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RESEARCH ARTICLE

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DEFORMATION OF AEROSPACE MATERIAL BY HOT ROLLING TECHNIQUE

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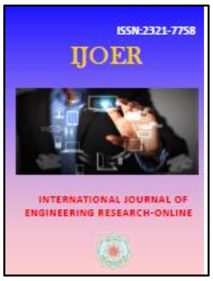

ABSTRACT

In metal working metal, rolling is a metal forming process in which metal stock is passed through one or more pairs of rolls to reduce the thickness and to make the thickness uniform. The concept is similar to the rolling of dough. Rolling is classified according to the temperature of the metal rolled. If the temperature of the metal is above its recrystallization temperature, then the process is known as hot rolling. Change in shape or dimension of a body caused by application of force (stress). Deformation is proportion to the stress applied within the elastics limit. Titanium is a chemical element with symbol Ti and atomic number22. It is lustrous transition metal with a silver color, low density and high strength. It is highly resistance to corrosion in sea water aqua regia, and chlorine. Its melting point is 1941K, boiling point is 3560K. In detail we are going to study the deformation of titanium metal by hot rolling technique.

Keywords: Midhani, Titanium, Conditioning and Hot Rolling Mills, Plasma Electrode Welding etc

1. Introduction of Midhani

Mishra Dhatu Nigam Ltd.(Midhani) located at KanchanBagh in Hyderabad,was incorporated in 1973.This Enterprise is one of the unique, modern and integrated metallurgical plants for manufacturing a wide range of special metals and alloys. MIDHANI is one of the few metallurgical plants of its kind in the world, designed to manufacture a wide range of special metals and alloys using integrated and highly flexible manufacturing systems. Strategic sectors served by MIDHANI include space, defence, aeronautics, nuclear power and kindred industries. MIDHANI manufacturer's high-grade metals for India's main battle tank (MBT), planes and motors guns. MIDHANI'S product range includes super alloys, titanium alloys, maraging steels, heat resistance alloys, controlled expansion alloys, tungsten, molybdenum etc. in a variety of mill forms. MIDHANI is the only manufacturer in the country producing commercially pure titanium and host of titanium alloys for a wide range of industrial applications. Both of commercial and strategic nature. Most of the products of MIDHANI are import substitution items for the automobile, electrical, telecommunications, petrochemicals, lamp and general engineering industries. The Company has about 1500 employees, including 240 technical executives, with 8 PhDs,52 M.Tech and 38 Graduates engineering's .Hybridizations of technologies developed in India during the 1970s,acquired from western sources as well as the former USSR and the company's in-house efforts enabled MIDHANI to offer solution by tailor-making special metals and alloys specifically suited to crucial application requirements.

For MIDHANI, It has been an unparalleled experiment and a challenge undertaken to create the technological ability for manufacture of perhaps the widest range of advanced metals and alloys anywhere in the world, under one roof.

MIDHANI successfully brought about hybridization of home-grown technologies with production scale know-how acquired from western and East-Bloc sources, contributing to creating a rich knowledge-base. The company has gone beyond the scope of the original product-mix and the collaborations and developed over 100 grades to meet the felt need of strategic and commercial sectors. Through generation of an in-depth understanding of the processing-structure evolution-Material performance/Behavior interrelationships. MIDHANI has contributed to solving several daunting technological problems including manufacture of maraging steel surpassing international standard, when first developed, during the early 1980s.

For nearly two decades now, MIDHANI has been handling challenging developmental tasks, taking a lead position in indigenization of critical technologies and products to render support to several programmers of national importance and hi-tech segments of Indian industries. Practically every order executed by the company is an import substitute. MIDHANI has now started offering its core competence of developing and manufacturing custom alloys tailor-made to suit the specific requirements of customers for their critical applications

"MISHRA DHATU" is Sanskrit equivalent of English word "ALLOY". The company is the brainchild of some renowned metallurgists of the country and scientist of adjoining, Defence Metallurgical Research Laborator (DMRL), Mishra Dhatu Nigam Limited(MIDHANI) is one of the modern and integrated metallurgical plants for manufacturing a wide range of special Metals and Alloys. MIDHANI's special alloys meet the critical requirements of strategic areas such as Space, Nuclear Power, Defence, Aeronautics, and Automobile. Electrical, Telecommunications. Petrochemicals and general engineering industries. The high technology plant is a Government of India's Enterprise under the Ministry of Defense. It is modern and integrated metallurgical plant of its kind for manufacturing a wide range of special metals and alloys under one roof.

