

# 新一代船舶用鐸接技術 與鐸接材料



張家銘博士  
廣泰金屬公司研發課長

# 鋼材與鐸接材料的關係

鋼材

- 做為鐸接的母材
- 提供盤圓製作SMAW、GMAW及GTAW鐸材
- 提供鋼帶製作FCAW鐸材

冶金原理  
材料特性

鐸材

- 使鋼材經鐸接後成為結構材料  
擴大應用範圍
- 覆面於鋼材進行表面改質

# 銲接材料的分類



**SMAW**



**GMAW/  
FCAW**



**SAW**

# 船舶種類

HIGHER STRENGTH  
CORROSION RESISTANT  
**DUPLIX** stainless steel



**CHEMICAL TANKERS**

USED WELDING PROCESSES

SMAW • GMAW • FCAW • SAW

tempered steels

HIGH STRENGTH



**SUBMARINE VESSELS**

USED WELDING PROCESSES

SMAW • GMAW • FCAW • SAW

CRYOGENIC STEELS  
-163°C methane



**LIQUID GAS CARRIERS**

USED WELDING PROCESSES

SMAW • GTAW • GMAW • FCAW • SAW

Good impact toughness

LIGHT WEIGHT  
corrosion resistant



**ALUMINIUM BOATS**

USED WELDING PROCESSES

GTAW • GMAW

# 船舶用鋼

## Mild steels grades



## High Strength Steel Grade



## Grades of Steels

**MILD STEEL CE**

$C [\%] + [Mn [\%] / 6]$

**HIGH STRENGTH STEEL CE**

$C + [Mn / 6] + [Cr + Mo + V] / 5 + [Ni + Cu] / 15$

# 船艦種類

- ▶ 水面艦
- ▶ 航空母艦
- ▶ 潛艦



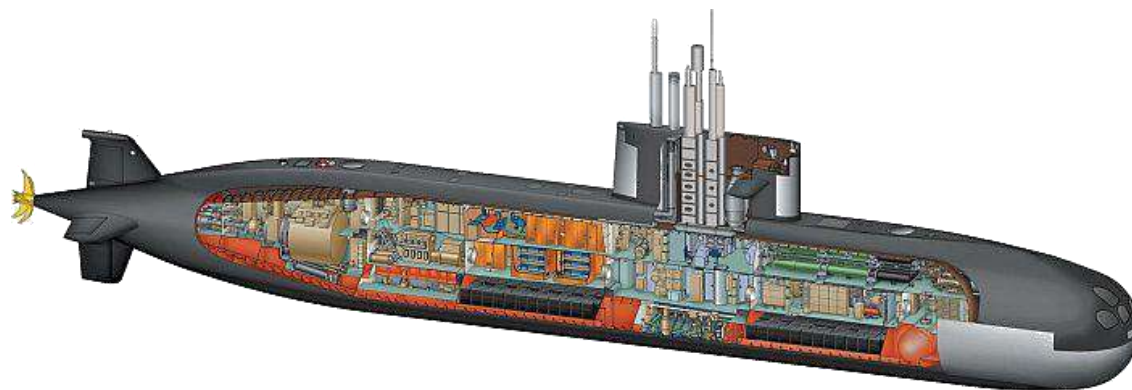
# 潛艦用低合金高強度高韌性鋼

## ▶ 美國

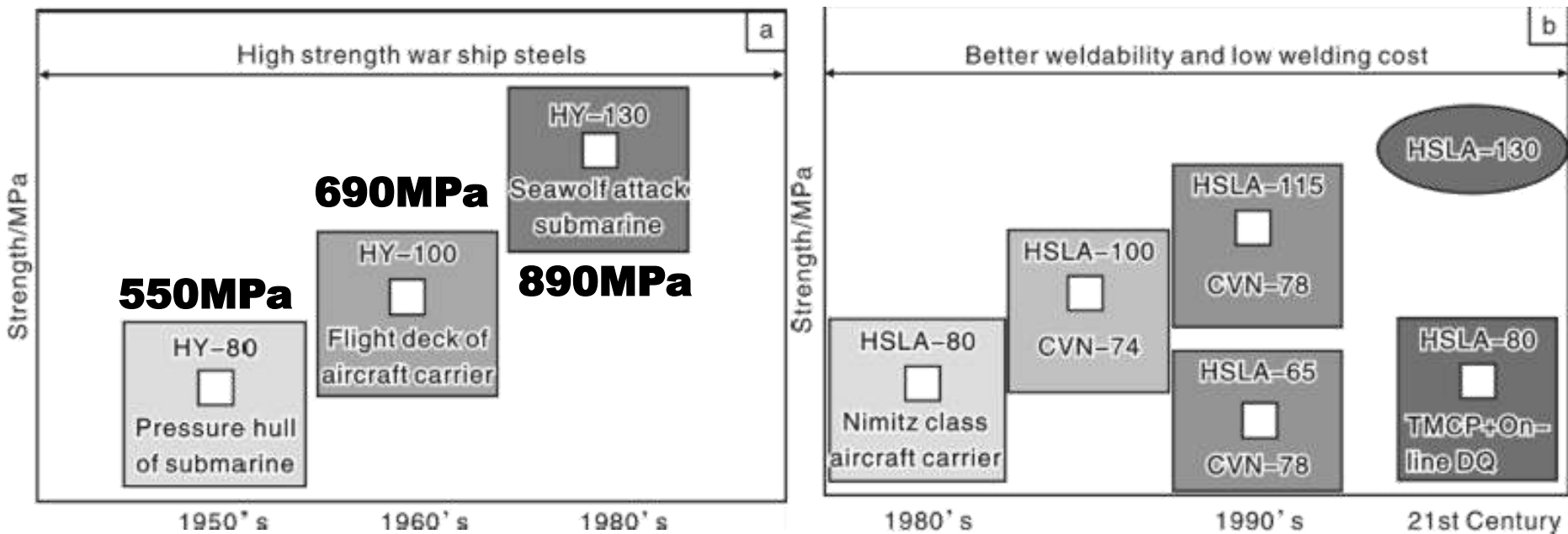
- HY-80 & HSLA-80
- HY-100 & HSLA-100
- HY-130

## ▶ 日本

- NS 46
- NS 63
- NS 80
- NS 90
- NS 110

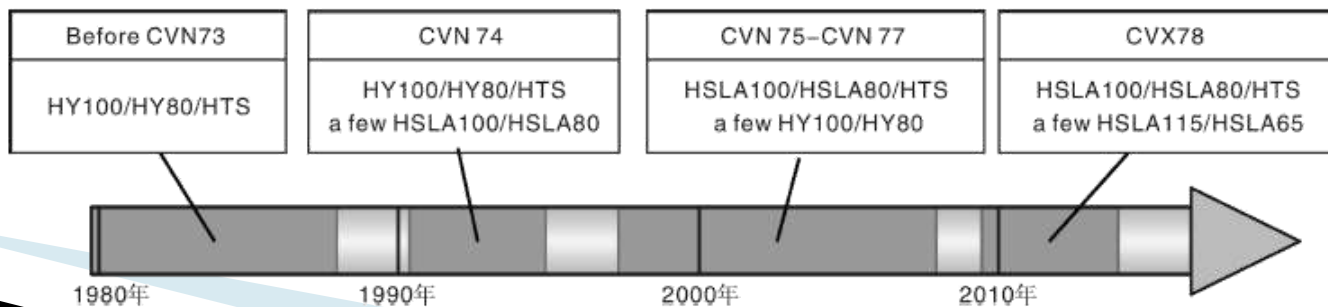


# 美國船艦用鋼發展



鎳鉻鉬系的淬火回火

銅析出硬化+DQ



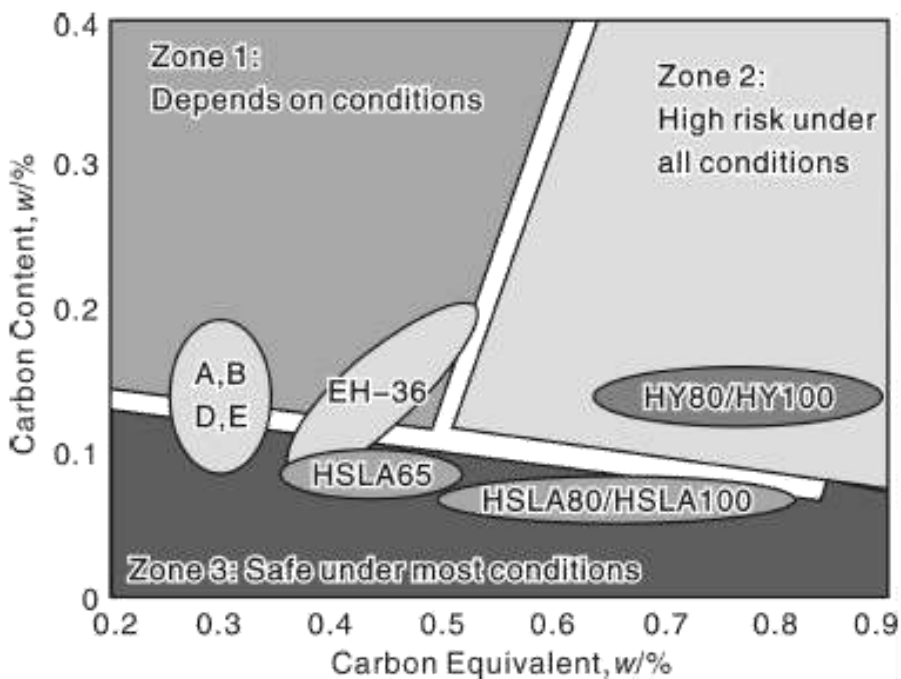
# HY-80 VS HLSA-80

## ▶ Cost

- Alloy (Ni 、 Cr 、 Mo) ↓
- Save 2000~3000 USD/ ton

## ▶ Weldability

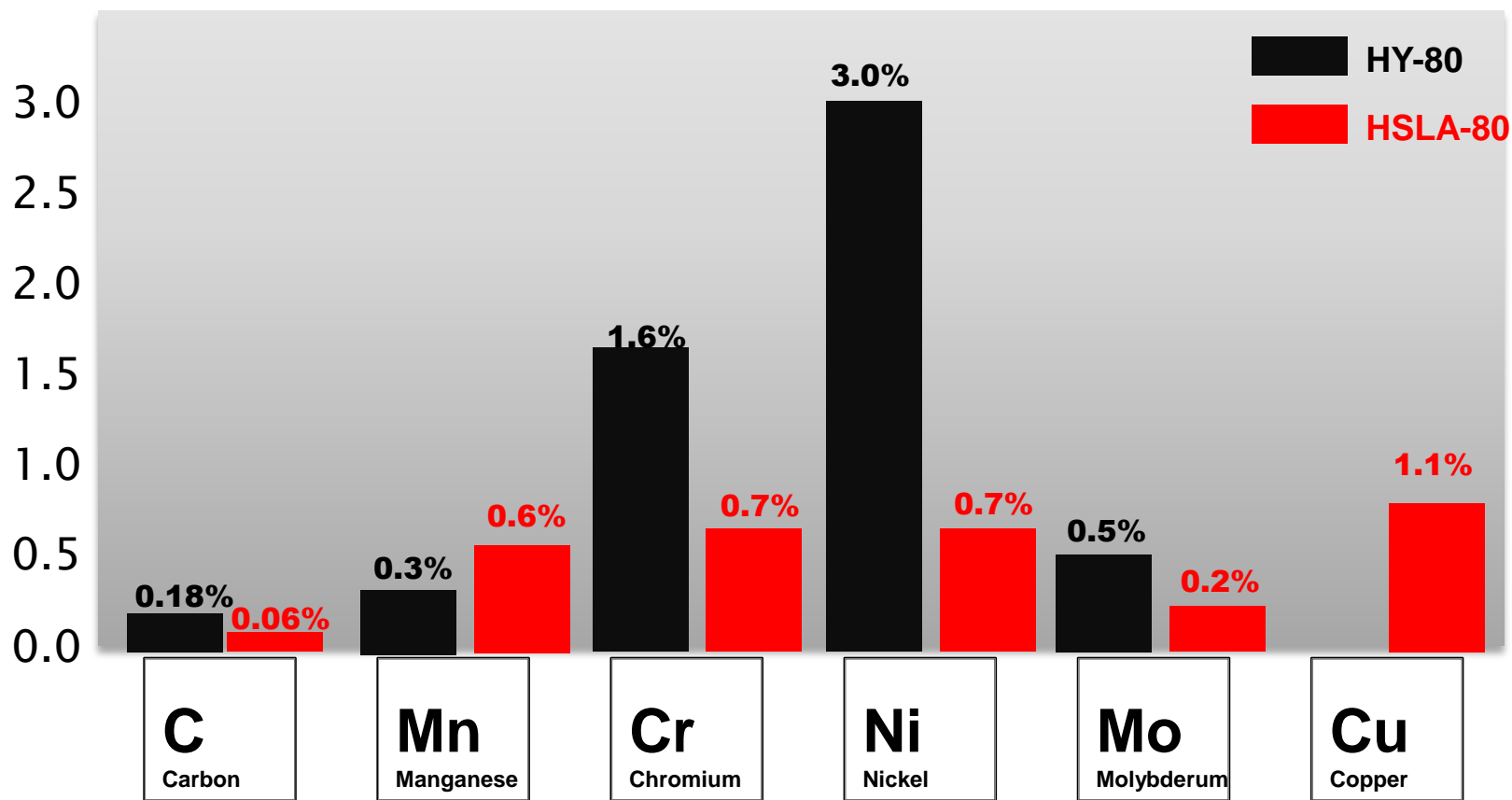
- $C_E$  ↓
- Preheat temperature ↓
- Interpass temperature ↓



**HIGH STRENGTH STEEL  $C_E$**

$C + [Mn / 6] + [Cr + Mo + V] / 5 + [Ni + Cu] / 15$

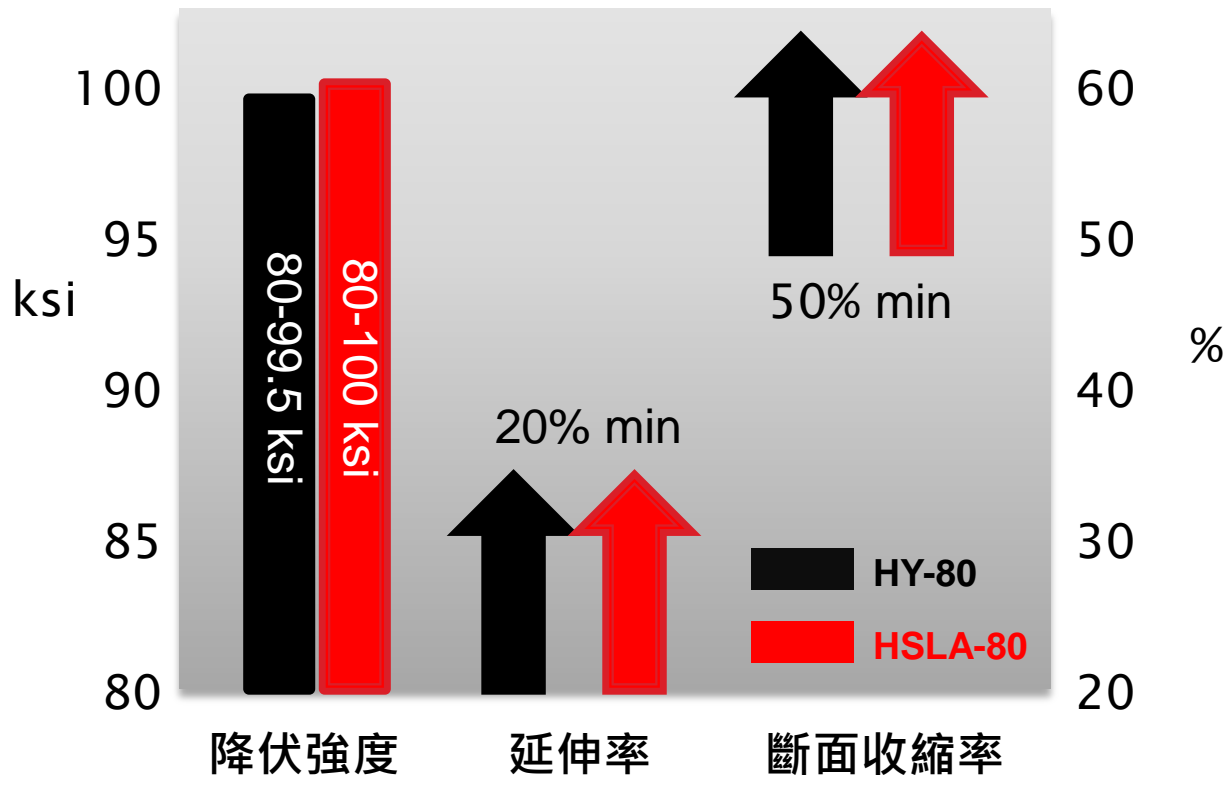
# HY & HLSA-成份比較



SUBMARINE VESSELS



# HY&HLSA-物性比較



低溫衝擊值	-18°C	-84°C
HY-80	65J	47J
HSLA-80	-	65J

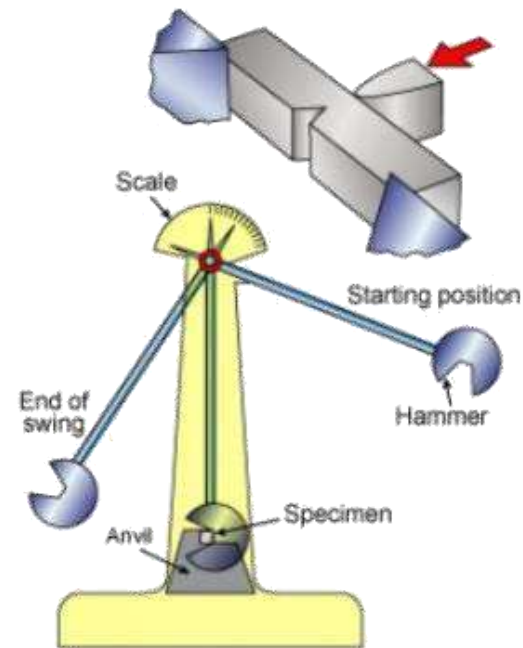
# 船艦用鋼要求

## ▶ 高強度

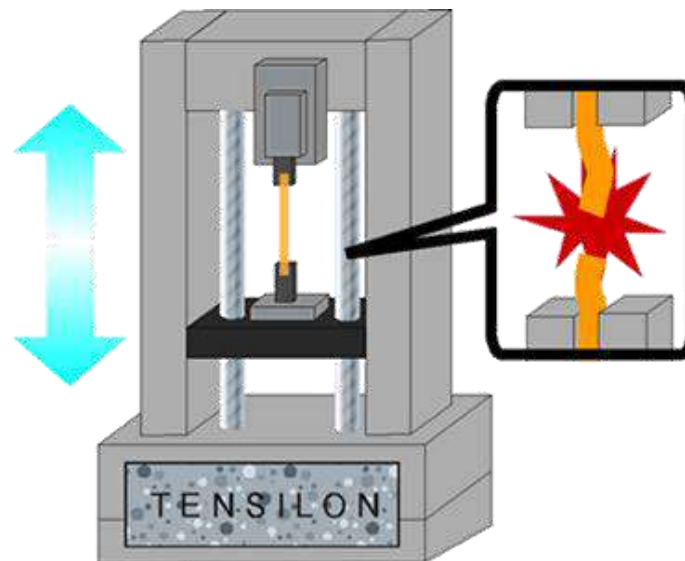
- 降伏強度: 550~1100MPa

## ▶ 高韌性

- 低溫韌性: 47J min
- 韌脆轉換溫度



biwisoft



# 船艦用鋼要求

## ▶ 爆炸試驗

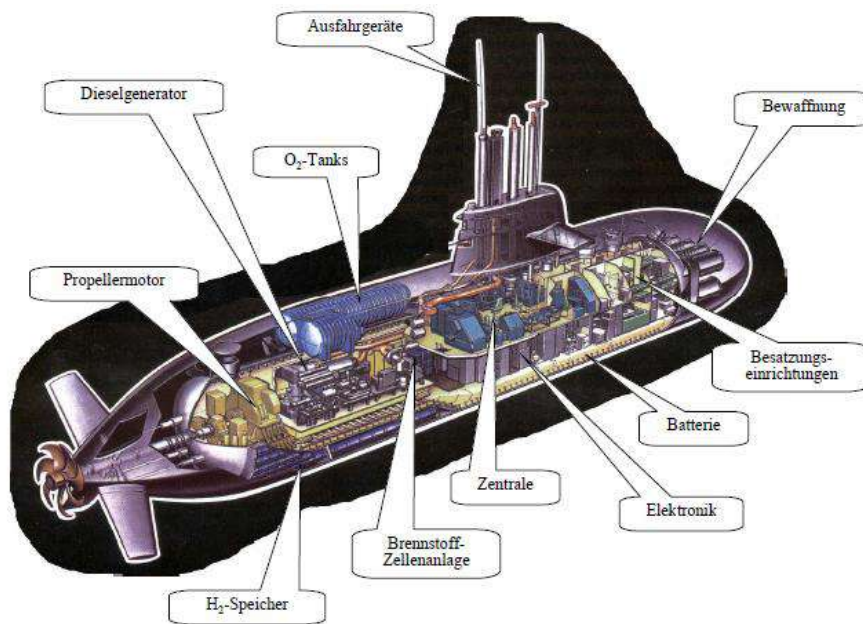


# 潛艦用鐸材

*Welding Consumable specification:*

T9074-BC-GIB-010/0200

FILLER MATERIALS FOR CRITICAL APPLICATIONS:  
REQUIREMENTS FOR FLUX-CORED WELDING ELECTRODES, BARE WELDING  
ELECTRODES AND FLUXES, AND COVERED WELDING ELECTRODES FOR  
LOW-ALLOY STEEL APPLICATIONS



