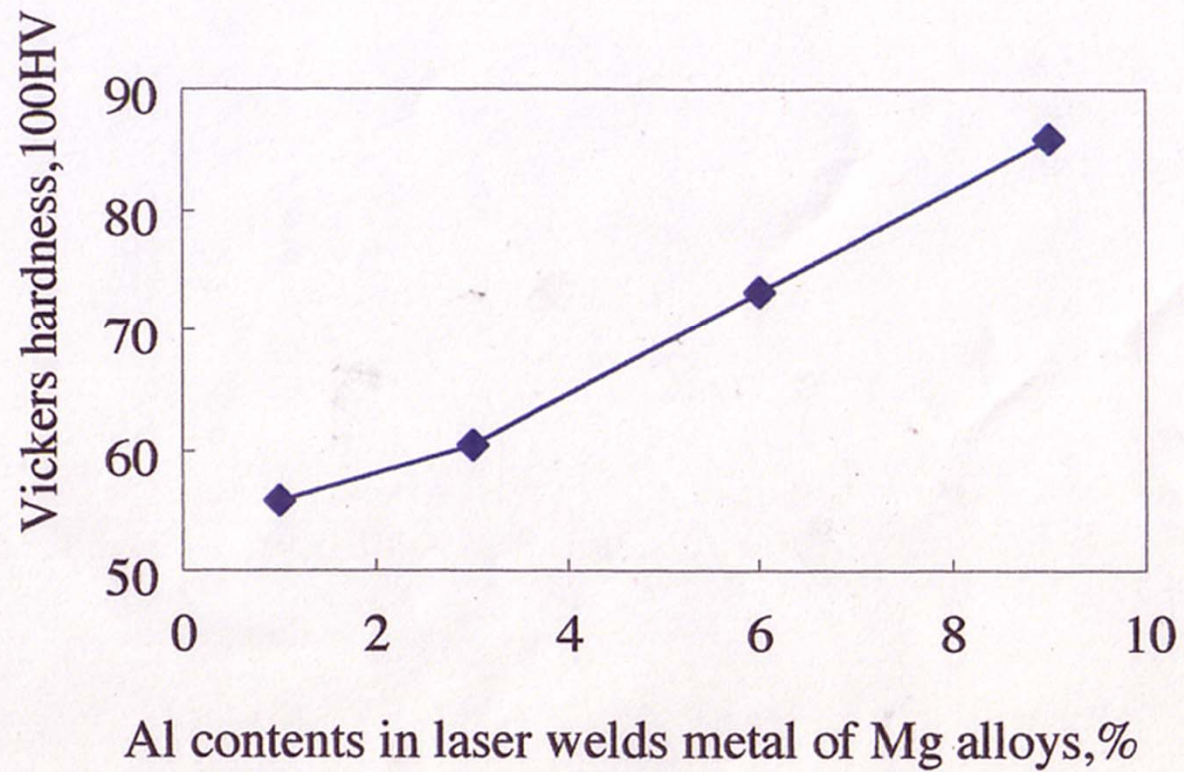


20  $\mu$  m

(c) AZ91 (Al 9%)

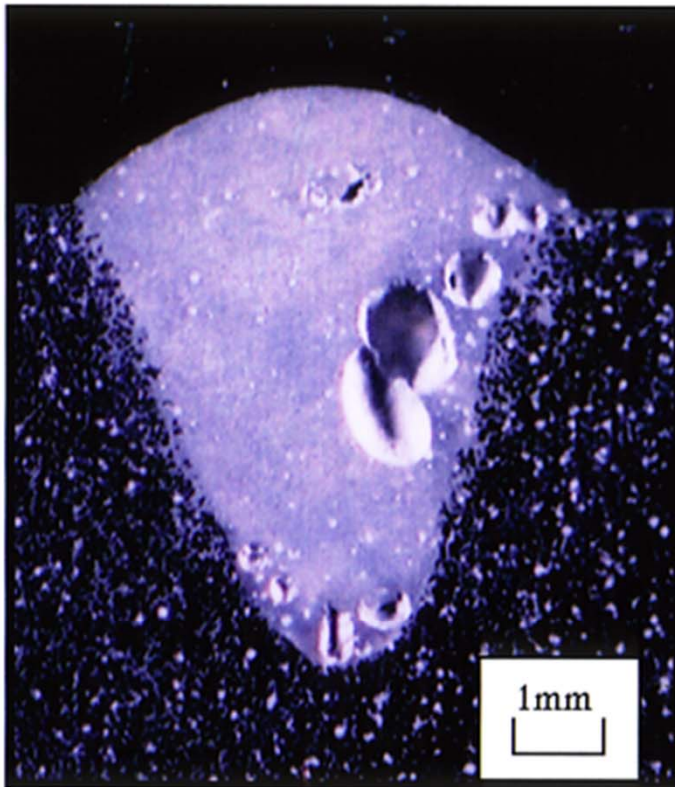


20  $\mu$  m

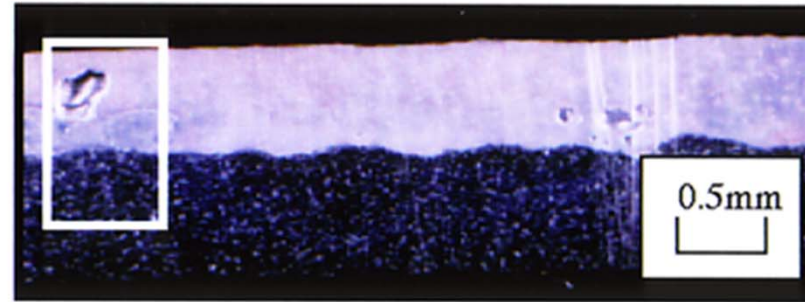


# レーザー溶接における気孔発生機構

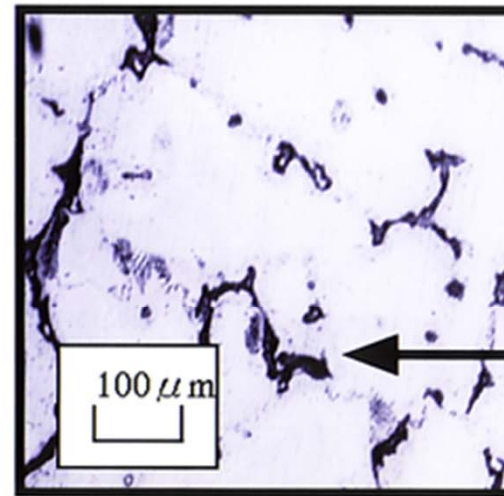
## マグネシウム鋳造合金溶接部のポロシティ



(a) Cross section of laser weld of AZ91 cast alloy



(b) Bead appearance



(c) Base metal (AZ91 cast alloy)



# ポロシティのSEM像

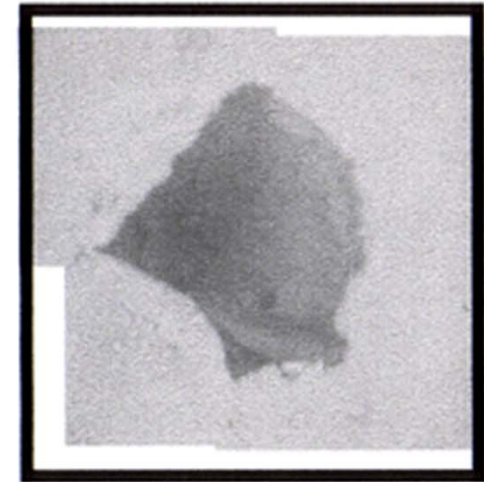
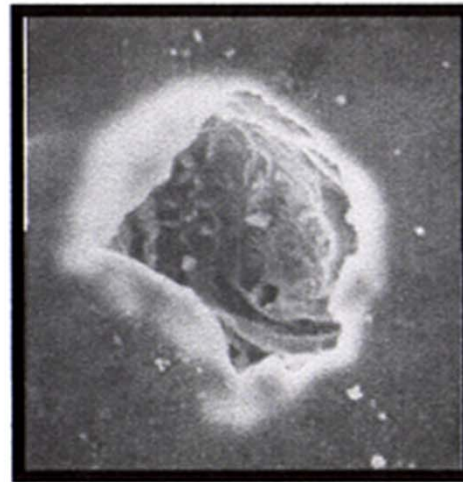
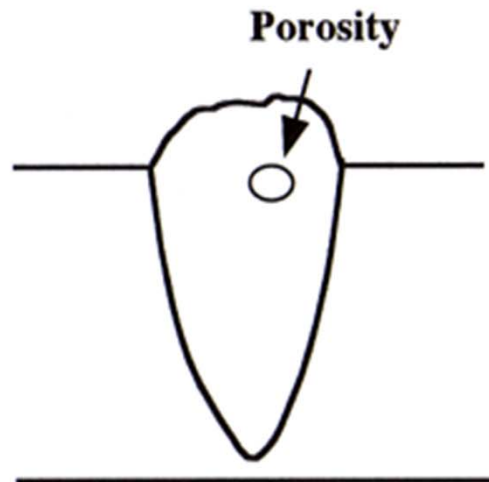
Laser power 1kW