MIDHANI was incorporated in November-1973 with a view to achieve self-reliance in some strategic alloys needed by critical sectors such as Defence, Aeronautics, Nuclear and Space. After a lengthy debate about desirability and variability of such plant, "go ahead" for the project was given in February 1976 and plant was set up in collaboration with world leaders like Creusot-Loire and Pechinery–Ugine-k-uhlamann of France and Krupp-kloeckner AG Germany and was commissioned progressively between 1980 and 1982.

MIDHANI's product range includes super alloys, Titanium, Molybdenum, Special purpose steels and other special alloys. It is a unique in concept and is probably the only plant of its kind where integrated facilities are available for the manufactured of such a diverse range of special metals and alloys in a wide variety of mill forms, such as a bars, Sheets, Strips, Rods and Wires. A wide variety of production and testing equipment has been installed to test numerous types of alloys produced to stringent specification of different customers.

Based on the Characteristics of the various generic groups of alloys and their application areas Midhani products are grouped into the following:-

- Super Alloys.
- Super purpose Steels.
- Titanium and Titanium Alloys.
- Powder Metallurgy Products.
- Electrical and Electronics Alloys.

Materials support for following programs:-

1. Battle Tanks: MBT Arjun, T-72 tank.
2. LCA.
3. MIG Engines.

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4. IGMDP (Integrated Missile Development Program of DRDO).
5. PSLV.
6. GSLV.
7. ATVP (Navy).
8. Fast Breeder Reactor.

Technologies:-

- "Isothermal forging of super alloys and Titanium's alloy Discs gas Turbines" (Under Development.
- "Plasma Welding and Cutting for Reactive Metals and Alloys".
- "Super Plastic forming of titanium hemisphere".
- Technology for production of Ultra low corrosion resistant stainless steel plates for nuclear amplification".

Corporate Objectives of Mishra Dhatu Nigam Limited

➢ To attain technological competence and self-reliance to help reduce vulnerability particularly in the strategic sector, critical sector and industrial sector of economy, by establishing indigenous production capability in the field of high technology based metals and alloys.

➢ To achieve Technical excellence and maintain technological leadership in the special metals and super alloys field through continual up (dating of product technology, manufacturing methods and production facilities by promoting interaction with established R&D organizations.

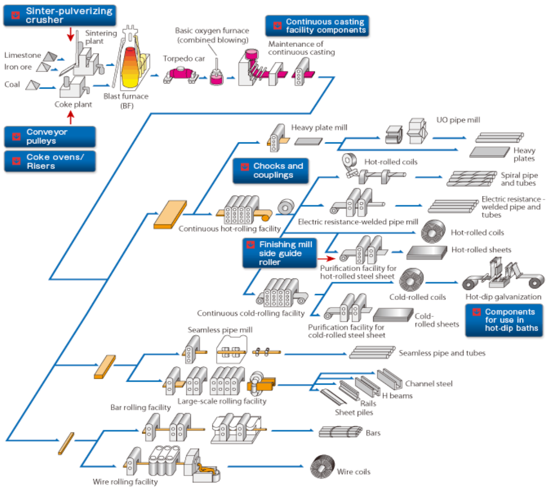
➢ To supply products and services of the highest possible value to our customers, thereby gaining the customer confidence and support and to establish a corporal image.

➢ To serve as a center for advance metals technology in the country to make specific contributions in the country's pool if technology knowledge.

The main customers of Midhani include.

1. Vikram sarabhai space Research Center.
2. Bhabha atomic Research Center.
3. Bharat Heavy Electrical Limited.
4. Larsen and Turbo Ltd.
5. Nuclear Fuel Complex (NFC).
6. Bharat Dynamics limited (BDL).

PROCESS FLOW CHART MISHRA DHATU NIGAM LIMITED



2. TITANIUM GRADES

Midhani employs its highly integrated and flexible manufacturing facilities to produce a wide variety of special metals and alloys in various mill forms such as ingots, forged bars, hot rolled sheets and bars, cold rolled sheets, strips and foils, wires, castings and tubes. Major facilities include:

Titanium alloys are metals that contain a mixture of titanium and other chemical elements. Such alloys have very high tensile strength and toughness (even at extreme temperatures).They are light in weight, have extraordinary corrosion resistance and the ability to with stand extreme temperatures. However, the high cost of both raw material and processing limit their use to military applications, aircraft, spacecraft, medical device devices, highly stressed components such as connecting rods on expensive sports cars and some premium s[ports equipment and consumer electronics.

