

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—

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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 ³	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 ³ ·K	20℃	1778	2430	3494
熱膨張率	10 ⁻⁶ /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 ⁻⁸ Ω·m	20℃	4.2	2.67	10.1
ヤング率	10 ¹¹ 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

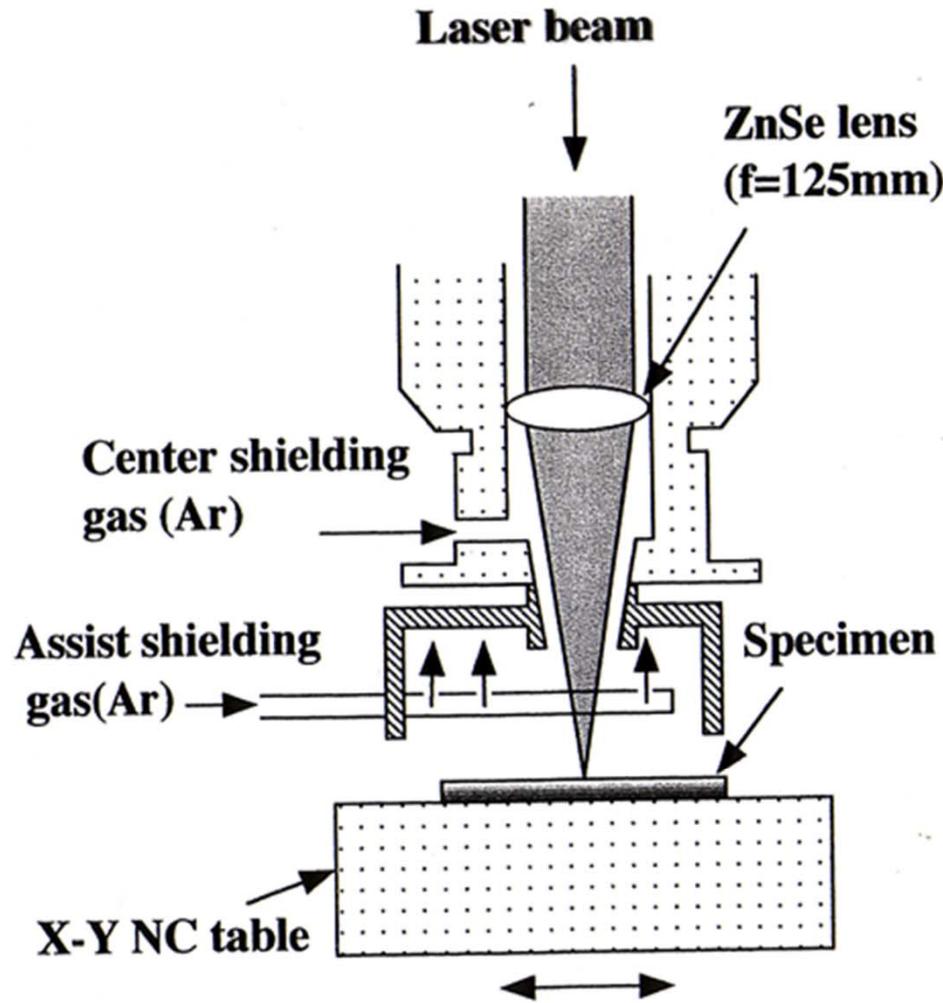
高エネルギー密度により、深溶込みを得られる。

非接触で溶接が可能である。

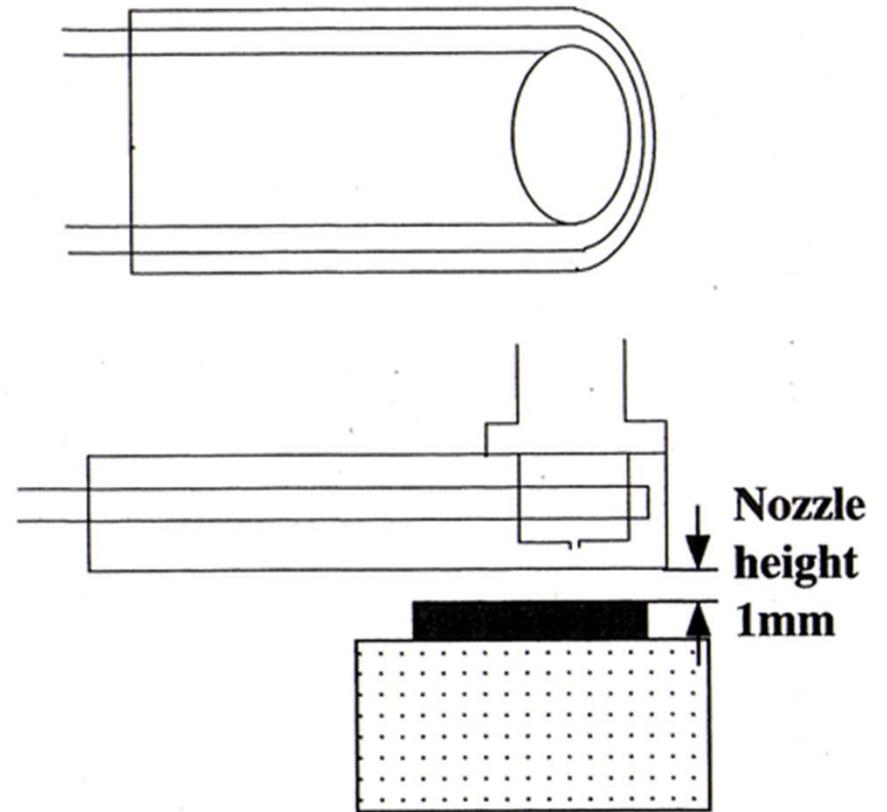
微細で精密な加工が可能である。

小入熱で溶接変形が少ない

レーザー溶接実験概要

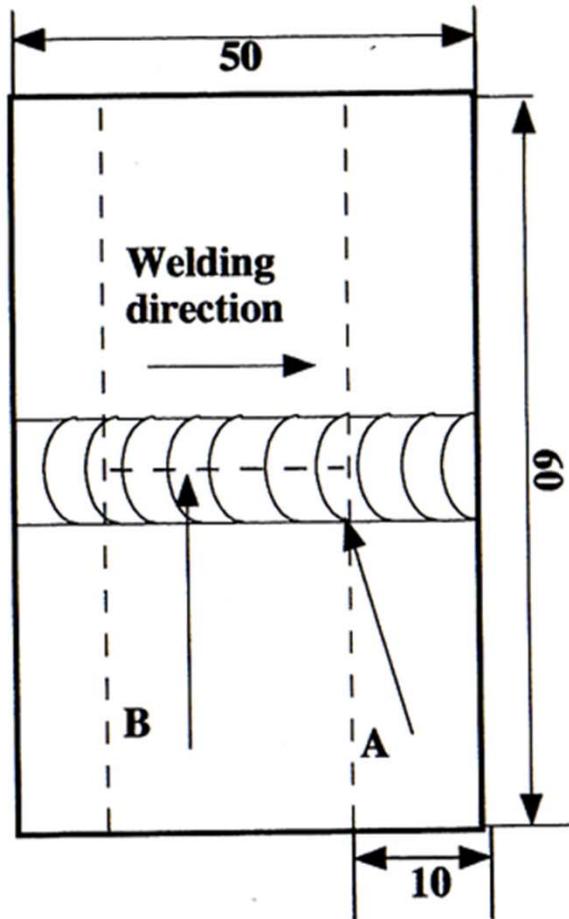


(a) CO₂ laser system



(b) Tail shielding gas nozzle

供試材



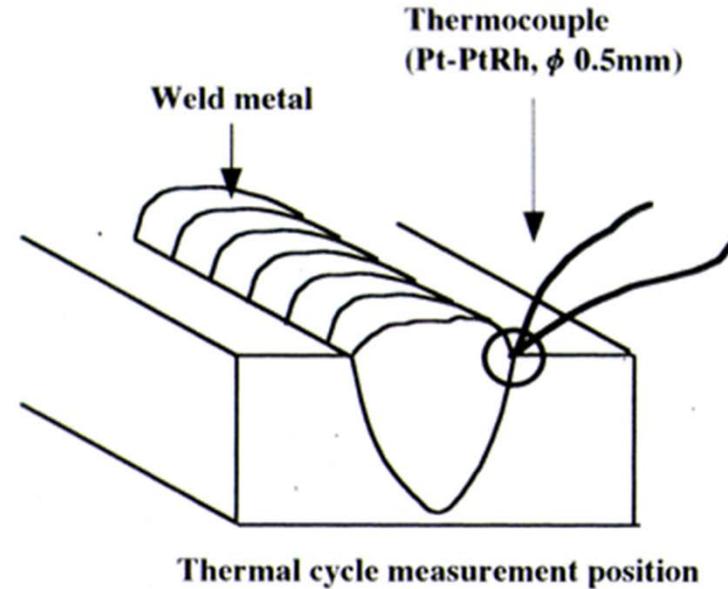
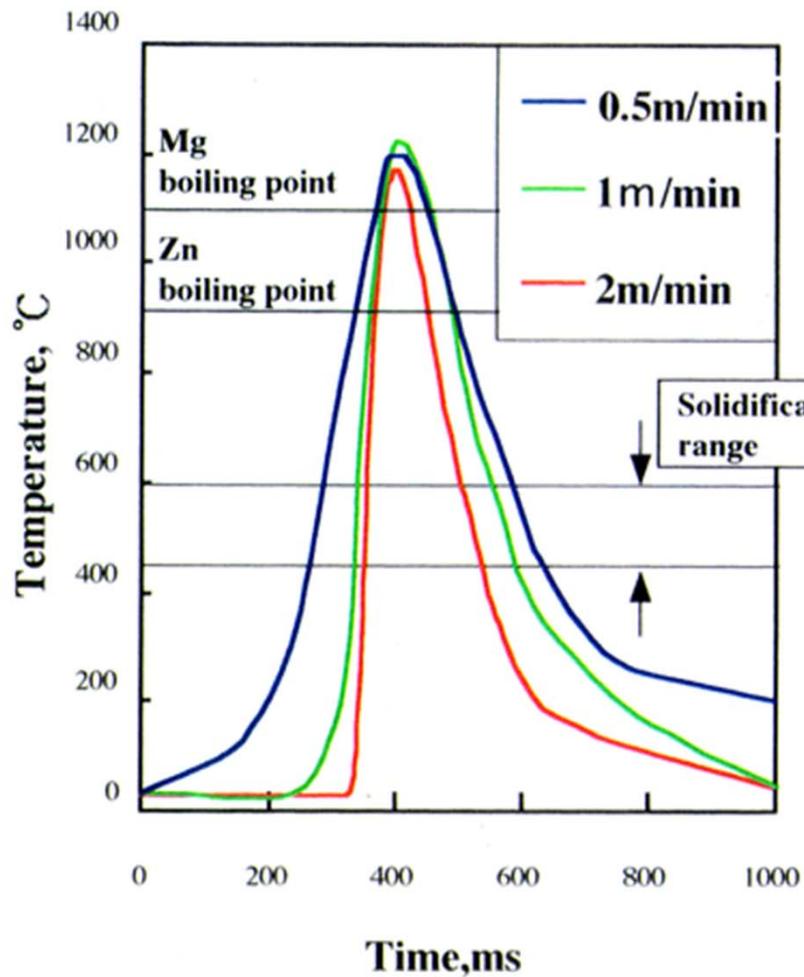
(a) Specimen size

