"Materials Korea – 소재강국 실현을 위한 프론티어"

Current Industrial Application and R&D Status on Titanium in Korea

Dr. Yong Tai LEE

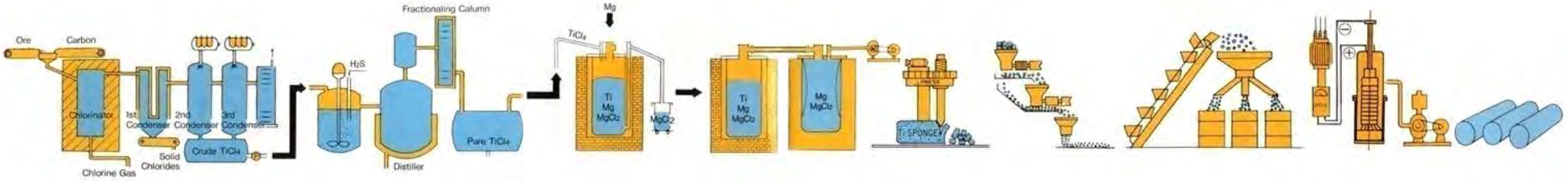
Director of Light Metals Division

Contents

- ❖ Titanium Production & Consumption
- ❖ Titanium Import & Export in Korea
- ❖ Titanium Industrial Applications in Korea
- ❖ Titanium R&D in Korea

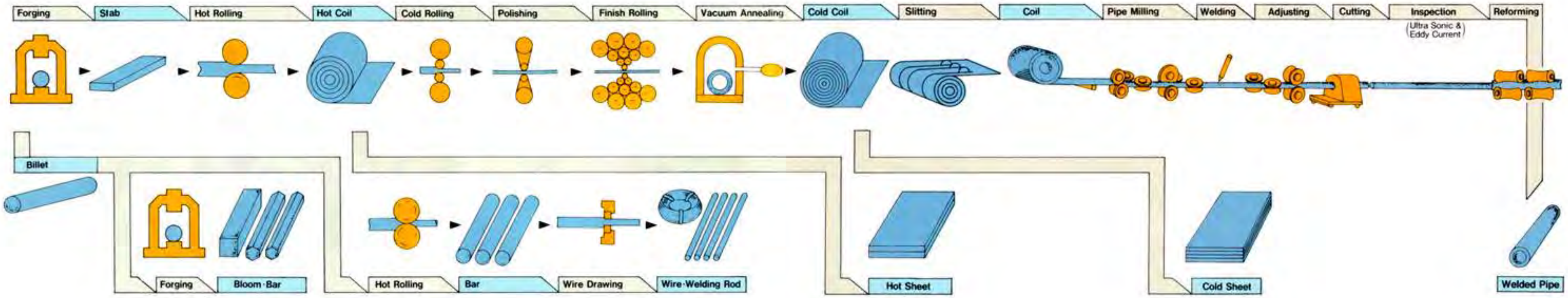
Titanium Production Flow

Titanium Sponge



Chlorination → Purification → Reduction → Vacuum → Distillation → Crushing → Blending & Packaging → Vacuum Arc Melting → Ingot

Titanium Mill Product

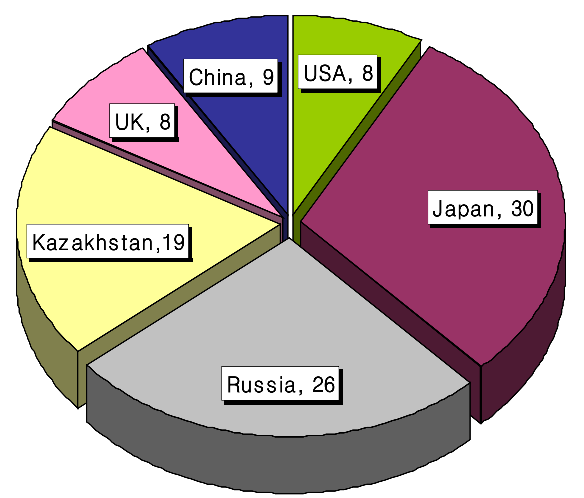


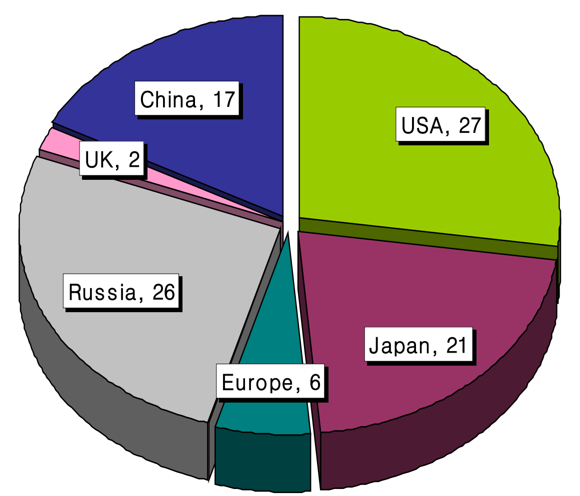
Titanium Production & Consumption in the World(2007)

SPONGE

Production

	ton	%
USA	8,000	8
Japan	31,000	30
Europe	0	0
Russia	27,000	26
Kaza	19,000	19
UK	8,000	8
China	9,500	9
Total	102,500	100





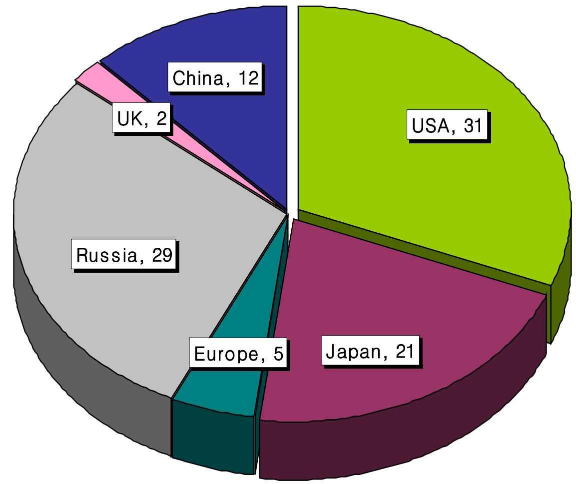
Consumption

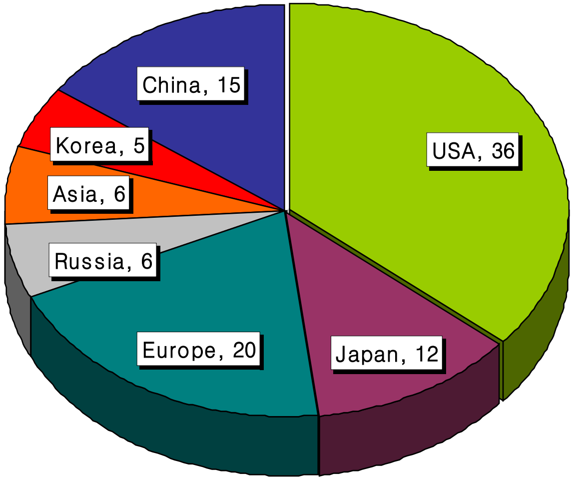
	ton	%
USA	28,000	27
Japan	22,000	21
Europe	6,500	6
Russia	27,000	26
UK	2,000	2
China	17,000	17
Total	102,500	100

Mill Products

Production

	ton	%
USA	26,300	31
Japan	18,000	21
Europe	4,500	5
Russia	24,000	29
UK	1,900	2
China	9,300	12
Total	84,000	100



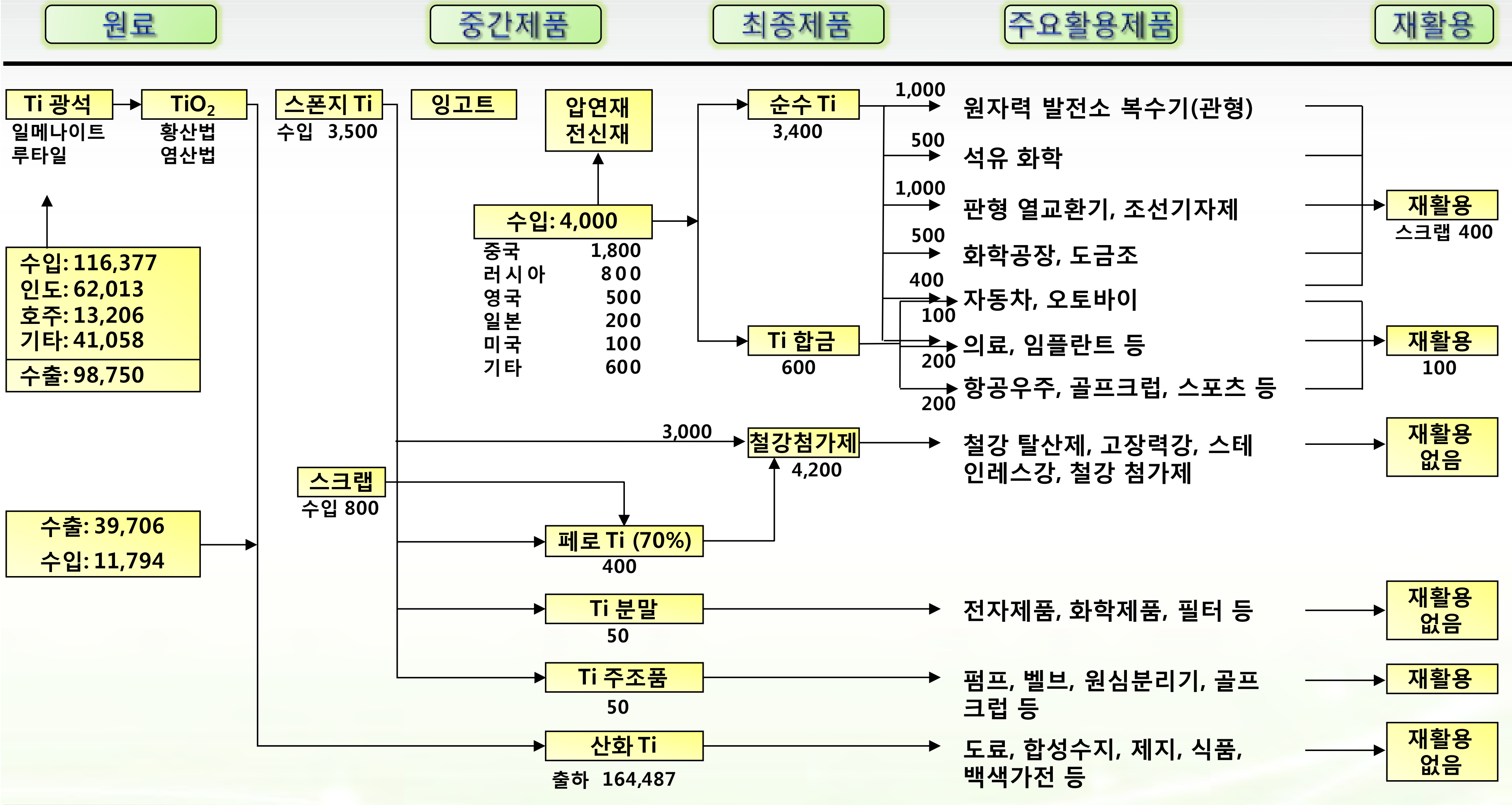


Consumption

	ton	%
USA	30,000	36
Japan	10,000	12
Europe	17,000	20
Russia	5,000	6
Asia	5,000	6
Korea	4,000	5
China	13,000	15
Total	84,000	100

Source : Fundermentals of Titanium and Its Works (2008)

Titanium Flow in Korea (2009)



원료

중간제품

최종제품

주요활용제품

재활용

Ti 광석
일메나이트
루타일

TiO_2
황산법
염산법

수입: 116,377
인도: 62,013
호주: 13,206
기타: 41,058
수출: 98,750

스폰지 Ti
수입 3,500

잉고트

압연재 전신재

수입: 4,000

중국	1,800
러시아	800
영국	500
일본	200
미국	100
기타	600

순수 Ti
3,400

Ti 합금
600

1,000 → 원자력 발전소 복수기(관형)

500 → 석유 화학

1,000 → 판형 열교환기, 조선기자재

500 → 화학공장, 도금조

400 → 자동차, 오토바이

100 → 의료, 임플란트 등

200 → 의료, 임플란트 등

200 → 항공우주, 골프크럽, 스포츠 등

재활용
스크랩 400

재활용
100

3,000 → **철강첨가제**
4,200

철강 탈산제, 고장력강, 스테인레스강, 철강 첨가제

재활용 없음

스크랩
수입 800

수출: 39,706
수입: 11,794

페로 Ti (70%)
400

Ti 분말
50

전자제품, 화학제품, 필터 등

재활용 없음

Ti 주조품
50

펌프, 벨브, 원심분리기, 골프크럽 등

재활용

산화 Ti
출하 164,487

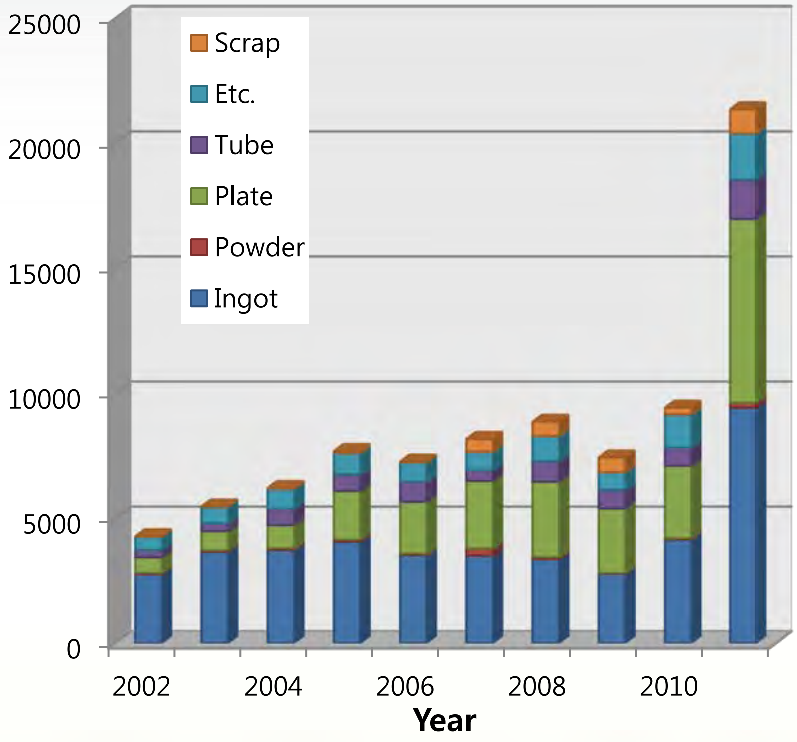
도료, 합성수지, 제지, 식품, 백색가전 등

재활용 없음

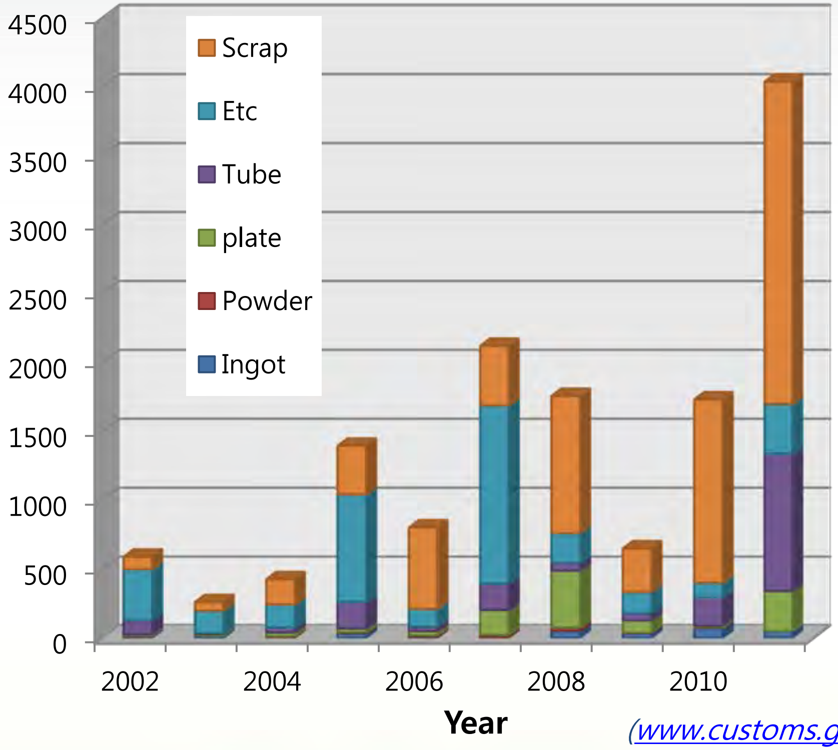
출처 : 한국무역통계 (2007) 및 추정자료 (이용태)

Export and import of Titanium in Korea

❖ **Imports of Ti products (ton), 2002 to 2011**



❖ **Exports of Ti products(ton), 2002 to 2011**

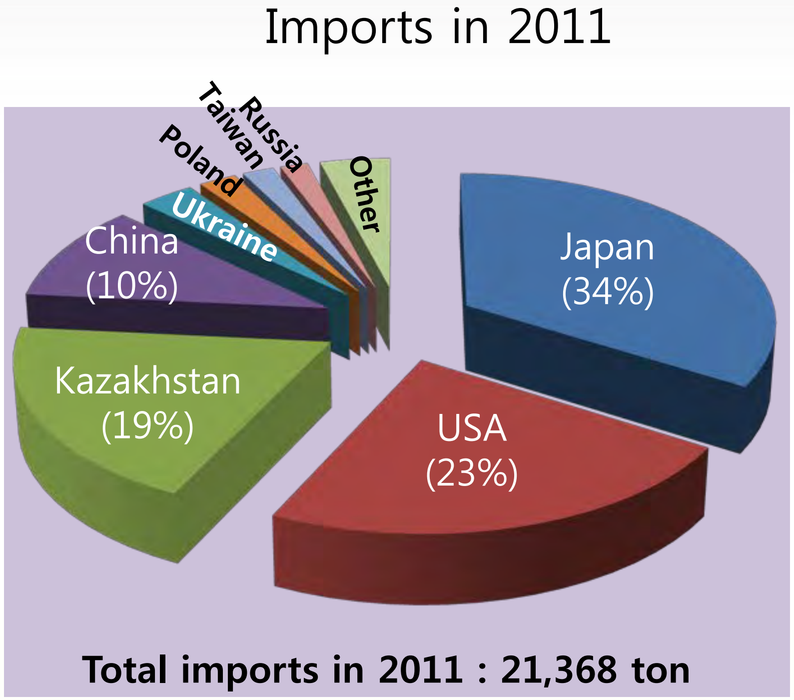


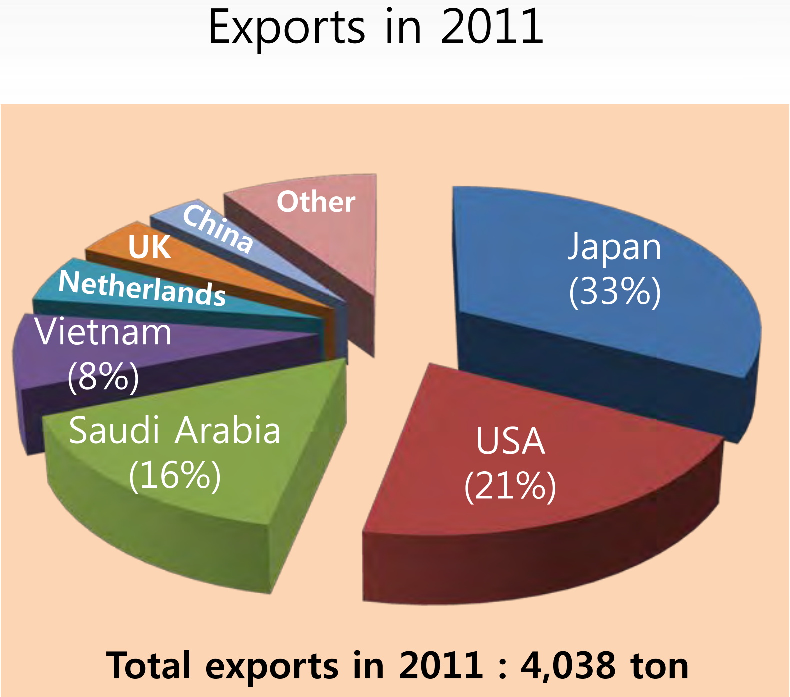
(www.customs.go.kr)

- ▷ Domestic Ti consumption relies mostly on overseas supply.
- ▷ Ti consumption has increased steadily over the last 10 years. Imports of Ti products peaked at 21.3kt in 2011.
- ▷ Exports of Ti in Korea are mainly scrap and secondary processing articles (tube, plate etc.). They are also increasing and reached 4kt in 2011.

Import and Export of Titanium to the World

KIMS





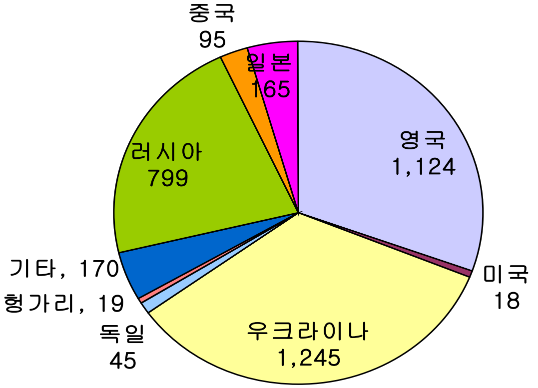
- ▷ Korea is an important market for Ti with imports of sponge and mill products coming mainly from Kazakhstan, the UK, Ukraine, Russia, Japan, USA and China.
- ▷ Imports of unwrought Ti and mill products were 21.4kt in 2011.
- ▷ Imports of Ti mill products and articles came mainly from Japan, Poland and the USA.

