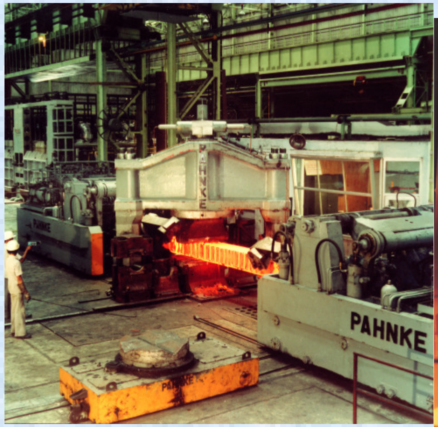
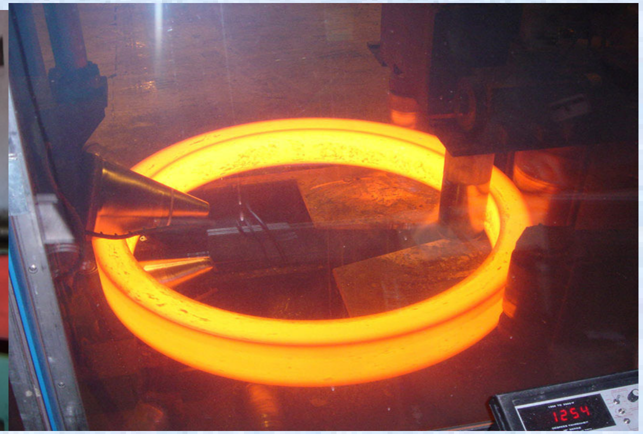
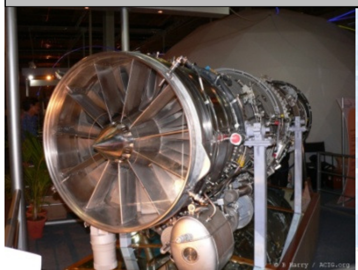






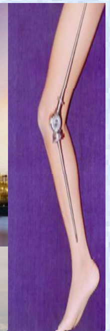
Emerging trends in Steels, Superalloys and Titanium alloys