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

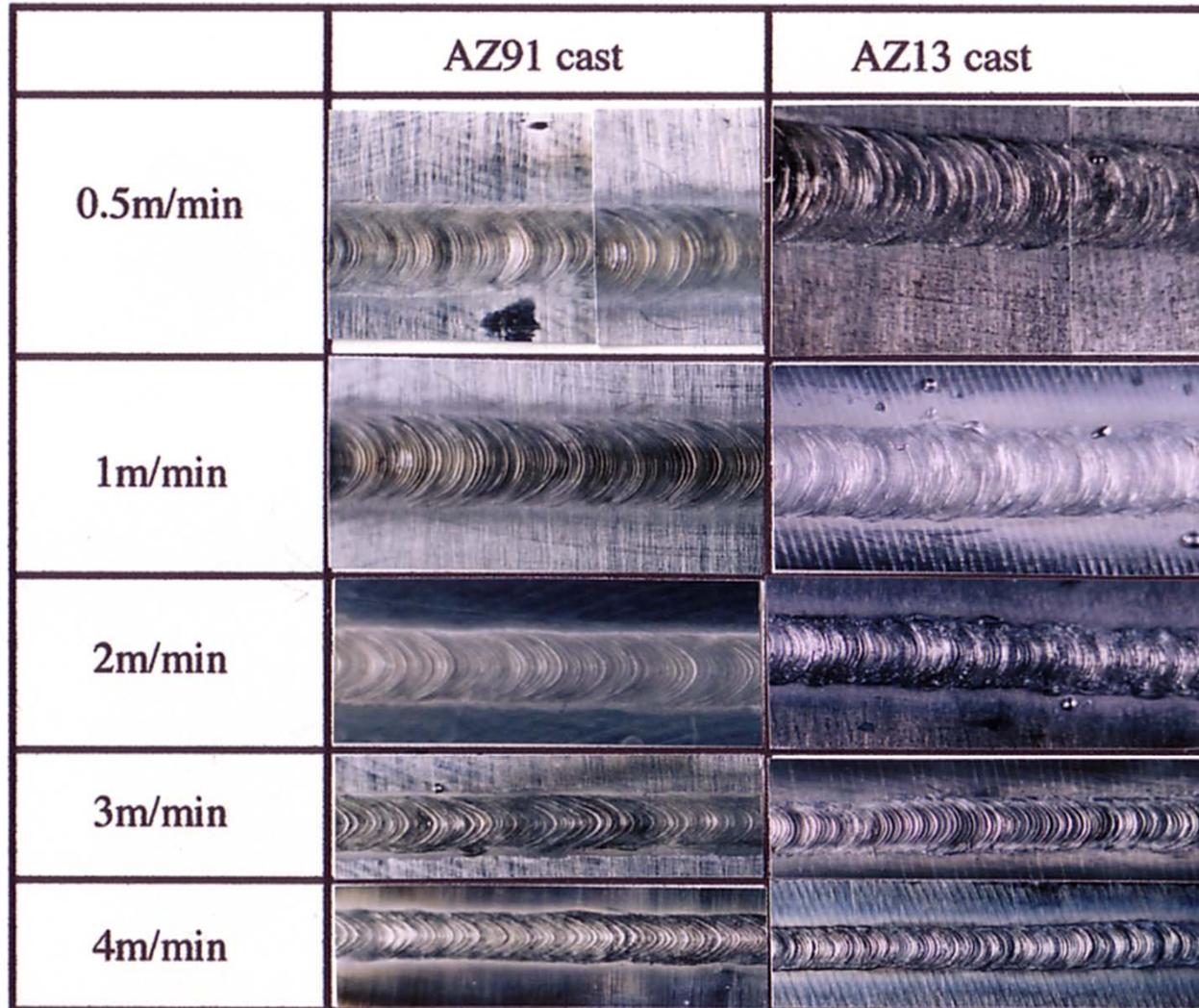
Fig Shape of laser welded specimen for analysis
(Cross section A , longitudinal section B for analysis)

熱サイクル測定



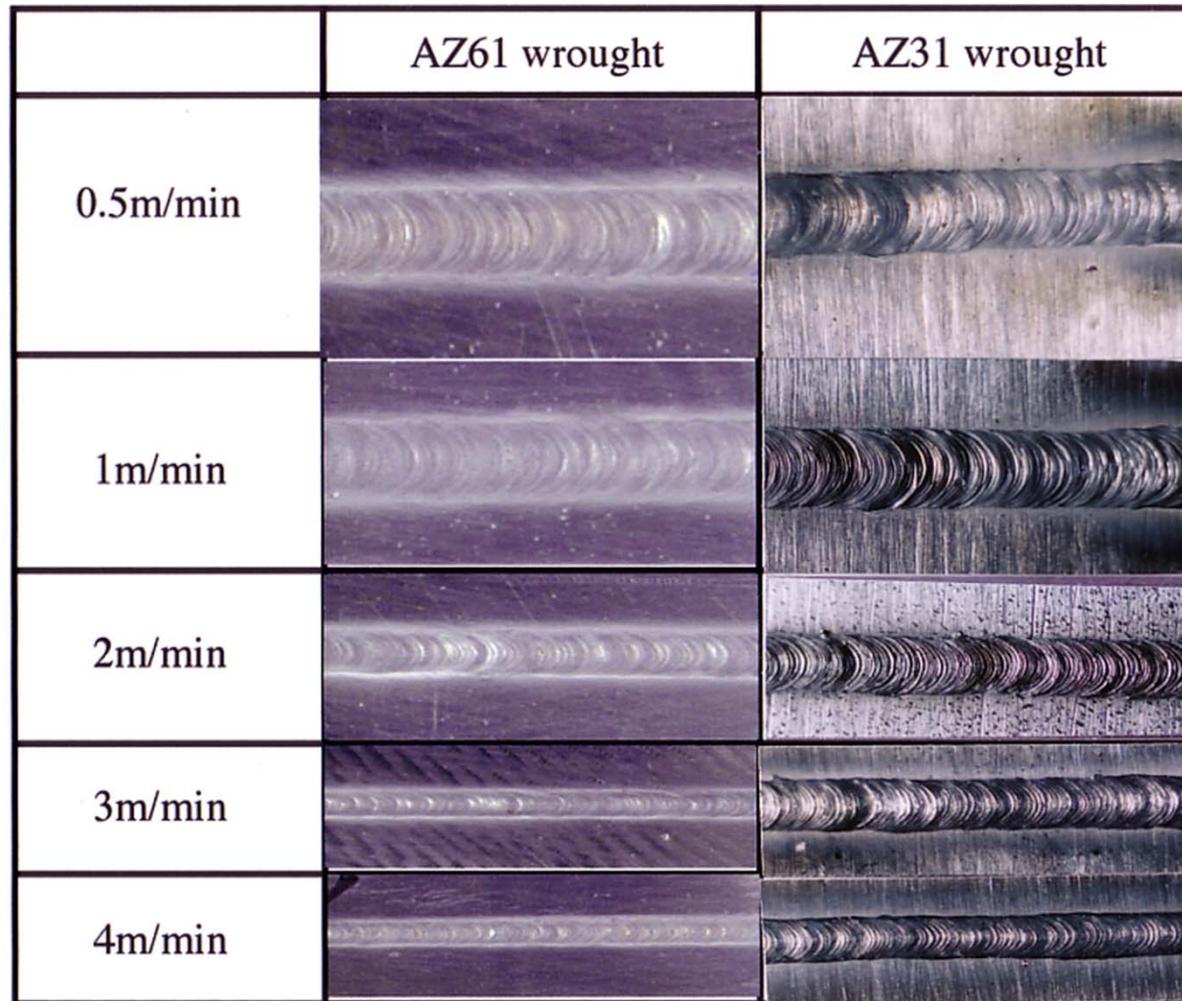
Welding speed, m/min	Cooling rate, K/s (600~465°C)	Solidification time, s (600°C ~ 465°C)
0.5	3.09×10^3	4.37×10^{-2}
1.0	3.55×10^3	3.8×10^{-2}
2.0	5.19×10^3	2.66×10^{-2}