Titanium Import Countries in Korea

KIMS

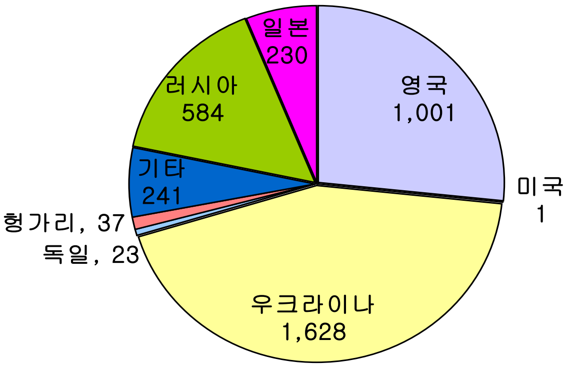
2003

I	3,680
E	16



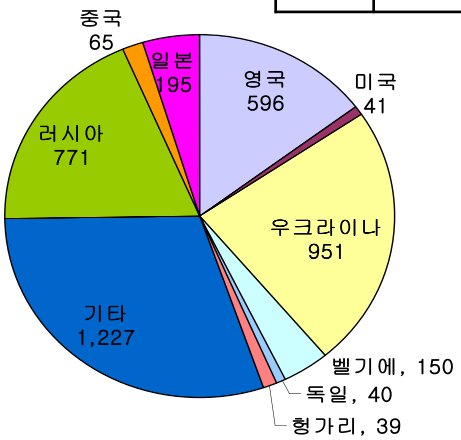
2004

I	3,745
E	2



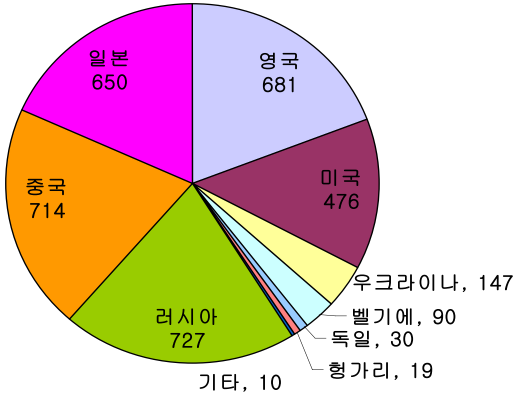
2005

I	4,075
E	34



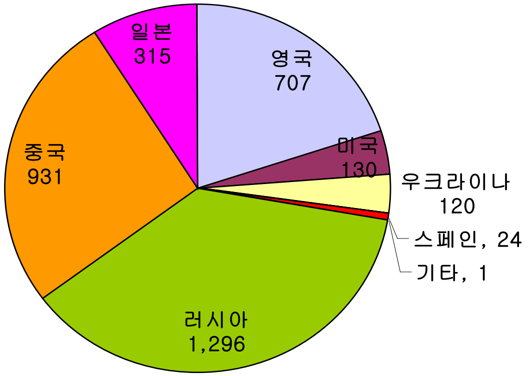
2006

I	3,544
E	6



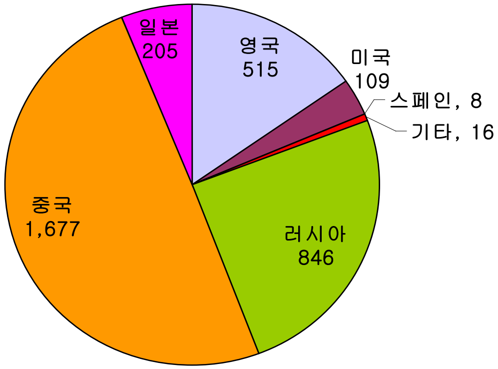
2007

I	3,524
E	2



2008

I	3,376
E	52

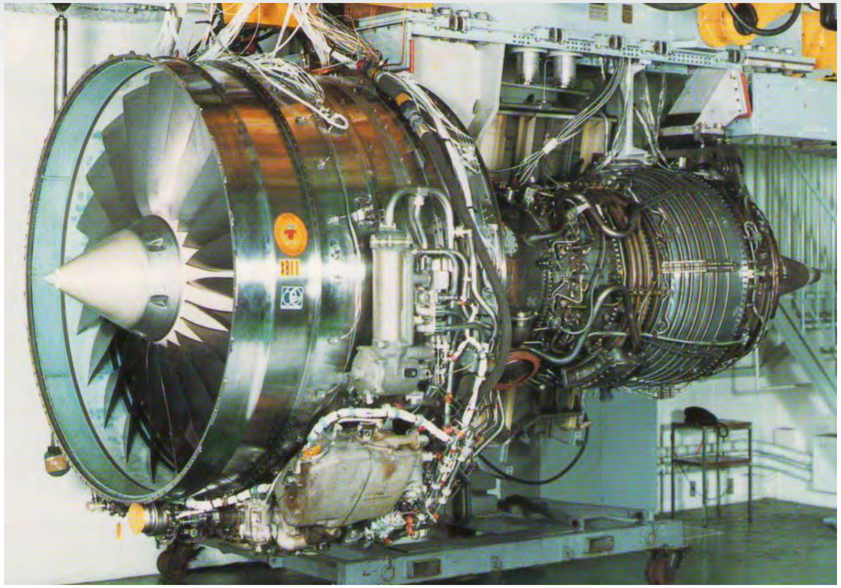


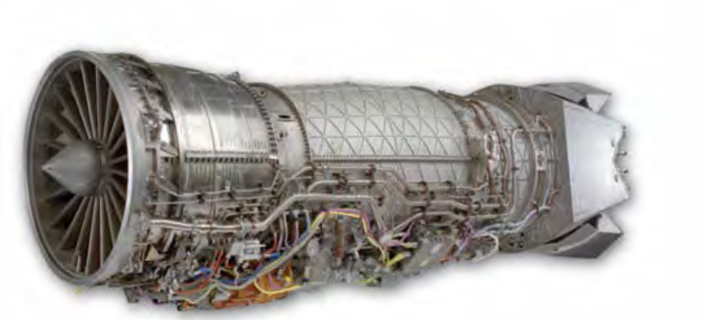
Titanium Rod & Wire Imports for Medical Purpose

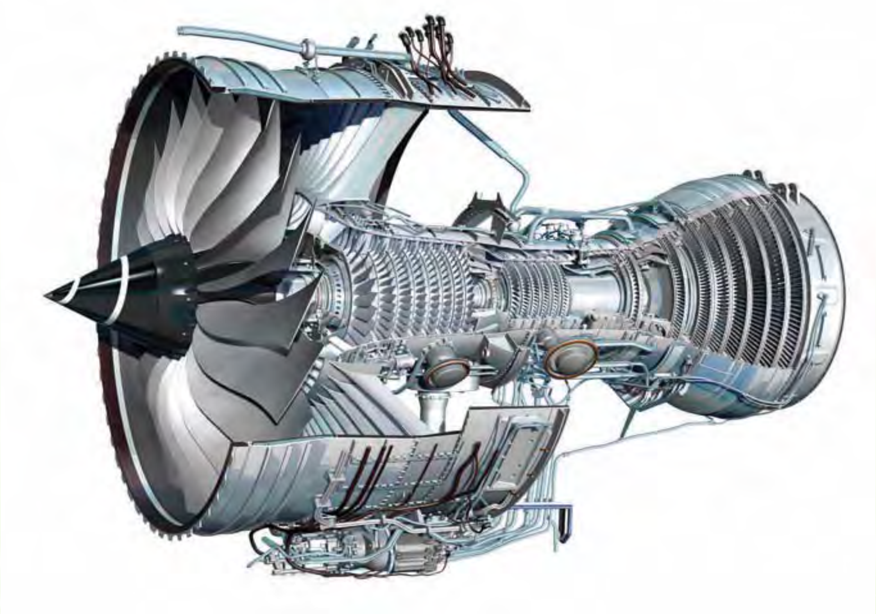
Source: Korea Customs Service, Unit: ton

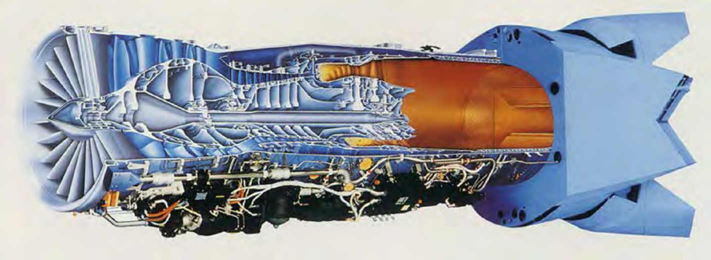
Year	2005	2006	2007	2008	2009	2010	2011	2012(1-4)
USA	344	259	277	515	270	876	1,010	366
Japan	448	380	229	261	248	188	457	62
China	23	40	49	78	66	123	242	93
Germany	3	9	11	5	3	37	15	6
England	-	4	17	5	4	10	12	2
Taiwan	-	2	10	14	9	12	16	3
France	12	33	52	53	45	64	43	6
Italy	13	-	74	55	21	-	14	1
Liechtenstein	-	-	-	1	1	1	1	-
Israel	-	-	-	-	-	-	1	-
Norway	-	-	-	-	1	-	16	-
Swiss	1	1	1	-	-	-	-	-
Netherland	-	21	-	-	-	-	-	-
Poland	-	18	1	-	-	-	-	-
Australia	-	-	-	-	-	-	1	-
Hong Kong	-	-	-	-	-	-	1	-
Sweden	-	-	-	-	-	1	1	-
Russia	16	9	15	10	15	14	20	-
Singapore	-	-	-	1	3	-	1	-
Total	852	776	737	998	686	1,328	1,851	541

Aerospace (1)

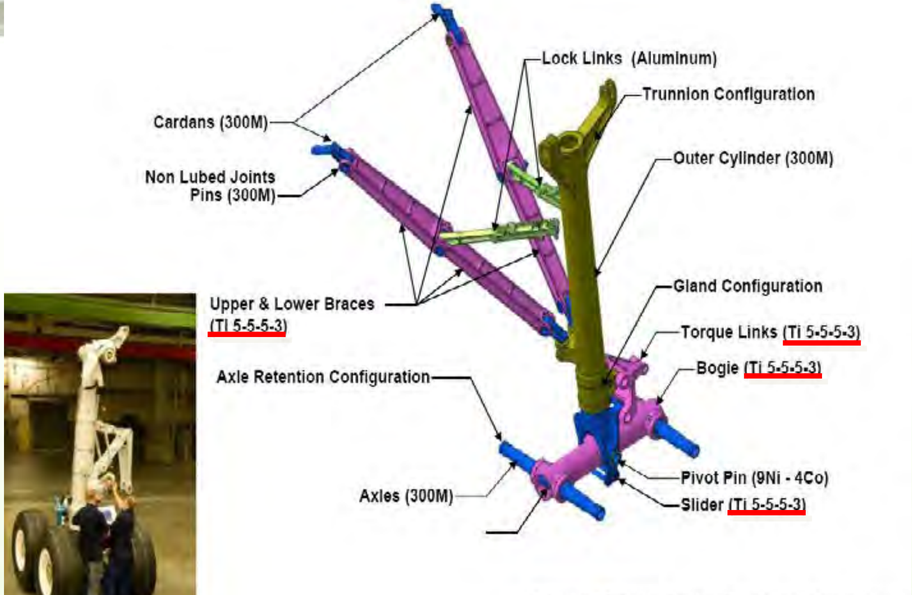








Aerospace (2)



Reference: G Tomchick, "Overview of Titanium Applications on Advanced Commercial Transports," AeroMat Conf., May 2006 Presentation

Aerospace (3)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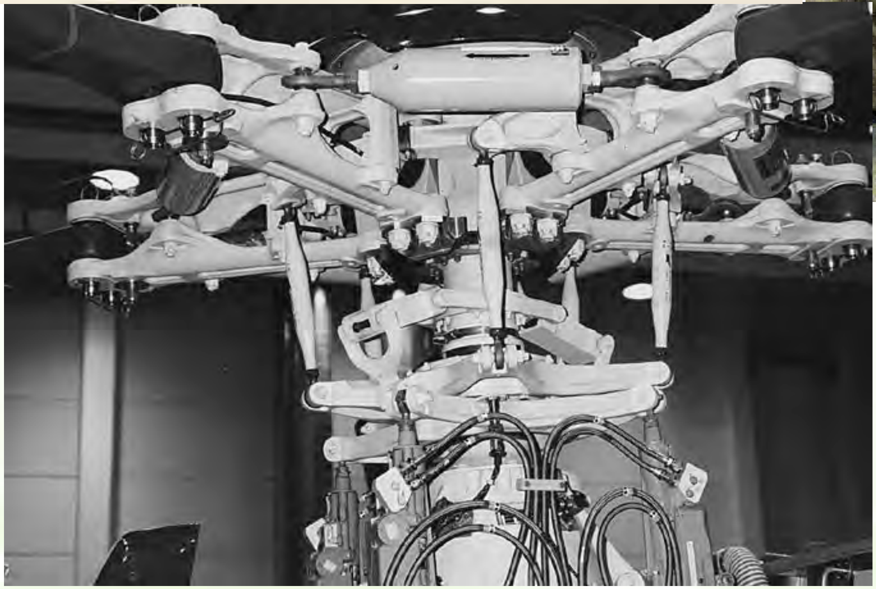
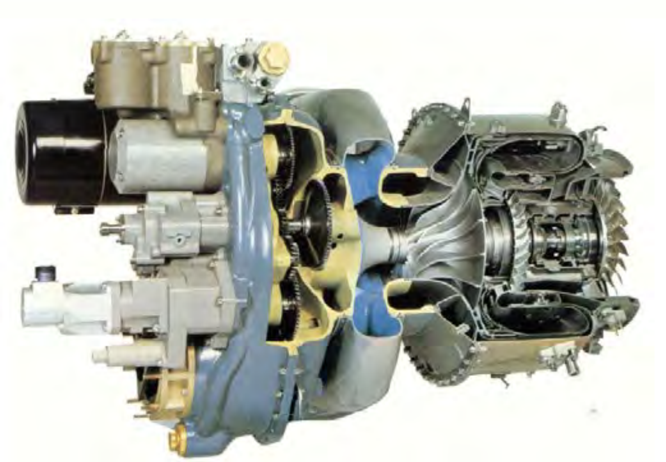
Viggen's Blog @Yahoo.co.kr





Aerospace (4)


KOREA
KSLV-I
HYUNDAI
HYUNDAI
KARI

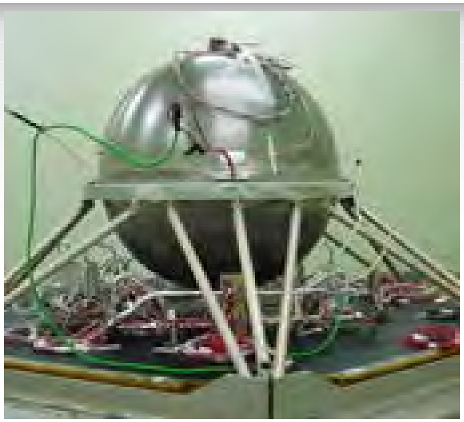
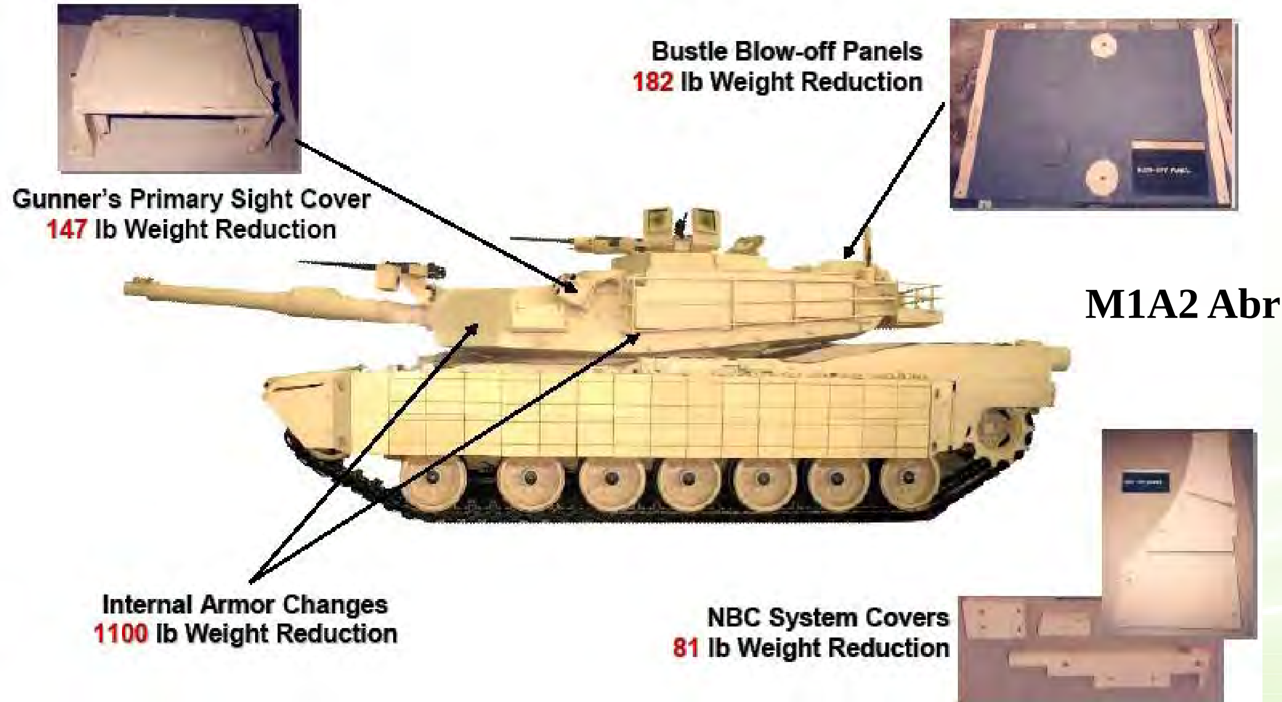



Photo by Shin inkyun
www.koreadefense.net

Militaries (1)



Bustle Blow-off Panels
182 lb Weight Reduction

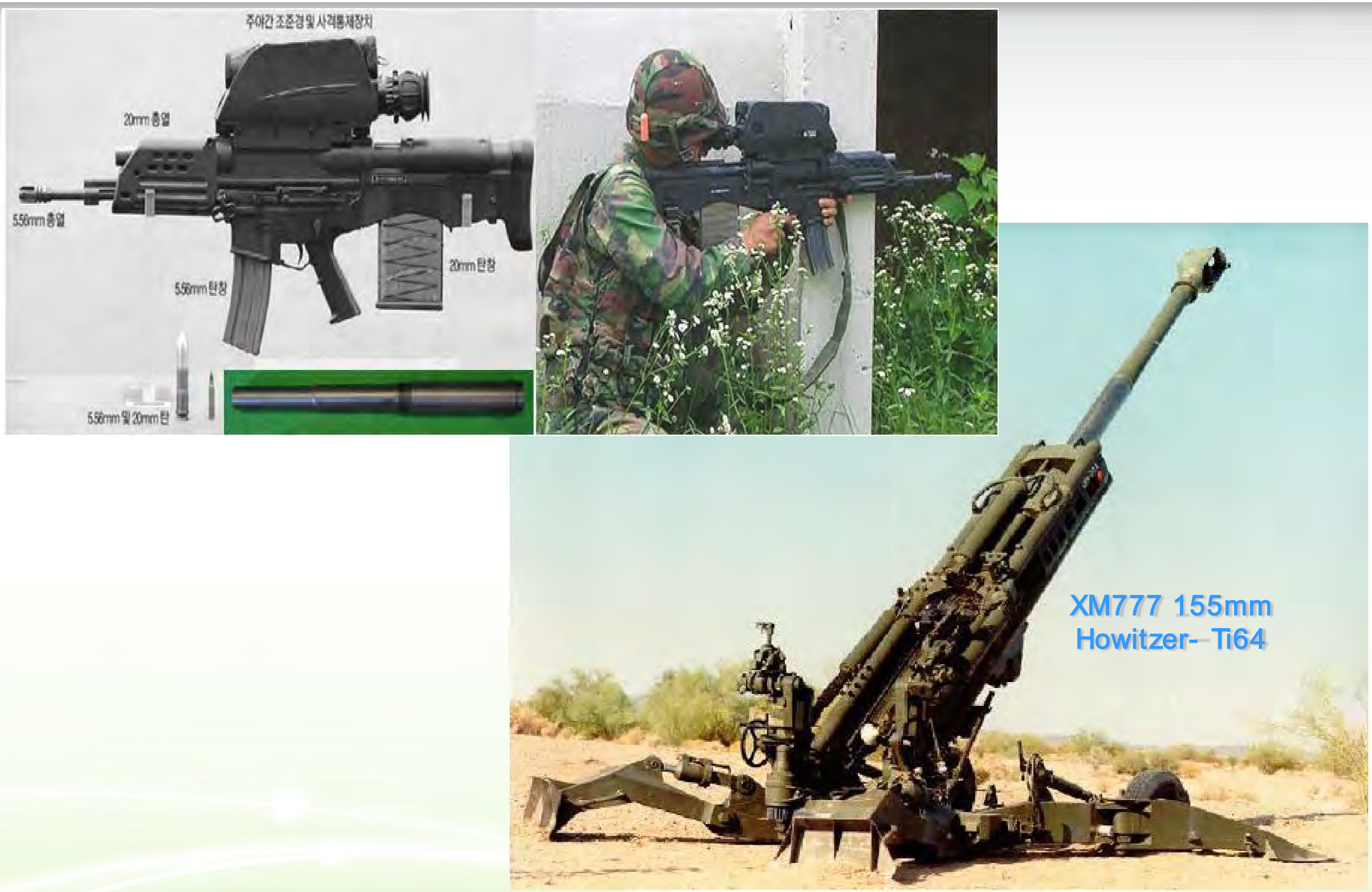
Gunner's Primary Sight Cover
147 lb Weight Reduction

Internal Armor Changes
1100 lb Weight Reduction

NBC System Covers
81 lb Weight Reduction

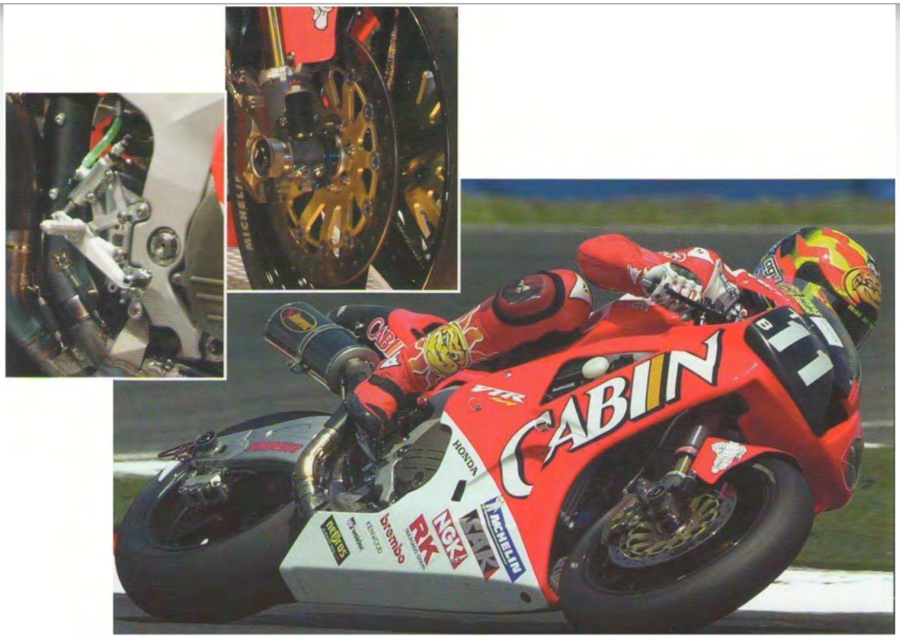
M1A2 Abrams Battle Tank

Militaries (2)