Although "commercially pure" titanium has acceptable mechanical properties and has been used for orthopedic and dental implants, for most applications titanium is alloyed with small amounts of aluminum and vanadium, typically 6% and 4% respectively, by weight. This mixture has a solid solubility which varies dramatically with temperature, allowing it to undergo precipitation strengthening. This heat treatment process is carried out after the alloy has been worked into its final shape but before it is put to use, allowing much easier fabrication of a high-strength product.

TITANIUM RAW MATERIAL

3. Material classification

Material:

- The material selected for our purpose is titanium alloy.
- The grade selected is Titanium-31 alloy-Grade 5.
- Titanium-31 consists of master alloys mainly as Aluminum and Vanadium.

Ti 6Al-4V –Grade-5

- Chemical composition of this alloy is as follows:
  - AL - 5.50 to 6.75 %
  - V - 3.50 to 4.50 %
  - C - 0.10 %
  - N - 0.05 %
  - Fe - 0.40 %
  - O - 0.020 %
  - H - 0.015 %
  - Others - 0.40 % (Each = 0.1 %)
- For AMS 4928 (Bar, Billet, Forgings)

H = 0.0125 % and Fe = 0.3 %

Allotropic Forms: (Ti)

'α' 'β'
(HCP) ← 882.5°C
(BCC)

- These alloys are strengthened by heat treatment.
- These alloying elements are being added in order to act to stabilize either 'β' or 'α' phase.
- And also to stabilize so that β phase co-exists with 'α' phase at room temperature by addition of alloying elements.

Classification:

These are three types of titanium alloys.

1. α alloys.
2. α+β alloys.
3. β alloys.

1. α alloys :

- These contain neutral elements such (eg) Sn.
- They have 'α' stabilized such as Al, O_2 etc.
- These are not heat treatable.

i. α+β alloys :

These are heat treatable to various temperatures.

2. β alloys :

- These exist at Meta stable state.
- These mainly contain Mo, V which acts as 'β' stabilizers.
- These completely retain the 'β' phase upon quenching and solution treated.
- Ti 6Al – 4V is also called as "Work Horse".
- It is α+β alloy which as stabilizers as Al for 'α' and V for 'β' phase.
- This material is heat treatable which achieve moderate increase in strength.
- This can be used at high temperature for instance cryogenic temperature like 427°C.
- Its offers high strength, light in weight, formability, corrosion resistance.

Applications:

Aircraft Turbine, Engine components, Aircraft structural components, Aerospace Fastness, High performance automobiles, Marine applications, medical, sports etc.

Physical properties:

- Specific gravity - 0.160
- Modulus of elasticity - 15.2 X 10^3 ksi.
- Beta transition temperature - 1800° to 1850° F →
- Liquidius temperature - 2976° to 3046° F
- Solidus temperature - 2900° to 2940° F
- It has no magnetic attraction.
- For an annealed sample, strength can be theoretically defined as

1. Ultimate Bending Strength - 1380 – 2070 Mpa
2. Compressive yield Strength - 825 - 895 Mpa
3. Ultimate Shear Stress - 480 – 690 Mpa

Corrosion Resistance: The alloy immediately spontaneously forms stable, tights, continuous adherent oxide film when exposed to O_2 in Air/H_20.

- Resistant to corrosion in aqueous solutions / Sea water, Oxidizing acids, chlorides in water, rocket propellants and alkalis.
- It is susceptible to corrosion in presence of reducing acids.
- High cycle fatigue limits are highly influence by both microstructure and surface conditions.

Fracture toughness:

- The fracture toughness of this alloy lies between aluminum alloys and steels.
- The microstructures have high toughness if it contains greater amounts of lamellar α/β and coarse structures.
- ELI grade of Ti 6Al – 4V has high temperature resistant, high toughness superior to standards.

4. HEAT TREATMENT

- The wrought products undergo either

(i) Annealing,
(ii) Solution Treatment,
(iii) Aged conditioning.

- It undergoes quenching rapidly with water or its equivalent after solution treatment is done to increase the formation of 'α' martensite phase, thus it increases the aging response.
- For a forming or a welded product, stress relieving happens in heat treatment.
- Beta annealing is done to improve damage tolerance.
- Ti – 6Al - 4V has affinity towards gases like Oxygen, Nitrogen, and Hydrogen.
- When it absorbs oxygen, it becomes hard, brittle, oxygen stabilized by forming alpha phase layer known as alpha case upon heating in air.
- To avoid alpha case formation annealing are performed in vacuum/inert gas atmosphere.
- Annealing is performed in intermediate and final stages.
- To remove excessive hydrogen we can use vacuum annealing (vacuum degassing).

