Microalloying Technology for HS Hot-Rolled Rebars & Microstructural Inspection

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Seminar on Application of Vanadium in Rebars, Xichang, Sichuan, China, 2019-4-13

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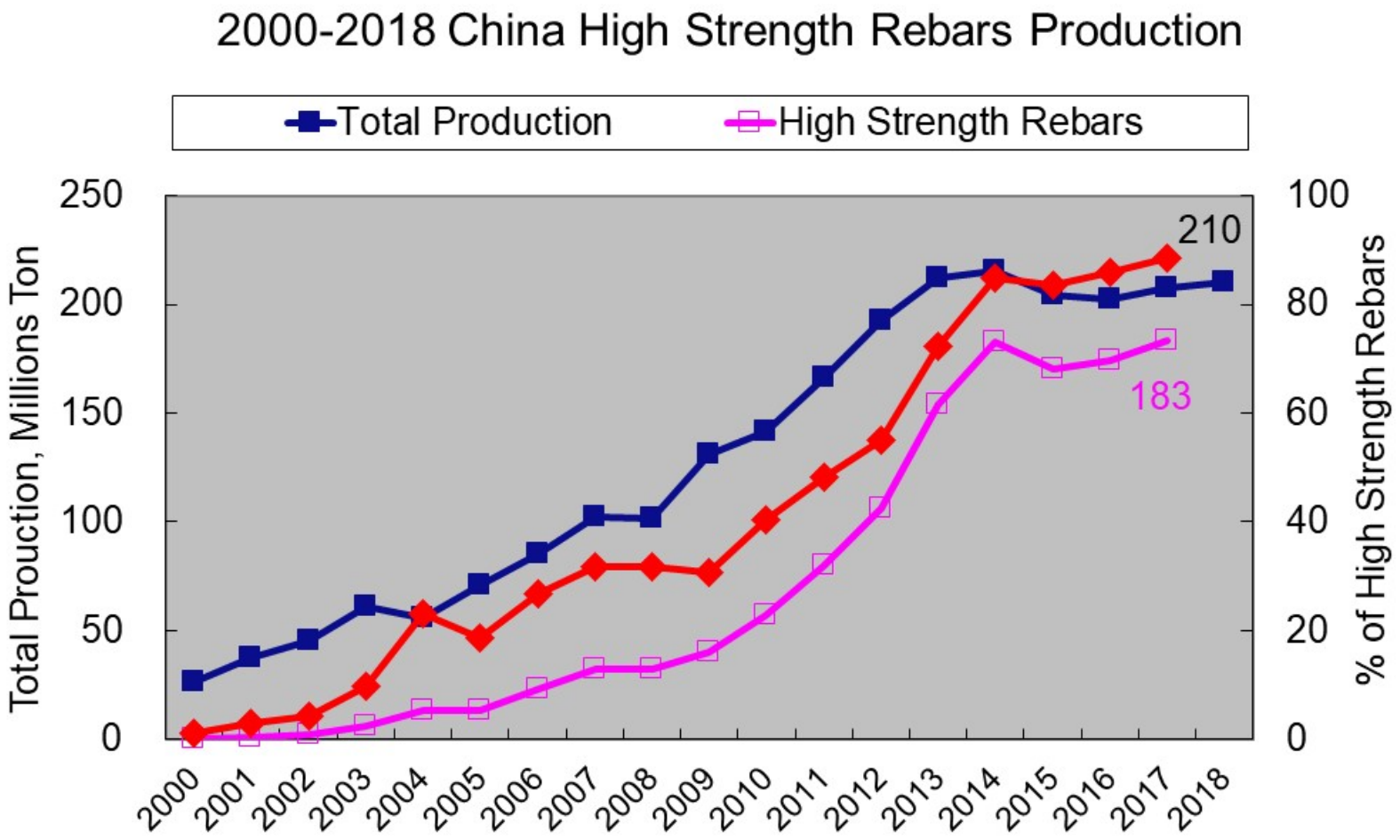
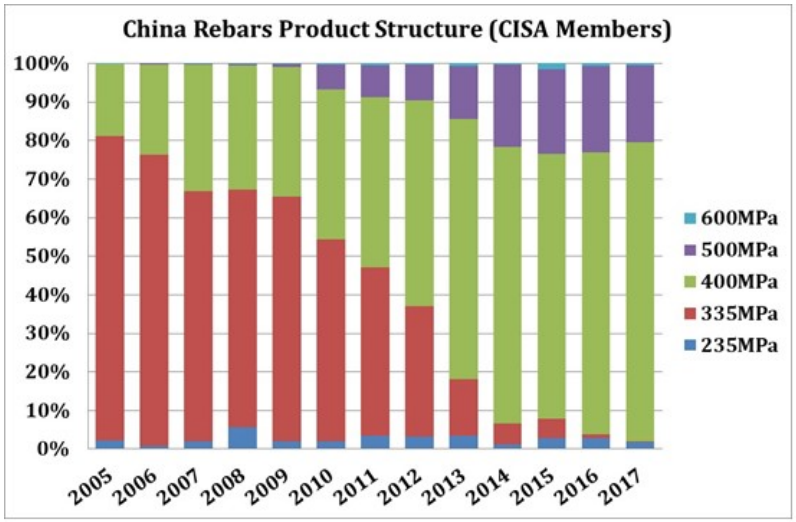
Outline

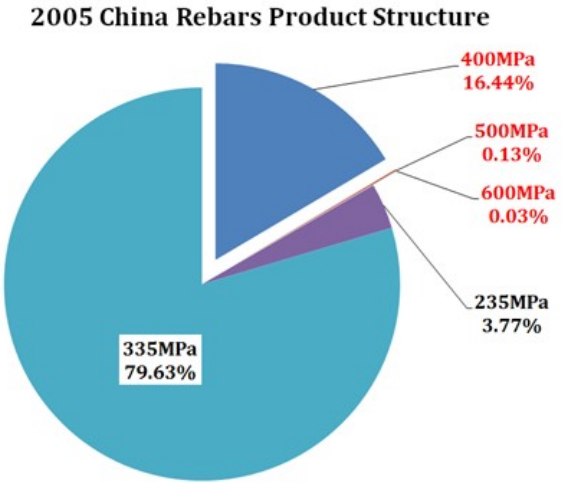
1. Background
2. Microalloying Technology of HS Rebars
3. Microstructural Inspection of HS Rebars

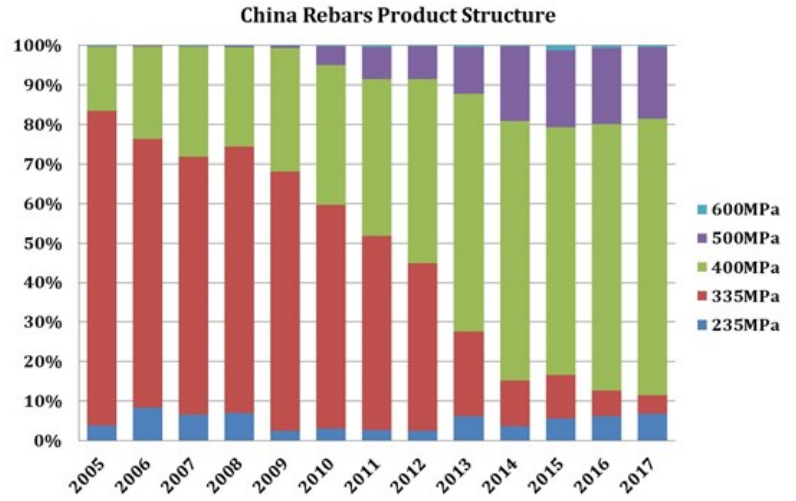
China Rebars Production

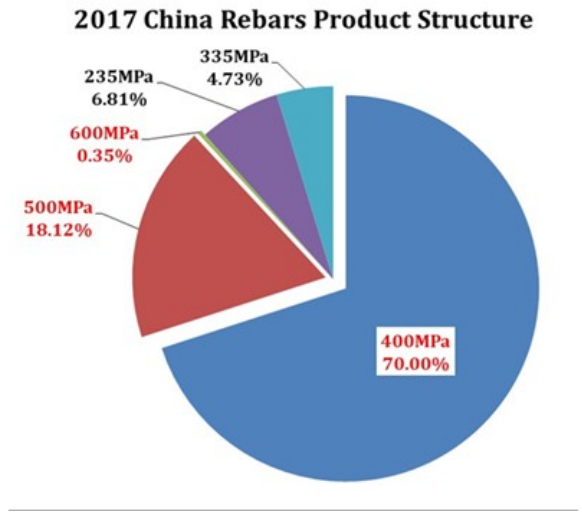


China Rebar Products Structure

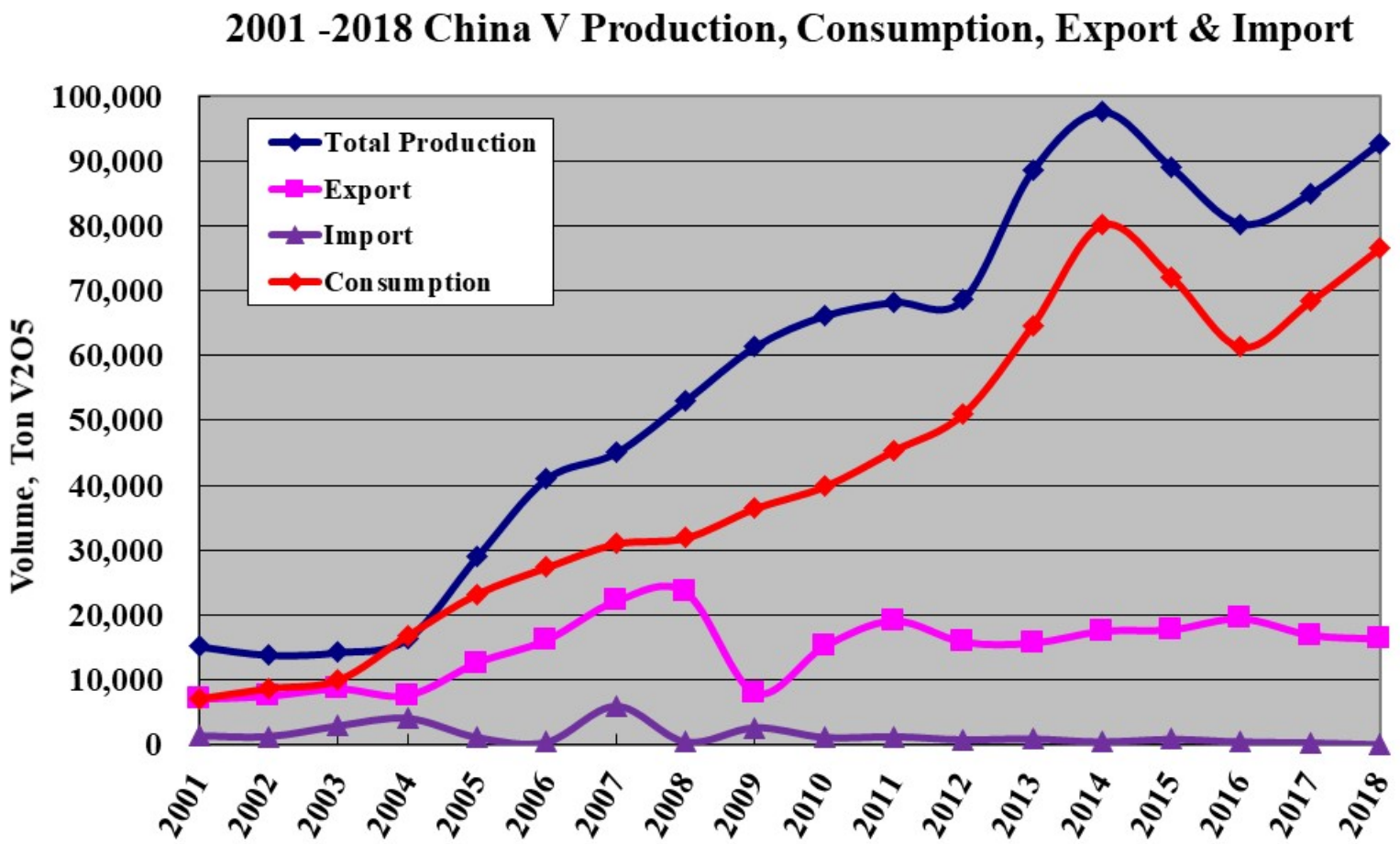








China V Production & Consumption



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Methods for Production of HS Rebars

1. **P Microstructure Strengthening:**

   medium C content（0.30-0.40%C）, low weldability

2. **Cold Forming:**

   high cost, low ductility（El<2%）

3. **TEMPORE（Q&T）**

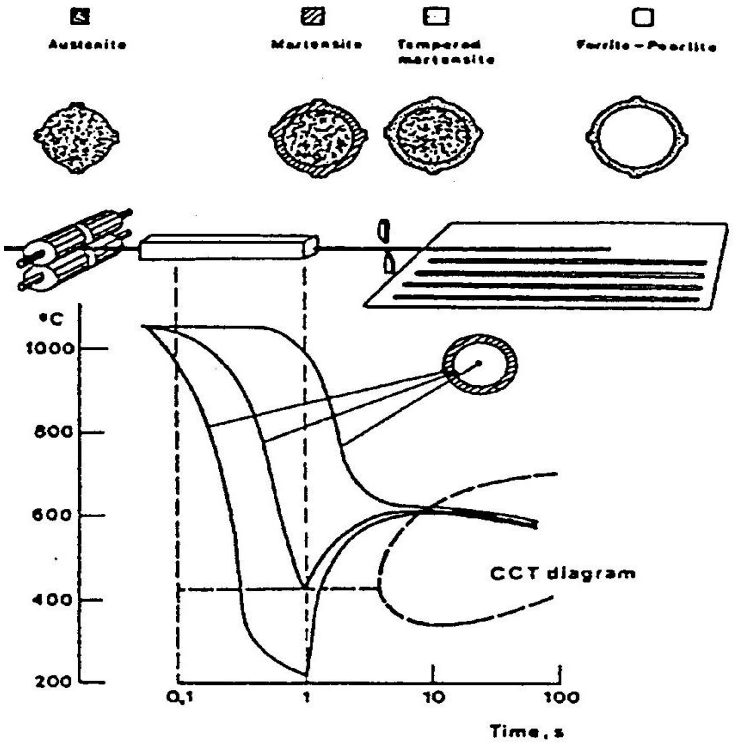
4. **Refine Ferrite Grain Size**

5. **Microalloying：V/V-N、Nb、Ti**

Specifications of China Rebars

Standard No.	Grade	Mechanical Properties	V% (V-N)
GB1499.1-2017 Hot-rolled Plain Bars	~~HPB235~~	235MPa	
	HPB300	300MPa	
GB1499.2 -2018 Hot-rolled Ribbed bars	~~HRB335~~	335MPa	
	HRB400/E	R_{eL}≥400MPa; A≥16%	0.025-0.05%
	HRB500/E	R_{eL}≥500MPa; A≥15%	0.06-0.09%
	HRB600	R_{eL}≥600MPa; A≥14%	0.10-0.15%
GB13014 -2013 Quenching and Self-Tempering Ribbed Bars	RRB400	R_{eL}≥400MPa; A≥14%	
	RRB500	R_{eL}≥500MPa; A≥13%	0.05-0.07%

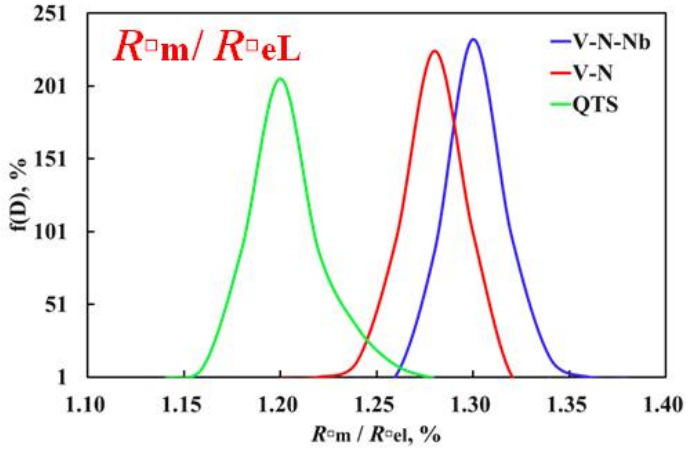
Tempcore (Q&T) Rebars



National Standard for Quenching and Self-Tempering Ribbed Bars (GB13014 -2013)

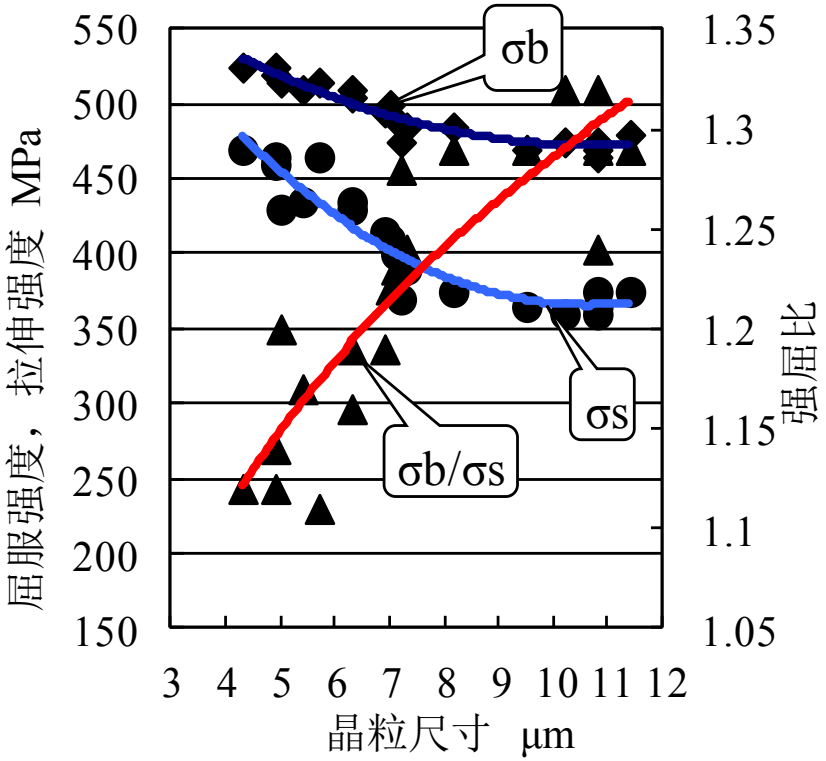
- Grade 3: RRB400/400W
- Grade 4: RRB500

- Low Cost
- China National Standard for Q&T Rebars: GB13014 -2013
- Not accepted by Chinese Building Industry
  - Weldability
  - Anti-Seismic Performance
  - Fatigue Behavior



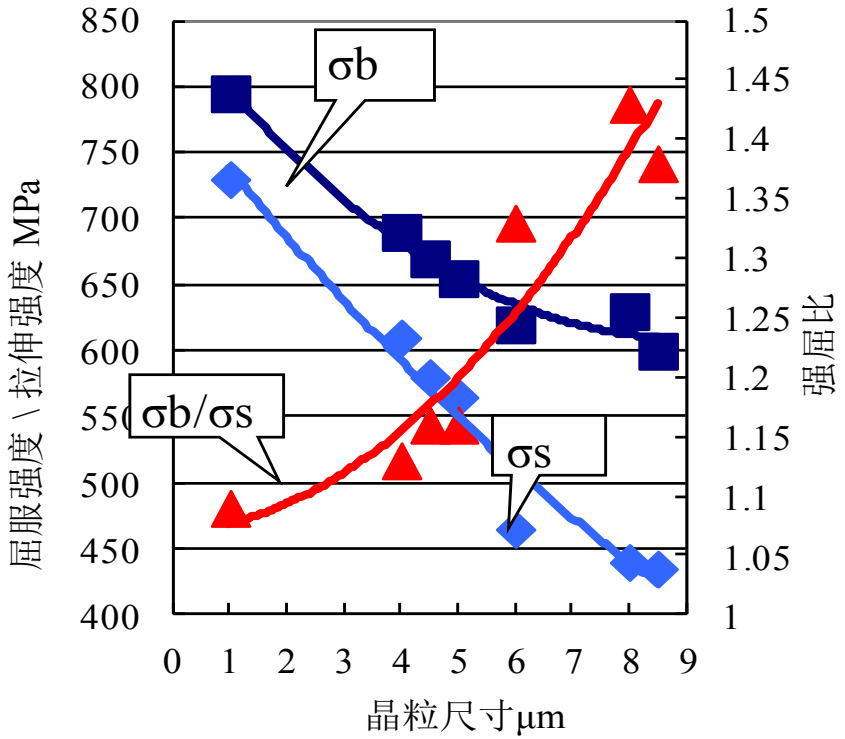
Fine Grain HS Rebars

- **HRBF 400/400E, 500/500E**
- **Low Ratio of TS/YS, problem in Anti-Seismic Performance and weldability**



