離子氮化表面硬化處理重型機械及卡車柴油引擎用球墨鑄鐵活塞之磨耗行為研究

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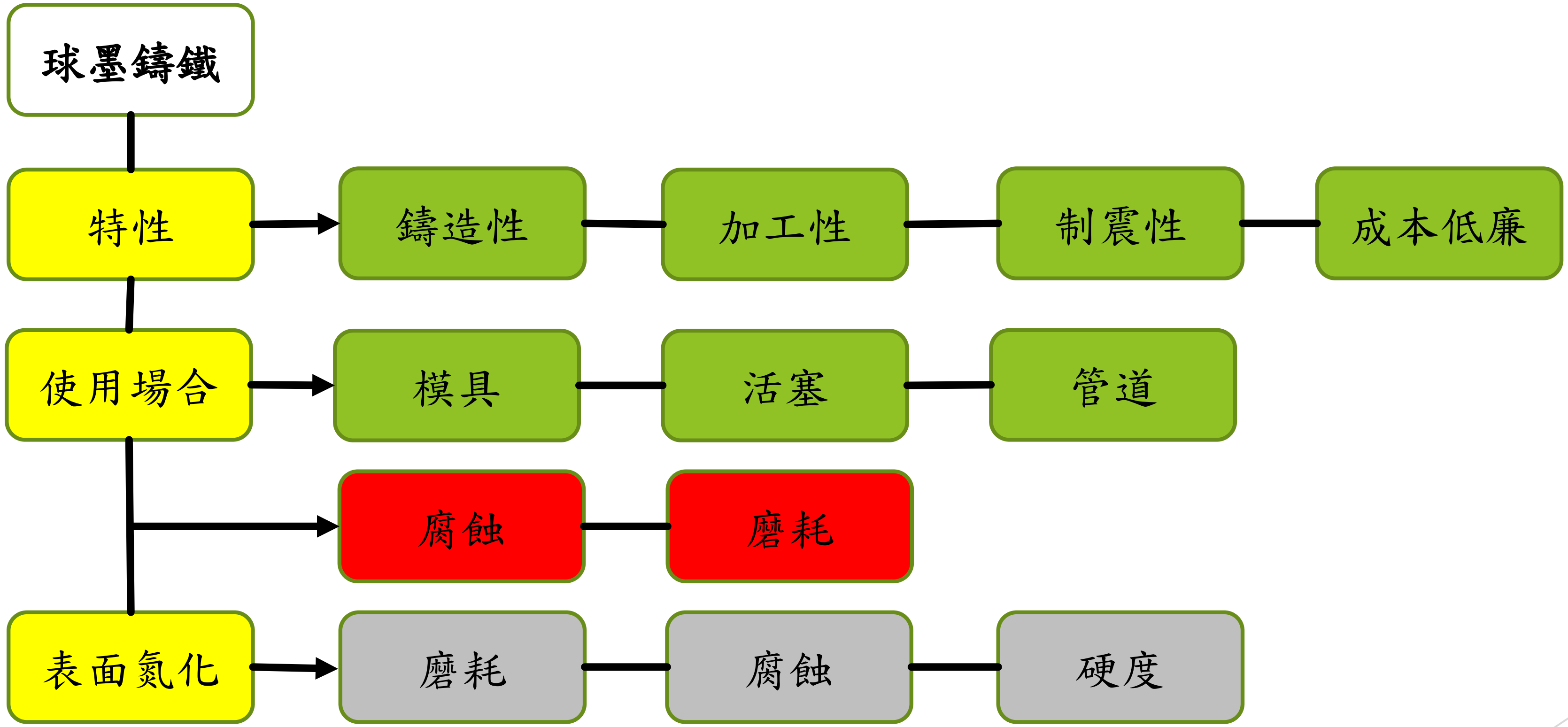
目 錄

前 言

- 球墨鑄鐵(FCD600）



傳統球墨鑄鐵(肥粒體-波來體混合組織)

⇨易受基地組織控制的球墨鑄鐵機械性能(抗拉強度、降伏強度、硬度及伸長率)，卻常因肥粒體-波來體混合比例的變動(主要是鑄件厚薄的不同冷卻速度造成)，導致其機械性能穩定性變化大

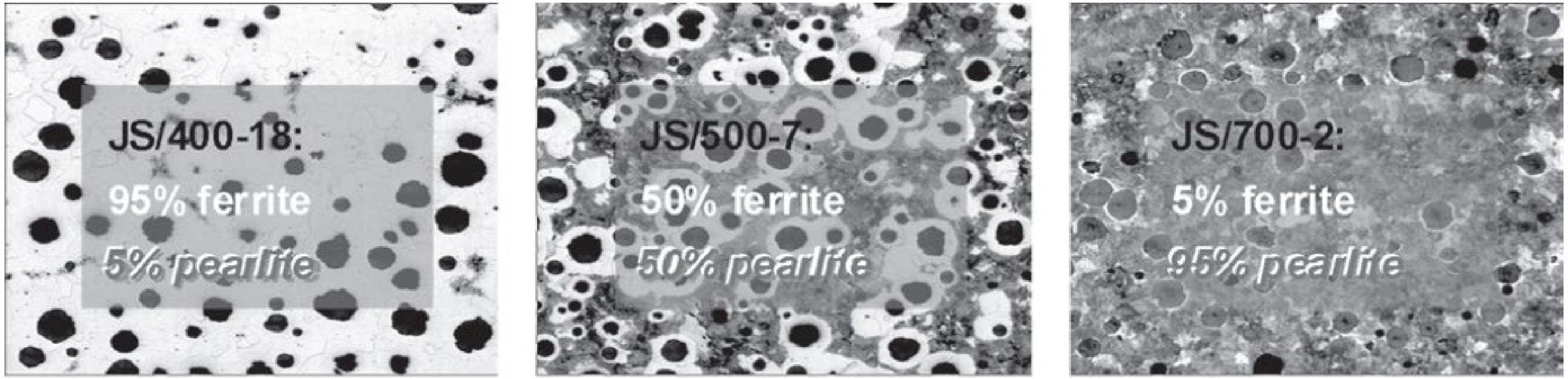
矽固溶強化肥粒體基球墨鑄鐵(Si-SSF)

⇨原有球墨鑄鐵生產中利用矽元素固溶強化特性，所開發的更有優異性能的球墨鑄鐵

⇨ISO 1083-2004球墨鑄鐵標準中，將高矽(固溶強化肥粒體基為主，容許5%波來鐵)球墨鑄鐵

⇨尋求常規波來體組織強化的代替方法。最有希望的替代方法是用固溶強化(添加矽或鈲)獲得具有中等強度和韌性的球墨鑄鐵

傳統球墨鑄鐵規範(肥粒體-波來體混合組織)



JS/400-18	JS/500-7	JS/700-2
H = 155 ±25 HBW	H = 200 ±30 HBW	H = 265 ±40 HBW
$R_{p0.2} \geqslant$ 250 MPa	$R_{p0.2} \geqslant$ 320 MPa	$R_{p0.2} \geqslant$ 420 MPa
$R_m \geqslant$ 400 MPa	$R_m \geqslant$ 500 MPa	$R_m \geqslant$ 700 MPa
$A5 \geqslant 18\%$	$A_5 \geqslant 7\%$	$A_5 \geqslant 2\%$

Fig.1: Microstructures and mechanical properties range for the 1st generation of ferritic-pearlitic ductile irons

FCD-400, 450, 500, 600, 700球墨鑄鐵之抗拉強度↑

⇨ 波來鐵面積率↑ ⇨ 延伸率↓

Table 1 — Mechanical properties measured on test pieces machined from cast samples for ferritic to pearlitic grades

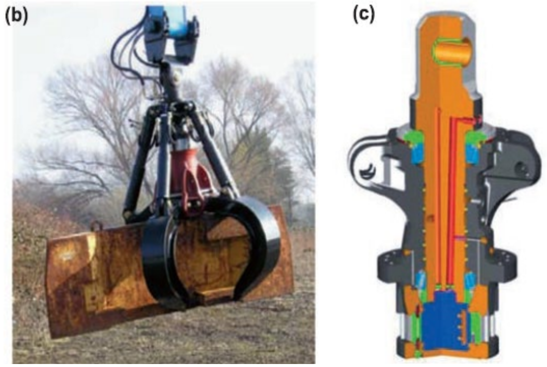
Material designation		Relevant wall thickness t mm	0,2 % proof strength $R_{p0,2}$ MPa min	Tensile strength R_m MPa min	Elongation A % min
Symbol	Number				
EN-GJS-350-22-LT [a]	5.3100	$t \leq 30$	220	350	22
		$30 < t \leq 60$	210	330	18
		$60 < t \leq 200$	200	320	15
EN-GJS-350-22-RT [b]	5.3101	$t \leq 30$	220	350	22
		$30 < t \leq 60$	220	330	18
		$60 < t \leq 200$	210	320	15
EN-GJS-350-22	5.3102	$t \leq 30$	220	350	22
		$30 < t \leq 60$	220	330	18
		$60 < t \leq 200$	210	320	15
EN-GJS-400-18-LT [a]	5.3103	$t \leq 30$	240	400	18
		$30 < t \leq 60$	230	380	15
		$60 < t \leq 200$	220	360	12
EN-GJS-400-18-RT [b]	5.3104	$t \leq 30$	250	400	18
		$30 < t \leq 60$	250	390	15
		$60 < t \leq 200$	240	370	12
EN-GJS-400-18	5.3105	$t \leq 30$	250	400	18
		$30 < t \leq 60$	250	390	15
		$60 < t \leq 200$	240	370	12
EN-GJS-400-15	5.3106	$t \leq 30$	250	400	15
		$30 < t \leq 60$	250	390	14
		$60 < t \leq 200$	240	370	11
EN-GJS-450-10	5.3107	$t \leq 30$	310	450	10
		$30 < t \leq 60$	to be agreed upon between the manufacturer and the purchaser		
		$60 < t \leq 200$			
EN-GJS-500-7	5.3200	$t \leq 30$	320	500	7
		$30 < t \leq 60$	300	450	7
		$60 < t \leq 200$	290	420	5
EN-GJS-600-3	5.3201	$t \leq 30$	370	600	3
		$30 < t \leq 60$	360	600	2
		$60 < t \leq 200$	340	550	1
EN-GJS-700-2	5.3300	$t \leq 30$	420	700	2
		$30 < t \leq 60$	400	700	2
		$60 < t \leq 200$	380	650	1
EN-GJS-800-2	5.3301	$t \leq 30$	480	800	2
		$30 < t \leq 60$	to be agreed upon between the manufacturer and the purchaser		
		$60 < t \leq 200$			
EN-GJS-900-2	5.3302	$t \leq 30$	600	900	2
		$30 < t \leq 60$	to be agreed upon between the manufacturer and the purchaser		
		$60 < t \leq 200$			

NOTE The mechanical properties of test pieces machined from cast samples may not reflect exactly the properties of the casting itself. Values for tensile properties of the casting are given in Annex B for guidance.

[a] LT for low temperature.

[b] RT for room temperature.

矽固溶強化肥粒體基球墨鑄鐵應用場合（濕模砂造模法）



液壓鑄鐵轉向節

需要良好的切削性及加工精度之應用場合

Fig. 17: Hydraulic control block made of spheroidal graphite cast iron

自動化設備用鑄鐵液壓控制閥之固溶強化肥粒體基球墨鑄鐵

固溶強化合金元素對球墨鑄鐵之影響

(1)合金的降伏強度、抗拉強度及硬度皆以純金屬高。

(2)大多數的情形，合金的延性比純金屬差。但有少部份，例如銅鋅合金，固溶強化卻能同時增加強度和延性。

(3)合金的導電度遠低於純金屬。

(4)利用固溶強化可以改善變形的抵抗力，或高温下的強度損失。高溫對於固溶強化合金的性質不會造成巨大的改變。

矽元素

➔固溶強化及肥粒體化元素

➔石墨成核劑

➔高溫相穩定性提高

散佈強化

藉由在金屬中添加硬顆粒，例如碳化矽，或是添加合金元素，使材料凝固過程中形成高硬度的金屬化合物。這些硬脆的第二項能夠阻擋差排得移動，使材料變形不易，此即達到強化效果

釩元素

➔是合金元素

➔固溶後釩的含量越高 ⇨ 促使石墨化的組織 ⇨ 硬度↑及耐磨耗性↑

➔與鑄鐵固溶後使得鑄鐵表面形成較硬的石墨化組織，鑄鐵的硬度↑與較好的耐磨耗性↑

固溶強化肥粒體基球墨鑄鐵規範
DIN EN1563-2011

Table 2-3. SSF grades specified in the EN 1563[1]

Material designation		Relevant wall thickness	0,2 % proof strength	Tensile strength	Elongation
		t	$R_{p0,2}$	R_m	A
		mm	MPa	MPa	%
Symbol	Number		min.	min.	min.
EN-GJS-450-18C	5.3108	$t \leq 30$	350	440	16
		$30 < t \leq 60$	340	420	12
		$60 < t \leq 200$	Guidance values to be provided by the manufacturer		
EN-GJS-500-14C	5.3109	$t \leq 30$	400	480	12
		$30 < t \leq 60$	390	460	10
		$60 < t \leq 200$	Guidance values to be provided by the manufacturer		
EN-GJS-600-10C	5.3110	$t \leq 30$	450	580	8
		$30 < t \leq 60$	430	560	6
		$60 < t \leq 200$	Guidance values to be provided by the manufacturer		

歐規 球墨含量600 伸長率10%

固溶強化肥粒體基球墨鑄鐵材質化學組成規範
DIN EN1563-2011

Table A.1 — Guidance values for chemical composition

Designation		Si	P	Mn
Symbol	Number	% approx. [a]	% max.	% max. [b]
EN-GJS-450-18	5.3108	3,20	0,05	0,50
EN-GJS-500-14	5.3109	3,80	0,05	0,50
EN-GJS-600-10	5.3110	4,30	0,05	0,50

[a] Si content may be lower due to other alloying elements.

[b] With lower Mn content (e.g. 0,30 %), machinability and elongation will be improved.