Cleaning of parts is a must in this process.

Precaution during process of Titanium:

We should avoid chlorinated solvents, cutting fluids to prevent stress corrosion cracking and crevice corrosion which occur due to chlorides, halides etc.

Hydrogen Embrittlement:

Gaseous/Cathodic H_2O can diffuse into metal forming brittle hydrides.

- To minimize this should be during processing, heat treatment and acid pickling.
- Thus Ti 6Al 4V should contain H_2 not more than 1500 ppm.
- Factor that affect corrosion resistance include temperature, concentration P^H level, impurities,aeration,velocity,crevices,deposits ,metallurgicalcondition,stress,surface finish and dissimilar metal contact.

5. Hot Rolling Mills

EQUIPMENT:

1. Hot rolling is a process of deforming the metal which is heated to above its re-crystallization temperature between the rolls.
2. The main purpose of rolling the material in hot condition is that the plasticity of material increases so it is easy to deform.
3. Hot rolling mill consists of three bays.

1. Conditioning bay.
2. Hot rolling bay.
3. Dispatch bay.

1. Conditioning bay:

It consists of various machines which are used to prepare the job for rolling.

The major equips are:

a) Band saw
b) Becolathe
c) Behinger
d) Amada band saw
e) Swing frame grinding
f) Shot blasting machine
g) Ekomix.

2. Hot rolling bay:

This consists of heating ovens for preheating the metal which are heated by using LPG.

- The other equipment's in this bays are :

a) Rough mill.
b) Finishing mill
c) Strip mill

d) Bars and rod mill

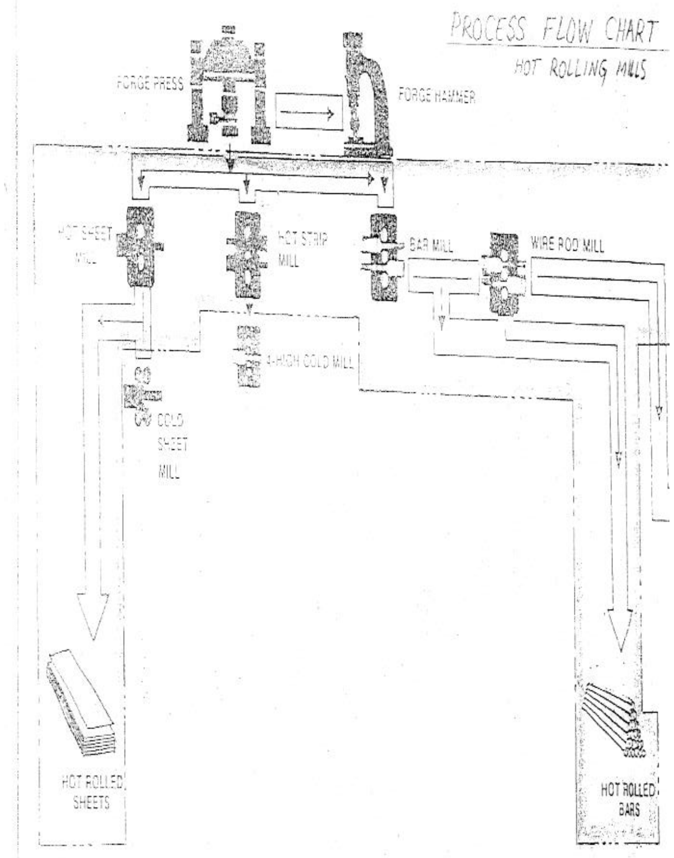
e) Wire and rod mill.