# 測試項目

Table III. Summary of weld metal tests required for qualification, 1/

Test	Schedule		Test procedures	Requirements
	A	B <u>2/</u> , <u>6/</u>		
Chemical analysis	X	---	AWS A5.29 and Main Body 4.8	Table I herein
Alloy identity	X	---	AWS A5.01	Main Body 3.8
Diffusible hydrogen <u>5/</u>	X	---	AWS A4.3	A.3.1.3 and A.3.1.4 herein
Welded test assembly	X	X	AWS A5.29 and A.4.4.1 herein	AWS A5.29
Nondestructive testing	X	X	Main Body 4.5.1 and 4.5.2	Main Body 3.7.1 and 3.7.2
Visual and Dimensional Examination	X	X	Main Body 4.4.2	A.3.1.5
Tension	X	X	AWS B4.0	Table II herein
Transverse side bend	X	X	AWS B4.0	Table II herein
Charpy V-notch <u>3/</u>	X	X	AWS B4.0	Table II herein
Dynamic tear <u>3/</u>	X	X	AWS B4.0	Table II herein
Explosion test series <u>4/</u>	---	X	A.4.4.2 herein	Table II herein

# SMAW-APPEDIX C

## ▶ *SMAW-Chemical Composition*

Element	MIL-10018-M1	MIL-10718-M	MIL-12018-M2
Carbon	0.06	0.07	0.07
Manganese	0.80 - 1.85	0.80 - 1.85	0.80 - 1.85
Silicon	0.65	0.60	0.65
Phosphorus	0.025	0.025	0.025
Sulfur	0.017	0.017	0.012
Chromium	0.40 <u>4/</u>	0.40 <u>4/</u>	0.65
Nickel	1.25 - 3.00	1.25 - 2.50	1.50 - 4.00
Molybdenum	0.50	0.25 - 0.50	0.90
Vanadium	0.05	0.05	0.05
Copper	<u>2/</u>	<u>2/</u> , <u>3/</u>	<u>2/</u> , <u>3/</u>
Boron	---	<u>3/</u>	<u>3/</u>



# FCAW-APPEDIX A

## ► FCAW-Chemical Composition & Mechanical Properties

MIL-type <u>1/</u>	Chemical composition (wt. percent) <u>2/</u> <u>3/</u>									
	Carbon	Manganese	Silicon	Phosphorus	Sulfur	Nickel	Chromium	Molybdenum	Vanadium	Copper
MIL-101TC MIL-101TM	0.07	0.50 to 1.50	0.60	0.015	0.015	1.30 to 3.75	0.20	0.50	0.05	0.06

MIL-type	101TC 101TM
Yield strength (1000 pounds per square inch) (ksi) <u>2/</u>	82 to 110
Elongation in 2 inches min. (percent)	18
Transverse side bend	<u>3/</u>
Charpy V-notch. Energy ft-lb minimum average @ Temperature (degrees Fahrenheit) (F) <u>4/</u>	35@(-60F) 60@(0F)
Dynamic tear. Energy ft-lb minimum average @ Temperature (degrees Fahrenheit) (F)	300@(-20F) <u>5/</u> 450 @(+30F) <u>6/</u>
Explosion crack starter test	<u>7/</u>

# GMAW&SAW-APPEDIX B

## ▶ *GMAW & SAW-Chemical Composition*

Welding process	ALL	GMAW SAW	ALL	GMAW SAW
Type <u>2/</u>	100S-1 100S-2	100S-1C 100S-2C	120S-1 120S-2	120S-1C 120S-2C
Chemical composition (weight percent) <u>1/</u>				
Carbon	0.07 <u>3/</u>	0.07 <u>3/</u>	0.070 <u>3/, 4/</u>	0.070 <u>3/, 4/</u>
Manganese	1.25-1.8	1.25-2.5	0.90-2.35	1.4-3.8
Silicon	0.20-0.55	0.20-0.55	0.60	0.20-0.55
Phosphorus	0.012	0.012	0.012	0.012
Sulfur	0.008	0.010	0.008	0.010
Nickel	1.40-2.10	1.40-2.10	1.00-3.0	1.00-3.5
Molybdenum	0.25-0.55	0.25-0.55	0.30-1.00	0.30-1.10
Chromium	0.30 <u>8/</u>	0.30 <u>8/</u>	0.80	0.60
Vanadium	0.05	0.04	0.03	0.04
Aluminum	0.10	0.05	0.10	0.05
Titanium	0.10	0.10	0.10	0.10
Zirconium	0.10	0.10	0.10	0.10
Copper	<u>5/, 6/, 7/</u>	<u>5/, 6/, 7/</u>	<u>5/, 6/, 7/</u>	<u>5/, 6/, 7/</u>
Boron	<u>7/</u>	<u>7/</u>	<u>7/</u>	<u>7/</u>

# GMAW&SAW-APPEDIX B

## ▶ *GMAW & SAW-Mechanic Properties*

Type <u>2</u> /	100S-1 100S-1F 100S-2 100S-2F	120S-1 120S-1F 120S-2 120S-2F
Yield Strength (1000 pounds per square inch) (ksi)	82 to 120 <u>3</u> /, <u>12</u> /	102 to 123 <u>3</u> /, <u>4</u> /, <u>12</u> /
Elongation in 2 inches min. (percent)	16	15
Transverse side bend	<u>5</u> /	<u>5</u> /
Charpy V-notch. Energy ft-lb min. average @ Temperature (degrees Fahrenheit) (F)	35@(-60F) <u>6</u> / 60@(0F) <u>6</u> /	45@(-60F) <u>6</u> /, <u>7</u> / 60@(0F) <u>6</u> /
Dynamic tear. Energy ft-lb minimum average @ Temperature (degrees Fahrenheit) (F)	300@(-20F) <u>8</u> /, <u>9</u> / 450@(+30F) <u>9</u> /, <u>10</u> /	400@(-20F) <u>8</u> /, <u>9</u> / 575@(+30F) <u>9</u> /, <u>10</u> /
Explosion test series	<u>11</u> /	<u>11</u> /

# SMAW-APPEDIX C

## ▶ *SMAW-Mechanical Properties*

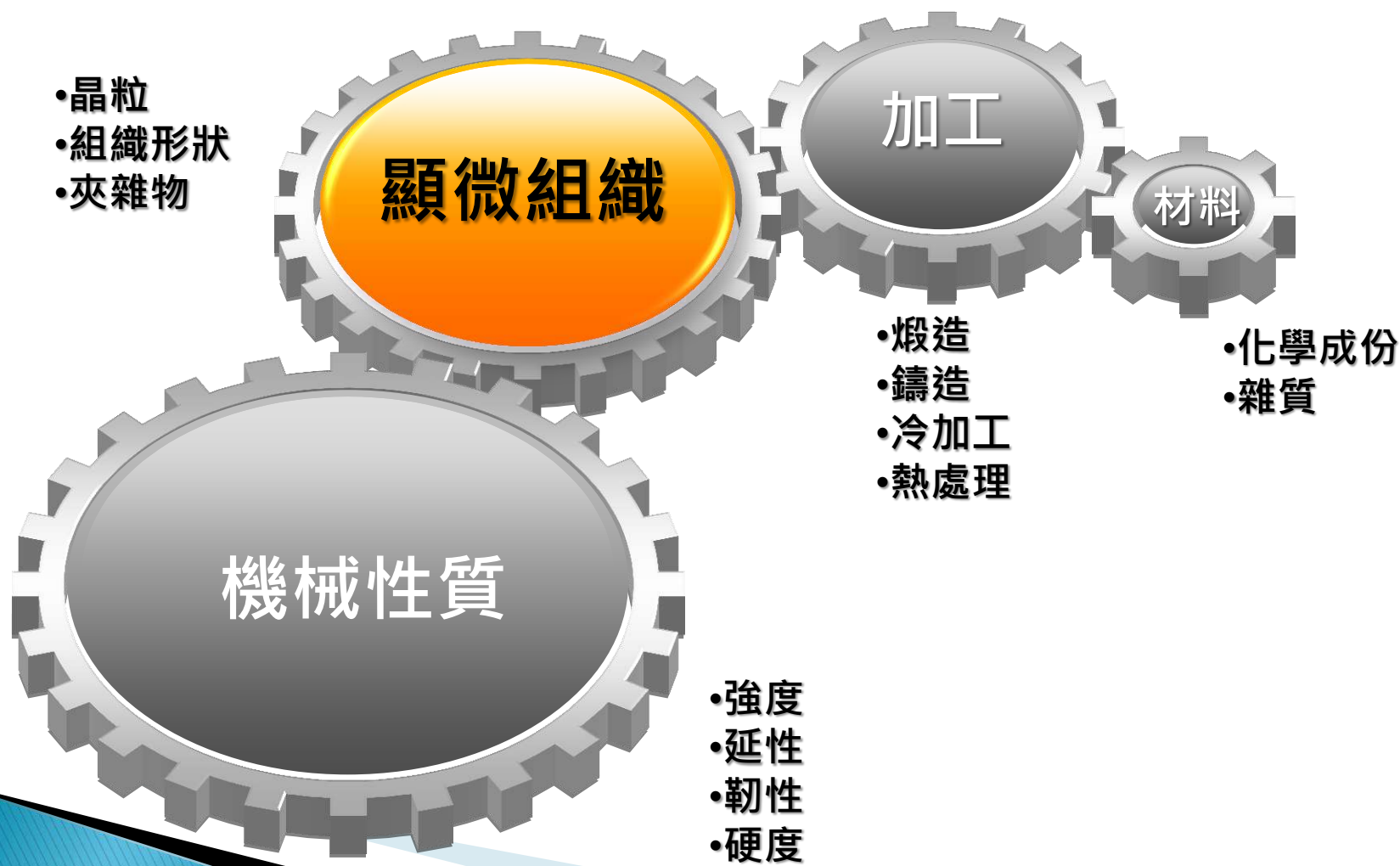
Property	Condition	MIL-10018-M1	MIL-10718-M	MIL-12018-M2
Yield strength (ksi)	As-welded	82 - 110 <u>2/</u>	88 - 122 <u>2/</u> , <u>12/</u>	102 - 123 <u>2/</u> , <u>3/</u>
	Stress relieved	80	86	---
Ultimate tensile strength (ksi)		<u>4/</u>	<u>4/</u>	<u>4/</u>
Elongation in 2 inches (percent)	As-welded	20 <u>5/</u>	20 <u>5/</u>	18 <u>5/</u>
	Stress relieved	20	20	---
Transverse side bend		<u>6/</u>	<u>6/</u>	<u>6/</u>
Charpy V-notch <u>g/</u> Energy ft-lb average @ Temperature (F)	As-welded	35@(-60F) 60@(0F)	35@(-60F) 60@(0F)	45@(-60F) <u>8/</u> 60@(0F)
	Stress relieved	20@(-60F) 50@(0F)	20@(-60F) 50@(0F)	---
Dynamic tear, Energy ft-lb average @ Temperature (F) <u>9/</u> , <u>10/</u>	As-welded	300@(-20F) 450@(30F)	300@(-20F) 450@(30F)	400@(-20F) 575@(30F)
Explosion test series		<u>11/</u>	<u>11/</u>	<u>11/</u>



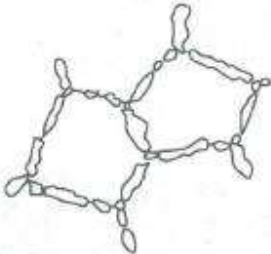
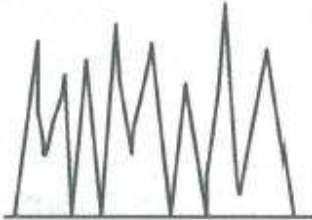

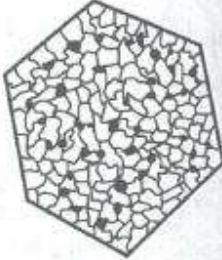



# 銲接材料設計

- ▶ 高強度
  - 合金設計 C、Mn、Si、Cr、Ni、Mo
- ▶ 高韌性
  - 合金化
  - Ti/B韌化
  - 控制有害元素:H、O、N
- ▶ 低擴散氫
  - 低水素原料
  - 除氫機制








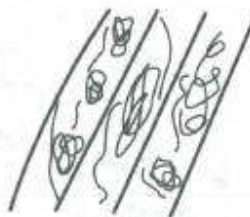




# 材料性質關聯



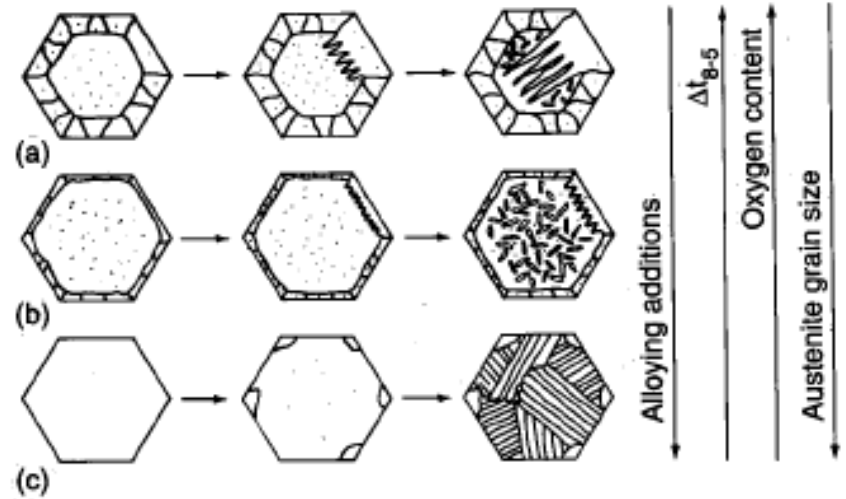
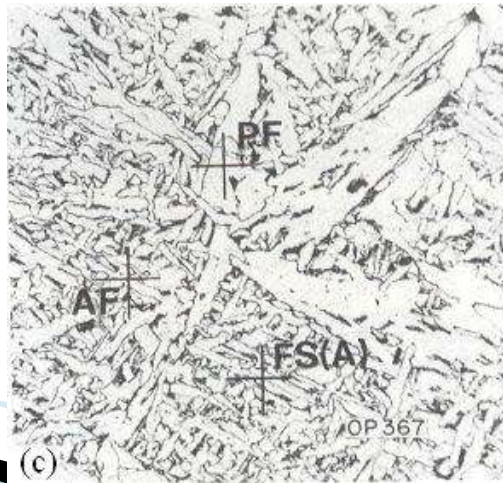
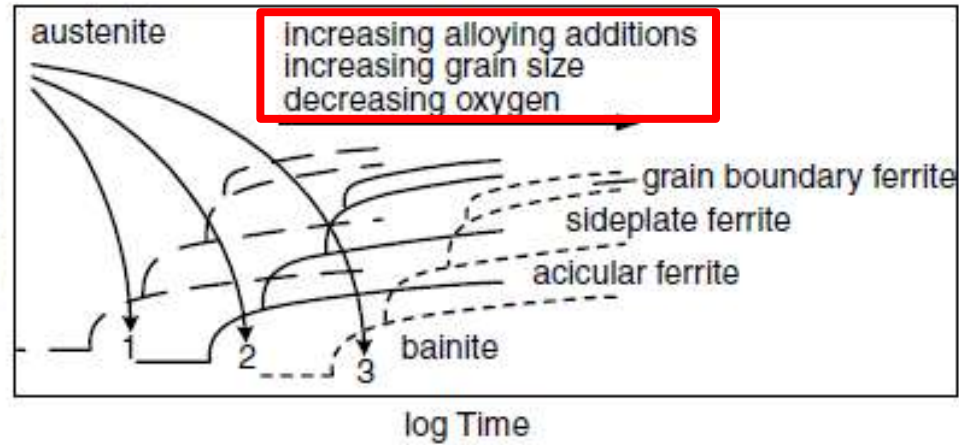
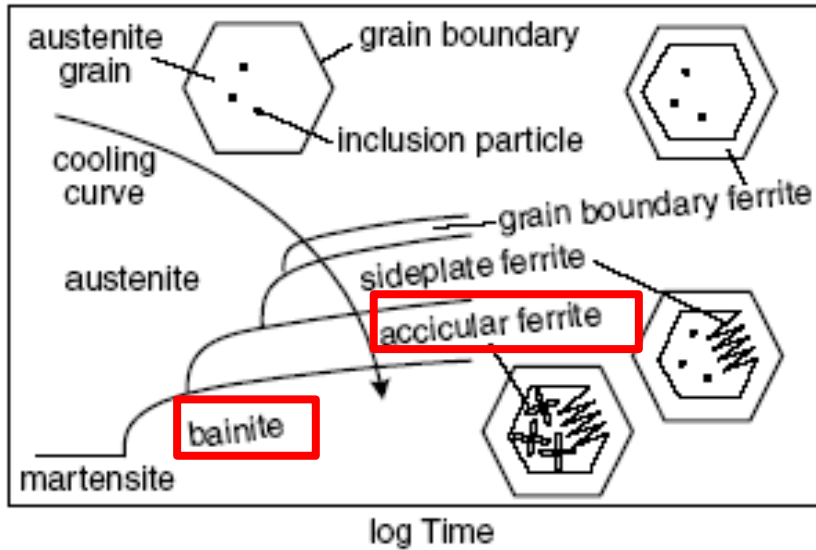
# 碳鋼與低合金鋼組織

	先共析鐵素體(GBF)	側板條鐵素體(FSP)	針狀鐵素體(AF)	細晶鐵素體(FGF)
鐵素體 (F)				
	片層珠光體(P <sub>L</sub> )	索氏體(P <sub>S</sub> )	托氏體(P <sub>T</sub> )	
珠光體 (P)	 片層間距 > 0.3 μm	 片層間距 0.1 ~ 0.3 μm	 片層間距 < 0.1 μm	

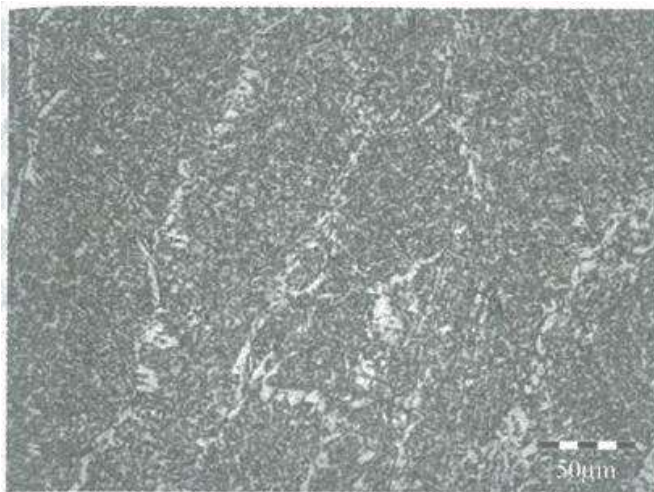
# 碳鋼與低合金鋼組織

貝氏體 (B)	上貝氏體( $B_u$ )		下貝氏體( $B_L$ )		粒狀貝氏體( $B_g$ )	條狀貝氏體( $B_p$ )
	組織形態	显微結構	組織形態	显微結構		
						
馬氏體 (M)	板條馬氏體( $M_D$ )			片狀馬氏體( $M_T$ )		
	組織形態	显微結構	組織形態	显微結構	組織形態	显微結構
						

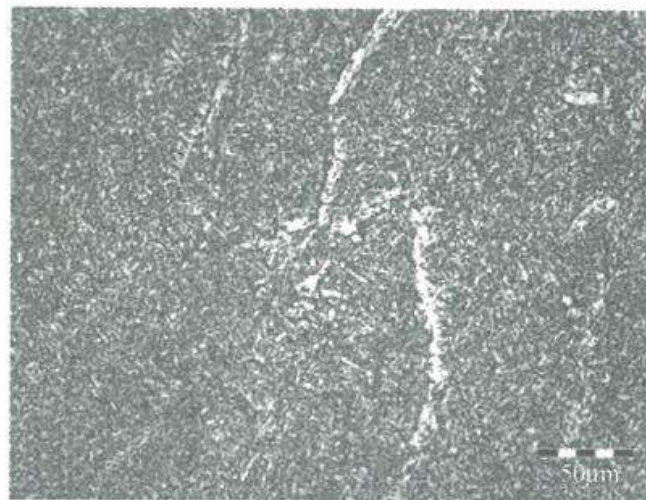
# 組織變化因素



# 合金元素影響



a) 0.004Ti



b) 0.02Ti

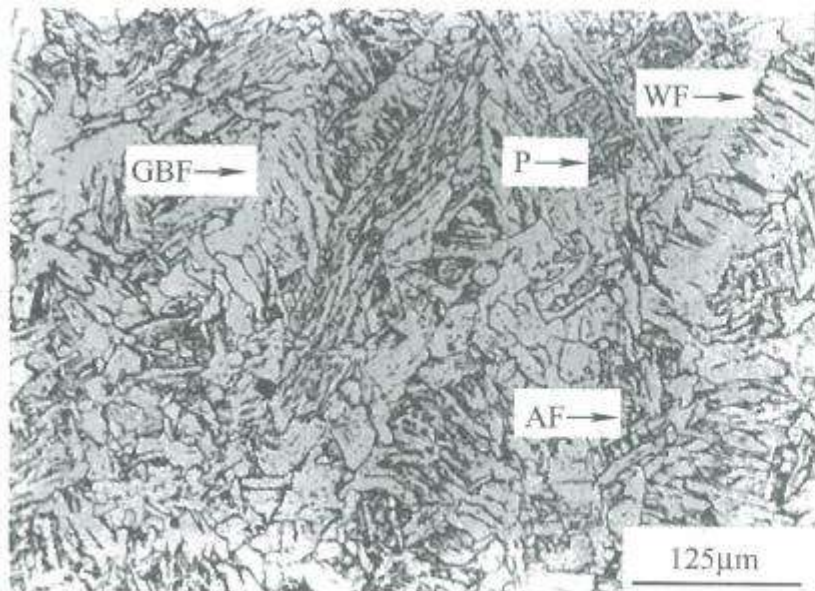


0.05Ti

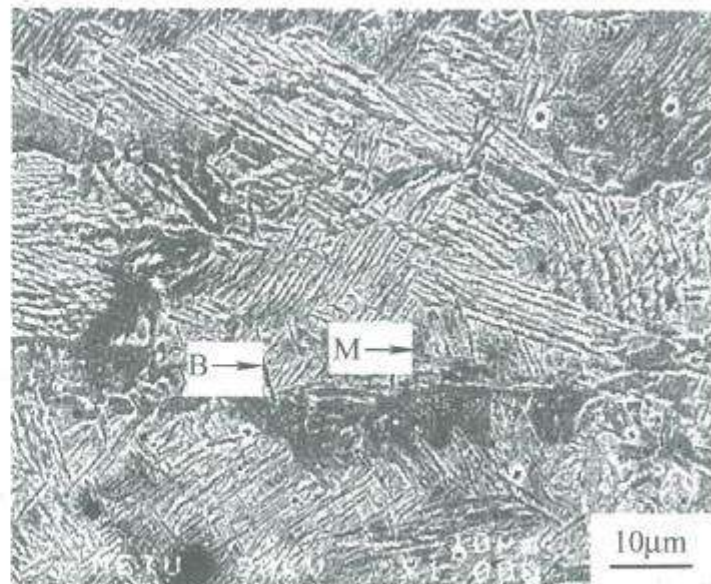


0.09Ti

# 入熱量影響

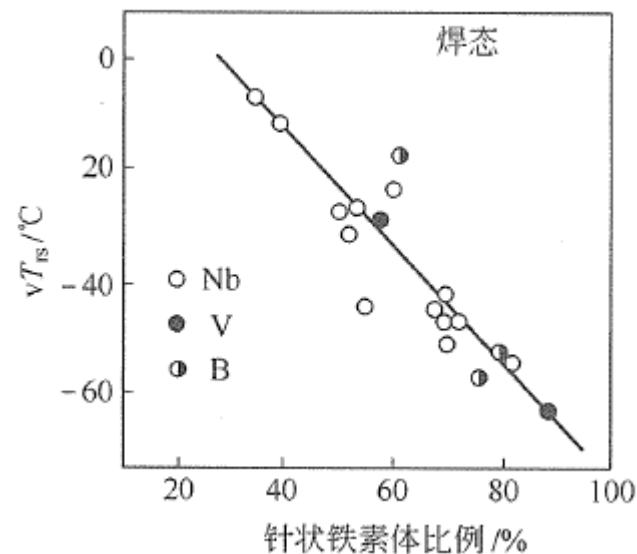
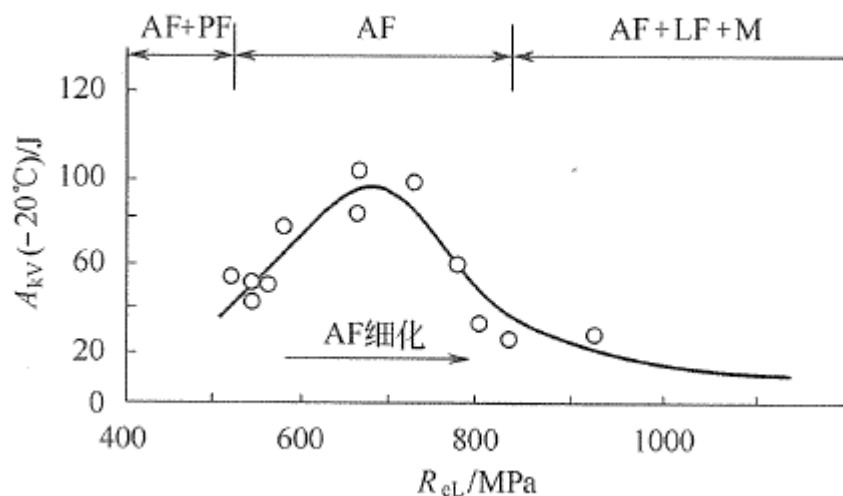