Dr D.K. Likhi,C&MD,MIDHANI

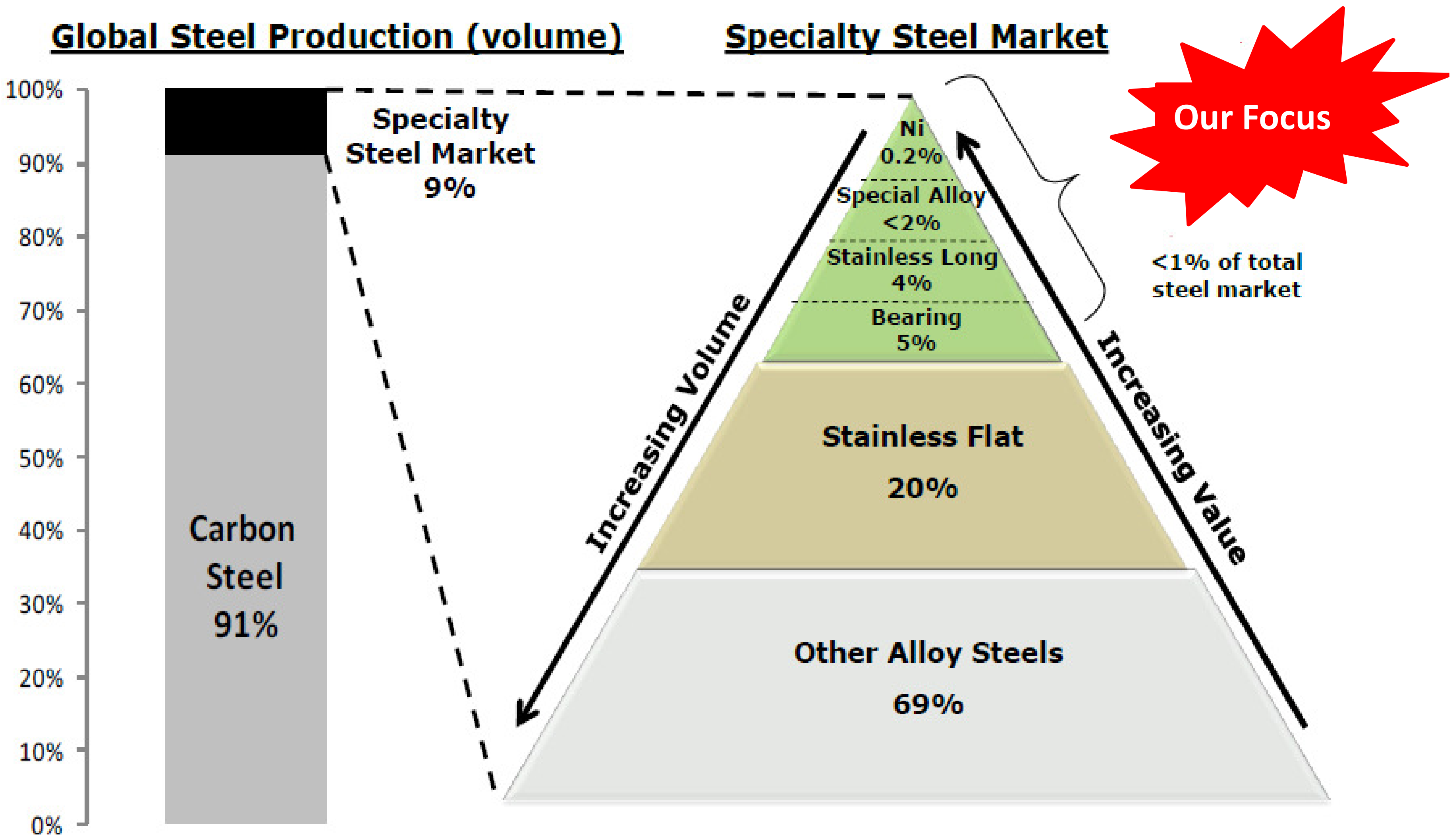












Global Steel Production (volume)
Specialty Steel Market
Our Focus
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Carbon Steel 91%
Specialty Steel Market 9%
Ni 0.2%
Special Alloy <2%
Stainless Long 4%
Bearing 5%
Stainless Flat 20%
Other Alloy Steels 69%
Increasing Volume
Increasing Value
<1% of total steel market

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Challenges before the metal processing industries.

- Quality
- Price
- Delivery

How to meet the challenges?

- ❖ Understanding the customer requirement
- ❖ Develop new product, process for meeting the requirement
- ❖ Address management – technology interface

Aim – To meet well identified commercial application

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Trends for Materials Development – Nuclear and Thermal power

✓Develop new core materials that can face high stress, temperature, corrosive environs and high flux of neutrons.

✓To devise methods for safe disposal of the active materials once they have performed.

✓In thermal power plants with the increase in steam temperatures above 600^0C advanced ferritic/ martensitic steels with sufficient long term creep rupture strength is being developed. For temperature above 650^0C Oxide Dispersion Strengthened Ferritic Steels is receiving attention.

✓ Selection depends on screening of materials based on sound knowledge about their behavior in conventional environments, theoretical and experimental simulation and actual existing experience with materials under irradiation environments.

Metal Processing

Machining process inherently wasteful – near net shape desirable.

- Forging of rounds / bars on Long Forging Machine with small machining allowance than on conventional open die forging press / hammer.
- Close die forging of component
- Near net shape forging of components

Improved casting (more accurate / precise) would result in less machining

- Investment casting
- 3 D Printing

Superalloys

PARTITIONING OF ALLOYING ELEMENTS and strengthening of Superalloys

1) *Solid solution strengthening*
2) *Precipitation hardening*
3) *Grain boundary strengthening*

Criticality of melting high end superalloys

Superni 718

Ele	Wt%	Ele	Wt%	Ele	Wt%
C	0.08max	Mo	2.8-3.3	Pb	0.0005max
Mn	0.35max	Nb	4.75-5.5	Bi	0.00003max
Si	0.35max	Ti	0.65-1.15	Se	0.0003max
P	0.015max	Al	0.2-0.8	Sn	0.005max
S	0.015max	Co	1 max	Ag	0.001max
Cr	17-21	B	0.006max		
Ni	50-55	Cu	0.3max		