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

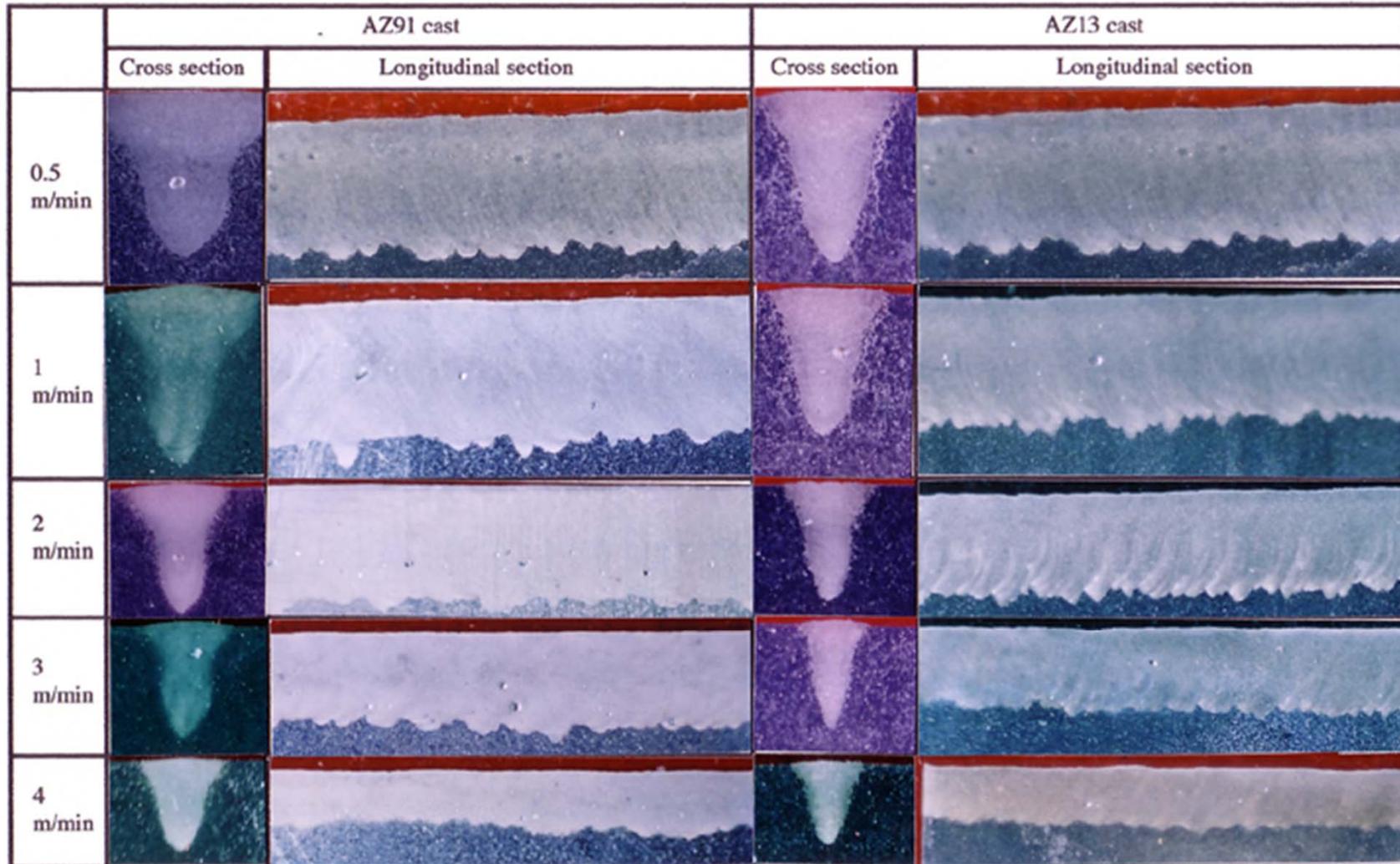


Fig.2-8 Macro cross section of Mg alloys in laser welds

2mm

ビードのマクロ断面写真

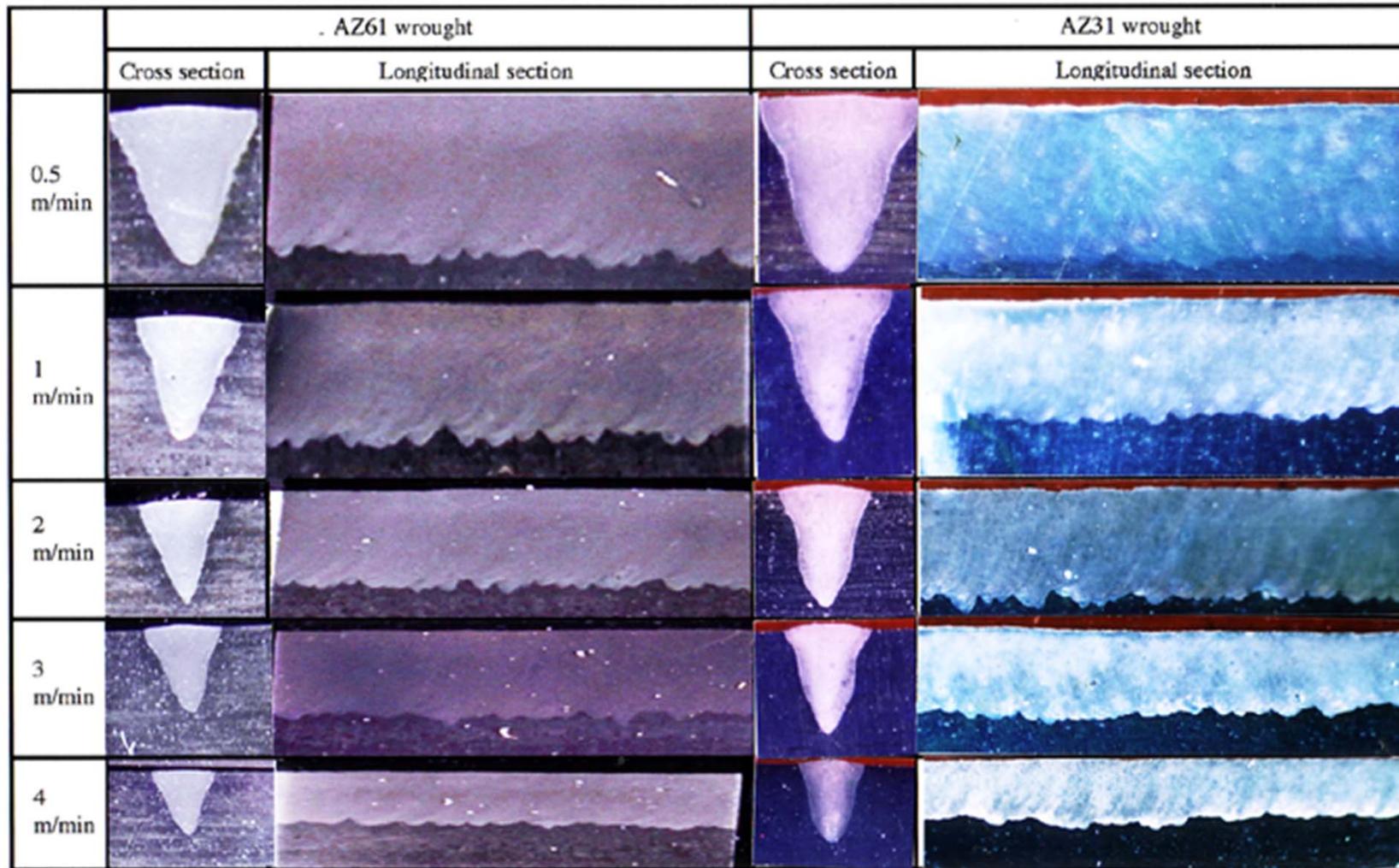
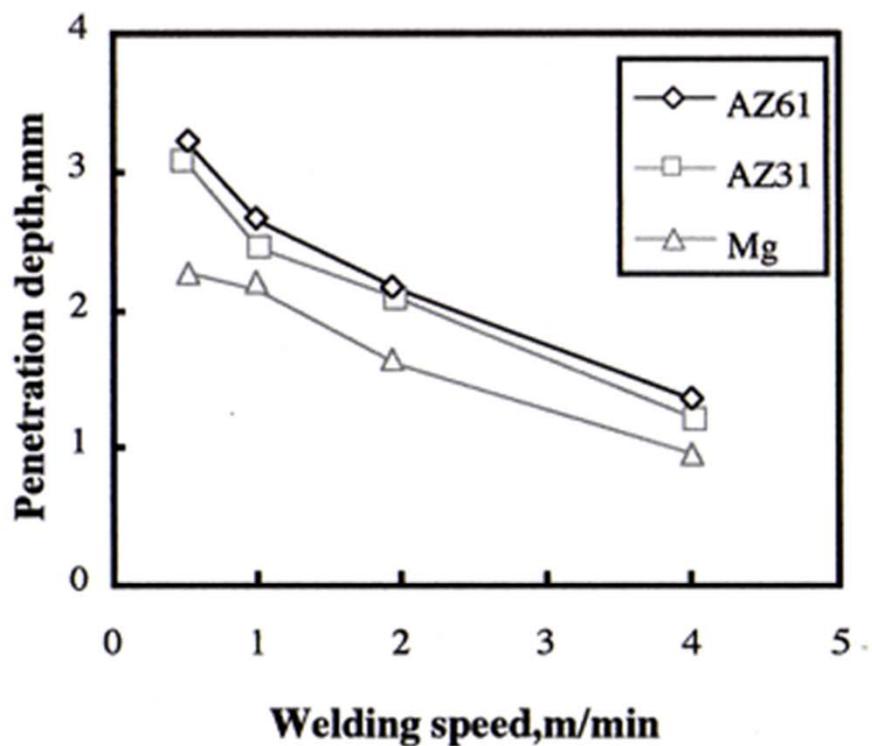


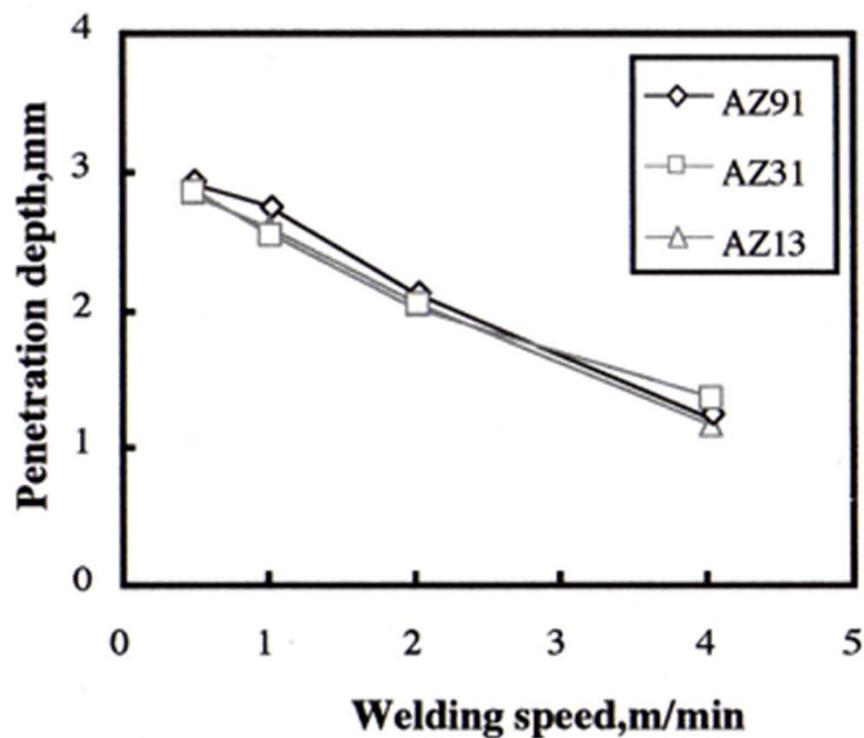
Fig.2-9 Macro cross section of Mg alloys in laser welds

2mm

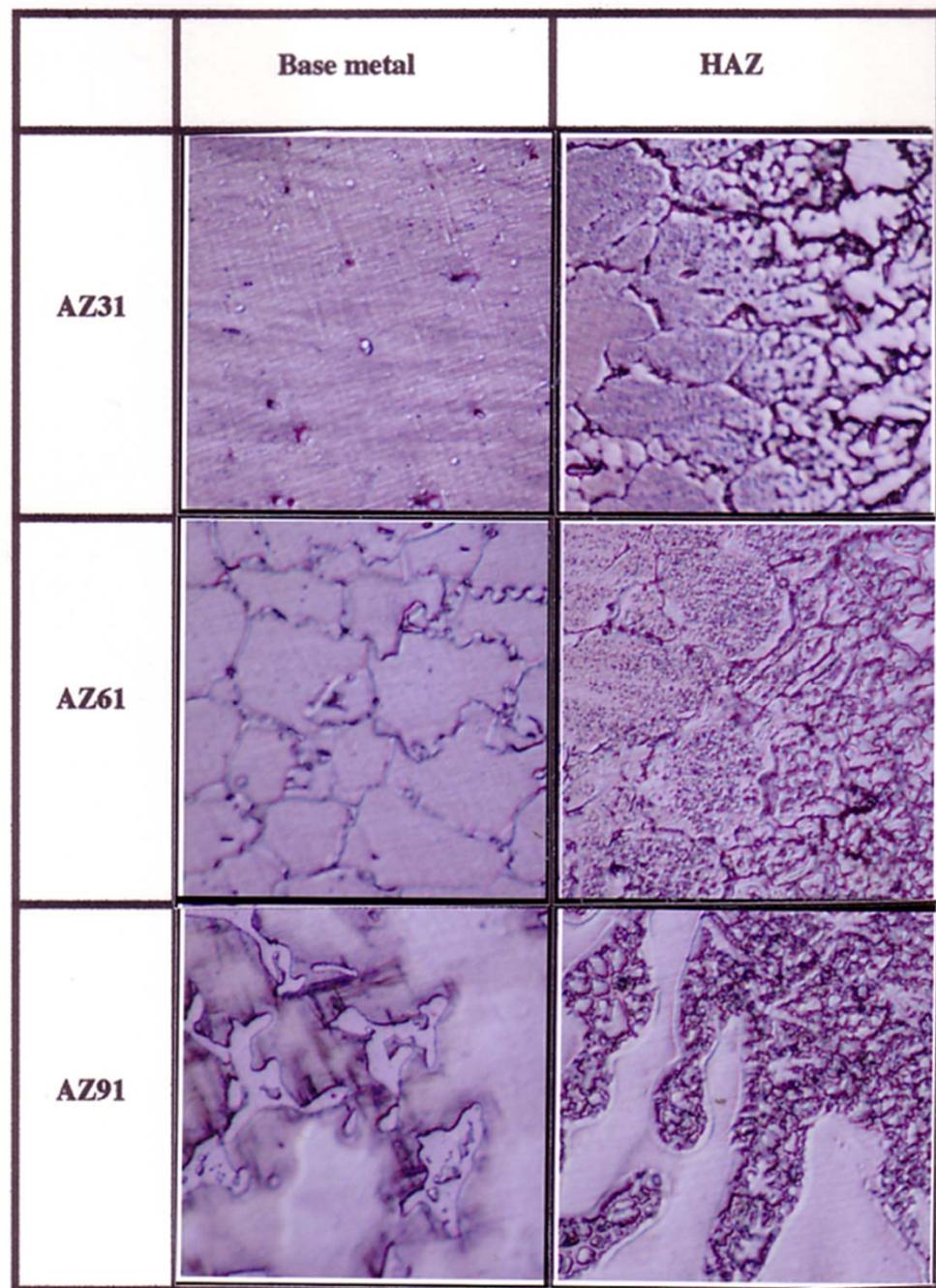
溶込み深さの変化



(a) Wrought Alloys



(b) Cast Alloys

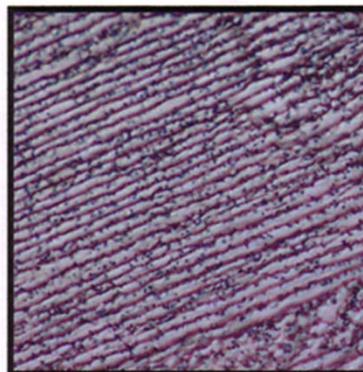


100 μ m



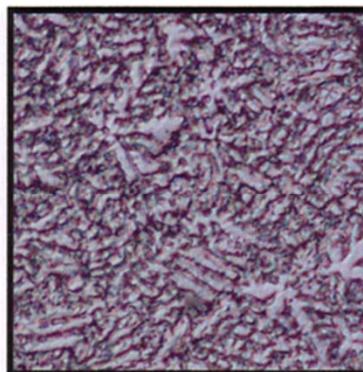
溶質元素の増加とともに
セル状からデンドライト状
に移行

(a)AZ31(Al 3%)



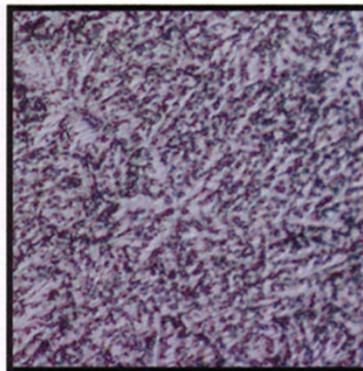
20 μ m

(b)AZ61(Al 6%)



20 μ m

(c)AZ91(Al 9%)



20 μ m

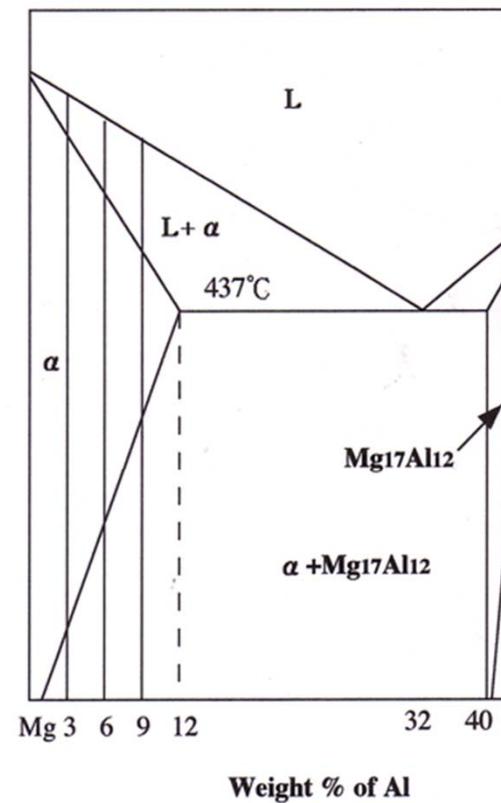
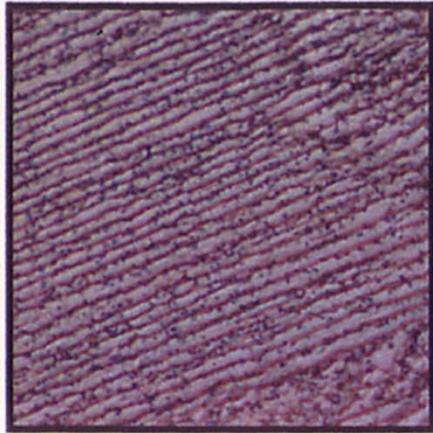