a)  $E=2\text{kJ/mm}$

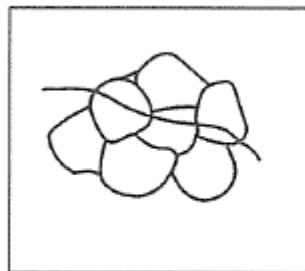


b)  $E=0.5\text{kJ/mm}$

# 顯微組織與強度韌性關係

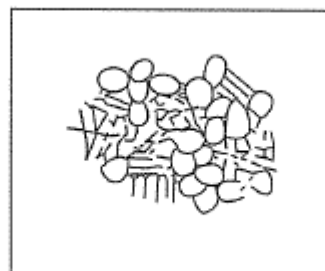


高温形成



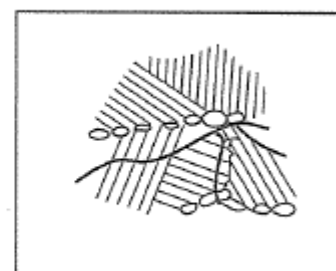
(a) 粗大铁素体，韧性差

中温形成



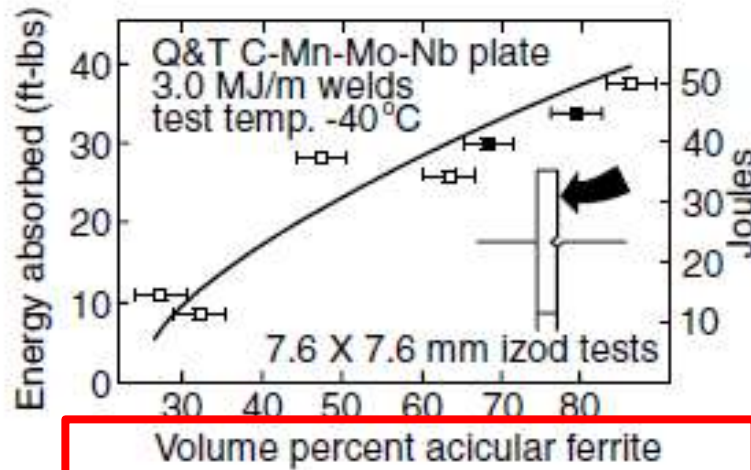
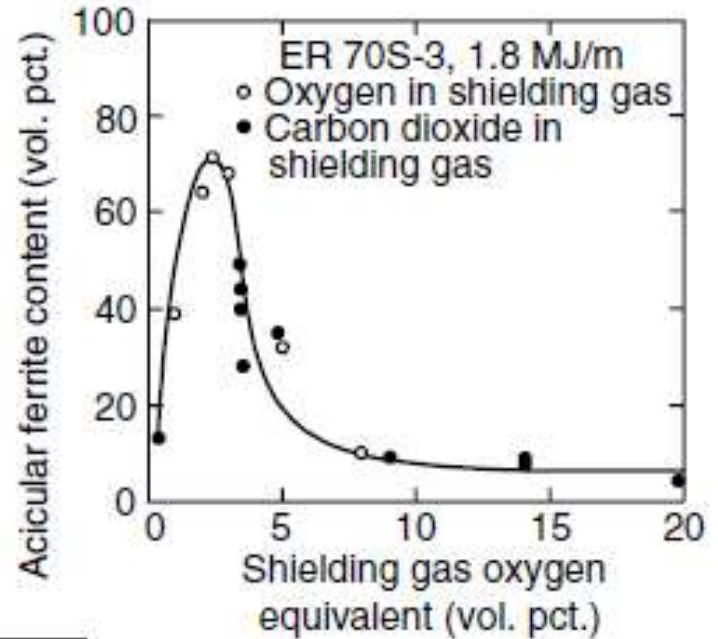
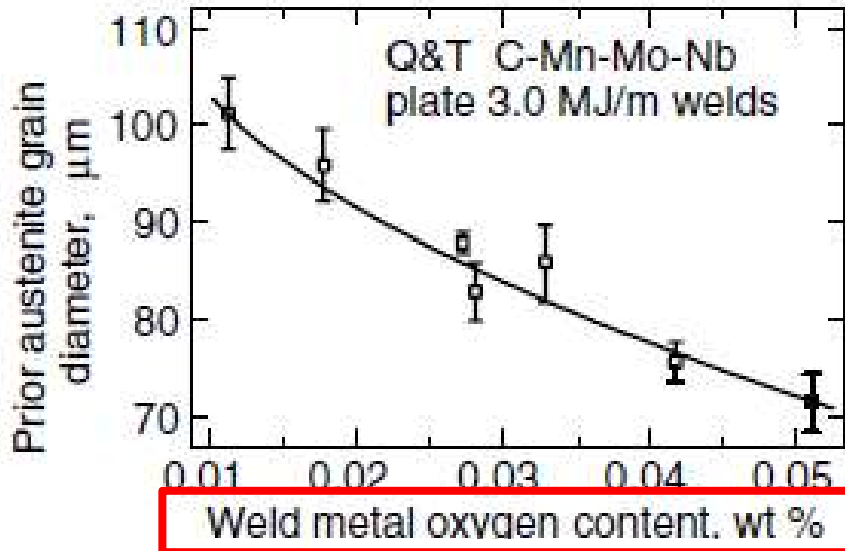
(b) 粒状十条状，高韧性

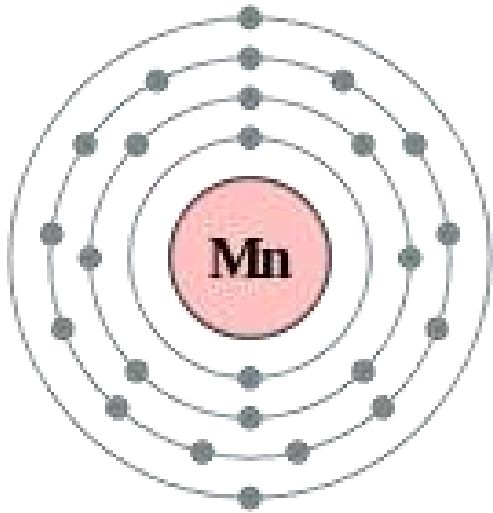
低温形成



(c) 条状铁素体，韧性差

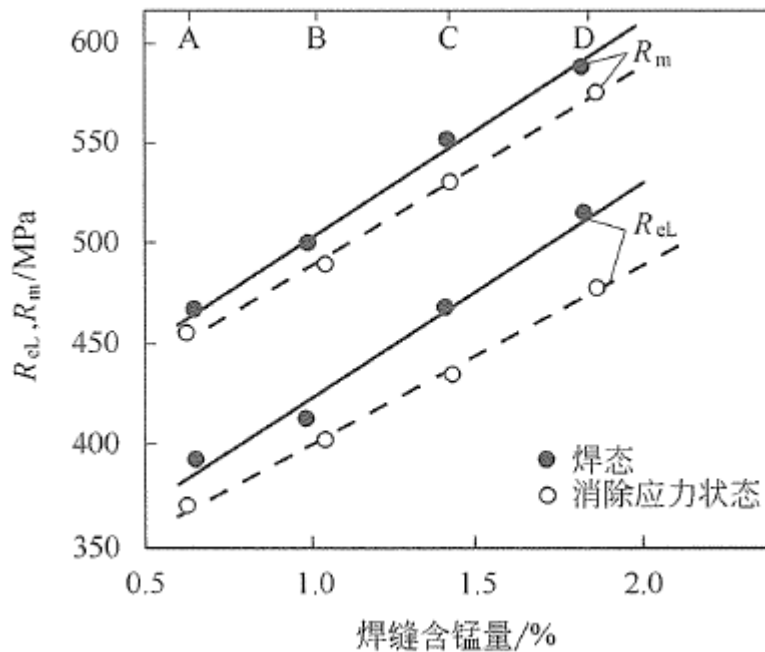
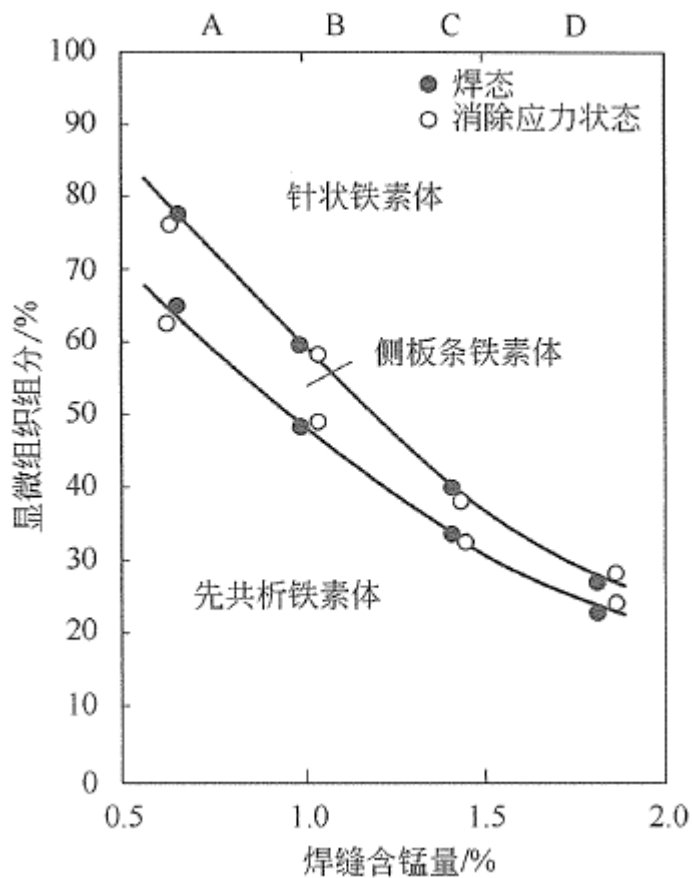
# 低溫衝擊韌性





# 合金設計-Mn

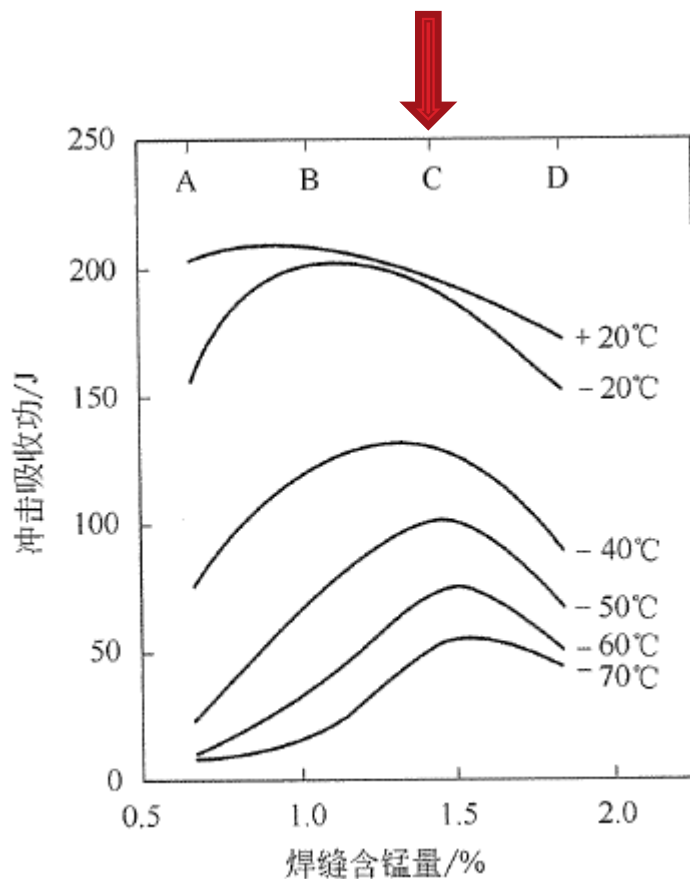
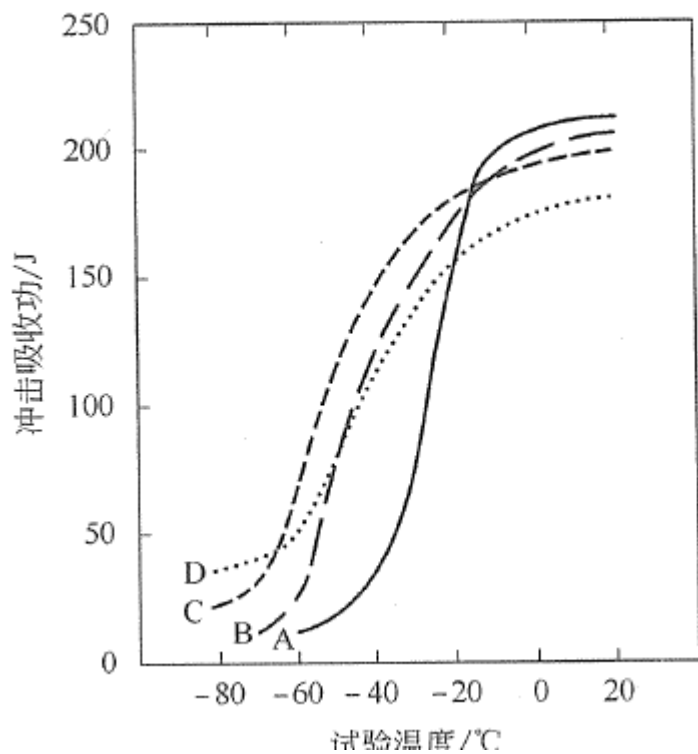
# 錳元素影響-組織&強度



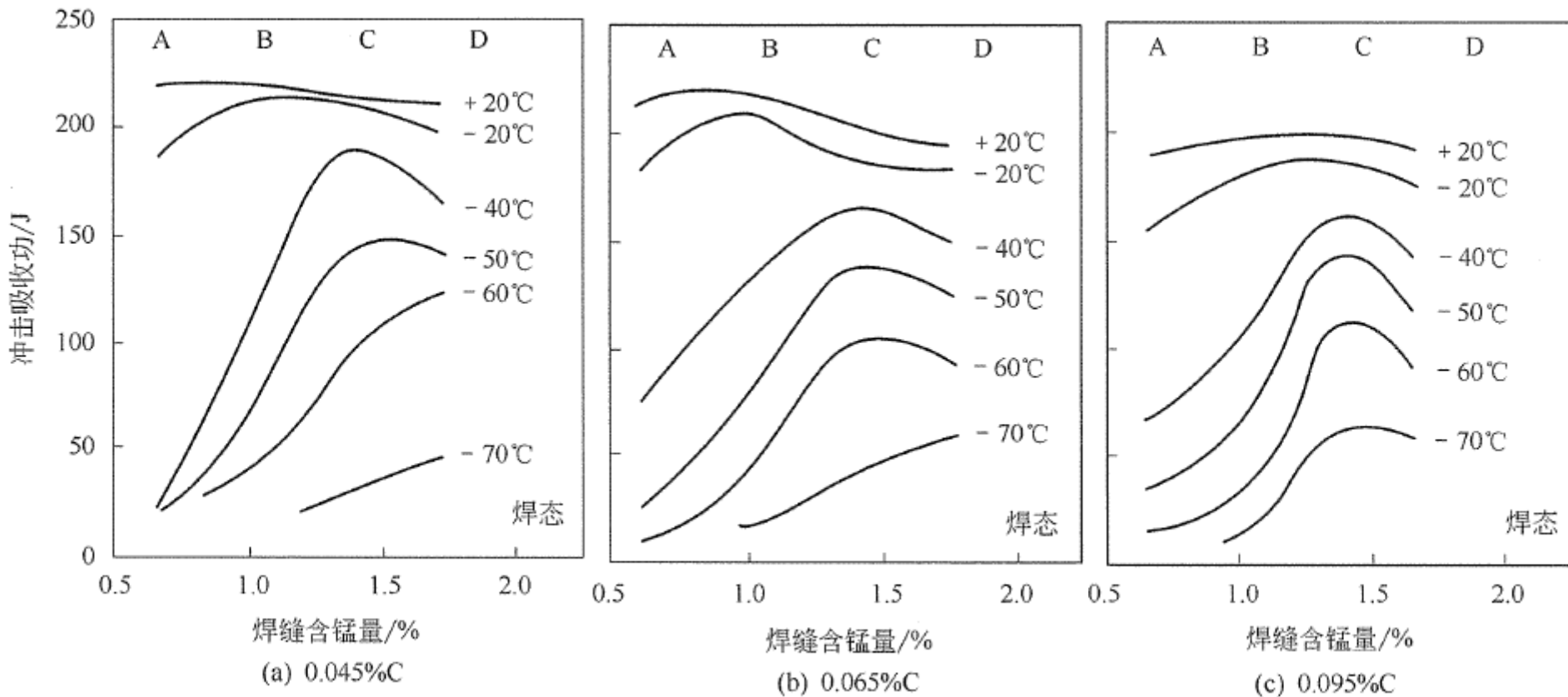
$$R_{eL} = 314 + 108w \quad (\text{Mn})$$

$$R_m = 394 + 108w \quad (\text{Mn})$$

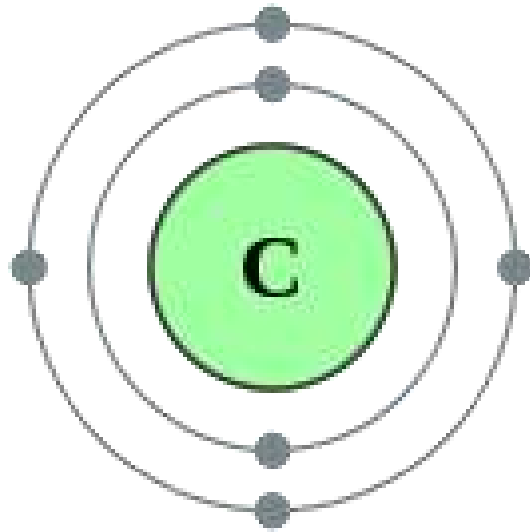
# 錳元素影響-低溫韌性



# 不同碳含量錳元素影響

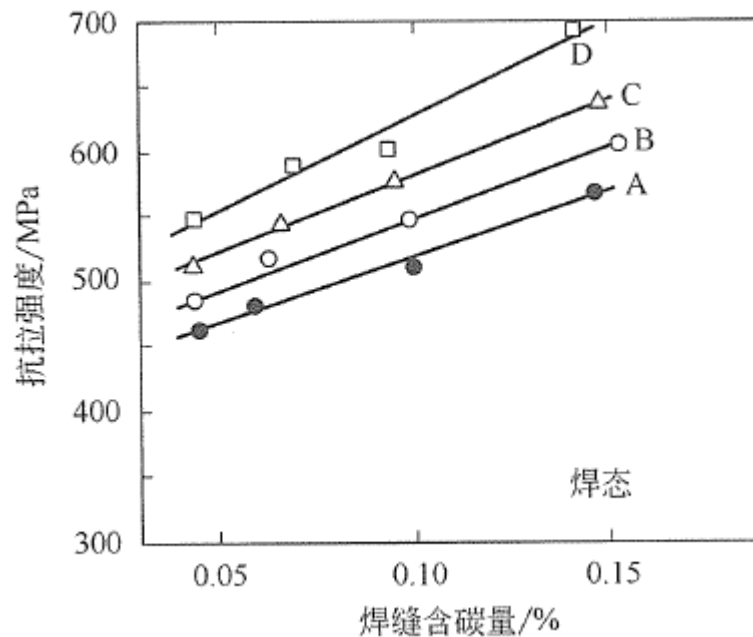
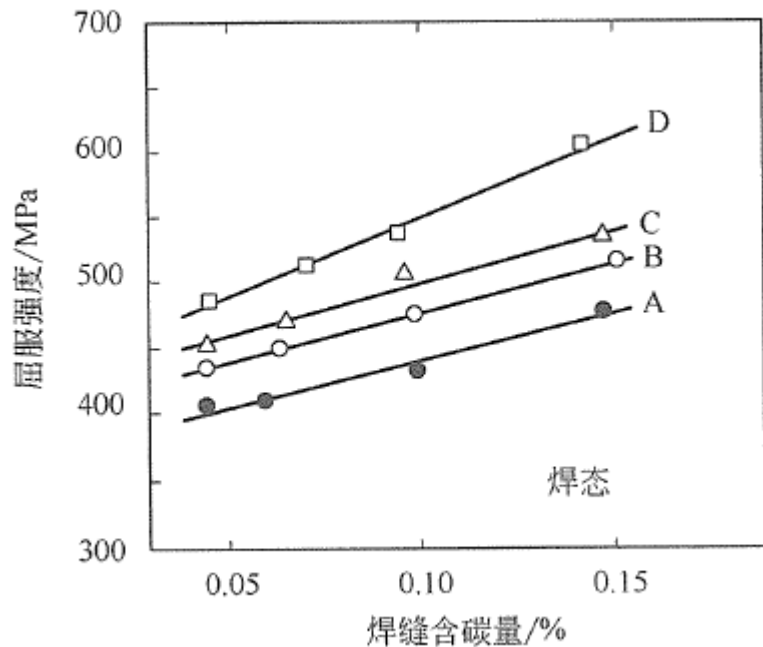