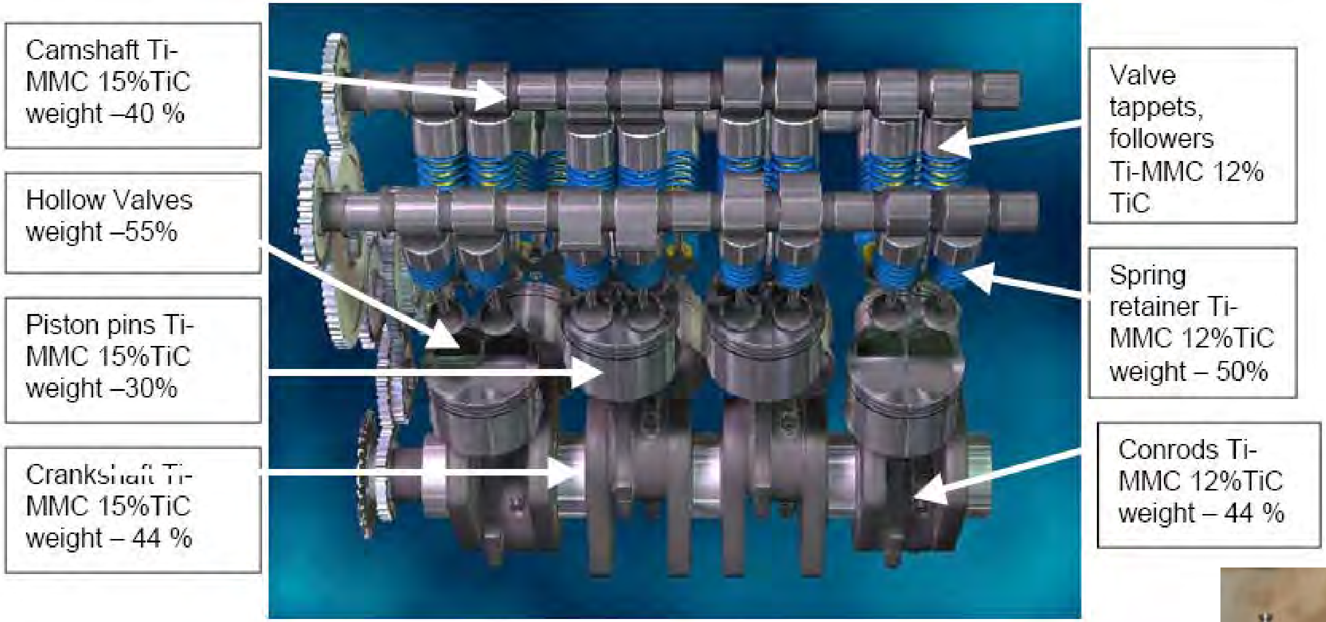


XM777 155mm
Howitzer--Ti64

Automobiles (1)



Automobiles (2)



Camshaft Ti-MMC 15%TiC weight –40 %

Hollow Valves weight –55%

Piston pins Ti-MMC 15%TiC weight –30%

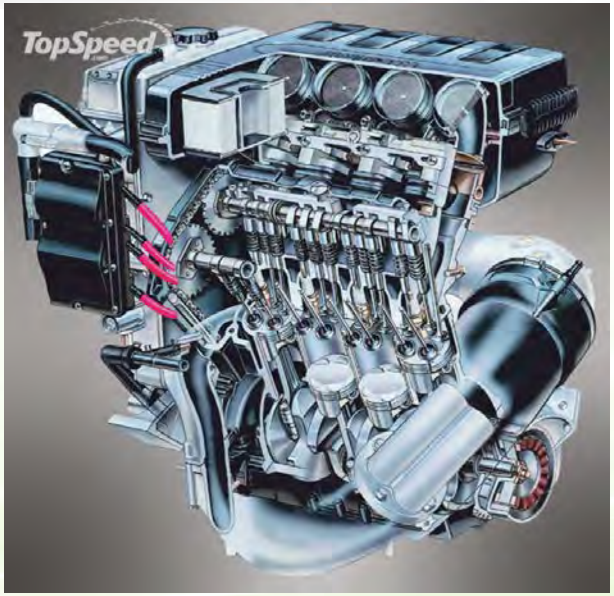
Crankshaft Ti-MMC 15%TiC weight – 44 %

Valve tappets, followers Ti-MMC 12% TiC

Spring retainer Ti-MMC 12%TiC weight – 50%

Conrods Ti-MMC 12%TiC weight – 44 %

Automobiles (3)



Off- shores


해미래
HEMIRE


かいこう
KAIKO
JAMSTEC
しんかい6500
Corrosion resistance
High strength
Ti-6Al-4V ELI

Desalination (MSF Single Module Evaporator Transportation)

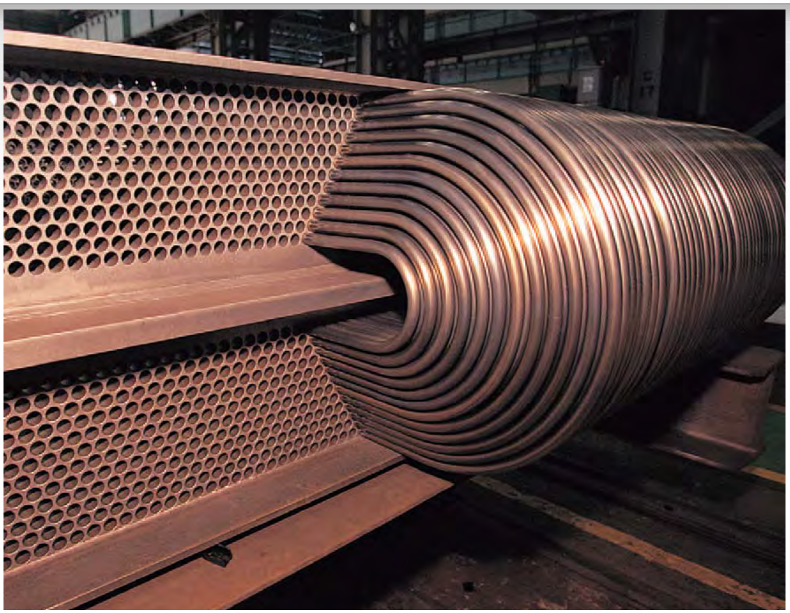
FEB. 04, 2001

MSF Evaporator of Umm Al Nar Desalination Plant Station 'B' (UAE, 12.5 MIGD x 5 Units, W x H x L = 20 x 5 x 100 m)

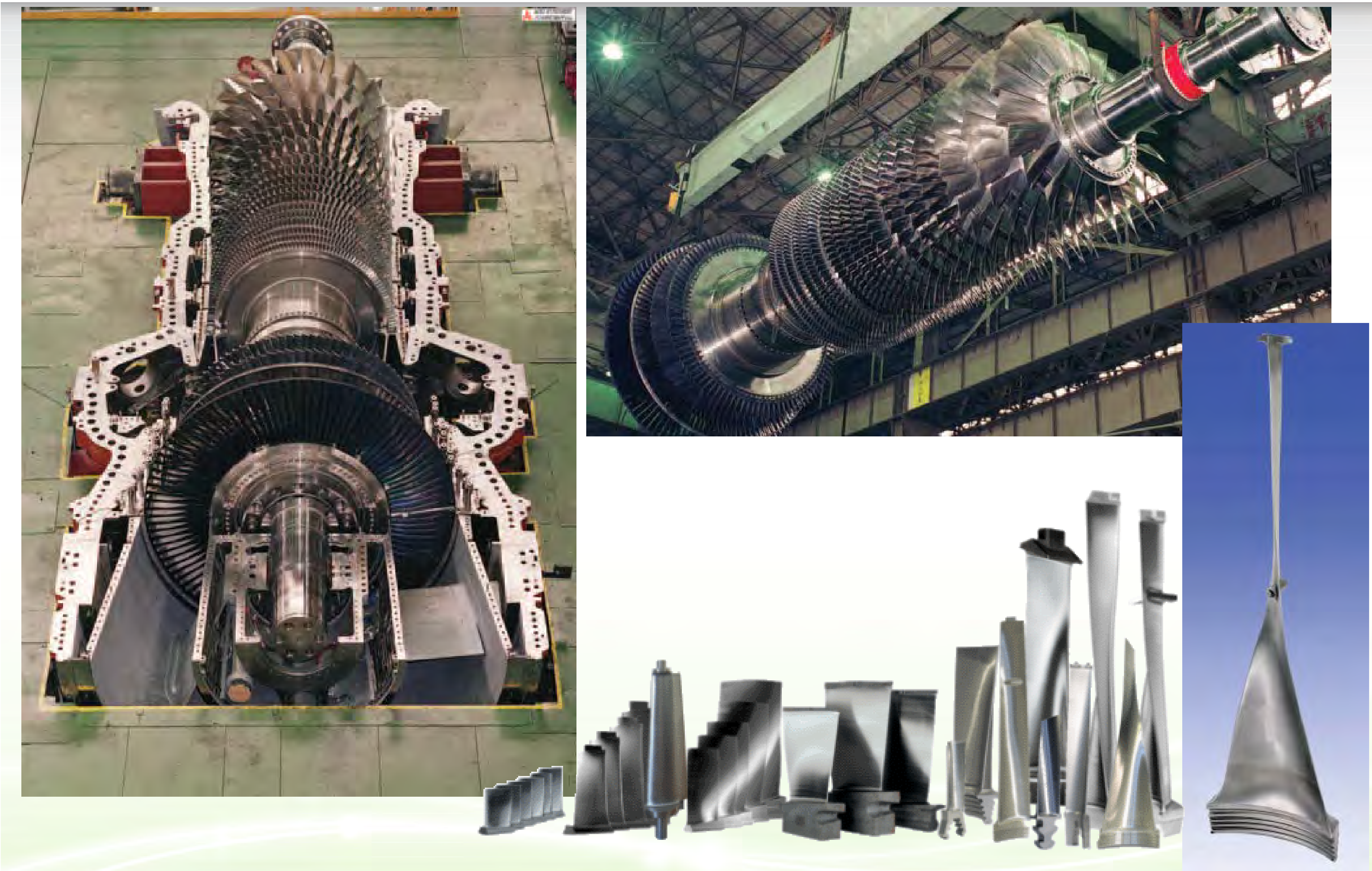
Desalination (Benghazi North CCPP MED Plant)

Benghazi North CCPP MED Plant (Libya, 0.55 MIGD x 2 Units)

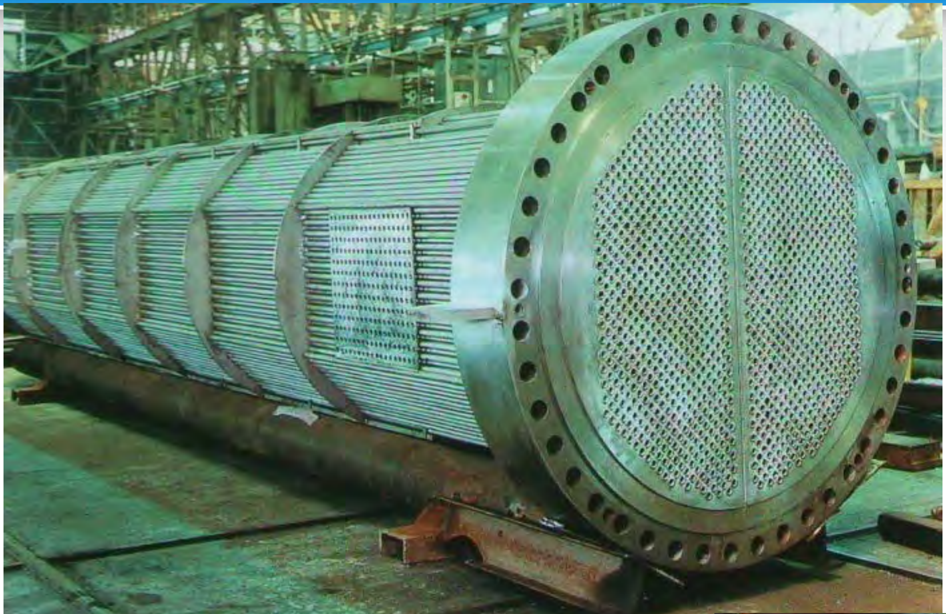
Desalination

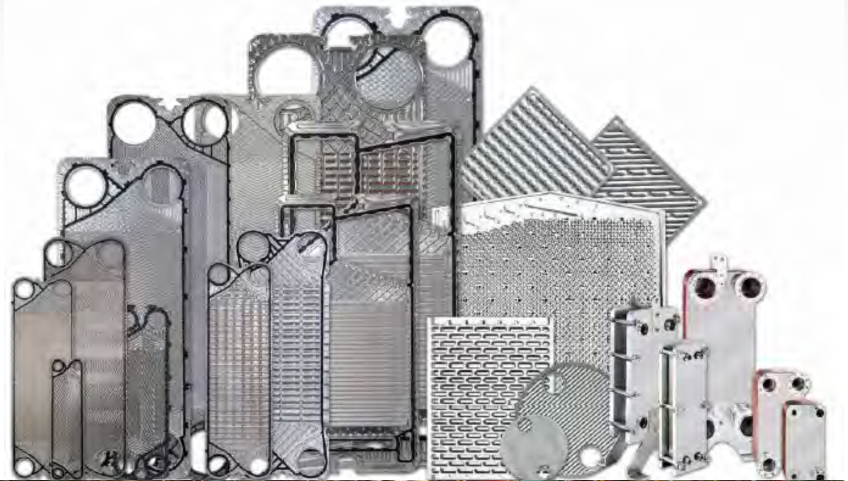


Power Generations (1)

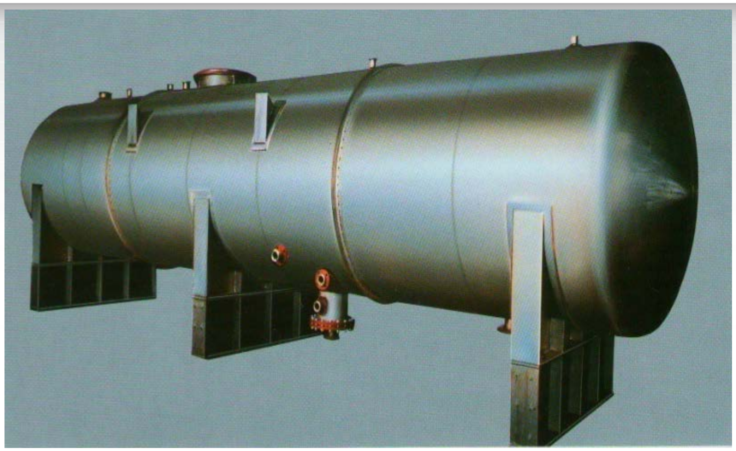


Power Generations (2)



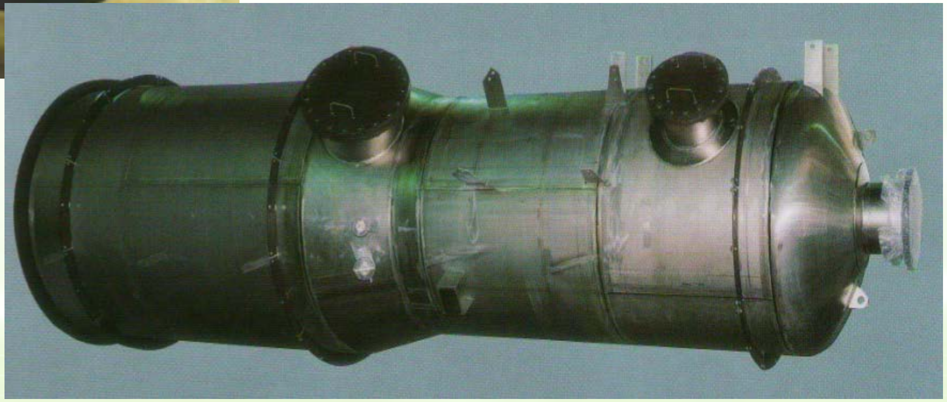


Chemicals

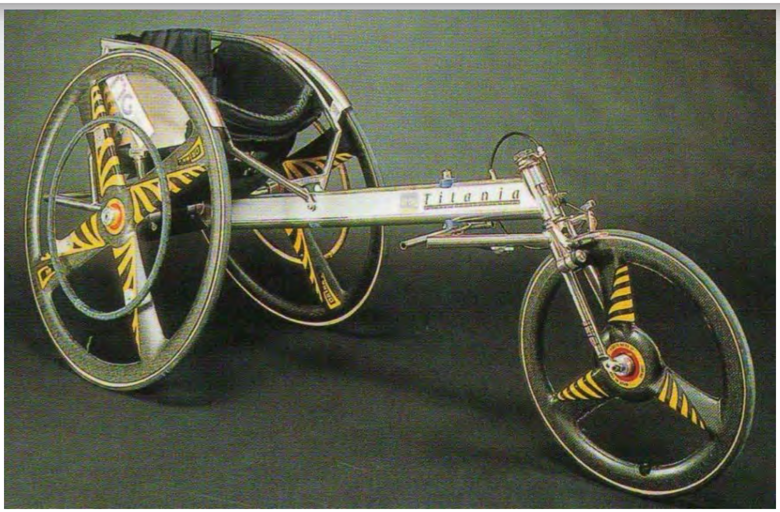


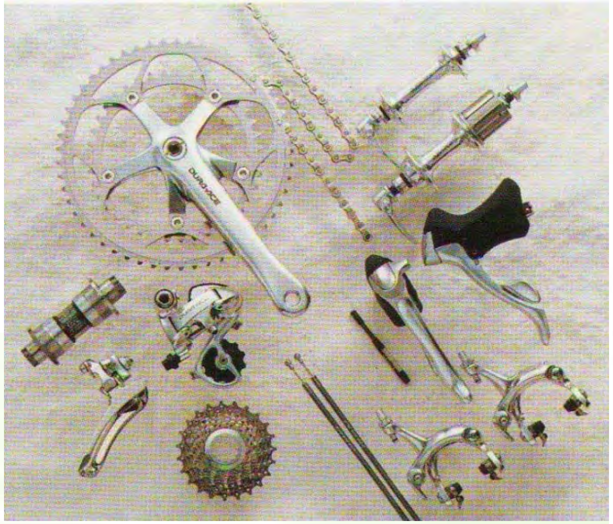
Titanium reaction tank

Titanium piping for chemical plants



Sports & Leisure (1)

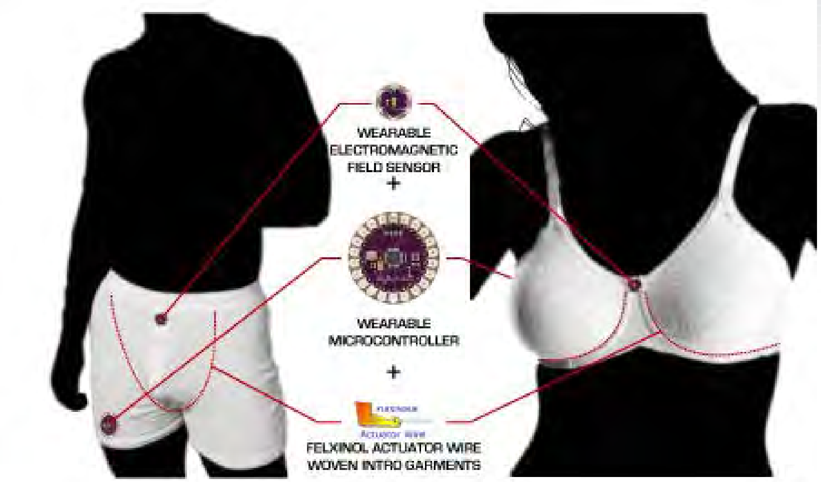


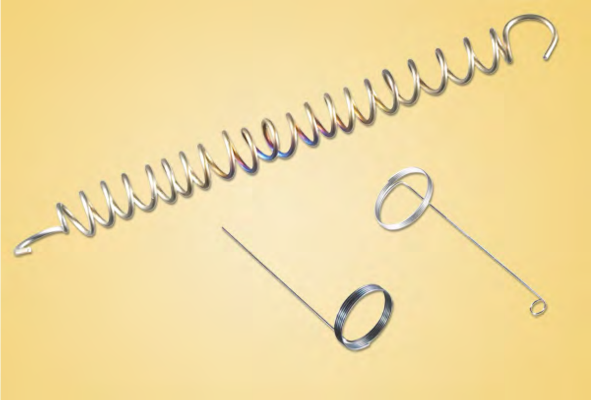


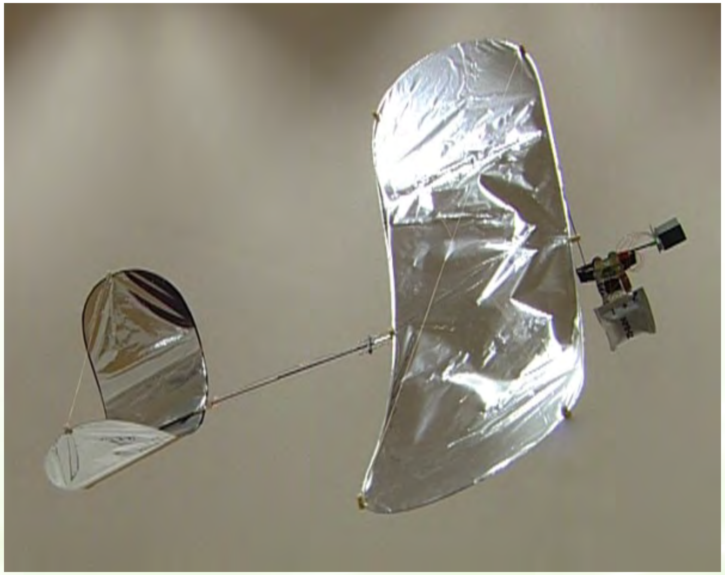
Sports & Leisure (2)