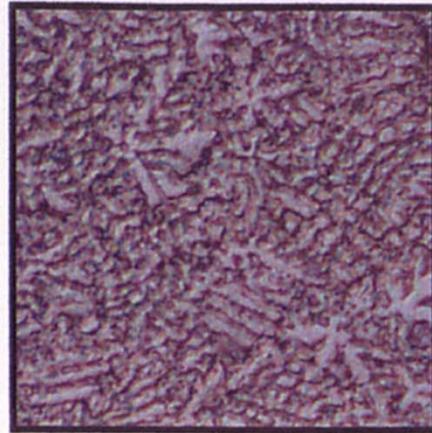
Fig.Mg-Al phase diagram

(a) AZ31 (Al 3%)



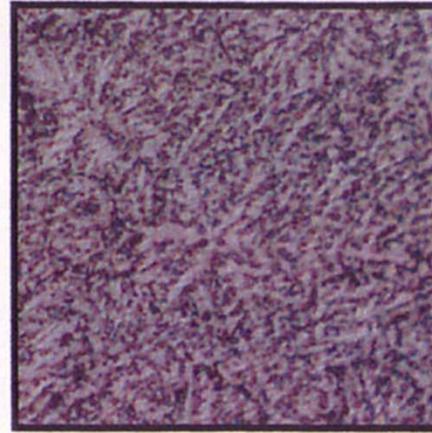
20 μ m

(b) AZ61 (Al 6%)

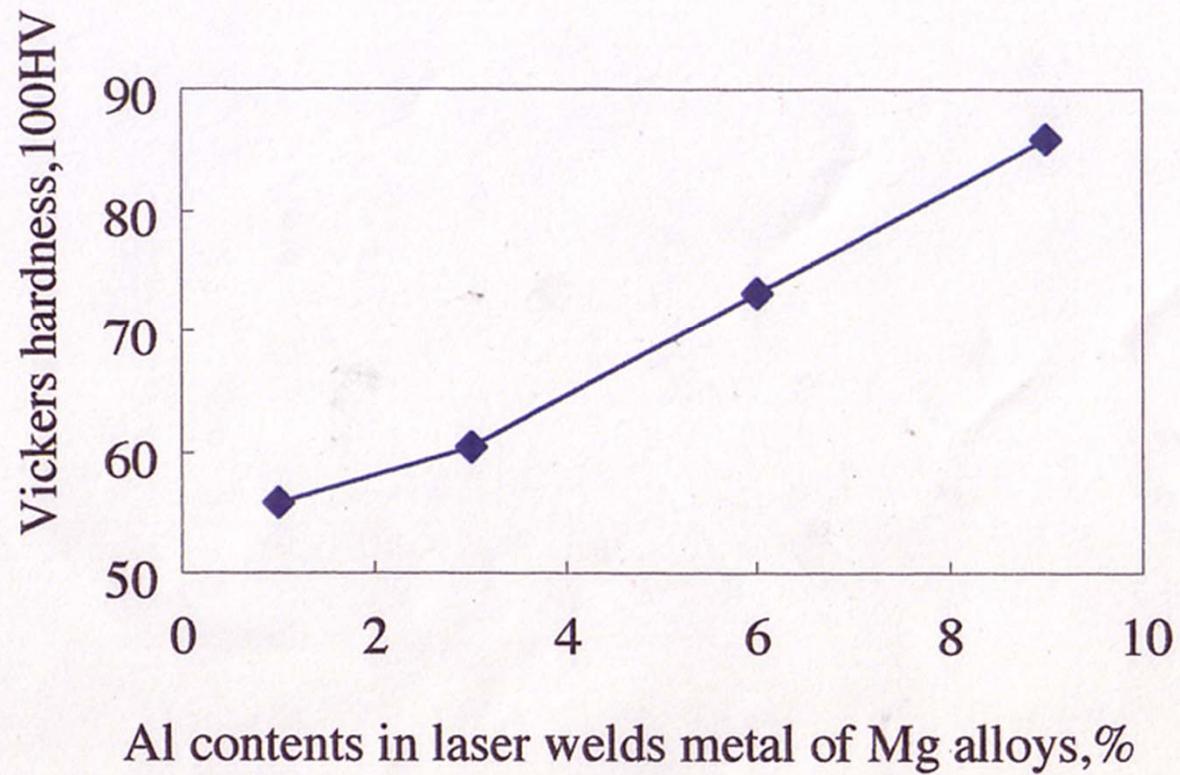


20 μ m

(c) AZ91 (Al 9%)

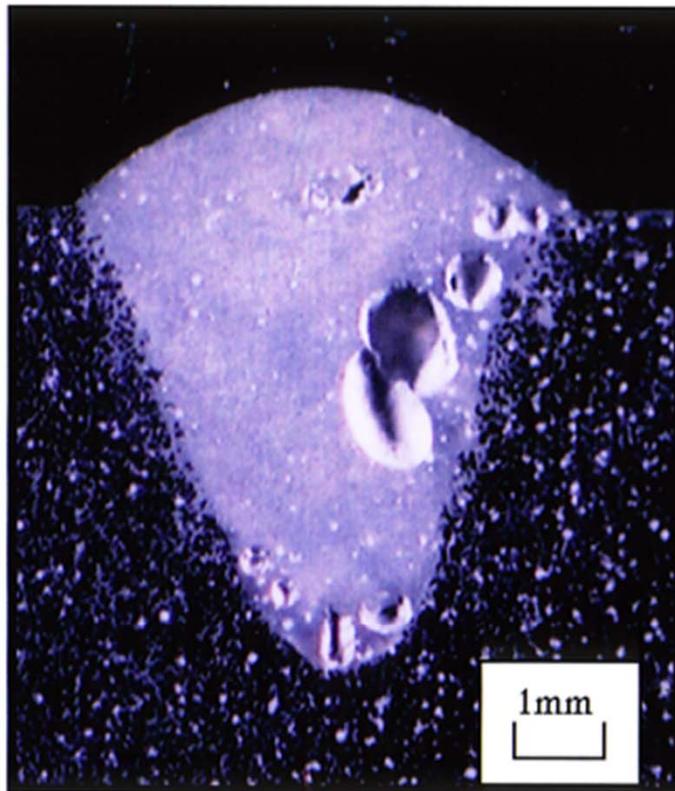


20 μ m

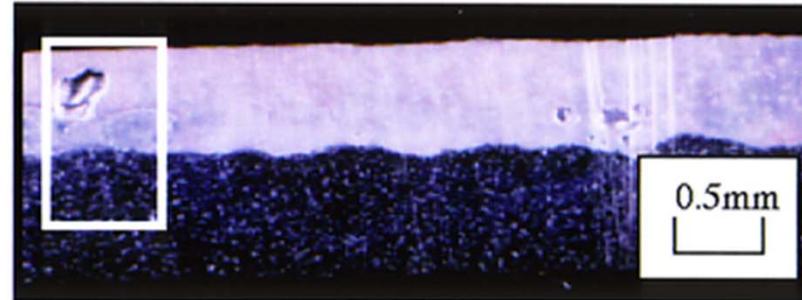


レーザー溶接における気孔発生機構

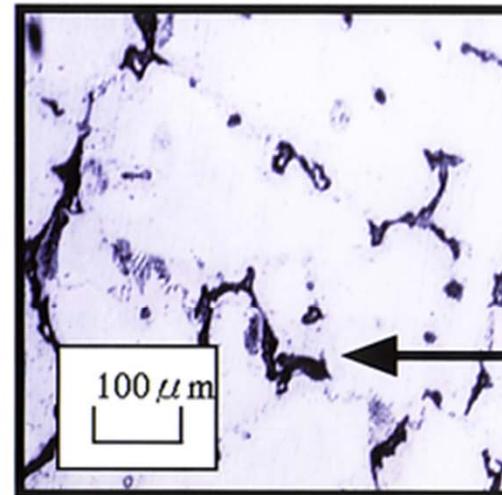
マグネシウム鑄造合金溶接部のポロシティ



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



(b) Bead appearance



(c) Base metal (AZ91 cast alloy)

Defect

ポロシティのSEM像

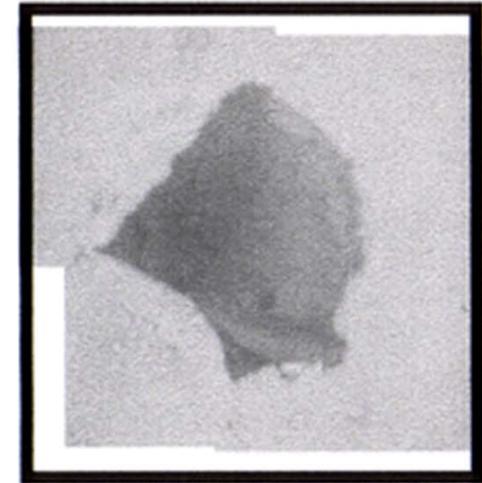
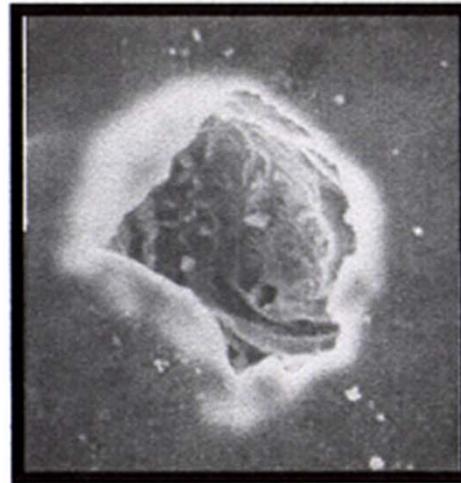
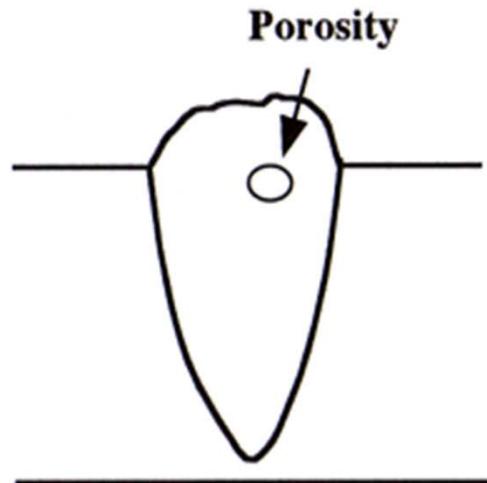
Laser power 1kW