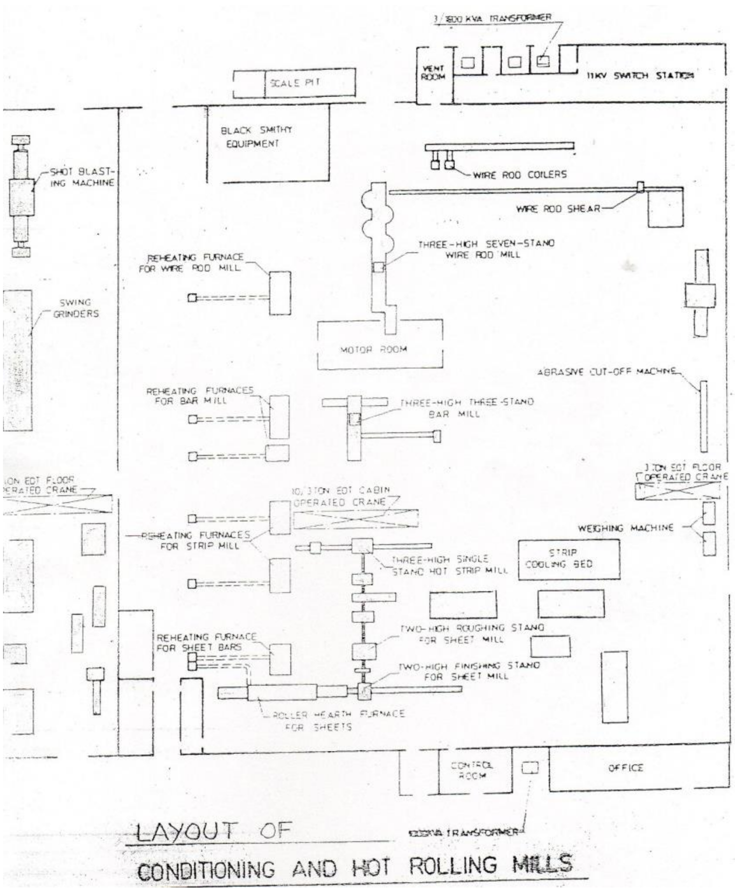
- The furnace here are heated up to re-crystallization temperature or above of the metal.
- The maximum temperature that can be attained is up to 1600°C.
- The heated metal is brought near machines with help of ingot and rolling is done.
- In rolling mills
  - Flat rolls are used in sheet and strip mill.
  - Grooved rolls are used in bar and wire rod mills.
- The grooves which are cut in the rolls to produce a given shape are known as “passes”.
- Rolling depends upon the strength, temperature of metal piece.
- The maximum of 50mm thick can be changed and a minimum thickness that can be made to size is 10mm.
- Finally by rolling in these machines a final thickness that can be made to size obtained.
- Below that thickness, finishing mill of 2–high type is used.
- In finishing mill the minimum thickness that can be obtained is 3mm.there is a strip mill beside that of the finishing mill.
- It is 3-high mill. In this mill a maximum of 650 mm length can be rolled.

The Diameter of the rolls: - 60 mm

Rotating speed: - 60-70 rpm

- Bar and rod mill are also 3-high mills. It consists of grooved rolls. The bar and rod of required size is obtained by rolling in this machine.





3. Dispatch bay:

In this bay the rolled product i.e. Strip, rod, wires etc. are cut to a required length by the following machine:-

i. Shearing machine.
ii. Leveling machine.
iii. Abrasive machine.

Heating for hot rolling:

- Heating cycles for hot rolling are simples than heating cycles for forge shop. Because products are comparatively small in size.
- Furnace atmosphere: The furnace atmosphere is indicated reducing, neutralizing or oxidizing in manufacturing specification for heating cycles.
- Reducing atmosphere is characterized by the absence of O_2 and by a certain amount of CO. This doesn't burn.

3-5 % of CO and pressure of certain amounts of excess O_2.

- An oxidizing atmosphere is characterized by the absence of CO and presence of certain amounts of excess O_2.
- A neutral atmosphere is rather theoretical case when there is neither excess O_2 nor CO.

The atmosphere is not quite homogeneous and for instance the O_2 content is likely to be higher near the door than the back of the cell.

Heating cycle: The temperature given in the heating cycle is the temperature of the furnace not the product between two successive treatments, the minimum duration in the furnace mostly depends on the smallest product dimension.

Thickness(mm)	Duration of the hold in the furnace(min)
70	15-20
40	10-15
<35	10

The slabs or billets are arranged side by side so as to form layers. It is recommended to place a sheet of stainless steel on the avoid wear of the lining and to facilitate the dragging of the slab when they heavy.

- For slabs heated at 1250°C and above which are used to avoid sticking problems due to diffusion. It improves heat transfer.

- During heat cycle sheets of stainless steel are placed on the top of the charge. This protection limits oxidation and avoids burning when products are fairly close to the burners.
- In case of cold furnace, the cold products are put in the furnace before starting the furnace and the starting temperature of the cycle reached with the product already in the furnace.
- The actual charge of the furnace should be below or equal to the maximum charge of the furnace.
- In case of an over load, the temperature rise would be too slow and the temperature distribution would not be uniform.

Furnace operation: The products are placed in the furnace and the location af the product is noted carefully with heat number and grade.

- This furnace secured is essential to avoid missing and error and to obtain traceability.
- It is a standard practice to start charging the furnace on the burner side.