Commodities

Functional Applications

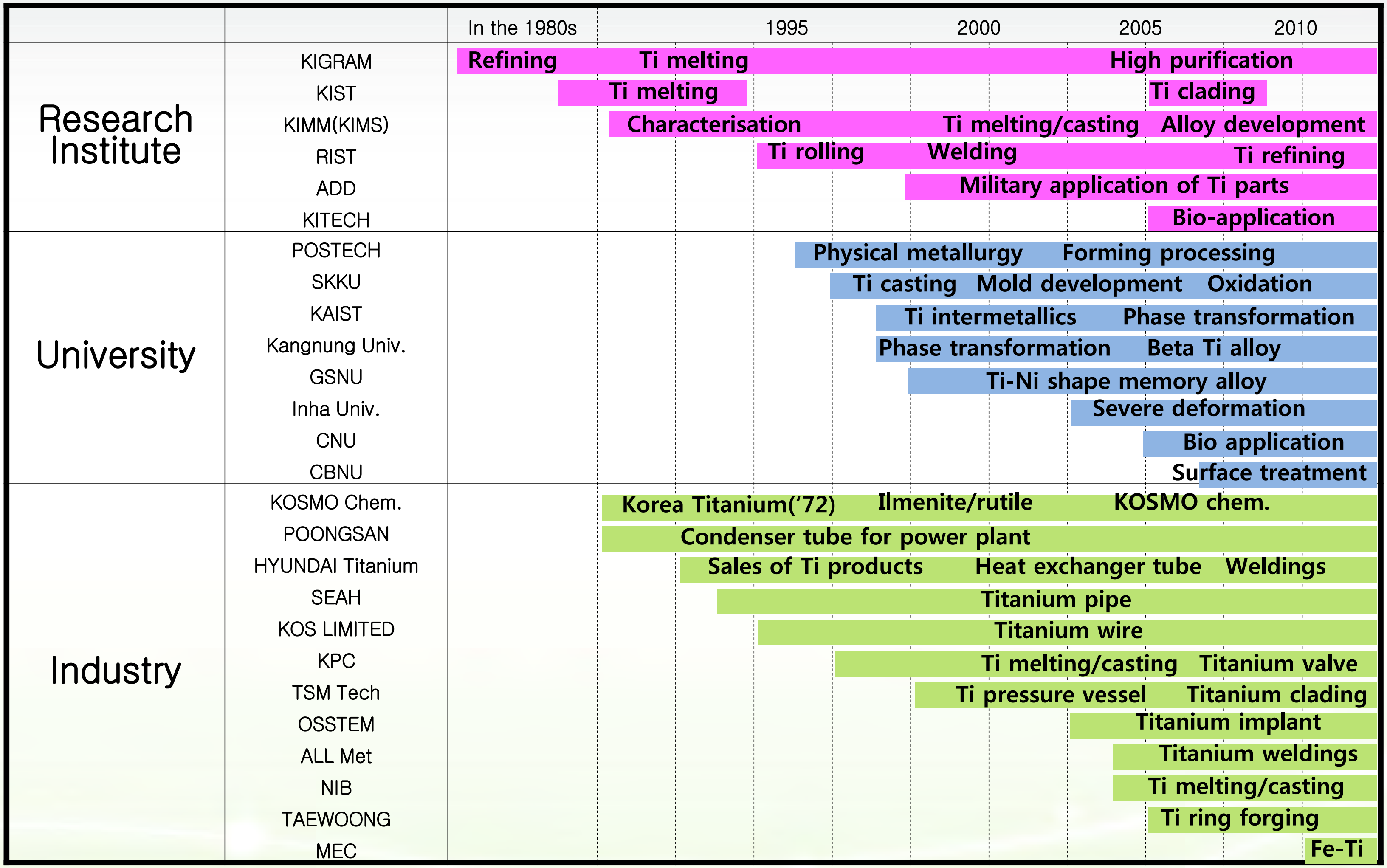






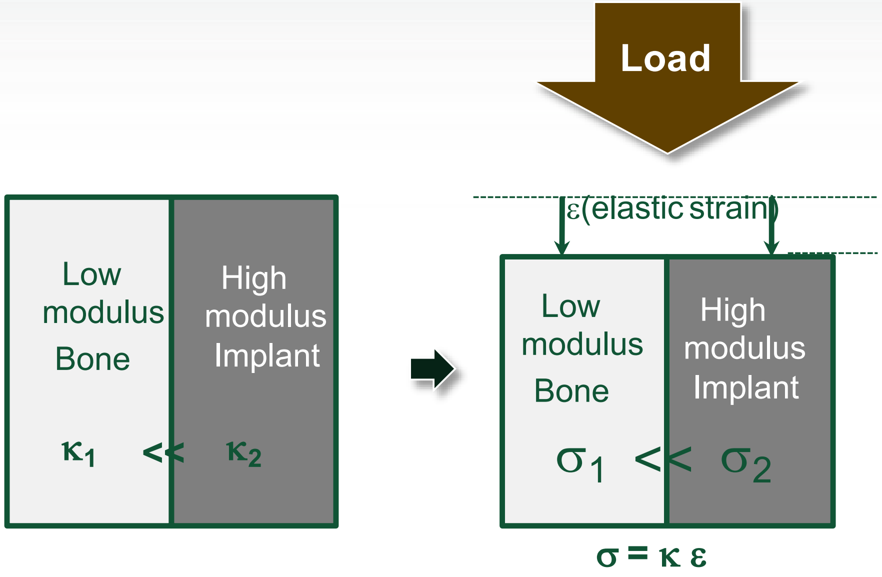
Biomedicals

R&D and Production History of Titanium in Korea



Research Institute	KIGRAM	Refining Ti melting High purification
	KIST	Ti melting Ti clading
	KIMM(KIMS)	Characterisation Ti melting/casting Alloy development
	RIST	Ti rolling Welding Ti refining
	ADD	Military application of Ti parts
	KITECH	Bio-application
University	POSTECH	Physical metallurgy Forming processing
	SKKU	Ti casting Mold development Oxidation
	KAIST	Ti intermetallics Phase transformation
	Kangnung Univ.	Phase transformation Beta Ti alloy
	GSNU	Ti-Ni shape memory alloy
	Inha Univ.	Severe deformation
	CNU	Bio application
	CBNU	Surface treatment
Industry	KOSMO Chem.	Korea Titanium('72) Ilmenite/rutile KOSMO chem.
	POONGSAN	Condenser tube for power plant
	HYUNDAI Titanium	Sales of Ti products Heat exchanger tube Weldings
	SEAH	Titanium pipe
	KOS LIMITED	Titanium wire
	KPC	Ti melting/casting Titanium valve
	TSM Tech	Ti pressure vessel Titanium clading
	OSSTEM	Titanium implant
	ALL Met	Titanium weldings
	NIB	Ti melting/casting
	TAEWOONG	Ti ring forging
	MEC	Fe-Ti

Why Titanium? – Stress Shield Effect



Load

ε(elastic strain)

Low modulus Bone

High modulus Implant

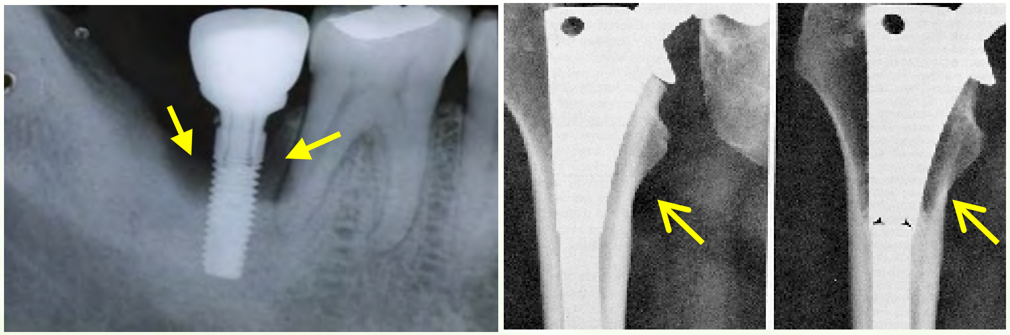
$\kappa_1 << \kappa_2$

Low modulus Bone

High modulus Implant

$\sigma_1 << \sigma_2$

$\sigma = \kappa \varepsilon$



Cortical bone : 10~30GPa
Ti alloys : 100~110GPa
Co alloys : 200GPa
STS316L : 205GPa

Elastic Modulus Difference between Bone/Implant

↓

Stress Shielding Effect

↓

Bone In-growth failure
Cortical bone loss; osseointegration

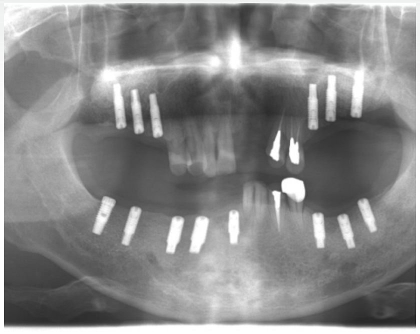
↓

Implant failure/re-operation

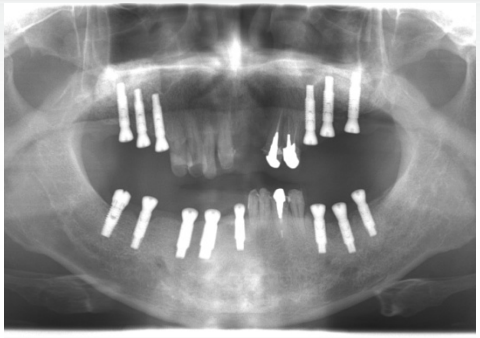
↓

Development of low modulus alloys

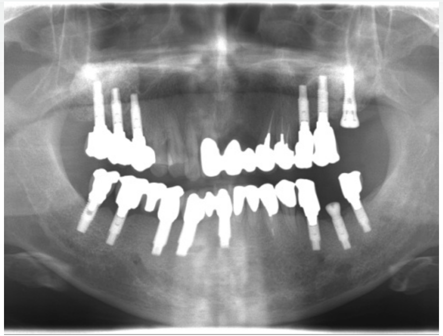
Failure Analysis of Implant



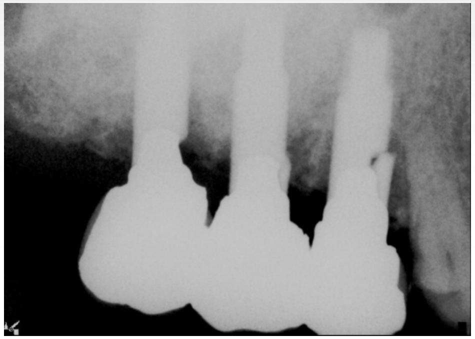
2006.09.26



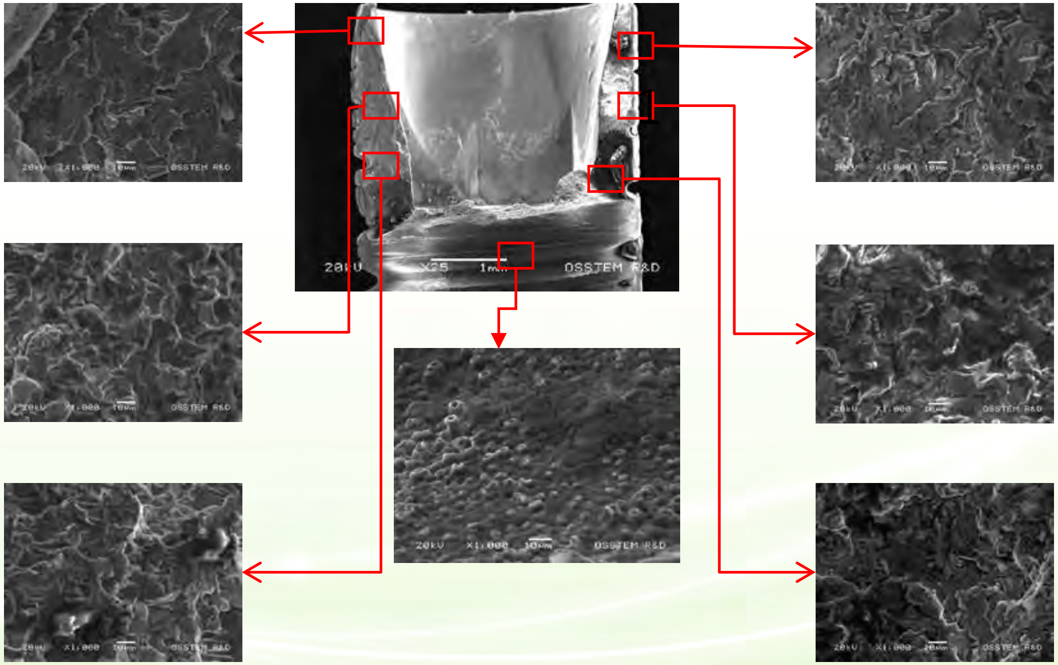
2007.03.13



2008.03.28

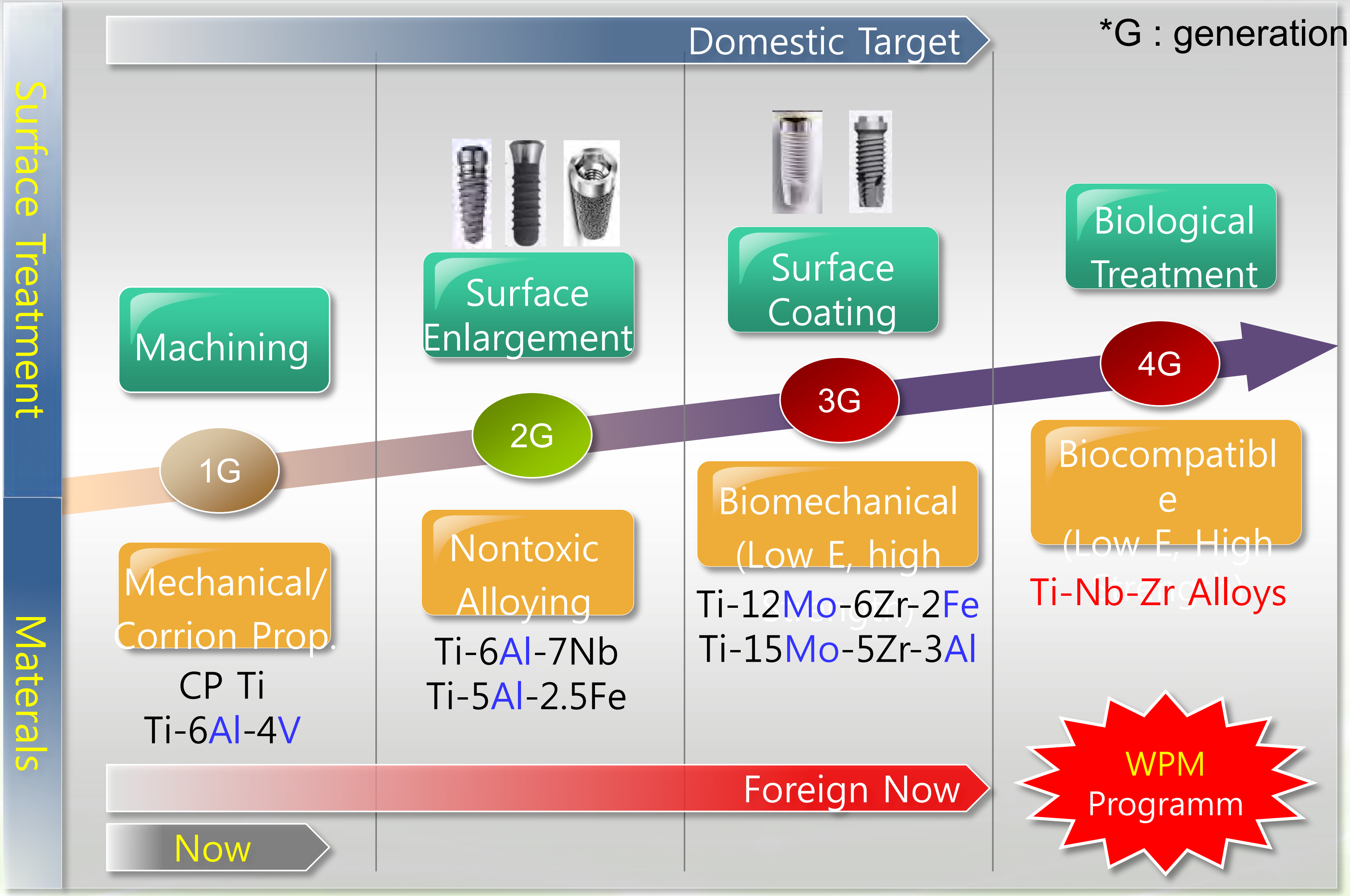


2010.04.20



Development of Titanium Implants

KIMS



*G : generation

Surface Treatment

Materials

Domestic Target

1G

Machining

Mechanical/ Corrion Prop.

CP Ti

Ti-6Al-4V

2G

Surface Enlargement

Nontoxic Alloying

Ti-6Al-7Nb

Ti-5Al-2.5Fe

3G

Surface Coating

Biomechanical (Low E, high Strength)

Ti-12Mo-6Zr-2Fe

Ti-15Mo-5Zr-3Al

4G

Biological Treatment

Biocompatibl e (Low E, High Strength)

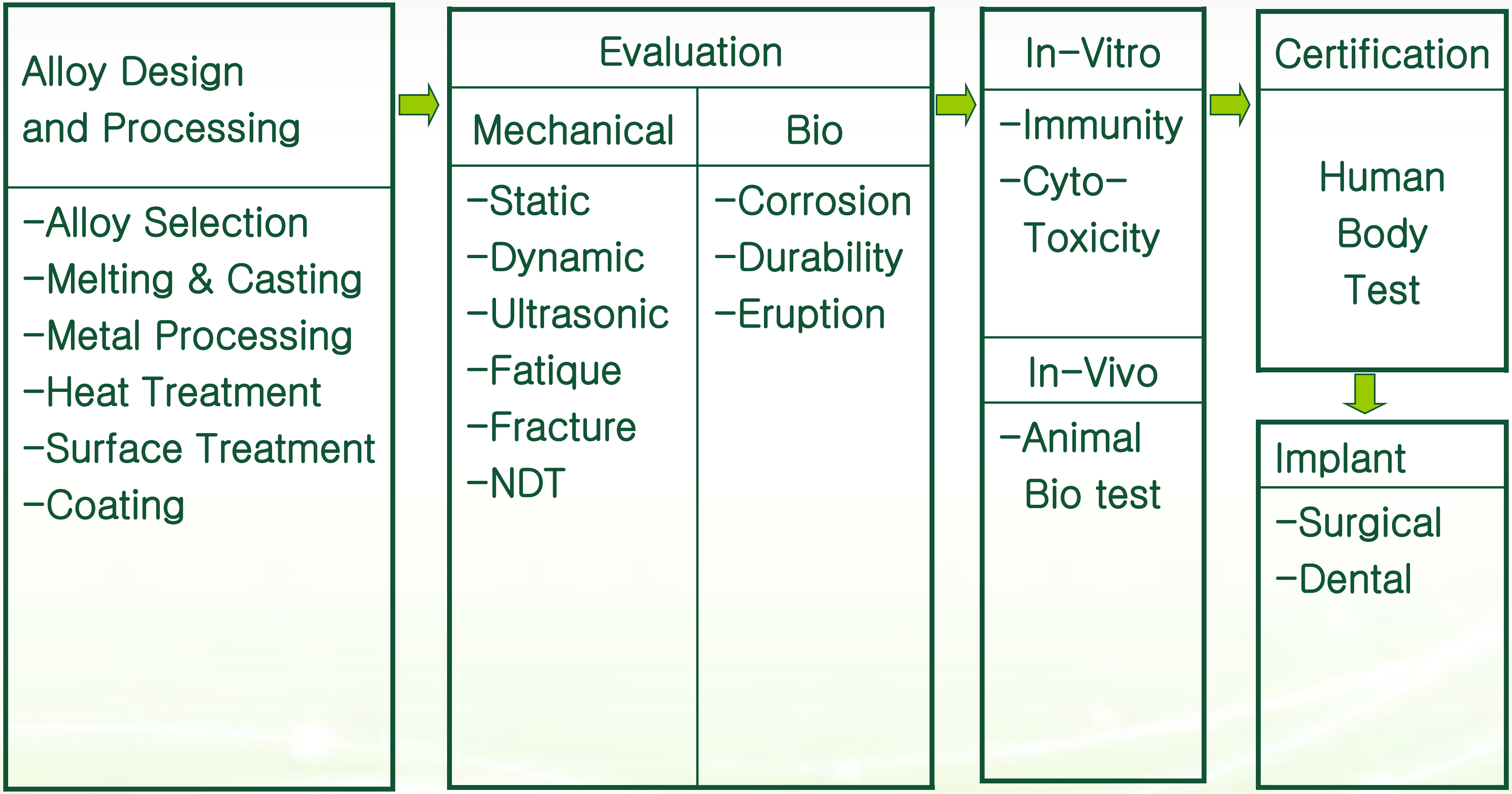
Ti-Nb-Zr Alloys

Foreign Now

Now

WPM Programm

Development of a Biomaterial Parts



Alloy Design and Processing

- −Alloy Selection
- −Melting & Casting
- −Metal Processing
- −Heat Treatment
- −Surface Treatment
- −Coating

Evaluation

Mechanical	Bio
−Static −Dynamic −Ultrasonic −Fatique −Fracture −NDT	−Corrosion −Durability −Eruption

In−Vitro

- −Immunity
- −Cyto− Toxicity

In−Vivo

- −Animal Bio test

Certification

Human Body Test

Implant

- −Surgical
- −Dental

DV-Xα Cluster Method

This approach is based on the theory of molecule orbital by electron circulation.

- electrons move atomic orbitals
- LCAO (Linear combination of atomic orbitals) metho

아다치 히로히코(足立裕彦)
모리나가 마사히코(森永正彦)
나스 센자부로(那須三郎),
(1973)

Wave function is related to potential of atomic orbital

$$\emptyset_i = \sum_i C_{ij} x_i(1)$$

While molecular orbital function is expressed by

$$\sum_j (H_{ij} - \varepsilon_k S_{ij}) C_{jk} = 0$$

This function is transformed by Hamiltonian equation into the followed matrix

$$H_{ij} = \int x_i^*(1) H x_j(1)\ dv_1$$

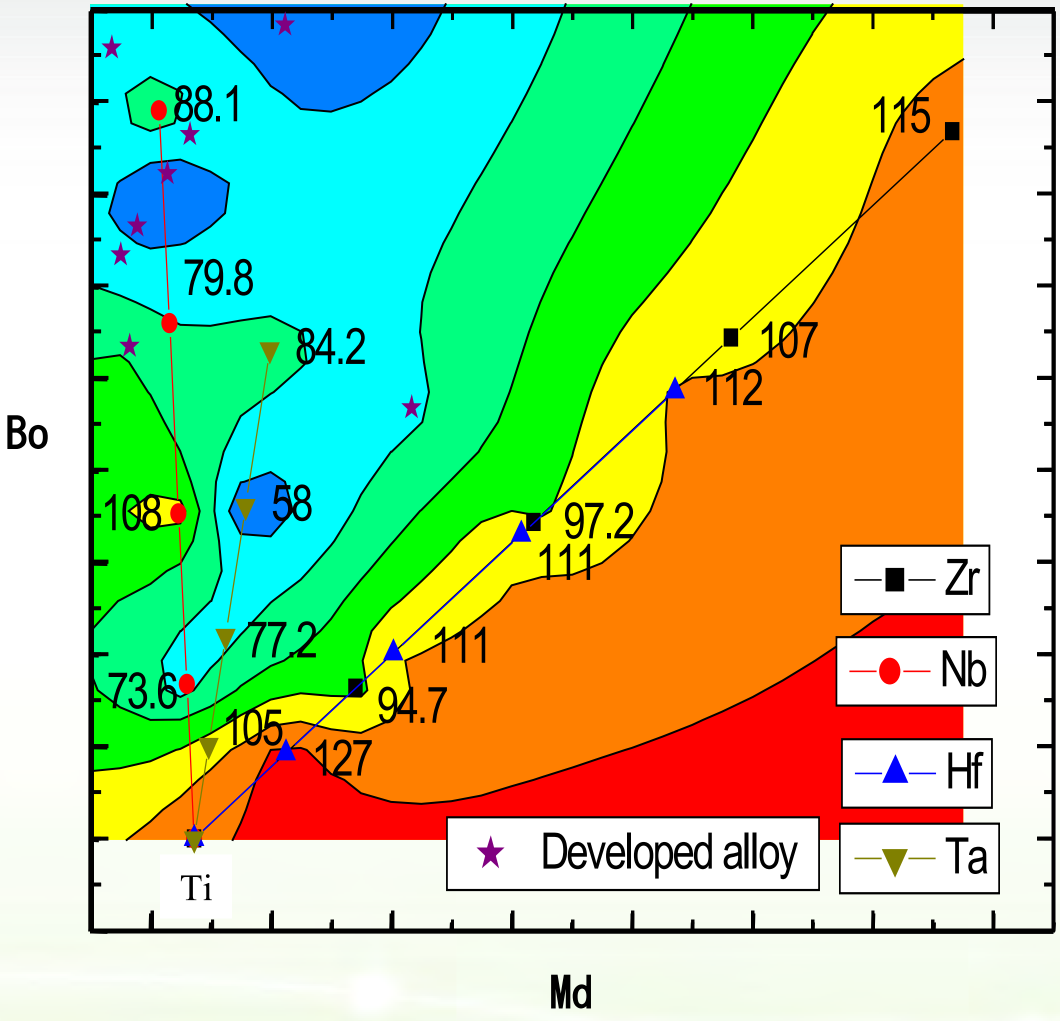
$$S_{ij} = \int x_i^*(1)\ x_j(1)\ dv_1$$

H: electron Hamiltonian

$$H(1) = -\frac{1}{2} \nabla_1^2 - \sum_v \frac{z_v}{r_{1v}} + \int \frac{\rho(2)}{r_{12}} dv_2 + v_{xc}(1)$$

By solving these equations, we can calculate electron density, electron number, then using these values, covalent bond strength between atomic orbital i and j in overlap population (Q_{ij}) can be calculated. Consequently, bond order of atoms showing covalent bond (Bo) and Fermi energy level of d-electrons (Md) can be determined.