0.17%C-0.60%Mn-0.29%Si-0.012Ti

Plain C Grade 3 Rebars



0.22%C-1.46%Mn-0.5%Si

20MnSi Grade 4 Rebars

Nb、V、Ti Microalloyed Rebars

- **More than 20 HS rebar products designed with different alloying system during 1970's-1990's in China: Si-V, Si-Ti, Si-Nb, Mn-Si-V, Mn-Si-Nb, Mn-Ti, etc. Three microalloyed grade 3 rebars had been listed in old version National Standard (GB1499.2-1984)**

钢种	C	Si	Mn	V	Nb	Ti
20MnSiV	0.17-0.25	0.20-0.80	1.20-1.60	**0.04-0.12**		
20MnSiNb	0.17-0.25	0.40-0.80	1.20-1.60		**0.02-0.04**	
20MnTi	0.17-0.25	0.17-0.37	1.20-1.60			**0.02-0.05**

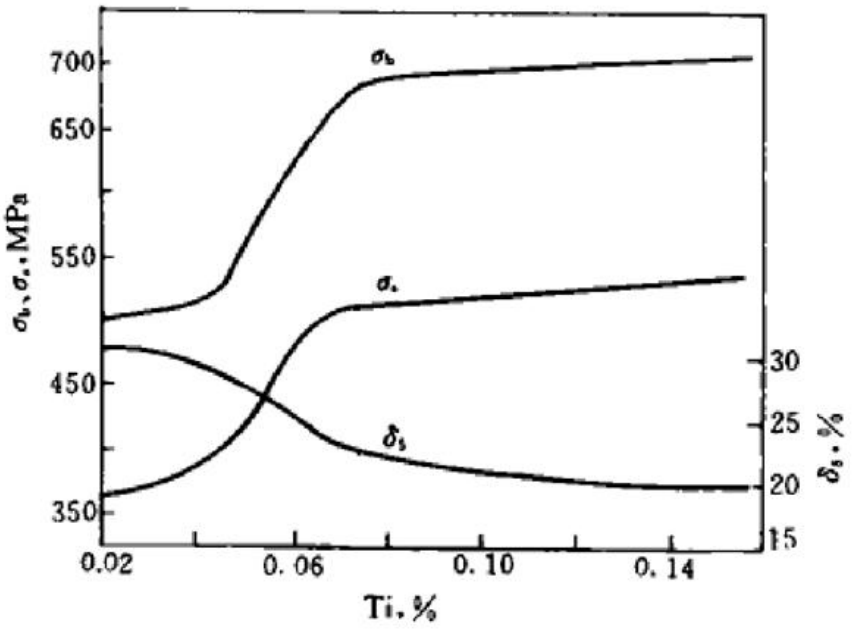
Ti Microalloyed Rebars

Ti-containing HSLA Steels：15MnTi、20MnTi、14MnVTi、10Ti、06Ti

Affinity of Microalloying Elements

	C	N	O	S
Ti	**	***	***	**
Nb	**	*	--	--
V	**	***	--	--

***:very strong; *: medium
**: strong; --: weak



Effect of Ti Content on Strength

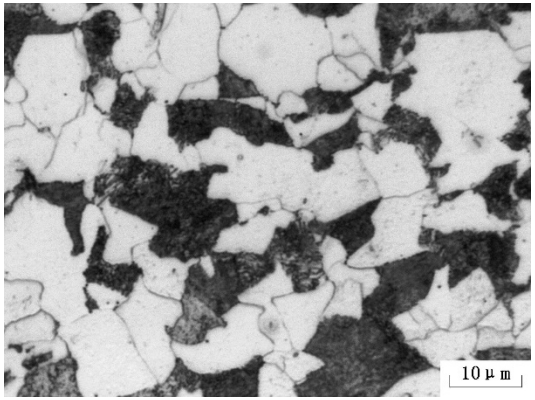
Problem:

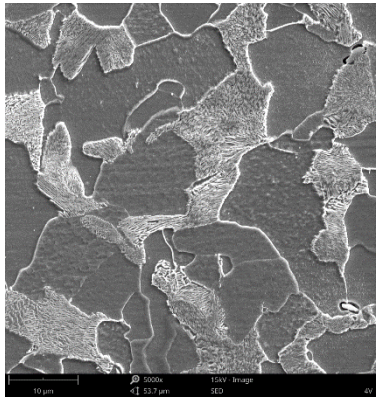
- ✓ **Stability in the Production of Ti microalloying steels**
- ✓ **Con-Casting for billet**

Nb Gr.3 rebar

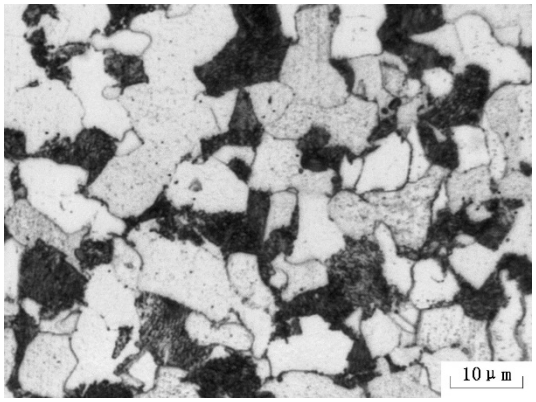
Steel	C	Si	Mn	V	Nb	Rm/MPa	Rel/MPa	A/%	Agt/%
V-steel	0.23	0.44	1.38	0.029	-	620	443	28	14
Nb-steel	0.23	0.54	1.38	-	0.032	624	450	28.5	14.8

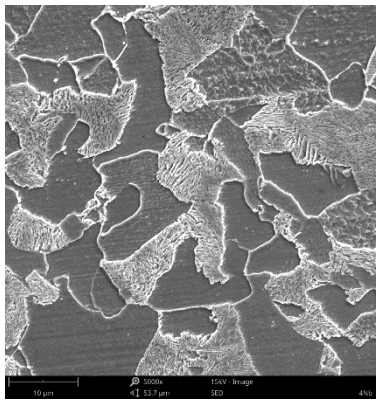
V-steel
7.7μm

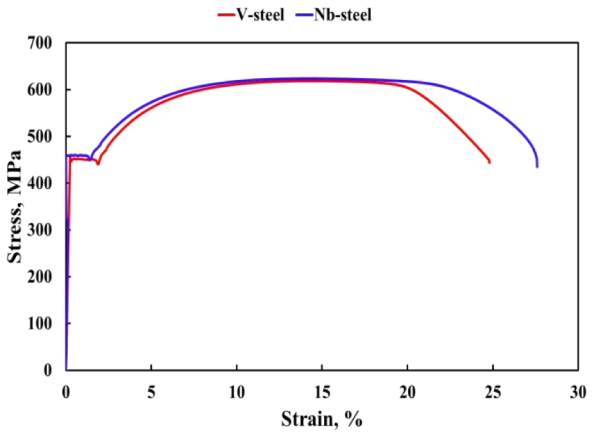




Nb-steel
6.7μm
AC

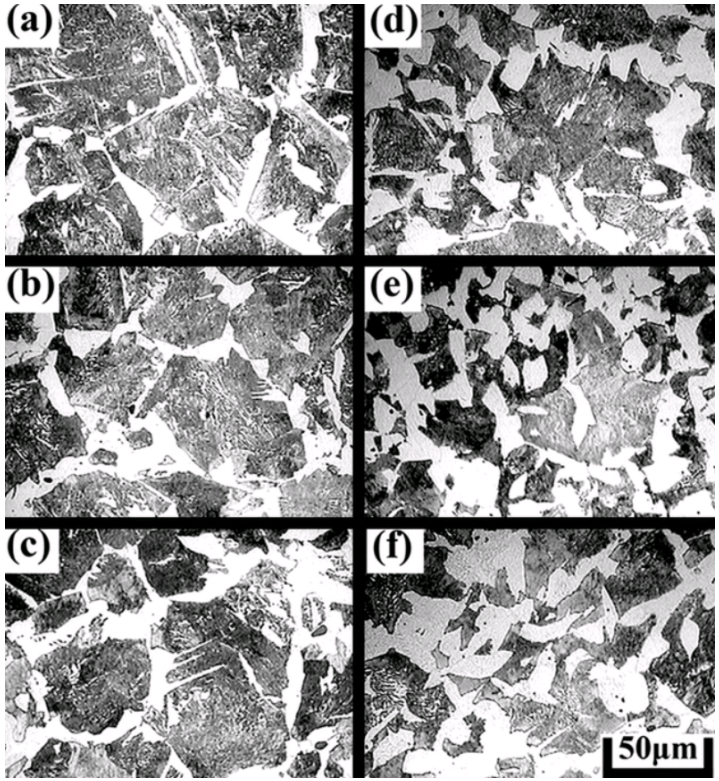




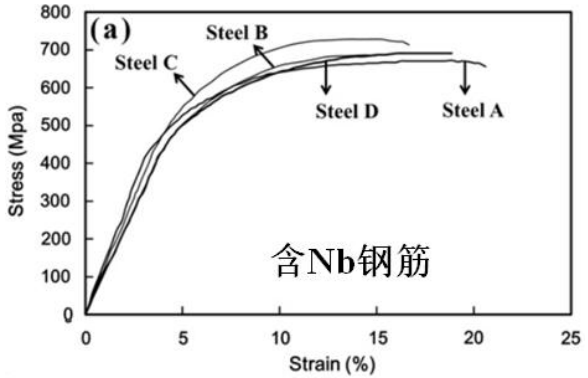


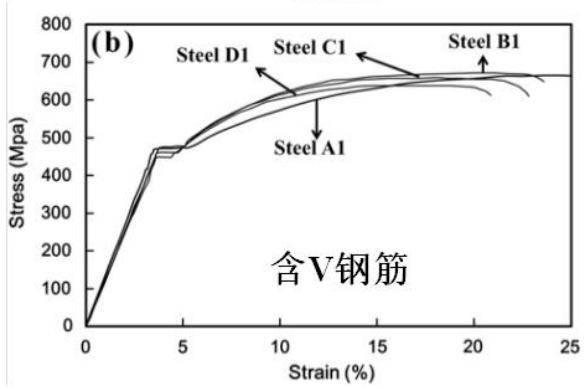
Quality Issue of Nb Grade 3 rebars

	C	Si	Mn	V	Nb	P	S
Nb Steel	0.27	0.13	1.43	/	0.04	0.04	0.03
V Steel	0.29	0.10	1.41	0.02	/	0.04	0.03



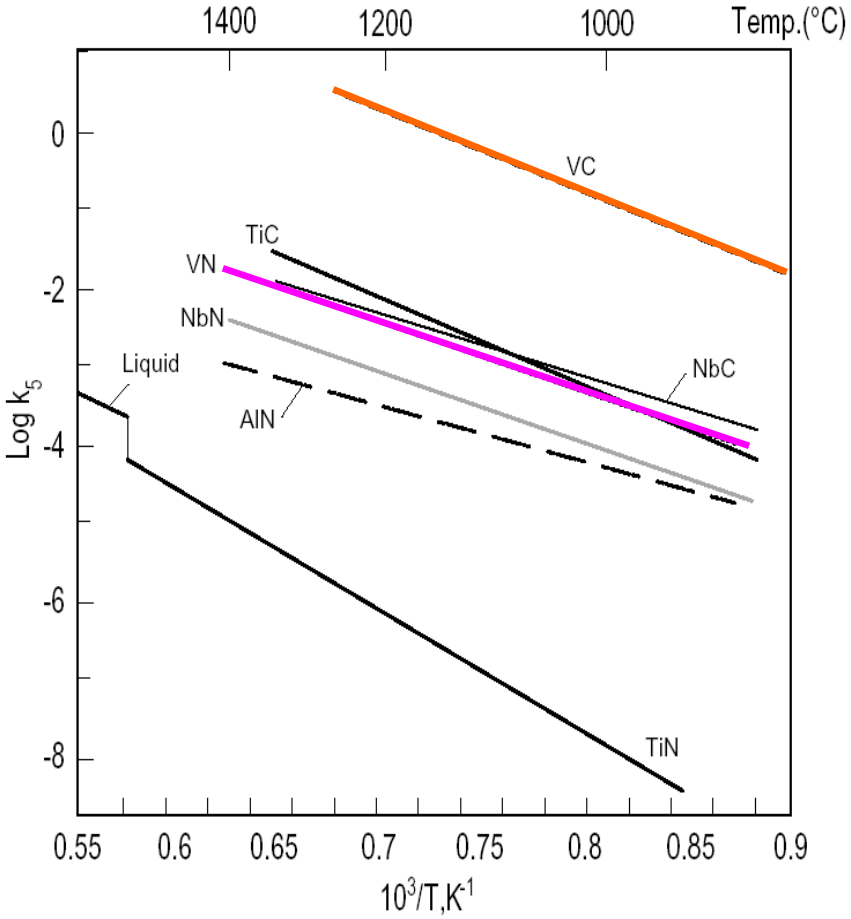
- microstucture：5% Widmannstatten structure in Nb rebars, hardness HV239, higher than the hardness of Ferrite (HV198)
- Nb rebar: no yeild point



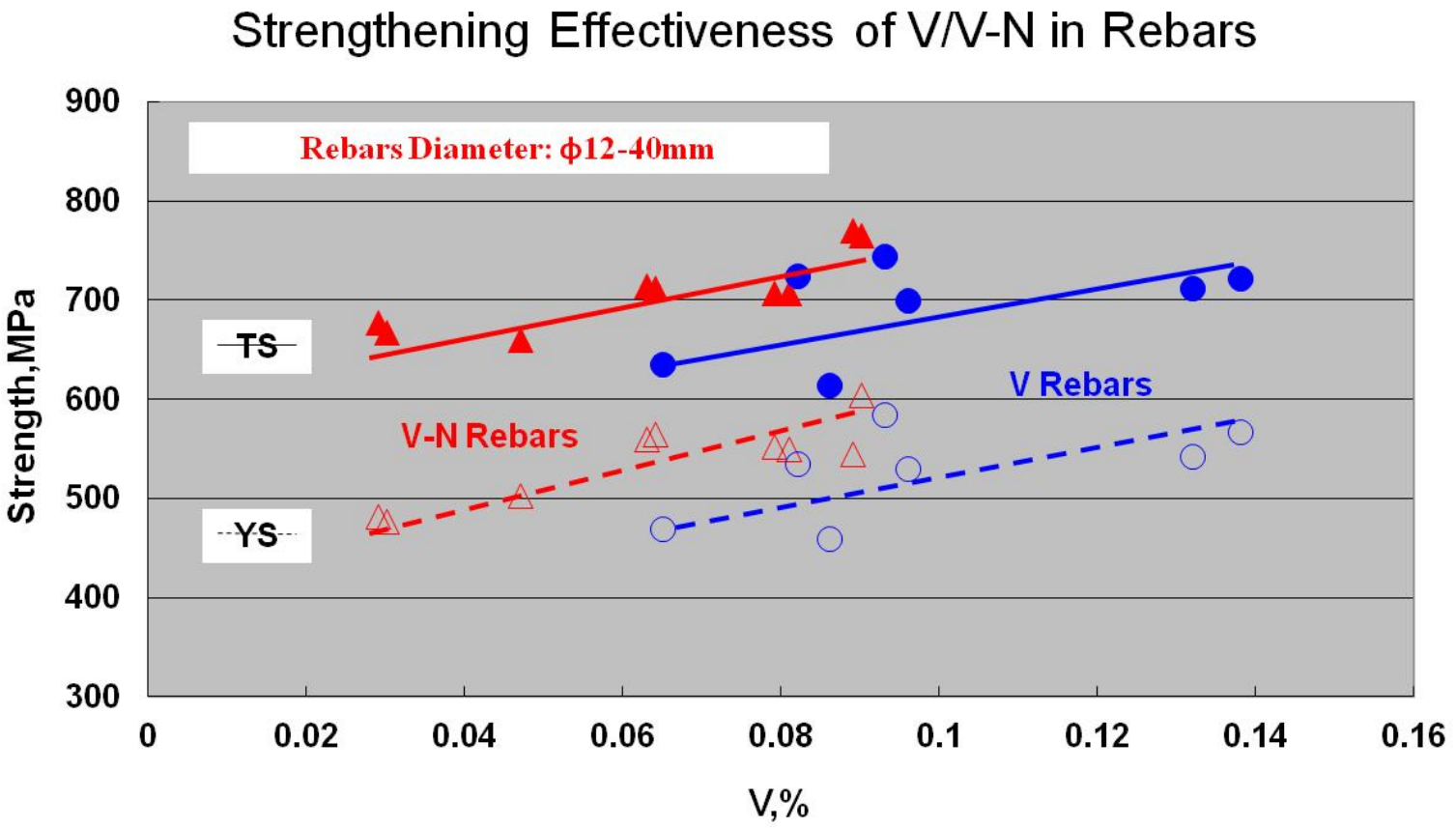


V/V-N Microalloyed Rebars

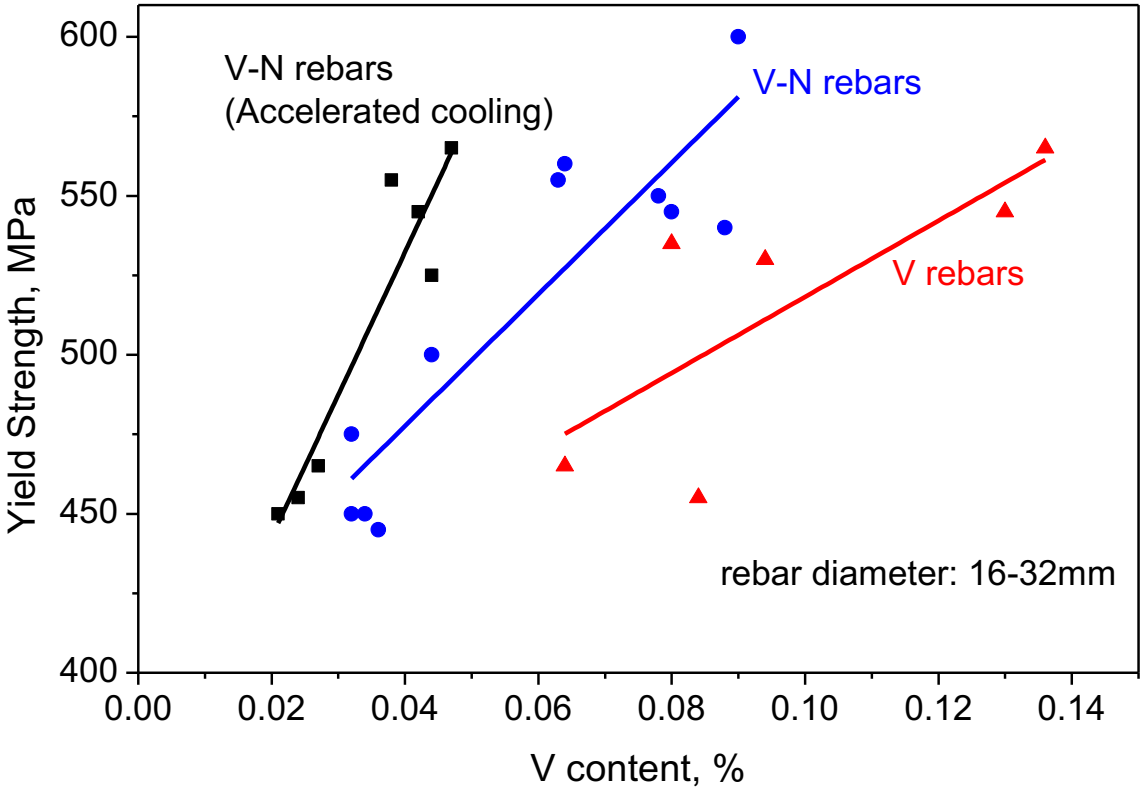
- **Advantage**
  - **High solubility, VCN easy to dissolve by heating**
  - **Good casting performanc easy continuous casting**
  - **Small deformation resistance, easy rolling production**
  - **The strengthening effect o vanadium is predictable**
  - **Rebars production: pass rolling, not easy for low temperature CR**