Welding speed 2m/min

Defocusing distance

SEM

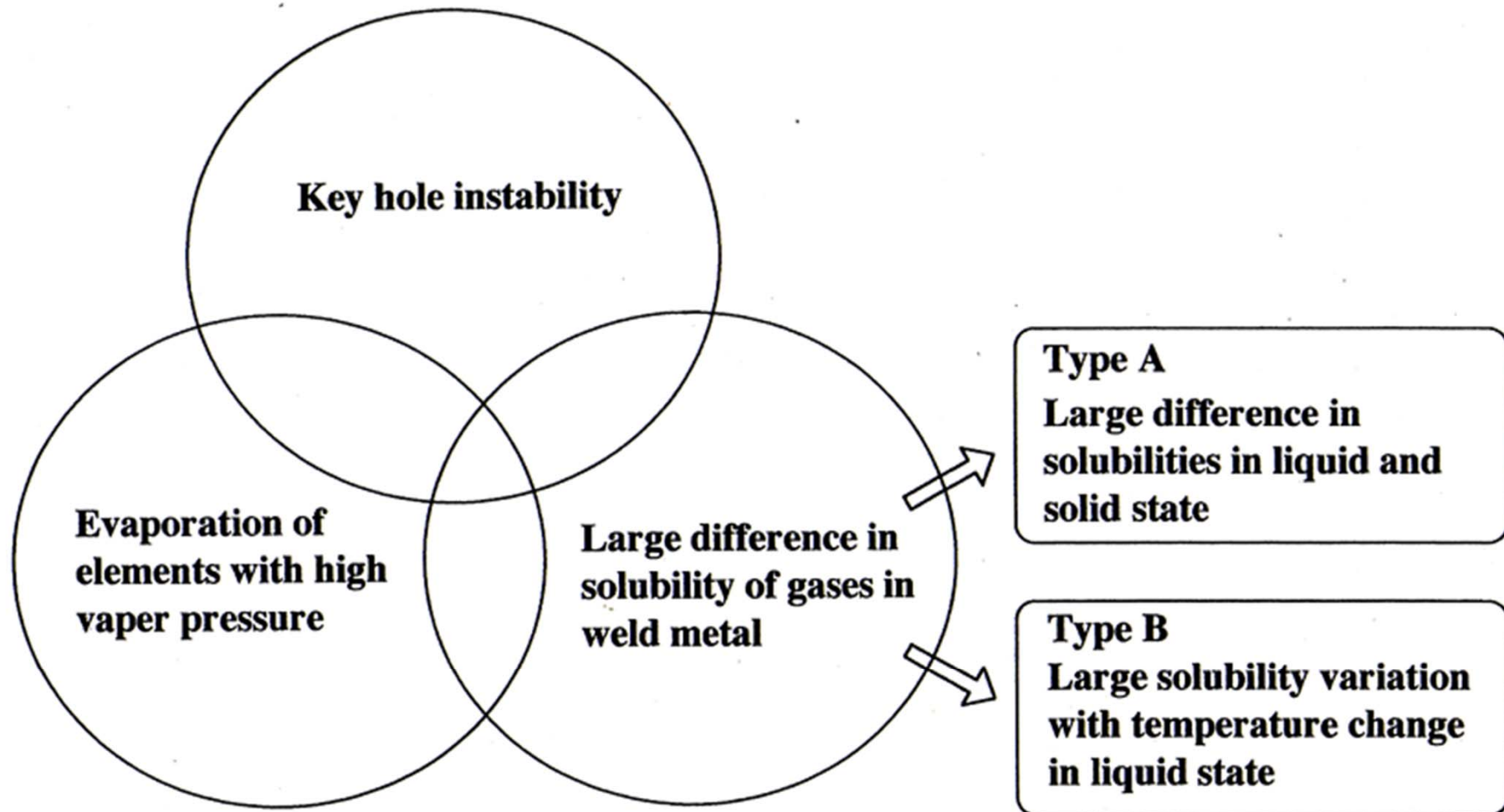
COMPO



40  $\mu$ m

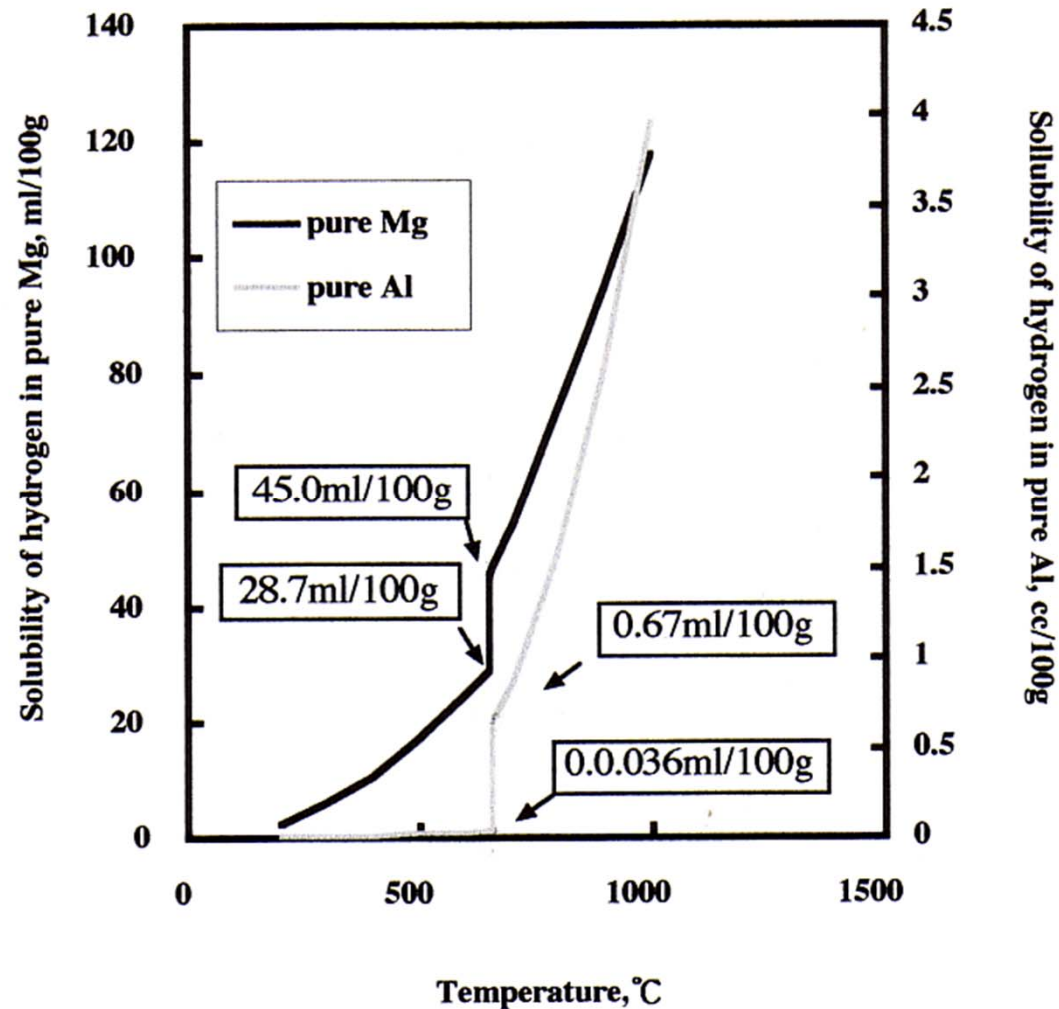


# 3つの気孔発生機構

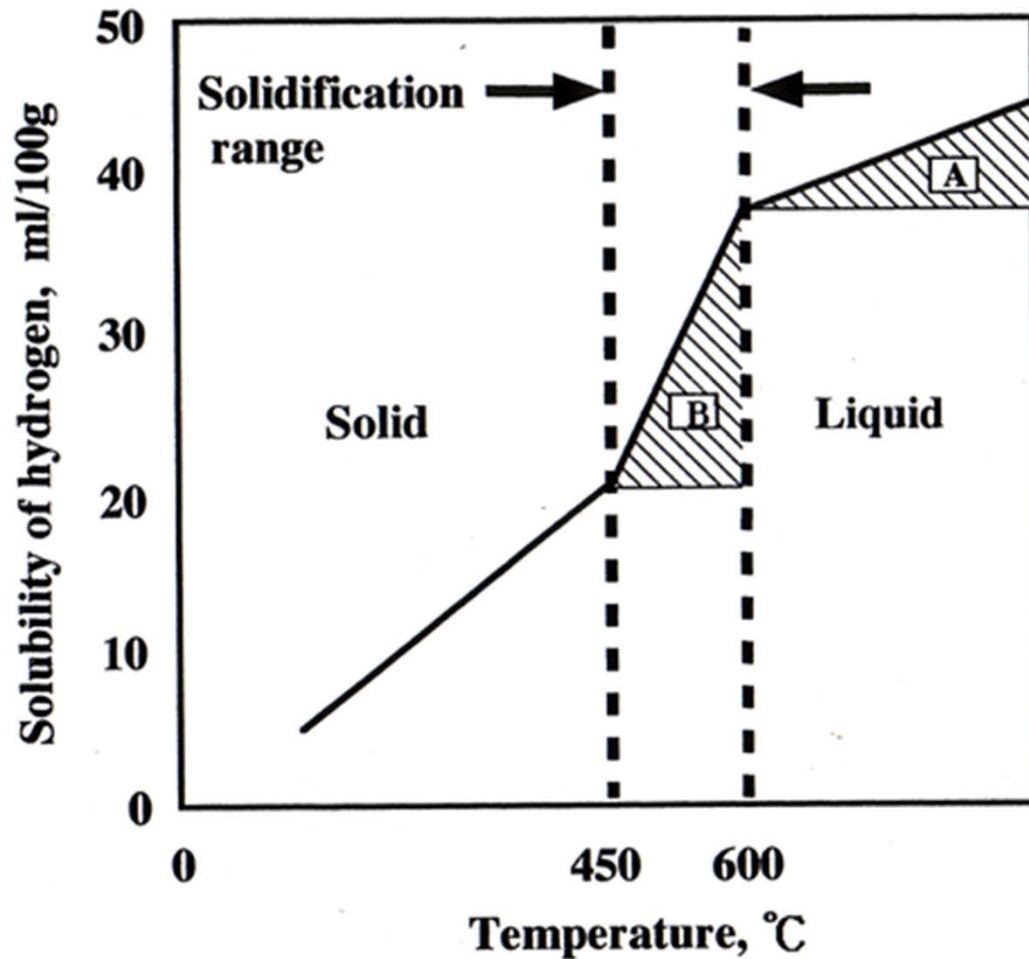


**Fig. Sources of porosity formation during laser welding**

# アルミニウムおよびマグネシウムの 水素溶解度



# AZ91合金の水素溶解度



**Solidification range**

600~450°C (AZ91)

**Solubility of hydrogen, ml/100g**

700°C                      40ml/100g

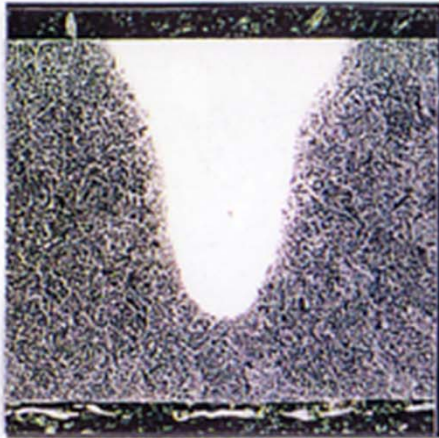
**Solidus temperature**                      20~30ml/100g



# アルミニウムとマグネシウムの レーザ溶接部の耐気孔性

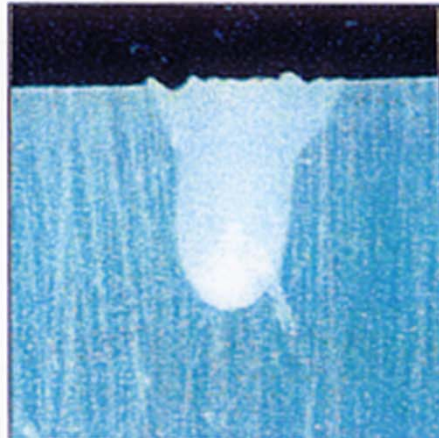
AZ91(with water sprayed)

Laser power 1kW  
Welding speed 1m/min



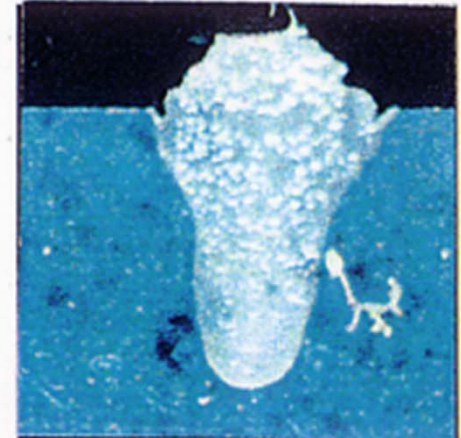
A5182(without water sprayed)

Laser power 4.2kW  
Welding speed 4m/min



A5182(with water sprayed)