歐規 球墨含量600
伸長率10%

表1　EN 1563-2011 中的矽固溶化型和傳統型球墨鑄鐵機械性能比較

Table 1　Mechanical Property comparison of Solid-strengthen and conventional ductile iron of EN 1563-2011

機械性能	EN-GJS-450-18		EN-GJS-500-14		EN-GJS-600-10	
	固溶化型	傳統型	固溶化型	傳統型	固溶化型	傳統型
抗拉強度(MPa)	450		500		600	
降伏強度(MPa)	350	310	400	320	470	370
伸長率(%)	18	10	14	7	10	3

矽固溶化型球墨鑄鐵**(EN-GJS-450, 500, 600)**的降伏強度**(0.8 σ_{UTS})**、延伸率都比傳統型球墨鑄鐵的降伏強度**(0.6 σ_{UTS})**、延伸率來的優異

FCD600球墨鑄鐵化學組成(wt.%)

sample	C	Si	Ni	Mo	Mn	P	S	Mg	Fe
FCD600	2.81	4.26	0.297	0.060	0.260	0.017	0.001	0.022	Bal.

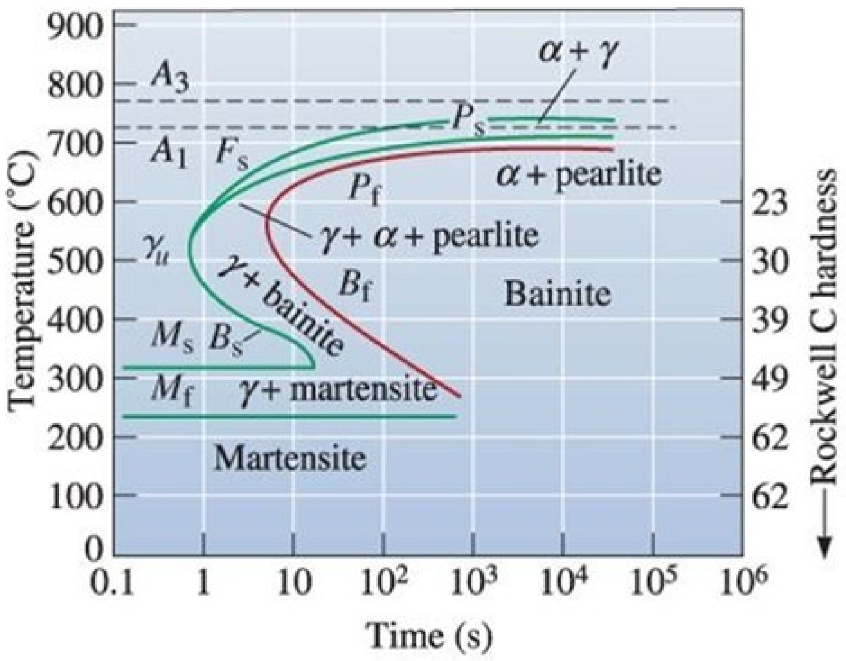
以上成分並固溶並添加1%V、 2%V 、3%V

添 加 釩 的 特 性

- +V(釩)(散佈強化)
  - 特性
    - 細化組織和晶粒
    - 增加鋼的淬透性
    - 抗磨損和抗爆裂性
    - 耐高溫又抗寒
    - 碳化釩
  - 使用場合
    - 軸承
    - 齒輪
    - 汽車零件

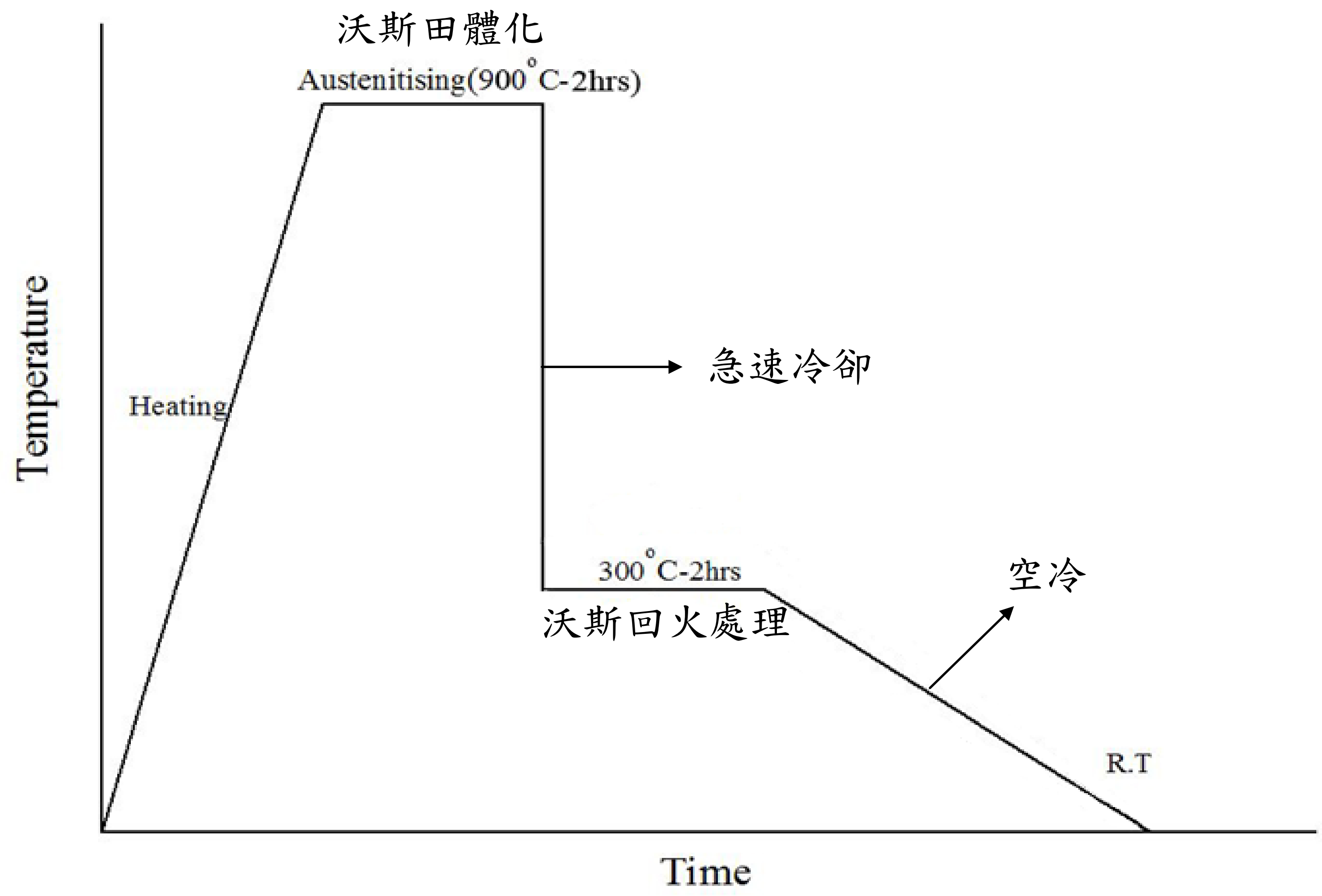
沃 斯 回 火 製 程

原材 → 加熱 → 高溫沃斯田體 → 冷卻 → 恆溫鹽浴 → 成品



將沃斯回鐵狀態的鋼料淬入溫度介於 S 曲線鼻部與 MS 變態點間的熱浴，直到過冷沃斯回鐵完全變態為版狀上沃斯肥粒鐵才取出空冷的一種熱處理工法，稱為沃斯回火（ Austempering ）。

ADI 熱處理過程圖


沃斯田體化
Austenitising(900°C-2hrs)
Temperature
Heating
急速冷卻
300°C-2hrs
沃斯回火處理
空冷
R.T
Time

沃 斯 回 火 特 性

- 優點：

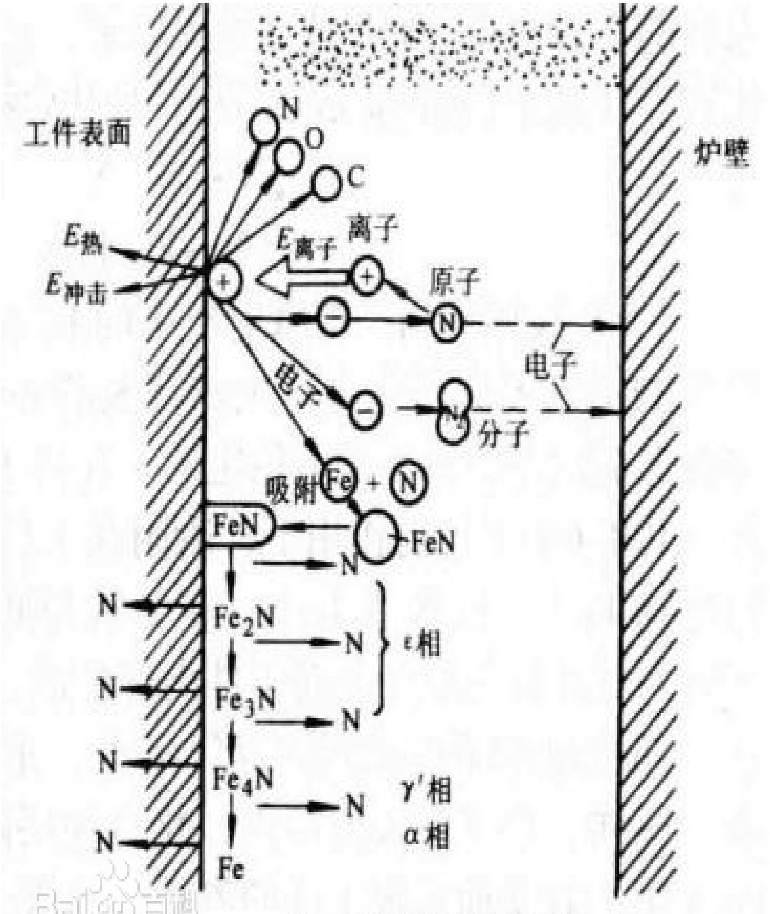
高強度 | 高韌性 | 變形量極小 | 不易脆裂

- 缺點：

有牙孔時殘鹽洗淨不易 | 生產效率低 | 生產成本高

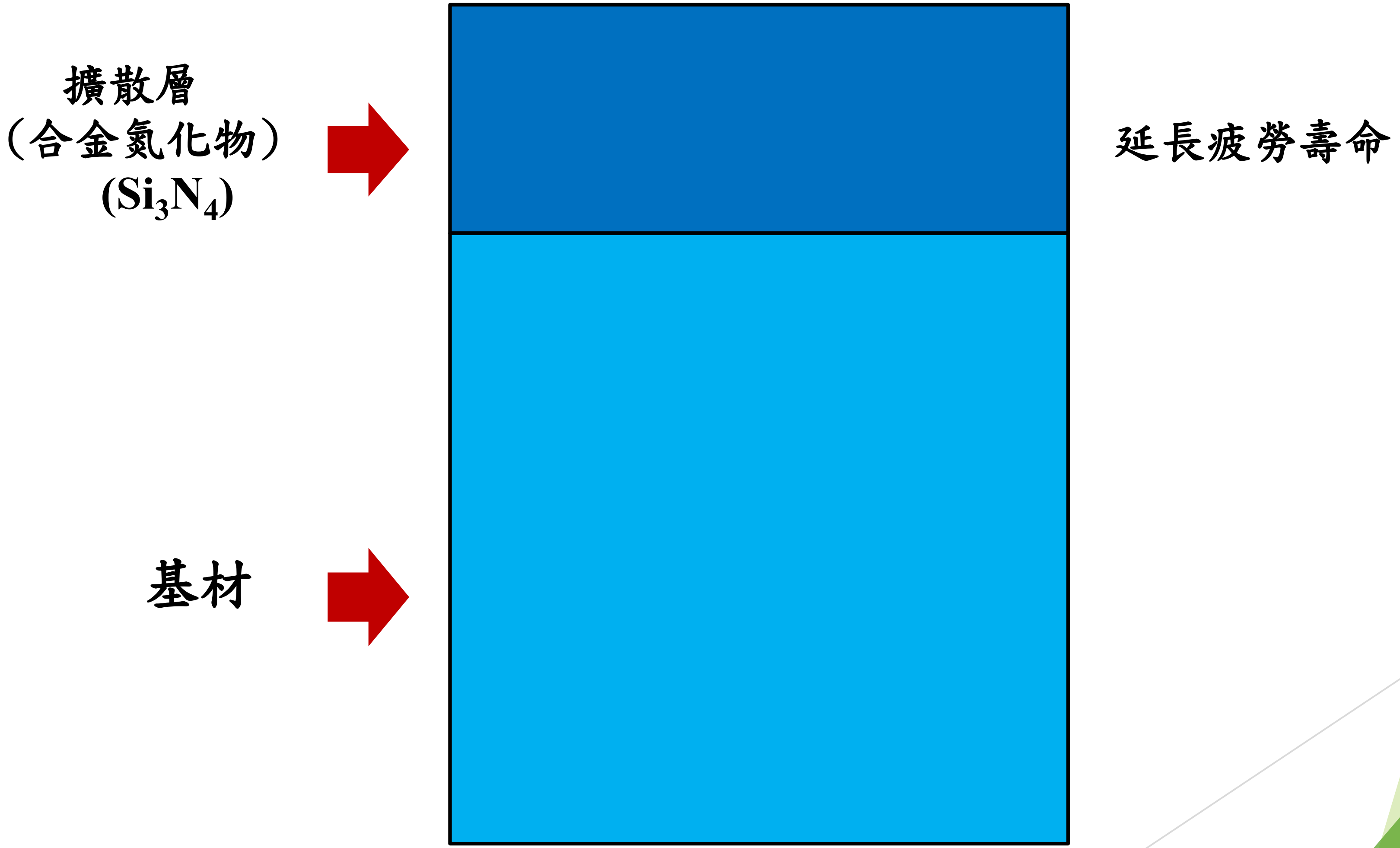
離子氮化製程原理

- 離子滲氮也稱為電漿滲氮，其離子氮化是利用高電壓，使得氮氣及氫氣在電場作用下碰撞至陰極促使氮原子與氫原子反覆的碰撞下與碰撞產生的鐵原子結合形成FeN。



离子滲氮原理图

離子氮化製程特性



離子氮化製程優點

- 氮化層與表面組織緻密較不易發生氮化脆性。
- 離子氮化處理的溫度較低時間較短氮化後工件的變形量較少，減少後精加工成本較優於其他傳統氮化處理。
- 離子氮化對不規則形狀工件也容易加工。
- 離子氮化後提升表面的硬度、耐磨性及腐蝕特性。

- 離子氮化常運用的材料:

  低中高碳鋼、牙板、模具鋼、不銹鋼及合金鋼

- 離子氮化廣泛運用的產品

  適用於:螺桿、軸承、齒輪、模具、螺絲牙板、機械五金、航太及精密儀器

實驗動機

- FCD600經由ADI及離子氮化製程加工，能夠提升基材的表面強度、耐磨性質、抗腐蝕性。

實 驗 目 的

1. 探討釩含量添加FCD600肥粒體基球墨鑄鐵經沃斯回火後表面硬度、耐磨耗性及耐腐蝕性之影響

2. 藉由離子氮化製程經沃斯回火之FCD600耐磨耗性及耐腐蝕性之差異

實 驗 目 的

FCD600

SSF(固溶強化)+V(釩)

ADI(沃斯回火熱處理)

Ion Nitrogen(離子氮化)

課程相關知識

材料科學與工程(一)(二)	材料技術實習(二)	物理冶金
擴散(離子氮化) 恆溫變態曲線 合金化及固溶強化製程	熱處理金相製作硬度量測 磨耗試驗 XRD,SEM/EDS	沃斯回火製程(ADI) 離子氮化原理與製程

實驗結果與討論

進度(一)：金相(未ADI)

金相(未腐蝕)		
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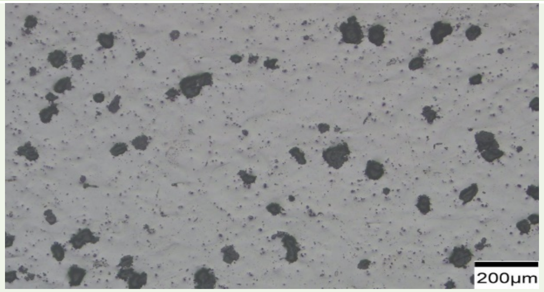	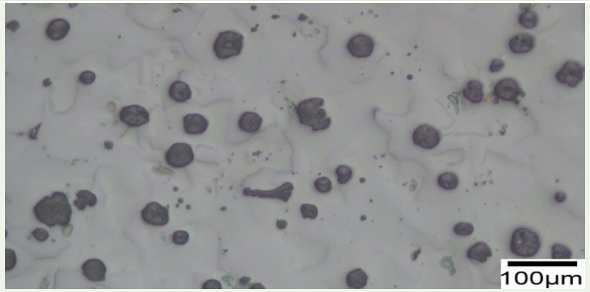	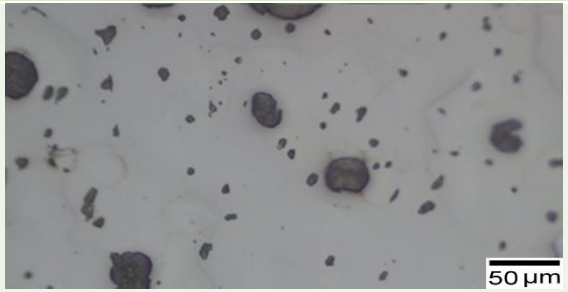
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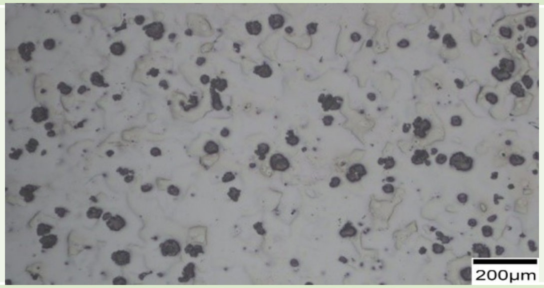	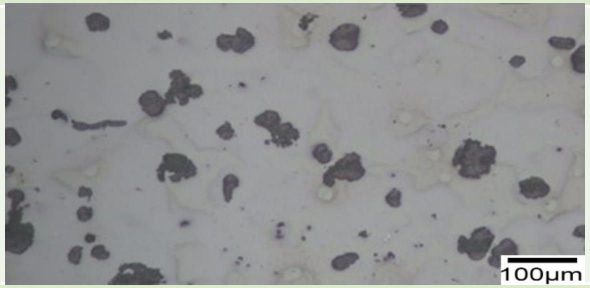	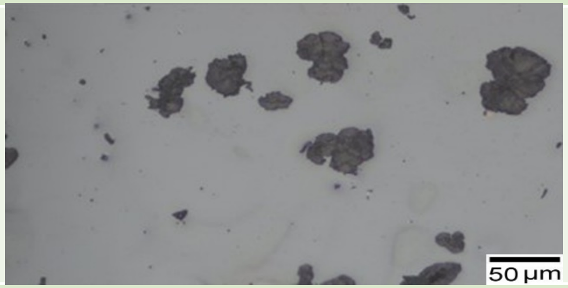
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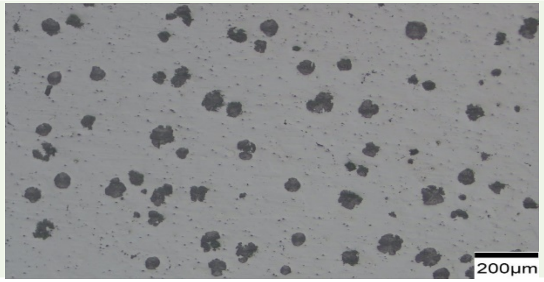	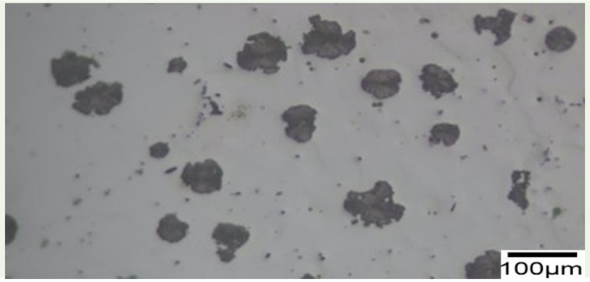	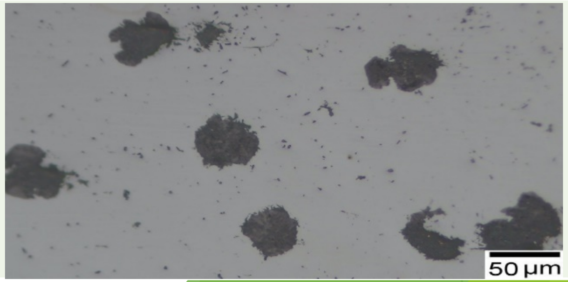

金相(腐蝕後)		
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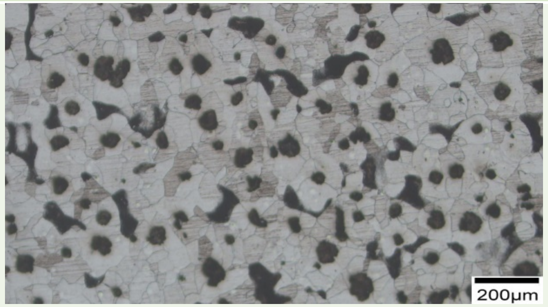	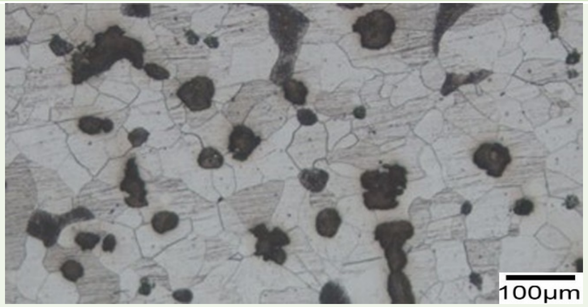	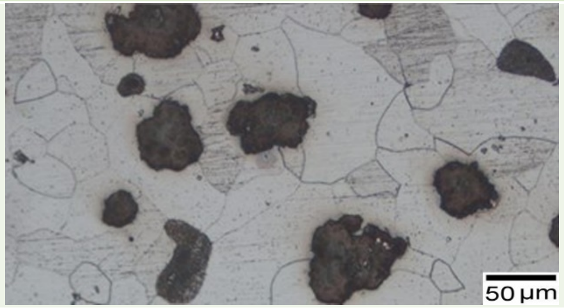
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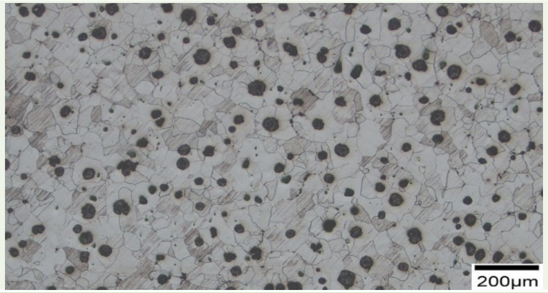	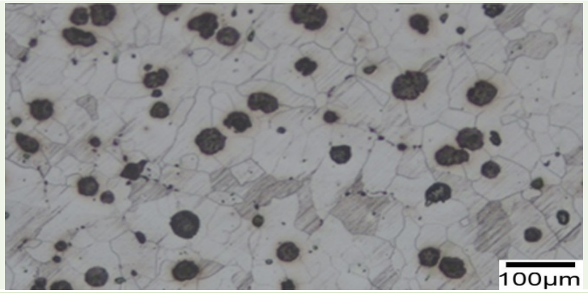	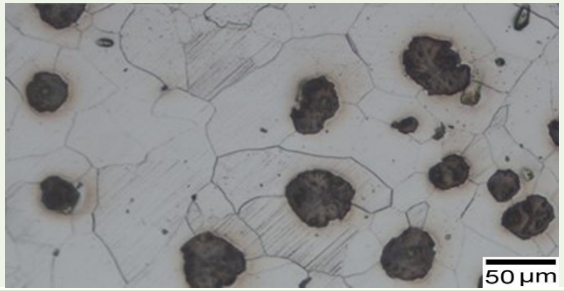
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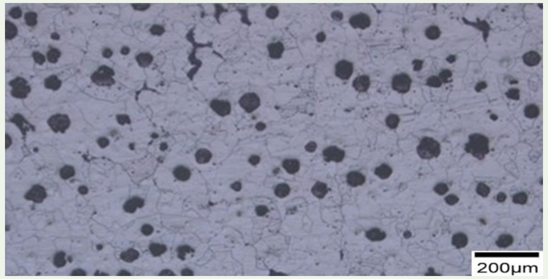	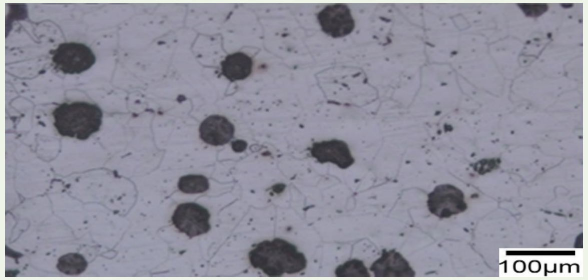	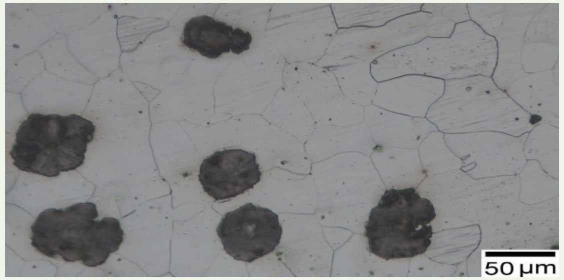