Effect of V,N in Rebars



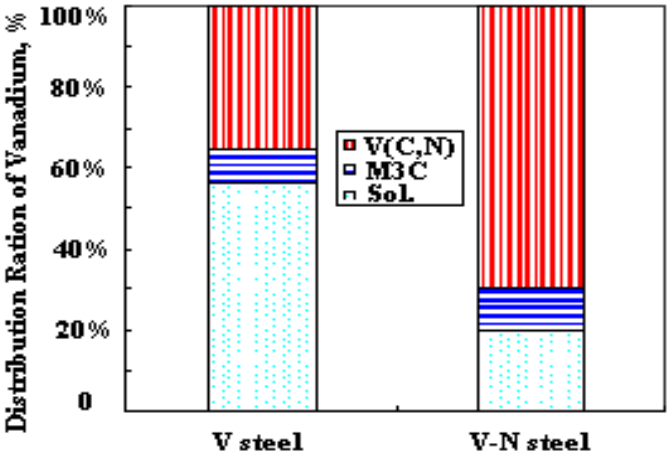
V Strengthening Effect

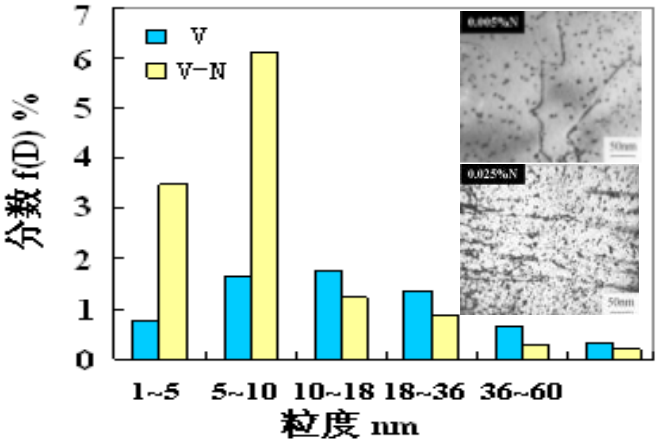


- **Regression equation on V strengthening effect:**
  - **V-Steel：　σs＝σs(20MnSi)＋1056×[V]**
  - **V-N Steel：　σs＝σs(20MnSi)＋1994×[V]**

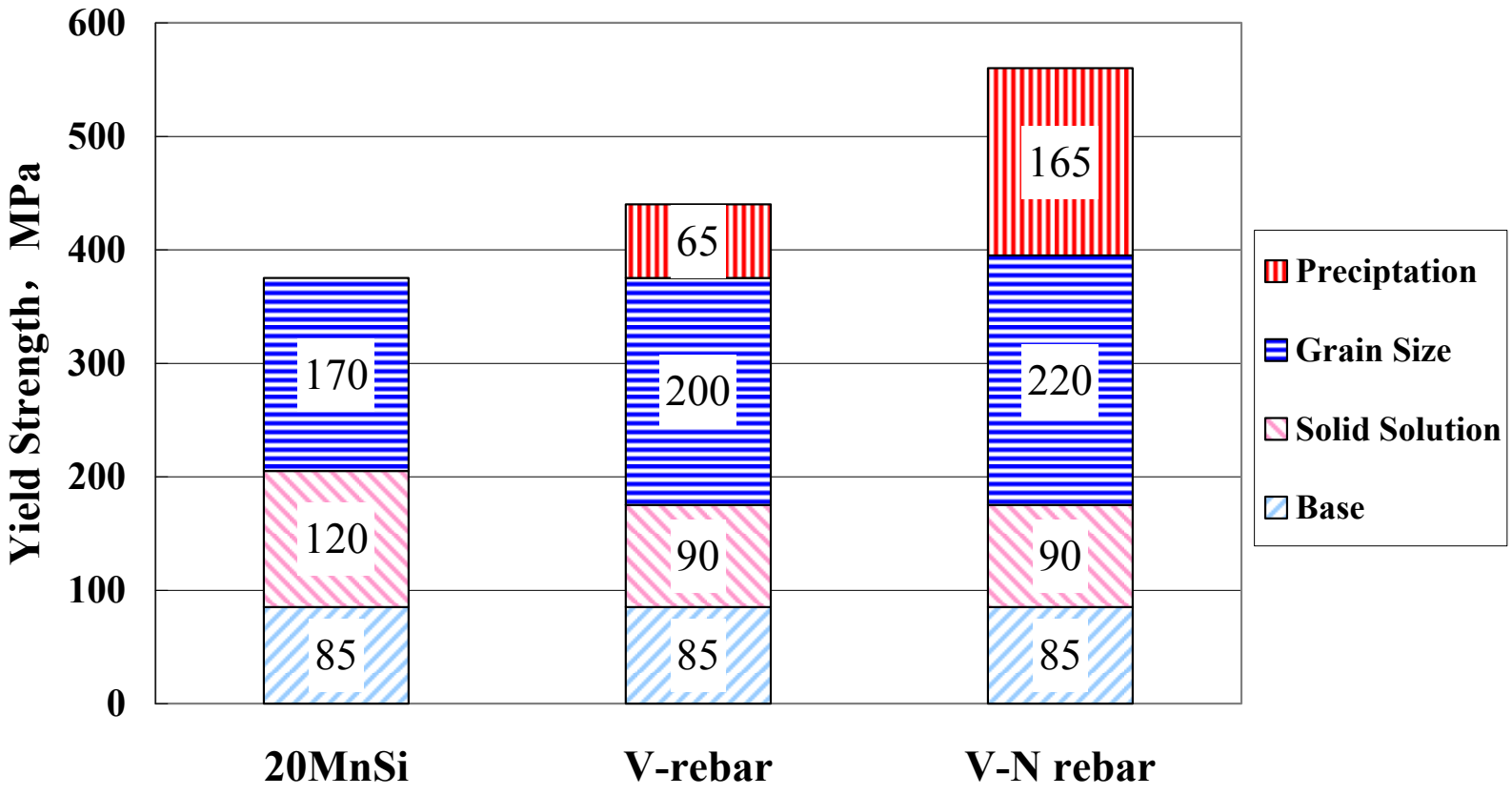
Role of N in V steels

- **Stengthening Effect of N：**
  - **△YS 10MPa / 10ppm[N]**
- **Effect of N on V distribution in Steel**
  - **V Steel：56%V in solution，35%V in precipitation**
  - **V-N Steel：22%V in solution, 70% V in precipitation**
- **Effect of N on VCN particles size**
  - **Significantly increase the volume of fine VCN particles with the size less than 10nm**

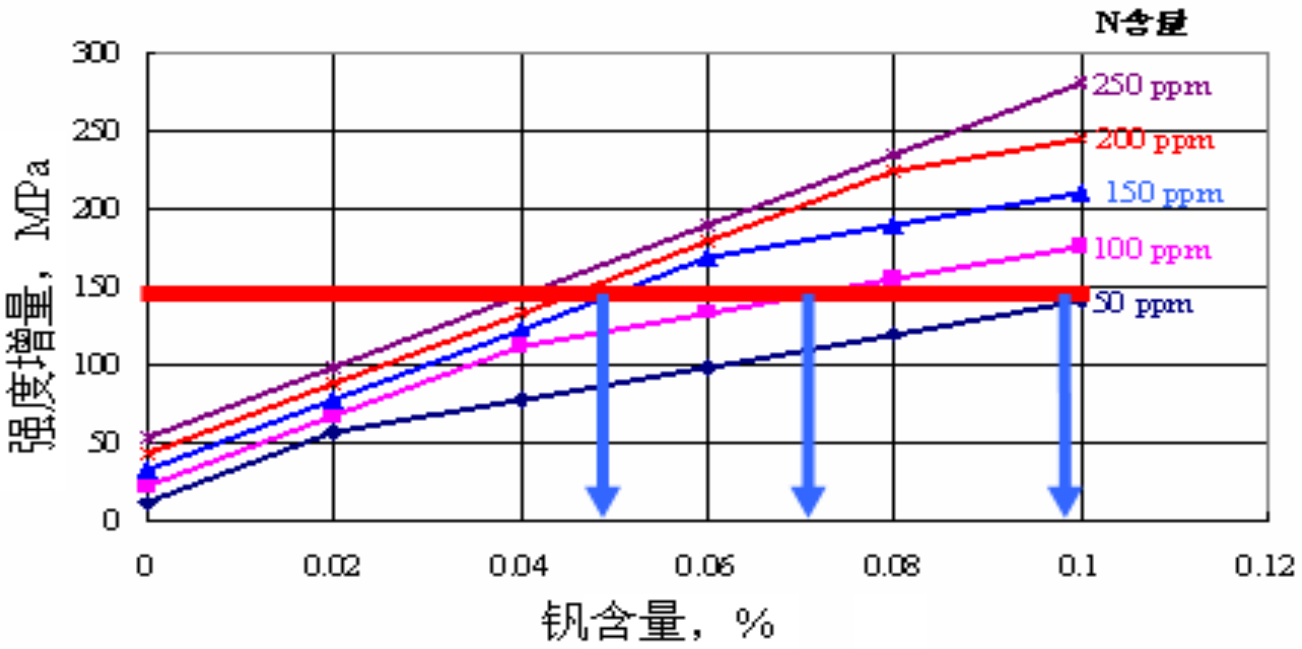




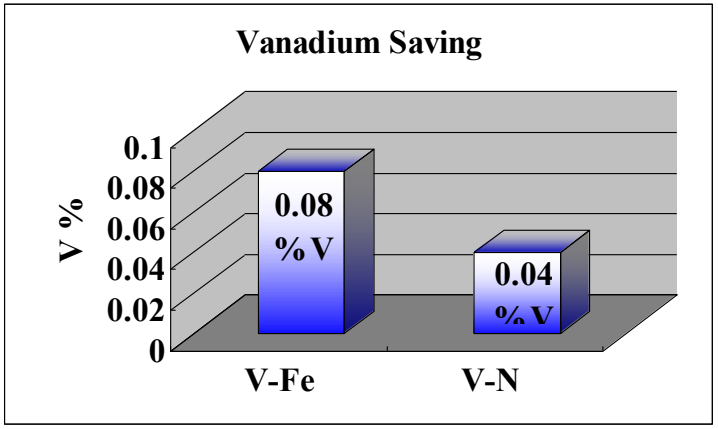
Strengthening Mechanism of V-N Rebars



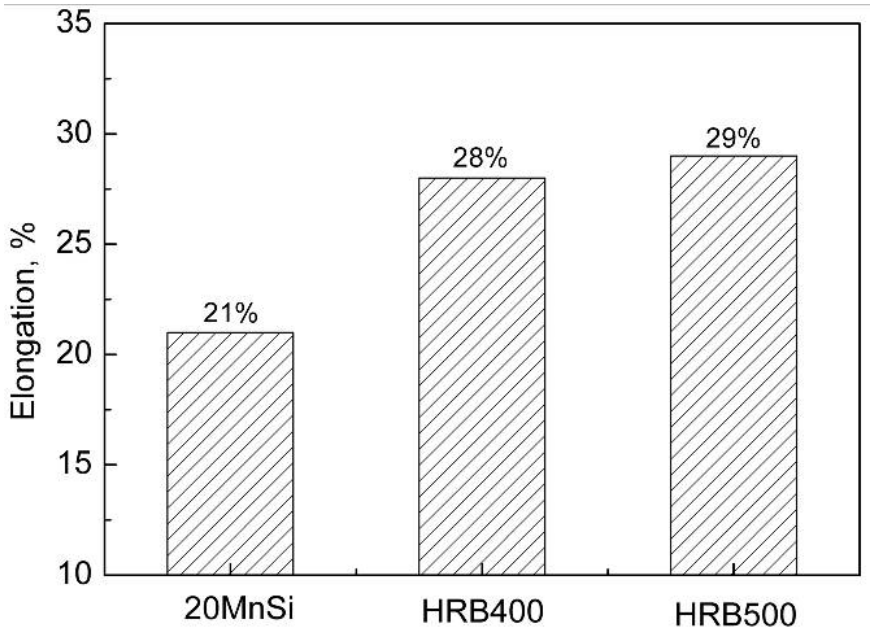
V-N Microalloying－cost-effective、predictable

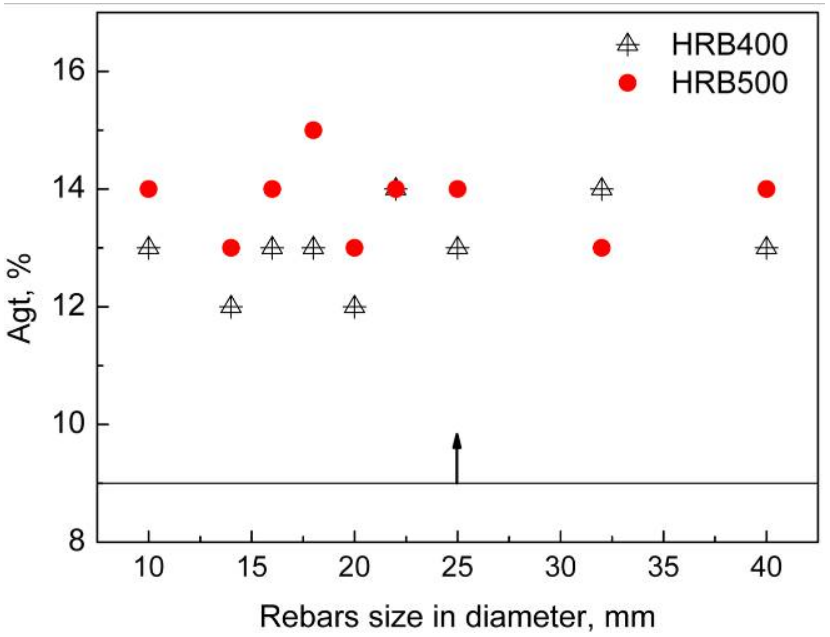


△YS / 0.01%V	
Low N V Steels	5-10 MPa
High N V Steels	25 MPa

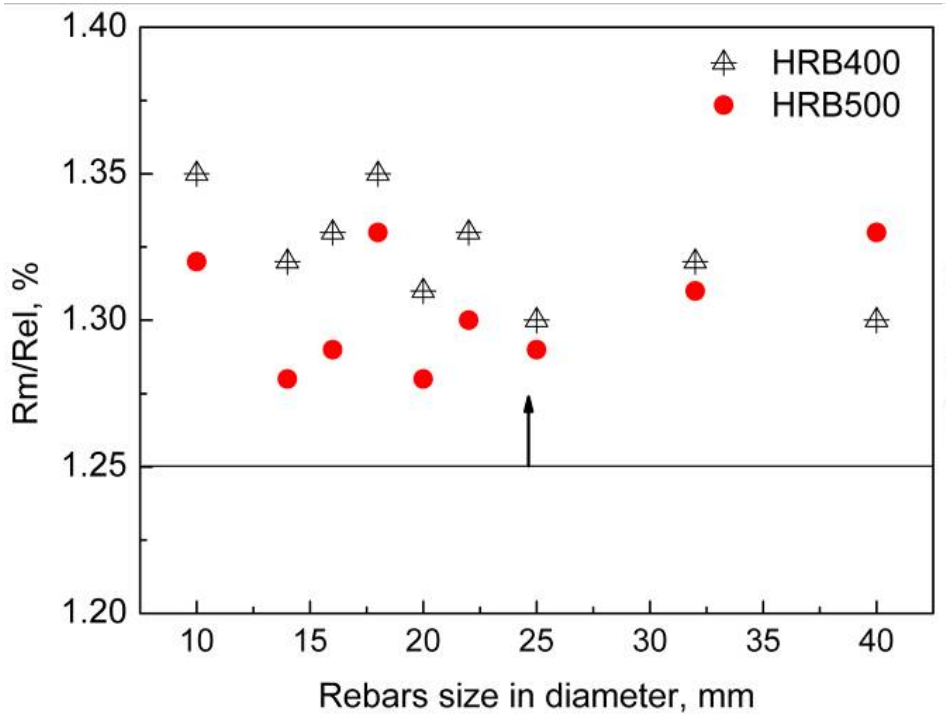


Seismic behavior of V-N Rebars

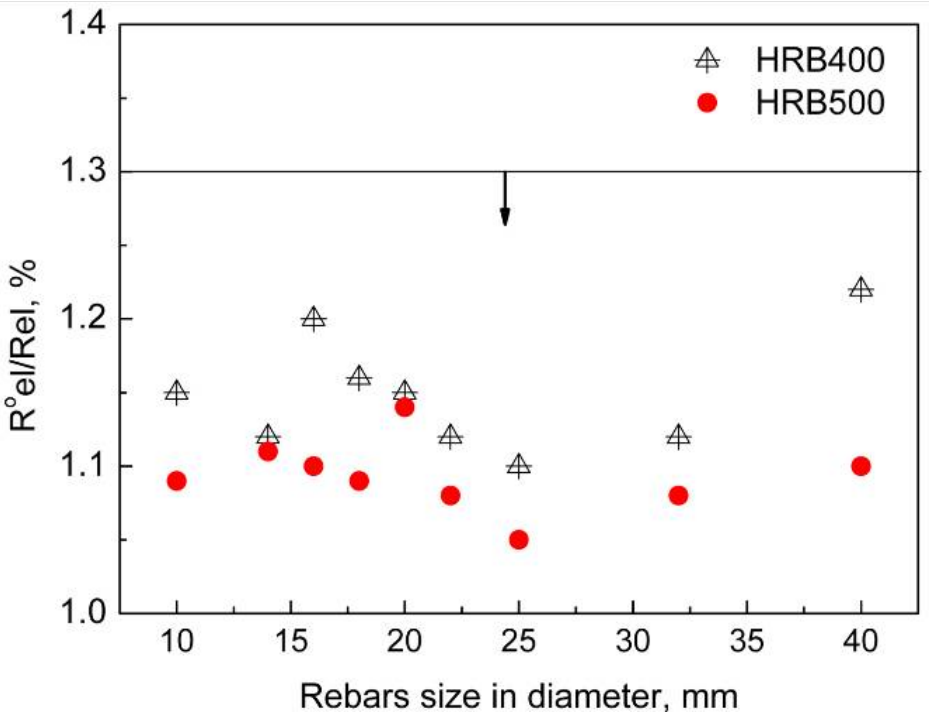




Seismic behavior of V-N Rebars

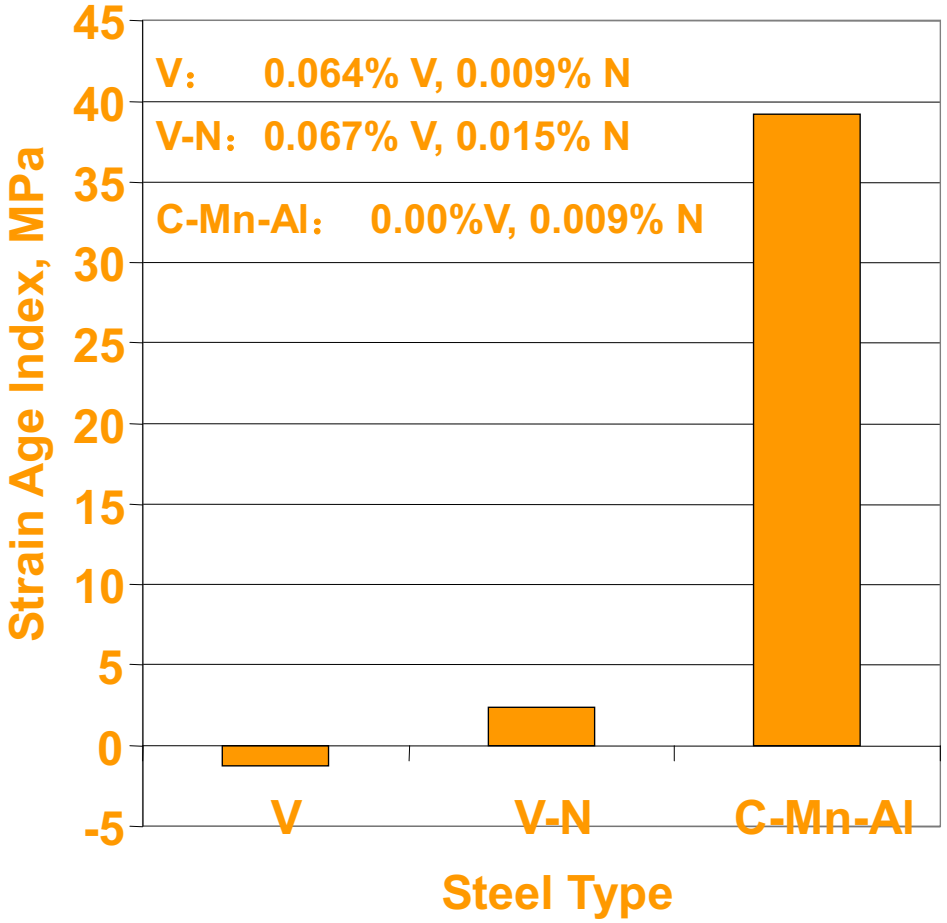


R_m / R_{eL}



R_{el} / R_{eL}

Strain ageing of V-N Rebars



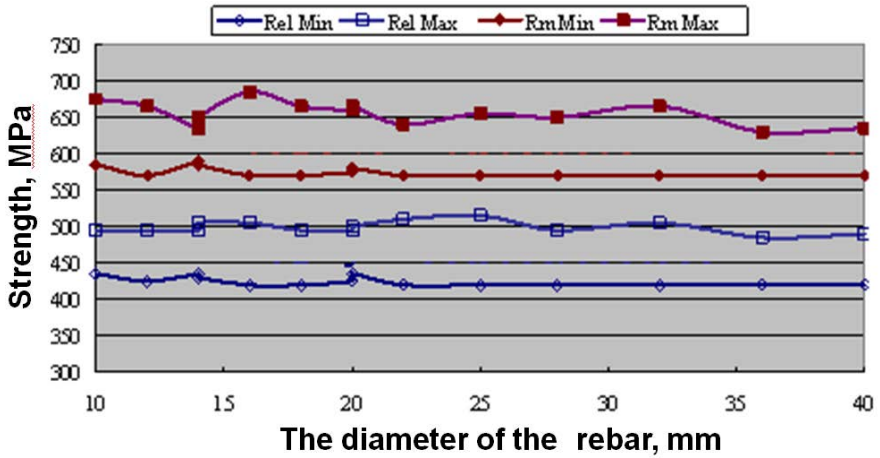
- C-Mn steek：Strain ageing
- V/V-N steel：Strain ageing eliminated by V addition