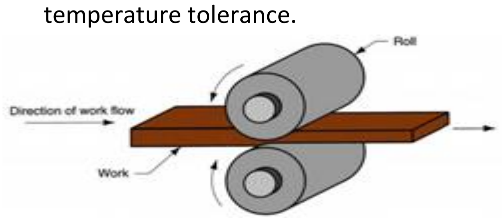
Stand by furnace: In all hot rolling operations, a stand by furnace is kept at the hot rolling temperature or slightly below.

This serves various purposes:

- To be ready to accommodate any bar this would be stopped due to an incident in the manufacturing sequence.
- To heat the adjustment billets which are used to calibrate the roll separation and the guides.

Temperature control: Due to possible in the control system of the furnace temperature, it is recommended to check the furnace temperature for each melting point plateau in the heating cycle.

- The check is performed with an optical pyrometer aimed at back furnace.
- The reading should be within the hot rolling temperature tolerance.



METHOD OF HOT ROLLER

6. TYPES OF MILLS

STRIP ROLLING MILL:

Principle: The rotation of the rolls is continuous at constant speed of 120 m/min and slab is brought quickly to the stand.

- Material is fed into the rolls and then it is held on the other side by other tilting table and the roll separation is adjusted.
- The important factor is to minimize the delay between the moments when slab is taken out of the furnace until the last pass is over.

Rolling tracks:

It is a 3-high stand implies it has six tracks, where 5 tracks are used.

- On one side of the stand, the intermediate passes are carried out.
- On the other side of the stand the intermediate passes are carried out.
- The final pass takes place in the Center of the stand.
- In other words the surface finish of the rolls improves when going from roughing to intermediate to finishing.

Rolling passes:

50 → 39 → 29 → 22 → 16.5 → 12.5 → 9.5 → 7.5 → 6 → 5

- The previous pass sequence means that at the first pass the rolls separation is 39 and at last pass the roll separation is 5 mm.
- It can be noted that the number of passes has to be an odd number in order for the strip to be on the other side of the stand after the last pass.

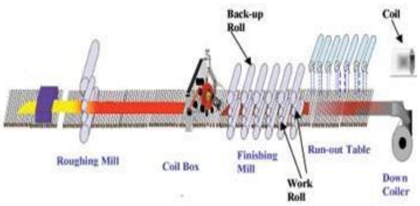
Coiling:

- Strips are coiled to facilitate annealing, handling and pickling.
- Coiling is performed after the last pass when the metal is still hot.
- It should to be done as it depends upon grades to leave space between turns, to allow pickling over entire strip surface.

Guides: For the roughing track guides are tightened because of variable widening of the strips.

Marking: A marking permits the rolling of material. The material is to be rolled only according to the markings.

Quenching: For certain a grade Quenching takes place after last pass, where in the temperature is above 800°C.



STRIP ROLLER MILL

SHEET HOT ROLLING MILL:

Principle: Rolling takes place on 2-high 2 stand where one is roughing and other finishing.

- The rolls are continuously rotated at constant speed for particular metals.
- Slab is quickly brought to feeder table using a charger.
- After each pass roll separation is quickly adjusted and sheet is returned to entry side.
- Both roughing and finishing stand works on same principle.

Slab preparation:

In sheet rolling the 3-dimensions of final product are to be controlled.

Thus slab preparation is done carefully with respect to slab dimensions i.e., to the weight of standing slab including the material losses.

- Grinding is done carefully by avoiding excessive heat. Fine grinding should remove all defects and also burns and sharp angles.

Cross Rolling: It is also called diagonal rolling and means that slab is fed to the rolls with its longitudinal axis at an angle 'α' with the direction of rolling. It exists when angle is neither 0° nor 90°.

- During this width and length elongations occur.
- To maintain rectangular shape, diagonal is changed each time.
- When α=60° lengthwise elongation occurs.
- When α=30° width wise elongation occurs.
- The major advantage of cross rolling is that it facilitates the feeding of slab in the roll bite and at the same time it avoids a shock that would occur if the whole length of the slab would be caught suddenly by the rolls.
- The major disadvantage is that it requires more skill from the operators when they position the slab at an angle during feeding.
- Cross rolling is done only during first passes on the roughing stand.

Reheats:

It depends upon temperature of sheet.

- If temperature reaches the minimum hot rolling temperature, reheating should take place.
- This is done in the range of 10-20 min for the batch program.
- To avoid refractory chips or disk the sheet is sweeped while it is taken out of batch furnace.
- On finishing stand reheating will be done using the roller hearth furnace.