金相（ADI）

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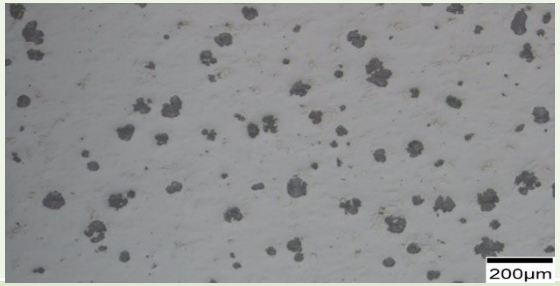
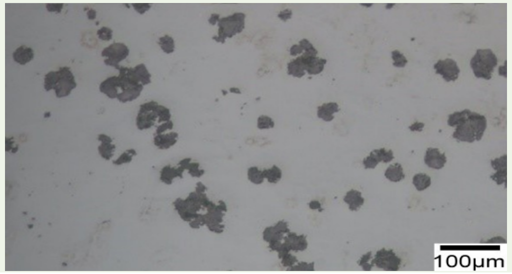
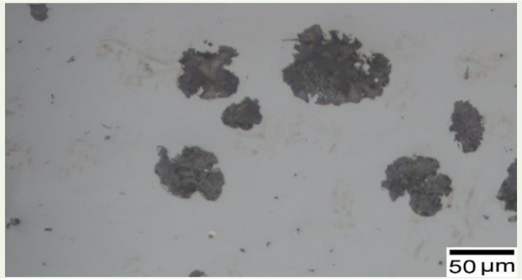
<tr><td>
</td><td>
</td><td>
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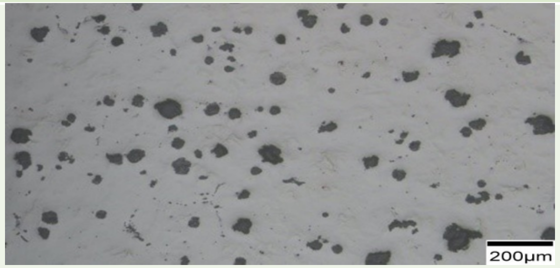
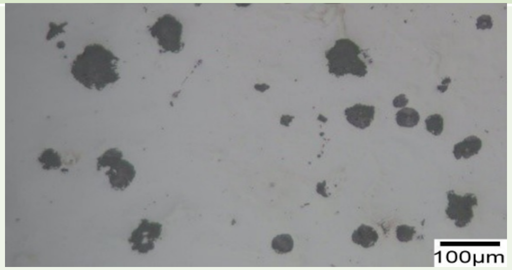
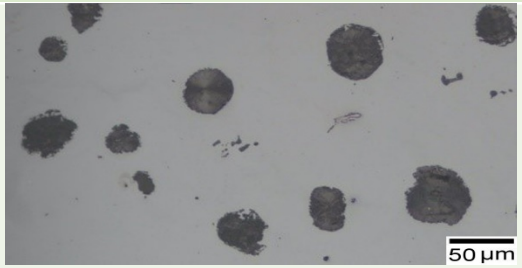
<tr><td>
</td><td>
</td><td>
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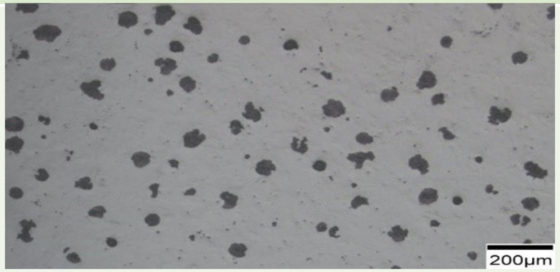
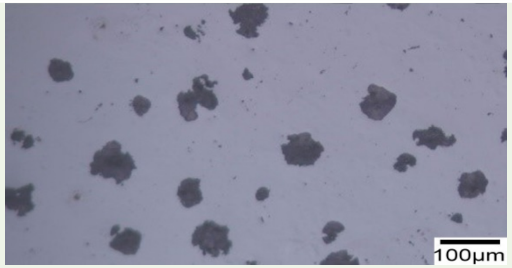
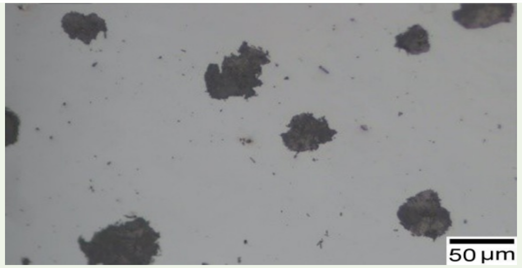
<tr><td>
</td><td>
</td><td>
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金相(腐蝕後)		
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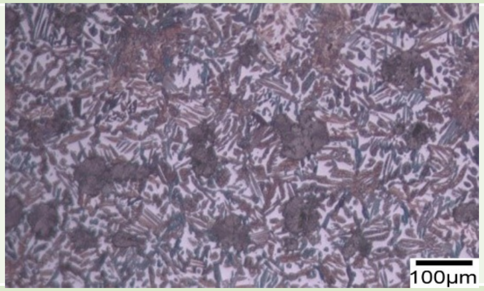
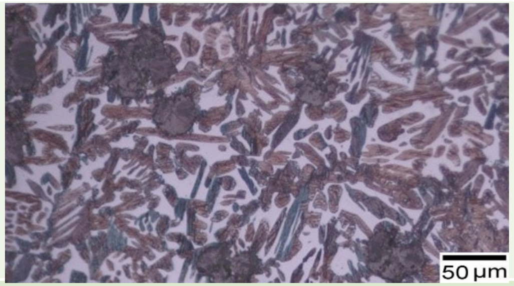
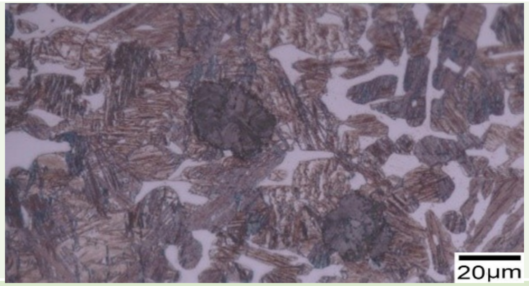
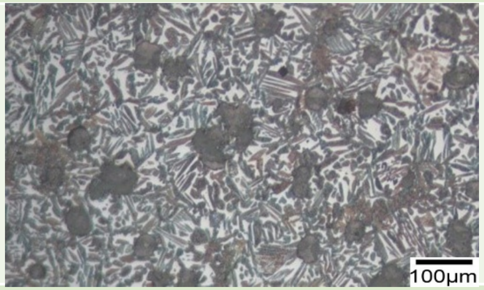
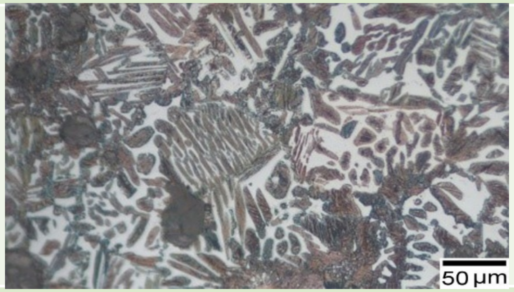
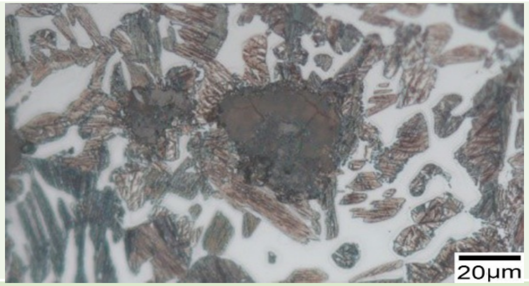
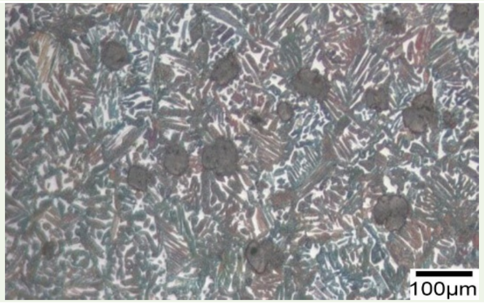
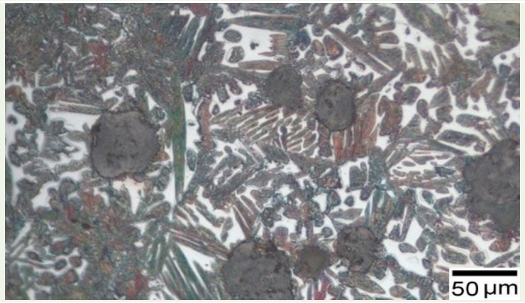
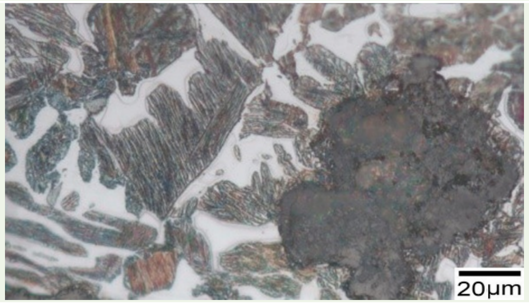
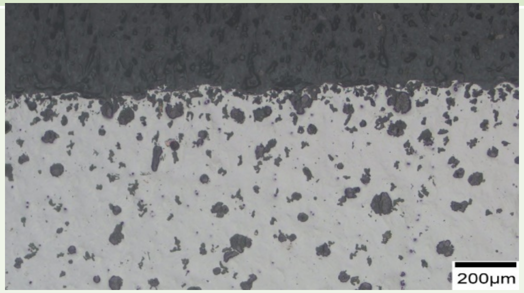
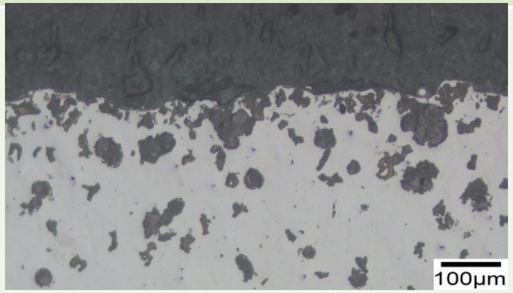
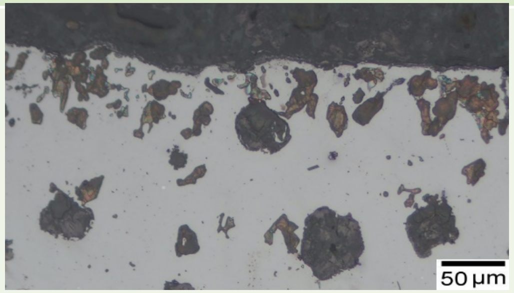
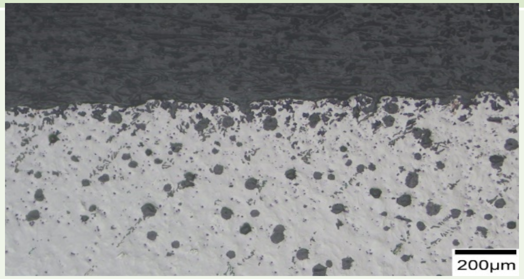
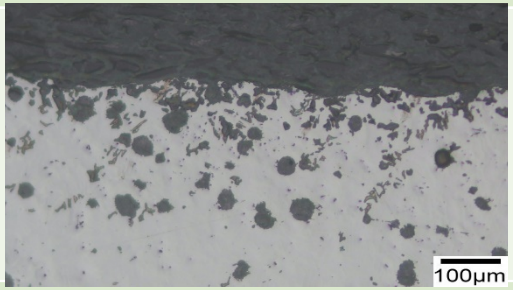
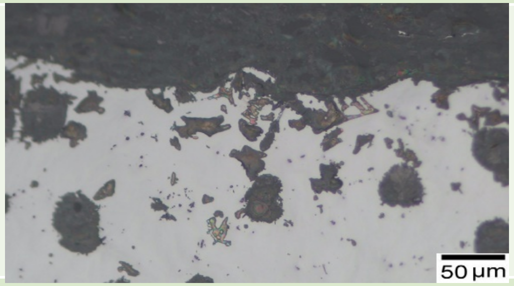
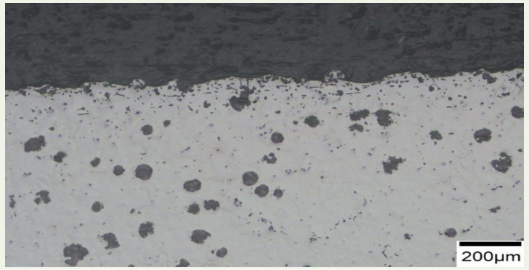
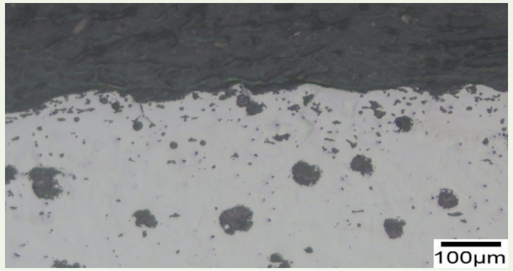
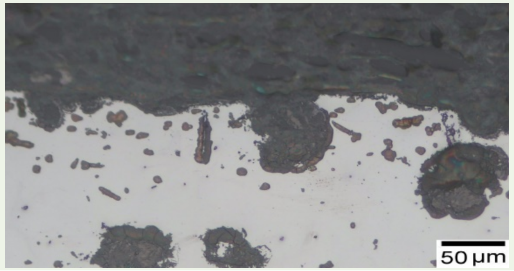
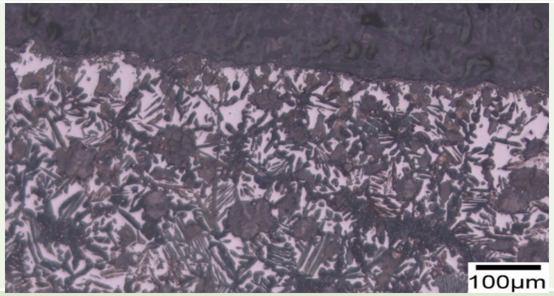
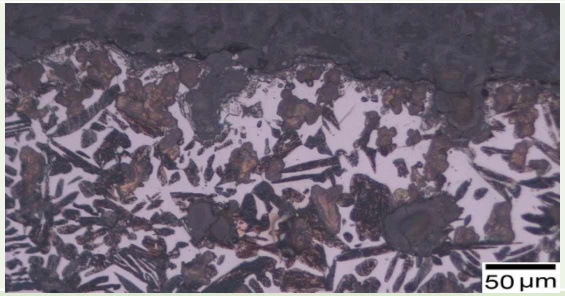
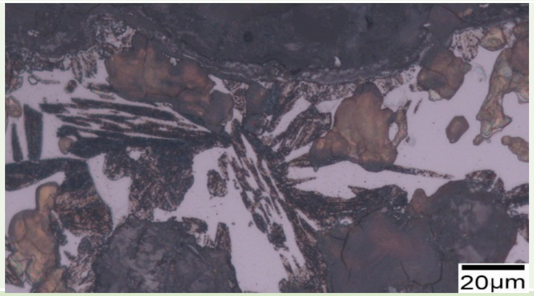
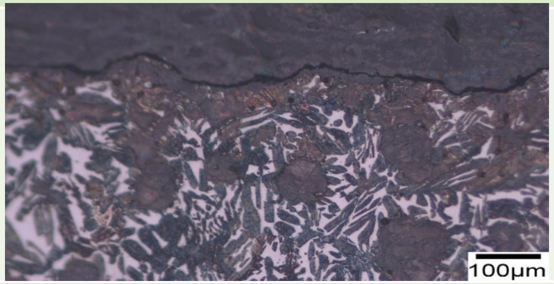
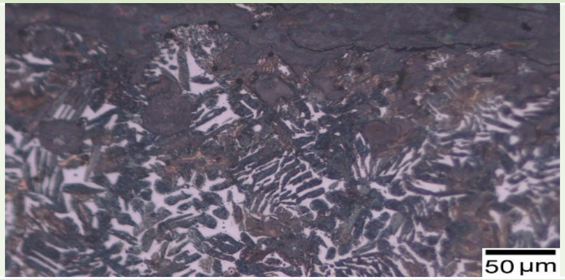
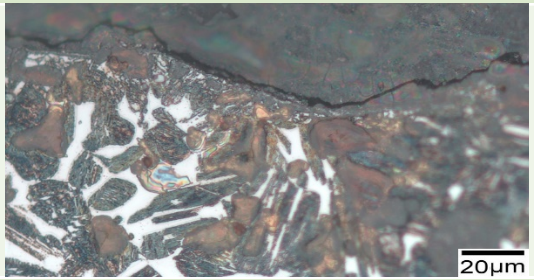
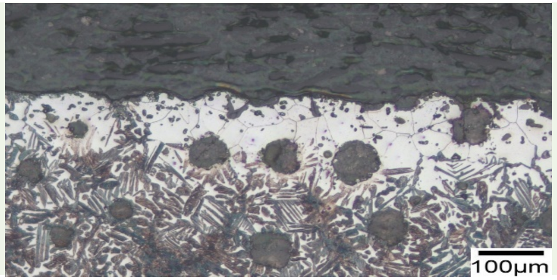
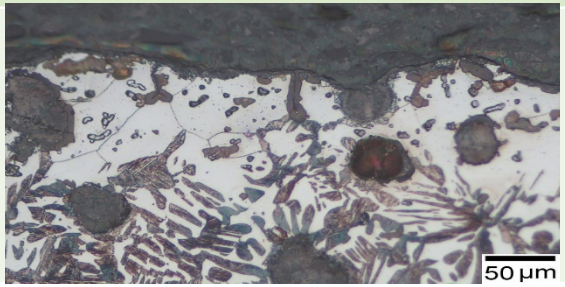
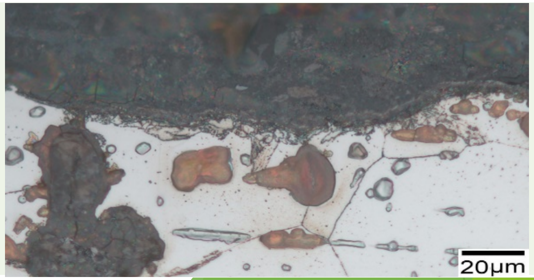
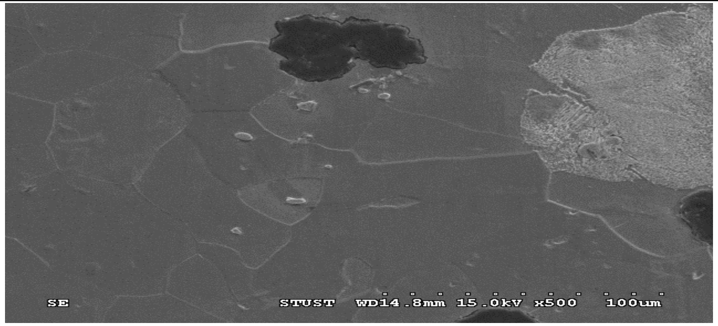
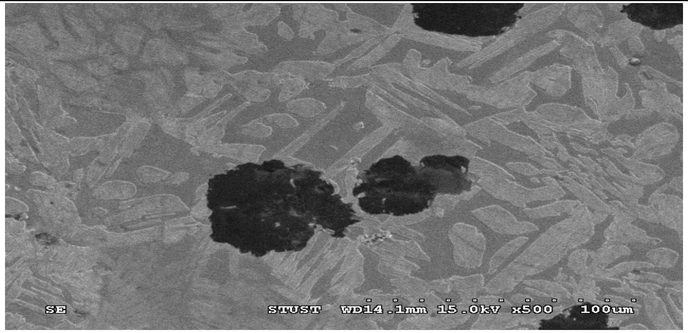
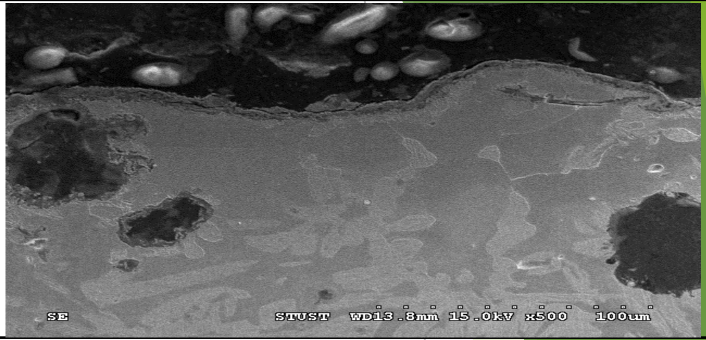
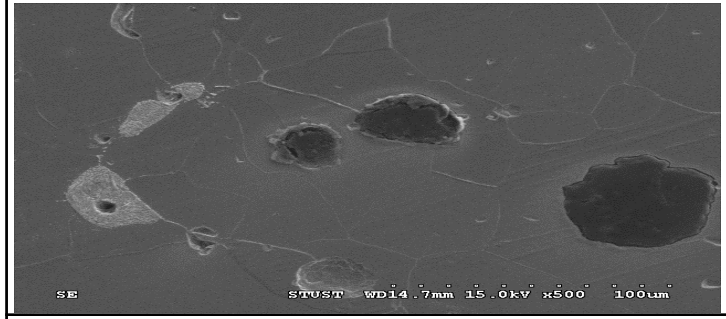
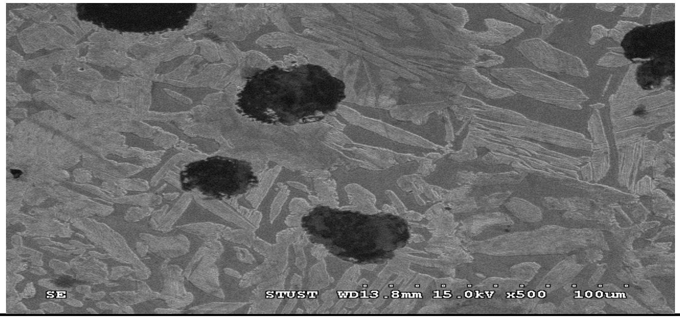
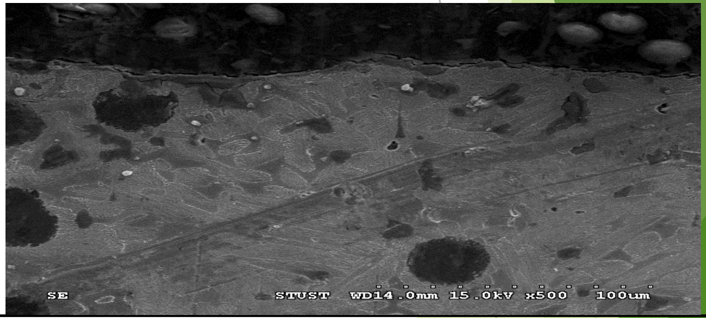
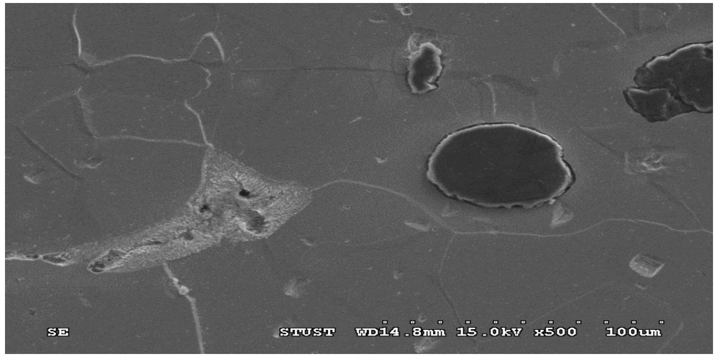
		