Mn設計在**1.2~1.6**之間

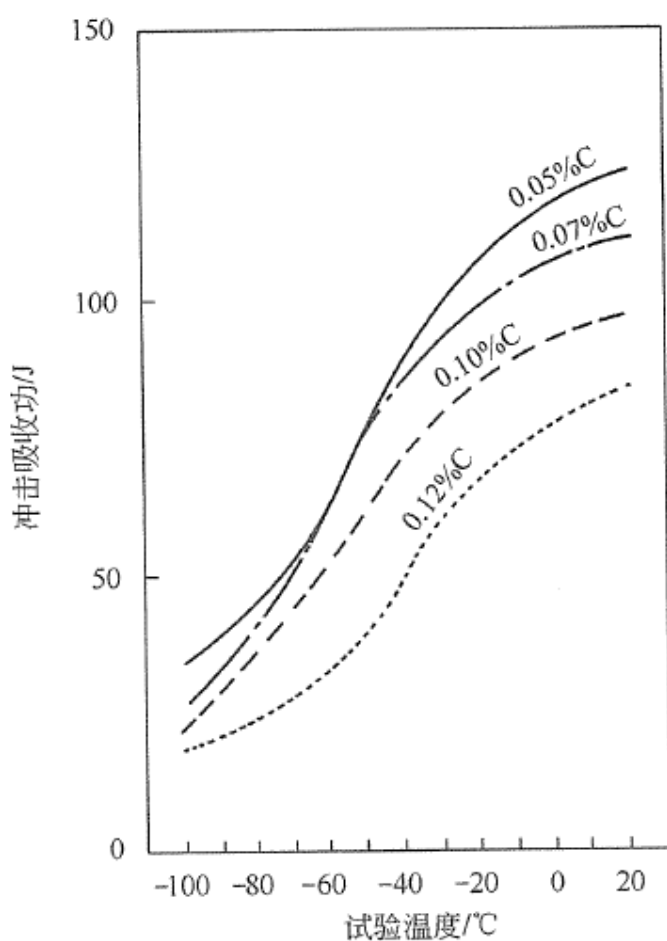


# 合金設計-C

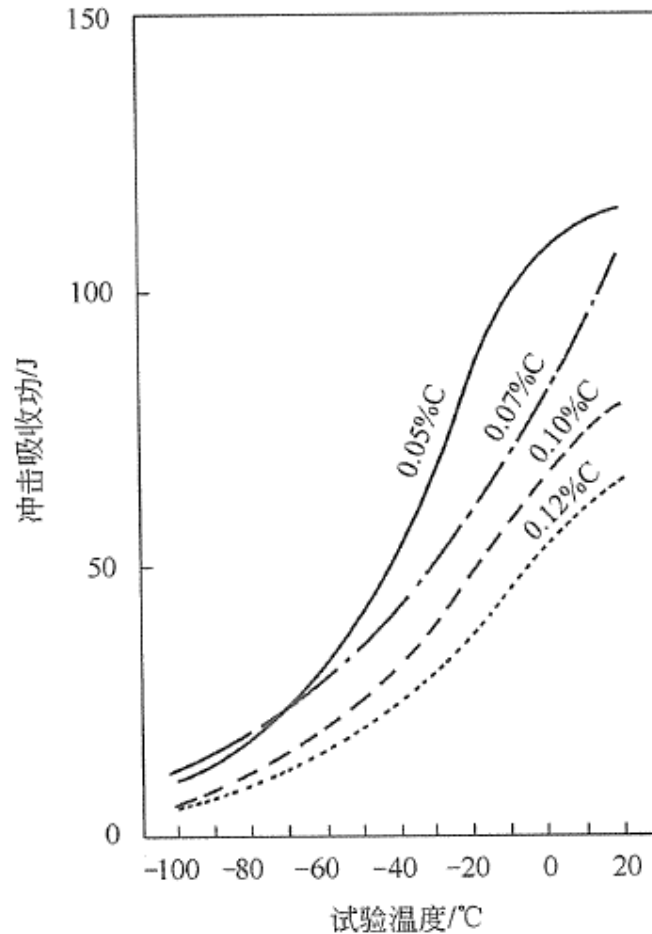
# 碳元素影響-強度



# 碳元素影響-低溫韌性



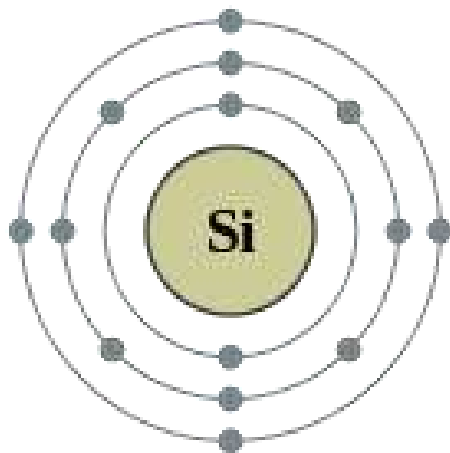
(a) 焊态



(b) 消除应力状态

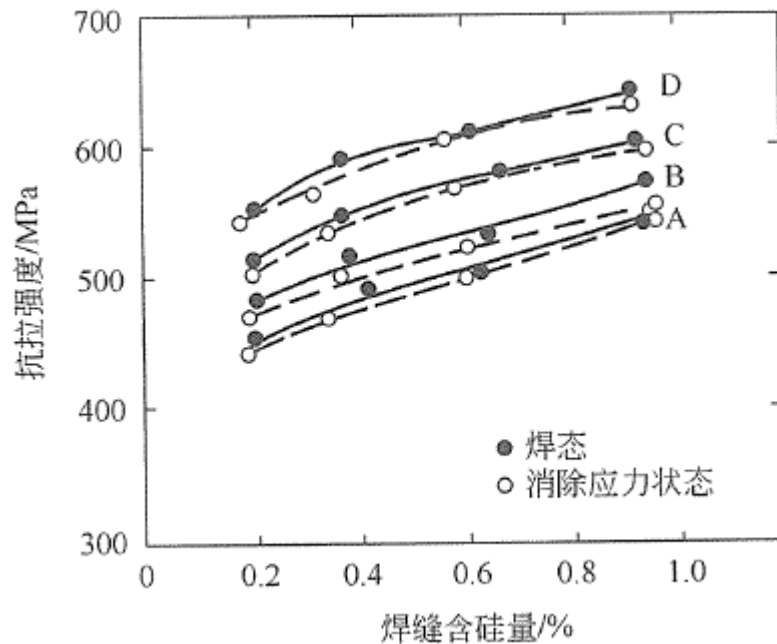
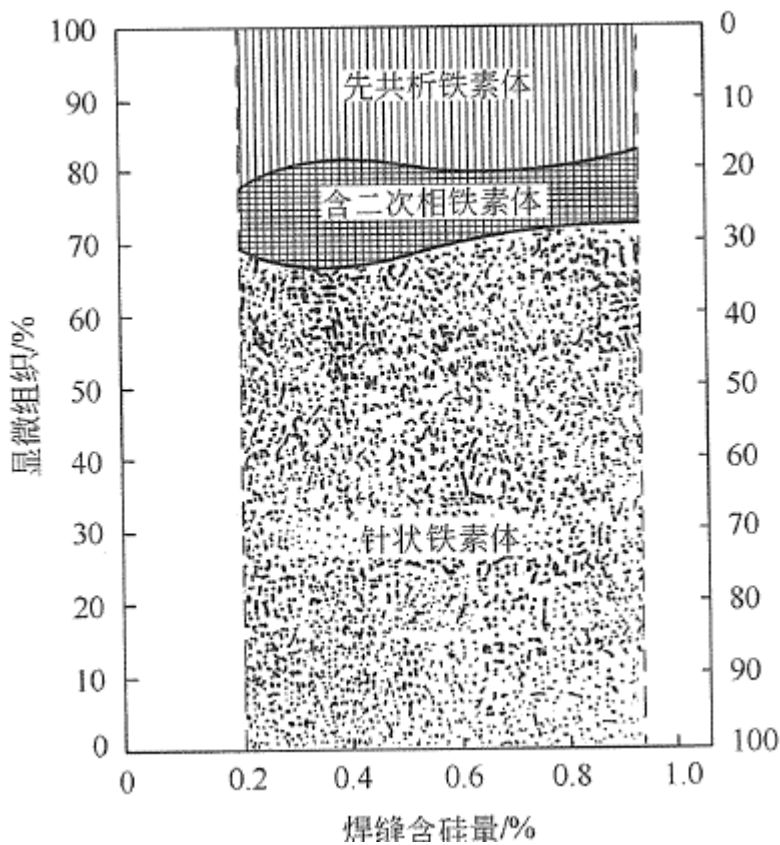


C設計在**0.06**左右

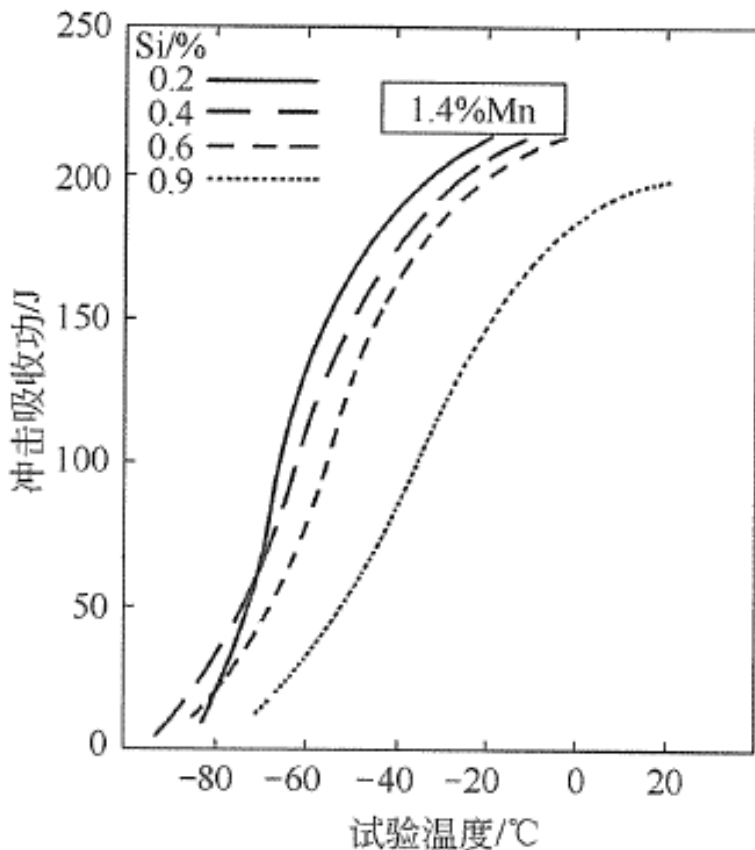


# 合金設計-Si

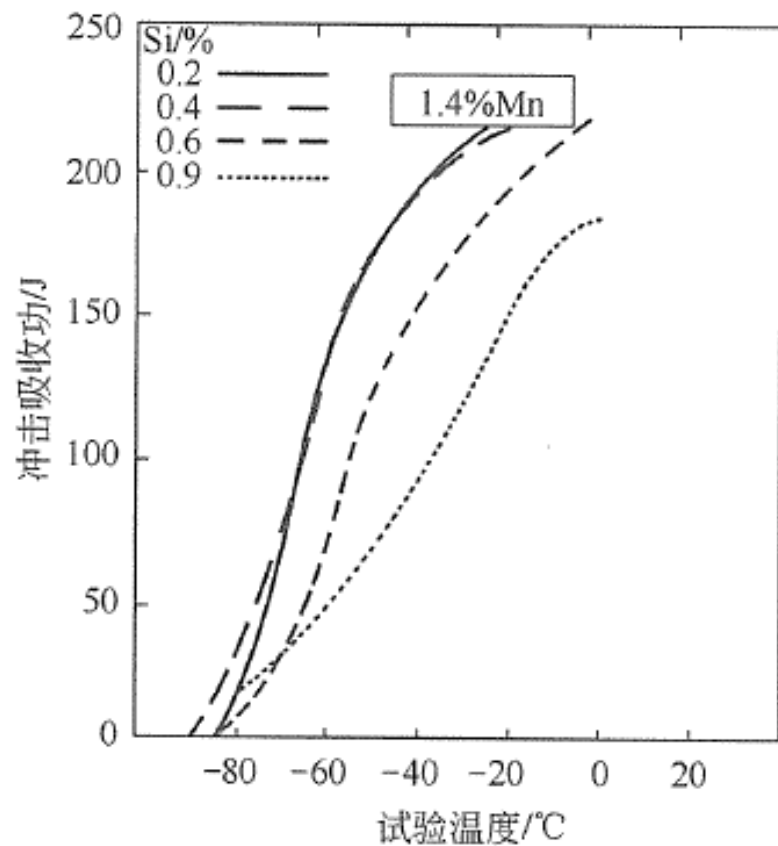
# 矽元素影響-組織&強度



# 矽元素影響-低溫韌性



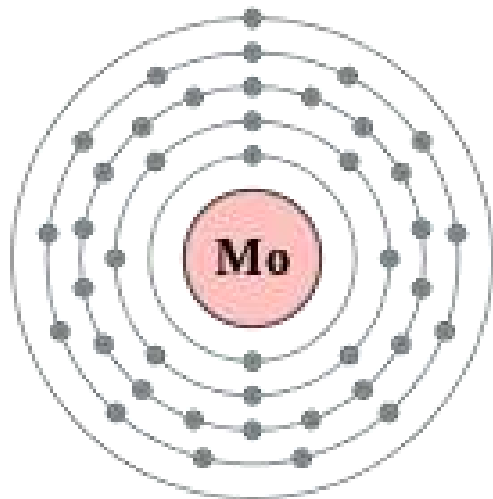
(a) 焊态



(b) 消除应力状态

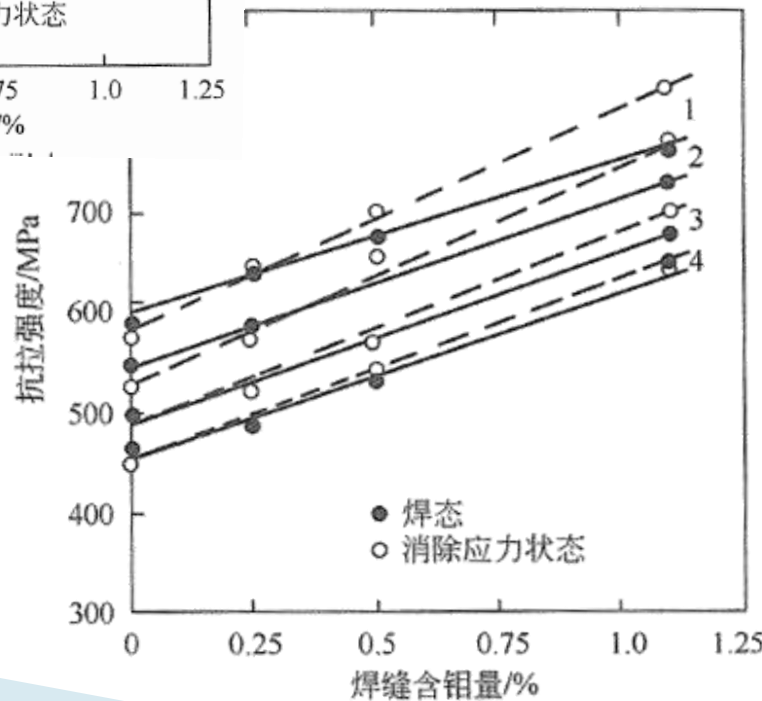
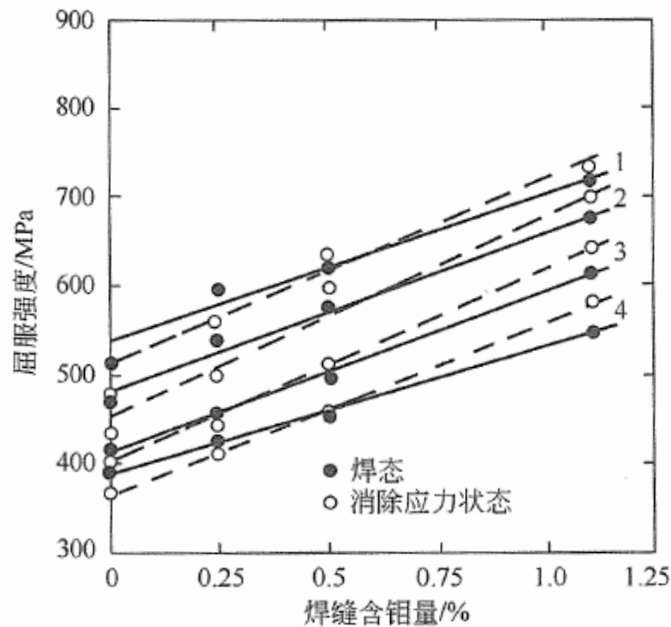
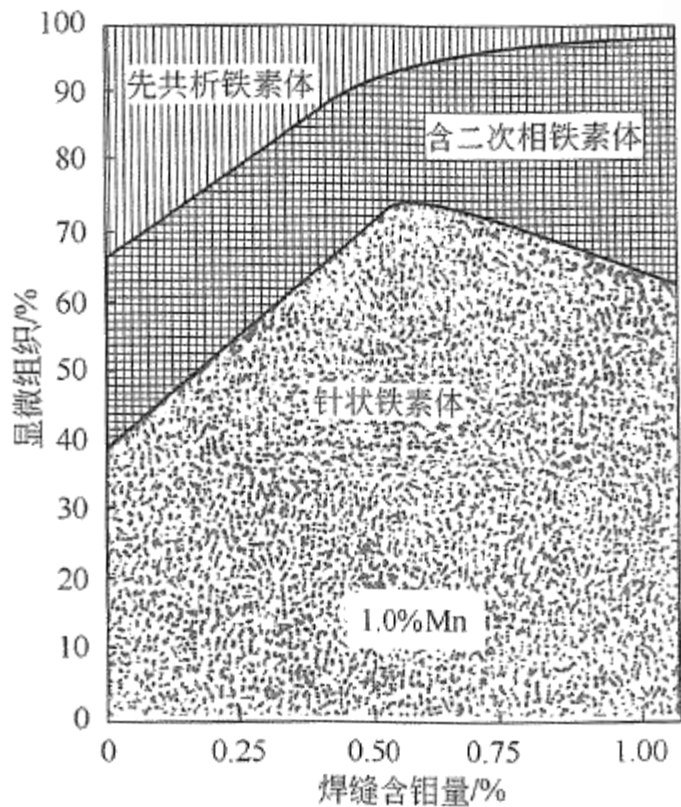