Low Elastic Modulus Group on Bo-Md Map



$$Bo = \sum[(P_{M-Ti,d})_i + (P_{Ti-Ti,d})_i]$$

$$Md = \frac{3E_{t2g} + 2E_{eg}}{5} - E_F$$

$$\overline{Bo} = \sum X_i Bo$$

$$\overline{Md} = \sum X_i Md$$

Bo : Bond Order

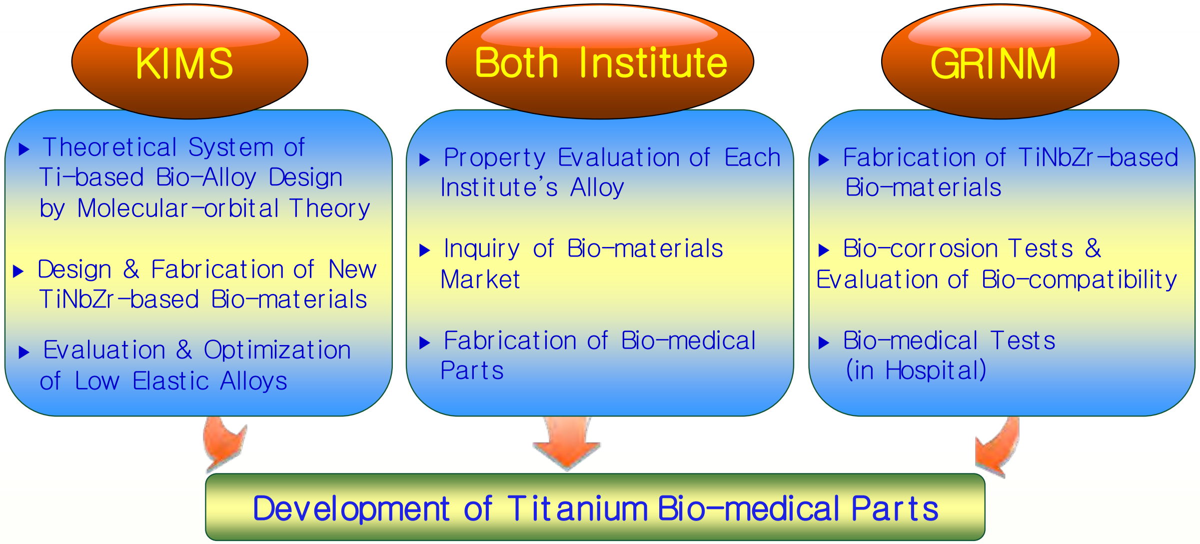
Md : d Electron Orbital Energy level

Titanium Alloy Design and Parts Development for Medical Implant

Research Purposes :

1. Alloy design of new β-based Ti alloy for bio-material parts
2. Titanium bio-materials with low elastic modulus (below 60 GPa) and excellent bio-compatibility, better formability

Research Contents :



KIMS

- Theoretical System of Ti-based Bio-Alloy Design by Molecular-orbital Theory
- Design & Fabrication of New TiNbZr-based Bio-materials
- Evaluation & Optimization of Low Elastic Alloys

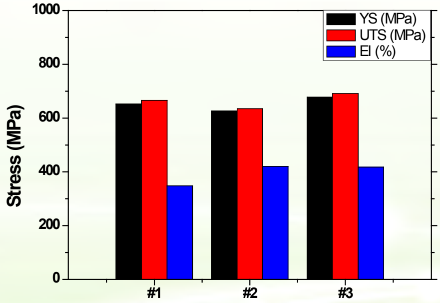
Both Institute

- Property Evaluation of Each Institute's Alloy
- Inquiry of Bio-materials Market
- Fabrication of Bio-medical Parts

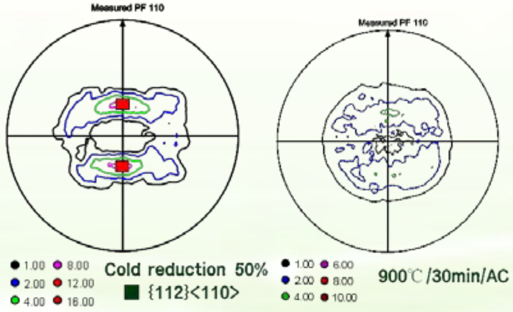
GRINM

- Fabrication of TiNbZr-based Bio-materials
- Bio-corrosion Tests & Evaluation of Bio-compatibility
- Bio-medical Tests (in Hospital)

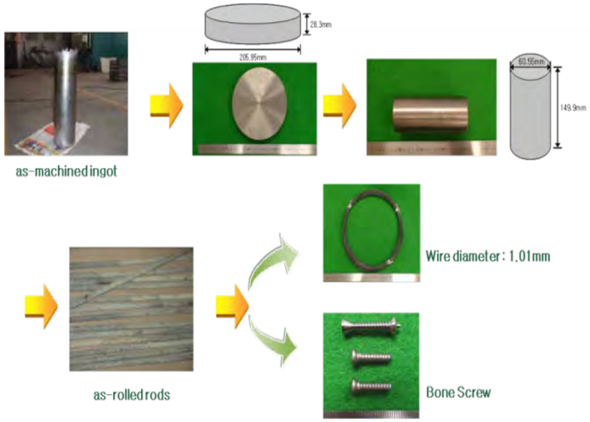
Development of Titanium Bio-medical Parts

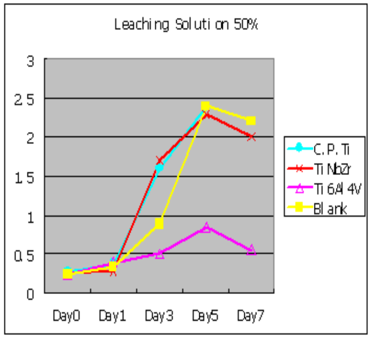


	탄성계수 (GPa)
#1	38.2
#2	39.7
#3	38.0
#4	39.8
Ave.	38.9



Fabrication of new TNZ40 Alloy :





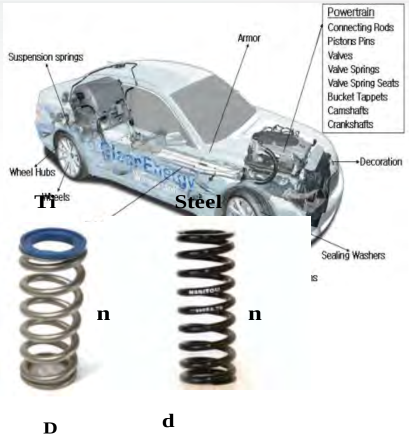
Light absorption (OD value)

1. Lee D-G, Lee Y.T., Mi, X.J., Ye W.J., Hui S.X. ; Korea Patent, 10-0971649, PCT/KR2008/007693
2. Mi, X.J., Ye W.J., Hui S.X., Lee D-G, Lee Y.T. : 200810240992.X, □□, □ several patents/papers/presentations

LCB Titanium Alloys

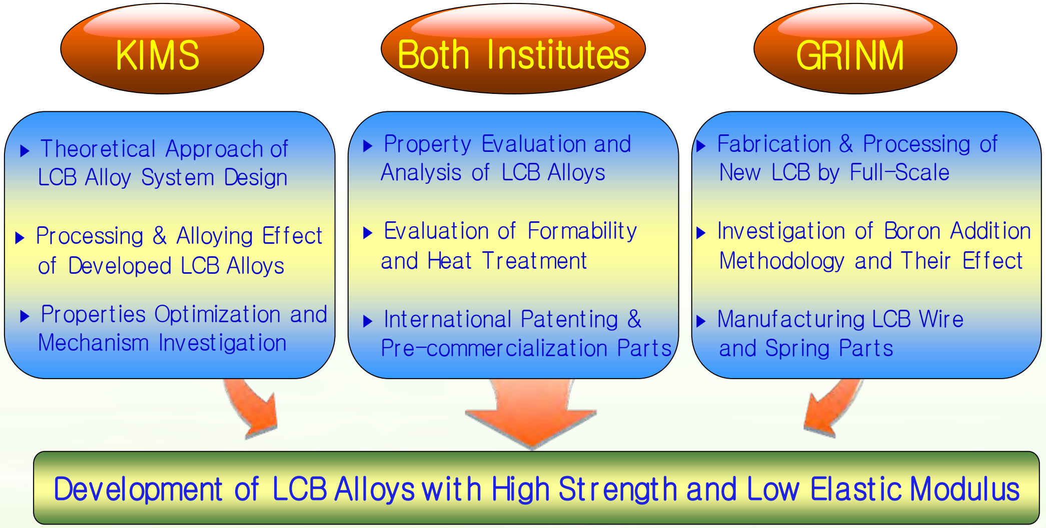
Research Purposes :

1. Development of the new beta titanium alloys having low elastic modulus and high strength by low cost alloying elements
2. Understanding of the alloying effect, microstructure evolution, strengthening mechanism and property optimization in the series of low cost beta titanium alloys
3. Development of a cost-effective material and processing method for automotive applications



Spring :	28 g	100 g
System :	47 %	100 %

Research Contents :



KIMS	Both Institutes	GRINM
Theoretical Approach of LCB Alloy System Design	Property Evaluation and Analysis of LCB Alloys	Fabrication & Processing of New LCB by Full-Scale
Processing & Alloying Effect of Developed LCB Alloys	Evaluation of Formability and Heat Treatment	Investigation of Boron Addition Methodology and Their Effect
Properties Optimization and Mechanism Investigation	International Patenting & Pre-commercialization Parts	Manufacturing LCB Wire and Spring Parts

Development of LCB Alloys with High Strength and Low Elastic Modulus

1. Lee D-G, Lee Y.T., Seo J.H. ; Korea Patent, 12-0057217, under PCT

Advantages :

♣ Low Cost-Cheap Materials

1. Low grade sponge
2. Cheap alloying element
3. Composition tolerance
4. Fabrication cost down
5. Mass production

as-machined ingot

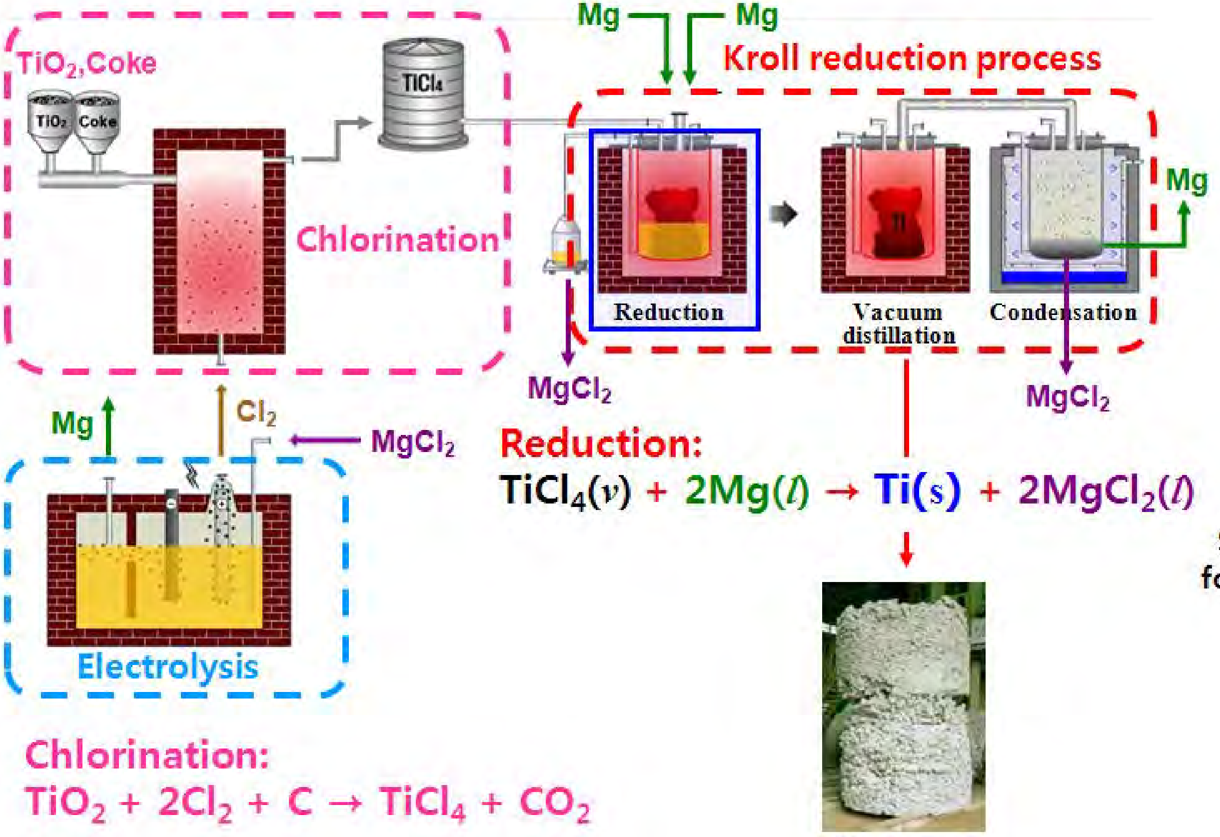
as-rolled rods

wires

Ti Steel

Kroll Process

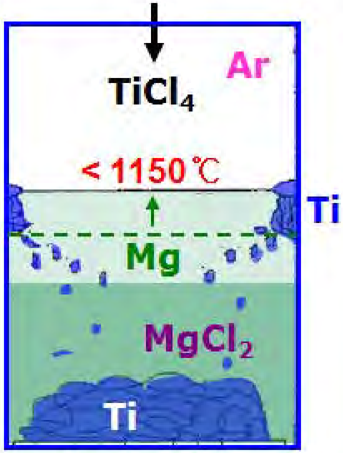
- Commercialized extraction process: >99% world Ti sponge production
- High productivity



Reduction:

$TiCl_4(v) + 2Mg(l) \rightarrow Ti(s) + 2MgCl_2(l)$

Ti sponge



Schematic view of Ti sponge formation from Kroll reduction (800~850℃)

Chlorination:

$TiO_2 + 2Cl_2 + C \rightarrow TiCl_4 + CO_2$

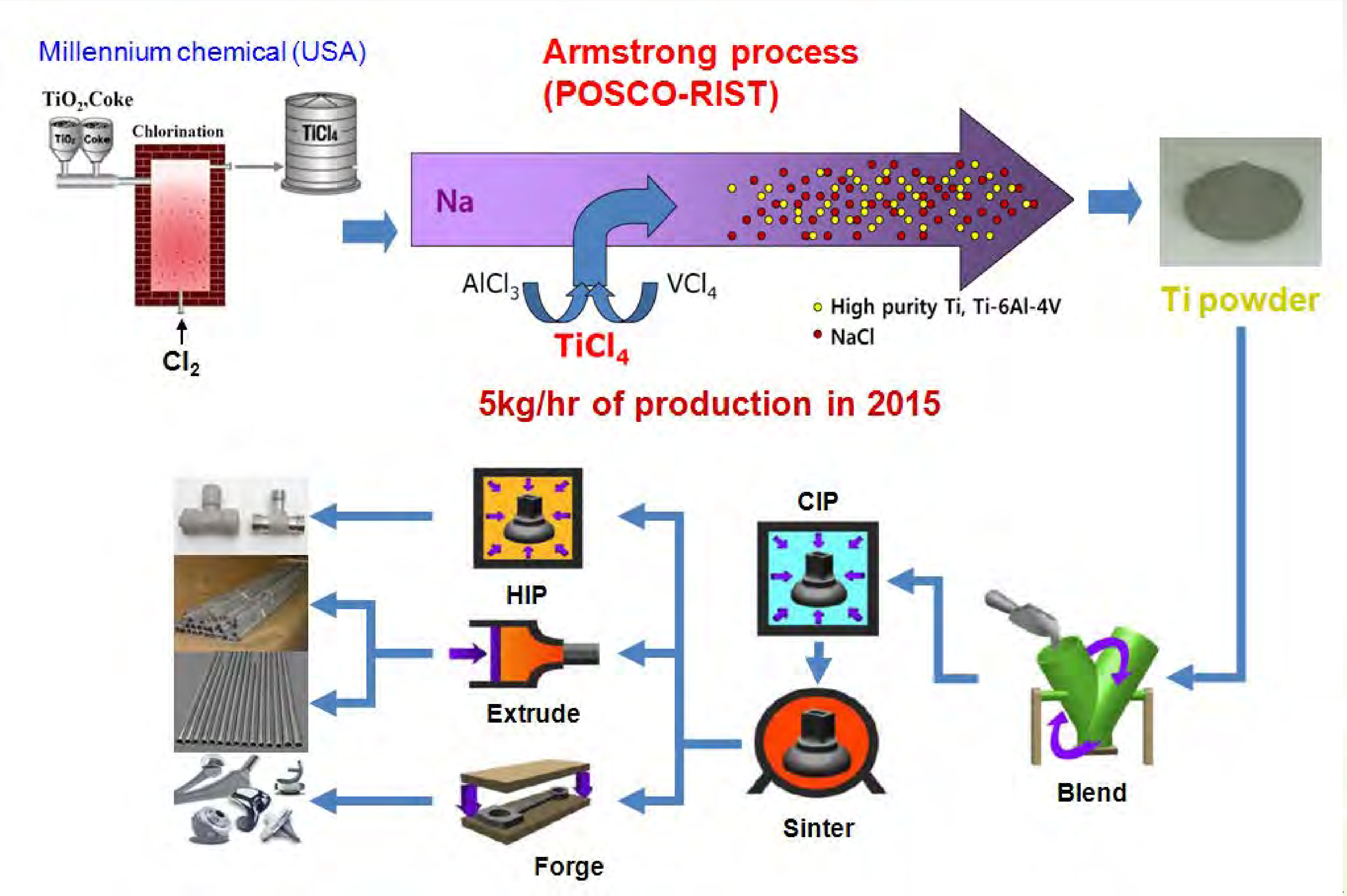
Electrolysis:

$MgCl_2 \rightarrow Mg + Cl_2$

(cathode: carbon, anode: Stainless steel)

Direct Titanium Powder Process

KIMS

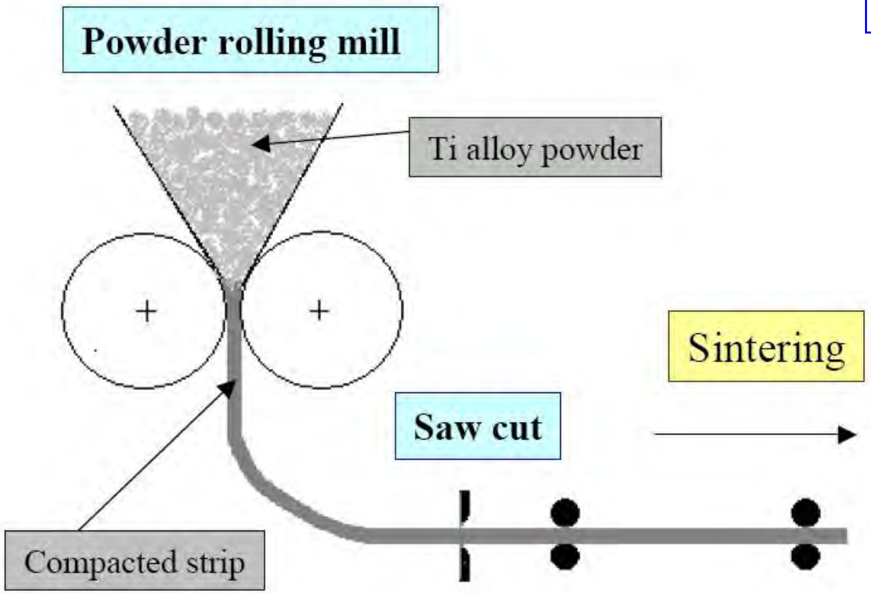


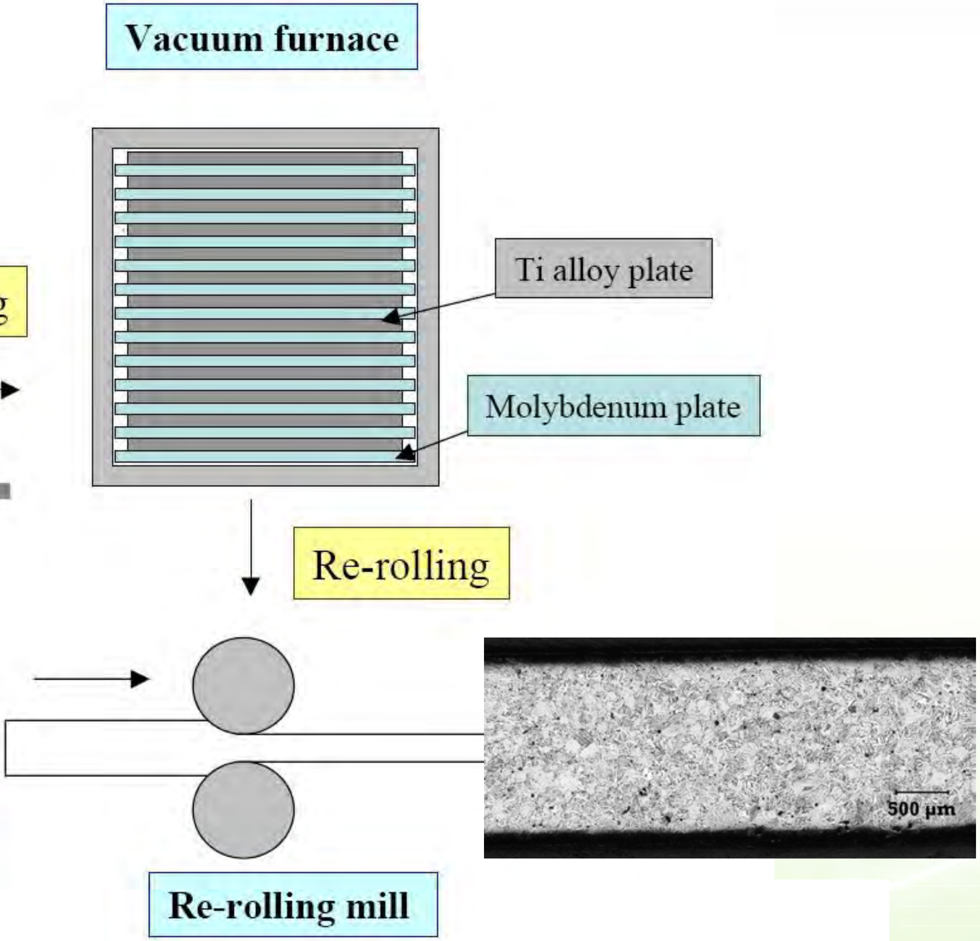
Direct Powder Rolling for Sheet

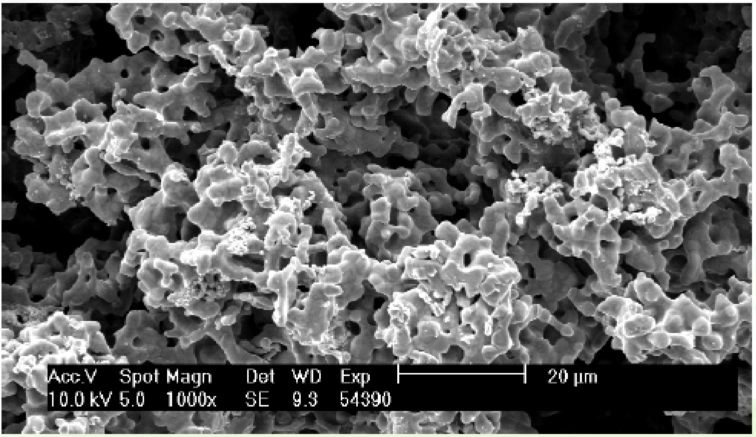
KIMS

Direct Powder Rolling

Materials Parameter: Purity, Size, Shape, Binder, Sinterability, etc.
Process Parameter: Roll Speed, Roll Gap, Roll Dia., Temperature, Humidity, etc.