- Where ***control of no. of alloying elements to much tighter levels*** required.
- Where ***low level of high-vapor-pressure elements*** required by specification
- Where considerable ***reduction in oxygen and nitrogen*** contents. Accordingly, with ***fewer oxides and nitrides formed, the micro cleanliness*** improves
- Where ***recovery of oxide forming elements*** (Ti, Al, Nb) required

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Melting Routes for some of Superalloys

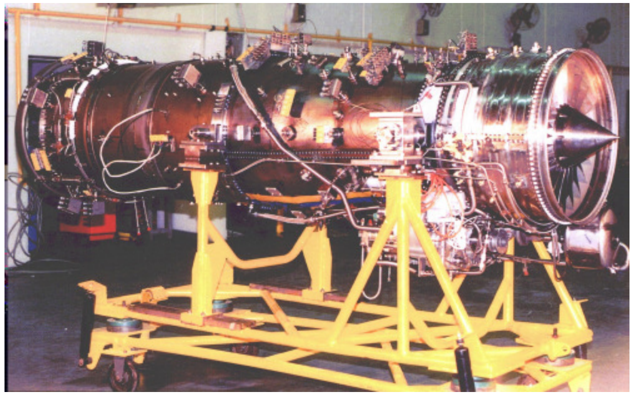
AIM + ESR : Inconel 600, 601, 690, 800, 825 etc

VIM + VAR : Inconel 706, 718, 750, 263, 80A etc

VIM + ESR : Inconel 617, 625, L605

VIM + ESR : Inconel 706, 718 etc
+ VAR

Ni-based Superalloys for Kaveri Engine



Alloy	Max Application Temp.°C	Typical Components
SUPERNI 263A	800	Flame tube, combustion chamber, reheat system, Thrust deflector system, casing, exhaust ducts, bearing housing, cooling rings, flanges.
SUPERNI 718A	700	Compressor blades, turbine discs, compressor disc, flanges, shafts, casings, rings, housing.

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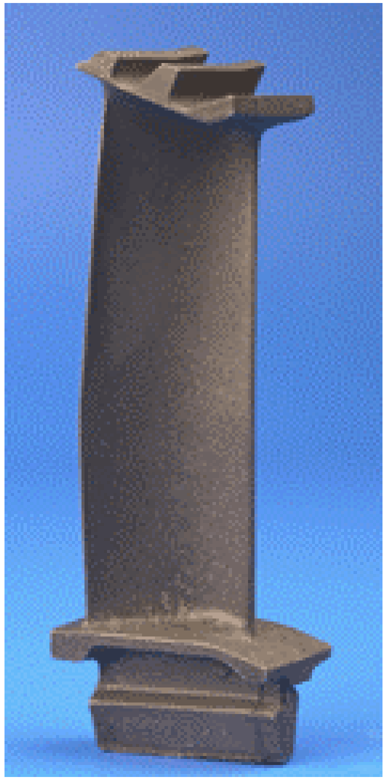
Cast Alloys

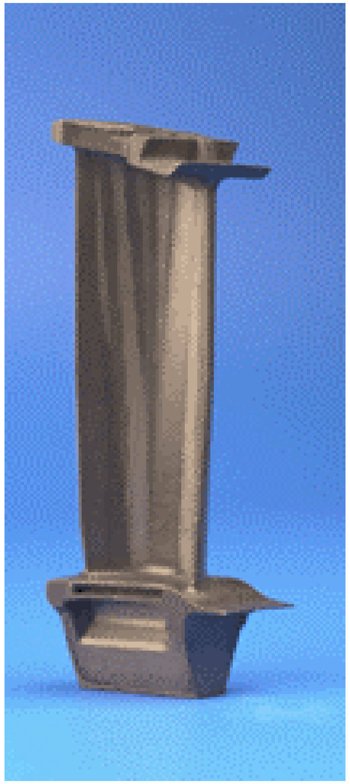
All cast super alloys can be grouped as

- Conventionally Cast (CC) Superalloys.
- Directionally Solidified (DS) Superalloys.
- Single Crystal (SC) superalloys.