Si設計在**0.2~0.6**之間

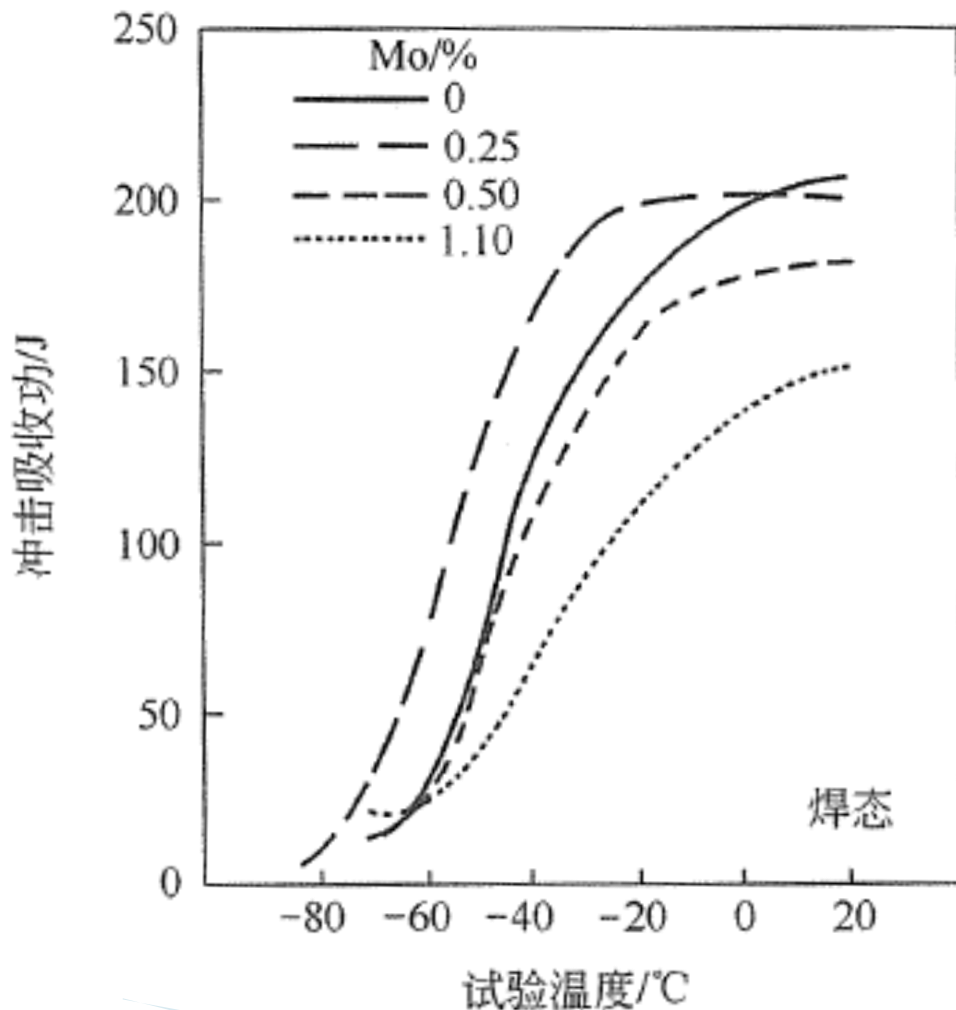


# 合金設計-Mo

# 鉬元素影響-組織&強度



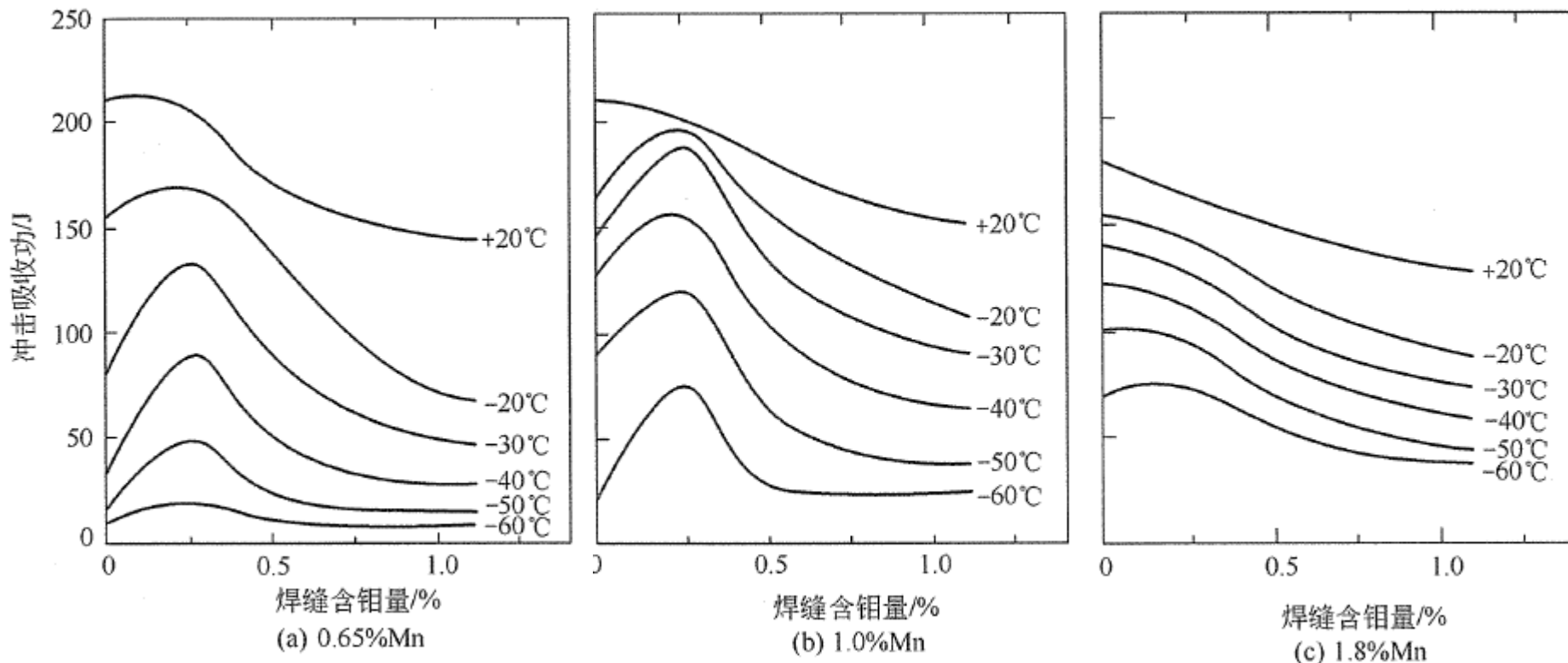
# 鉬元素影響-低溫韌性



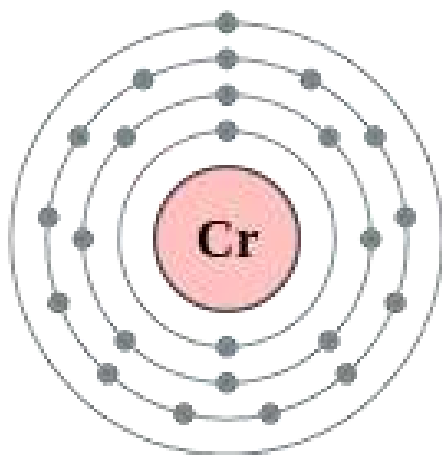
0.25%Mo 韌脆轉換溫度最低

1.1%Mo 韌脆轉換溫度最高

# 不同錳含量鉬元素影響

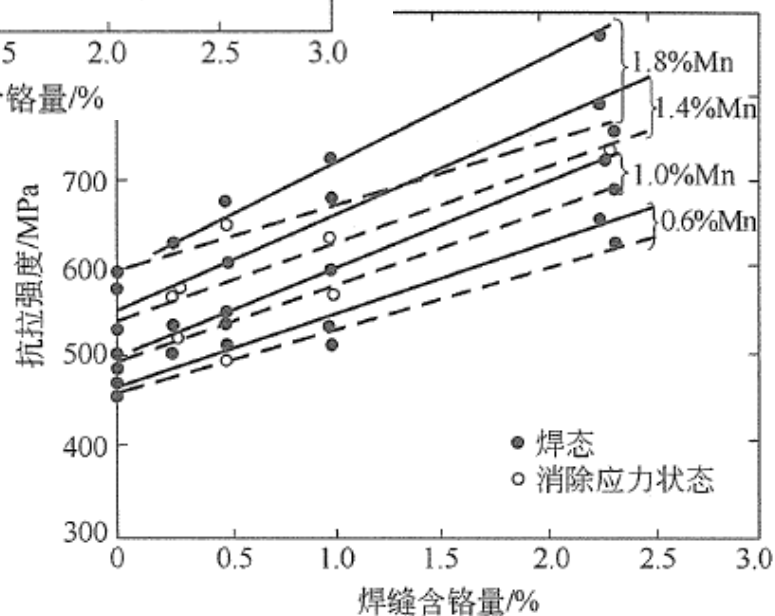
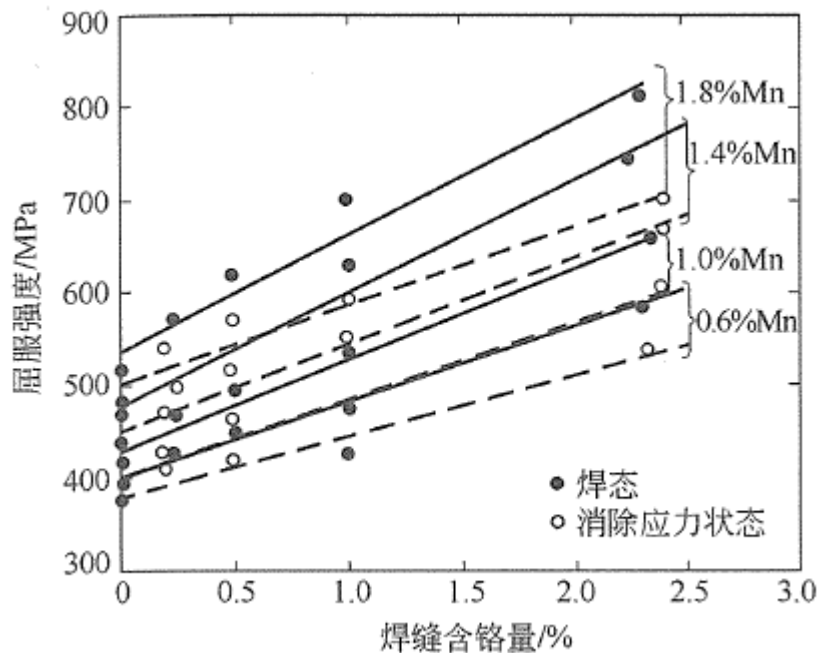
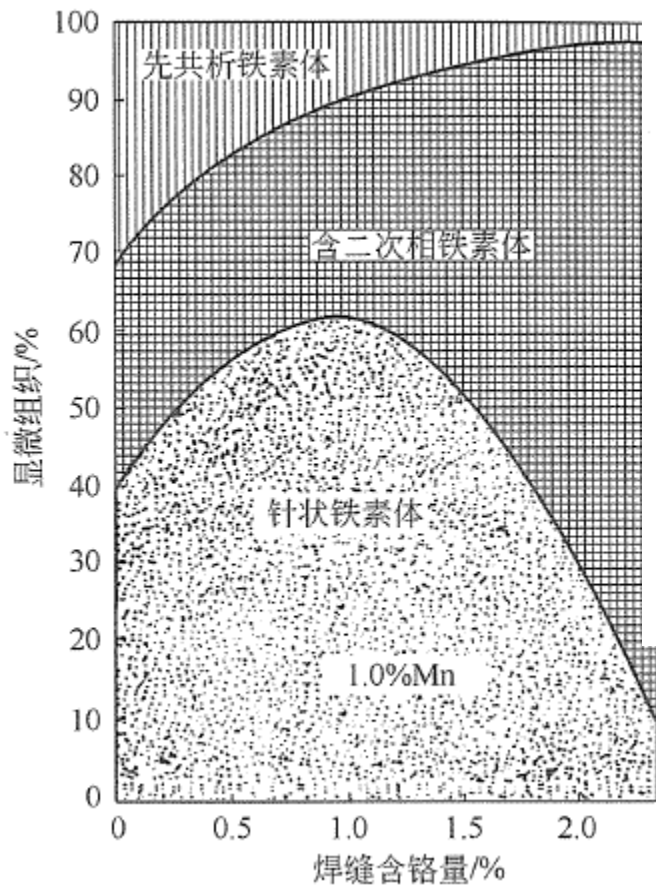


Mo設計在**0.2~0.4**之間

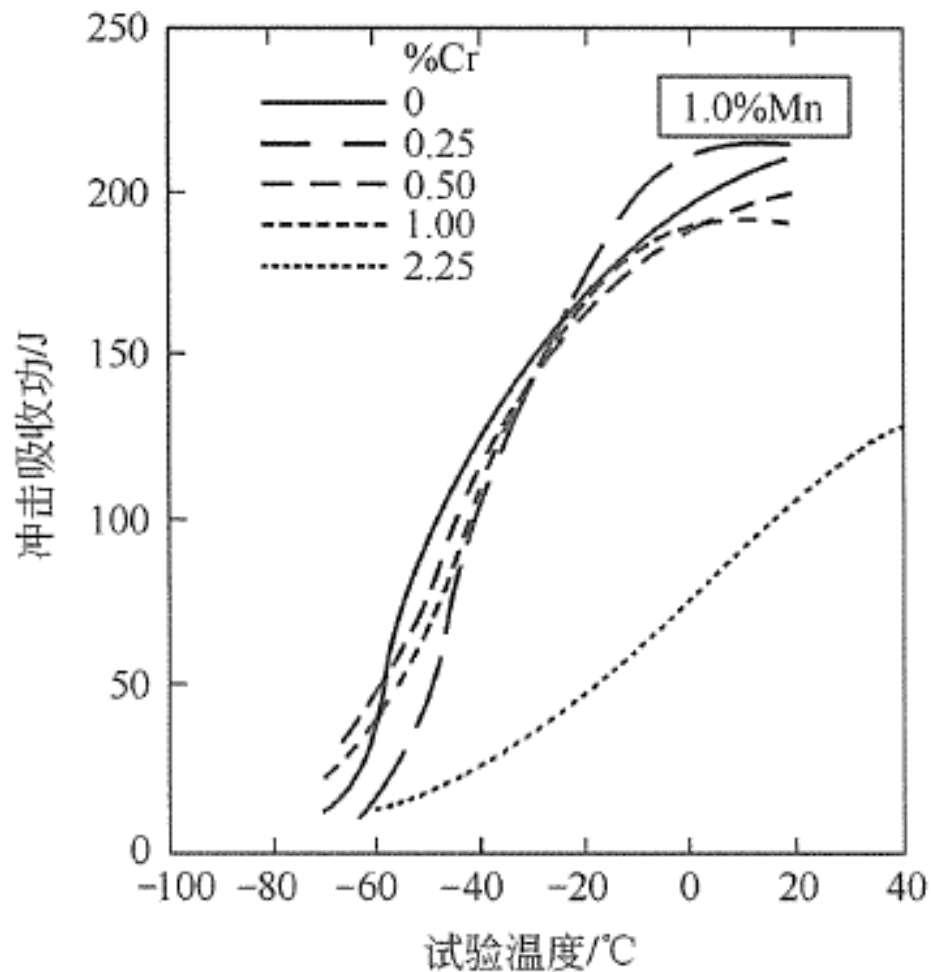


# 合金設計-Cr

# 鉻元素影響-組織&強度

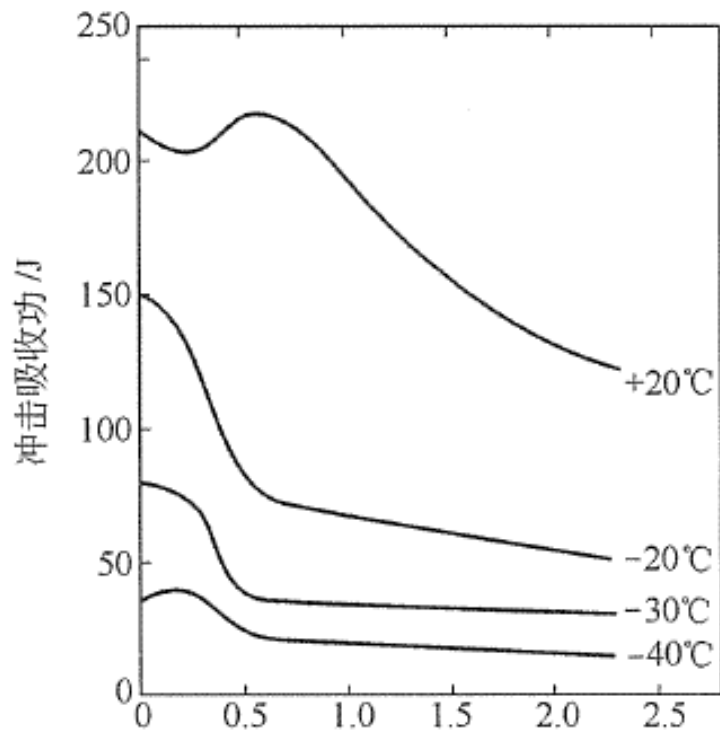


# 鉻元素影響-低溫韌性

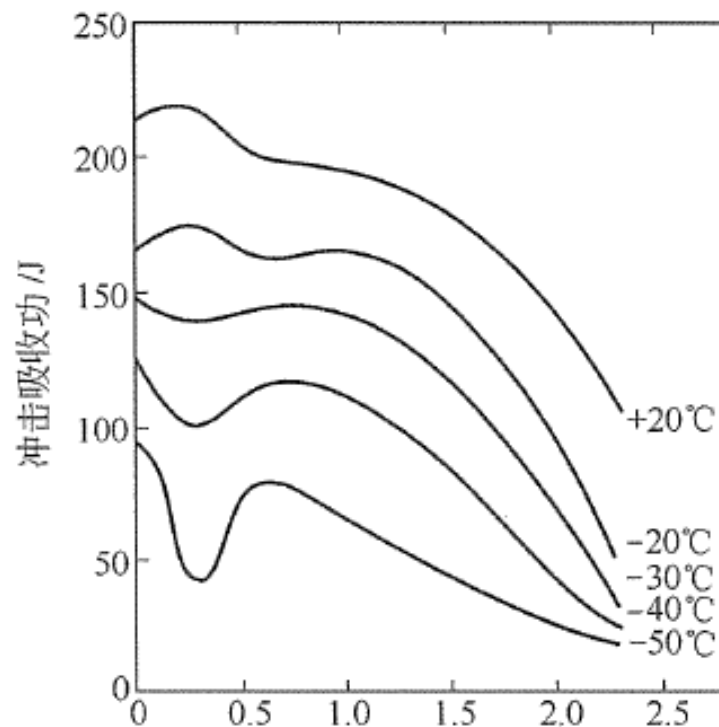


2.25%Cr 韌脆轉換溫度最高

# 不同錳含量鉻元素影響



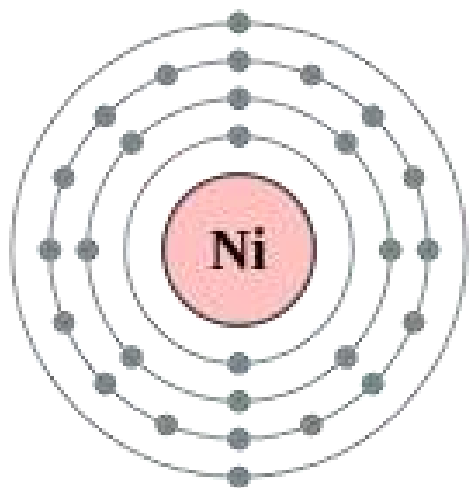
焊缝含铬量 / %  
(a) 焊态, 0.65%Mn



焊缝含铬量 / %  
(b) 焊态, 1.0%Mn

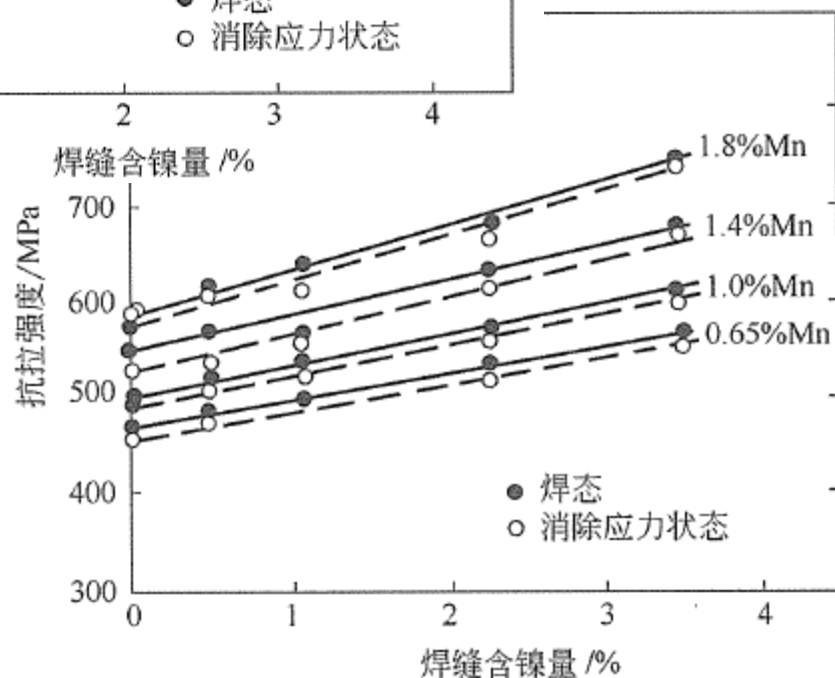
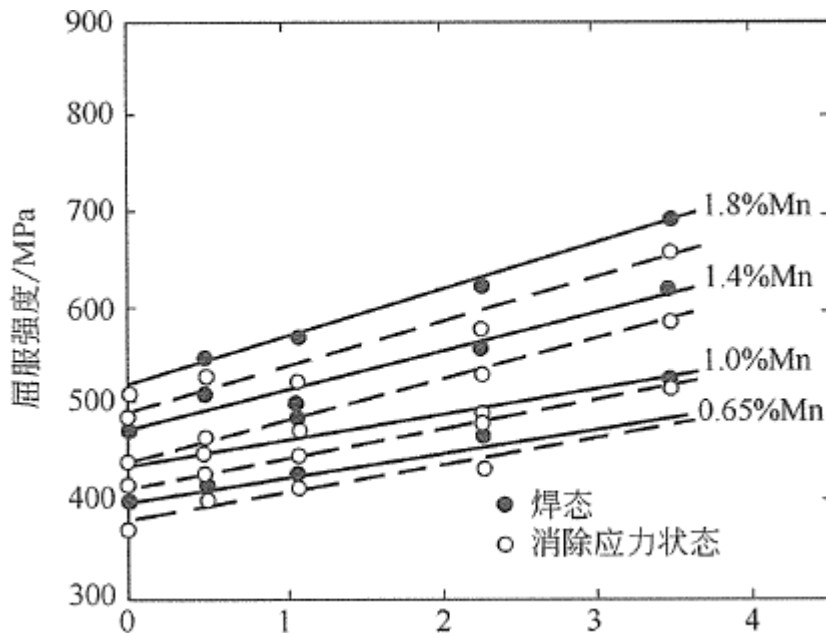
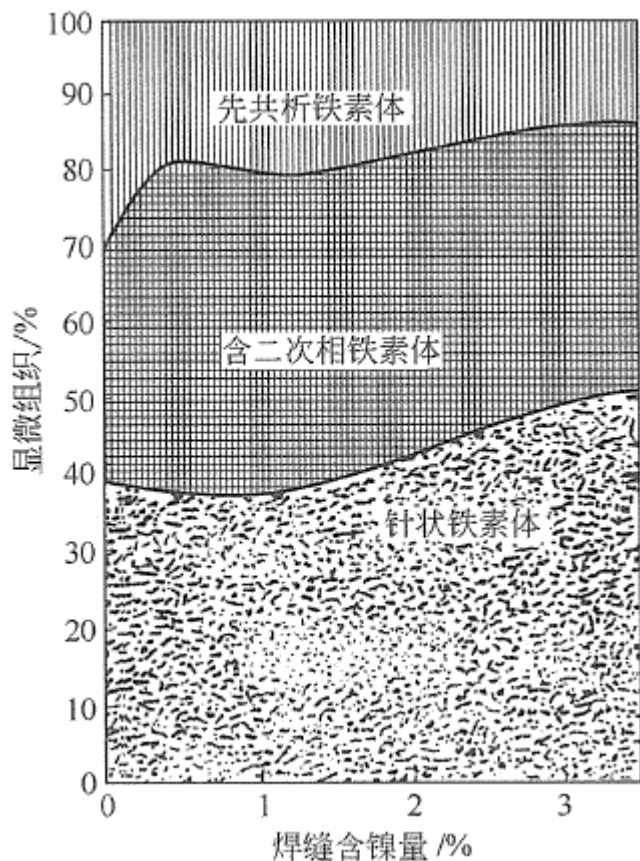