Welding speed 2m/min

Defocusing distance

SEM

COMPO



40 μ m



3つの気孔発生機構

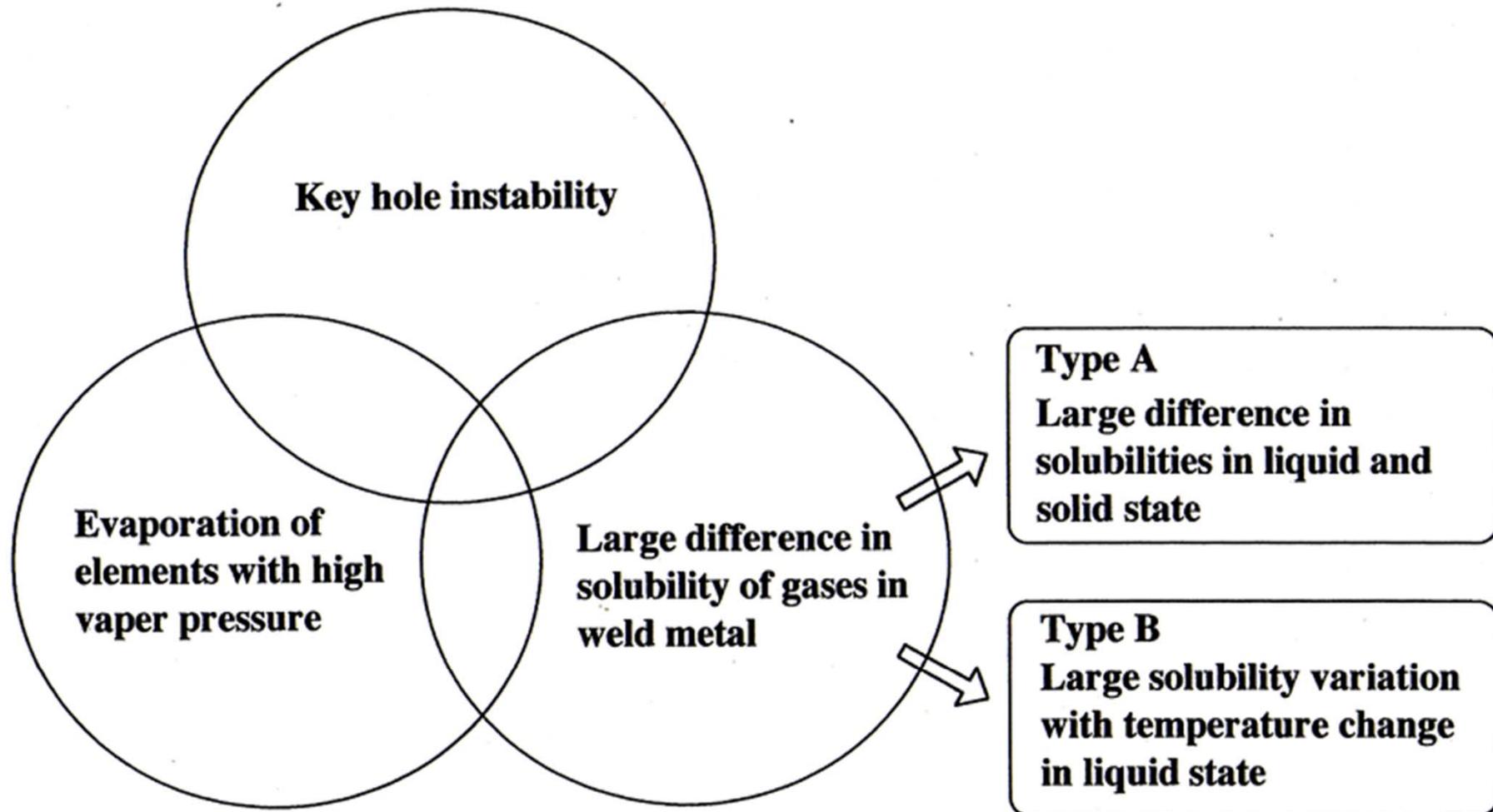
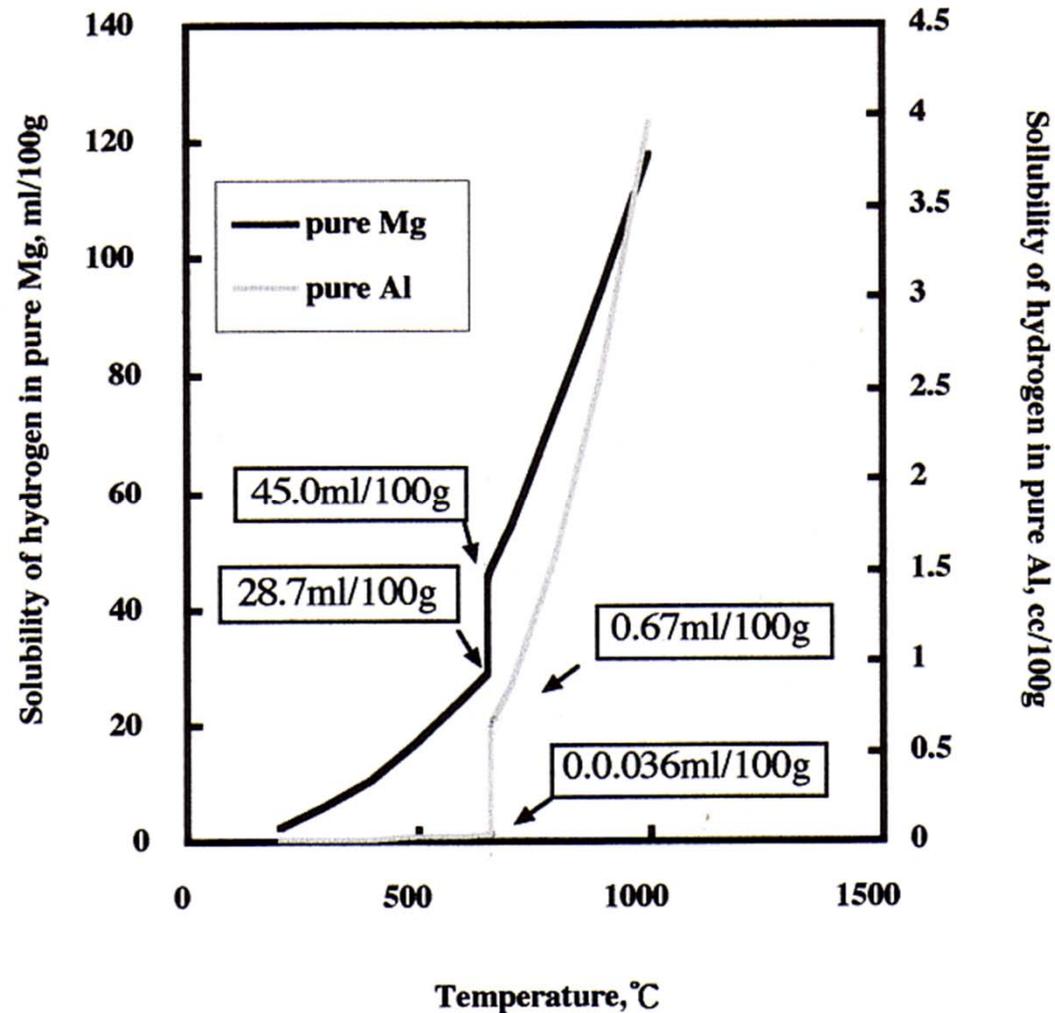
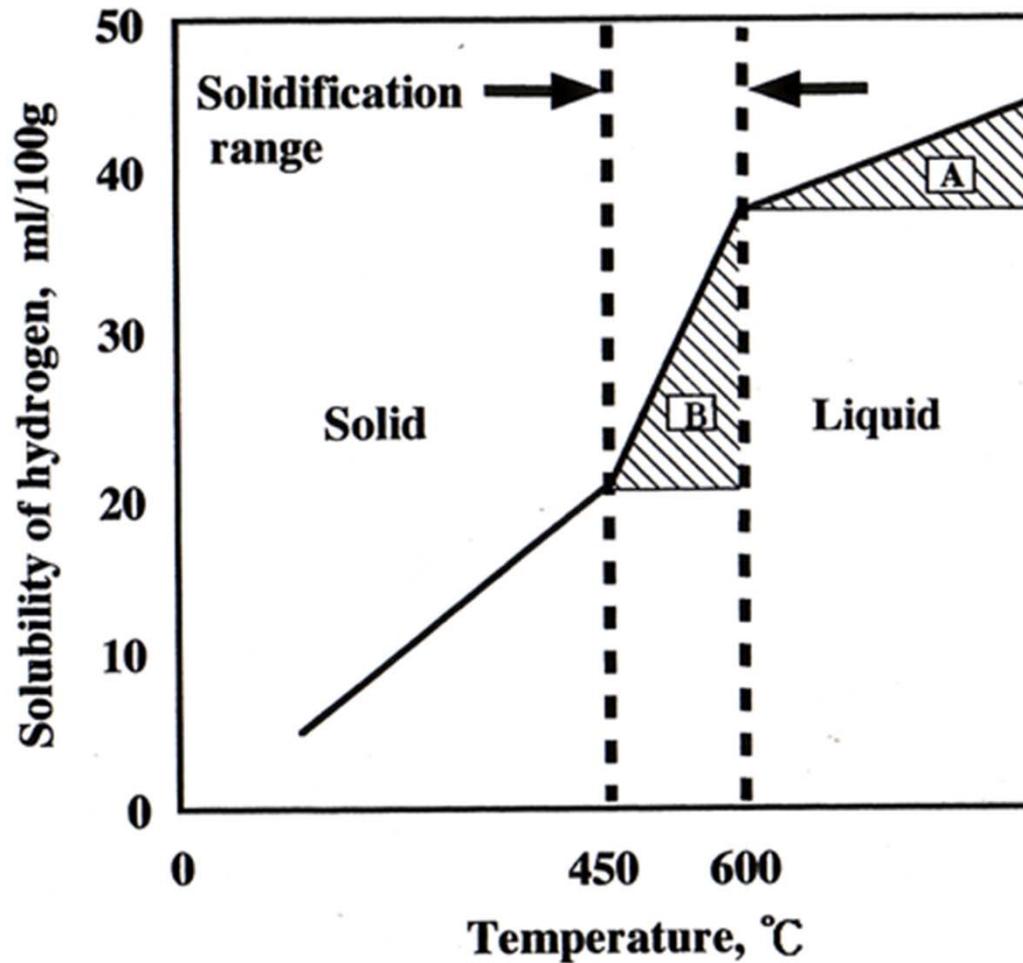


Fig. Sources of porosity formation during laser welding

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

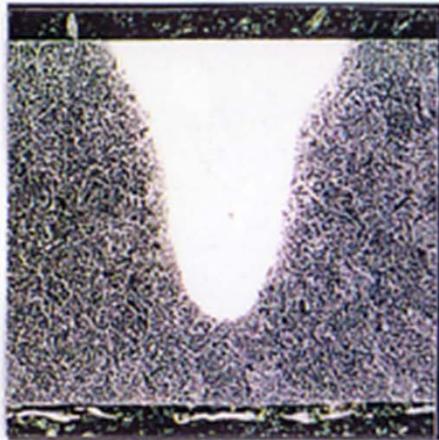
700°C 40ml/100g

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

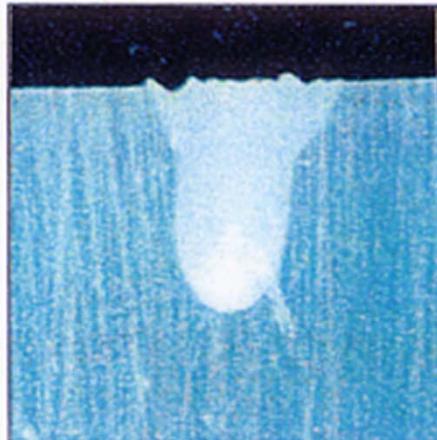
AZ91(with water sprayed)

Laser power 1kW
Welding speed 1m/min



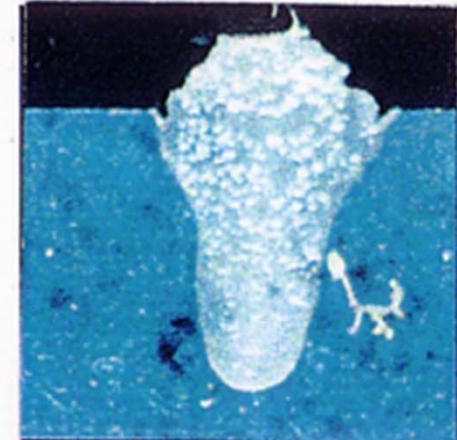
A5182(without water sprayed)

Laser power 4.2kW
Welding speed 4m/min



A5182(with water sprayed)