Few examples: CM247, ReneN6, CMSX4,TMS 162,
TMS 138, CMSX 10 etc.,



Equiaxed polycrystalline



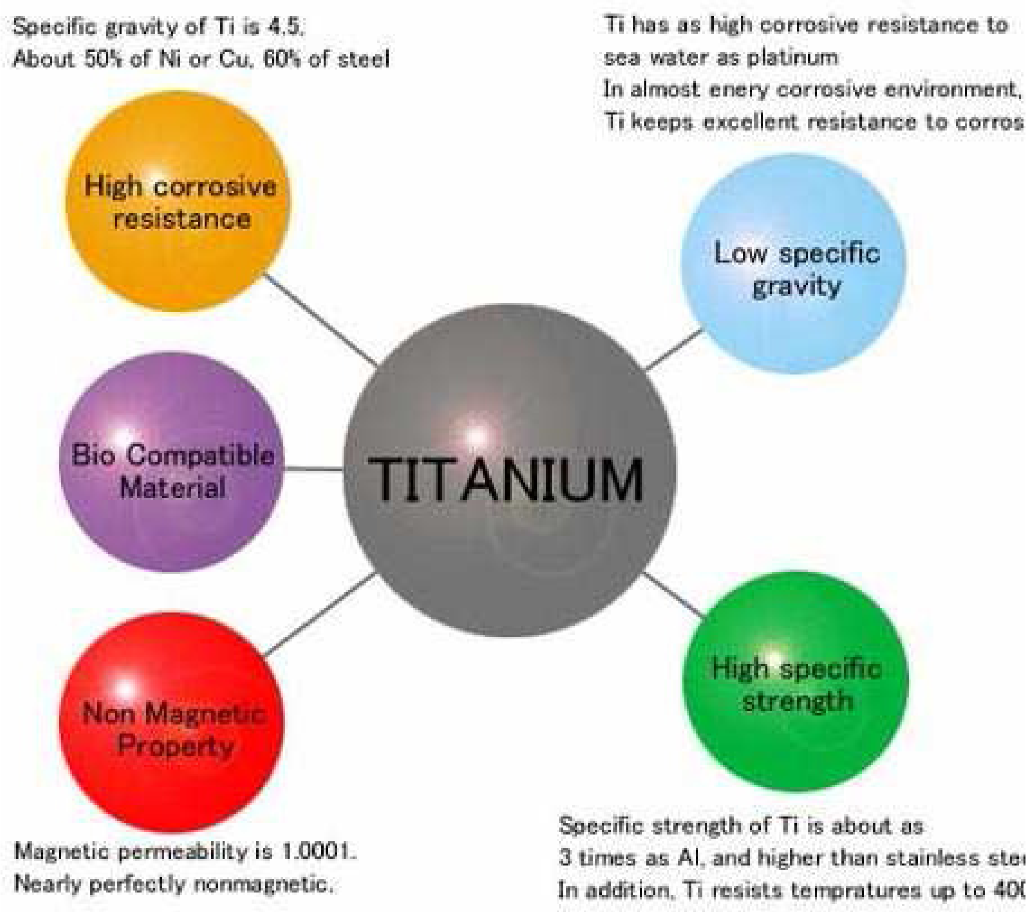
Directionally solidified columnar grains