Titanium Precision Castings

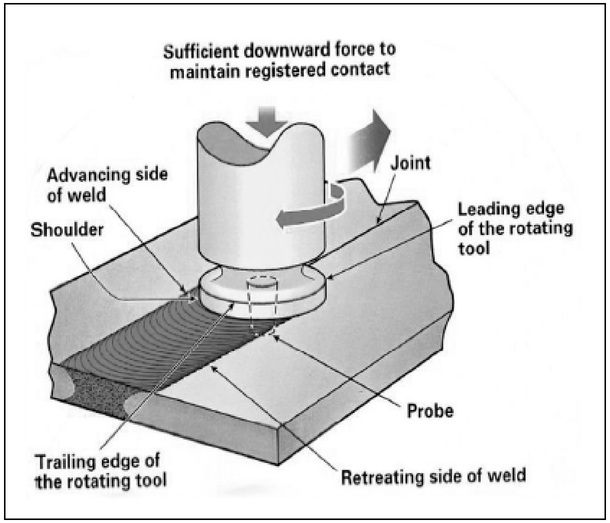
Titanium Ingot Defects and Causes

Processing	Origin of Defects	Type of Defects
Materials	- Raw Materials * Sponge Contamination * Recycled Titanium * Matster Alloy Contamination * TIG Welding - Ingot * Aggressive Grinding	 Type Ⅰ (LDI, HID, HA) Type Ⅰ, HDI (High Density Inclusion) Type Ⅰ Type Ⅰ, HDI Type Ⅰ
Melting	- Solidification * Segregation * Microstructure * Shrinkage - Processing * Air leak, Water leak * Arc Power Level Variation	 Type Ⅱ (HAD) Beta fleck, Blocky Alpha Large Dendrite Shrinking Pipe, Porosity Type Ⅰ Type Ⅱ, Beta Fleck, Blocky, Alpha
Forming	* Heating Process * Microstructure * Strain rate * Oxide Inclusion * Super Cooling	Alpha Case Elongated Alpha SIP (Strain Induced Porosity) Fold (Alpha case Folding) Crack in Corner

Solution of the Defects

Processing	Defects	Reasons	Solution
Solidification Defects	Type Ⅰ Type Ⅱ Blocky Alpha Beta Fleck Dendrite Micro Shrinkage Micro Porocity HDI	N, O Solidification Shrinkage Micro solidification Segregation Local Heating, Over Heating In profer solidification Local solidification Ce, N, O W, Ta, WC, Nb	Raw materials Control, Triple melts Triple melt, Top Cutting Diffusion of the billet Diffusion of the billet Egui axed microstructure Shrinkage Mechanical Welding Raw material control Screening the HMM
Processing Defects	Alpha Case Elongated Alpha SIP Fold Corner Crack	Oxidation In Sufficient Recrystallication Non uniform Deformation Folding the Ingot Local Cooling	Shot Blasting, Chem-Milling Sufficient Plastic deformation Uniform microstructure Die Design Edge cutting, Local Heating

Friction Stir Welding



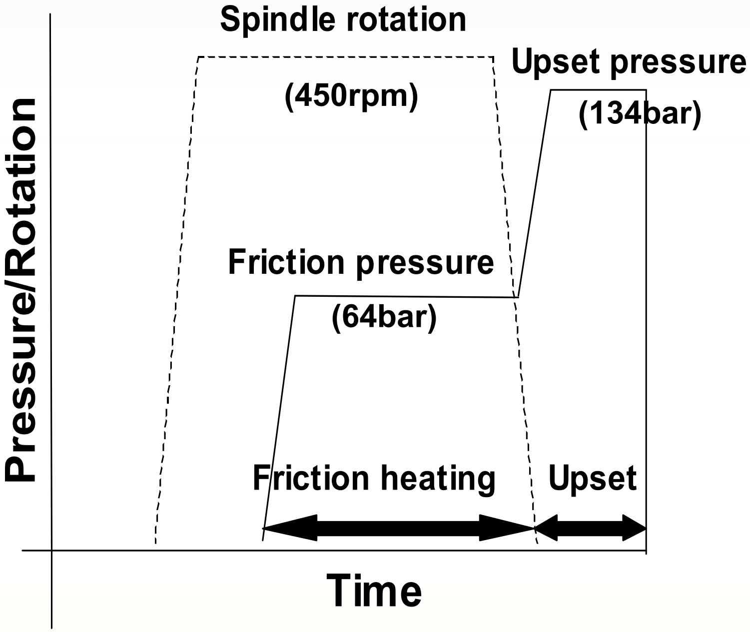
- FSW was invented by W M Thomas in 1991 (International patent application PCT/GB92/02203)
- Over 1600 patents have been filed on FSW.
- About 10 FSW equipment manufacturers are licensed by TWI as at 16 May 2005.
- FSW can be applied in shipbuilding and marine industries, aerospace industries, railway industries, car industries, etc.

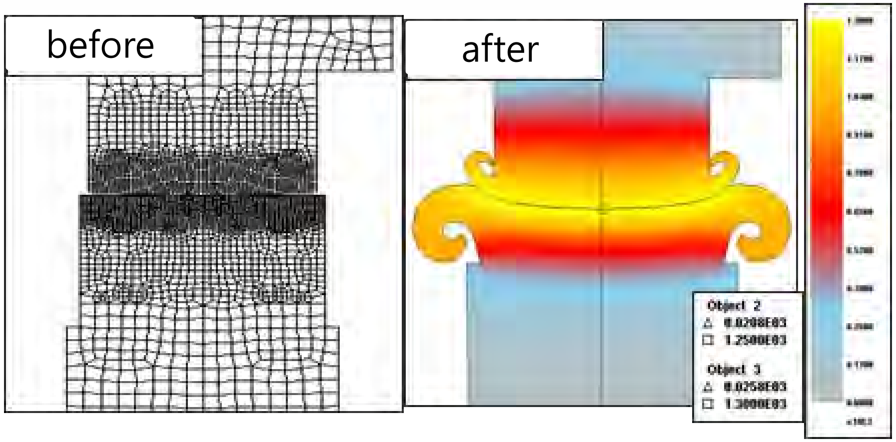
Process	Welding Speed (mm/min)	Power at Work kW	Gross Power Required (kW)	Heat Input kJ/mm
FSW	500	2	2.5*	0.24
MIG (Mech)	300	7.5	8.6	1.5
CO_2 Laser	5000 1600	10 5	112 55	0.12 0.18

* - using a geared drive would increase value

FSW of 6mm Ti-64 plate

Friction Stir Welding

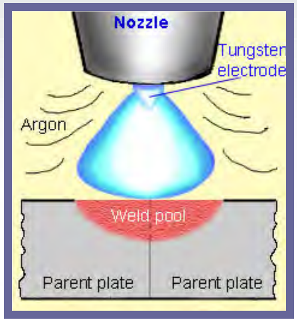




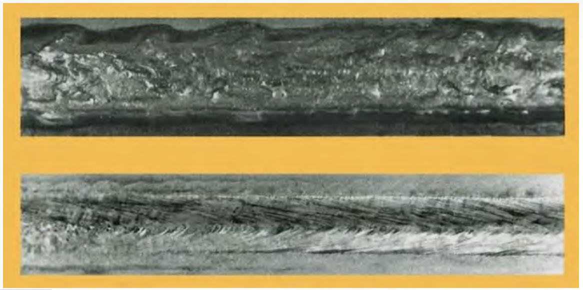
Properties	(α+β) – (α+β)	(α) – (α+β)	(β) – (α+β)
YS (MPa)	888.24	378.58	880.05
UTS (MPa)	958.13	509.38	883.72
El (%)	17.7	20.5	19.3

Titanium Welding with Flux

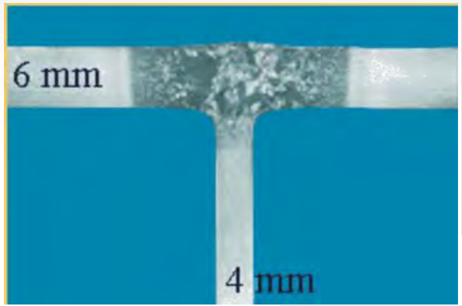
a

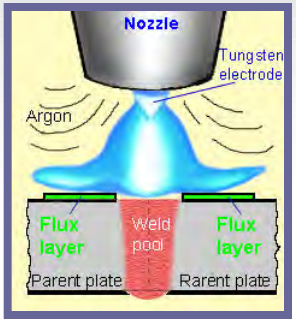


TIG-F

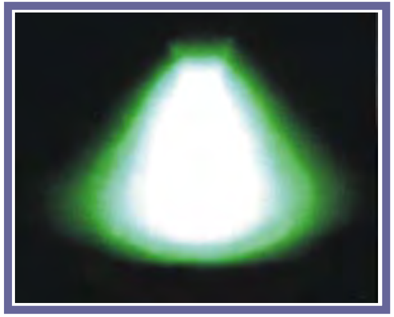


TIG-FW





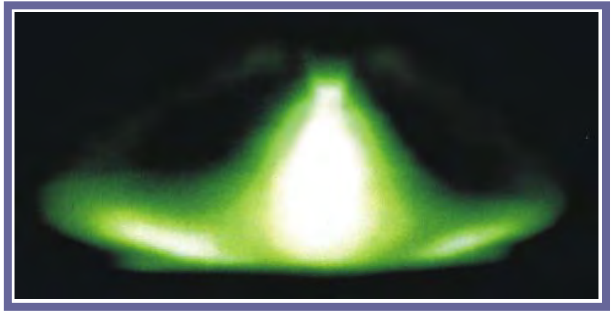
b

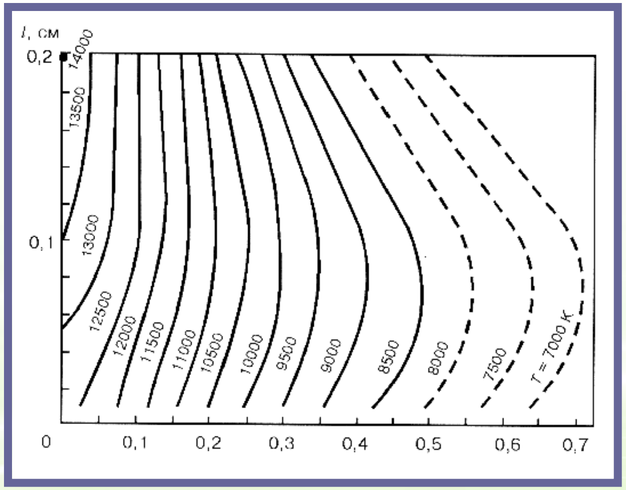


Video picture of the arc

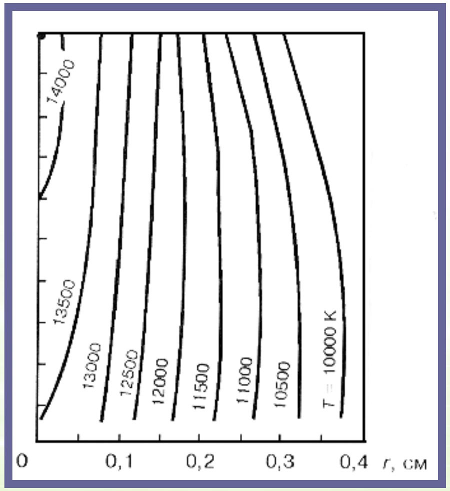
a – without flux

b – with flux

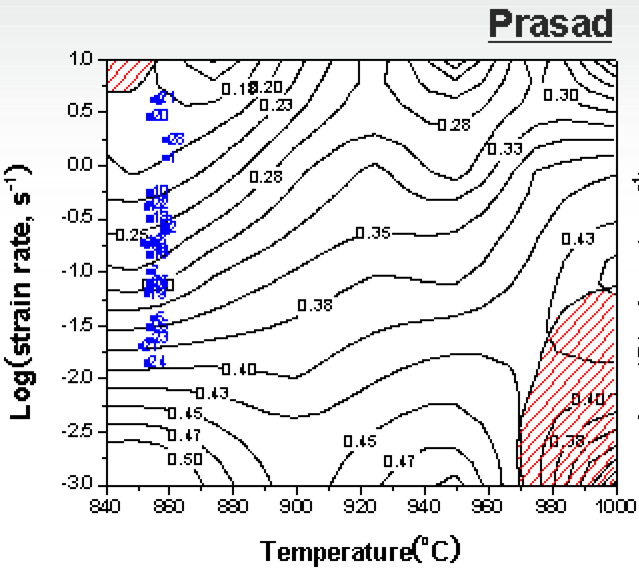




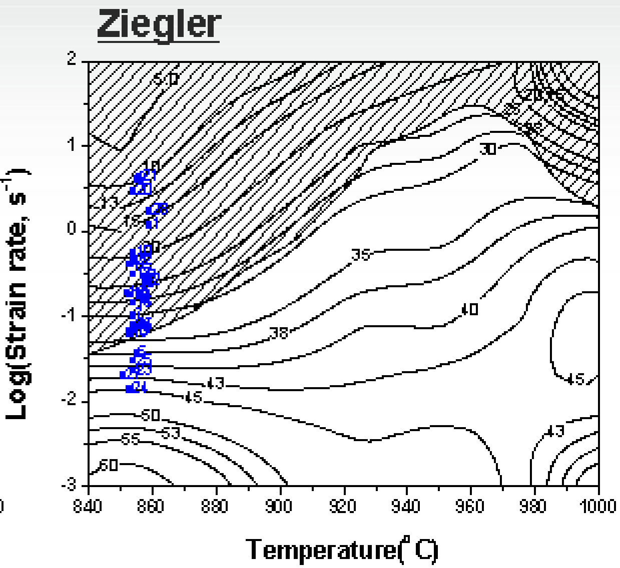
Distribution of temperature across the arc axis



Titanium Alloys Isothermal Forging

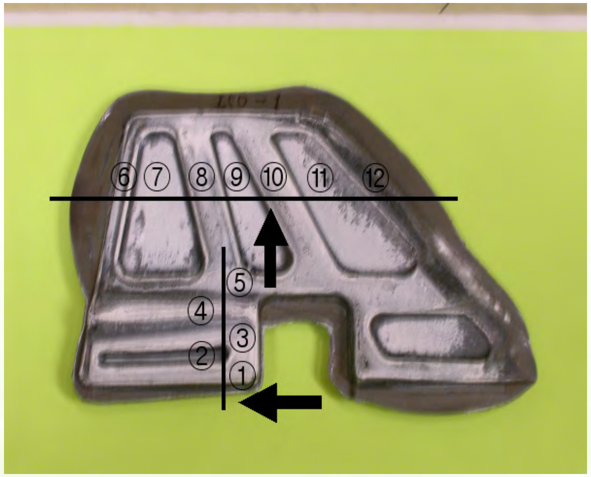


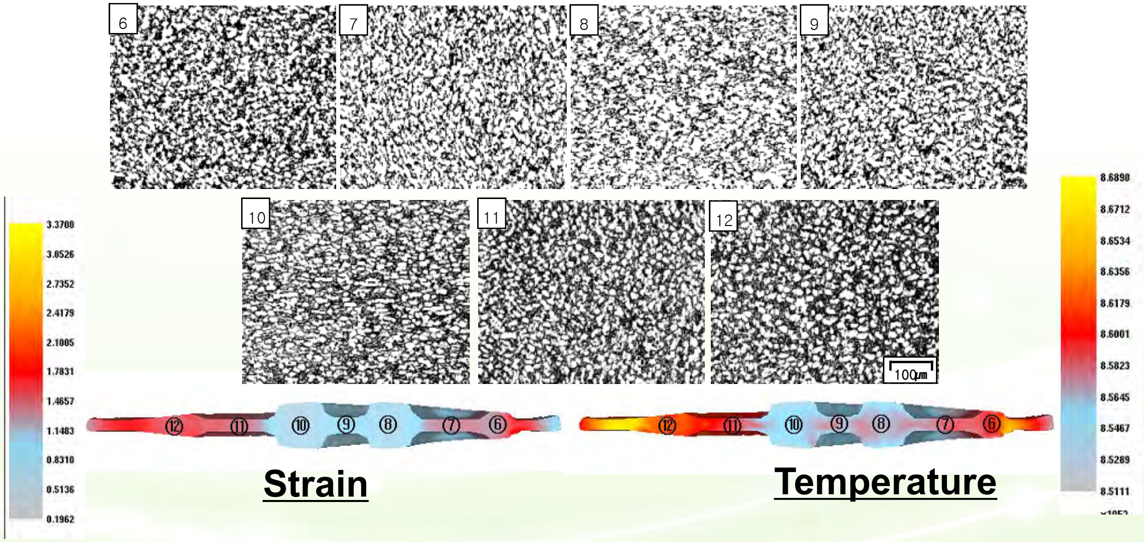
Prasad



Ziegler

- mold temp. : 850°C
- mat. temp. : 850°C
- ram speed : ~1mm/s





Strain

Temperature

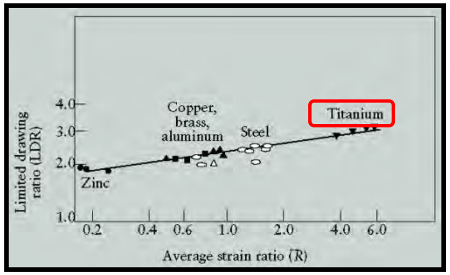
Precision Forming of Titanium Alloys

KIMS

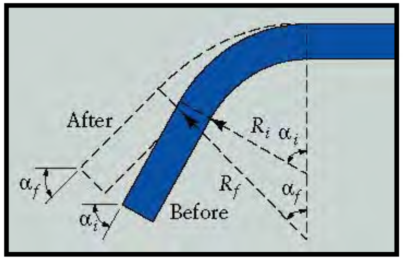
Work Scope

1. Process Windows for Sheet Metal Forming of Titanium Metals and Alloys
2. Characterization and Enhancement of Sheet Metal Formability of Titanium Alloys