2% X100	2% X200	2% X500
		
3% X100	3% X200	3% X500
		

金相(離子氮化經ADI後之FCD600+V)

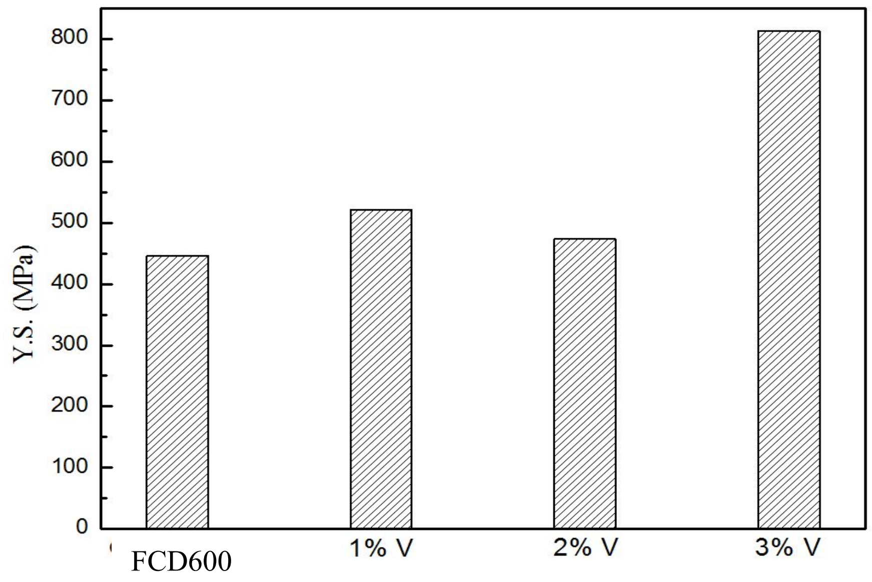
金相(未腐蝕)		
1% X50	1% X100	1% X200
		
2% X50	2% X100	2% X200
		
3% X50	3% X100	3% X200
		

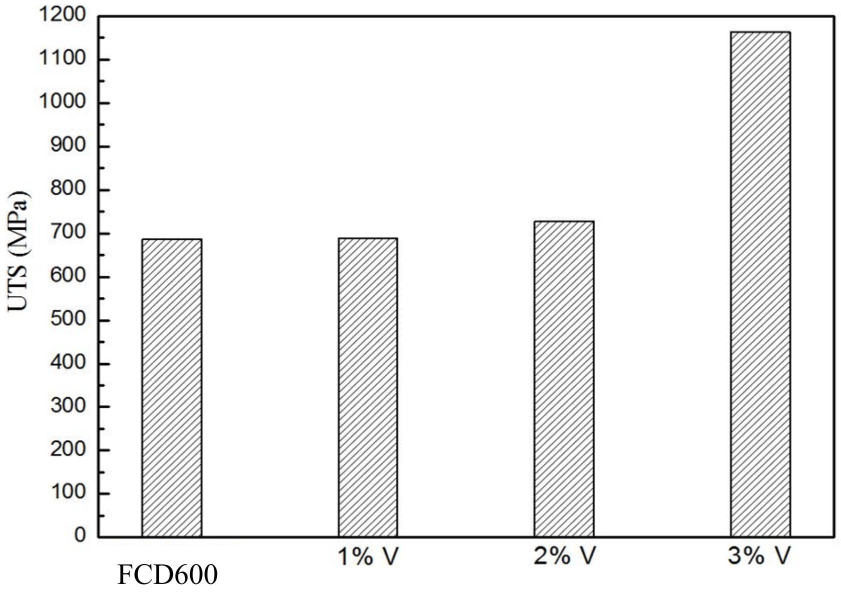
金相(腐蝕後)		
1% X100	1% X200	1% X500
		
2% X100	2% X200	2% X500
		
3% X100	3% X200	3% X500
		

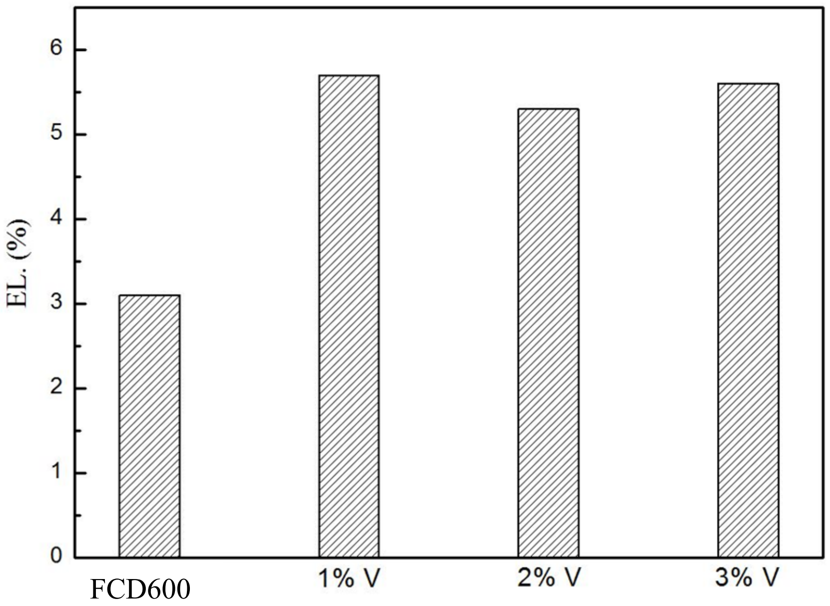
進度二.SEM

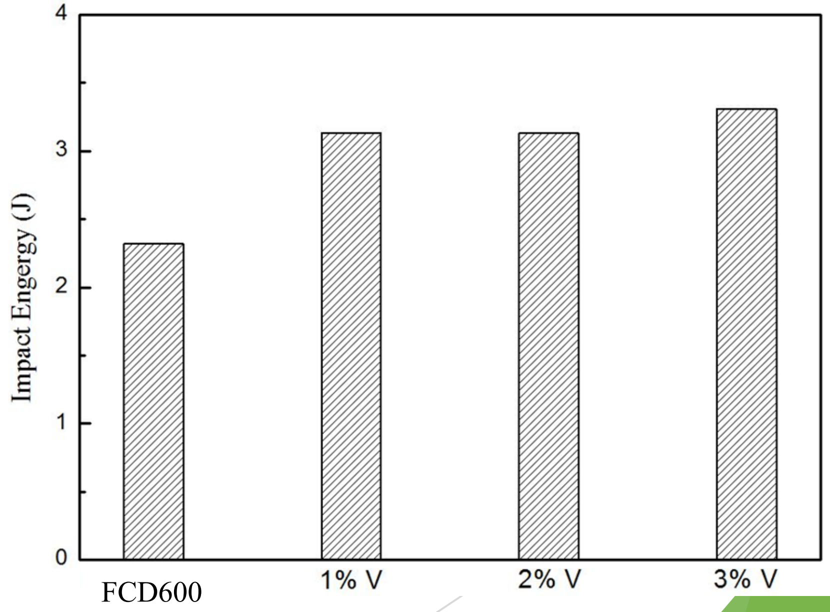
FCD600+V 1%	**FCD600+V(ADI) 1%**	**FCD600+V(ADI)+Nitriding 1%**
		