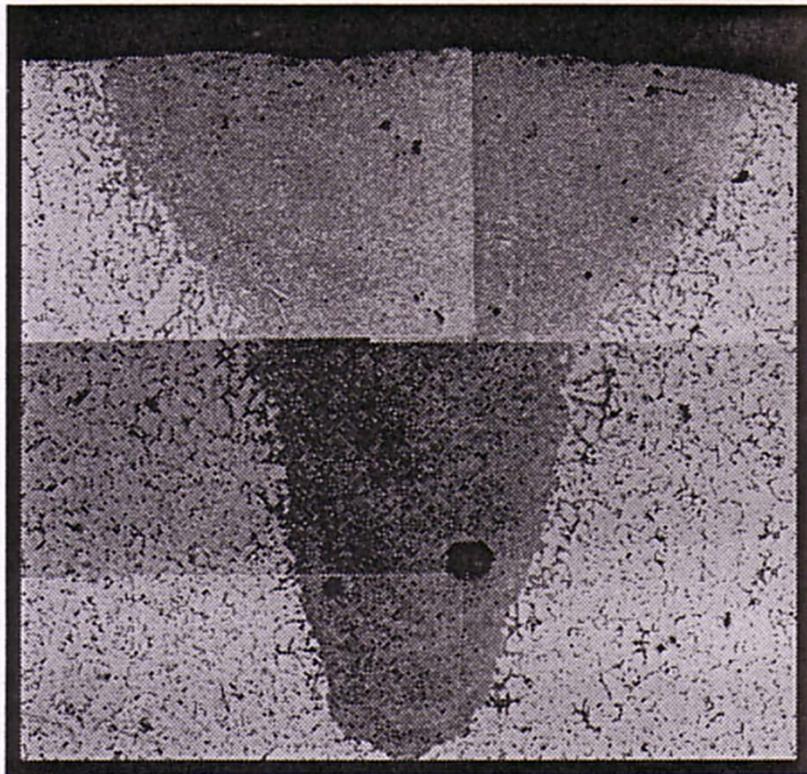
Laser power 4.2kW
Welding speed 4m/min



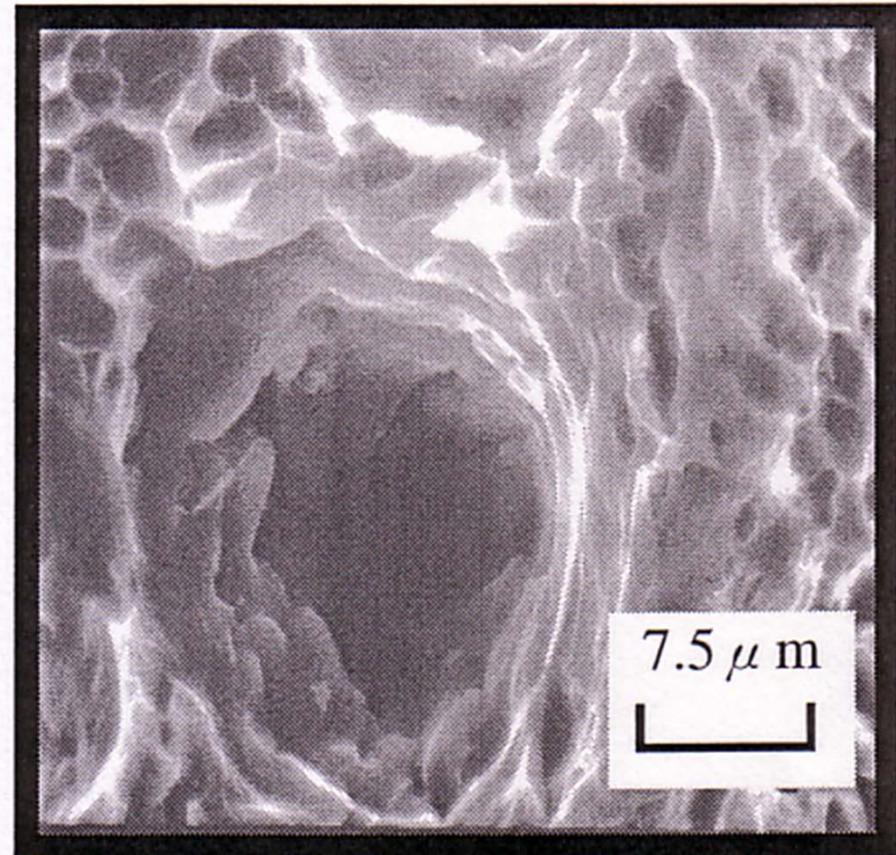
2mm

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

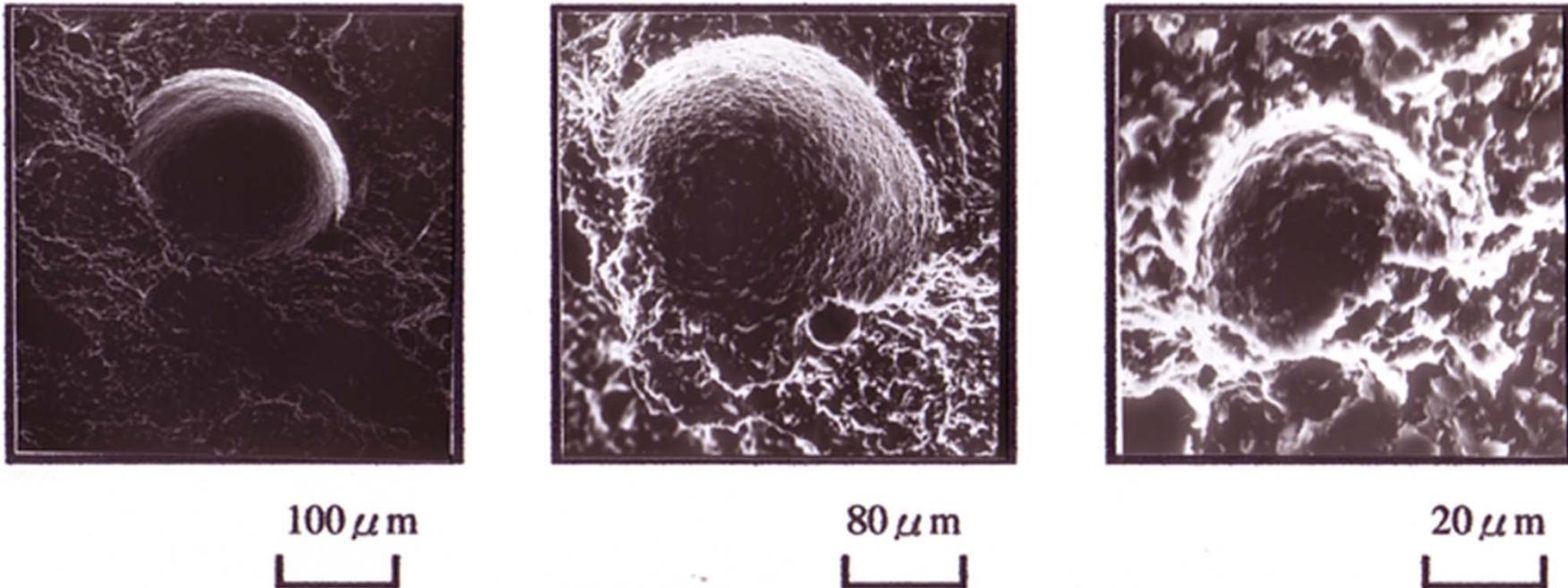
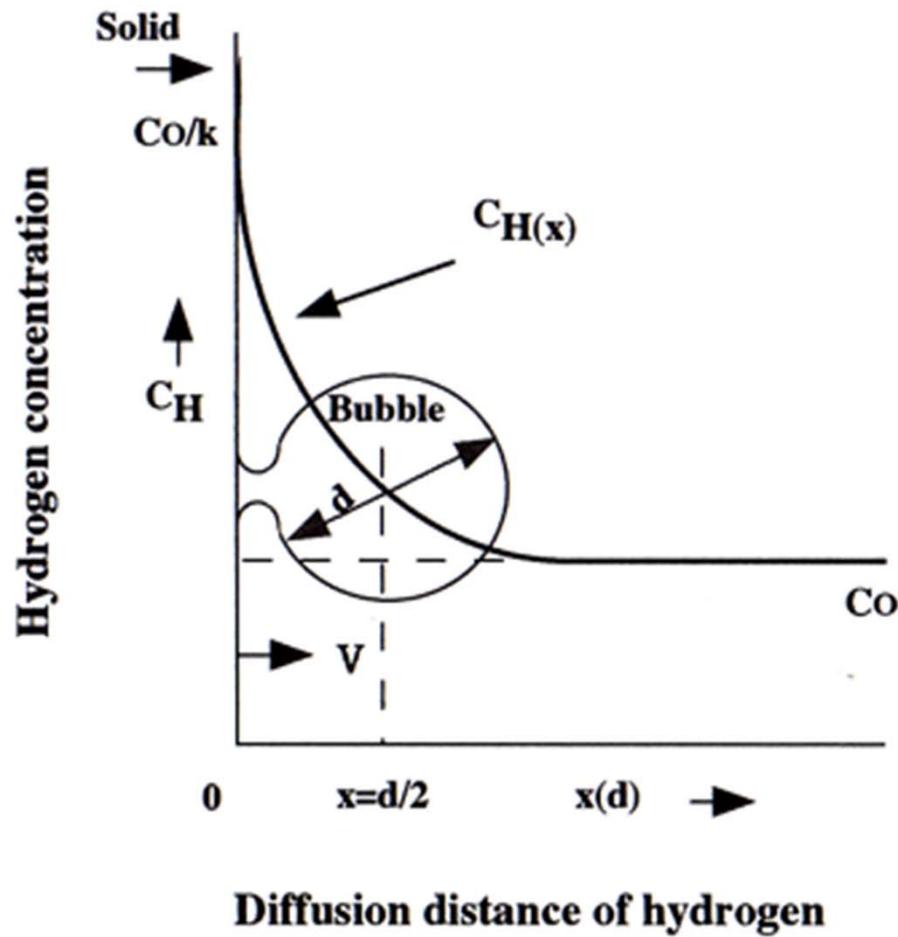


Fig.3-9 Typical porosity in fractographs of fractured weld metal of AZ91 cast alloy