Laser power 4.2kW  
Welding speed 4m/min

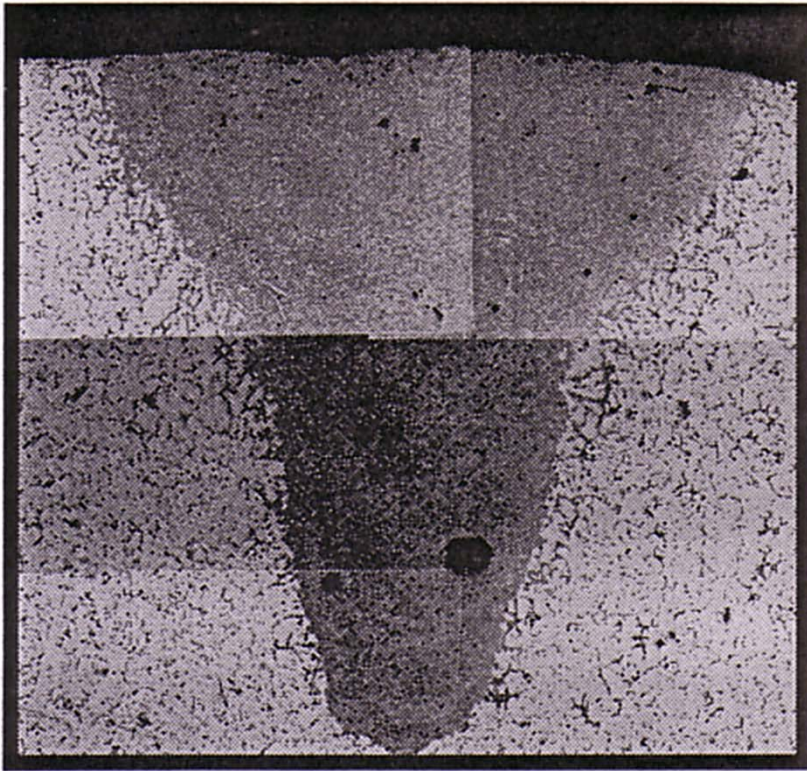


2mm

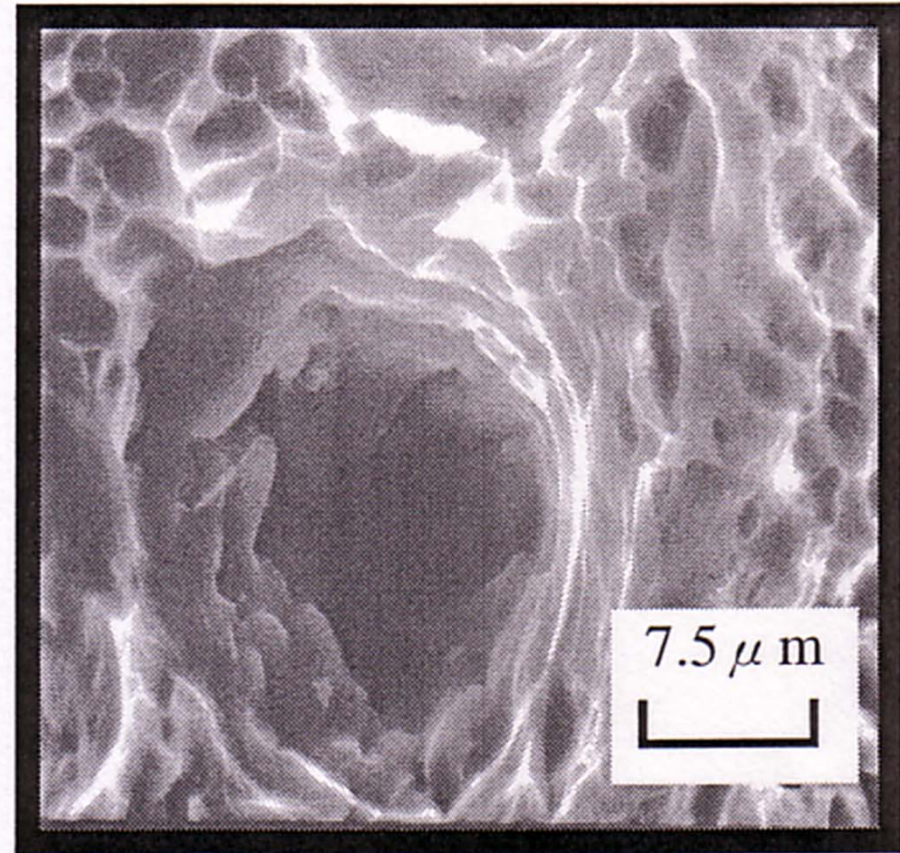


# AZ91合金レーザー溶接部の気孔

With water sprayed

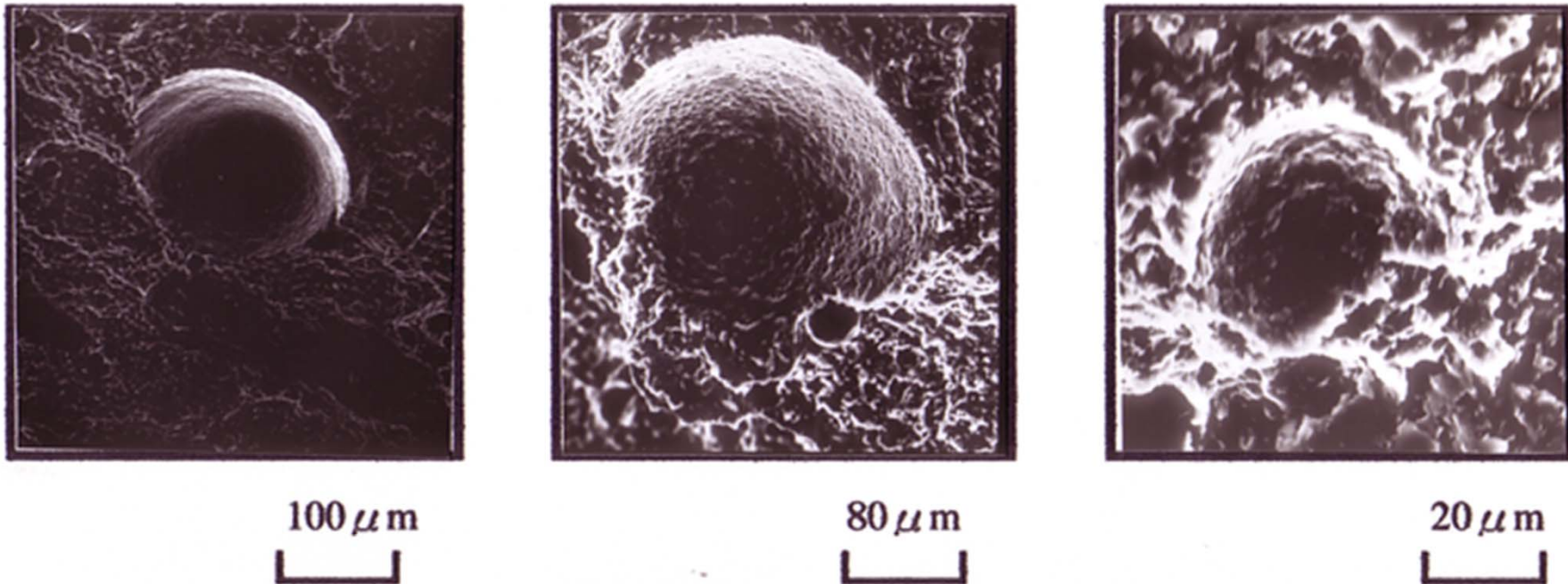


マクロ断面写真



SEM写真

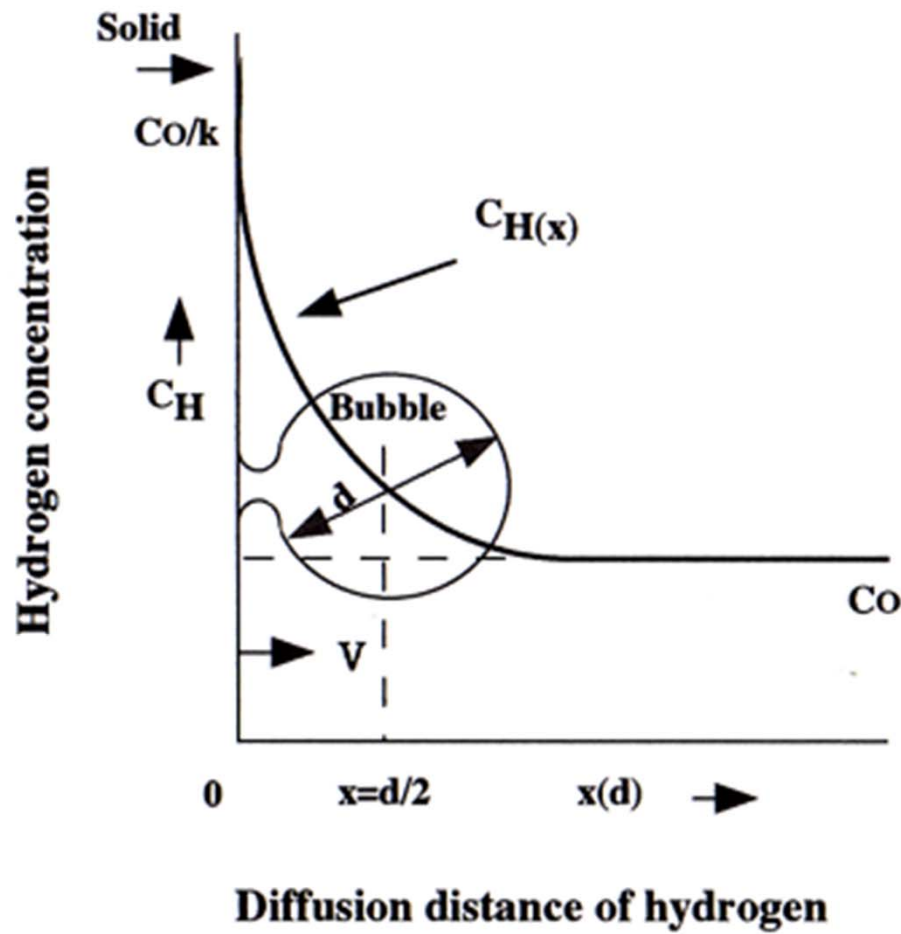
# AZ91溶接金属のポロシティ



**Fig.3-9 Typical porosity in fractographs of fractured weld metal of AZ91 cast alloy**



# 固液界面で気泡が生成するモデル



$$C_H(x) = C_0 \left\{ 1 + \frac{(1-k)}{k} \cdot \exp(-V \cdot x/D) \right\}$$

$C_H$ : Solubility of hydrogen