FCD600+V 2%	**FCD600+V(ADI) 2%**	**FCD600+V(ADI)+Nitriding 2%**
		
FCD600+V 3%	**FCD600+V(ADI) 3%**	**FCD600+V(ADI)+Nitriding 3%**
		

進度三.拉伸試驗

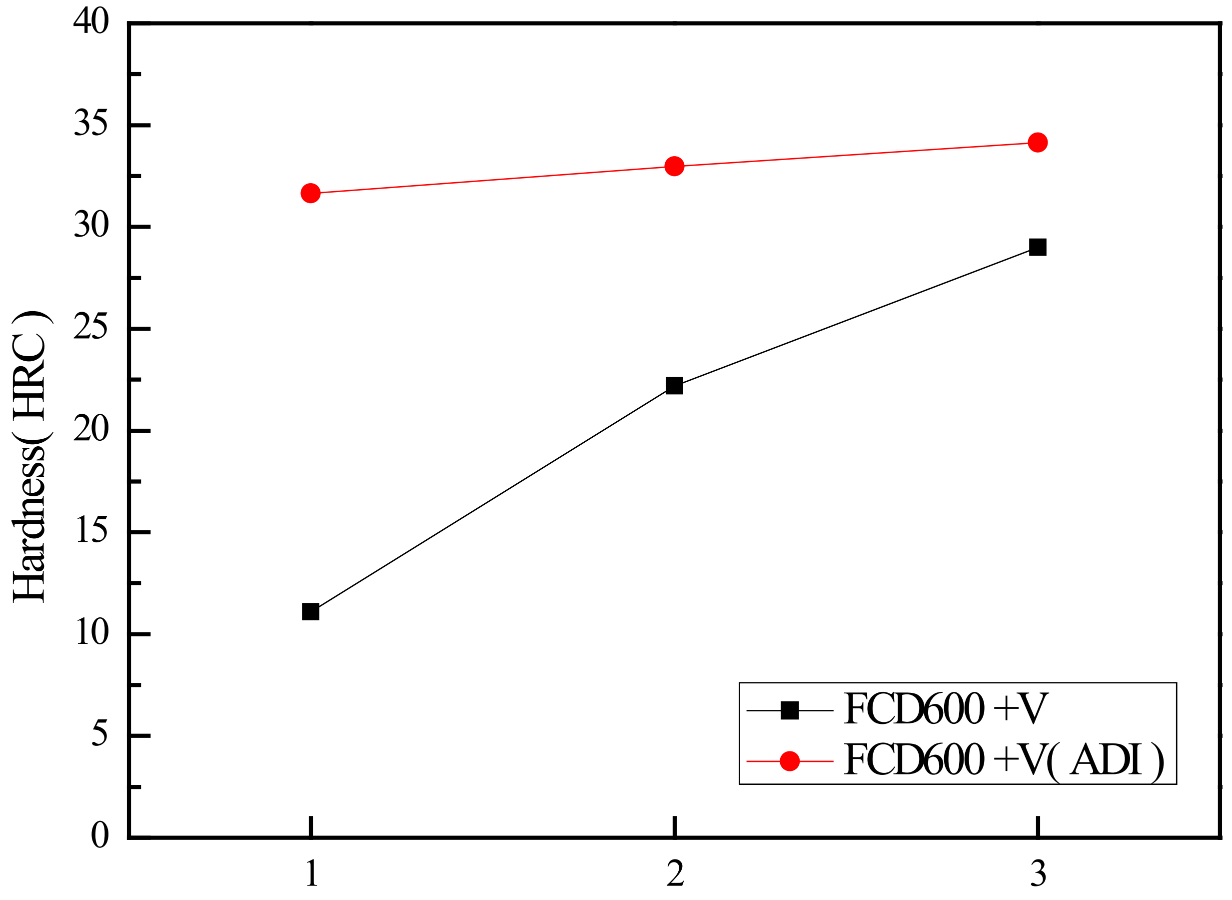

Y.S. (MPa)
0
100
200
300
400
500
600
700
800
FCD600
1% V
2% V
3% V


UTS (MPa)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
FCD600
1% V
2% V
3% V


EL. (%)
0
1
2
3
4
5
6
FCD600
1% V
2% V
3% V

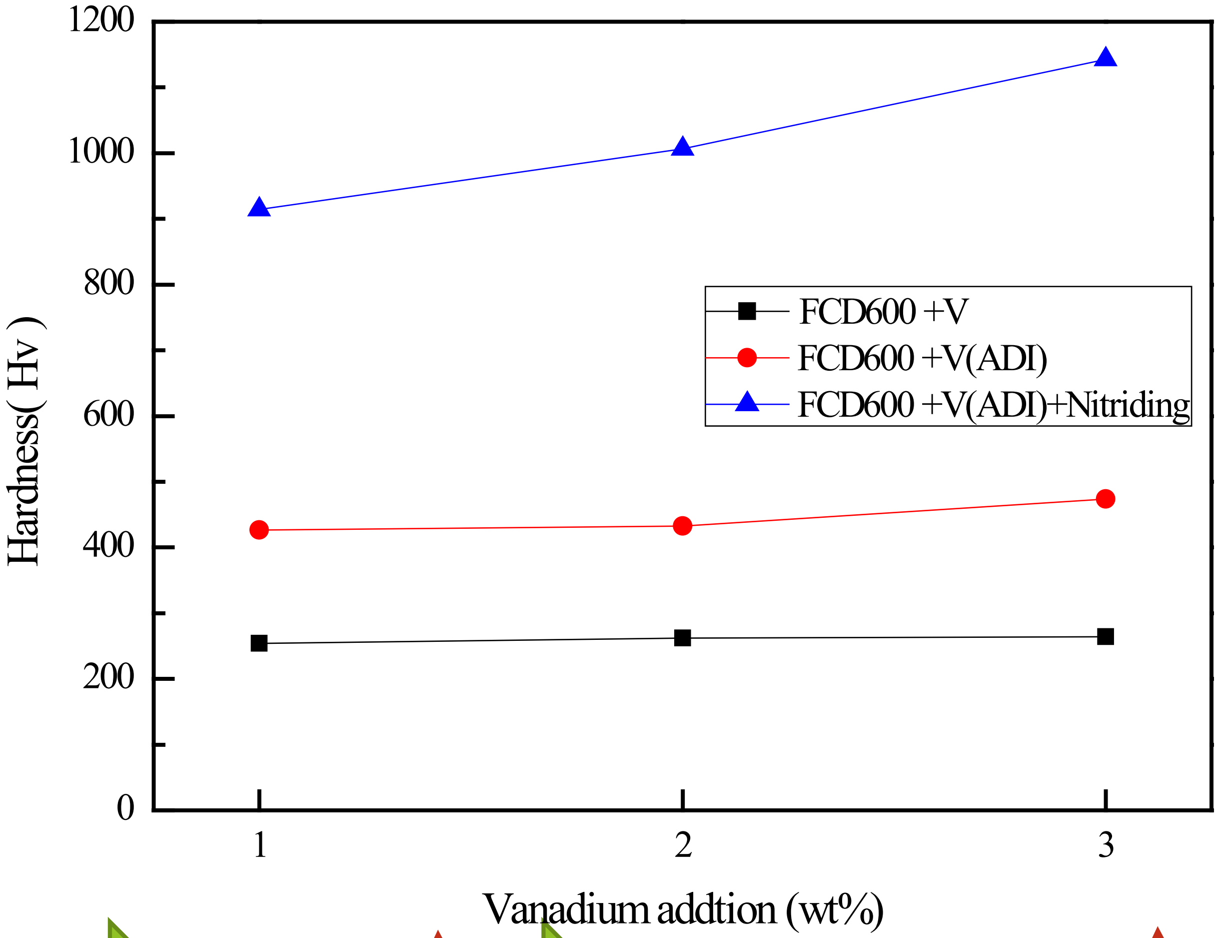

Impact Engergy (J)
0
1
2
3
4
FCD600
1% V
2% V
3% V

釩添加量對鑄態及ADI後球墨鑄鐵之HRC體硬度比較



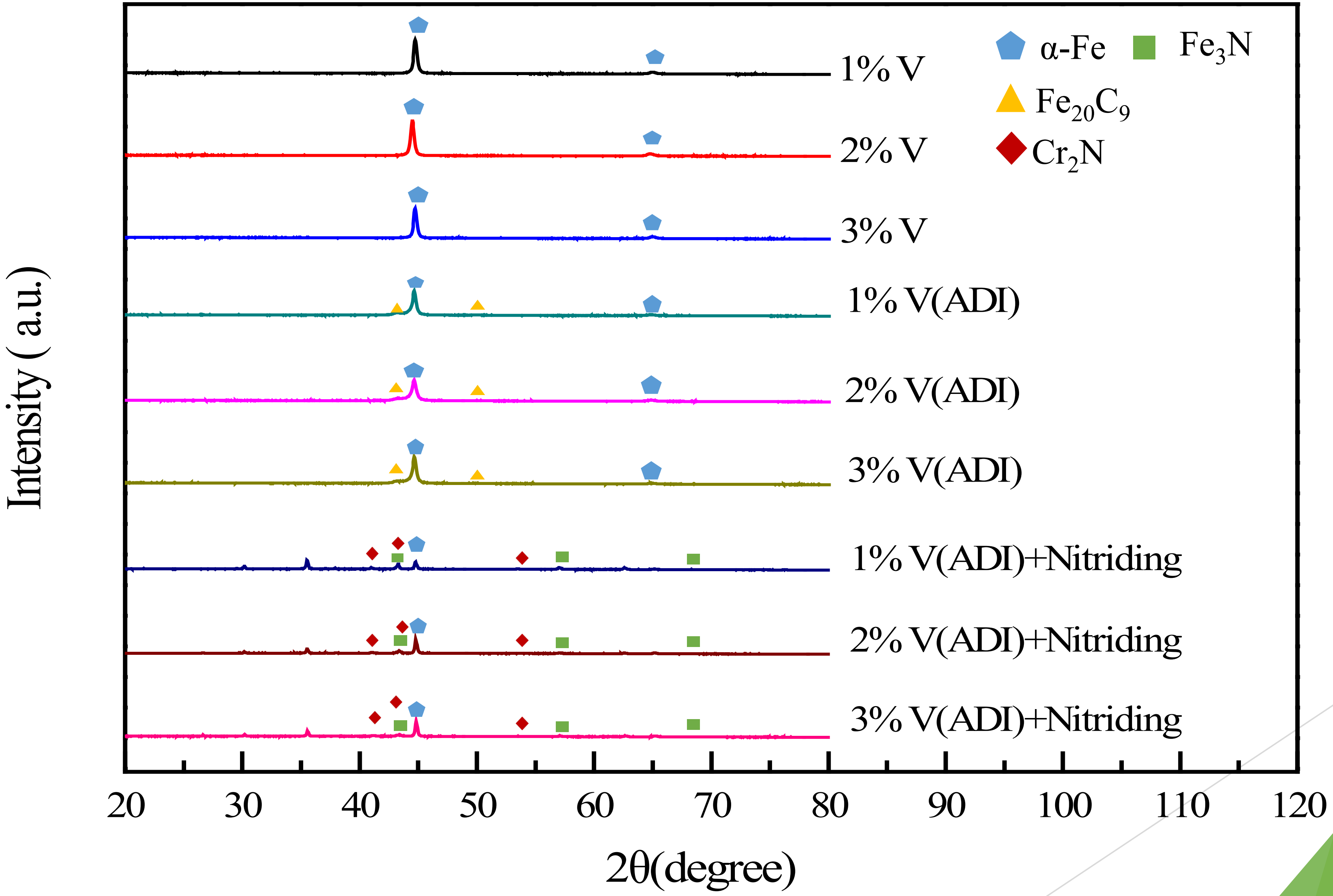
釩添加量↑ FCD600硬度值HRC ↑

釩添加量對鑄態、ADI後球墨鑄鐵及離子氮化後球墨鑄鐵之橫截面Hv微硬度比較



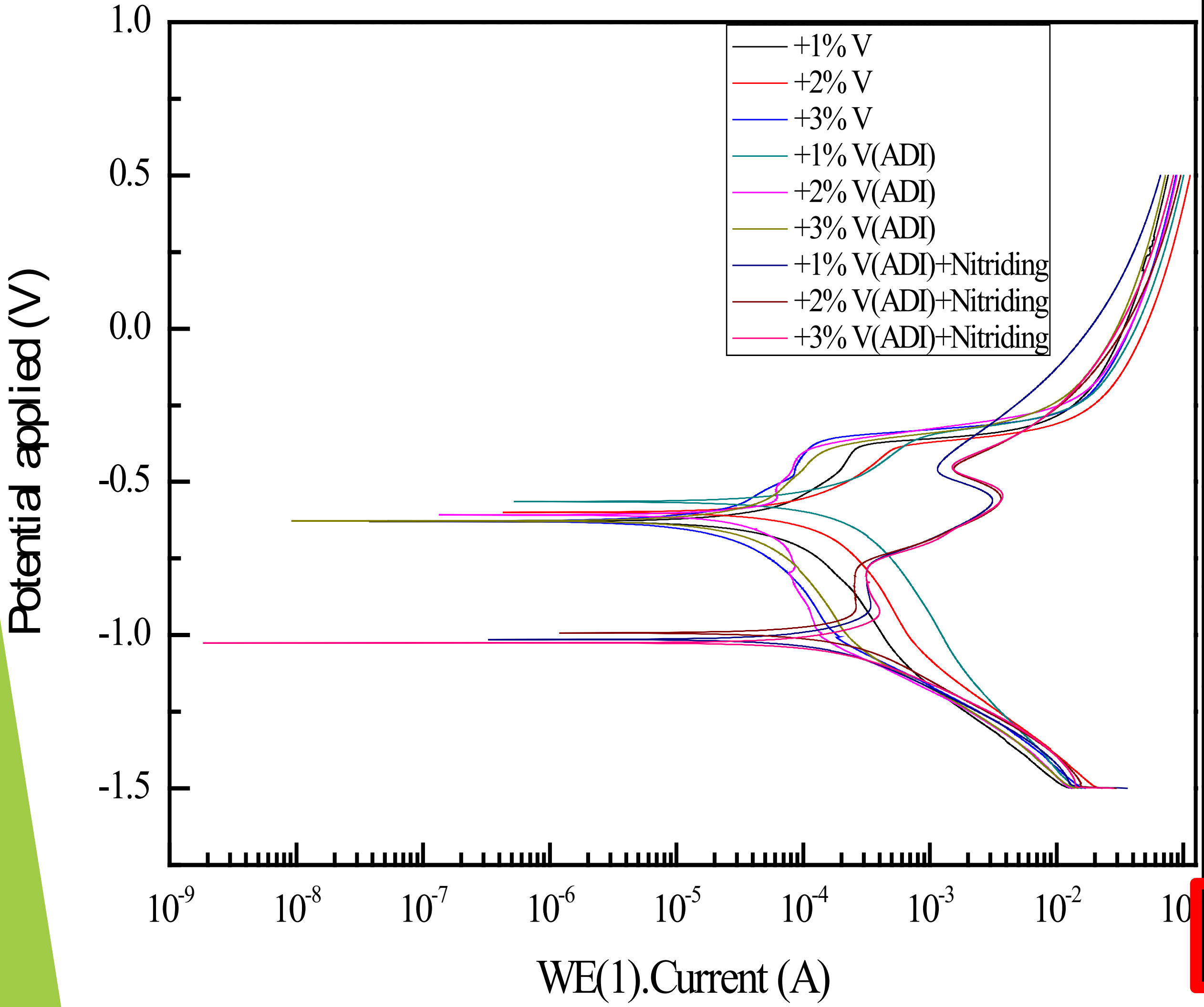
釩添加量↑ → FCD600硬度值Hv ↑

進度四.XRD



α-Fe
Fe3N
Fe20C9
Cr2N
1% V
2% V
3% V
1% V(ADI)
2% V(ADI)
3% V(ADI)
1% V(ADI)+Nitriding
2% V(ADI)+Nitriding
3% V(ADI)+Nitriding
Intensity (a.u.)
20
30
40
50
60
70
80
90
100
110
120
2θ(degree)