Technical economy of V-N Microalloyed HS Rebars

Grade	Alloy	C	Si	Mn	P, S	V	N	Gauge, mm
HRB400	V-N	0.20-0.24	0.45-0.60	1.25-1.45	<0.035	0.025-0.03	0.008-0.012	Φ6-Φ16
						0.03-0.04		Φ16-Φ40
	V-Fe	0.20-0.24	0.45-0.60	1.25-1.45	<0.035	0.05-0.07	0.003-0.006	Φ10-Φ16
						0.07-0.09		Φ16-Φ40
HRB500	V-N	0.20-0.24	0.45-0.60	1.40-1.55	<0.035	0.05~0.07	0.010-0.015	Φ16-Φ32
						0.07-0.09	0.012-0.018	Φ32-Φ40
	V-Fe	0.20-0.24	0.45-0.60	1.40-1.55	<0.035	0.07~0.12	0.003-0.006	Φ16-Φ32

Cost-Effective、High Performance

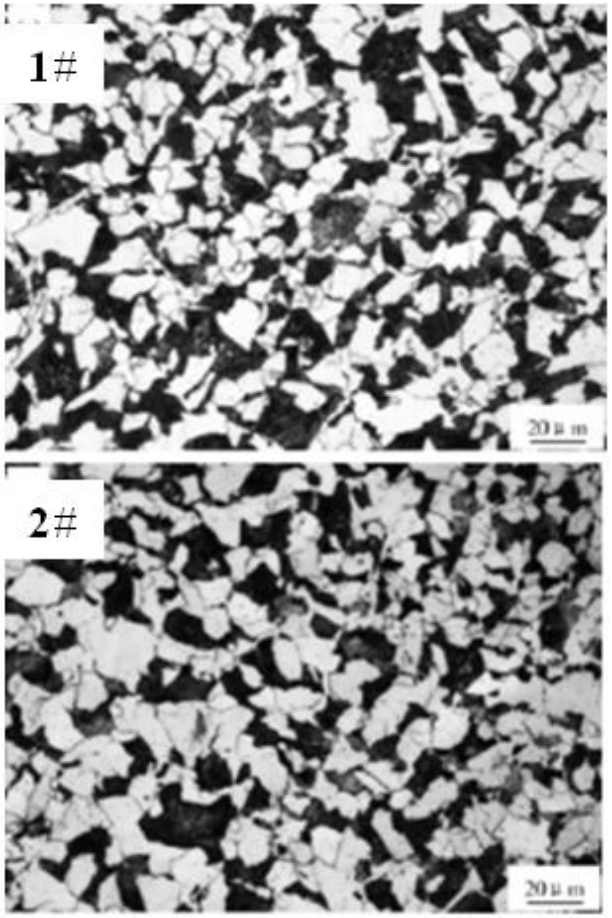
- — High Strength with Good El
- — Good Anti-Seismic Performance
  - ➢ Δσs<65MPa
  - ➢ TS/YS>1.40，Agt>14%
- — Good Weldability



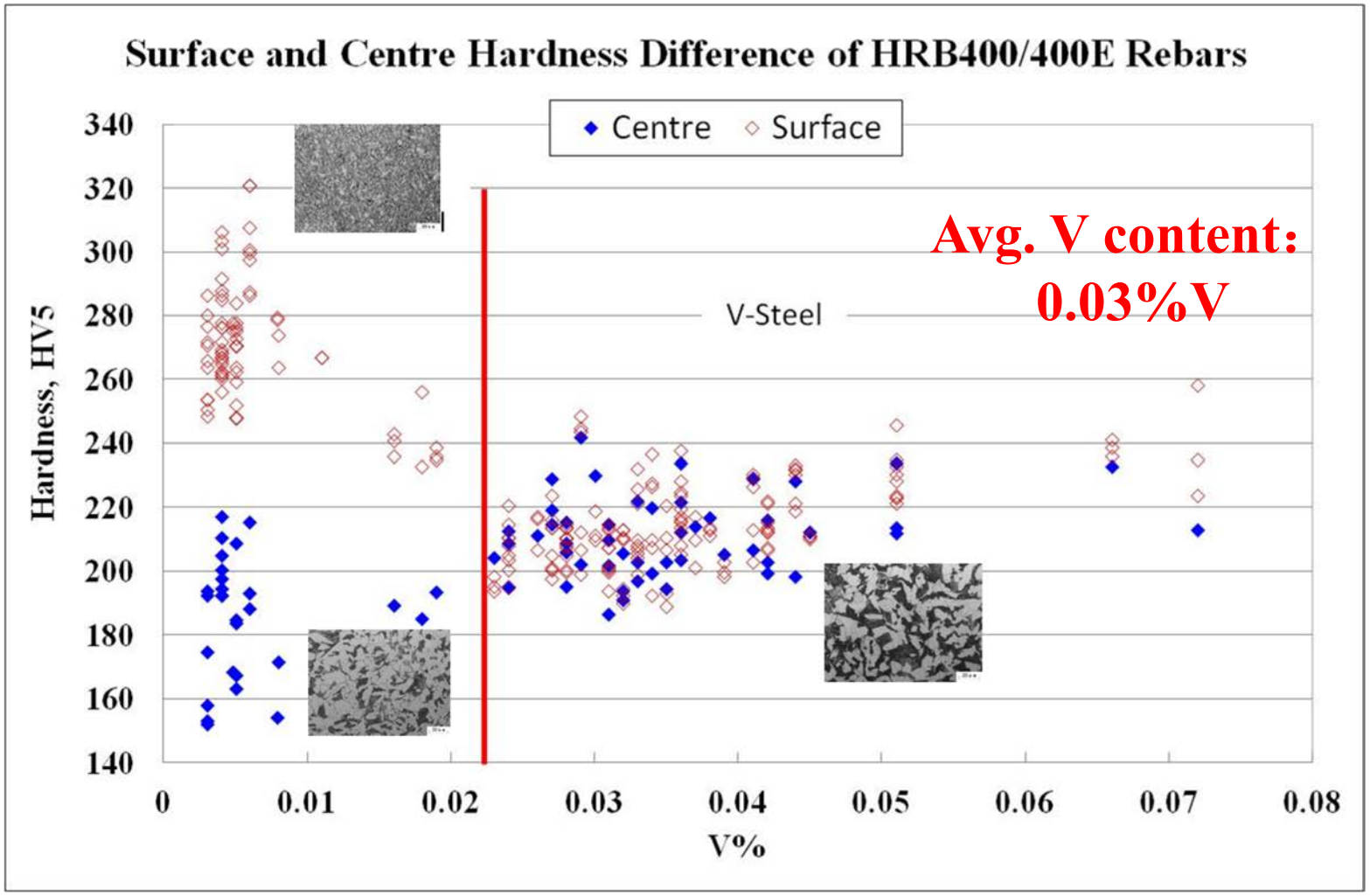
V-N microalloyed Gr.5 Rebars

编号	规格/mm	化学成分							
		C	Si	Mn	S	P	V	Cr	N
1#	18	0.23	0.44	1.46	0.017	0.024	0.104	≥0.25	0.0207
2#	22	0.25	0.47	1.48	0.014	0.020	0.108	≥0.25	0.0211

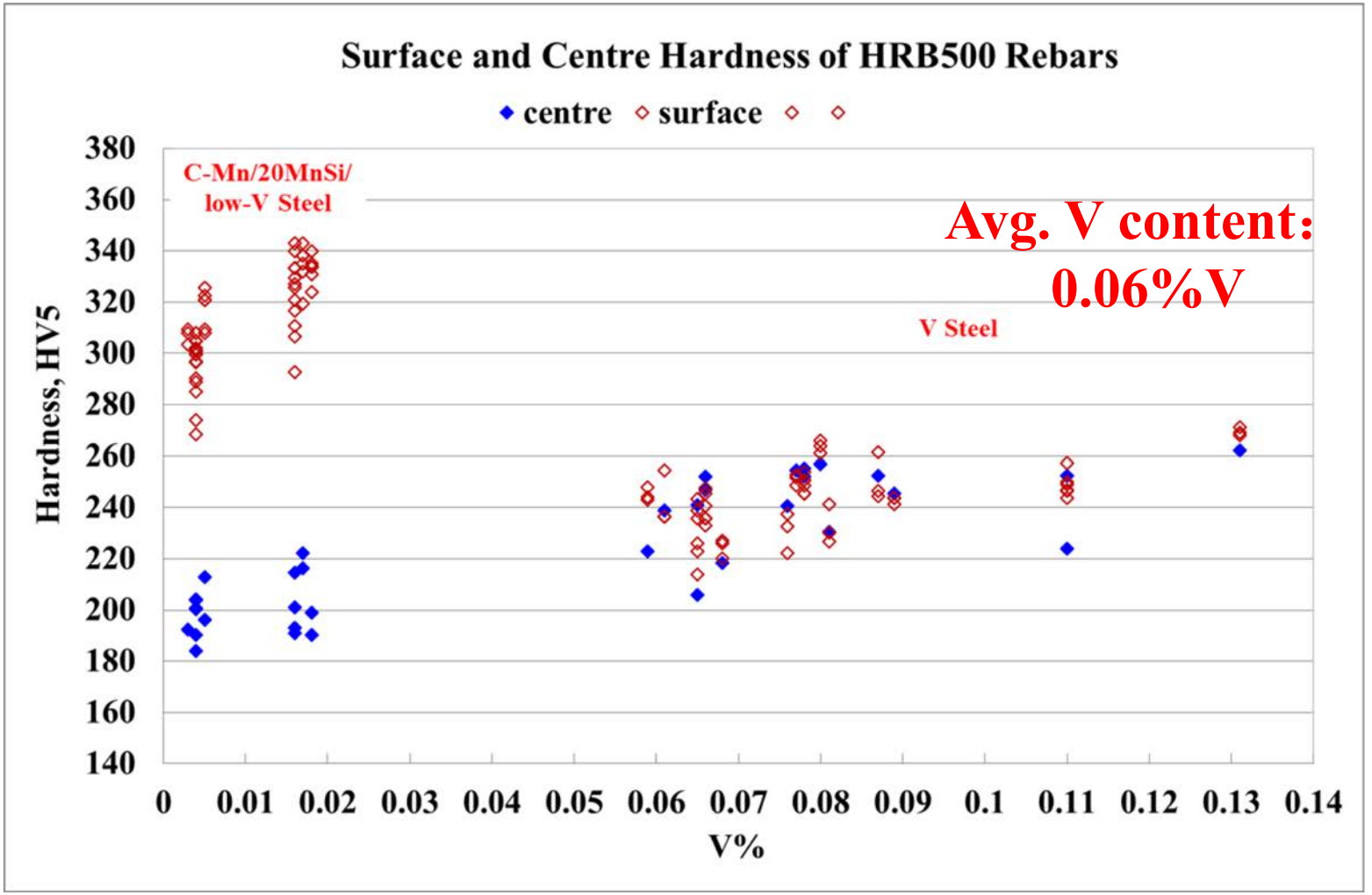
Rebar Size	R_{eL} /MPa	R_m /MPa	$R°_m$ /$R°_{eL}$	$R°_{eL}$ /R_{eL}	A_{gt} /%	A /%
18mm	627	792	1.26	1.05	12.0	21.5
22mm	636	802	1.26	1.06	11.5	20.5



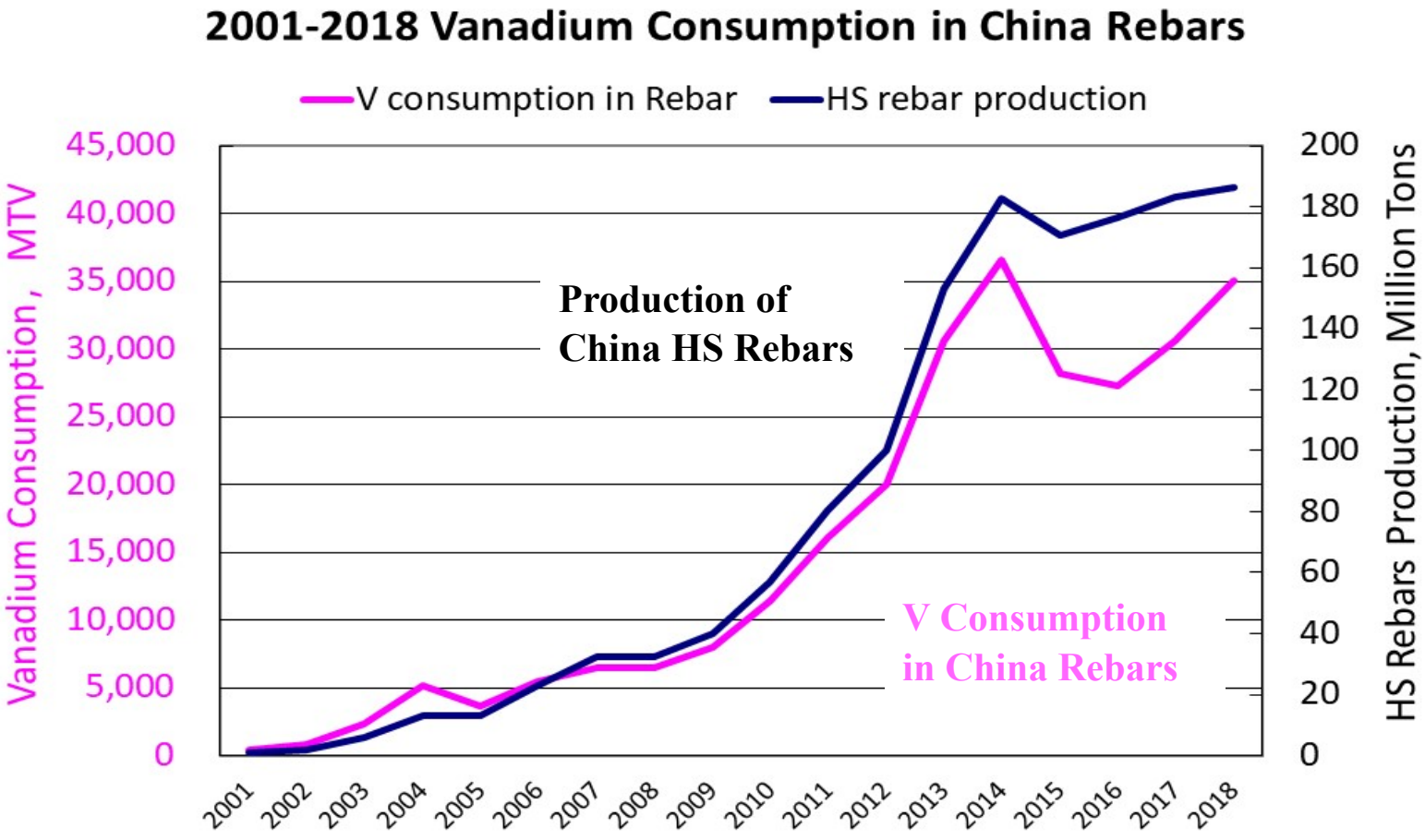
HRB400 Rebar—V Content



HRB500 Rebar—V Content



V Consumption in China HS Rebars



Potential V demand in China Rebars

Rebar Grade	2017 Rebar Production (*10,000 MT)	钢筋中V 消耗 (V Demand in Rebar)，MT V			
		含钒III级钢筋比例 (% of V-bearing Gr.3 Rebara)			
		30%	60%	70%	80%
Gr.1	1,412				
Gr.2	982				
Gr.3	14,508	13,057	27,014	30,467	34,819
Gr.4	3,754	18,019	18,019	18,019	18,019
Gr.5	72	720	720	720	720
	20,727	31,796	45,303	48,758	53,108

Assumption:

(1) 0.03%V average V content in Gr. 3 Rebar;

(2) 80% Gr.4 rebar to use V process, and 0.06%V average V content in Gr.4 rebars

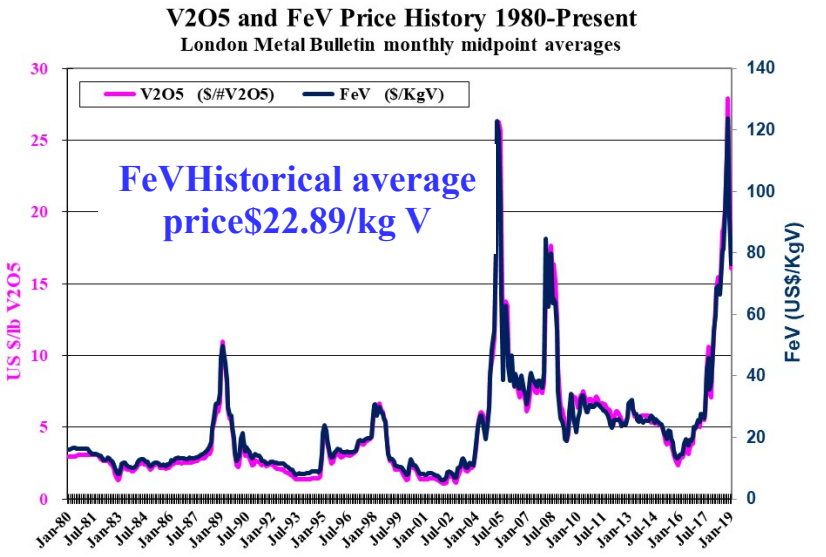
(3) 0.10%V Average V content in Gr.5 Rebars

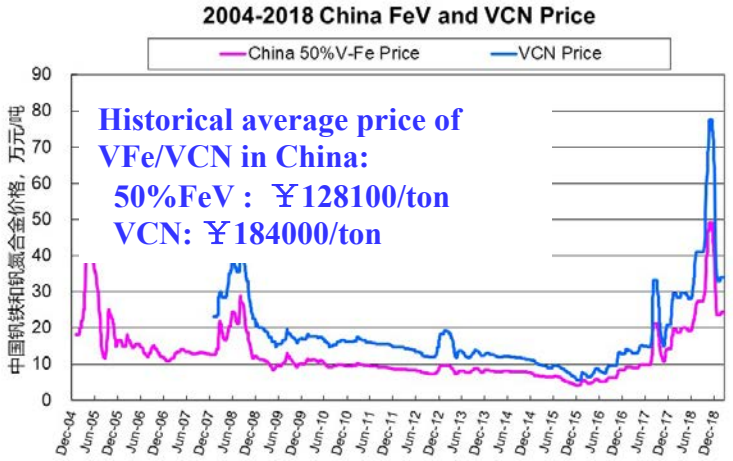
Economic analysis of vanadium Rebars

Economic analysis of hot rolled HS Rebars

Economic benefit of rebar upgrade			
rebar upgrade	Steel consumption saving	Construction cost reduction	The cost of rebar increases by 30%
II→III	**14%**	**￥560（4000*14%）**	**￥187/ton**
III→IV	**16%**	**640元（4000*16%）**	**￥400/ton**

V rebar cost			
	V%	**V price**	**Alloy cost ￥/ton**
HRB400	**0.03%**	**VCN=￥350000**	**136**
		VCN=￥800000	**312**
HRB500	**0.06%**	**VCN=￥350000**	**272**
		VCN=￥800000	**624**