Marking: Marking is done after cooling. Usually done by hot chalk.

Problems in Hot Rolling:

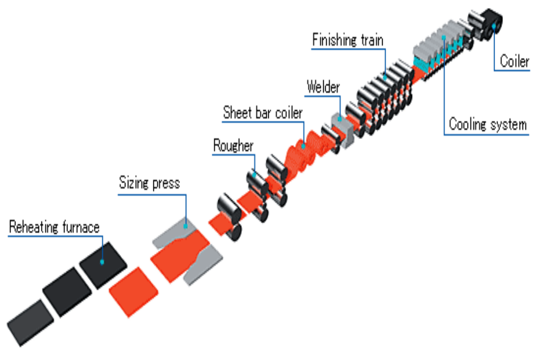
1. Sheet Camber: A sheet which has curvature is turned upside down with tongs and gives one pass at least with zero reduction if required.
2. Edge cracks: Hot Rolling is stopped if there are cracks in early stages.

Ignored if they can be removed during re-squaring operation (cropping), as they can open up in early stages.

3. Surface cracks: Surface cracks are not to be tolerated.
4. Laminated: This is also called as splitting.

After sheet passes through the rolls, it opens up in a horizontal plane along a given distance. Occurs mostly when sheet is thin, (thickness less than 5mm)

5. Scratches: These are generally due to exit guides which are not properly adjusted on feeding or catching table.
6. Marks: This defect occurs when distance or scale has been imprinted in the sheer surface thus making a small reversed area.



SHEET HOT ROLLER MILL

BAR AND WIRE ROD MILL:

Principle: Long Rolling can be defined as hot rolling in a groove without the use of entry guide.

- Feeding into the grooves is performed with the only help held tong.
- Bar is rotated 90° by operator between each groove.
- Square bars are obtained by long rolling and round bars through guide rolling.

Principle of guide rolling:

It is hot rolling with use of an entry guide. These entry guides maintain the bar and prevents its rotation.

- Guide Rolling is used in the bar mill for making round bars in the Ø30-Ø53.
- It is cannot be used for alloys with limited hot working capabilities.
- Tong rolling for round bar:
    - For bars of all grades the range of Ø54-Ø60 mm.
    - For bars between 30Ø-53Ø mm tong rolling can be also used.
- For this range (i) Super alloys which have a small forgebility.

  (ii) For small order are recommended.
- A drawbar of tong rolling is that the length of the bar is limited to only 3-4 mts.

Guide rolling of round bars:

- In this method, a lubricant is used with the entry guide to facilitate the contact between the material and the guides.

Rods and wire manufacturing method:

- On rod mill, diameter of finished products can vary Ø8-Ø30 mm.
- Except for roughing, the rest of transformation will be carried out in guide rolling mode because of very low diameter, tong rolling is very difficult.

Common defects:

1. Defect related to bar geometry:

- Symmetric oval/rectangular cross section:- Due to wrong alignment of exit guide or between the rolls.
- Symmetric flat on the 2 opposite sides:- Occurs when last groove is not large enough assuming the size of the final bar b adequate.
- Symmetric line:-Defect occurs when too much material is fed into the last groove.

Thus the previous groove should be released in order to overcome this defect

- Asymmetric fins of flat:-Mainly due to misalignment of entry guide or axial misalignment of rolls.
- Out of tolerance:-The bar is too large or it is too small such that the last groove should be tightened or release respectively.
- Twisting:-Bar has a helicoidally shape. Twisting can be done for ¼ turn per 3m length.

Due to improper positioning of guides with respect to groove.

- Bending:-It is generally due to exit guide. Bending during the first passes can be due to heterogeneous temperature i.e., one side being hotter than the other.

2. Defects not related to bar geometry:-

- Scratches: - Due to entry or exit guides. These are usually superficial. They can be due to accumulated scale or partial welding also.
- Longitudinal line:-It is due to formation of fin which is subsequently folded onto the surface and creates a line.
- It is deep and not easy to detect and the product is found defective only after pickling.
- Splitting: It is due to axial segregation combined with a cold end the split end should be cropped to allow the rolling process to continue.
- Transverse crack: Occurs usually with super alloys due to either too heavy or poor grinding or insufficient temperature (too high).
- Burns:-Due to direct impingement of a burner on the slab in furnace.
- Marks:-These defects occur at a regular interval and are due to a recessed area on rolls

BAR AND WIRE ROD MILL

7. Titanium ingot production

Raw materials obtained/used are as follows:

1. Titanium sponge
2. Master alloys (Al-VAl-MoTi)
3. Virgin metallic granules (Cu, Al, Si)
4. Titanium scrap
5. Zirconium sponge
6. TiO_2 powder.