Single Crystal

Gas Turbine Blades and Vanes

Titanium Alloys

Advantages of titanium alloys



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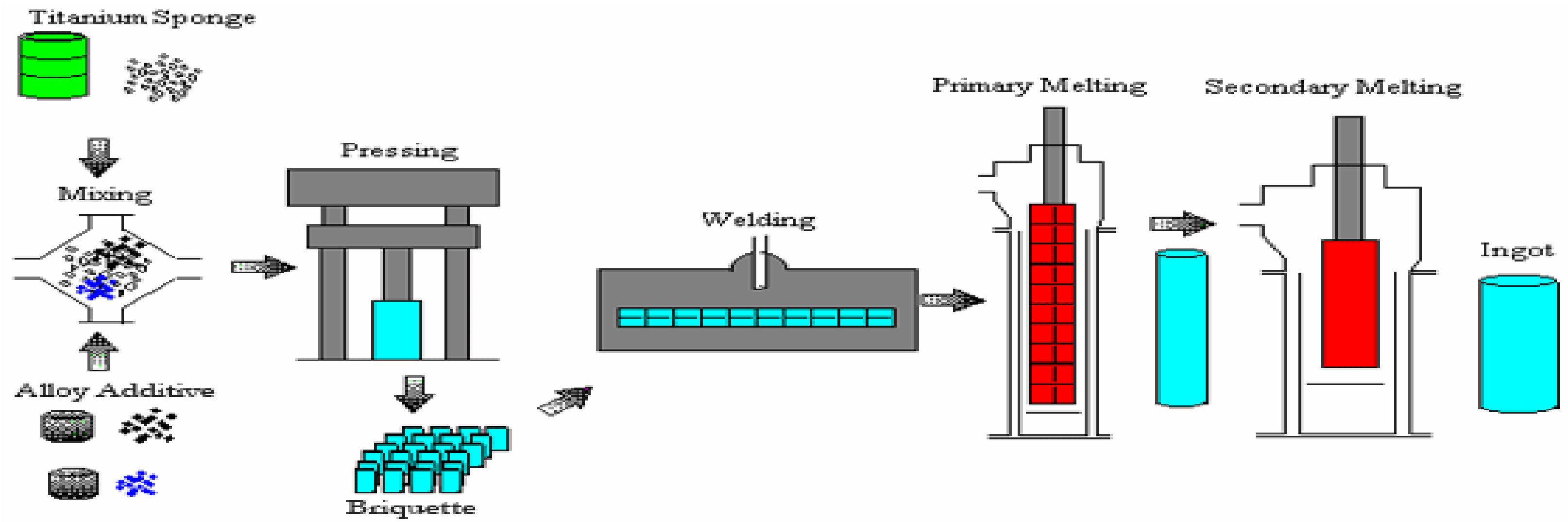
Production of titanium alloys

- **Melting processes**
  - Vacuum Arc Remelting (VAR)
  - Electron Beam Melting (EBM)
  - Skull Melting
- Casting processes
  - Casting : investment casting
- Forming processes
  - Rolling, extrusion, forging.
- Heat treatments

Melting of titanium alloys

Vacuum Arc Refining (VAR) - Process



•Sponge and alloying elements are blended together and then hydraulically pressed to produce blocks (briquette). Revert or scrap can also be used.

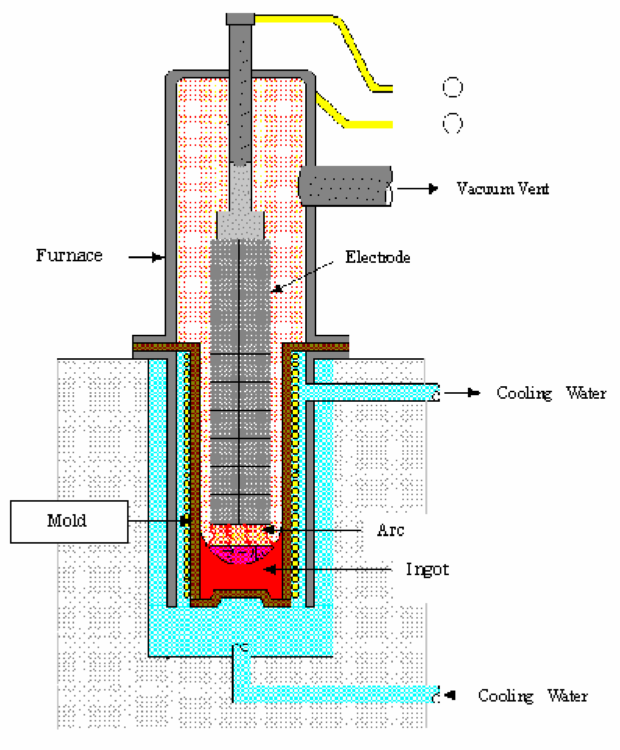
• The briquettes are welded together to produce first melt electrode or ‘stick’.

• The electrode is double or triple melted in the VAR furnace to produce sound ingot.

Melting of titanium alloys

Vacuum Arc Refining (VAR) - melting

- Electrode made from compacted briquette of nominal alloy composition is held in the VAR by a stub and first melted in a water-cooled copper crucible.
- A molten metal pool is on the top of the new ingot.
- The melting variables such as melting rate, molten pool depth, stirring, contamination is carefully control to obtain homogeneity and soundness of ingots.