Cr設計在**0.25** 以下

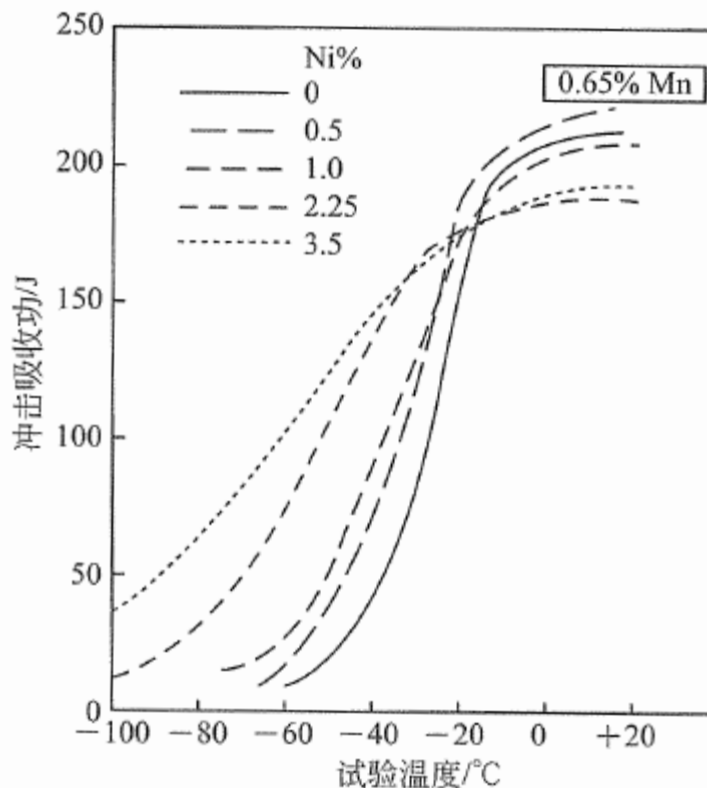


# 合金設計-Ni

# 鎳元素影響-組織&強度



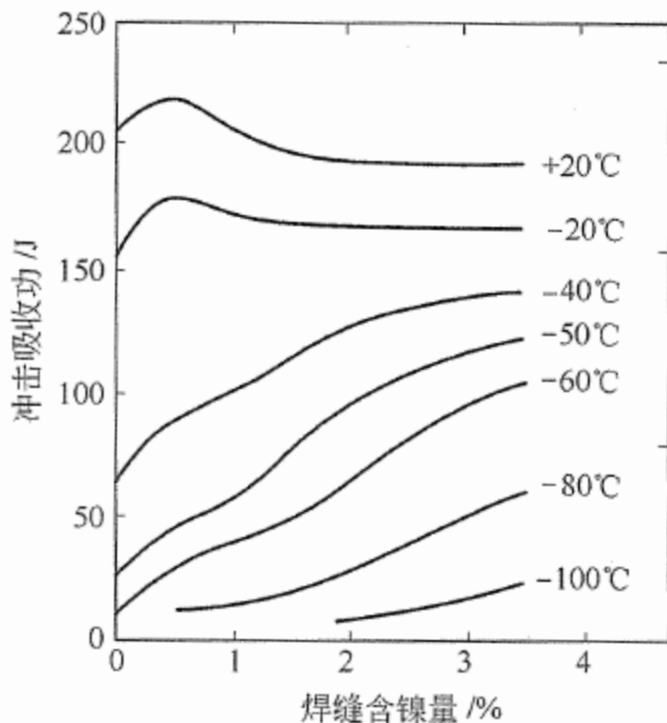
# 鎳元素影響-低溫韌性



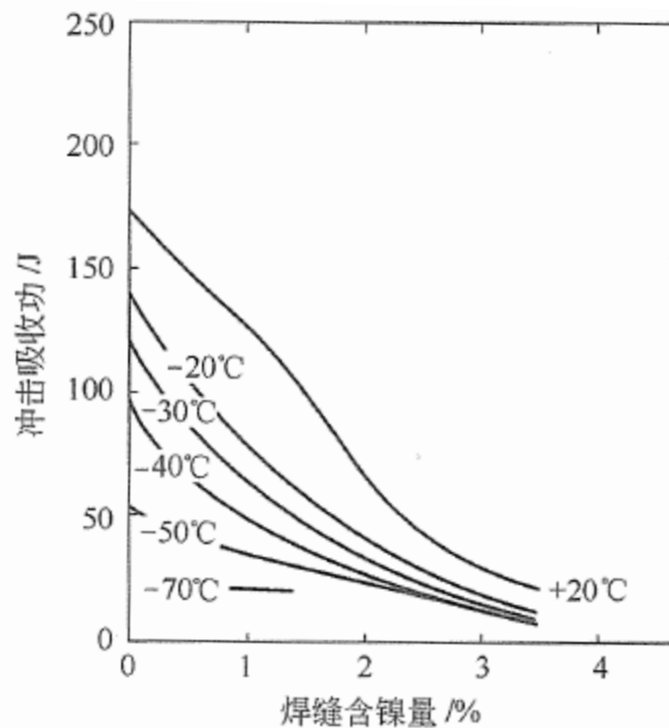
3.5%Ni 韌脆轉換溫度最低

0%Ni 韌脆轉換溫度最高

# 不同錳含量鎳元素影響



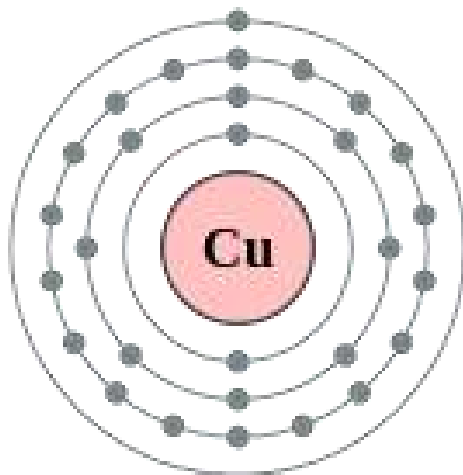
(a) 焊縫含0.65%Mn



(b) 焊縫含1.8%Mn

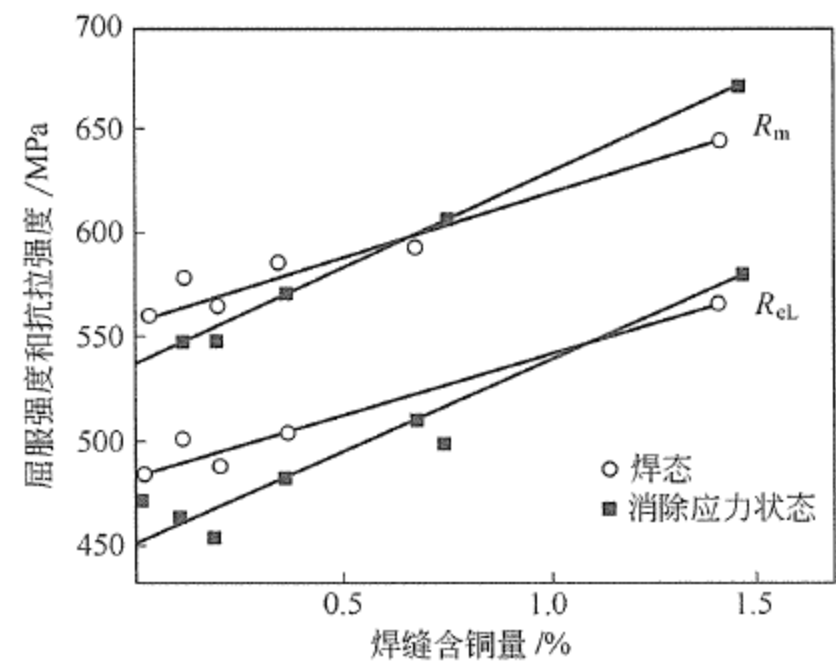


Ni設計在**1.5~2.5** 之間

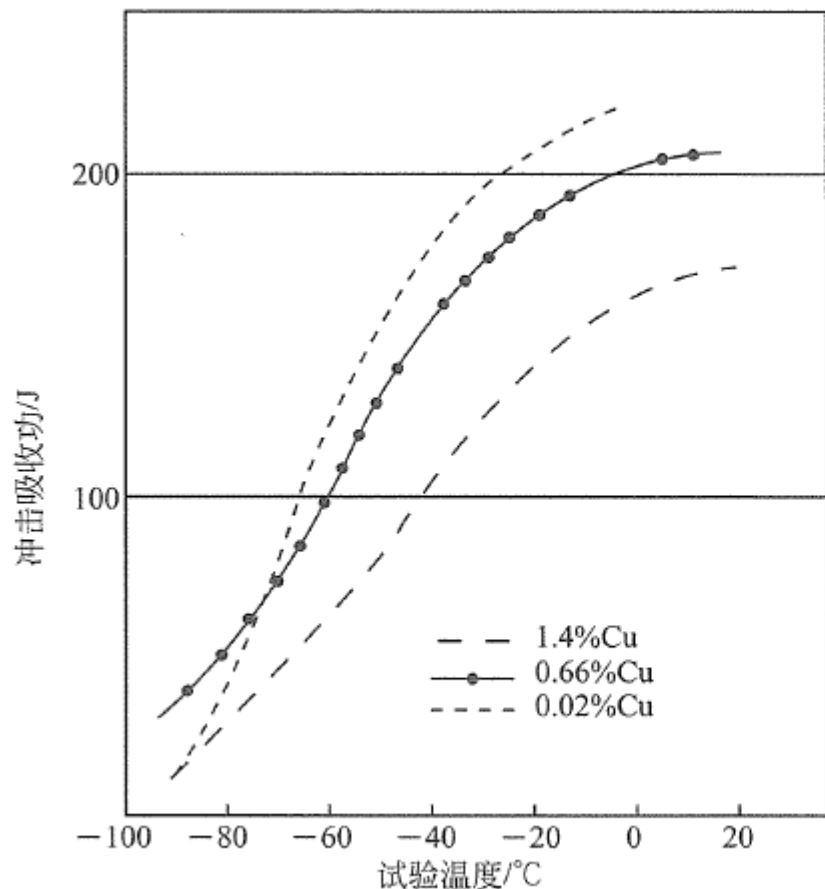


# 合金設計-Cu

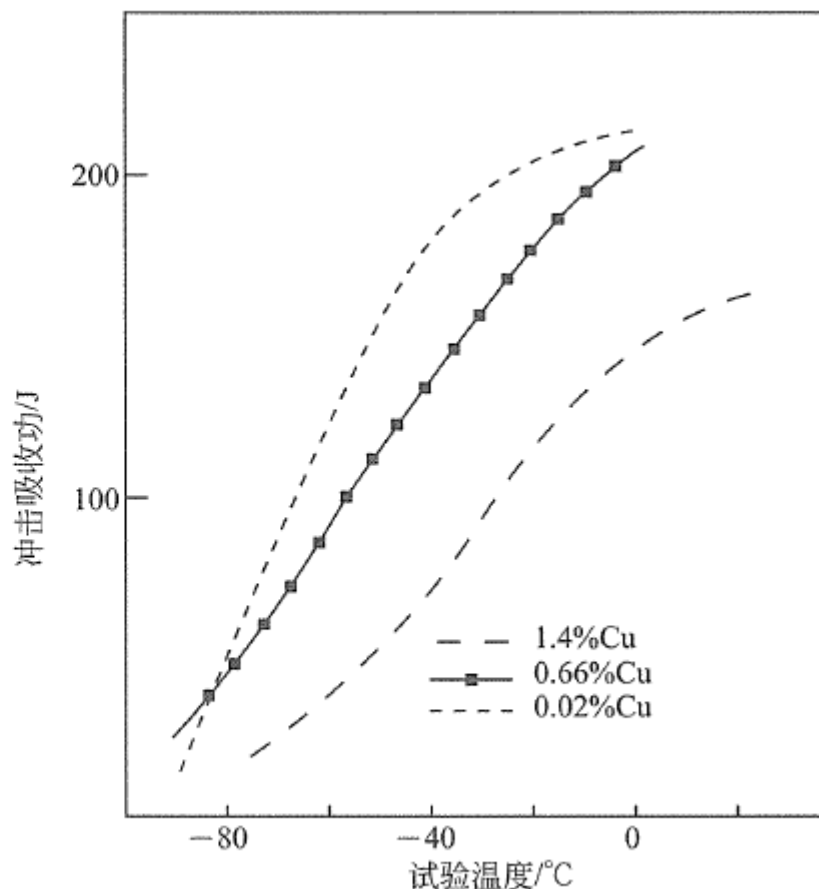
# 銅元素影響-強度



# 銅元素影響-低溫韌性



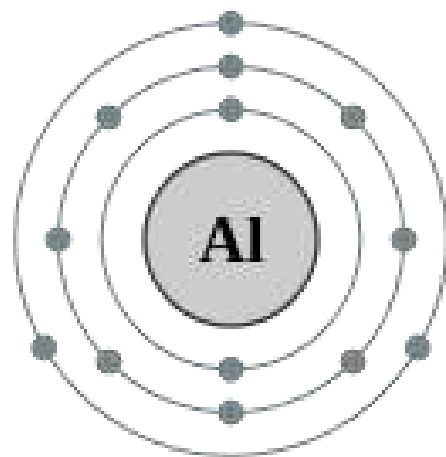
(a) 焊态



(b) 消除应力状态

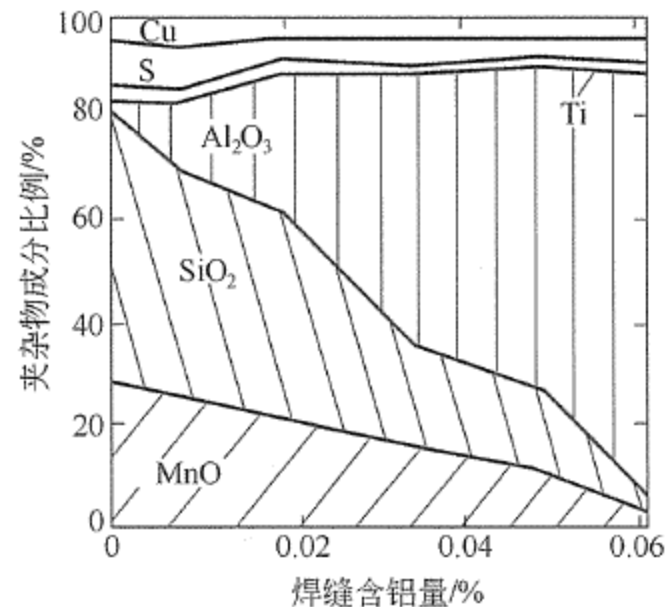
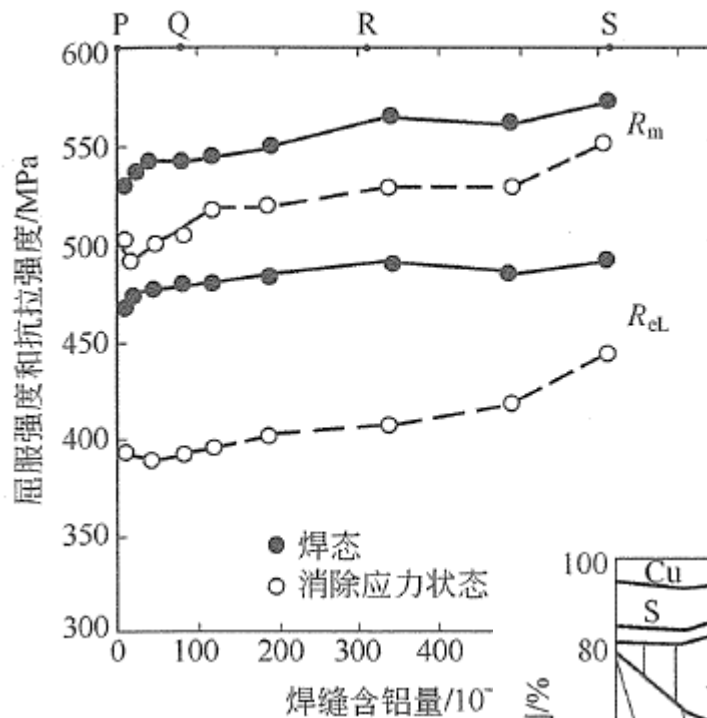
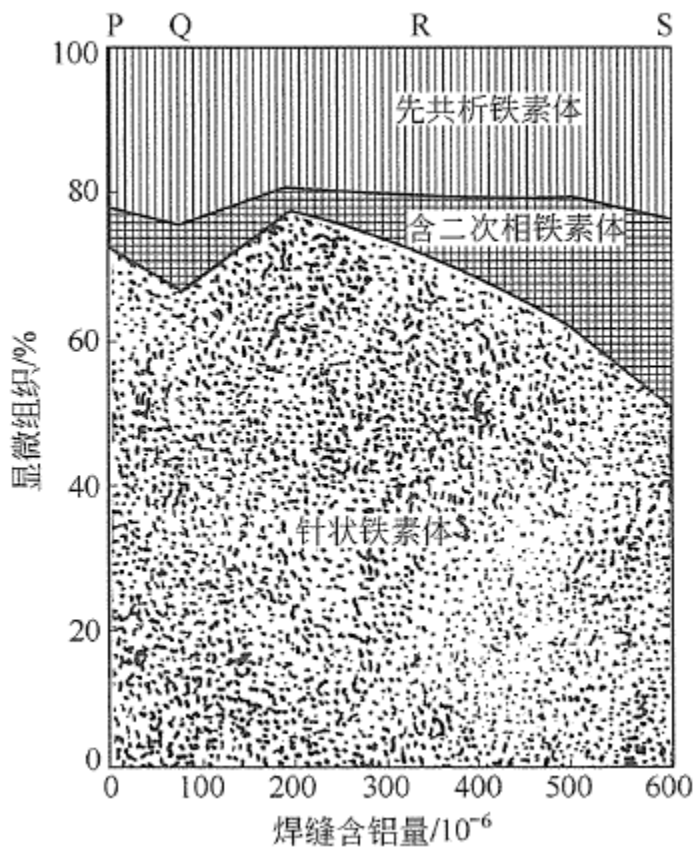


Cu設計在**0.05** 以下

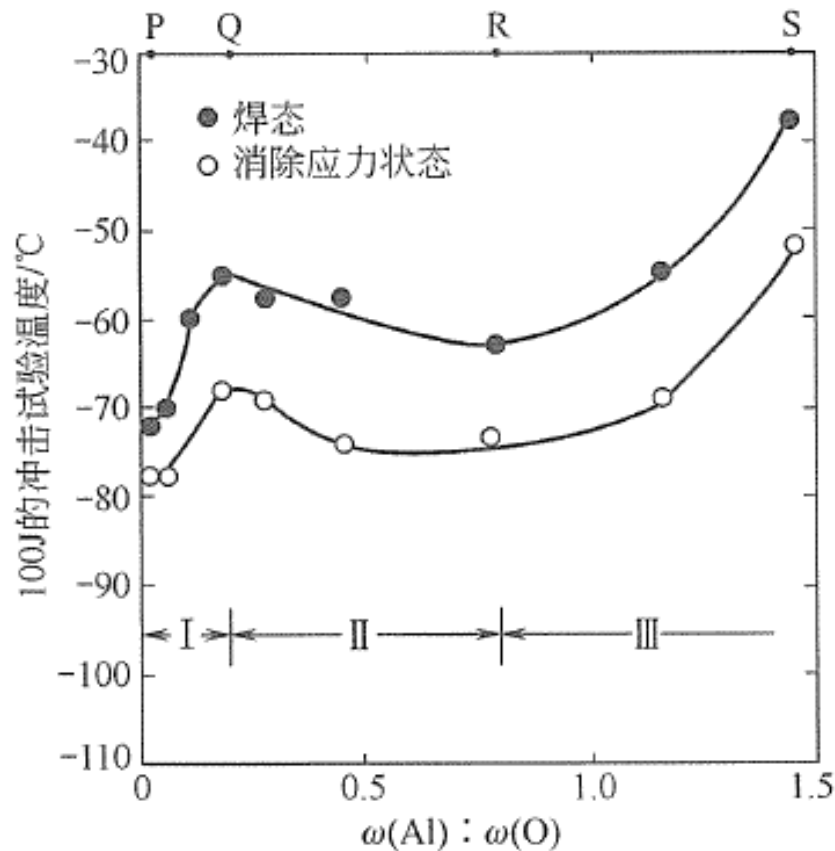
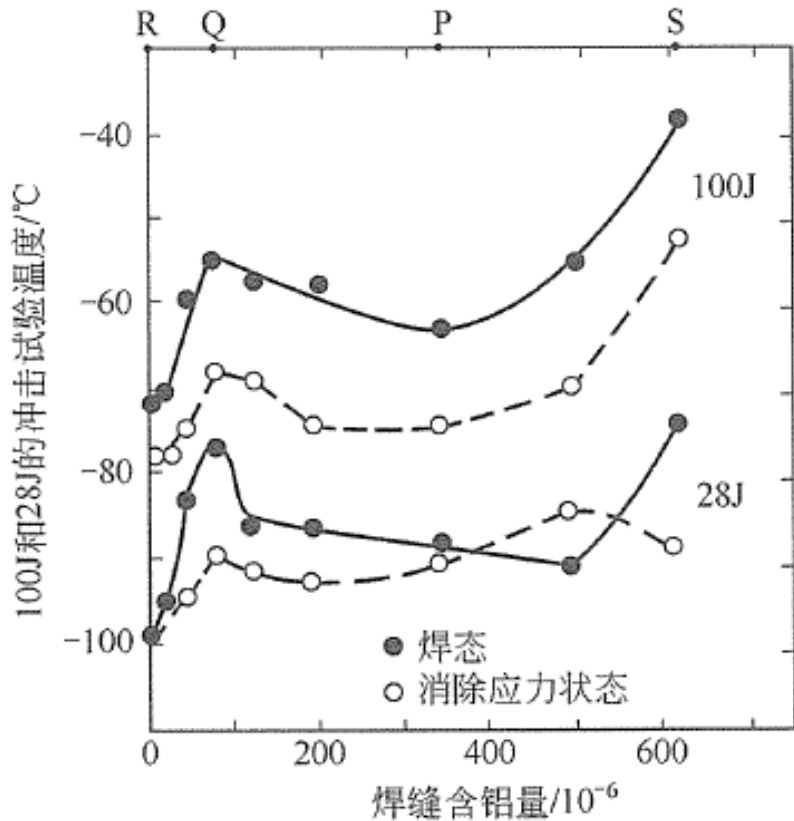