$D$ : Diffusion coefficient

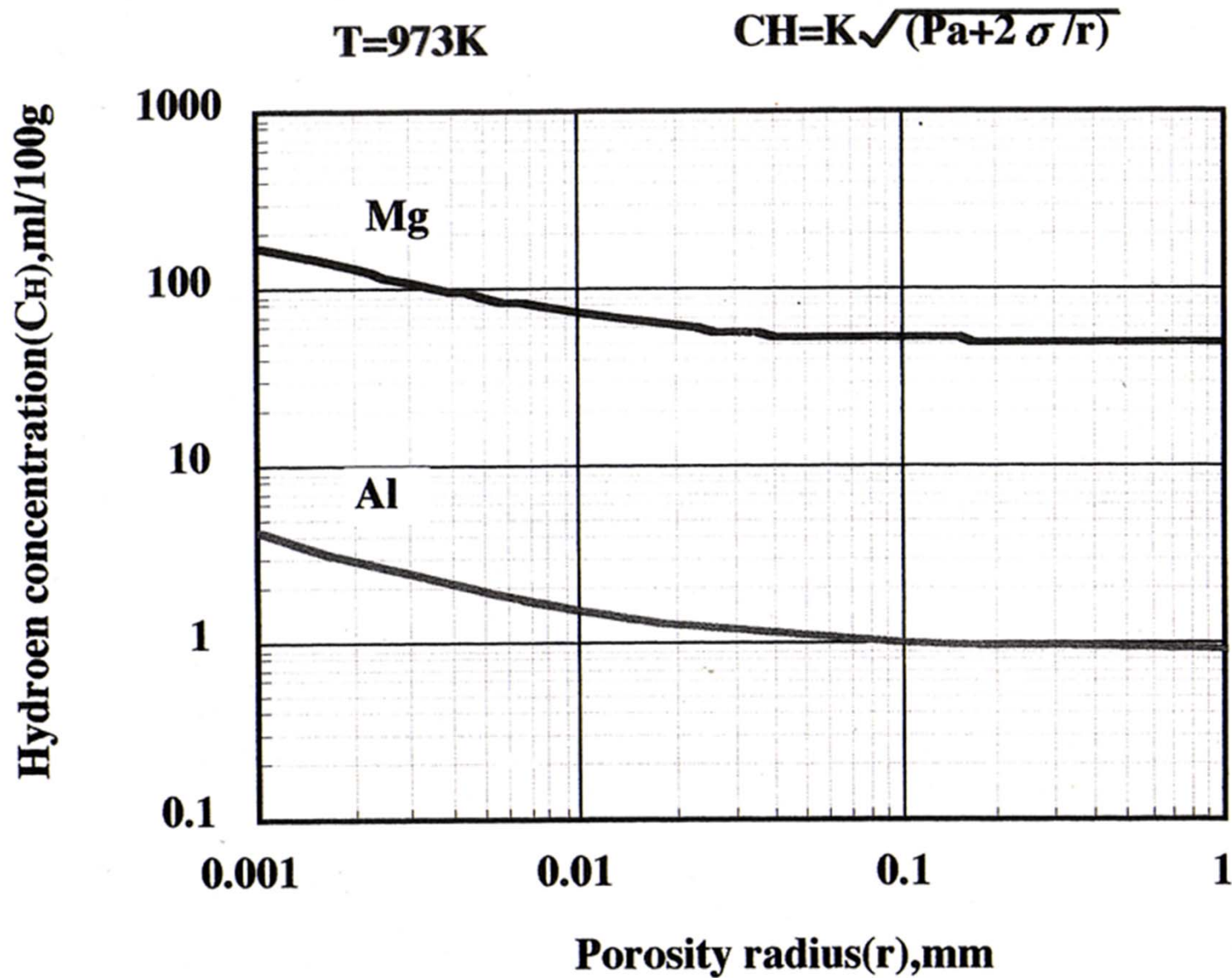
$V$ : Rate of advance of solidification front

$x$ : Distance of diffusion

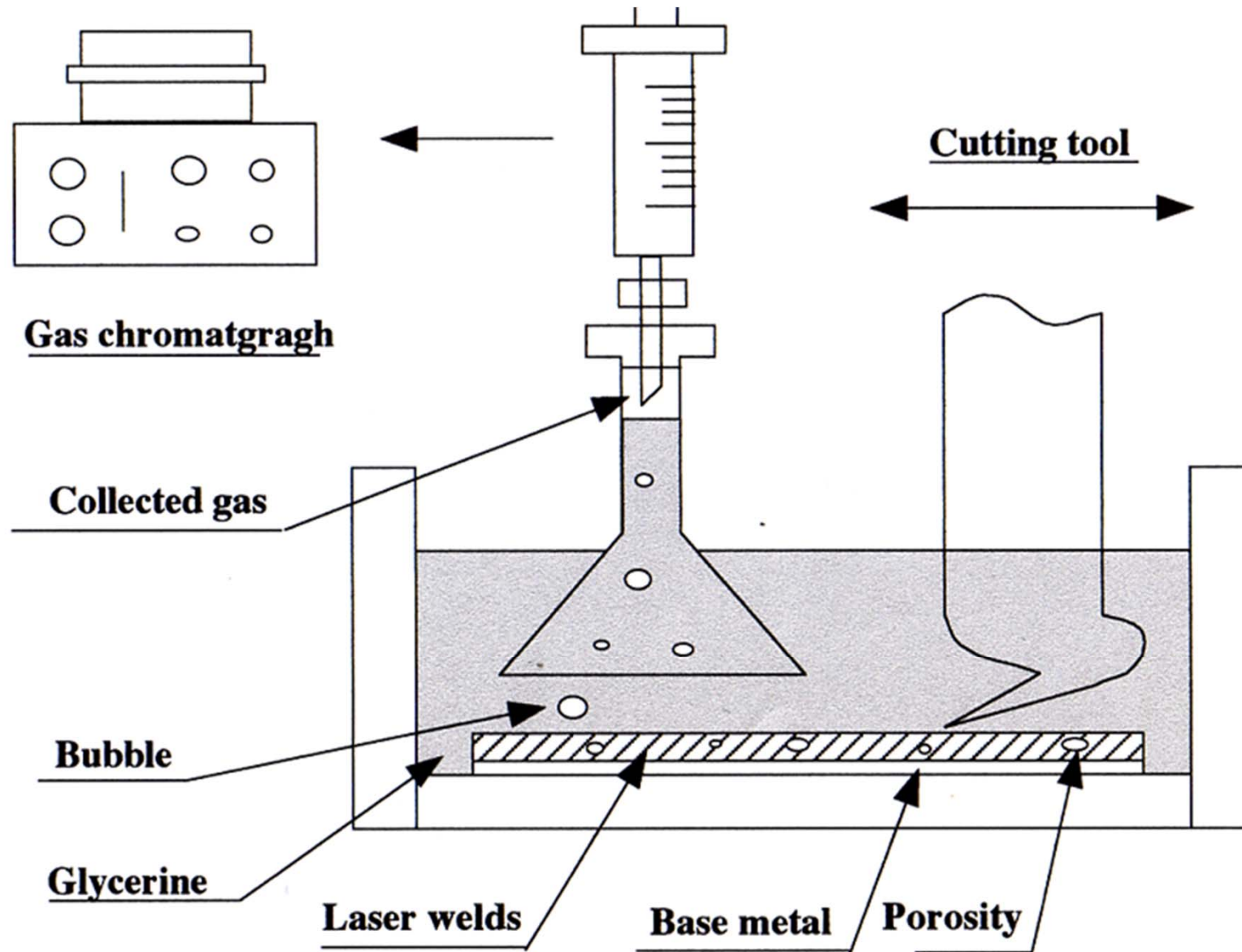
$k$ : Distribution coefficient



# 気泡発生のための水素濃度と気泡径



# ポロシティ内部ガスの捕集方法



**Cast Alloys  
Base metal**

**Cast Alloys  
Weld metal**

**Wrought alloys  
Weld metal**

**AZ91**

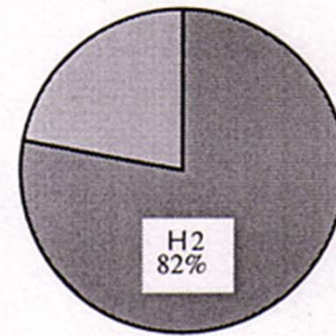
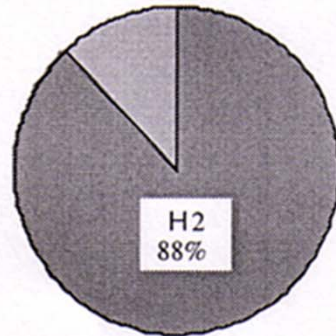
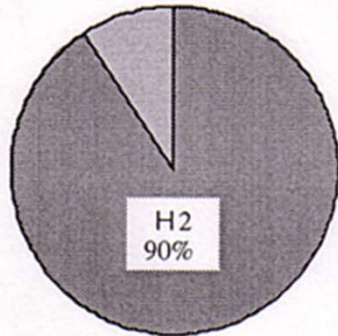
**AZ91**