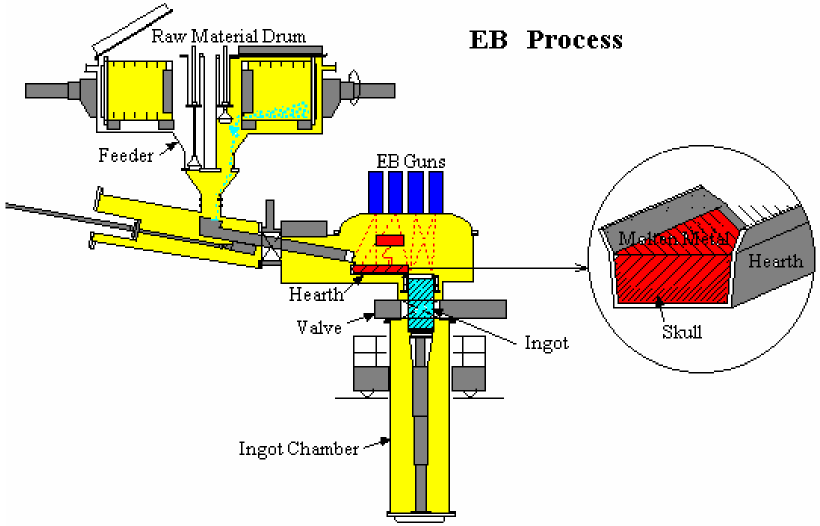
VAR furnace

Melting of titanium alloys

Electron Beam Melting (EBM)

- The floating metal is on the top of the skull, giving a sound ingot.

- Material is fed through the hearth and melted by heat source provided by electron beam



EBM ingot

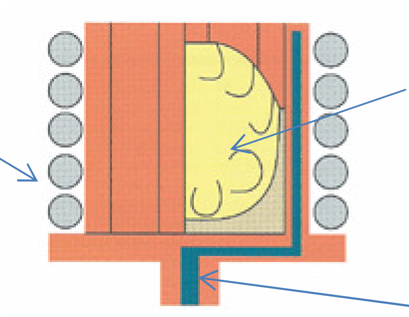
Note: Used for melting of reactive materials such as Ti, Ni, Ta, Zr.

Melting of titanium alloys

Induction Skull Melting

- A water-cooled copper crucible is used to avoid contamination of reactive materials.
- Metal is charged inside the crucible by induction power source applied by magnetic field.
- The charge is melted and freeze along the bottom and wall,
producing a shell or skull with molten metal in it.
- Revert or scrap can be used.
- Low cost, high quality titanium alloy production.

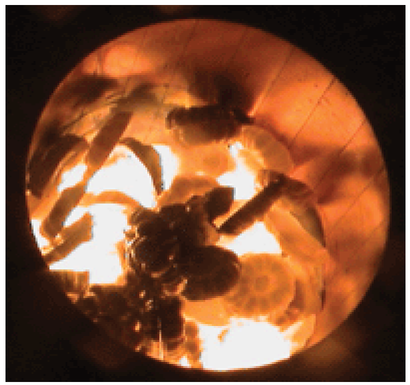
Induction coils



Molten metal in the skull

Water-cooled system

Induction skull melting



Charged metal melted with ISM

Classification of titanium alloys

1. Alpha and near alpha titanium alloys
2. Alpha-beta titanium alloys
3. Beta titanium alloys

Different crystal structures and properties allow manipulation of heat treatments to produce different types of alloy microstructures to suit the required mechanical properties.

Commercially pure (CP) titanium and alpha/near alpha alloys

Microstructure contains HCP α phase and can be divided into;

- Commercially pure titanium alloys
- Alpha titanium alloys
- Near alpha titanium alloys

Characteristics:

- Non-heat treatable
- Weldable.
- Medium strength
- Good notch toughness
- Good creep resistance at high temperature.

Alpha titanium alloy

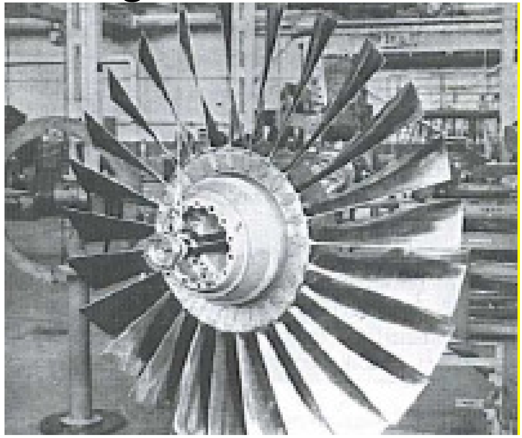
α stabilisers are more soluble in the α phase and raise the β transus temperature.