New Standard GB1499.2-2018 & Microstructural Inspection

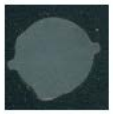
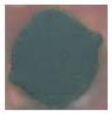
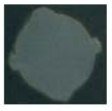
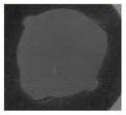
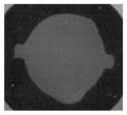
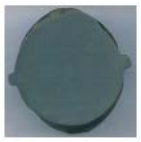
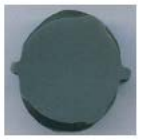
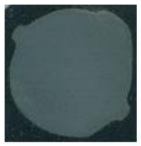
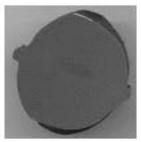
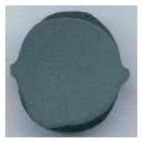
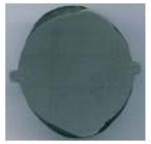
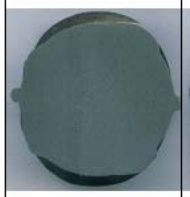
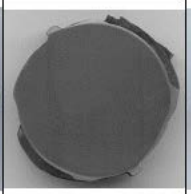
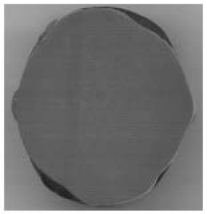
China New Rebar Standard

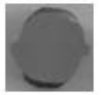
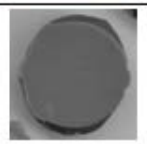
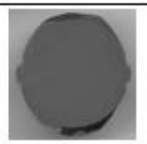
- **Object：Distinguish (RRB) and (HRB)**
  - **168 Samples from producer, market and construction site**
  - **Diameter: Φ8～Φ50;**
  - **Four categories:(1)V Steel、(2)Low-V Steel、(3)20MnSi (4)C/C-Mn**

HRB400/400E	C	Si	Mn	V
V Steel	≤0.25	0.25~0.60	1.2~1.5	0.023~0.072
Low V Steel	≤0.25	0.25~0.60	1.2~1.5	0.01~0.02
20MnSi	≤0.25	0.20~0.55	1.2~1.4	≤0.01
C/C-Mn	≤0.25	0.10~0.55	0.4~1.0	≤0.01

HRB500	C	Si	Mn	V
V Steel	≤0.25	0.30~0.60	1.0~1.5	0.06~0.11
Low V Steel	≤0.25	0.20~0.30	1.0~1.5	0.015~0.020
20MnSi	≤0.25	0.20~0.30	1.0~1.5	≤0.01

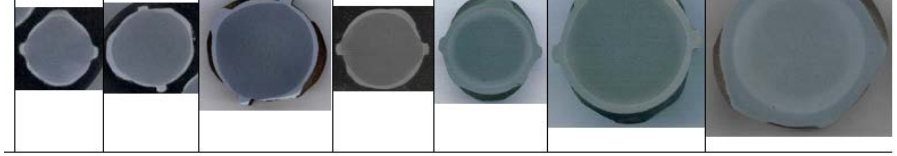
Macrograph—V Steel

Size	HRB400			HRB400E		
Φ12						
Φ18						
Φ20						
Φ25						
Φ32						
Φ36						

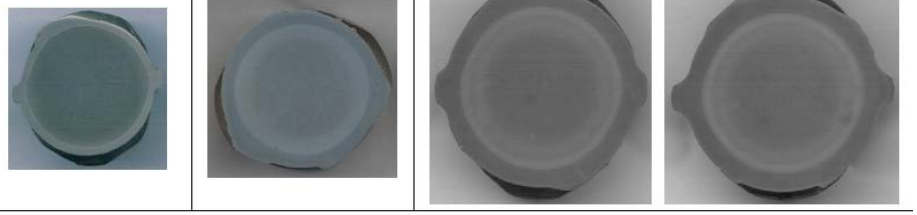
HRB500/500E		
Dia.	CISRI	CCSTC
Φ12		
Φ16		
Φ18		
Φ20		
Φ25		
Φ32		

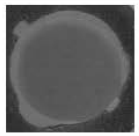
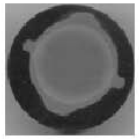
Macrograph— Low-V/20MnSi/C-Mn

Low-V Steel

HRB400			HRB400E		HRB500	
Φ12	Φ16	Φ25	Φ18	Φ20	Φ32	Φ40
						

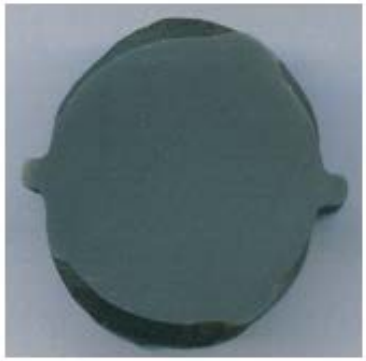
20MnSi HRB500

HRB500		
Φ32	Φ40	Φ50
		

Size	HRB400			HRB400E	
Φ12					
Φ14					
Φ16					
Φ20					
Φ22					
Φ25					
Φ28					
Φ32					

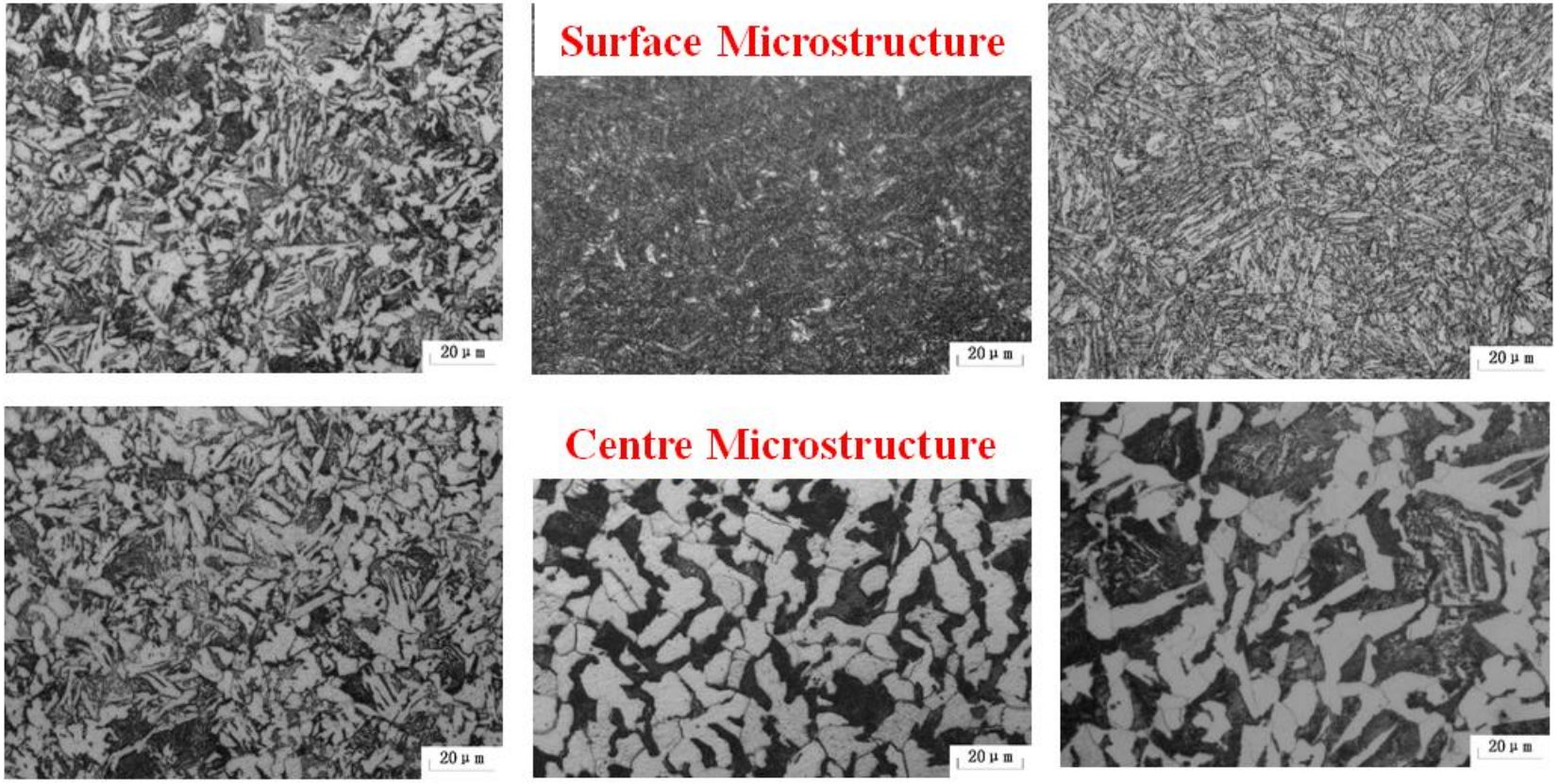
20MnSi/C-Mn HRB400

Typical Macrograph

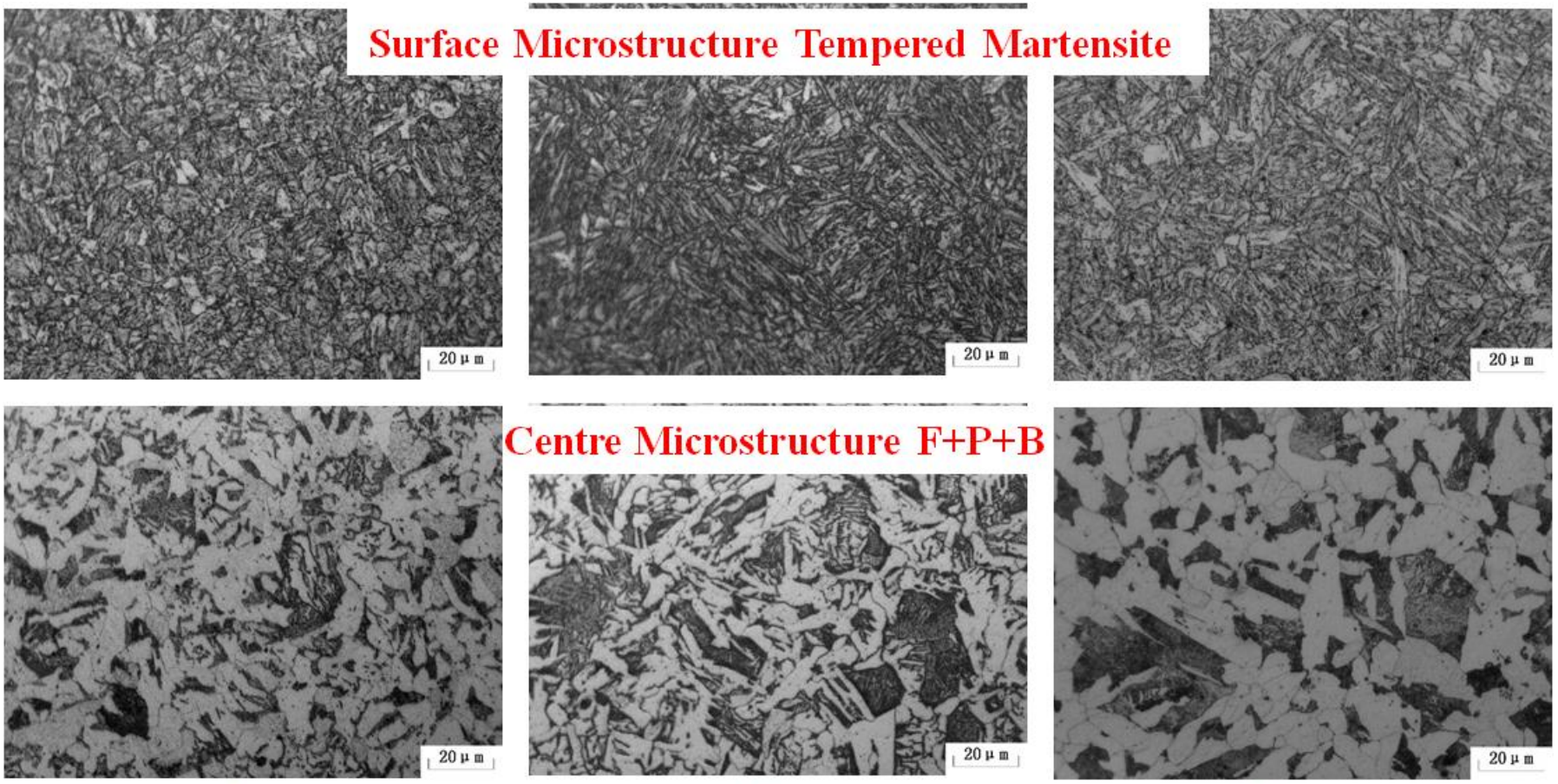
V Steel	Low-V Steel	20MnSi	C/C-Mn
			

- ✓ **Only V rebars meets the microstructure requirements of hot rolled rebars**
- ✓ **other three rebars does not meet the microstructure requirements of hot rolled rebars**

Microstructures of 20MnSi Gr.3 Rebars

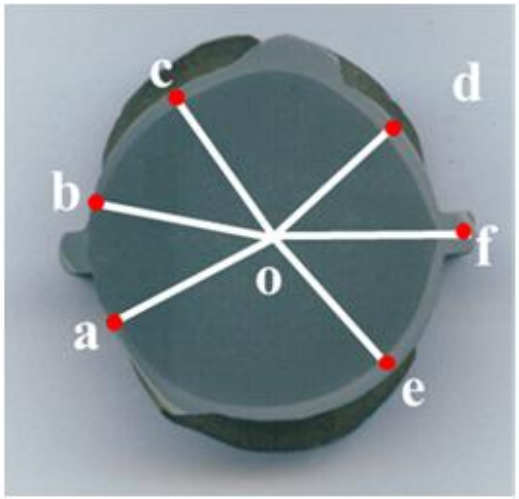


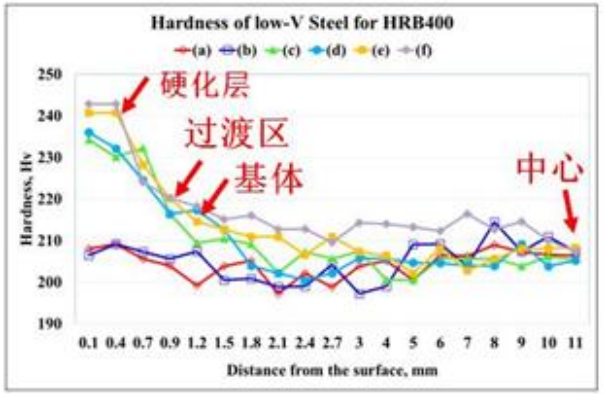
Microstructures of C/C-Mn Gr.3 Rebars

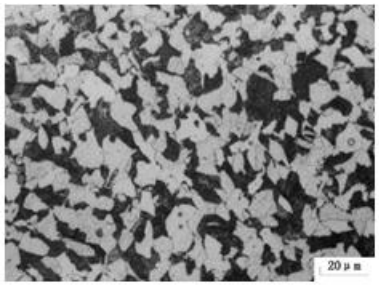


Microstructures of Low-V Gr.3 Rebars

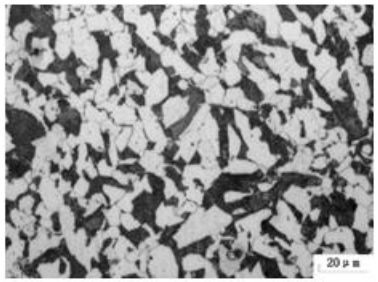
0.23C-0.34Si-1.51Mn-0.016V (Φ25)



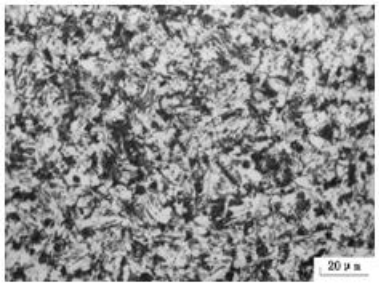




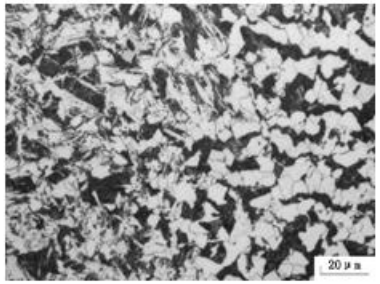
(a) F+P



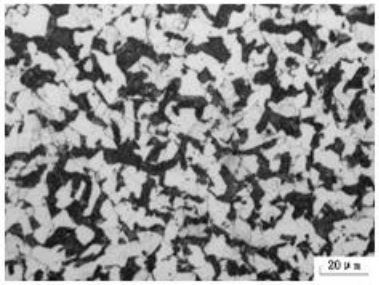
(b) F+P



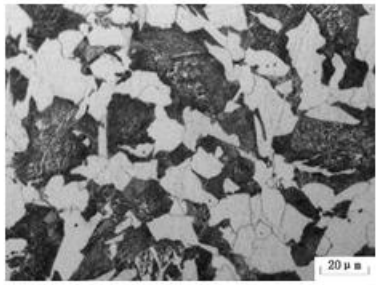
硬化层(回火M/B)



过渡区:回火M/B+F+P



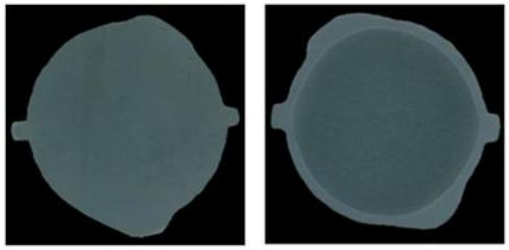
基体（细F+P）



中心(F+P)

China New Rebar Standard

- **Feb.06, 2018：SAC Announcement No.2018-02 published New Standard GB/T 1499.2－2018 “Steel for Reinforcement Concrete – Part 2: Hot Rolled Ribbed Bars” , it will take effect in Nov.1, 2018.**
- **Main changes in the New Standard：**
  1. Steelmaking Process：BOF or EAF
  2. Remove Low Strength HRB335 (Grade 2 rebar)；
  3. Add HRB600 rebar: 3 different grade HS rebars, HRB400、HRB500、HRB600；
  4. Microstructure Inspection: F+P microstructure and the term must be listed in producer’s COA. it will be very effectively to prevent Q&T process to be used in the production of hot-rolled HS rebars.
- **Good Opportunity to Promote V applications following up the new standard**



(a) (b)

Fig.B.1 The typical macrograph

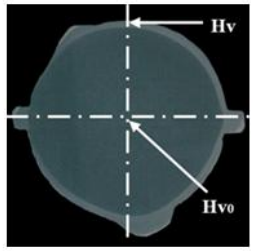


Fig.B.2 Hardness Testing

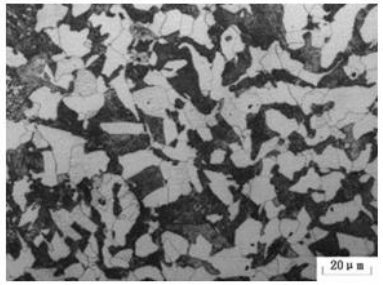
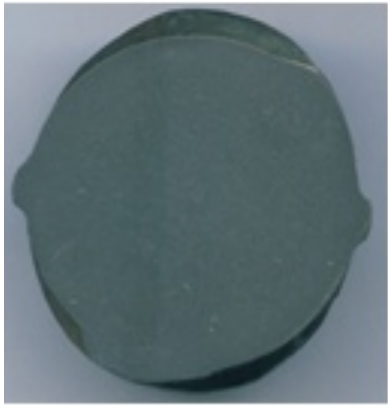
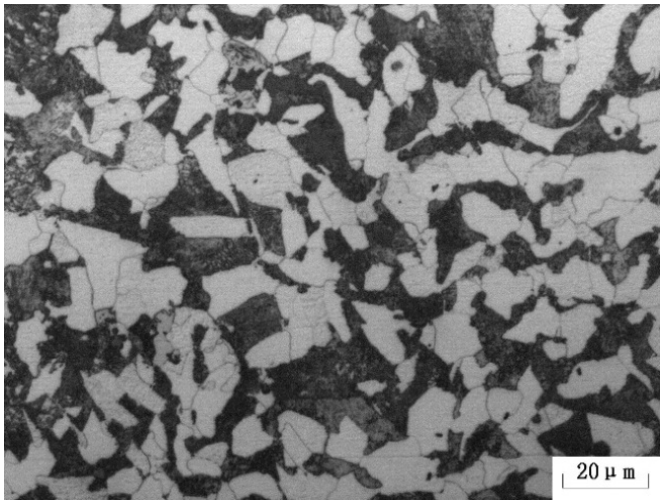