**AZ31**

Ar,N2  
10%

Ar,N2  
12%

Ar,N2  
18%



**AZ13**

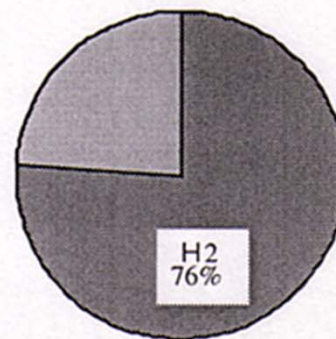
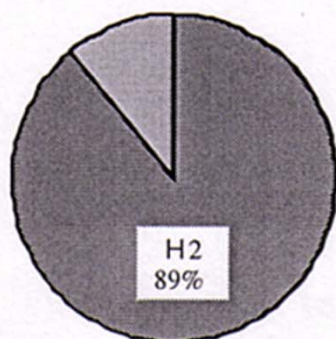
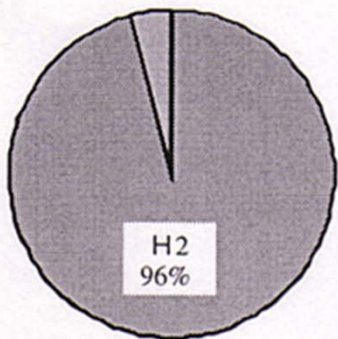
**AZ13**