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

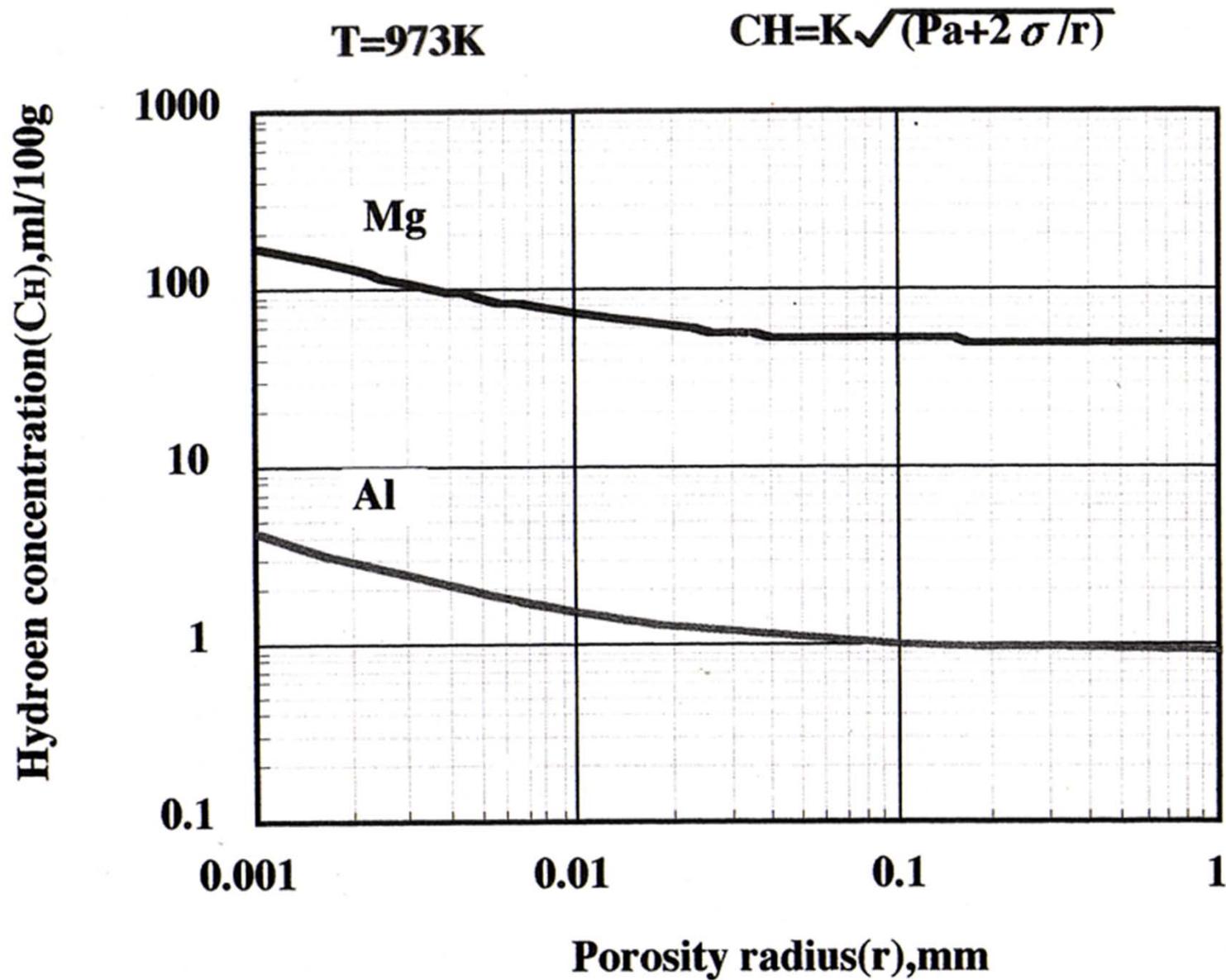
D : Diffusion coefficient

V : Rate of advance of solidification front

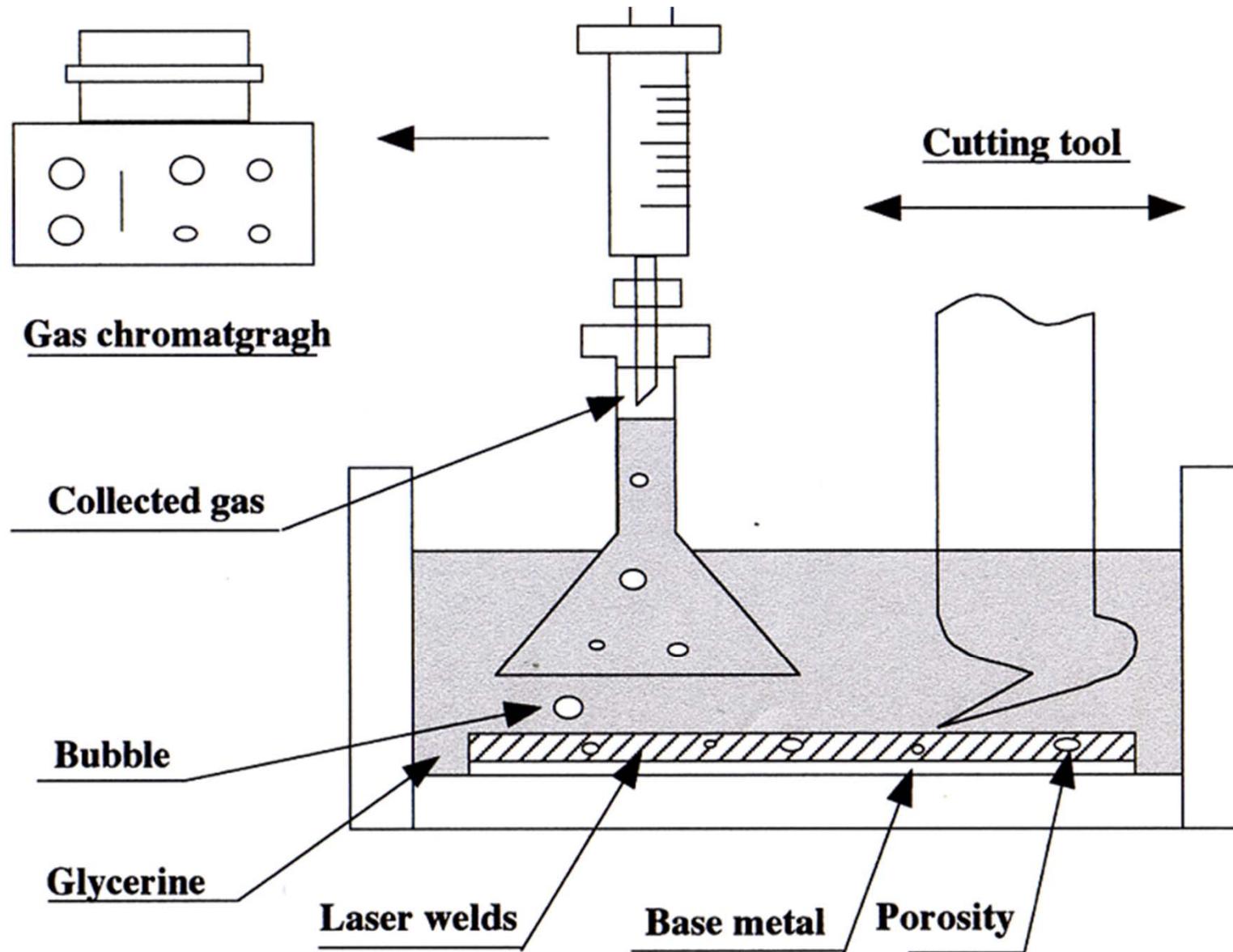
x : Distance of diffusion

k : Distribution coefficient

気泡発生の為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

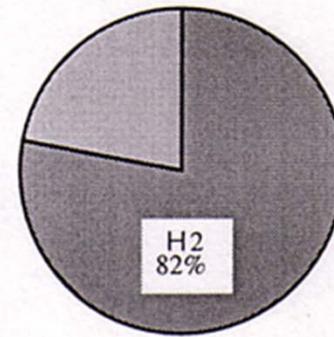
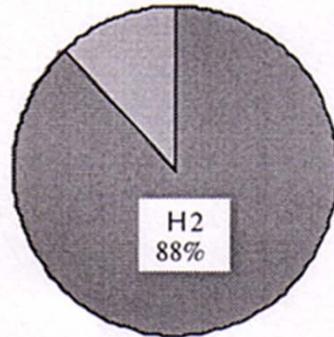
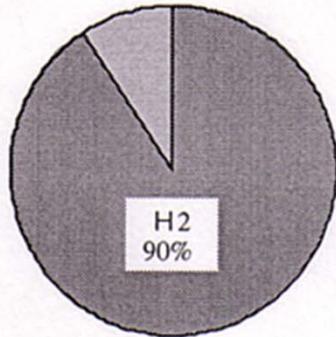
AZ91

AZ31

Ar,N2
10%

Ar,N2
12%

Ar,N2
18%



AZ13

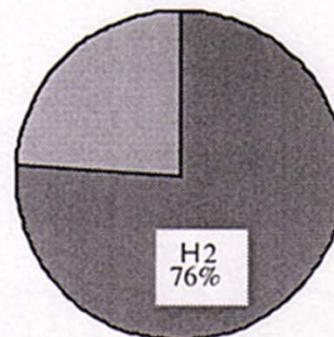
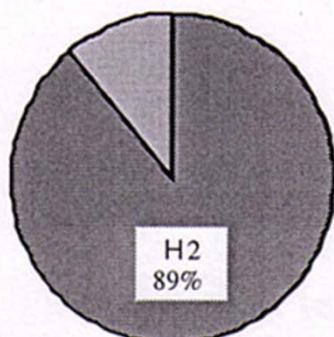
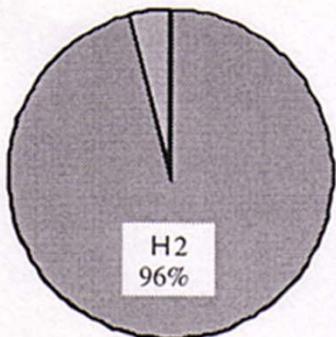
AZ13

AZ61

Ar,N2
4%

Ar,N2
11%

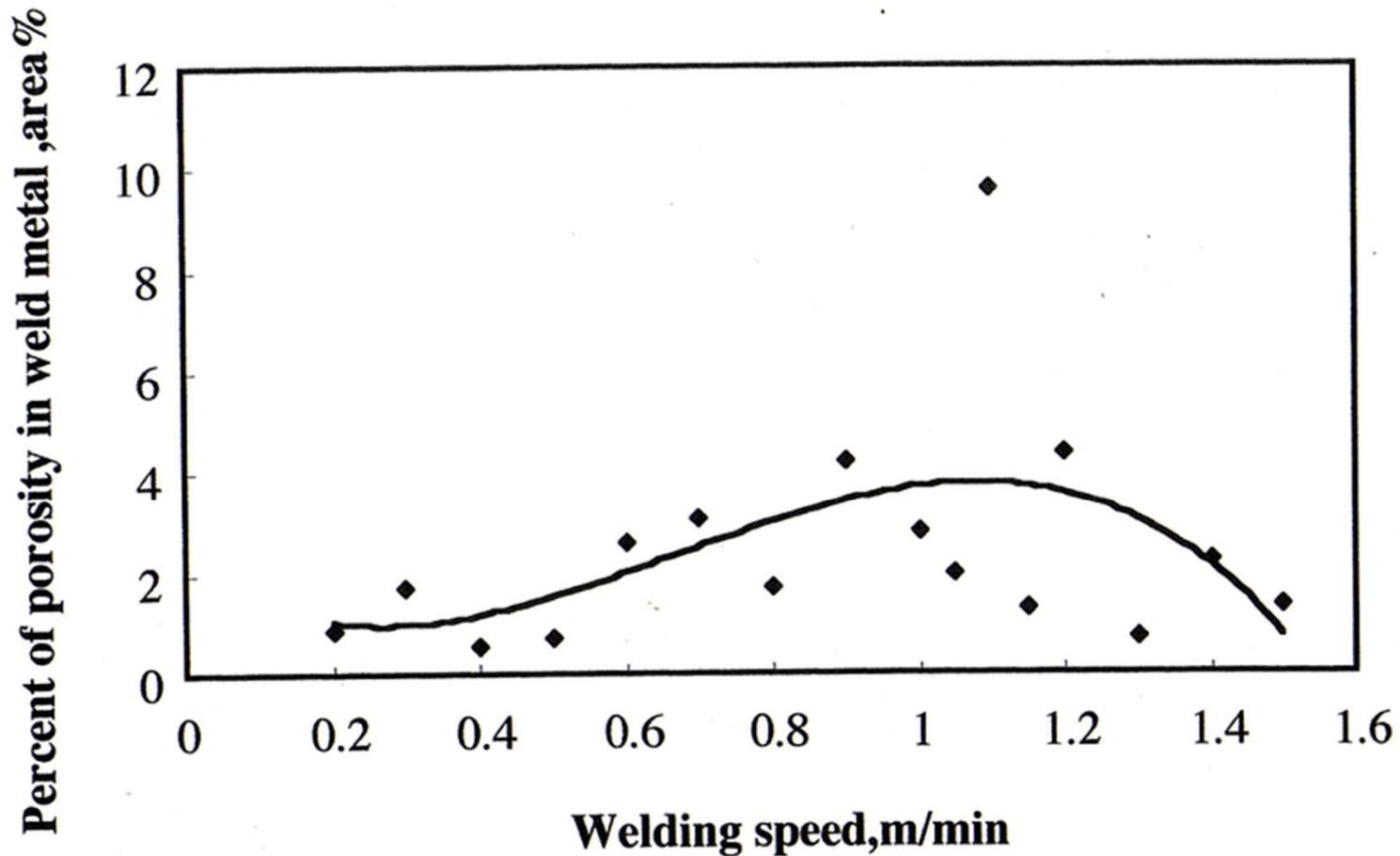
Ar,N2
24%



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



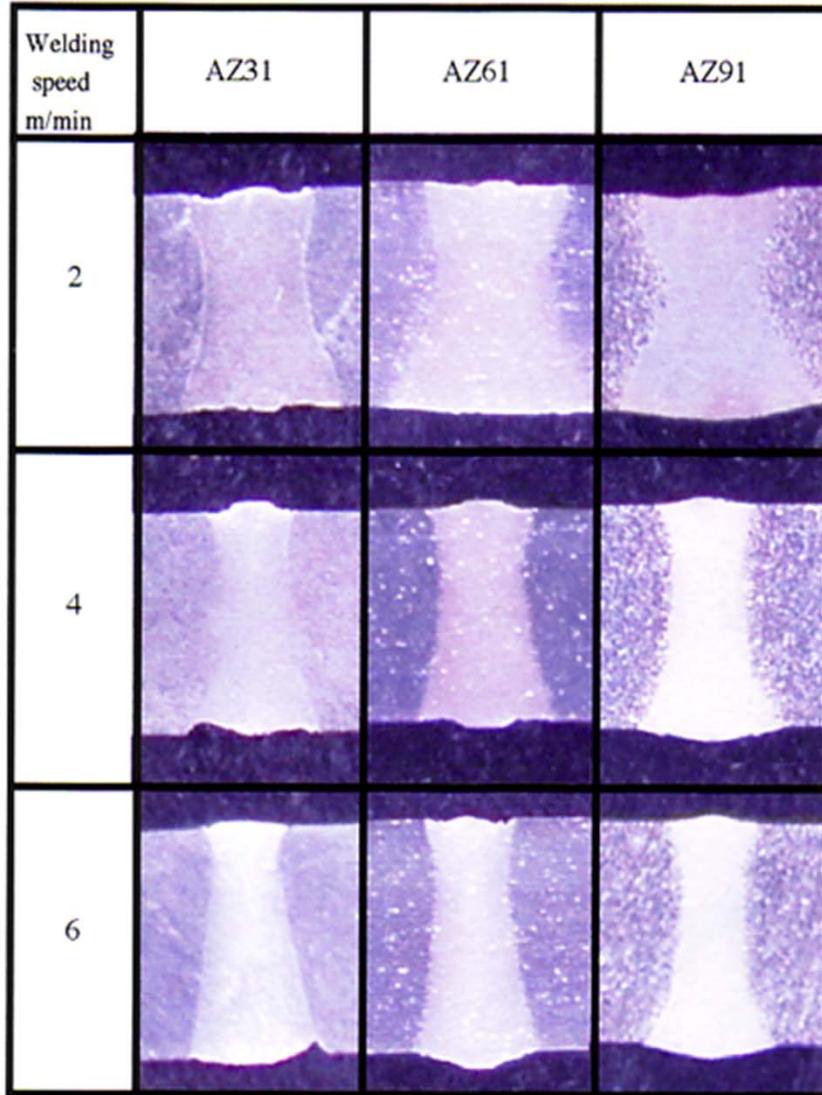
溶接部の継手性能

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 ²)	耐力 (N/mm ²)	伸び (%)	引張強度 (N/mm ²)	耐力 (N/mm ²)	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