Fig.B.3 F+P, 500×

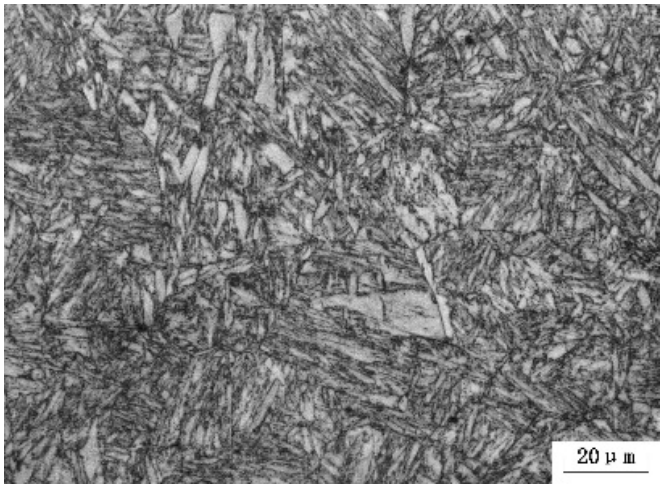
CISRI
中国钢研

Typical Microstructure



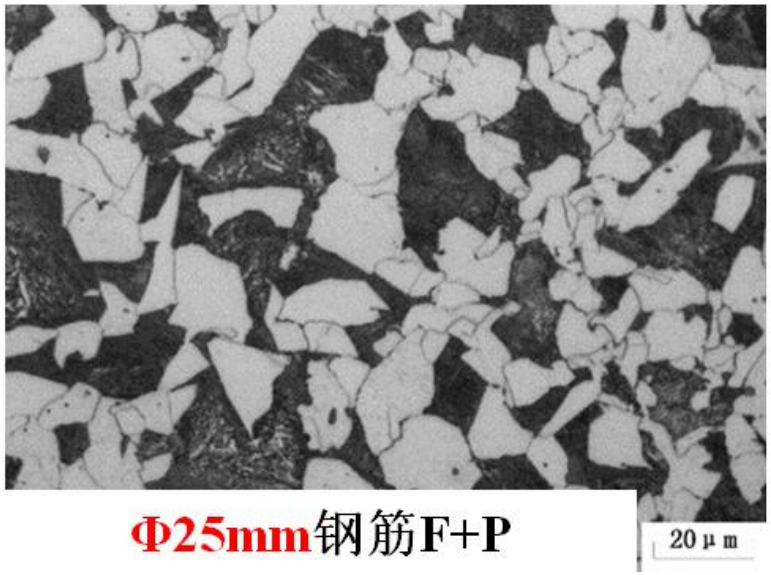


F+P

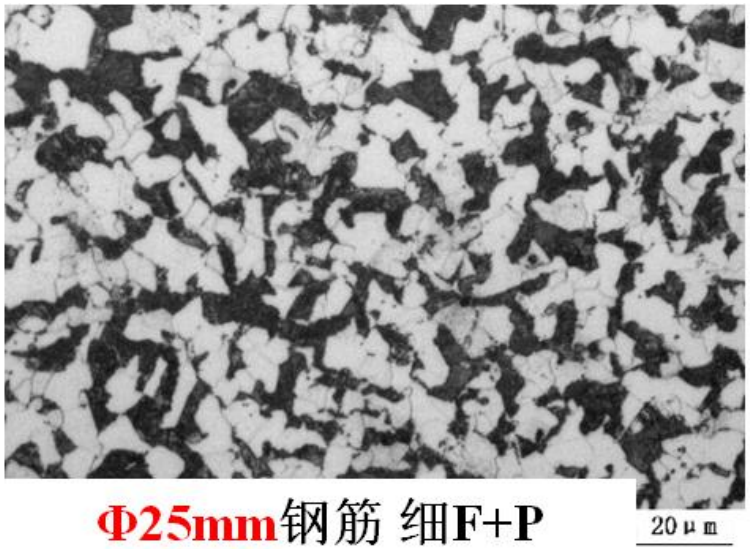


Temper
M

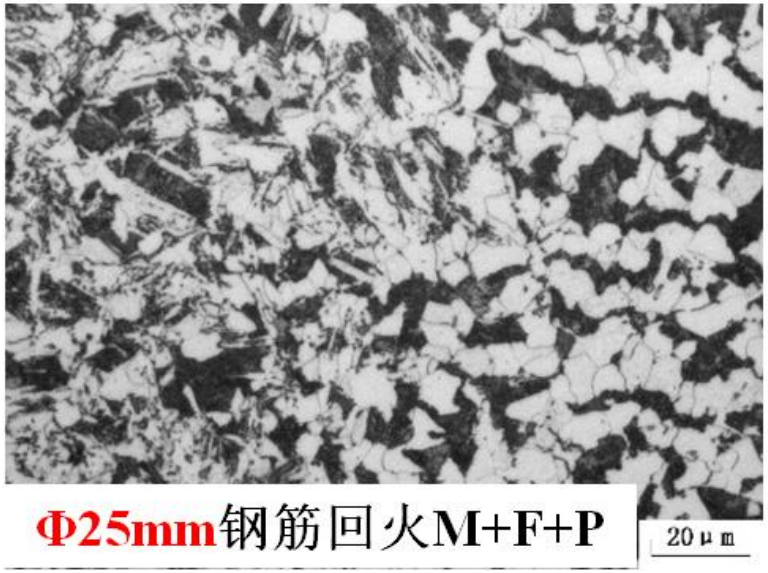
Microstructure－Judgment difficult



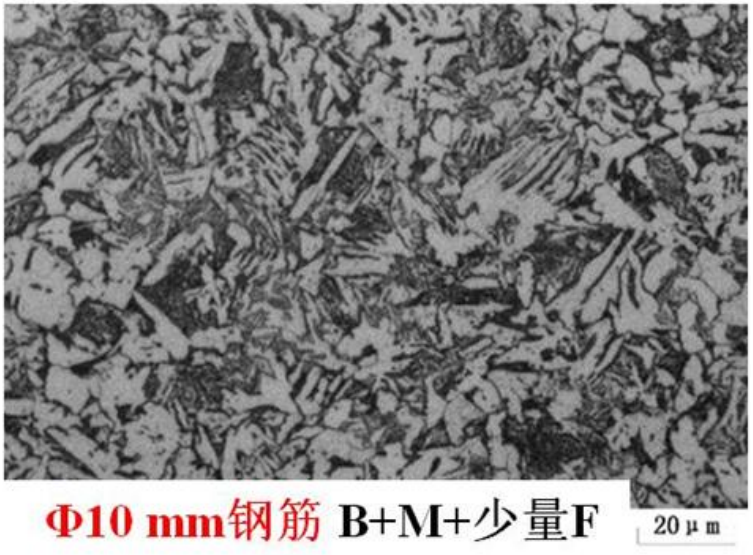
Φ25mm钢筋F+P



Φ25mm钢筋 细F+P



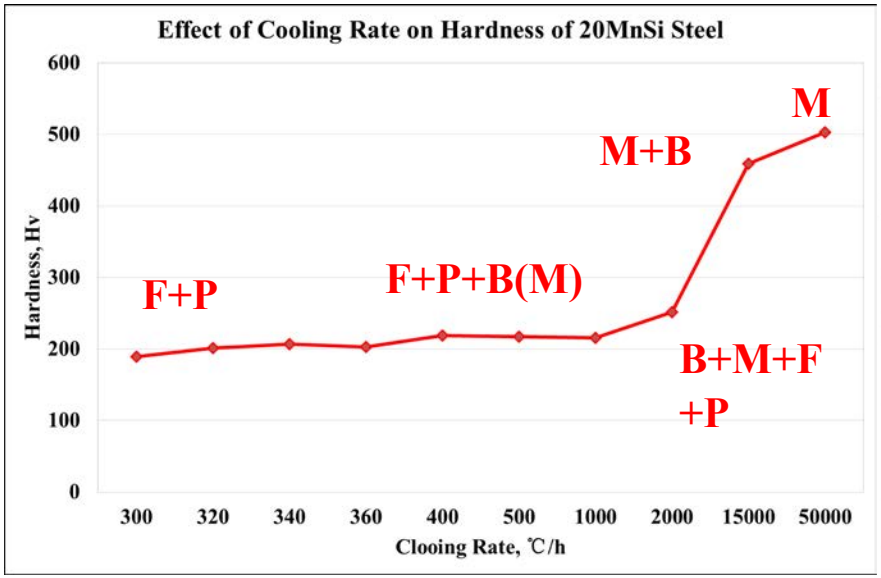
Φ25mm钢筋回火M+F+P



Φ10 mm钢筋 B+M+少量F

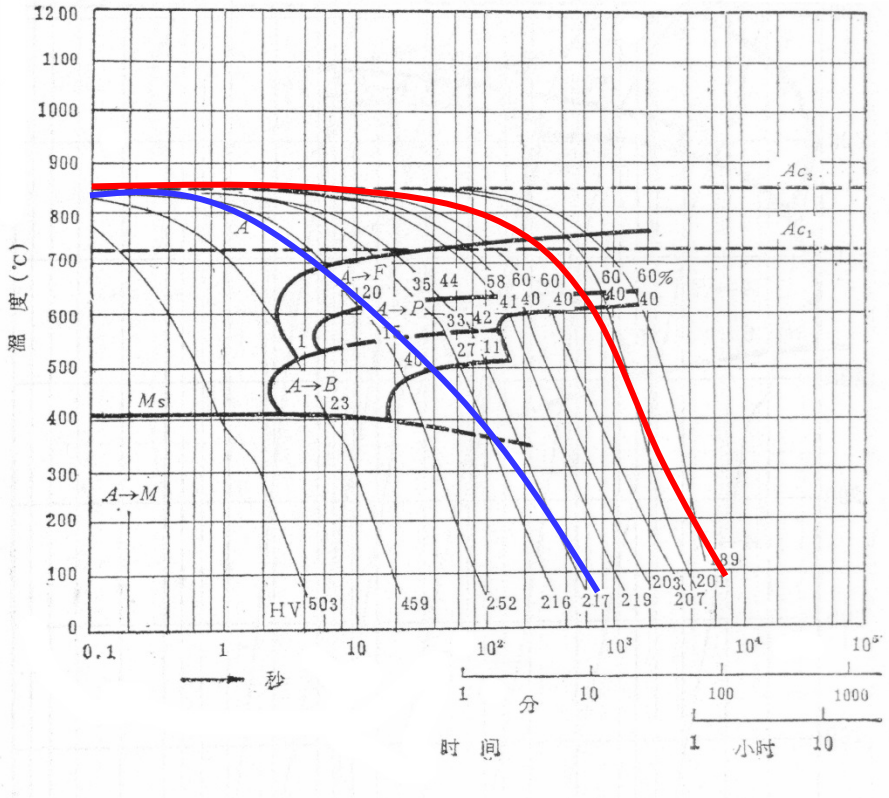
Auxiliary Judgment Method—Cross-section HV

Hardness and microstructure

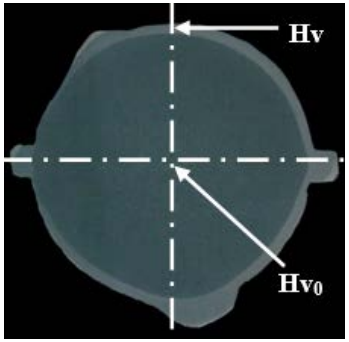


20MnSi rebar CCT curve

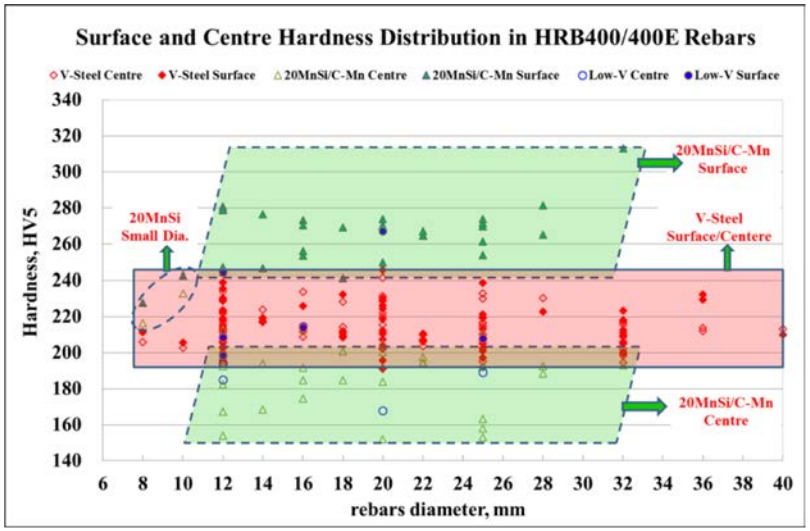
C	Si	Mn	P	S	Cr	Cu	Mo	Ni	V	T_A
0.23	0.45	1.32	0.029	0.022	0.05	—	—	—	—	900



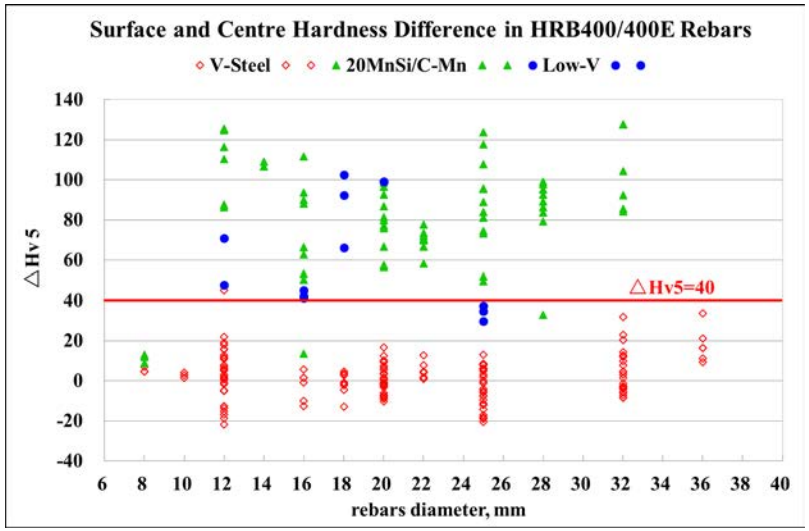
Section hardness method



Hv max

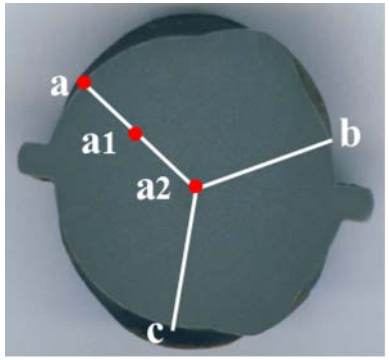


△Hv

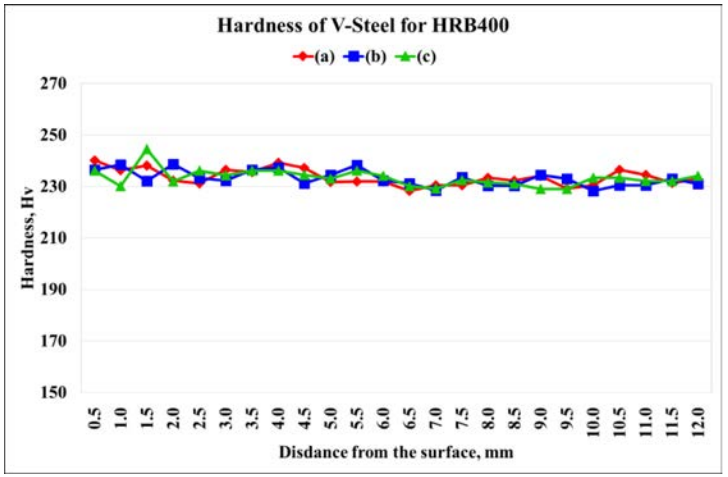


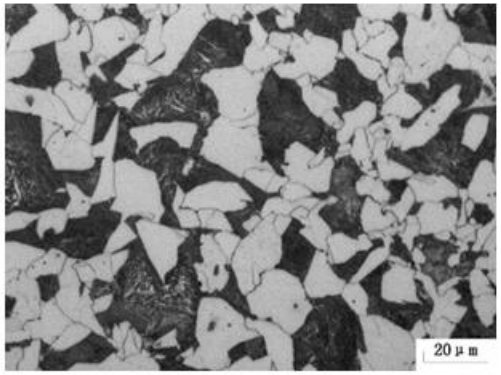
Microstructure and Hardness distribution

0.23C-0.49Si-1.34Mn-0.066V (Φ25)

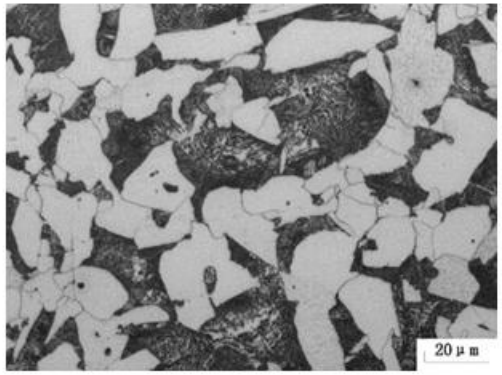


a	a1	a2
240.25Hv	232.05Hv	232.99Hv
238.49Hv	232.45Hv	228.13Hv
236.11Hv	234.15Hv	231.15Hv

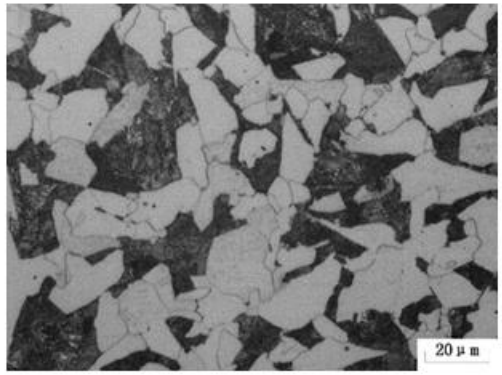




(a) F+P
（F晶粒度6.5级）



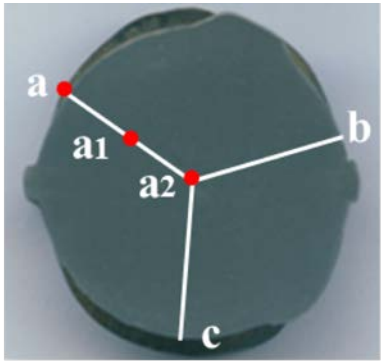
（a1）F+P
（F晶粒度6.5级）



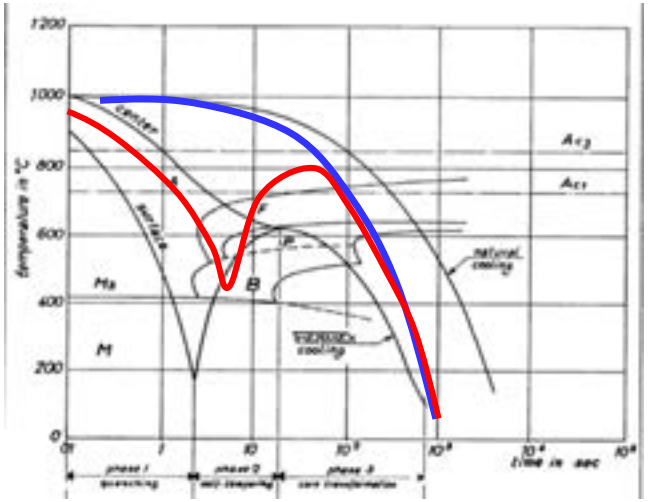
(a2) F+P
（F晶粒度6.5级）

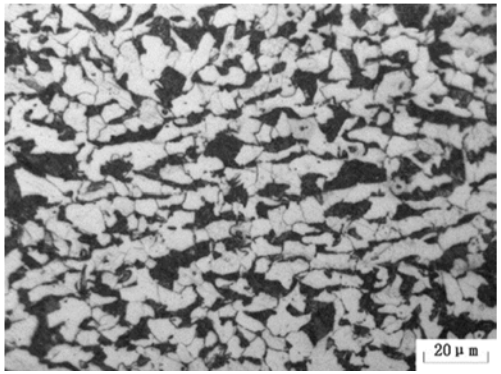
Microstructure and Hardness distribution

0.22C-0.38Si-1.33Mn-0.031V (Φ25)