**AZ61**

Ar,N2  
4%

Ar,N2  
11%

Ar,N2  
24%

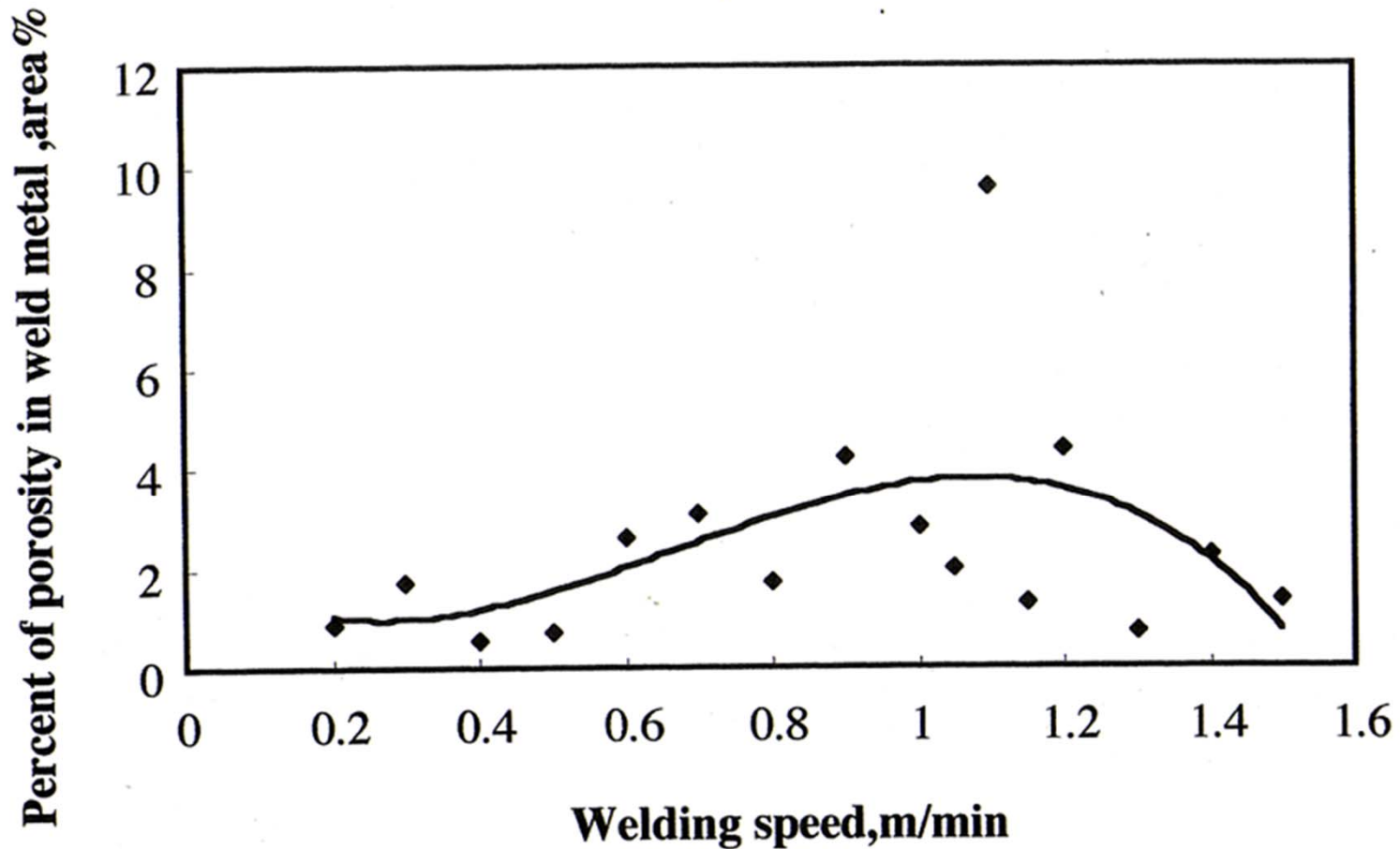


**ポロシティ内部のガス**



# レーザー溶接における気孔発生

Laser power :600W  
Defocusing distance:0mm



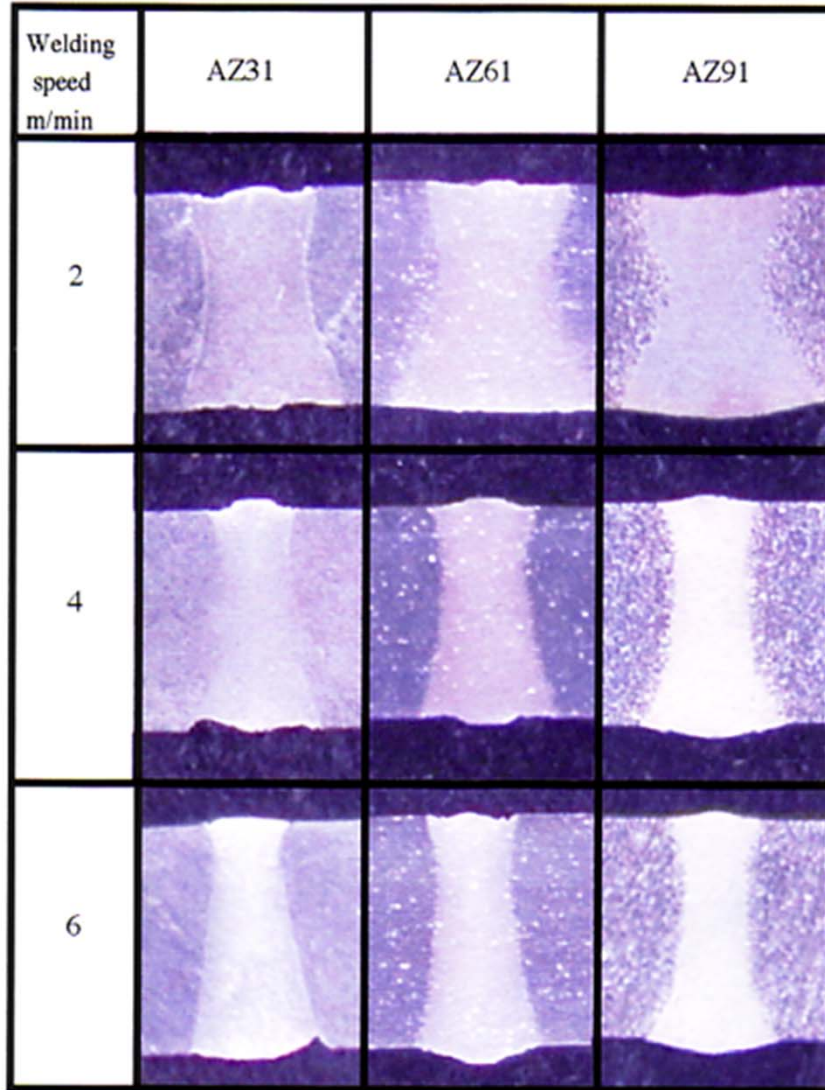
# 溶接部の継手性能

## TIG溶接部


Table 2. ティグ溶接継手の引張性質

母材	溶接棒	引張性質						継手効率(%)	
		母材			溶接継手				
		引張強度 (N/mm <sup>2</sup> )	耐力 (N/mm <sup>2</sup> )	伸び (%)	引張強度 (N/mm <sup>2</sup> )	耐力 (N/mm <sup>2</sup> )	伸び (%)		
鋳物用合金	MC 1 (AZ 63 A)-T6	AZ 63	275	131	5	212	—	2	77
	MC 2 (AZ 91 C)-T6	AZ 92	275	131	5	207	—	2	75
	MC 3 (AZ 92 A)-T6	AZ 92	275	145	2	241	145	2	88
展伸材用合金	MP 1 (AZ 31 B)-O	AZ 61 AZ 92	255	152	21	248	131	11	97
	MP 1 (AZ 31 B)-H24	AZ 61 AZ 92	289	221	15	255	152	5	88
	MS 1 (AZ 31 B)-F	AZ 61 AZ 92	262	200	15	255	—	7	97
	MS 2 (AZ 61 A)-F	AZ 61 AZ 92	310	227	16	274	—	6	89
	MS 3 (AZ 80 A)-F	AZ 61 AZ 92	338	262	11	289	—	4	86