進度五.極化曲線



	Icorr$(A/cm^2)^{-6}$	Ecorr$(V_{Ag/AgCl})$
1% V	6.575	-0.6288
2% V	5.832	-0.5992
3% V	2.594	-0.6278
1% V(ADI)	9.066	-0.674
2% V(ADI)	6.292	-0.565
3% V(ADI)	3.243	-0.6268
1% V(ADI)+Nitriding	2.594	-1.0143
2%V(ADI) +Nitriding	2.573	-0.9936
3% V(ADI)+Nitriding	1.814	-1.0257

進度六. 磨耗

FCD600添加釩(ADI)之循環式磨耗參數:

參數	條件
荷重	5 N、6 N、7 N
轉速	300 rpm
行走直徑	5 mm
滑動距離	100 m
對耗材	Al_2O_3

磨耗係數公式

磨耗損失率公式

$$K=\frac{\Delta W}{d\cdot p\cdot v\cdot t}(cm^3/N\cdot m)$$

(磨耗後重量-磨耗前重量)÷(滑動距離)×100%

式中：

K—磨耗係數

△W—磨損重量（g）

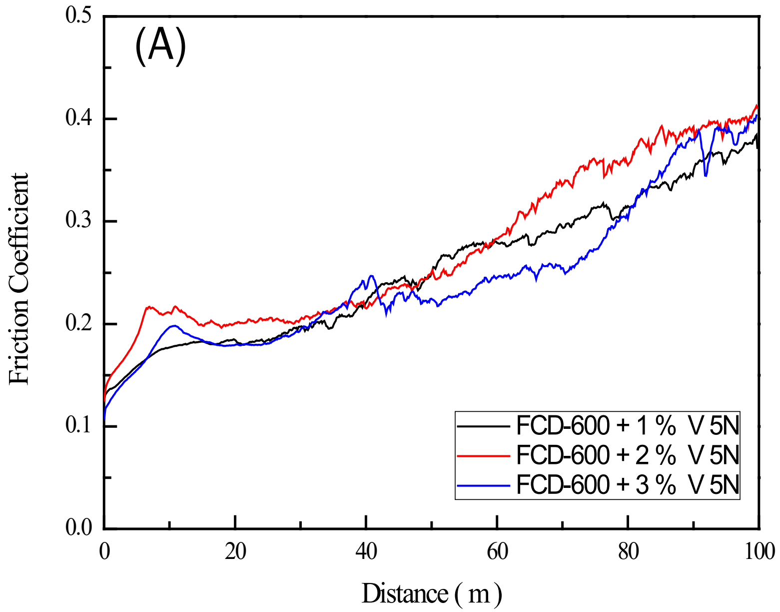
d—材料比重（g/cm^3）

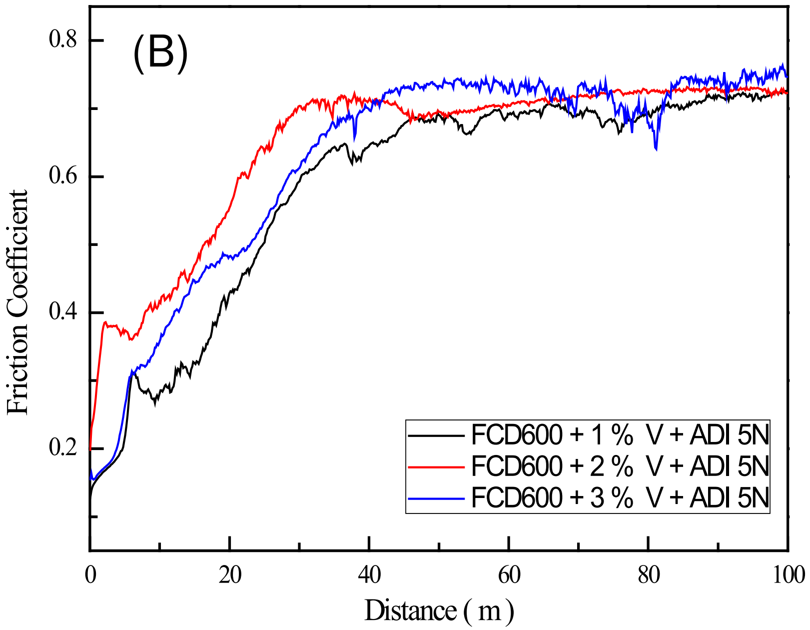
p—試驗負荷（N）

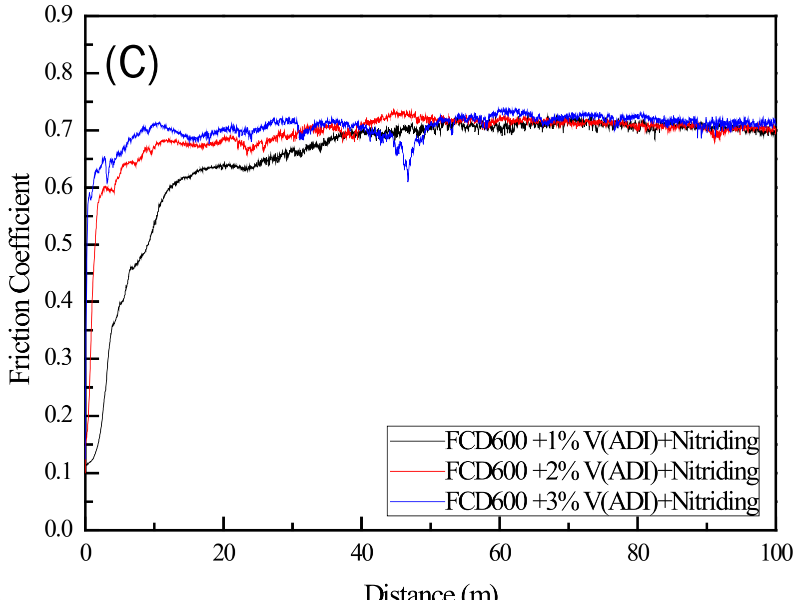
V—滑動線速度（m/s）

t—磨損時間（s）

釩添加量及荷重5N對鑄態、ADI後球墨鑄鐵及離子氮化後球墨鑄鐵之磨耗曲線比較圖

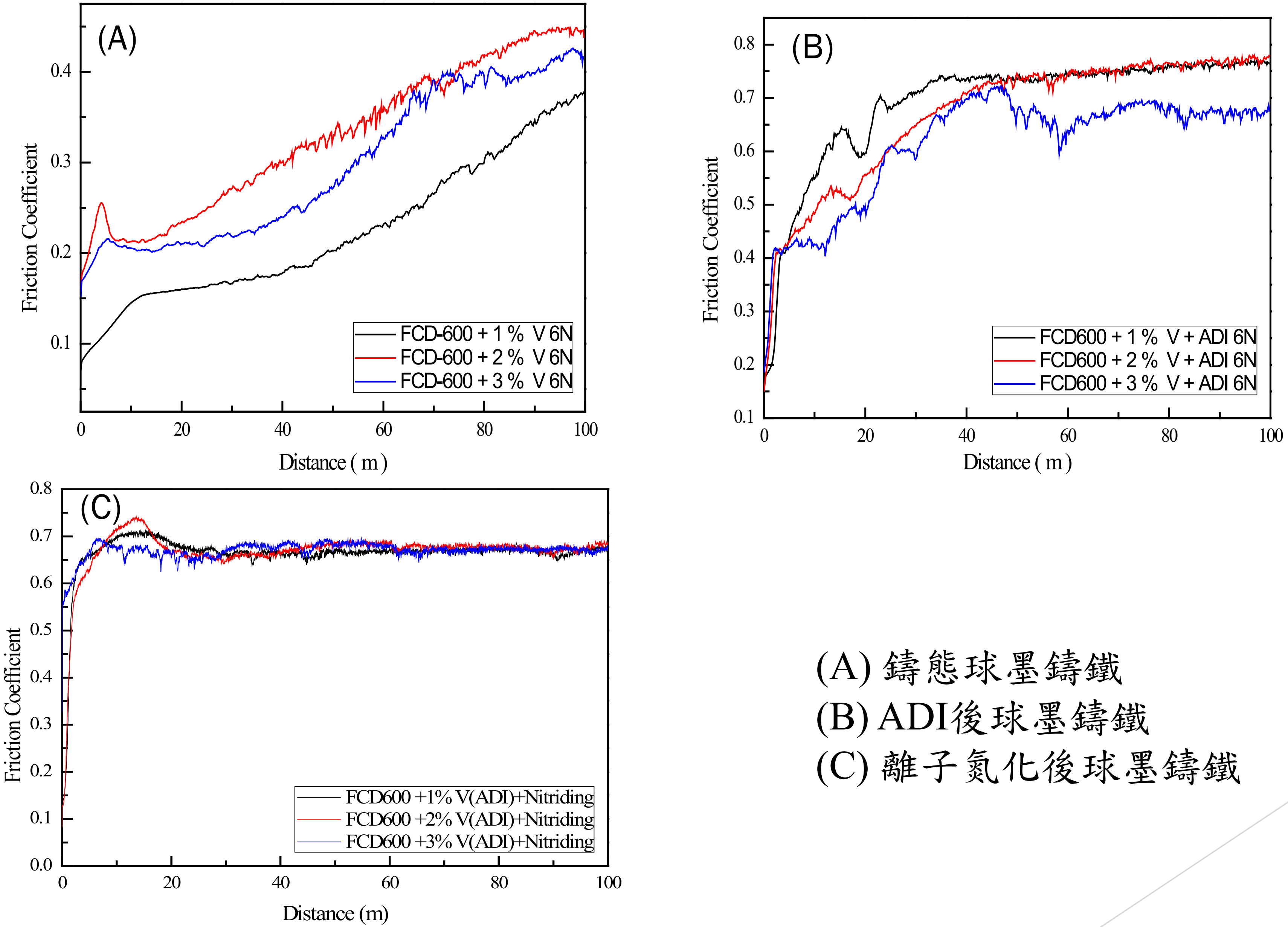






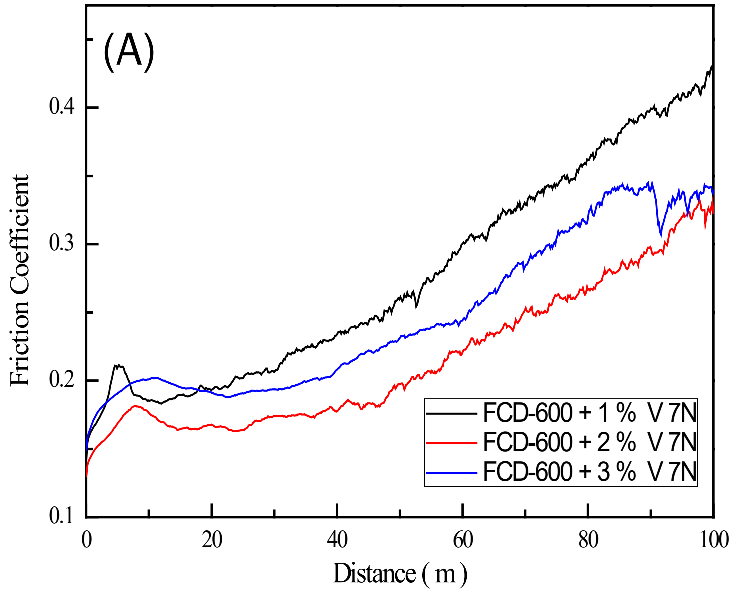
(A) 鑄態球墨鑄鐵
(B) ADI後球墨鑄鐵
(C) 離子氮化後球墨鑄鐵

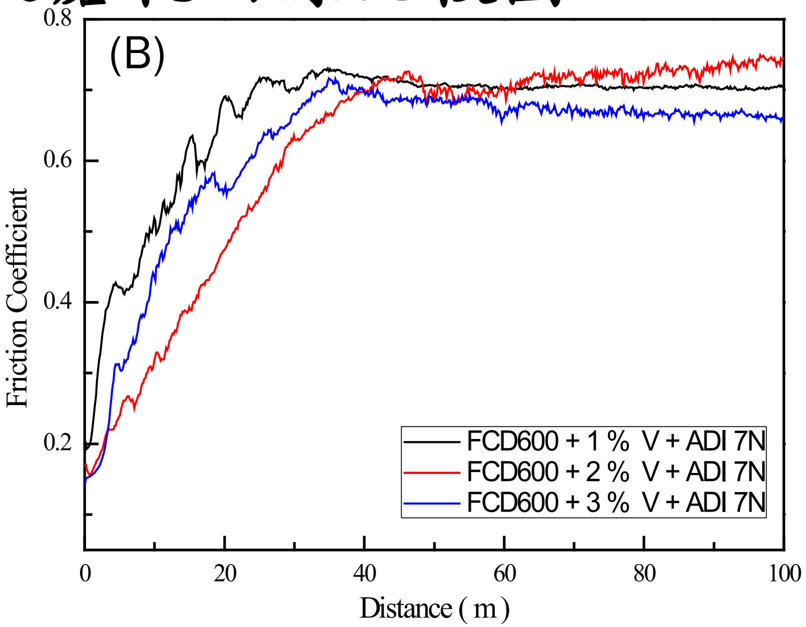
釩添加量及荷重6N對鑄態、ADI後球墨鑄鐵及離子氮化後球墨鑄鐵之磨耗曲線比較圖

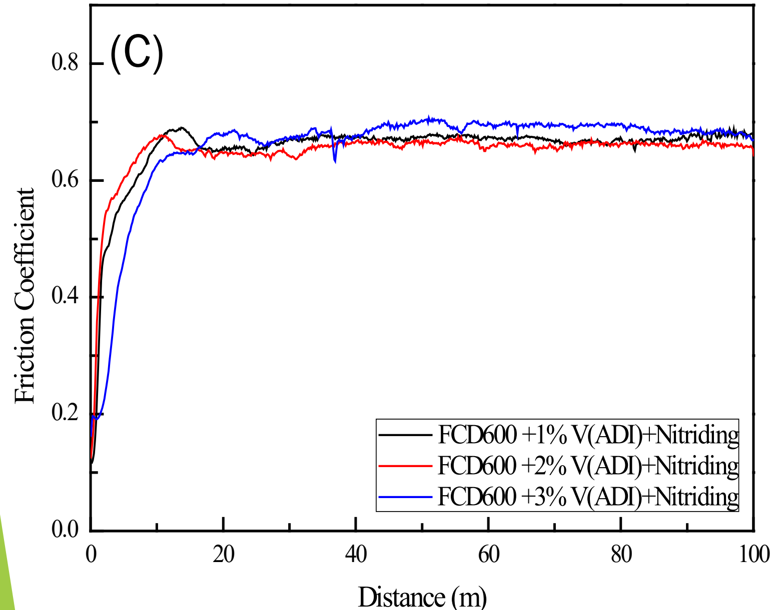