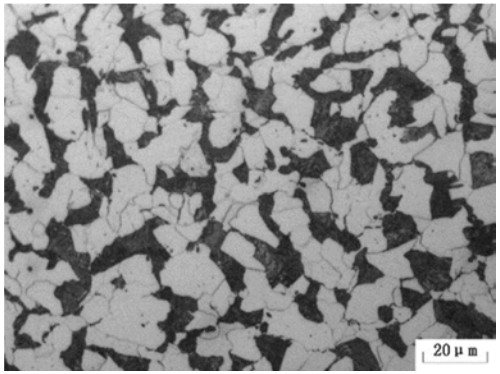


a	a1	a2
194.46Hv	198.99Hv	193.15Hv
195.09Hv	198.48Hv	192.65Hv
196.11Hv	196.11Hv	191.25Hv

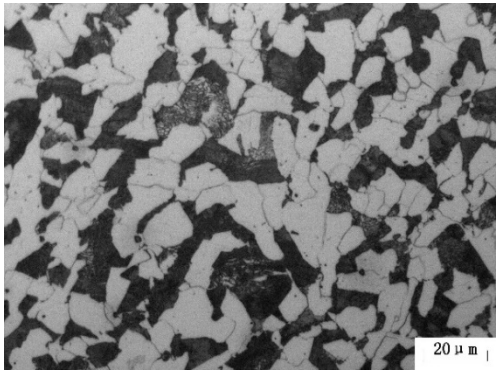




(a) F+P
（F grain 8）



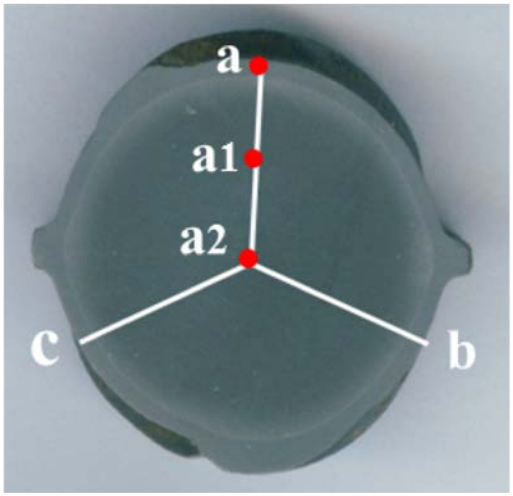
(a1) F+P
（F grain 7）

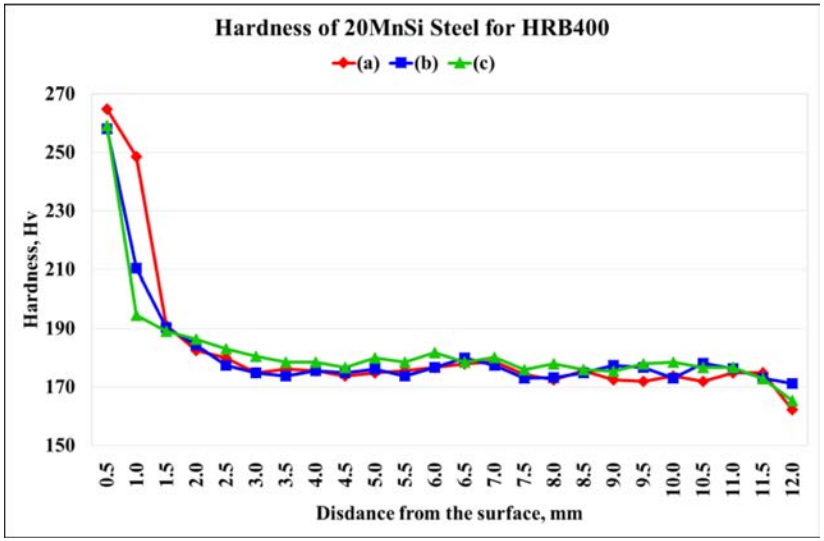


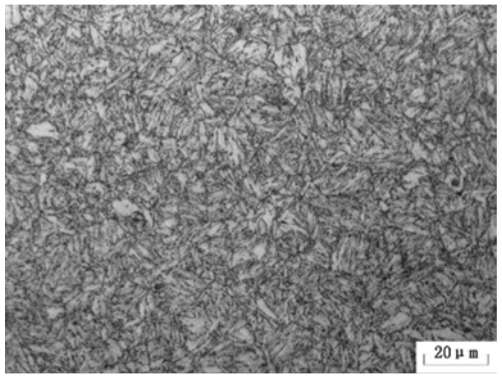
(a2) F+P
（F grain 7）

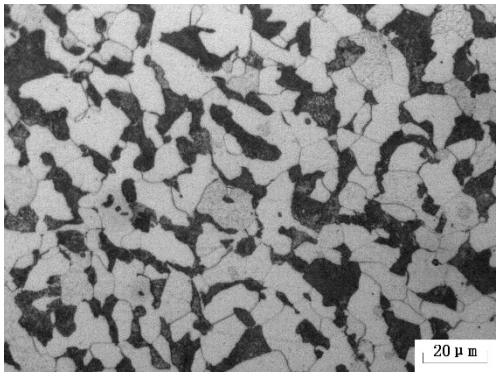
Microstructure and Hardness distribution

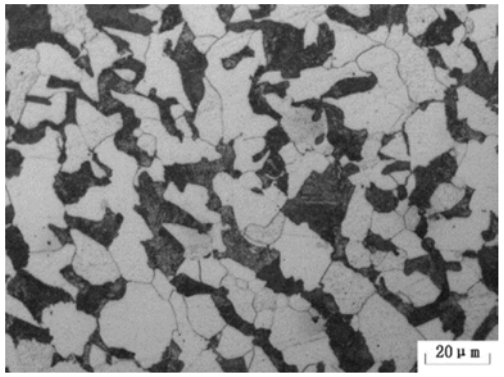
0.22C-0.27Si-1.28Mn (Φ25)







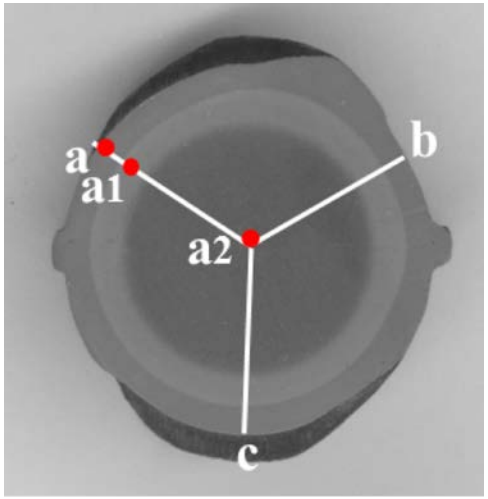


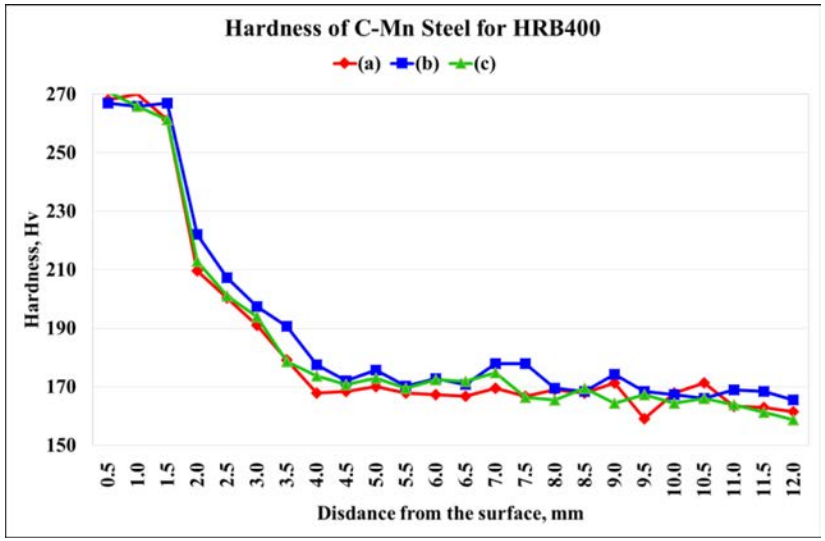


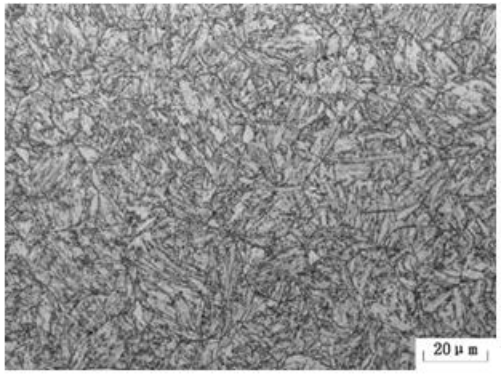
(a) Temper M(0.5mm) (a1) F+P 6mm） (a2) F+P (12mm)

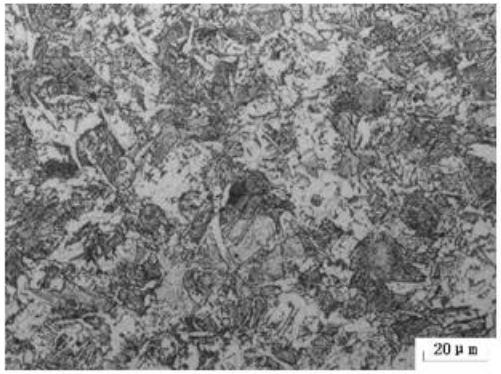
Microstructure and Hardness distribution

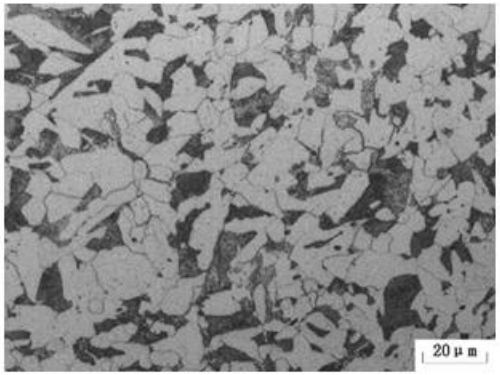
0.23C-0.20Si-0.91Mn (Φ25) (两层硬化层)







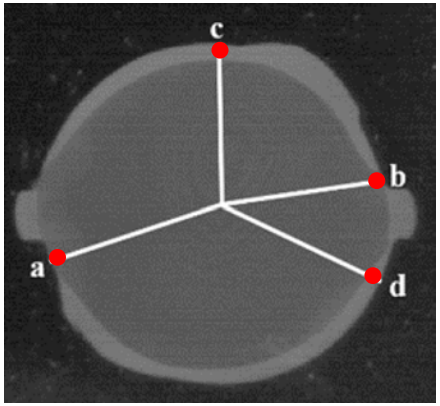


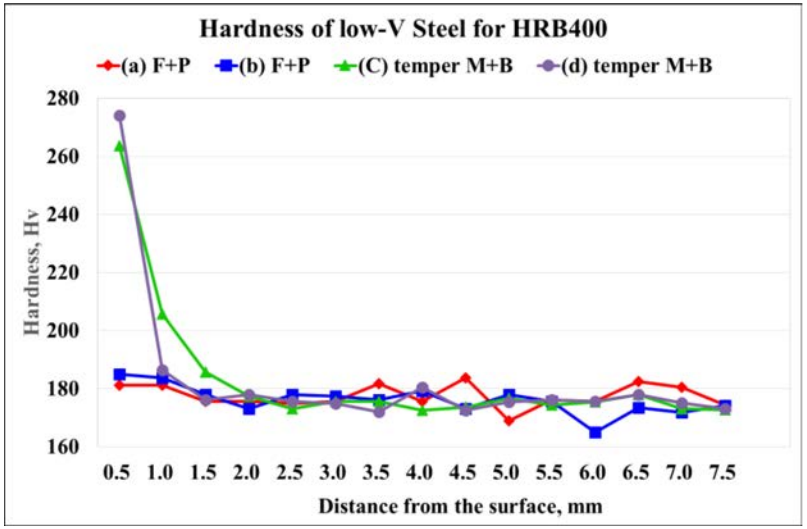


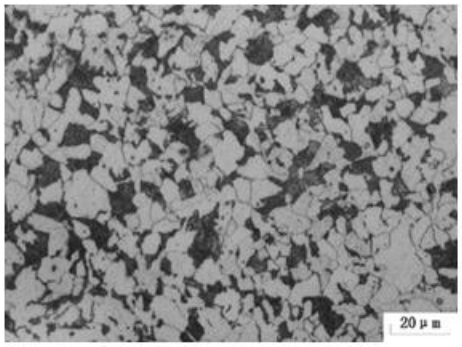
(a) 回火M (0.5mm) (a1) 回火M+B (2mm) (a2) F+P (12mm)

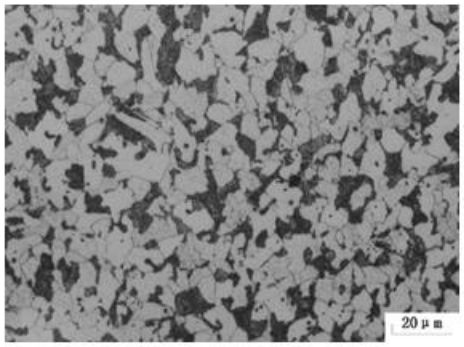
Microstructure and Hardness distribution

0.25C-0.31Si-0.81Mn-0.010V (Φ22) (不闭合的硬化层)

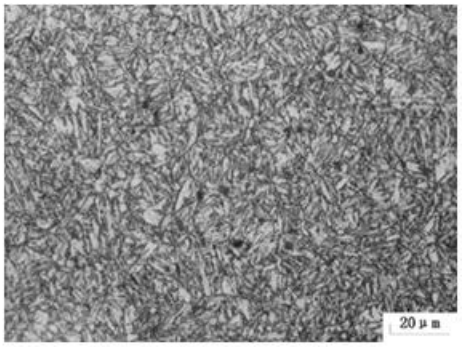




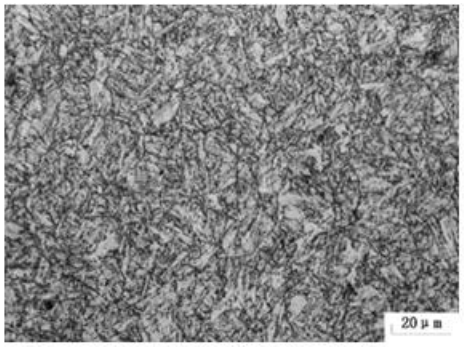




(a)、 (b) F+P



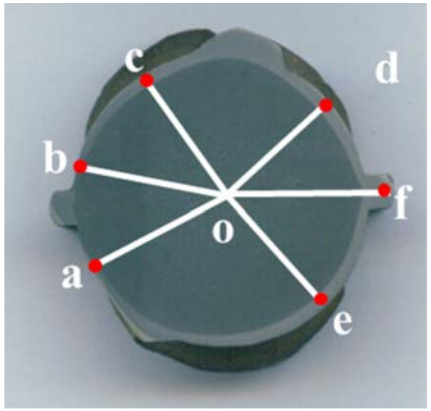
(c) 回火M

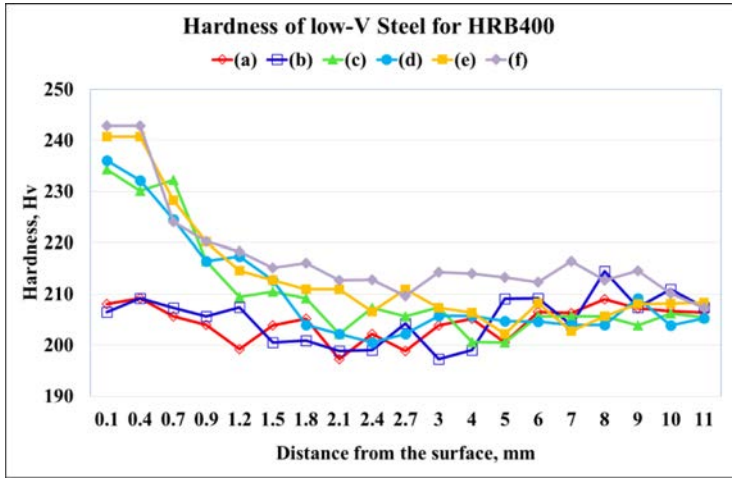


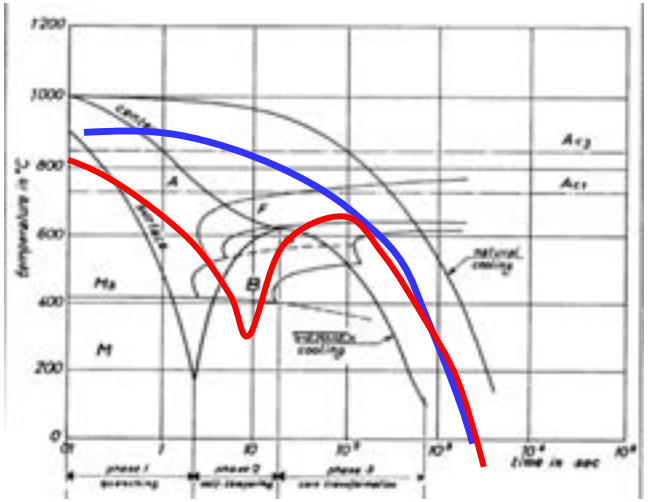
(d)回火M

Microstructure and Hardness distribution

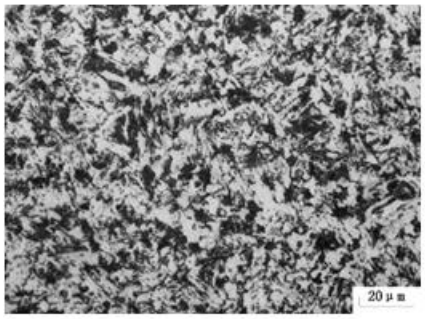
0.23C-0.34Si-1.51Mn-0.016V (Φ25) (不闭合的硬化层)





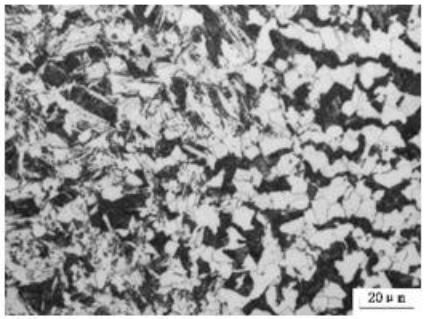


表面硬化层



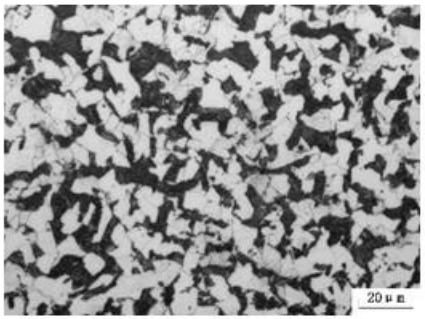
回火M(B)

交界过渡区



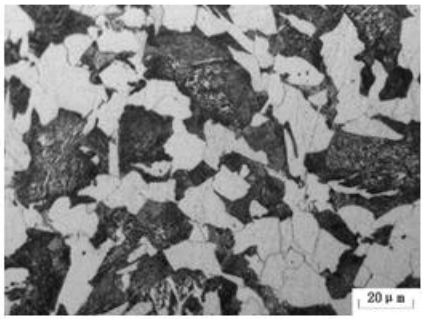
回火M(B)+F+P

表层内侧



细F+P

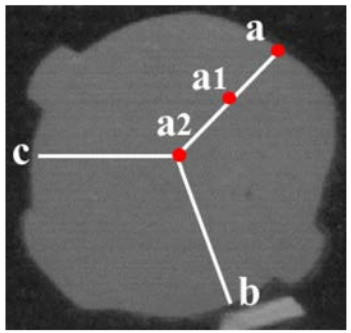
中心

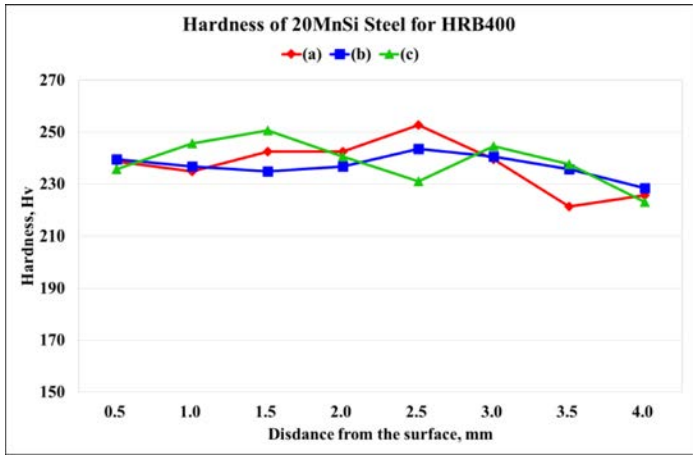


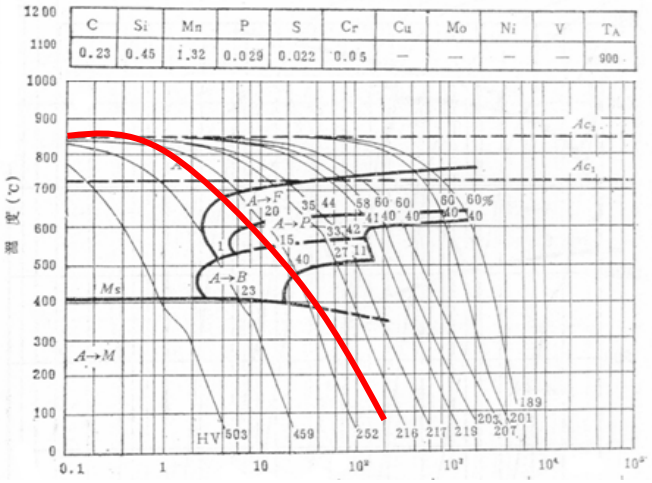
F+P

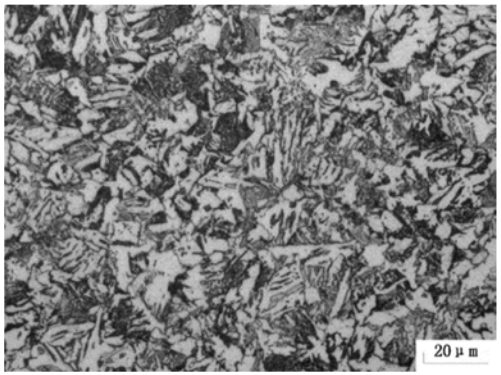
Microstructure and Hardness distribution