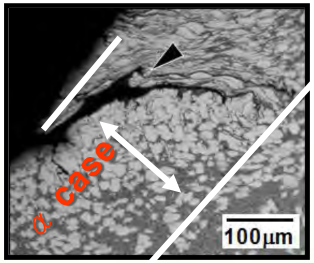
Anisotropic Deformation Behavior



Spring back

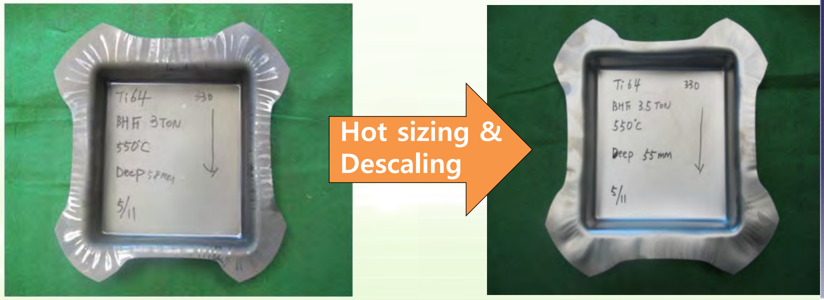


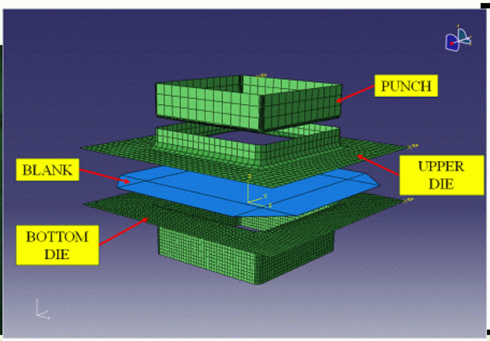
Formation of α Case and Surface Crack

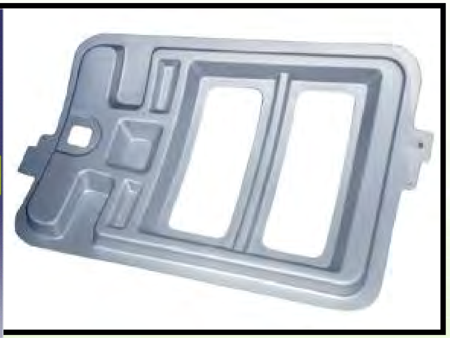


Sticking with Dies

Deep Drawing of Ti- 64 Alloys Sheets



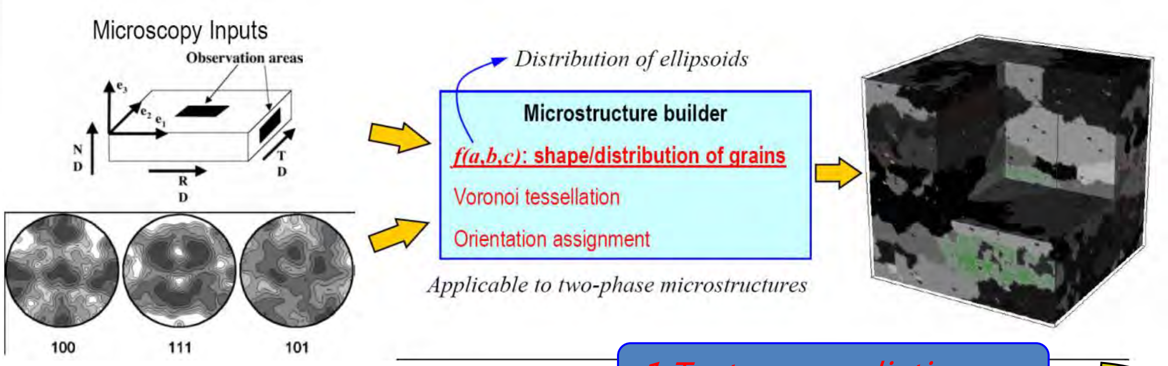




Precision Forming of Titanium Alloys

Work Scope

- FE Simulation of anisotropic deformation behavior and microstructure evolution


Microscopy Inputs

Distribution of ellipsoids

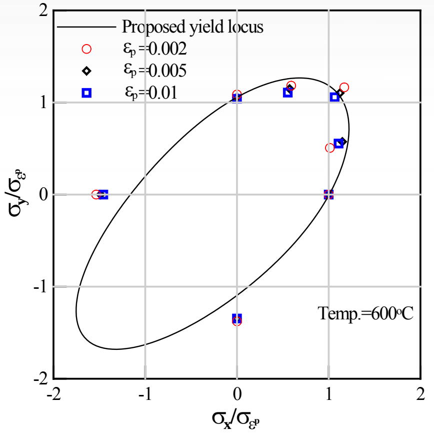
Microstructure builder

f(a,b,c): shape/distribution of grains

Voronoi tessellation

Orientation assignment

Applicable to two-phase microstructures

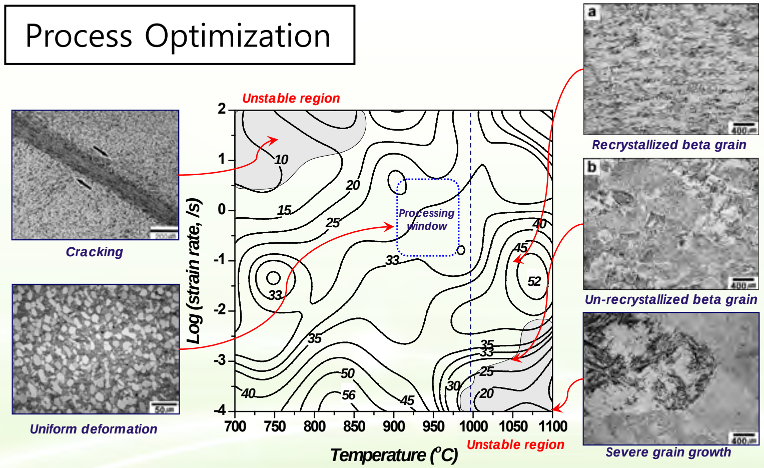


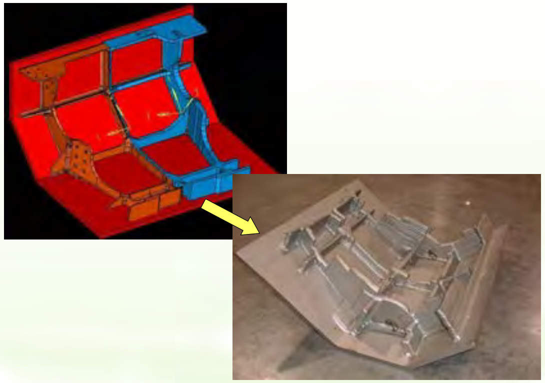
1.Texture prediction

2. Microstructrure evolution

3. Simulation and Manufacturing

Process Optimization





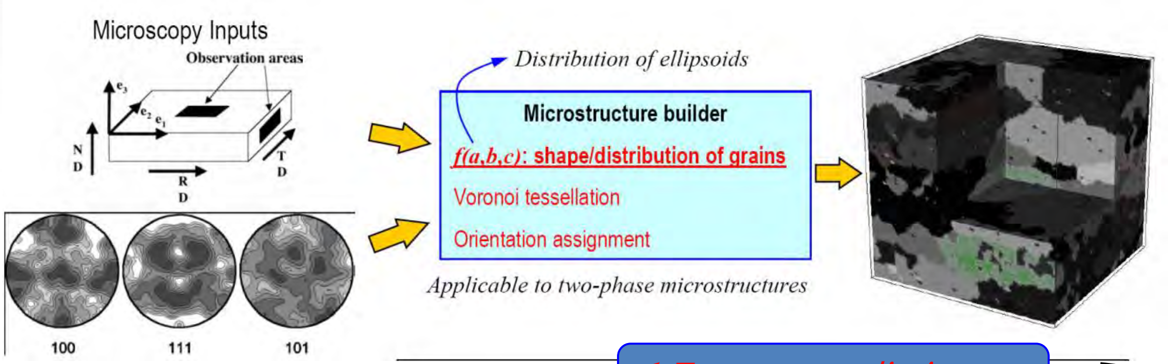
Isothermally Forged Part

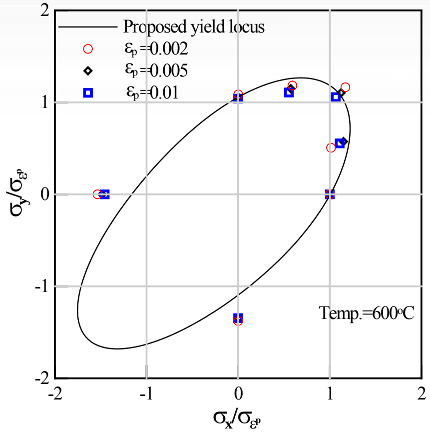
Precision Forming of Titanium Alloys

KIMS

Work Scope

- FE Simulation of anisotropic deformation behavior and microstructure evolution



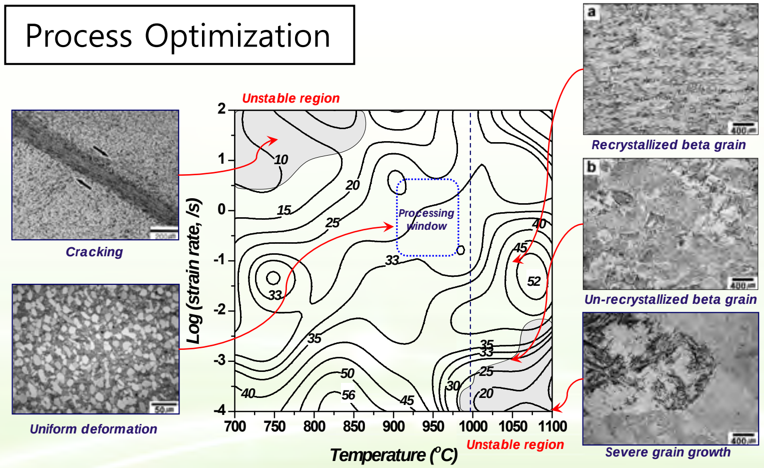


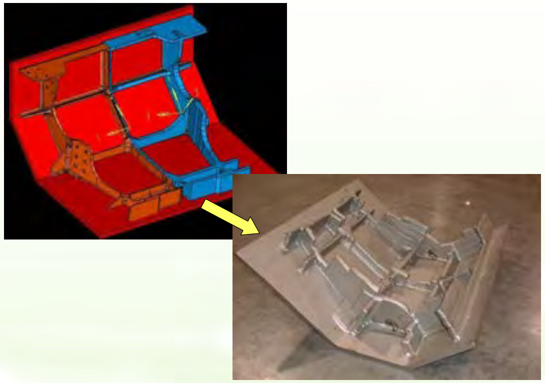
1.Texture prediction

2. Microstructrure evolution

3. Simulation and Manufacturing

Process Optimization





Isothermally Forged Part

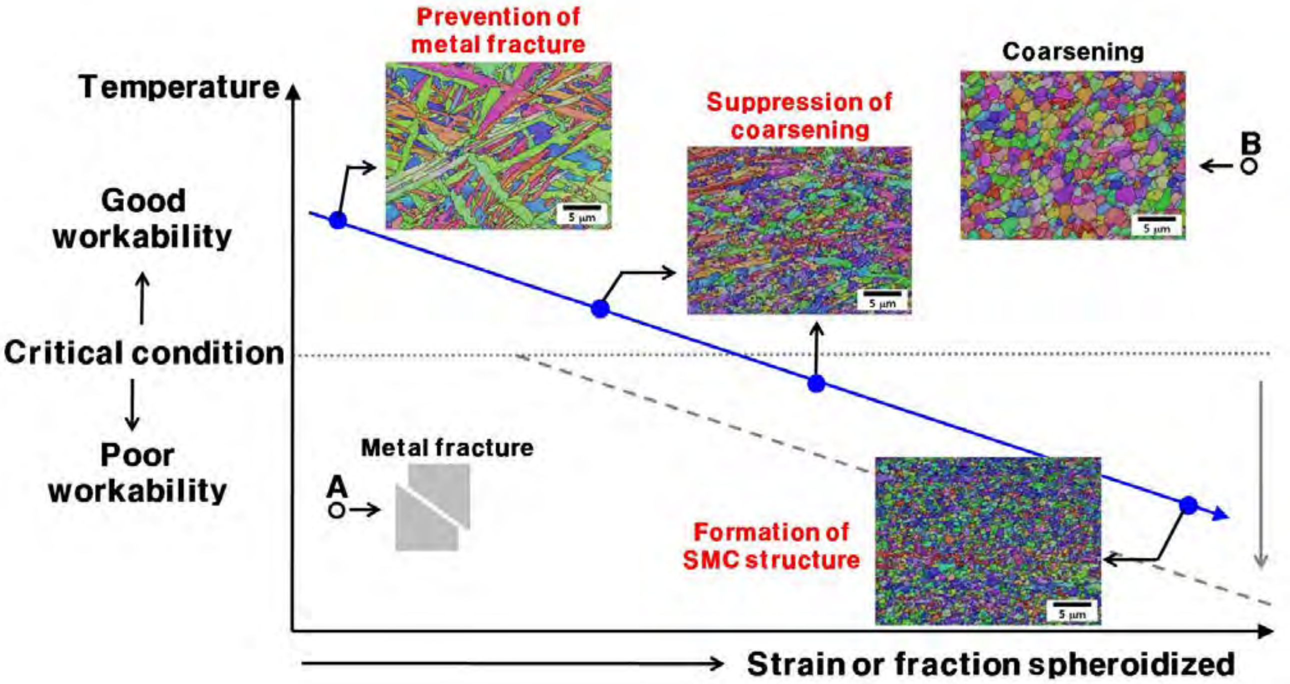
Development of UFG Ti alloys *without SPD*

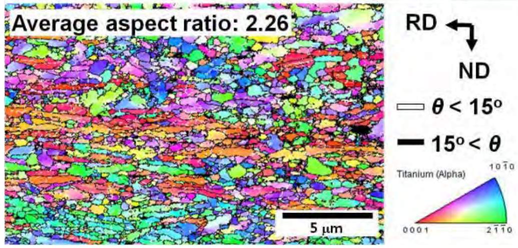
- Research Purposes :

  1. To control an UFG microstructure using lower strains and higher strain rates
  2. To fabricate UFG Ti alloys using conventional metal forming methods (rolling, extrusion, forging etc.)

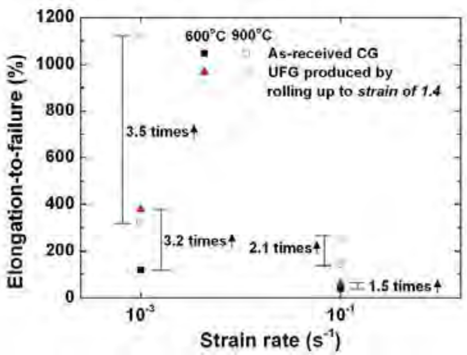
- Grain size ~ 400 nm
- Imposed Strain ~ 1.4
- Strain rate ~ 0.1/s

- Schematic illustration of novel process (Ti-6Al-4V)





- High-strain-rate/ low-temperature superplasticity

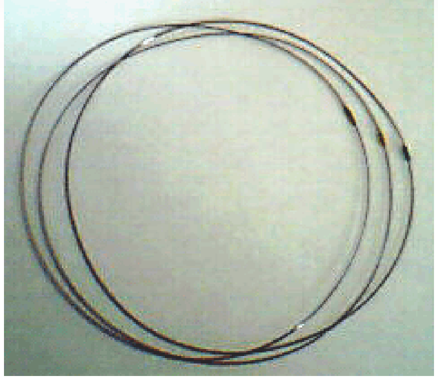


Patent: PCT/KR2012/001952 & PCT/KR2009/007069, Chan Hee Park

Superelastic NiTi thin wire for medical device

Research Purposes :

1. Superelasticity NiTi wire with a diameter of 0.1 mm by thermo-mechanical process
2. Development of high purity NiTi ingot using VAR skull/VAR process



Compositional deviation of Ni element: within 0.5% wt.

Oxygen and Carbon less than 0.1% wt.

Diameter: ~0.1 mm, Total elongation: >10%

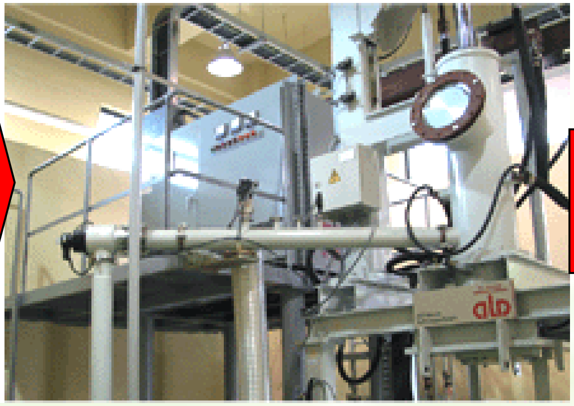
Tensile strength: > 1150 MPa

Research Contents :

Vacuum Skull Melting

- Capacity : 3kg melting & casting
- Centrifugal caster : 400 rpm

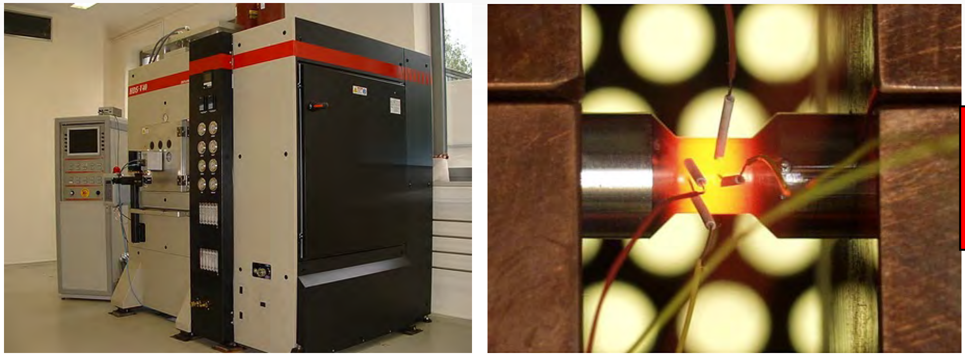
Vacuum Arc Re- melting



- Ingot dimension :200mm(dia) x 800mm (length)

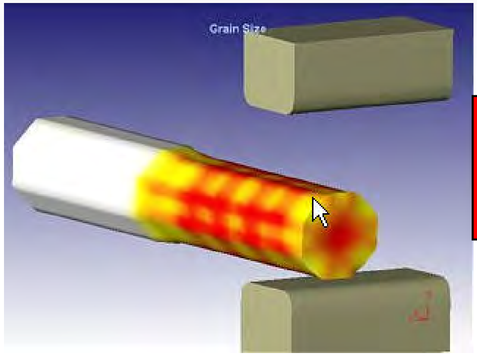
Superelastic NiTi thin wire for medical device

Gleeble Test Machine



- Basic mechanical property acquisition

FE analysis for Ingot breakdown



- Design of thermo-mechanical process

Swaging and groove rolling

Wire drawing

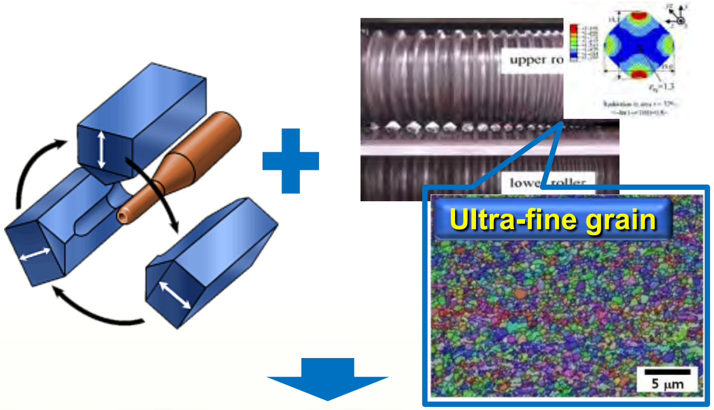
Development of TiNi and CoCr Precision Tube for Medical Implants (New project)

Research Purposes :

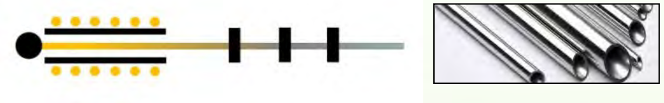
- Development of TiNi and CoCr precision tube for medical implants using the combination approach

Research Contents :