# 合金設計-Al

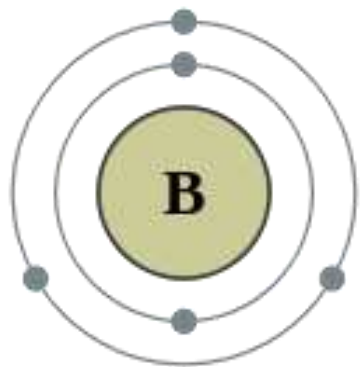
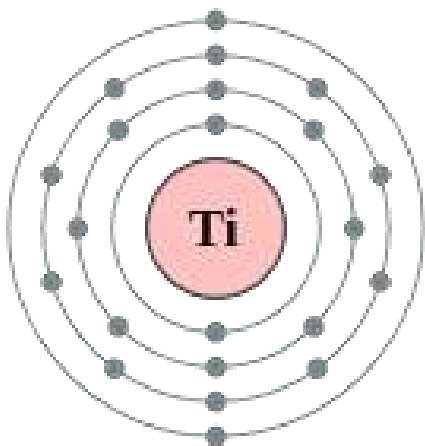
# 鋁元素影響-組織&強度



# 鋁元素影響-低溫韌性

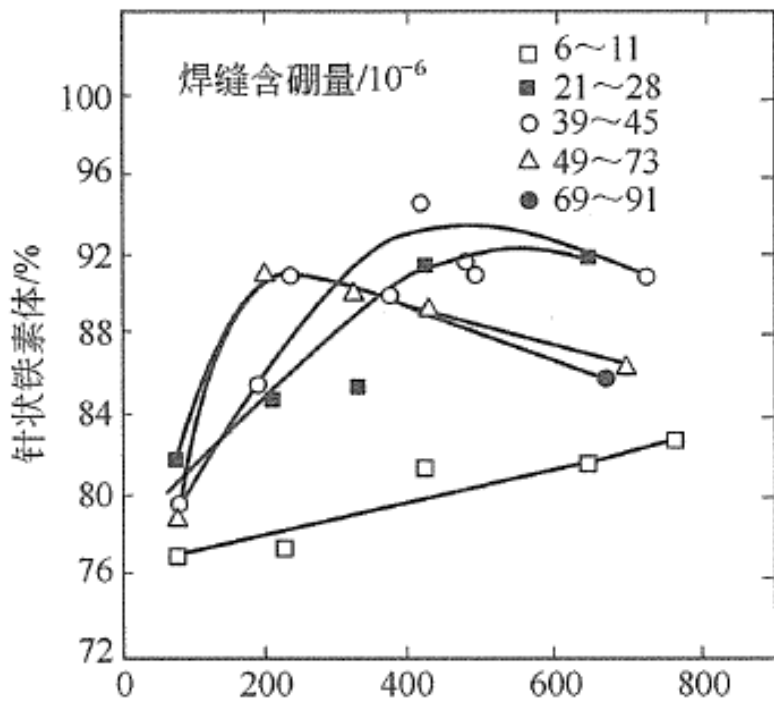


AI設計在**100ppm** 以下

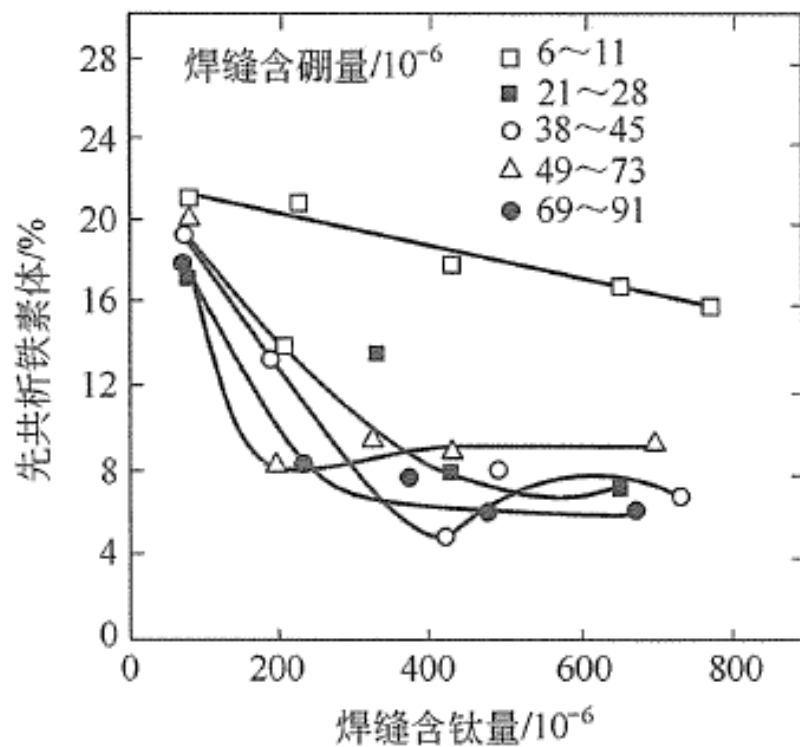


# 合金設計-Ti & B

# 鈦&硼元素影響-組織

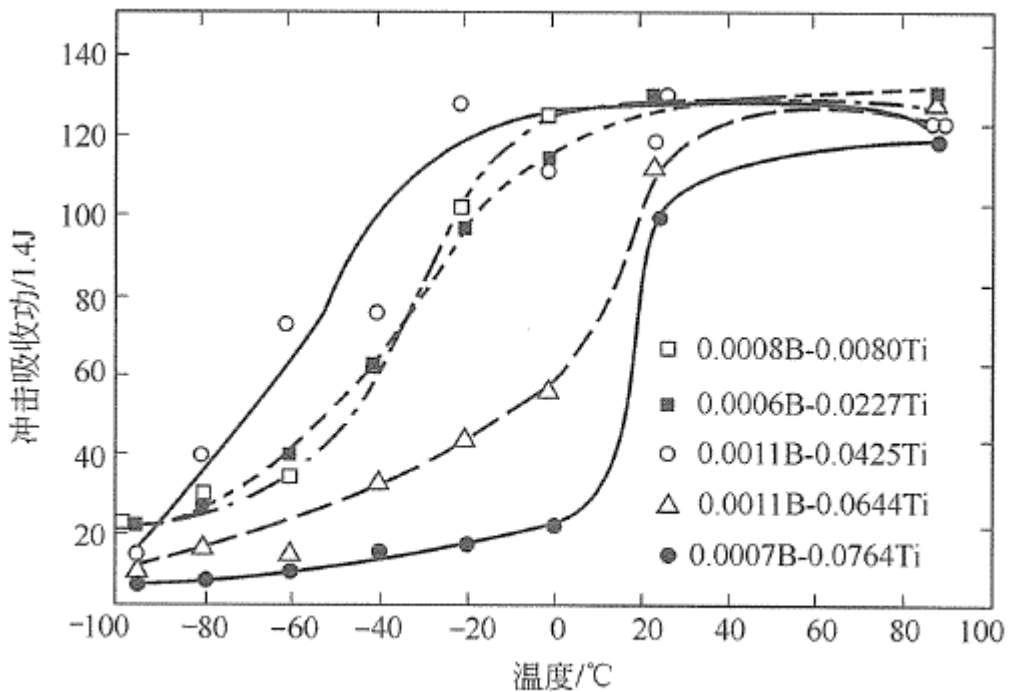


(a) 对针状铁素体影响

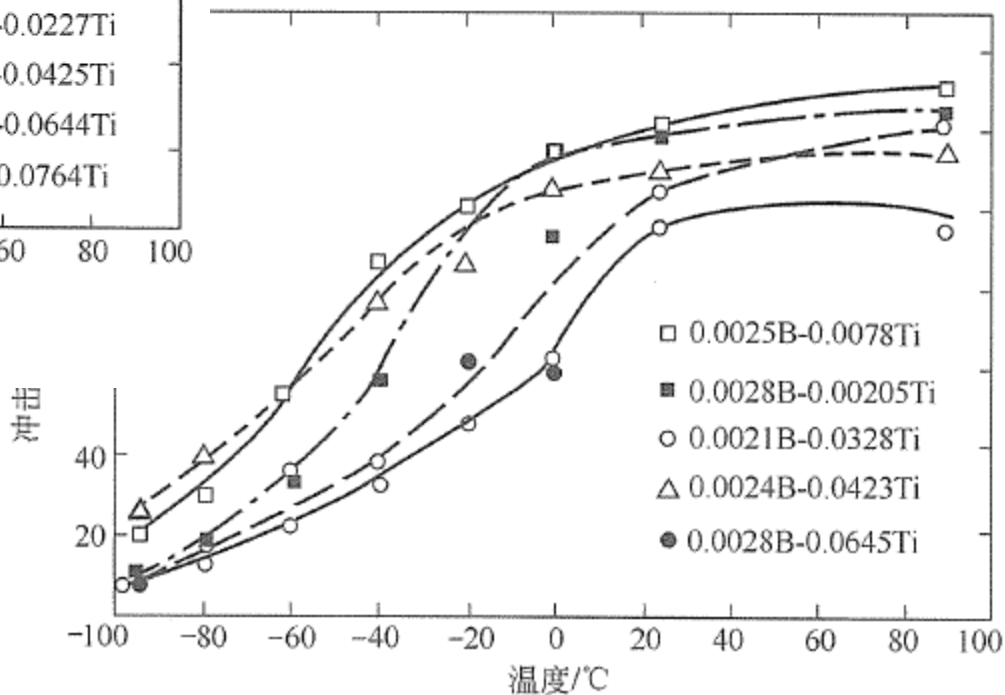


焊縫含鈦量/ $10^{-6}$

# 鈦&硼元素影響-低溫韌性

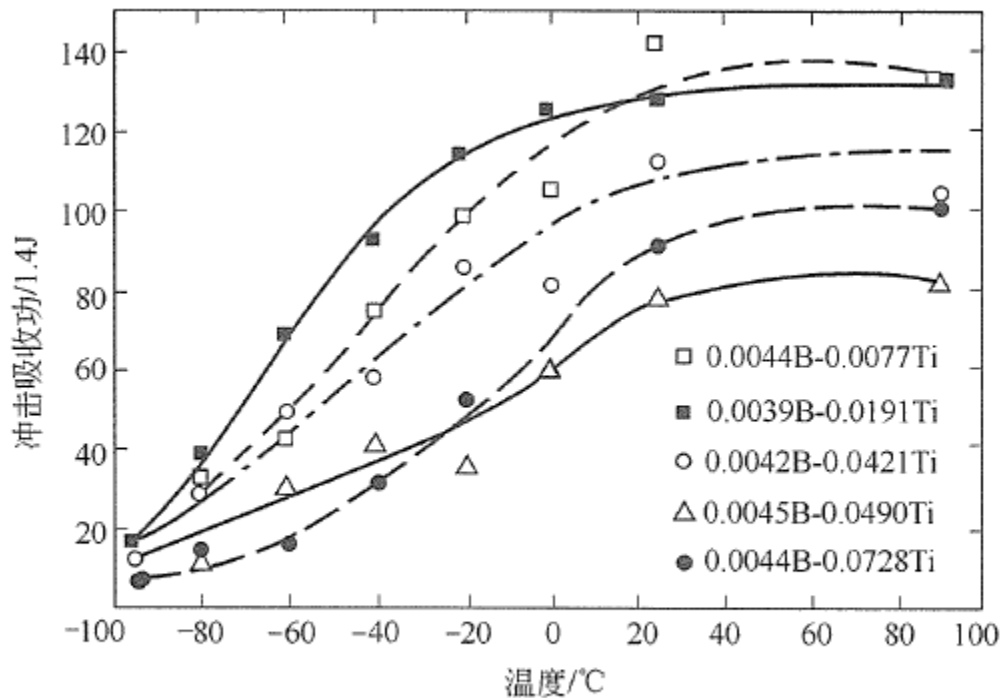


(a) 硼为 $(8\sim 11)\times 10^{-6}$

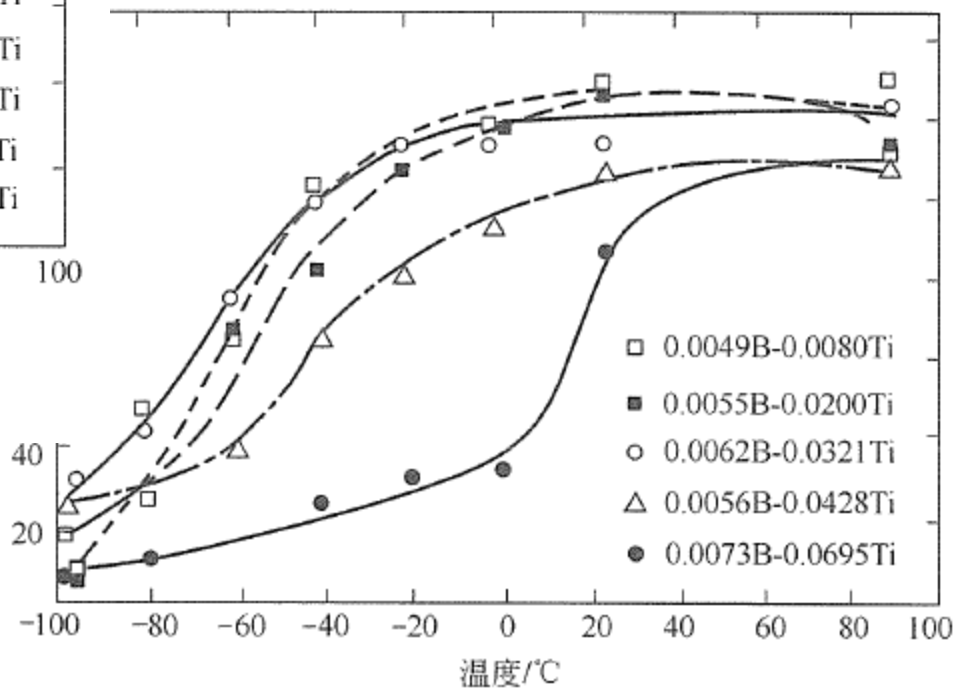


(b) 硼为 $(21\sim 28)\times 10^{-6}$

# 鈦&硼元素影響-低溫韌性



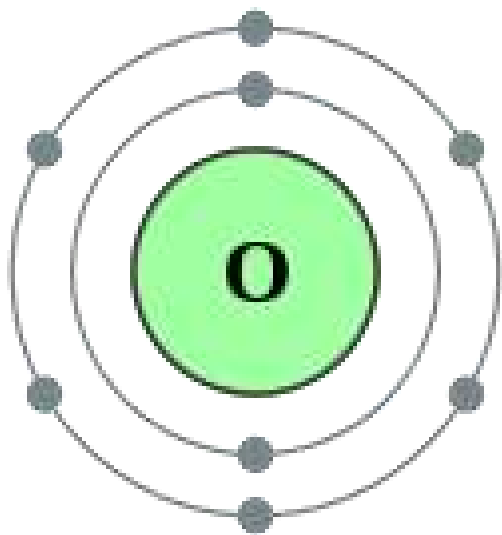
(c) 硼为 $(39\sim45)\times 10^{-6}$



(d) 硼为 $(49\sim73)\times 10^{-6}$



Ti設計在**200~400ppm** 之間  
B設計在**20-50ppm** 之間



# 有害氣體控制-O

# 氧氣對鐸接的作用

## 溶解方式.

- 以O和FeO兩種形式溶於液態鐵中
- 在室溫中以氧化物與矽酸鹽的形式存在

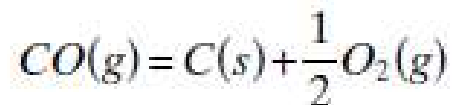
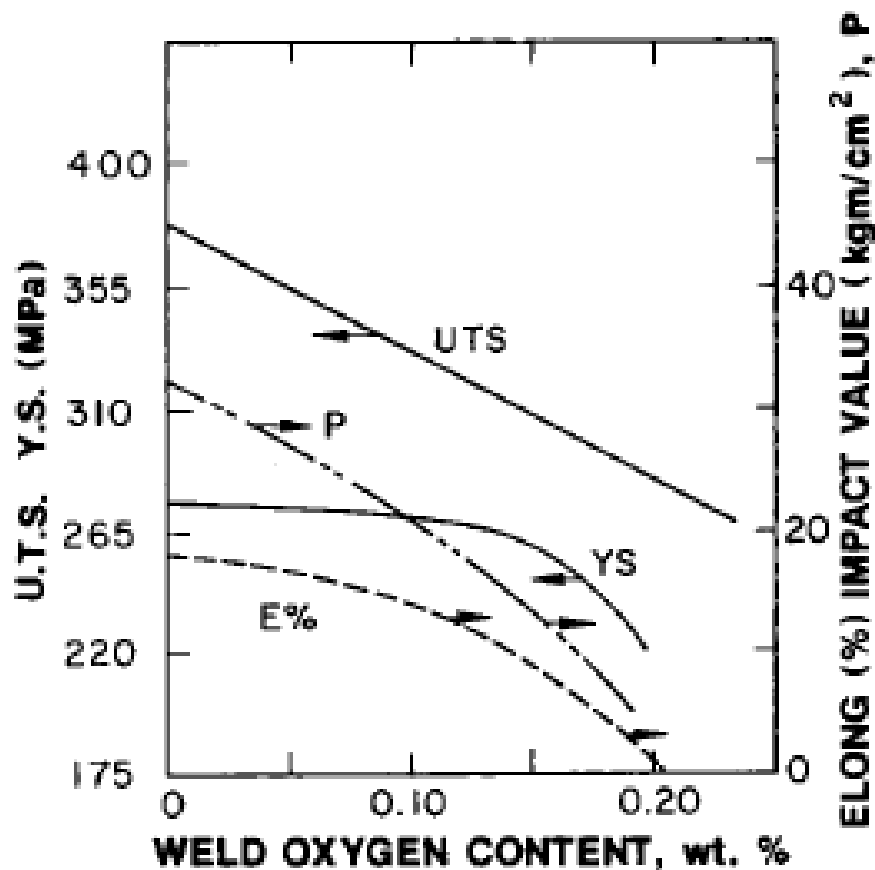
## 鐸接性質影響