0.23C-0.51Si-1.48Mn（ Φ10 ）

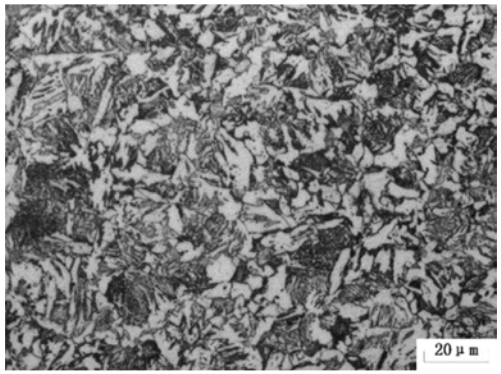




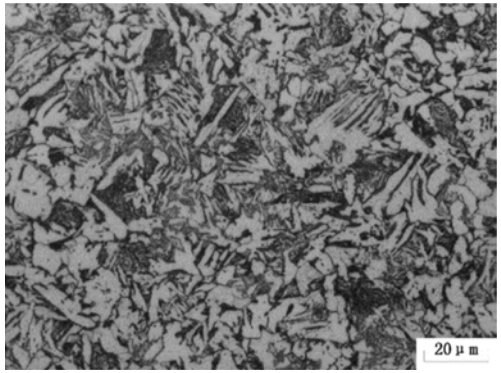




(a) B+F+P

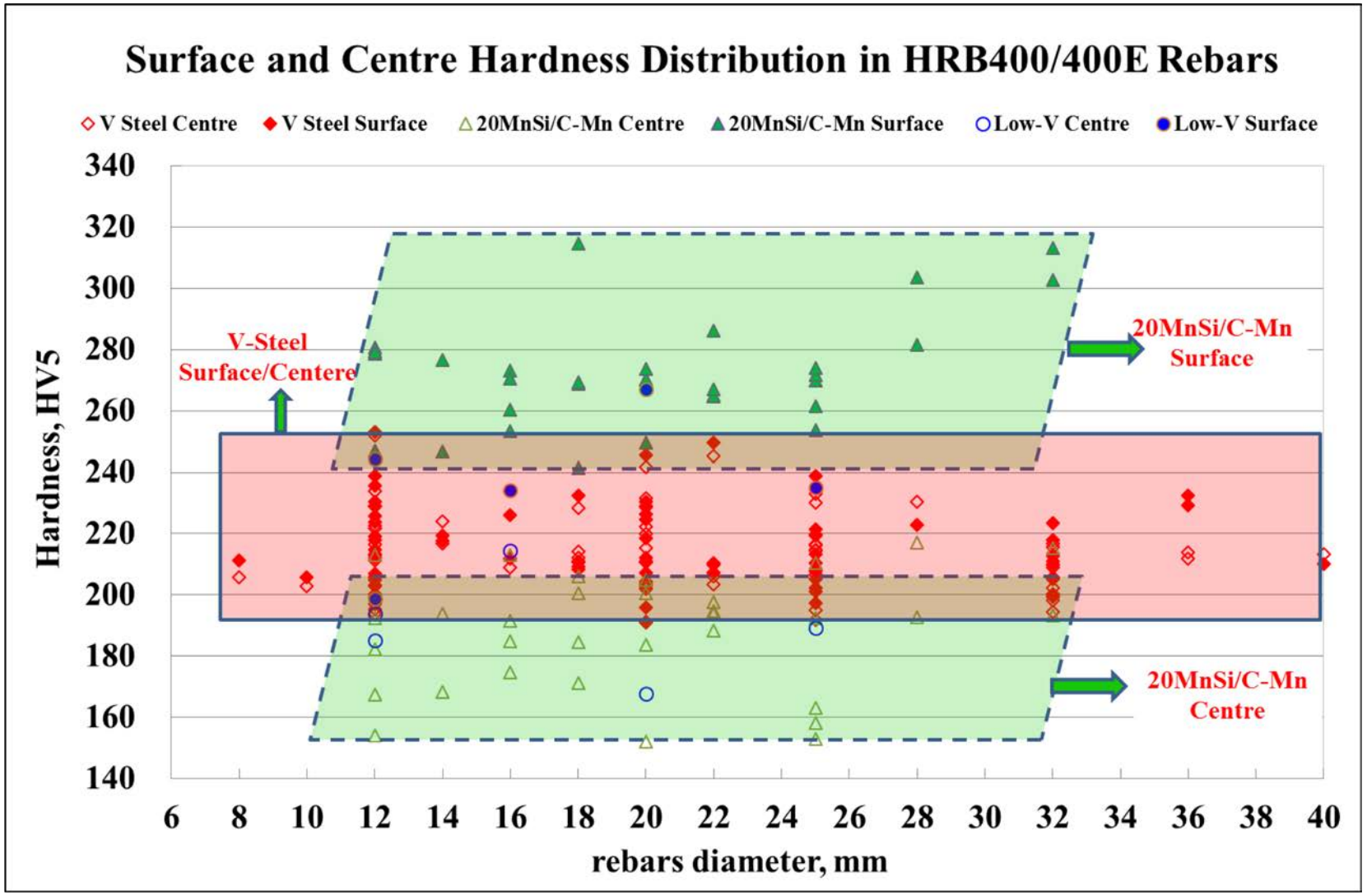


(a1) B+F+P

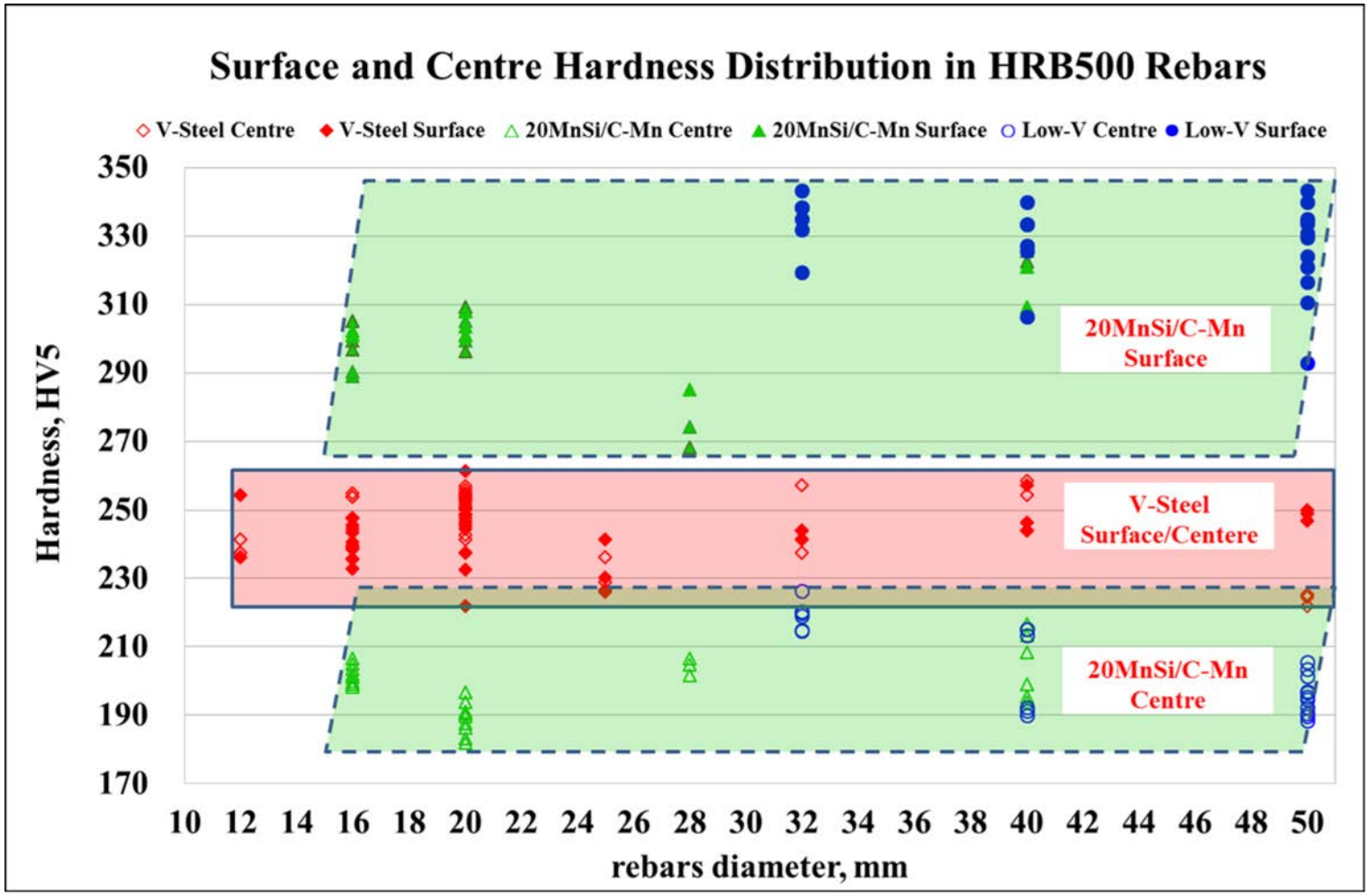


(a2) B+F+P

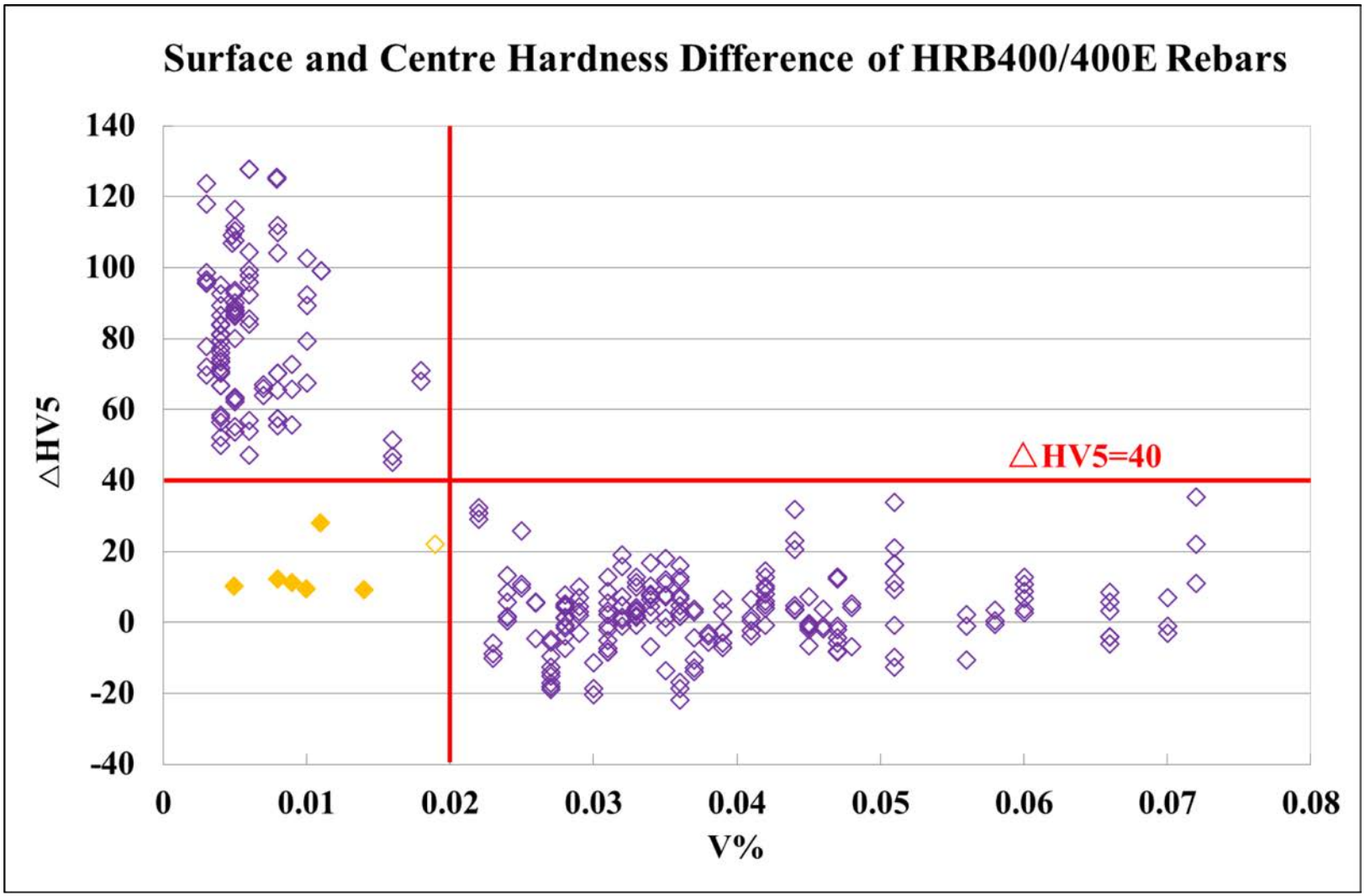
Surface and Centre Hardness Distribution in HRB400 Rebar



Surface and Centre Hardness Distribution in HRB500 Rebar



Cross-section △HV of HRB Rebars



Methods for Microstructure Test

B.2 Hardness Test

B.2.1 Vickers hardness test on cross-section of HRB rebar is conducted according to GB/T4340.1-2009. The load is 5kg and the holding time is 10s.

B.2.2 Test the hardness of the center point (HV_0) and the hard layer in the surface (HV), as shown in Fig.B.2.

B.2.3 The hardness difference ($HV-HV_0$) of HRB rebar should be below 40HV.

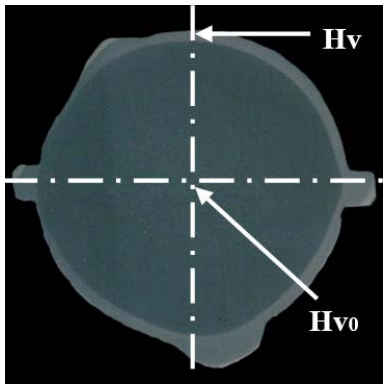


Fig.B.2 Testing points of Vickers hardness of the rebar

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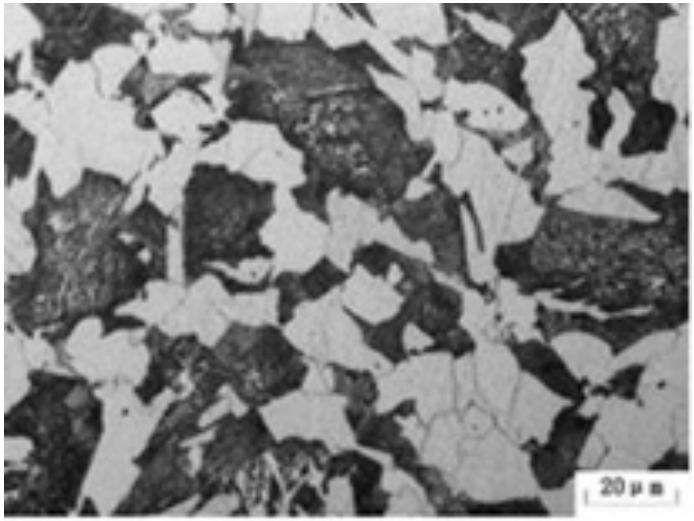
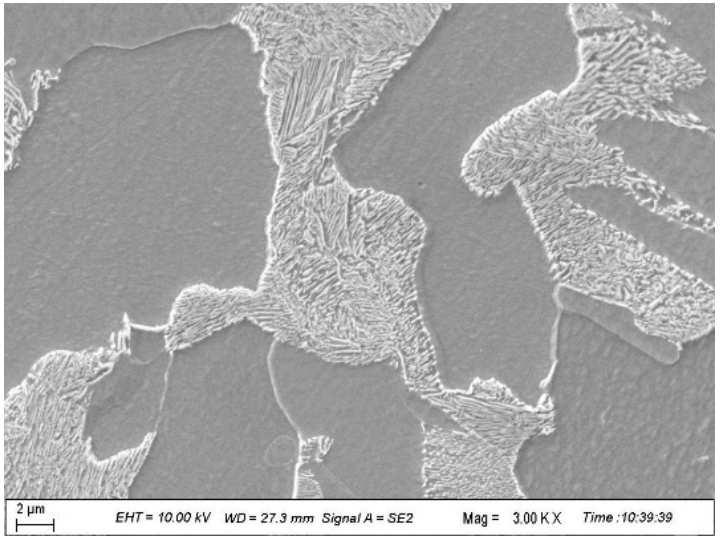
Arbitration－Microstructure

F+P





Tempe
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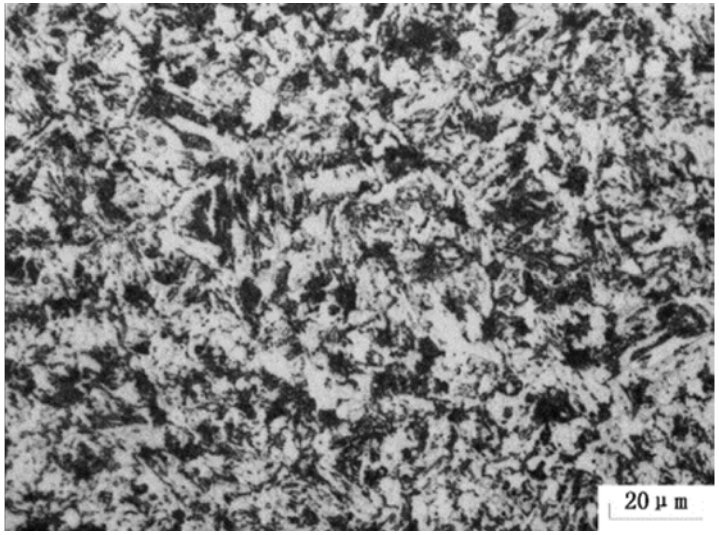

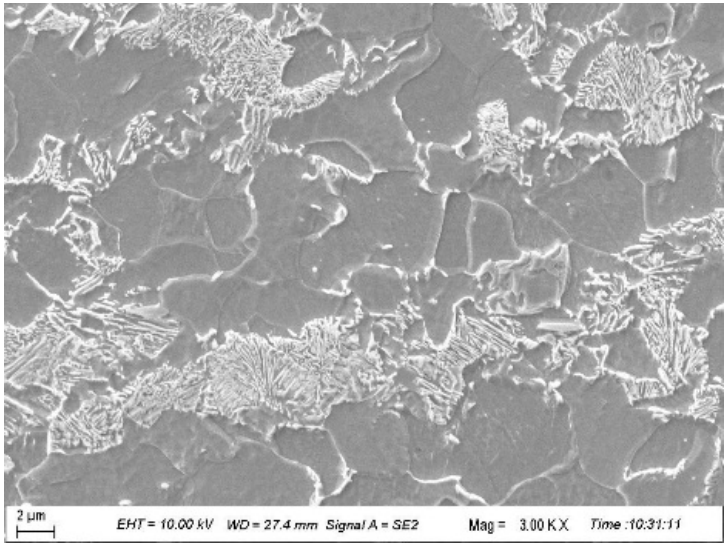

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Thanks for your attention!