(A) 鑄態球墨鑄鐵
(B) ADI後球墨鑄鐵
(C) 離子氮化後球墨鑄鐵

釩添加量及荷重7N對鑄態及ADI後球墨鑄鐵及離子氮化後球墨鑄鐵之磨耗曲線比較圖

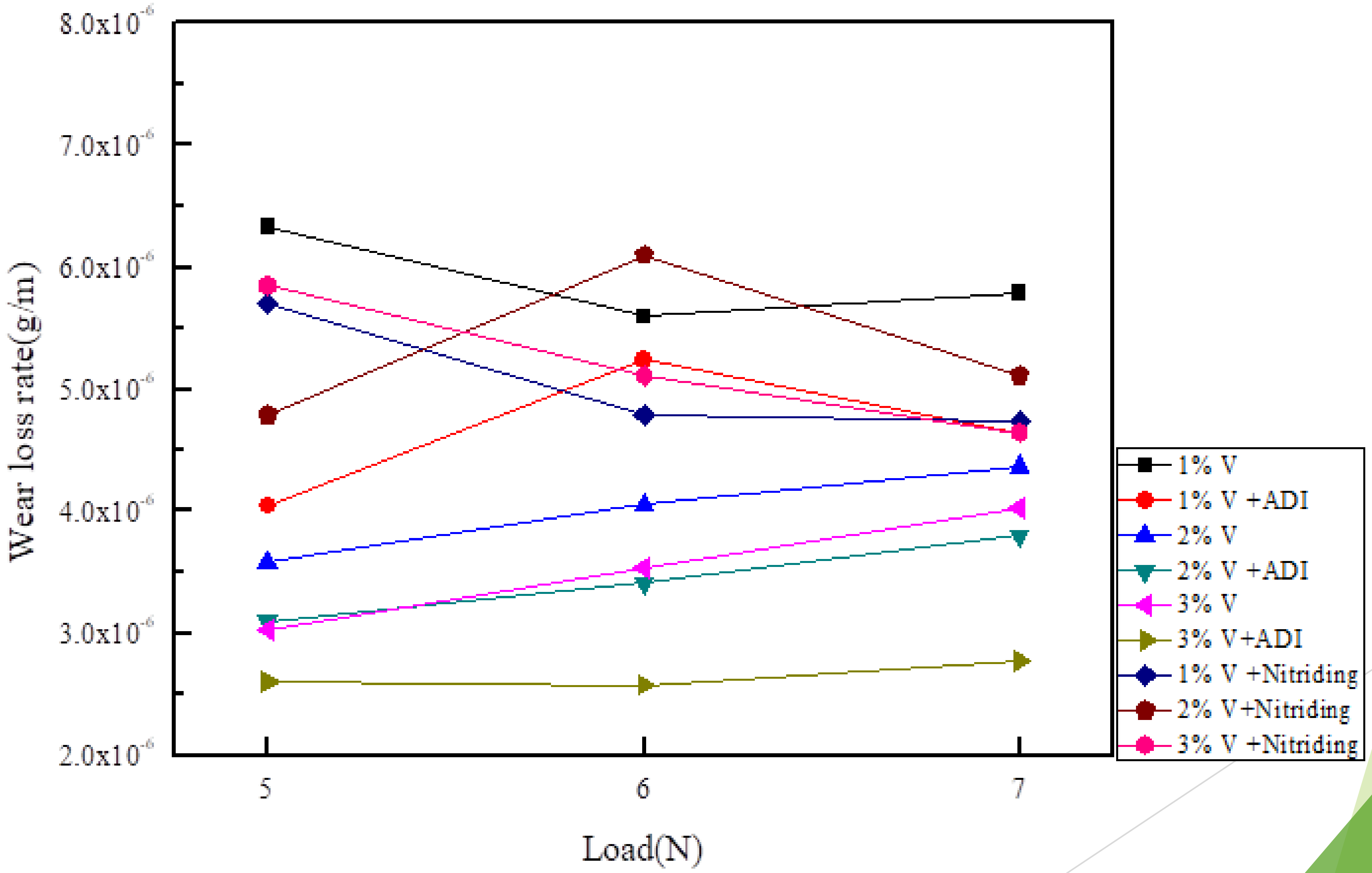




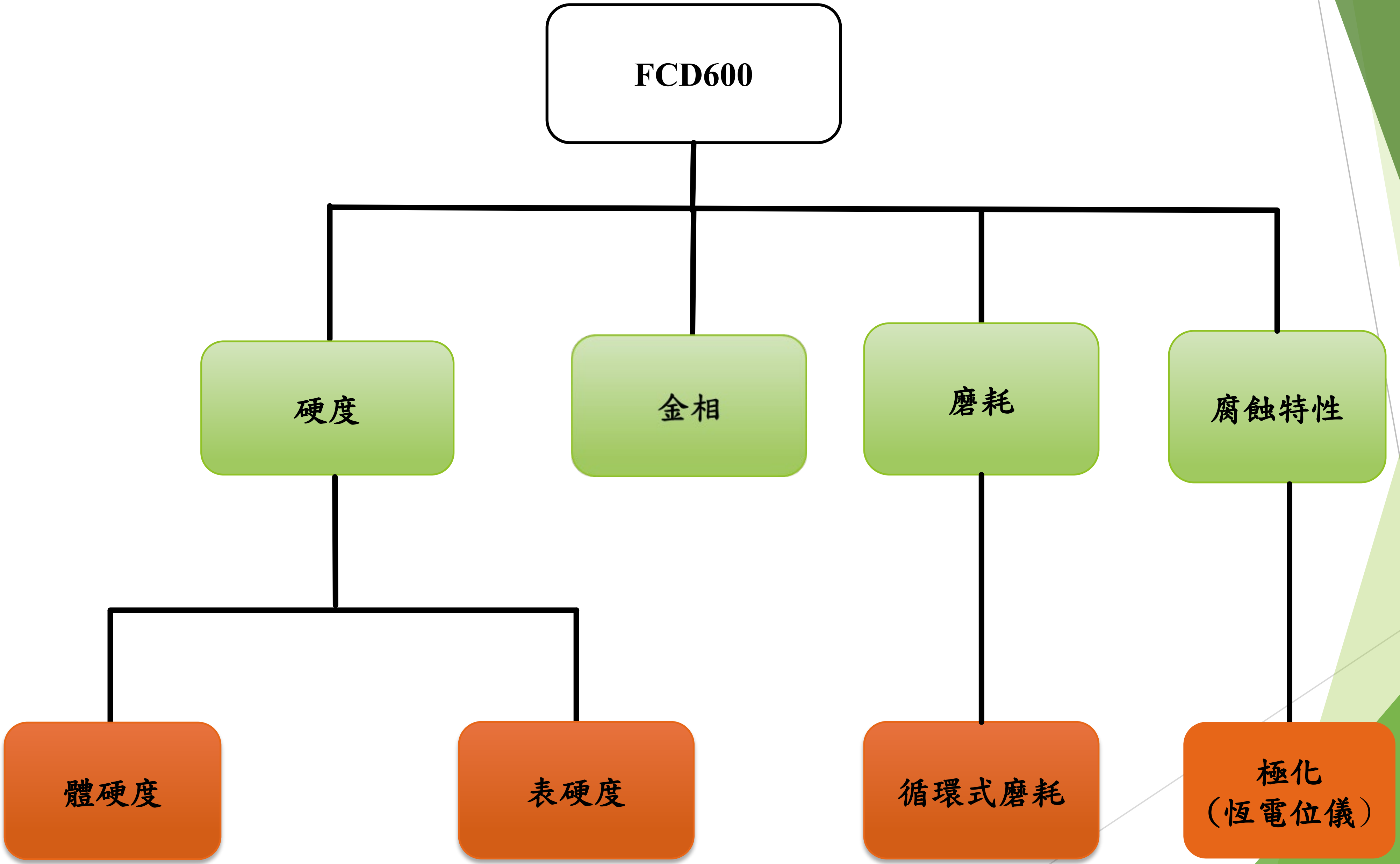


(A) 鑄態球墨鑄鐵
(B) ADI後球墨鑄鐵
(C) 離子氮化後球墨鑄鐵

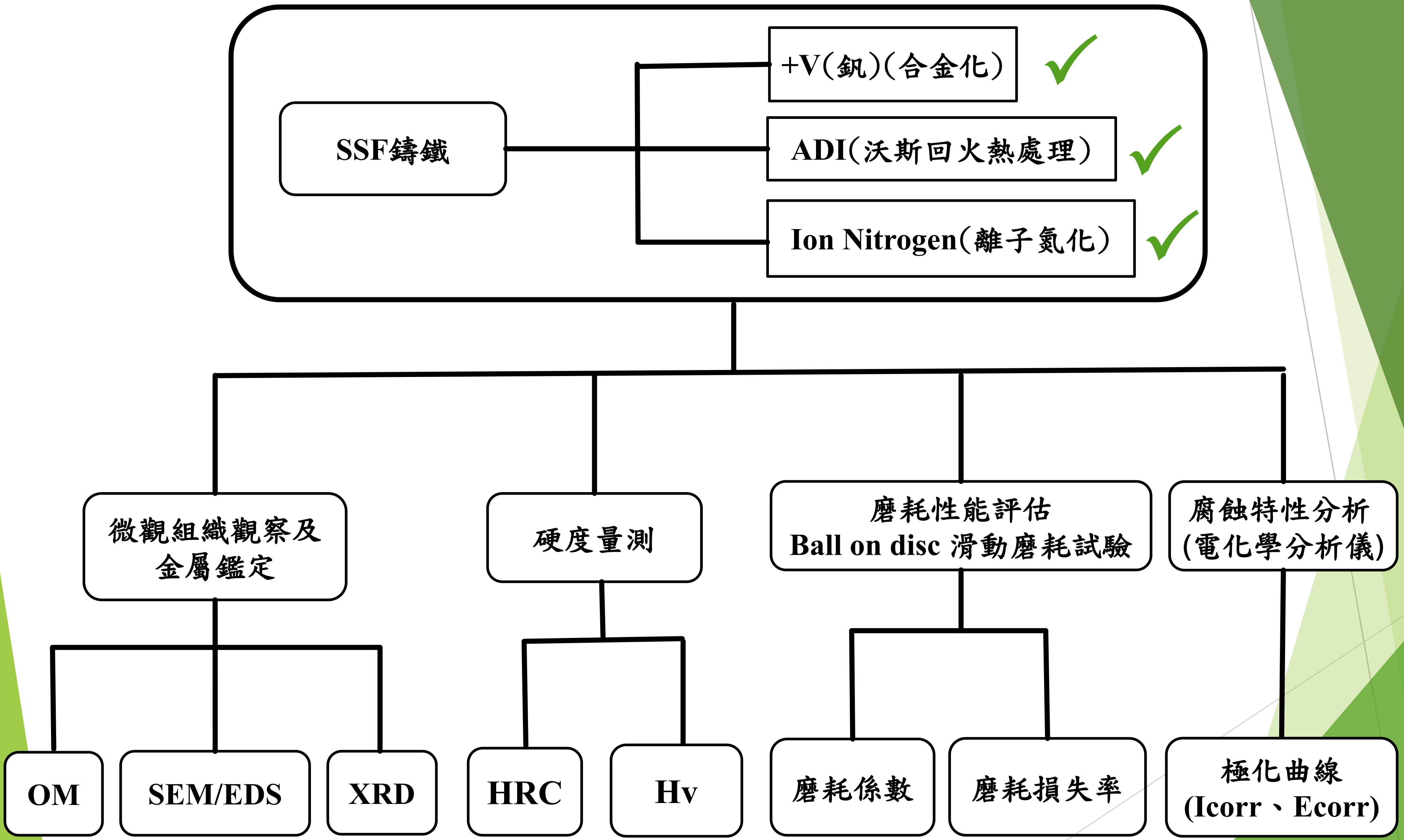
荷重對鑄態、ADI後球墨鑄鐵及離子氮化後球墨鑄鐵之磨耗損失率比較圖



目前進度



未來進度


SSF鑄鐵
+V(釩)(合金化)
ADI(沃斯回火熱處理)
Ion Nitrogen(離子氮化)
微觀組織觀察及
金屬鑑定
硬度量測
磨耗性能評估
Ball on disc 滑動磨耗試驗
腐蝕特性分析
(電化學分析儀)
OM
SEM/EDS
XRD
HRC
Hv
磨耗係數
磨耗損失率
極化曲線
(Icorr、Ecorr)

工作進度甘特圖

月次 工作項目	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Mar-21	Apr-21	May-21	Jul-21	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21	Jan-22	Feb-22	Mar-22	Apr-Jul-22
資料收集/練習	★	★	★	★	★	★	★	★	★	★	★	★	★	★	★	★	★	★
ADI製程						★	★	★	★	★	★	★	★	★	★	★	★	★
離子氮化													★	★	★	★	★	★
金相試驗				★	★	★	★	★	★	★	★	★	★	★	★	★	★	★
磨耗試驗										★	★	★	★	★	★	★	★	★
撰寫報告						★	★	★	★	★	★	★	★	★	★	★	★	★
海報製作																		
預定累積進度百分比	15%	15%	15%	30%	30%	60%	60%	60%	60%	75%	75%	75%	85%	85%	85%	85%	85%	85%

謝 謝 指 教