- Al and O are the main alloying elements, which provide solid solution strengthening. O and Npresent as impurities give interstitial hardening.
- The amount of α-stabilisers should not exceed 9% in the aluminium equivalent to prevent embrittlement due to ordering.
- 5-6% Al can lead to a finely dispersed, ordered phase (α2), which is coherent to lattice deleterious ductility.
- Sn and Zr are also added in small amount to stabilise the α phase and give strength.

Alpha-beta titanium alloys

- Alpha-beta titanium alloys contain both α and β.
- α stabilisers are used to give strength with 4-6% β stabilisers to allow the β phase to retain at RT after quenching from β or α+β phase field.
- Improved strength and formability in comparison to α -Ti alloys.
- Ti-6Al-4V (IMI 318) is the most widely commercially used.

Forged Ti-6-4 blades



Beta titanium alloys

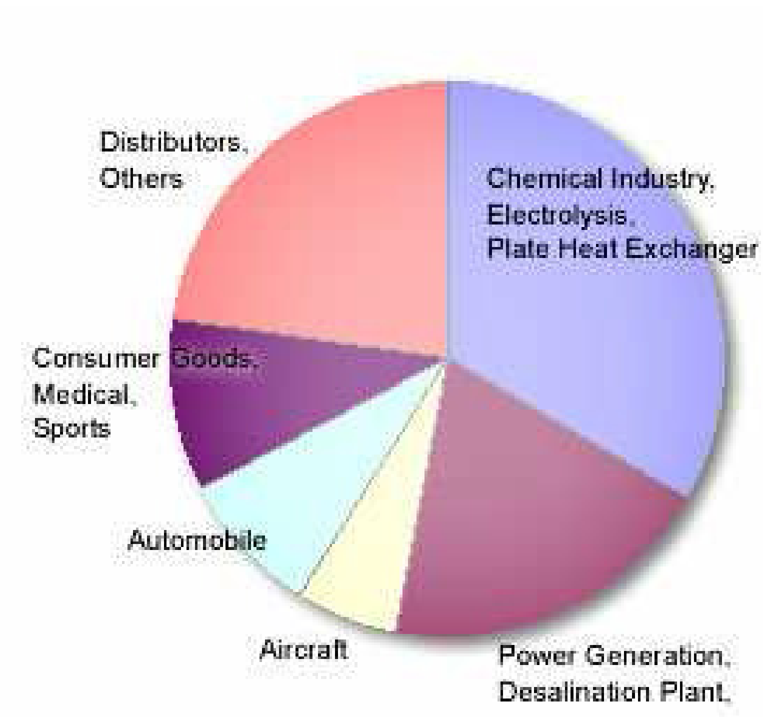
- Beta stabilisers are sufficiently added to retain a fully β structure (avoid martensite formation) when quenched from the β phase field.

Tab. 2.1 Advantages and disadvantages of beta titanium alloys [3].

Advantages	*Disadvantages*
– high strength-to-density ratio	– high density
– low modulus	– low modulus
– high strength/high toughness	– poor low and high temperature properties
– high fatigue strength	– small processing window (some alloys)
– good deep hardenability	– high formulation cost
– low forging temperature	– segregation problems
– strip producible – low-cost TMP* (some alloys)	– high springback
– cold formable (some alloys)	– microstructural instabilities
– easy to heat treat	– poor corrosion resistance (some alloys)
– excellent corrosion resistance (some alloys)	– interstitial pick up
– excellent combustion resistance (some alloys)	