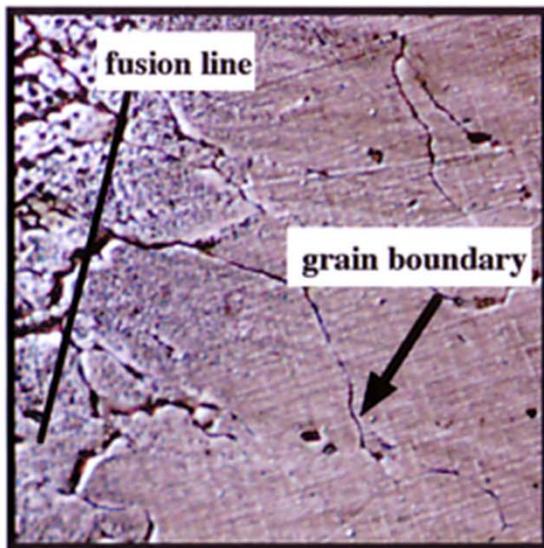
レーザーによる完全溶込み溶接



Laser power :1kW
Defocusing distance:0mm

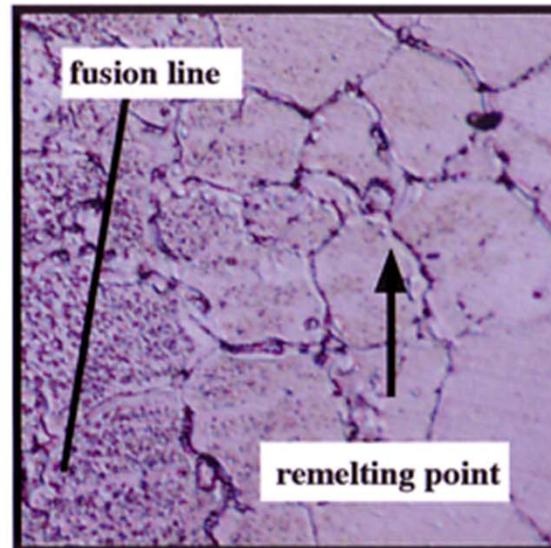
1mm


溶接熱影響部の組織



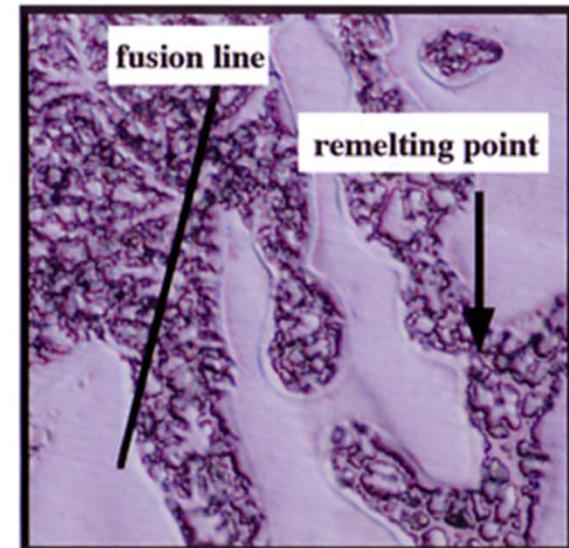
100 μ m

(a) AZ31



100 μ m

(b) AZ61



100 μ 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

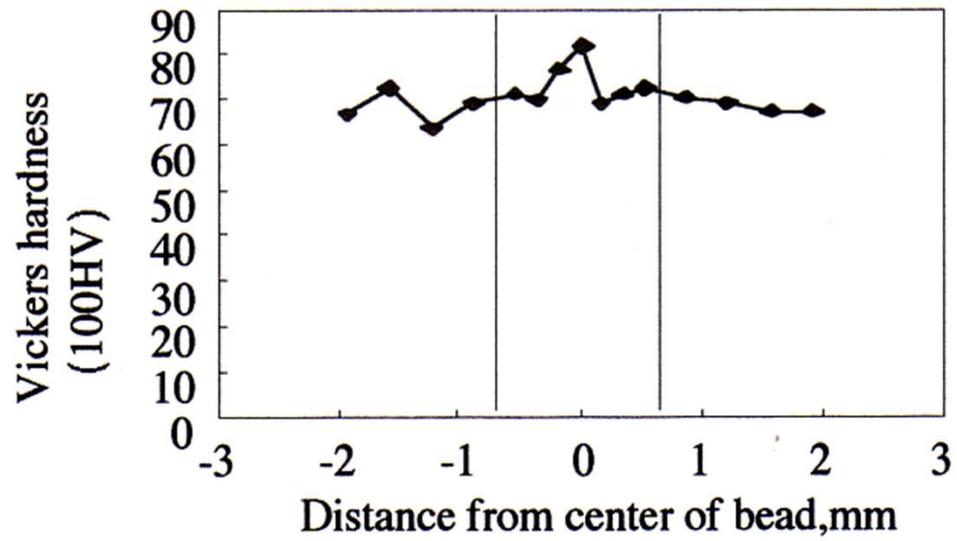
(b)AZ61

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

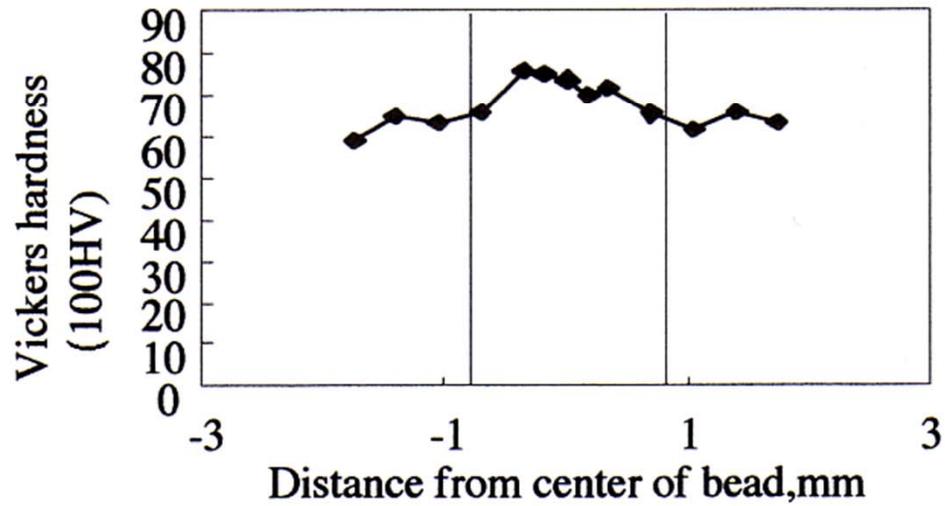
(c)AZ91

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

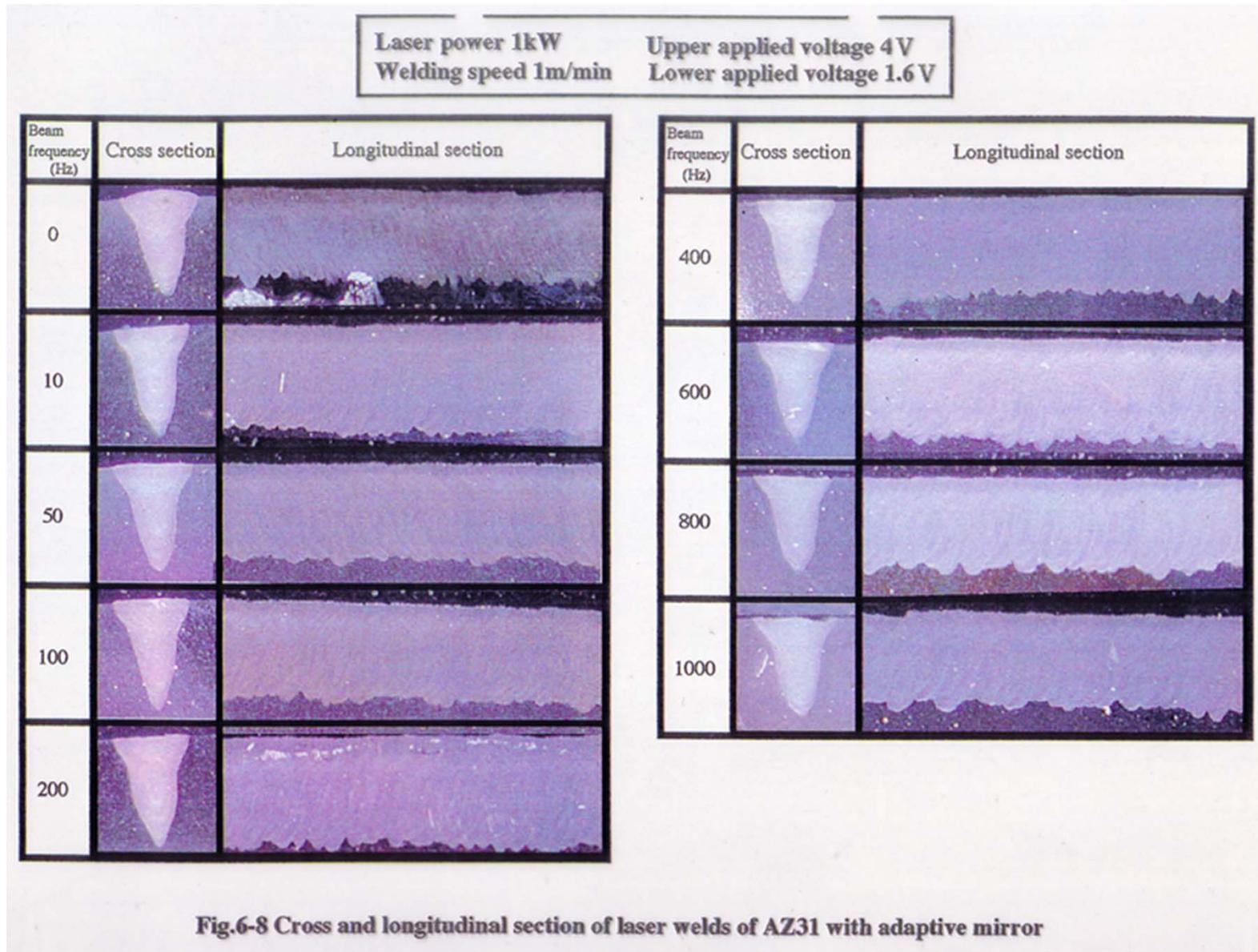


(b) 4m/min



(c) 6m/min

ビード断面マクロ写真



組織の微細化

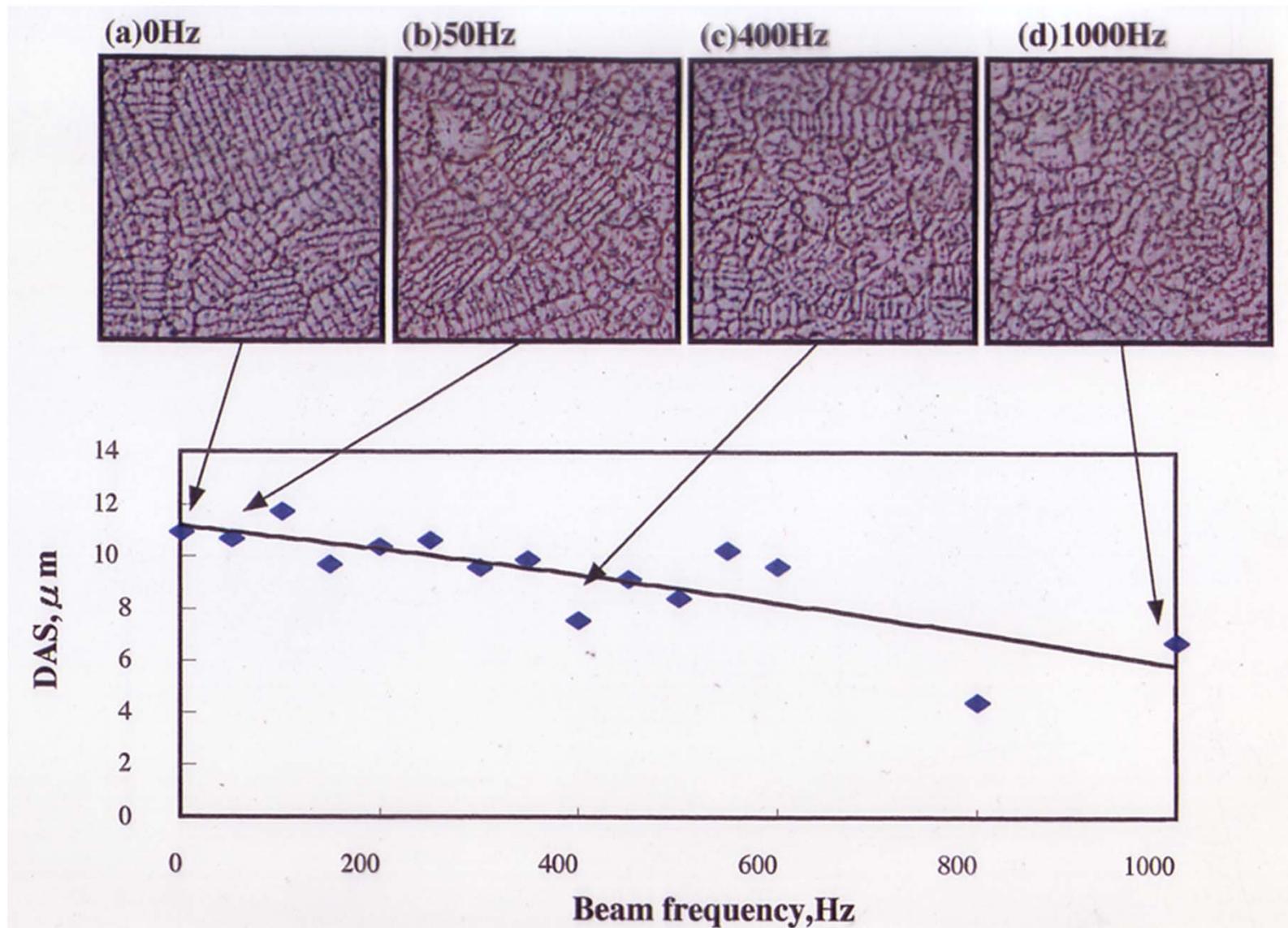


Fig. Relationship between DAS and beam frequency of laser welds of AZ31 with adaptive mirror by Liner intercept method

耐気孔性と周波数