# レーザーによる完全溶込み溶接

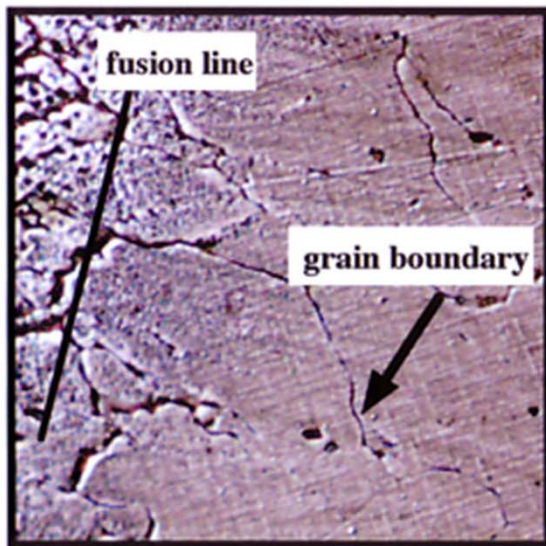


Laser power :1kW  
Defocusing distance:0mm

1mm  


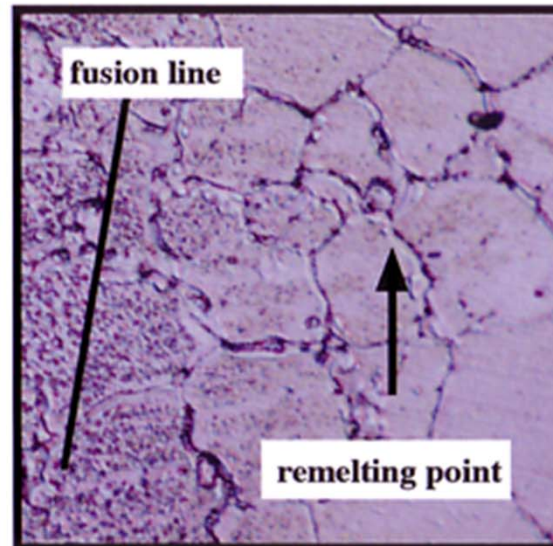


# 溶接熱影響部の組織



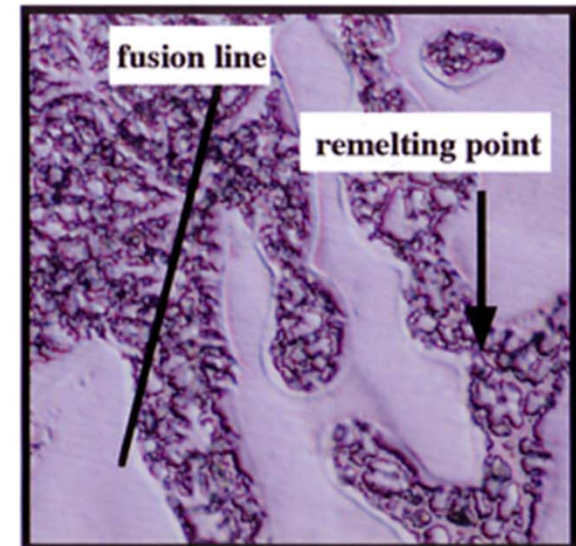
100  $\mu$ m

(a) AZ31



100  $\mu$ m

(b) AZ61



100  $\mu$ m

(c) AZ91

Table 5-1 Tensile strength of Mg alloy laser joint

(a)AZ31

Welding speed (m/min)	Fractal position	Tensile strength (MPa)	Efficiency (%)
2	Base metal	204	100
3	Base metal	204	100
4	Base metal	194	100

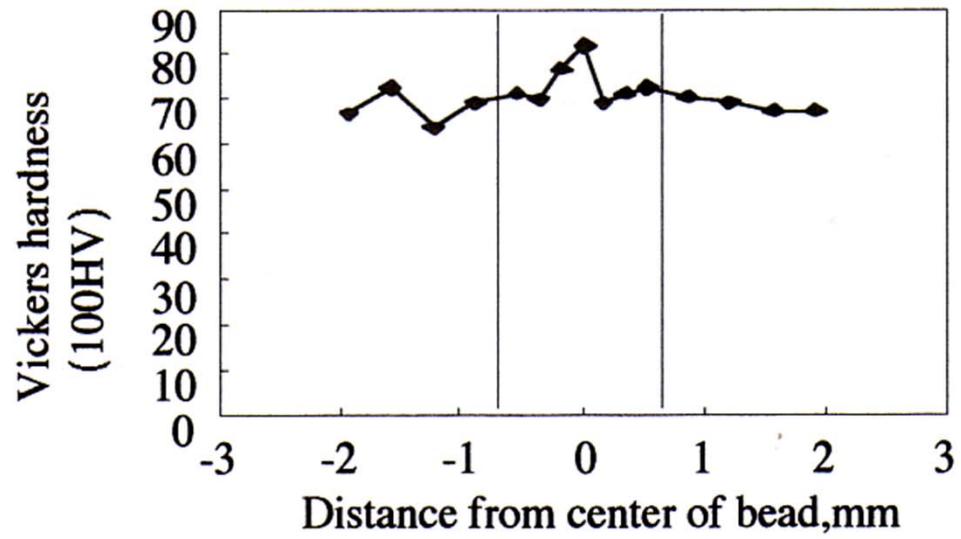
(b)AZ61

Welding speed (m/min)	Fractal position	Tensile strength (MPa)	Efficiency (%)
2	HAZ	238	85
3	HAZ	260	93
4	HAZ	252	90

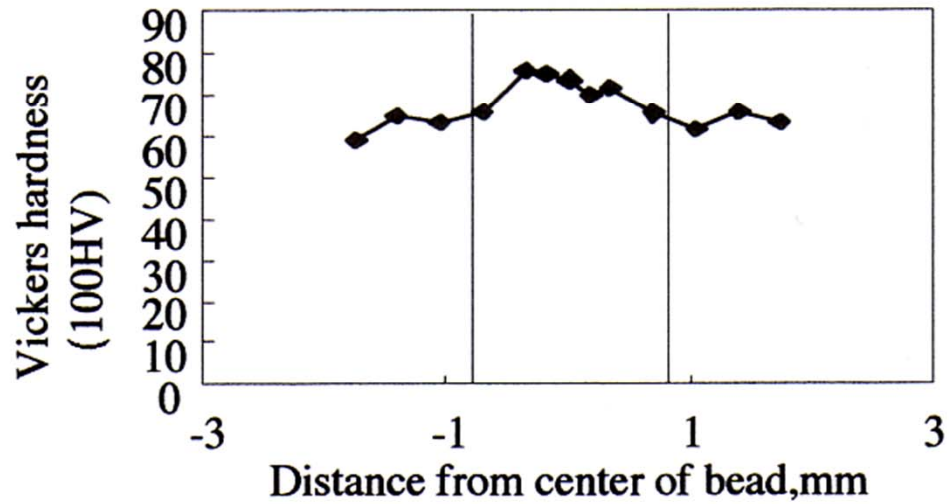
(c)AZ91

Welding speed (m/min)	Fractal position	Tensile strength (MPa)	Efficiency (%)
2	Base metal	127	100
3	Base metal	74	100
4	Base metal	40	100