* TMP: thermomechanical processing

Applications of titanium alloys



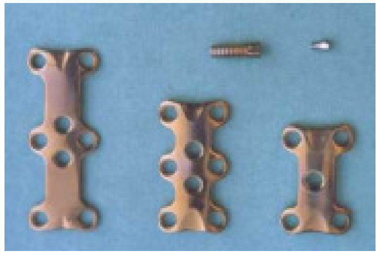
AEROSPACE
- Civil
- Military
- Space

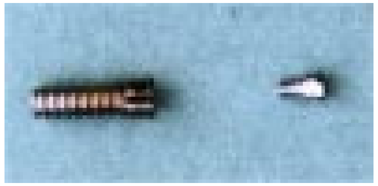
MEDICAL
- Orthopaedic Implants
- Bone Screws
- Trauma Plates
- Dental Fixtures
- Surgical
- Instruments

MEDICAL
- Petrochemical
- Offshore
- Subsea
- Metal Finishing
- Pulp & Paper
- General Engineering

SPECIALIST
- Body Jewellery
- Ultrasonic Welding
- Motor Racing Components
- Marine
- Bicycle
- Sports Equipment

MIDHANI has contributed to low-cost import substitute titanium bio-medical implants





135 types of Implants in 1061 varieties ready for commercial supply

Steels

MDN59

MDN59 is a 0.05 % C, 14.5% Cr, 5.5 % Ni, 1.5 % Mo, 1.5 % Cu, 0.5% Nb Precipitation Hardenable Martensitic Stainless Steel.

Delta ferrite is high temperature phase.

The phase forms either during solidification or soaking at a temperature above 1200 ^{O}C.

Closed die forged components

MDN 403 End Fitting Forgings

MDN 403 is specially used for making end fittings. The component is generally used in hardened and tempered condition. This grade fulfils the fundamental requirements such as:

- Corrosion resistance, resistance to hydrogen embrittlement, wear resistance
- A combination of strength, toughness and hardness
- Maintaining properties when exposed to irradiation
- Additionally to minimize thermal stresses and maintain a leak tight rolled joint, the end fitting should have a thermal coefficient of expansion as close as possible to the Zirconium alloy pressure tubes

ITER

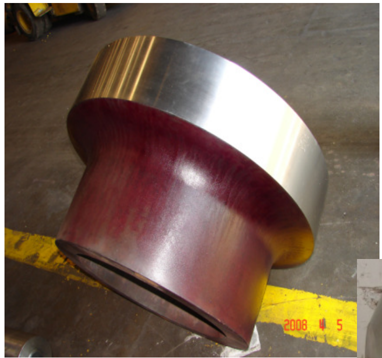
Reduced Activation Ferritic / Martensitic Steel

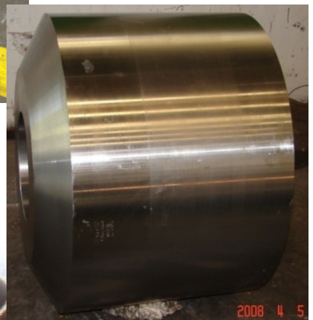
Indian RAFMS Alloying Elements	
Elements	**Content, wt. %**
Cr	8.80 – 9.20
C	0.10 – 0.12
Mn	0.40 – 0.60
V	0.18 – 0.24
W	1.30 – 1.40
Ta	0.06 – 0.08
N	0.02 – 0.04

Radiologically Undesired Elements	
Element	**Content, wt. %**
O	< 0.01
P	< 0.002
S	< 0.002
B	< 0.001
Ti	< 0.005
Nb	< 0.001
Mo	< 0.002
Ni	< 0.005
Cu	< 0.002
Al	< 0.005
Si	< 0.05
Co	< 0.005
As	< 0.03
Sn	
Sb	
Zr	

- **Radiation damage**
- **Mechanical properties**
- **Chemical compatibility**
- **Fabrication and joining**

Special Steel for Naval Applications






- Low alloy steel forgings, characterized by high cleanliness, structure homogeneity and fine scale microstructure were developed to achieve exceptionally high toughness at sub-zero temperatures and resistance to dynamic loading.

Grade	Steel Type	Application
AB2PK	Low Alloy	Forgings for pressure hull
AB2PKM	Low Alloy	Forgings for pressure hull, bearing casing
AB2/ABA	Low Alloy	Plates for structural applications
MDN 316Ti	Austenitic SS	High pressure hydraulic piping
12X18H10T	Austenitic SS	High pressure hydraulic pipeline
MDN U3	Austenitic	Non-magnetic hull for Mine sweeper
MDN U2	Austenitic	Ballast weights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