Tube Manufacturing Technology

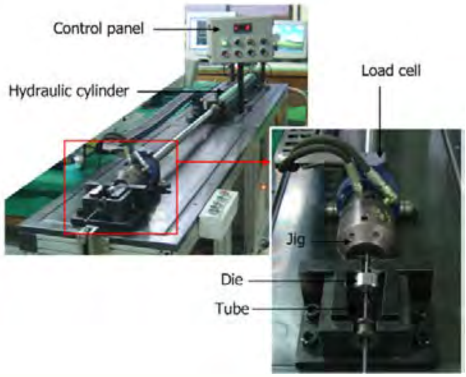


Warm or cold tube drawing



◆ Combination Technology : Swaging + Caliber rolling ⇒ **grain refinement**

Tube Drawing



◆ Design of **precision tube drawing equipment**

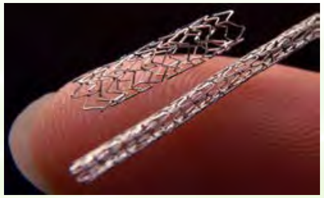
◆ **Bi-metal tube drawing**

End Product

High purity billet

Precision tube

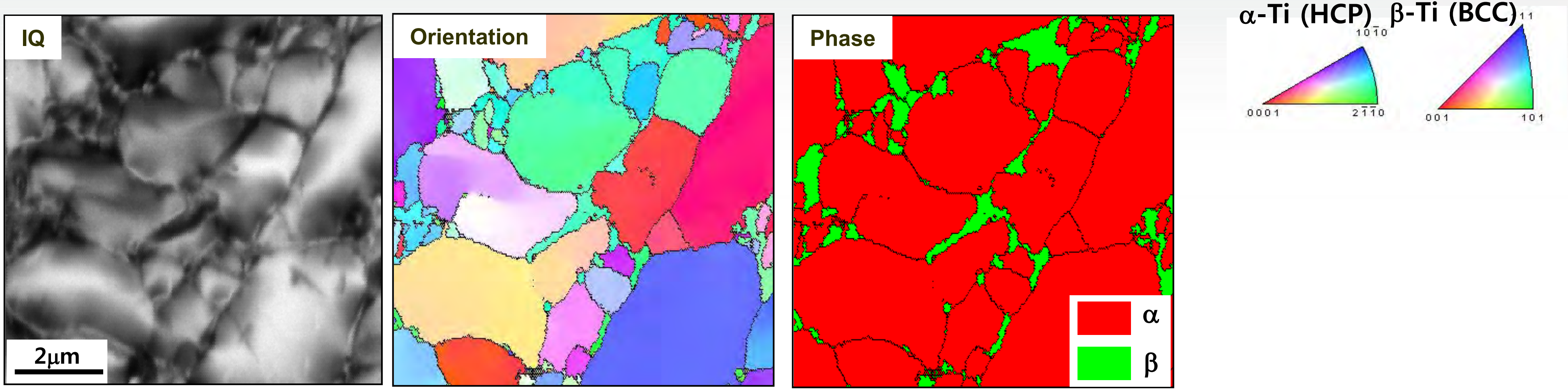
Medical devices



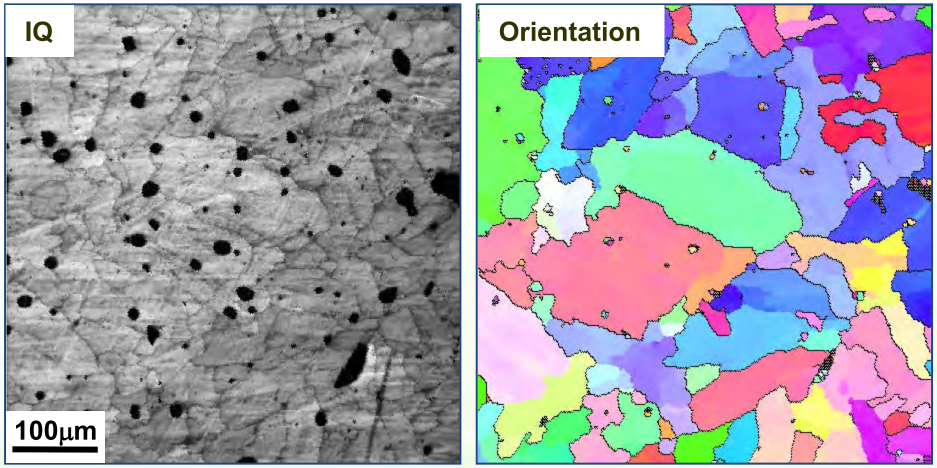
Stent

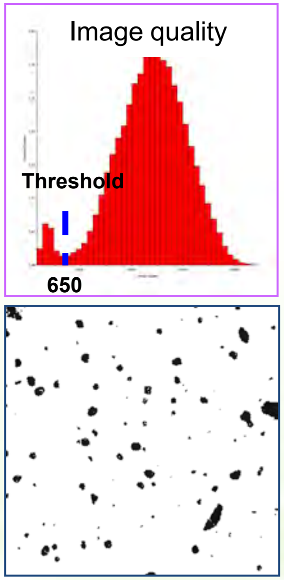
EBSD analysis of Titanium Alloys

- (α+β) alloy : Ti-6Al-4Fe-0.25Si



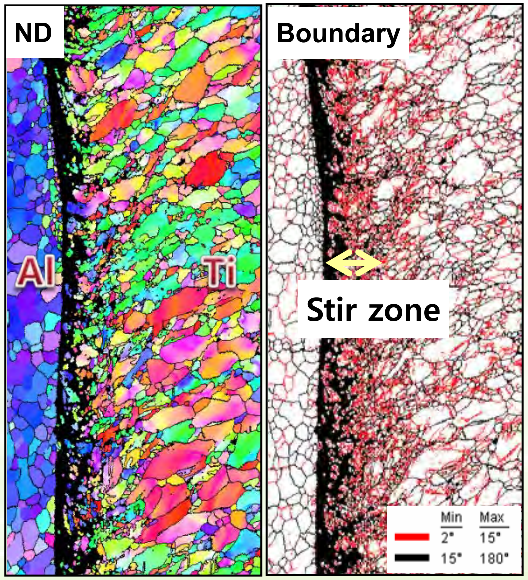
- Powder Rolled Titanium





Porosity :3.4%

- Friction Stir Welded Ti-Al



1. Song. Y.H. et al.,Korean J. Met. Mater, 50 (2012), To be published.
2. Kang J.- H.et al, IWJC 2012 (2012),

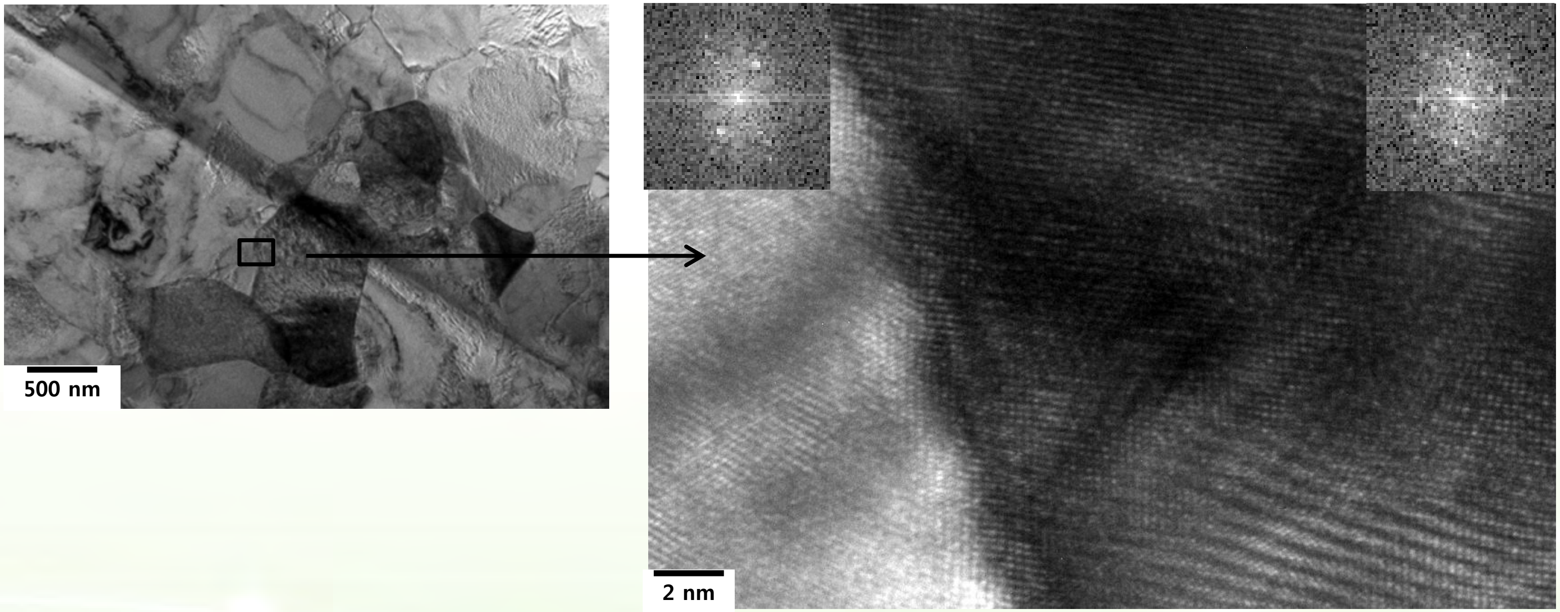
In-situ and Ex-situ TEM Observations of Titanium Alloy (Ti-6Al-4Fe alloy)

Research Purposes :

1. Understanding microstructure after deformation at R.T. and high temperature (~ 700°C)
2. Identification of precipitate (TiFe) during aging at different time and temperature.
3. Finding out crystallization condition of TiNi thin films for SMA application

Research Contents

1. Microstructure after deformation at 700°C of Ti-6Al-4Fe alloy

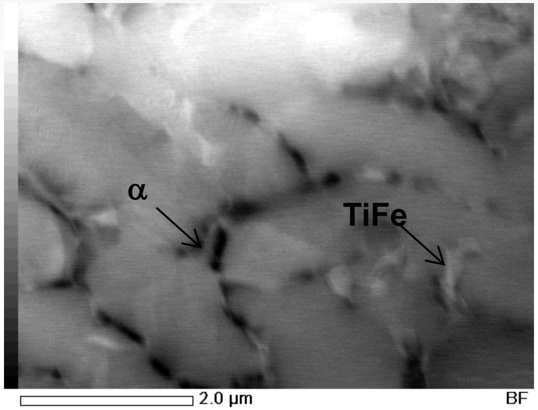


High angle grain boundaries with reduced grain size after deformation

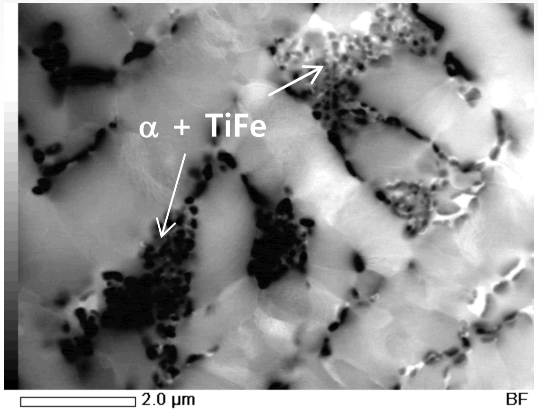
In-situ and Ex-situ TEM Observations of Titanium Alloy (Ti-6Al-4Fe-0.25Si and TiNi thin films)

Research Contents

2. Precipitate formation and growth during aging at 550°C



TiFe formation after 10h



Increased TiFe fraction after 100h

3. In-situ heating TEM observation of TiNi thin films

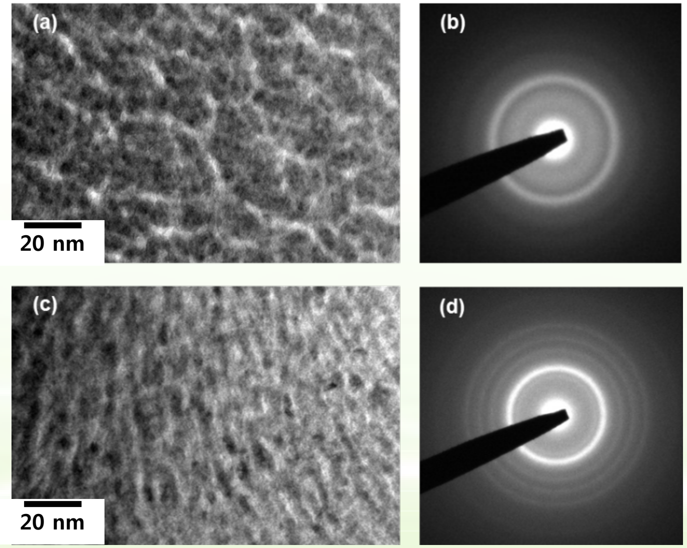


Fig. (a, c) Microstructures and (b, d) SADP of Ti-50.1Ni thin film by TEM (a, b) as-deposited and (c, d) after annealing at 500°C for 30 min. SADPs indicate that as-deposited film was amorphous structure (b) and fully crystallized after annealing (d).

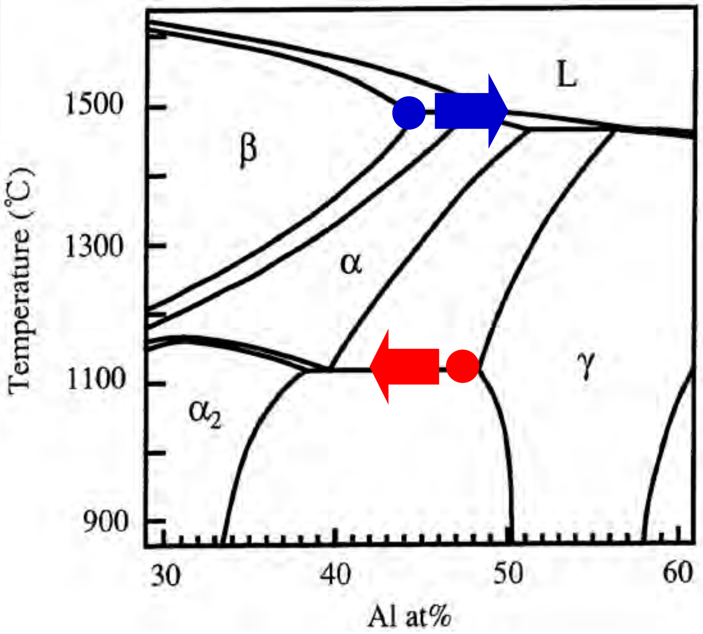
Development of Beta-Gamma TiAl

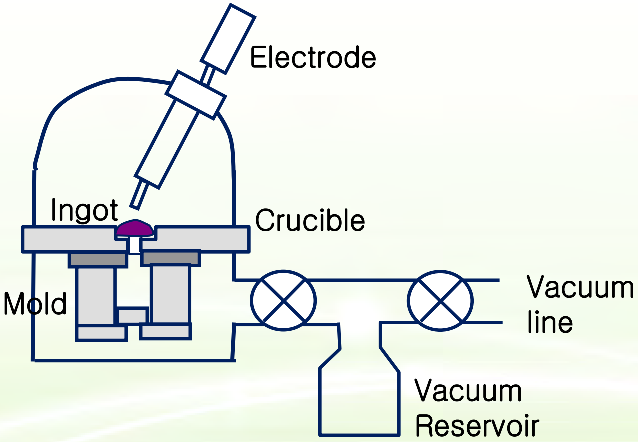
New alloy design : TiAl-xNb-yW-zC

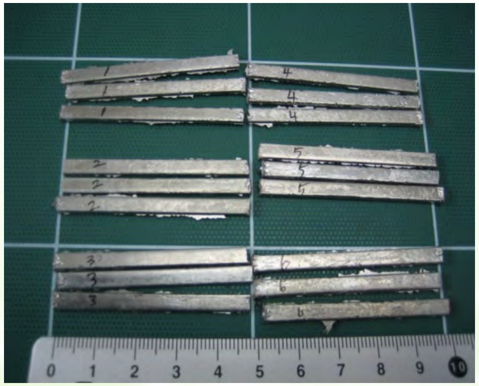
- **Effect of alloying elements**

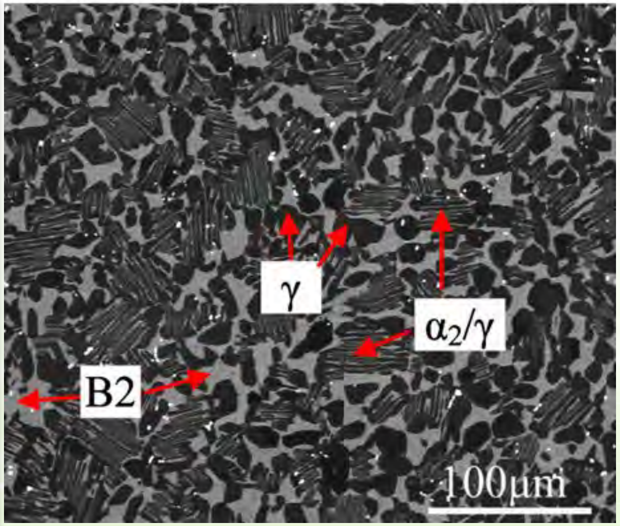
1. **Nb : Oxidation resistance, Formability**
2. **W : Beta phase stabilizer (more effective than Mo, V)**
3. **B, C : grain size refinement**

Target : UTS > 800 MPa, Ductility > 2.5%

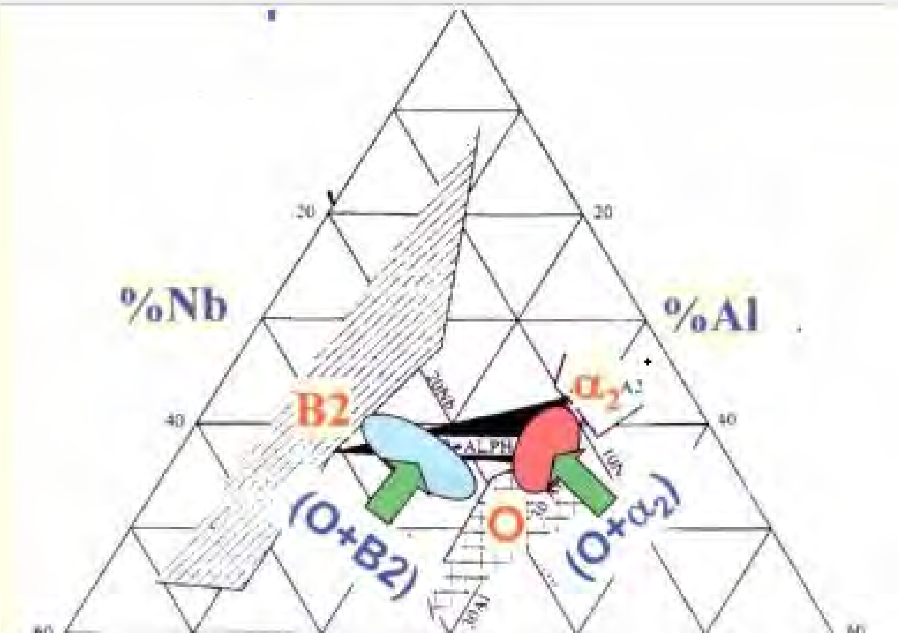


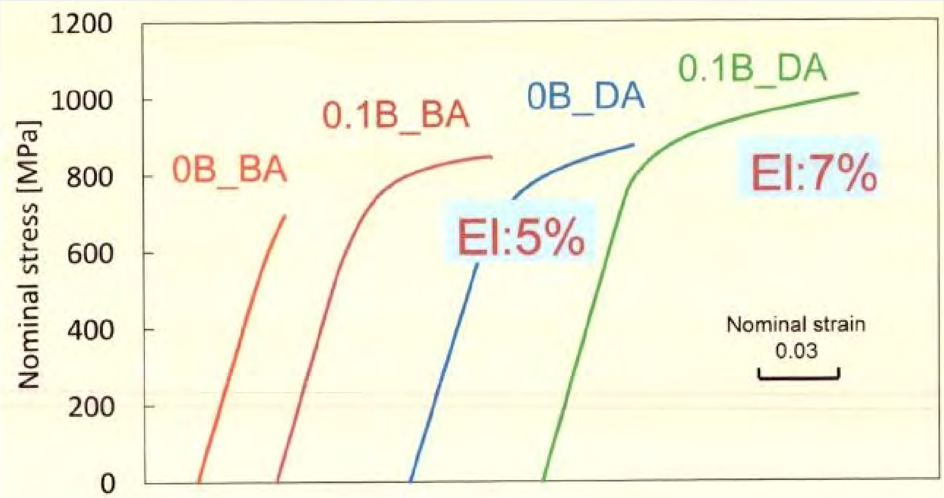


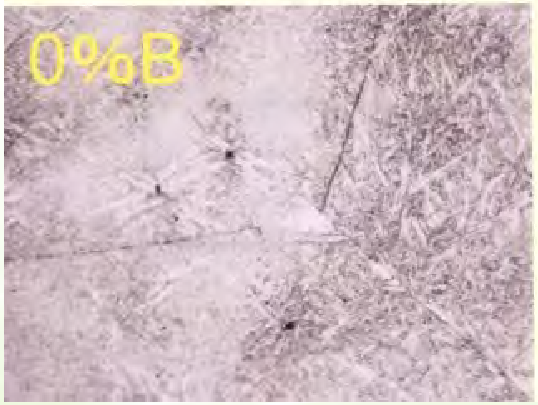


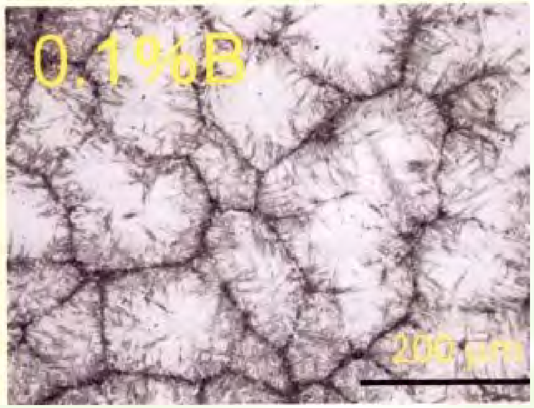


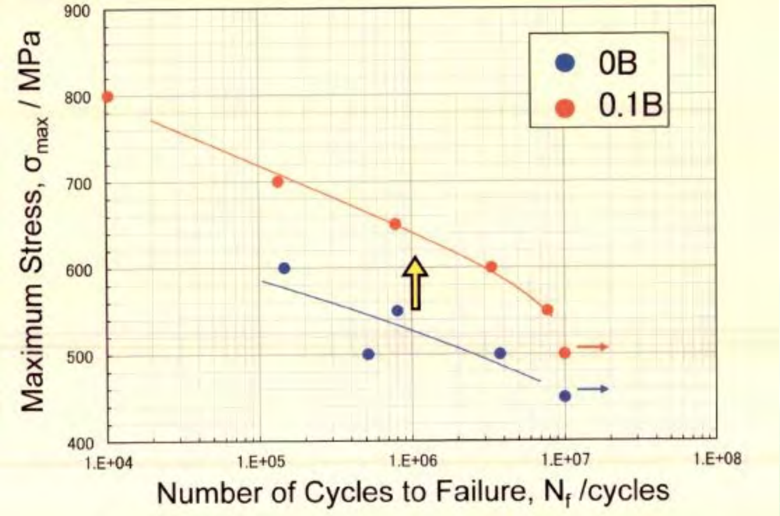
Intermetallics – O Phase











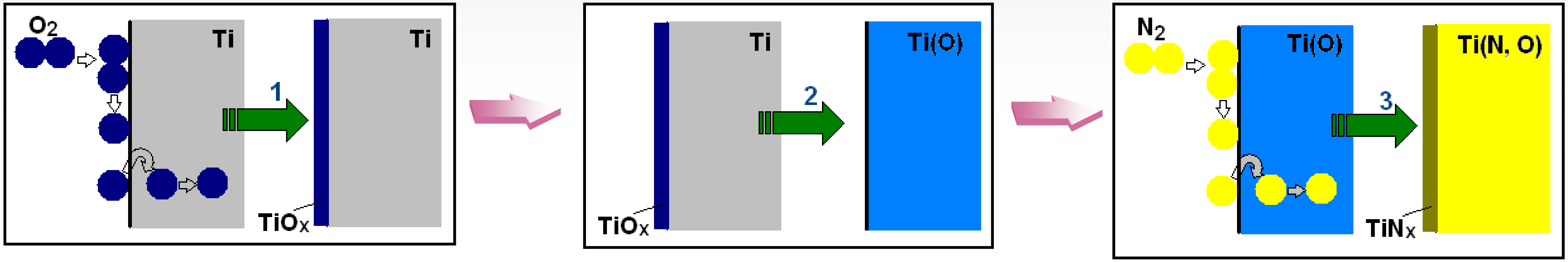
Mechanism of Surface Harding

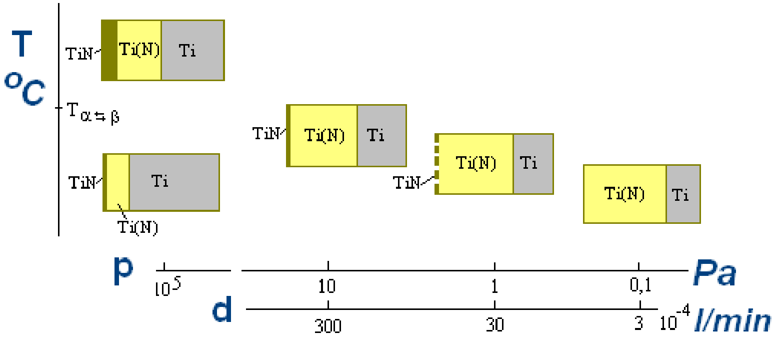
KIMS

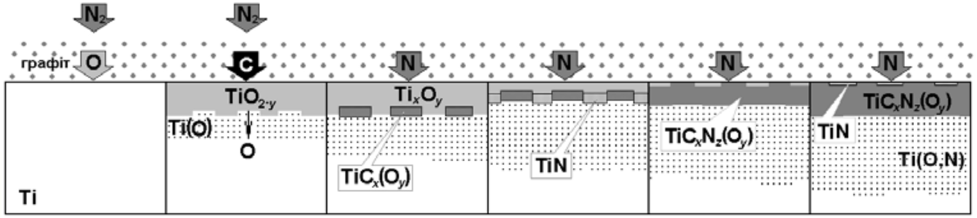
Surface oxide film formation

Oxide film dissolution

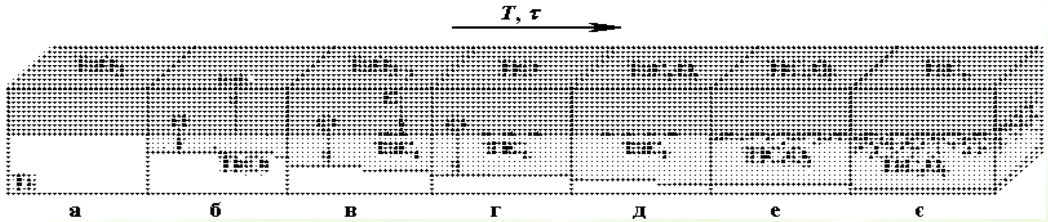
Nitride film formation







Ti-C-N system



Ti-C-O system