**(a) 2m/min**



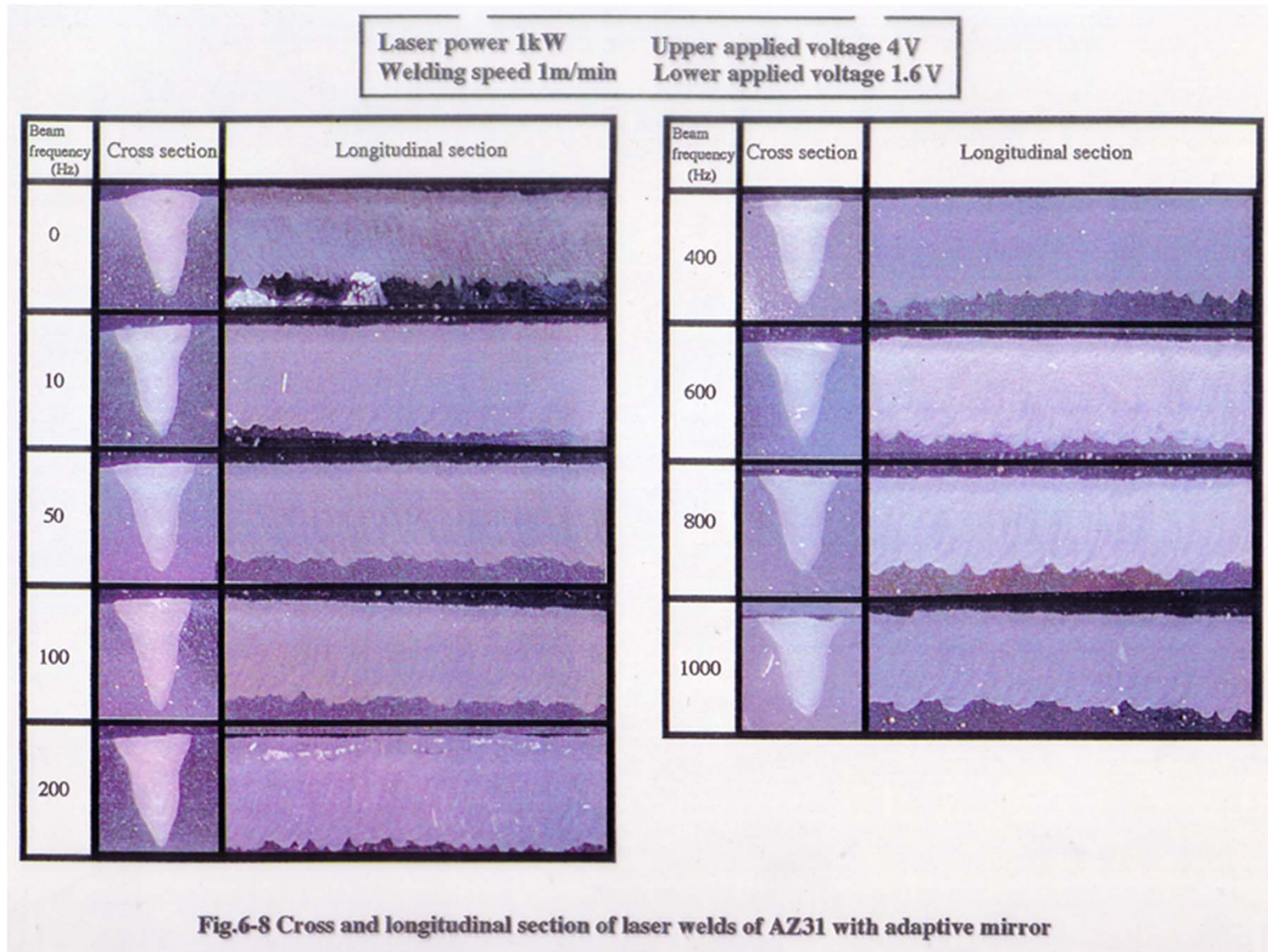
**(b) 4m/min**



**(c) 6m/min**



# ビード断面マクロ写真



# 組織の微細化

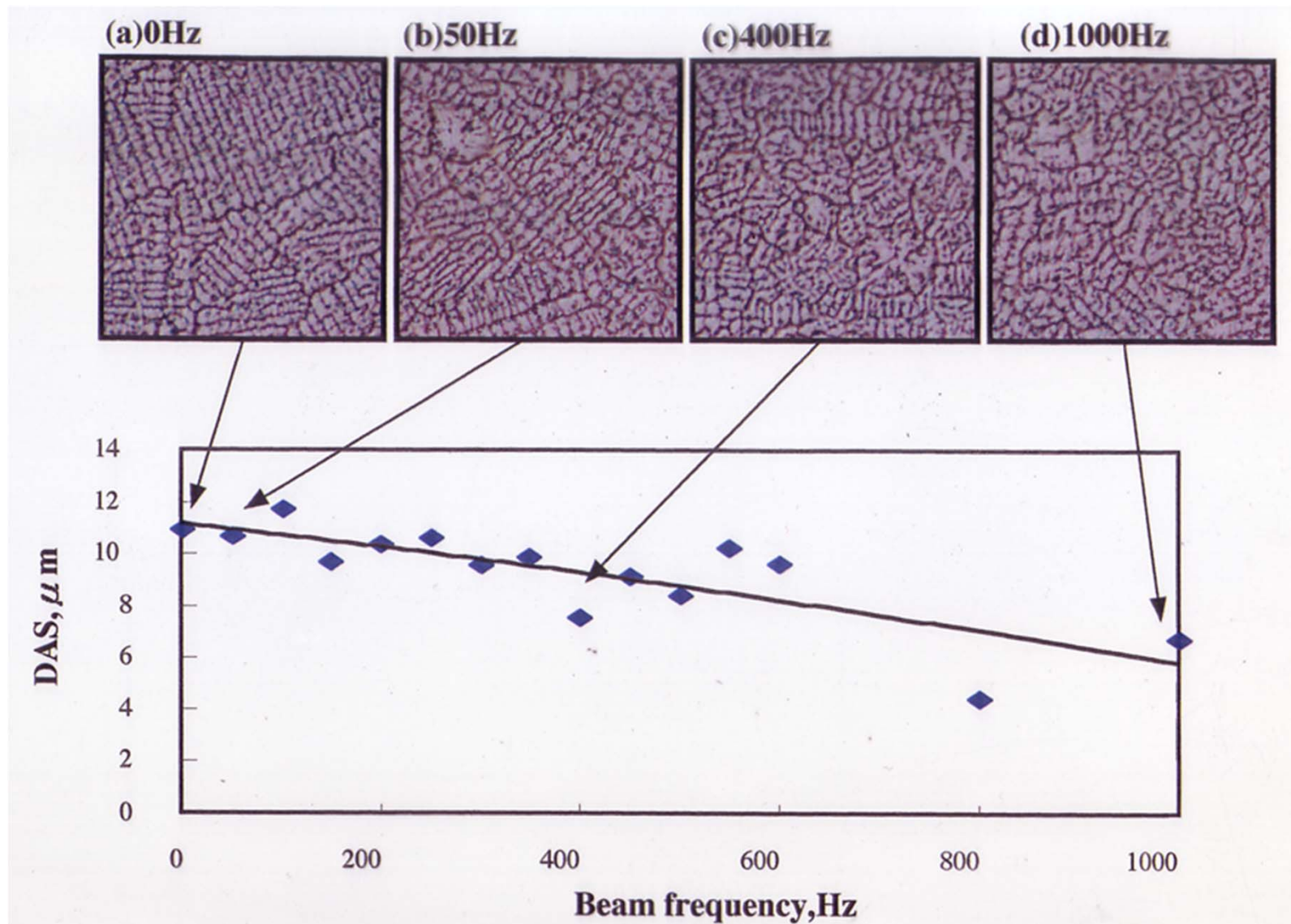


Fig. Relationship between DAS and beam frequency of laser welds of AZ31 with adaptive mirror by Liner intercept method

# 耐気孔性と周波数