- 鐸道機械性質不佳，強度塑性、韌性下降
- 耗損合金元素
- 氣孔
- 飛濺

## 控制方式

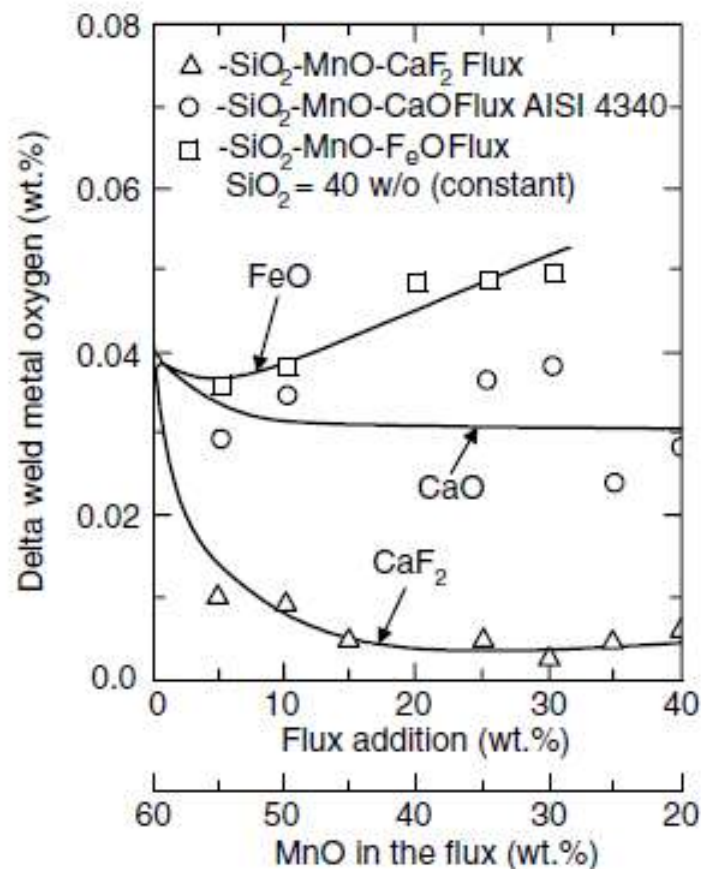
- 控制鐸接材料
- 控制鐸接參數
- 冶金反應

# 氧與機械性質的關係

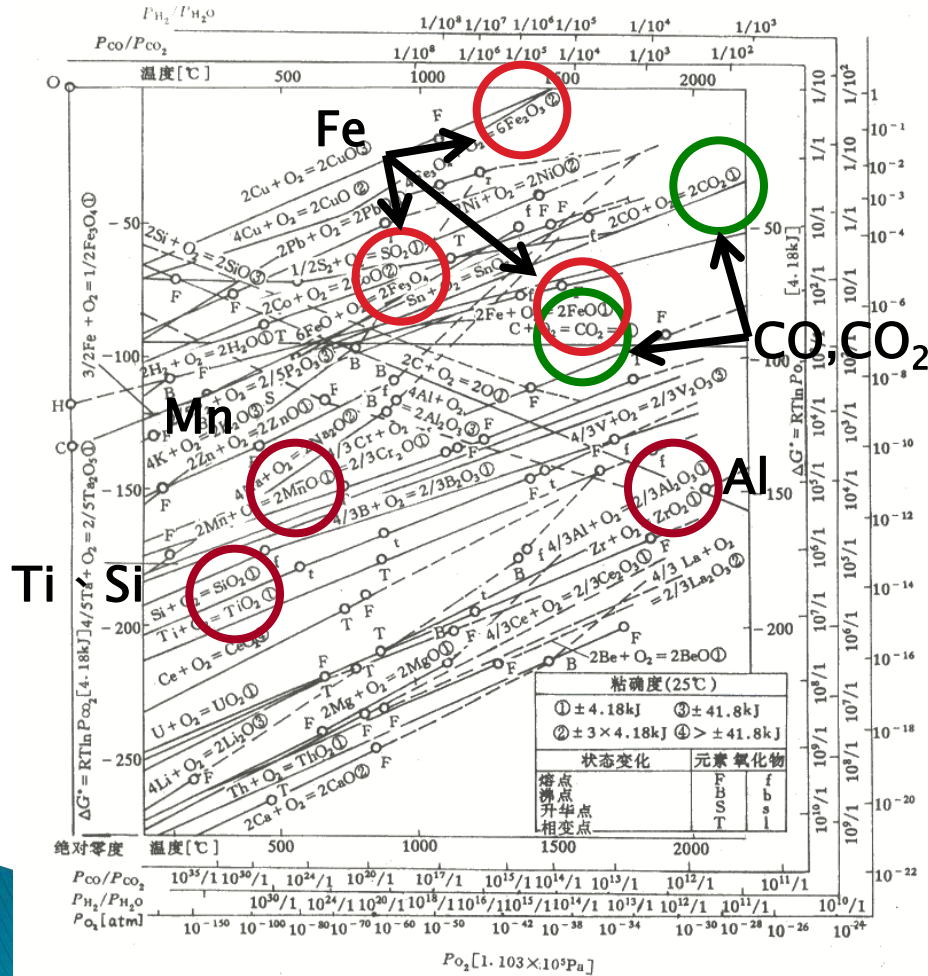


# 脫氧劑

脫氧劑	反應	
Ti Si Mn Al Cr V	先期	$\text{Fe}_2\text{O}_3 + \text{Ti} \rightarrow \text{TiO}_2 + 2\text{FeO}$ $2\text{FeO} + \text{Ti} \rightarrow \text{TiO}_2 + 2\text{Fe}$ $2\text{CaCO}_3 + \text{Ti} \rightarrow 2\text{CaO} + \text{TiO}_2 + 2\text{CO}$ $2\text{CO}_2 + \text{Ti} \rightarrow \text{TiO}_2 + 2\text{CO}$ $2\text{CO} + \text{Ti} \rightarrow \text{TiO}_2 + 2\text{C}$ $\text{Ti} + \text{O}_2 \rightarrow \text{TiO}_2$
Mg TiO <sub>2</sub>	沉澱	$[\text{M}] + [\text{FeO}] \rightarrow [\text{Fe}] + (\text{MO})$ $[\text{FeO}] + [\text{TiO}_2] \rightarrow (\text{FeTiO}_3)$



# 脫氧反應



- $M + O \rightarrow MO \quad \Delta G^\circ$
- 在銲接溫度對氧的親和力比被銲金屬大
- 脫氧的產物不溶於液態金屬，且密度也小於液態金屬

图 10 金属氧化物生成自由能变化与温度的关系

# 冶金反應除氧

## ➤ 熔渣與液態金屬界面：

- 擴散脫氧

## ➤ 藥皮反應區：

- 以惰性氣體稀釋電弧中的氧
- 先期脫氧

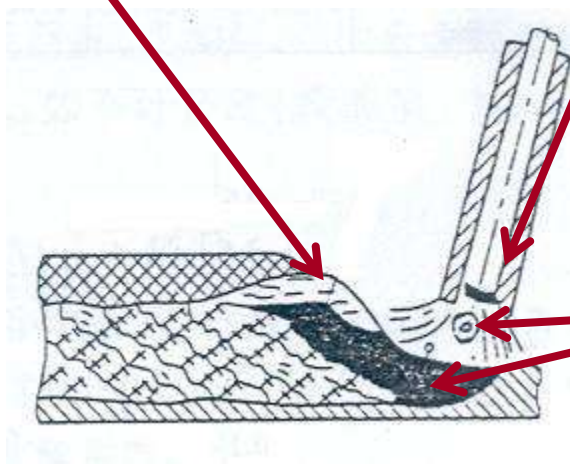
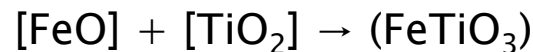
使用Al、Ti、Si、Mn或其合金等作為脫氧劑

## ➤ 熔滴與熔池反應區：

- 沉澱脫氧

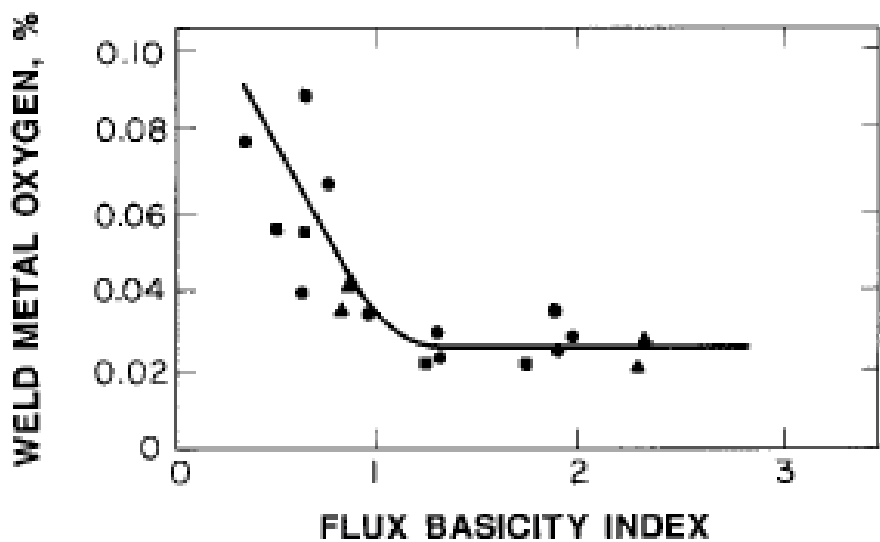
脫氧劑和FeO直接反應，產生的脫氧產物  
浮出液態金屬

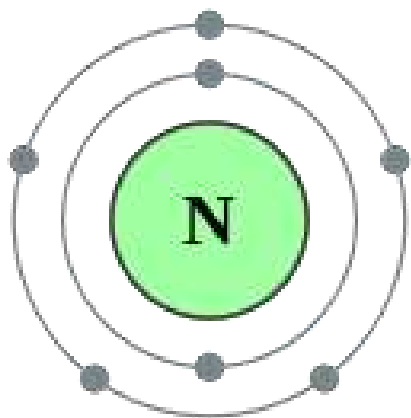
- TiO<sub>2</sub>與氧化鐵反應形成鈦酸鹽溶入渣中



# 提高錳藥鹼度

$$BI = \frac{CaF_2 + CaO + MgO + BaO + SrO + Na_2O + K_2O + Li_2O + 0.5(MnO + FeO)}{SiO_2 + 0.5(Al_2O_3 + TiO_2 + ZrO_2)}$$





# 有害氣體控制-N

# 氮氣對銲接的作用

## 溶解方式.

- 氣體分子吸附金屬表面後，分解為原子溶入金屬
- 室溫中部分過飽和的氮會析出形成  $\text{Fe}_4\text{N}$

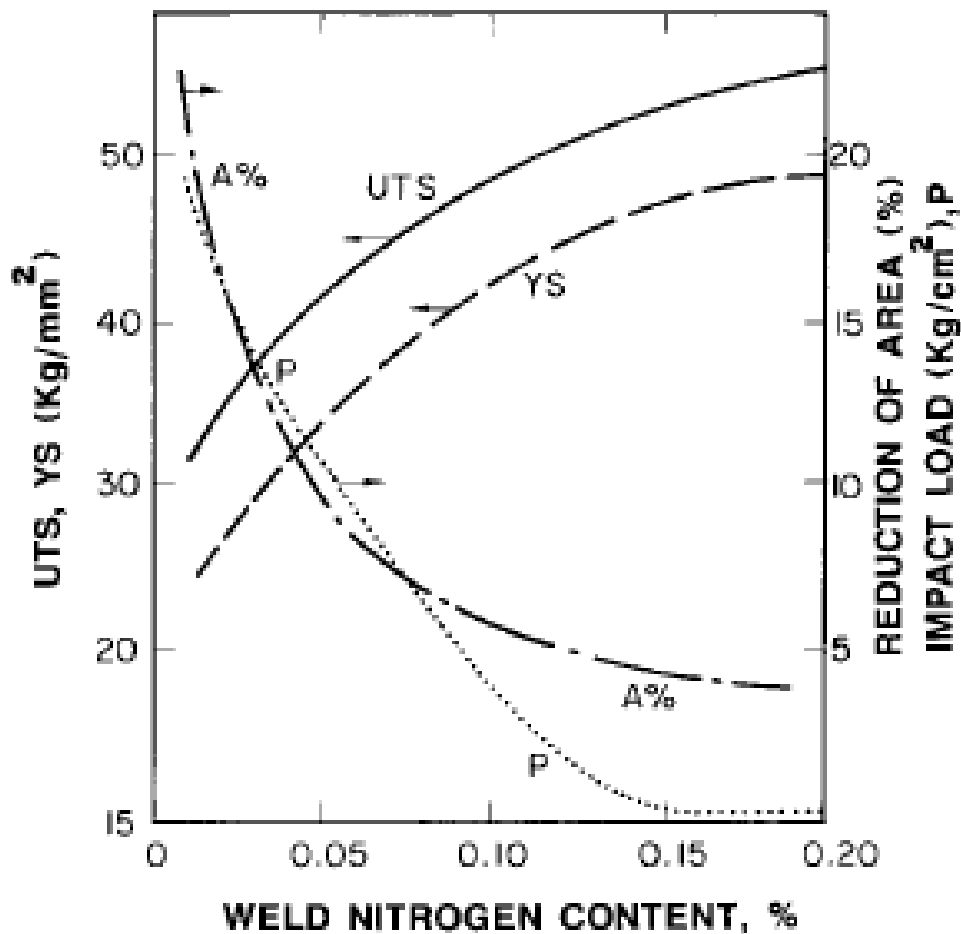
## 銲接性質影響

- 氣孔
- 強度硬度升高
- 塑性韌性下降

## 控制方式

- 保護銲接區
- 控制銲接參數
- 冶金反應

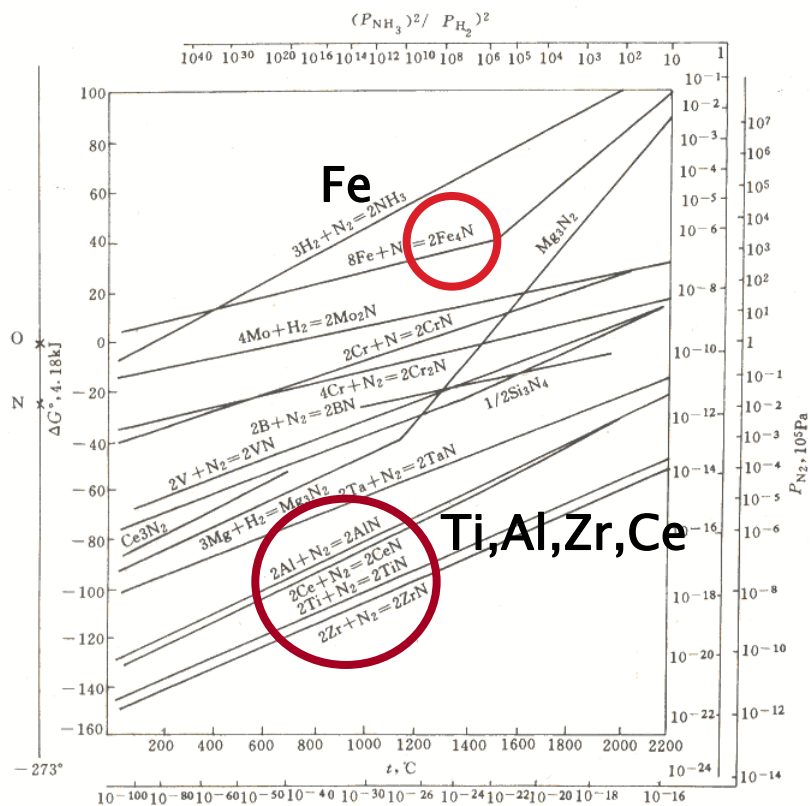
# 氧與機械性質的關係



# 脫氮劑

除氮劑	反應
Ti	
Al	$Ti + N \rightarrow TiN$
Zr	$Al + N \rightarrow AlN$
Ce	$V + N \rightarrow VN$
V	$2Ti + N_2 \rightarrow 2TiN$
Mg	$2Al + N_2 \rightarrow 2AlN$
B	$2V + N_2 \rightarrow 2VN$
Cr	
Mo	

# 脫氮反應

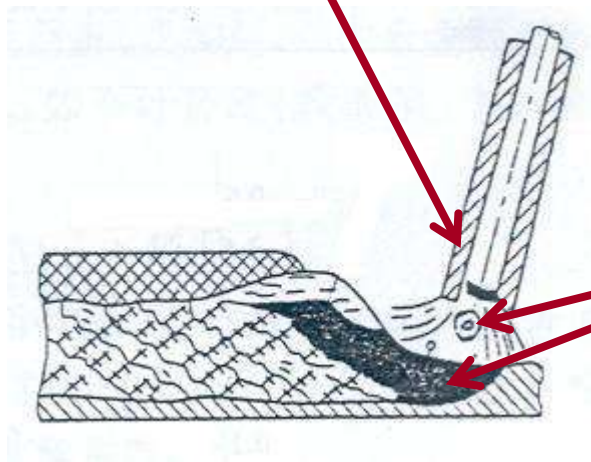


- $M + N \rightarrow MN \quad \Delta G^\circ$
- Ti、Al、Zr和Ce
  - 對氮的親和力大
  - 形成穩定的氮化物
  - 形成的氮化物不熔於液態鐵

# 冶金反應除氮

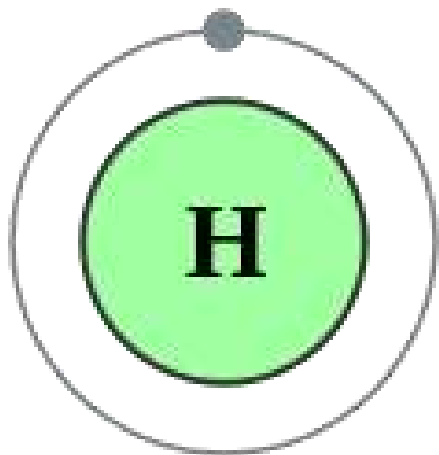
➤ 藥皮反應區：

以惰性氣體稀釋電弧中的氮



➤ 熔滴與熔池反應區：

鈦、鋁、鎳和稀土元素



# 有害氣體控制-H

# 氫氣對銲接的作用

## 溶解方式.

- 通過熔渣或氣相與液態金屬的界面溶入
- 以H、H<sup>+</sup> 或H<sup>-</sup> 的形式存在

## 銲接性質影響

- 氫脆性
- 氫白點
- 氣孔
- 延遲裂紋

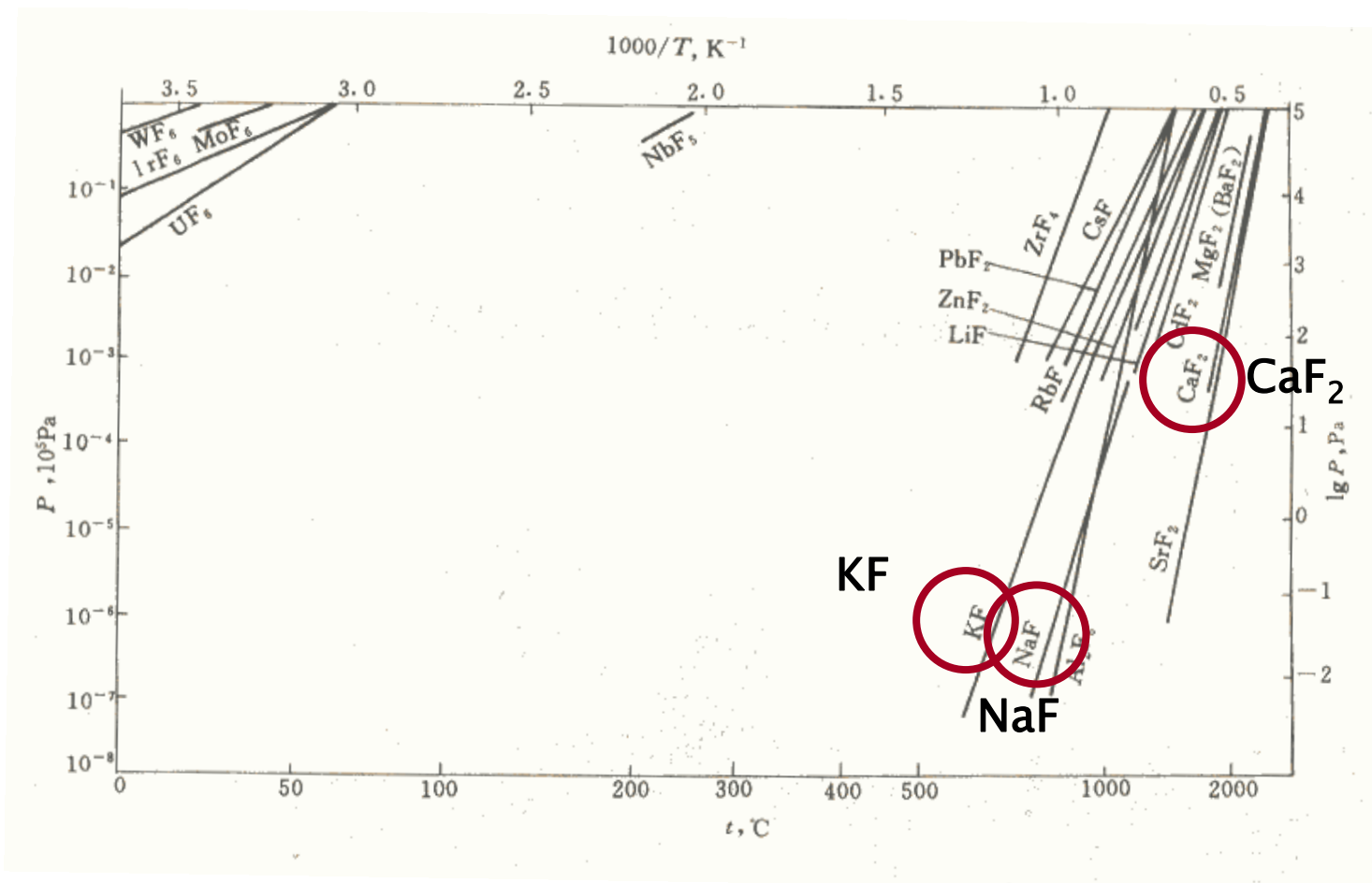
## 控制方式

- 限制氫的來源
- 以惰性氣體降低電弧中的氫分壓
- 冶金處理
- 銲後處理

# 脫氫劑

除氫劑		反應
氟化物	$\text{CaF}_2, \text{BaF}_2$ $\text{K}_3\text{AlF}_6$ $\text{Na}_2\text{SiF}_6, \text{K}_2\text{SiF}_6$ $\text{LiF}, \text{NaF}$ $\text{AlF}_3$	$\text{CaF}_2 + 2\text{H} \rightarrow \text{Ca} + 2\text{HF}$ $\text{NaF} + \text{H} \rightarrow \text{Na} + \text{HF}$ $\text{AlF}_3 + 3\text{H} \rightarrow \text{Al} + 3\text{HF}$
氧化性氣體	$\text{CO}_2$ $\text{O}$ $\text{O}_2$	$\text{CO}_2 + \text{H} \rightarrow \text{CO} + \text{OH}$ $\text{O} + \text{H} \rightarrow \text{OH}$ $\text{O}_2 + \text{H}_2 \rightarrow 2\text{OH}$

# 脫氫反應

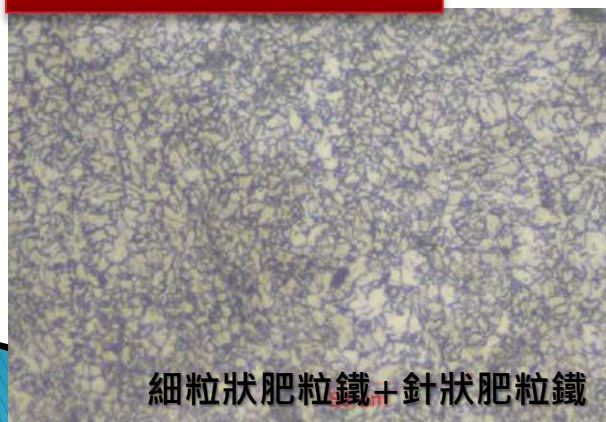


# 合金-氣體-組織-物性

## Chemistry

C	Si	Mn	P	S	Cr
0.05~0.07	0.2~0.6	1.2~1.6	0.02 max	0.02 max	0.25 max
Ni	Mo	Al	Cu	Ti	B
1.5~2.5	0.2~0.4	0.01 max	0.05 max	0.02~0.04	20~50 ppm
O	N	Diffusible H (ml/100g)			
200~300ppm	80ppm max	4			

## Microstructure



## Mechanical Properties

T.S. (MPa)	Y.P. (MPa)	EL(%)
719	668	22
Impact value @-51°C		
96		



Thanks for your attention