General steps followed for ingot production of titanium alloys:

1. Visual inspection of the raw materials.
2. Mixing
3. Compact pressing
4. Arranging of compacts.
5. Plasma electrode welding
6. De-humidification
7. Vacuum arc remelting (VAC)
8. Ingot
9. Ingot turning.

Weld ability:

- Ti 6Al-4V can be using Ti-6Al-4V filler metal.
- Inert gas shielding is necessary to prevent O_2 pick up & embrittlement in weld area.
- Gas tungsten are welding is also common.
- Gas metals are welding for thicker regions are done.

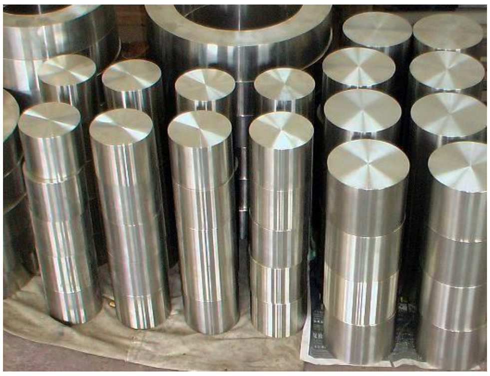
Machinability:

- For machinability this material raw cutting speeds, heavy feed rates, copies amounts of cutting fluids are recommends.
- In order to increase gall & smear of the titanium feeding should be continuous, no breaks when tool & work piece are in moving contact.
- Non-chlorinated cutting fluids should be preferred.
- Titanium chips are highly combustible.
- Removal of alpha case is done by grinding, machining, de-scaling (molten salt/abrasive) followed by pickling in HNO_3/HF mixture.
- Final heat treatments must be performed in vacuum if machinery or pickling is to be avoided.
- Protective oxide layer breakdown caused by HF, HCL, H_2SO_4, H_2PO_4 or attack by pure hydrocarbons.

Advantages of this alloy are as follows:

- Good corrosion resistance in seawater applications.

- Low density
- Low modulus of elasticity
- Low thermal expansion
- Non-magnetic in nature
- Good fatigue resistance
- Good high temperature mechanical properties.



TITANIUM INGOT

8. TYPES OF WELDING

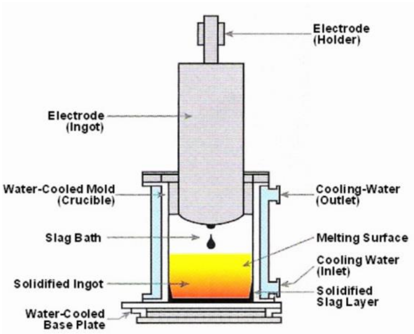
Vacuum Arc Remelting (VAC):

- It is a secondary melting process for production of metal ingots which has evaluated chemical and mechanical homogeneity for high demanding applications.
- This is essential for improving the quality of metal because it is both time consuming and expensive, a majority of commercial alloys do not employ the process.
- Nickel, Titanium and specialty steels are materials most often processed with this method.
- The conventional path for production of titanium alloys includes single, double or even triple VAR processing use of this technique over traditional methods presents several advantages.
- The solidification rate of molten materials can be tightly controlled. This allows a high degree of control over the microstructure as well as the ability to minimize segregation.
- The gases dissolved in liquid metal during melting metals in open furnaces, such as N_2, O_2& H_2 are considered to be detrimental to the majority of steels and alloys. Under vacuum conditions these gases escape from liquid metal to the vacuum chamber.
- Element with high vapor pressure such as carbon, Sulphur and magnesium (frequently contaminants) are lowered in concentrations.
- Centerline porosity and segregation are eliminated.
- Certain metals and alloys, such as Ti, cannot be melted in open air furnaces.

Process Description:

- The alloy to undergo VAR is deformed into a cylinder typically by vacuum induction melting or ladle refining.
- This cylinder referred to as an electrode is them put into a large cylindrical enclosed crucible and brought to a metallurgical vacuum (0.001-0.1 mm of Hg or 0.1-13.3pa).
- At the bottom of the crucible is small amount of the alloy to be remelted, which the top electrode is brought close to prior to starting the melt.
- Several kilo amperes of DC currents are used to start an arc between the two pieces and from these, a continuous melt is desired.
- The crucible (Typically made of copper) is surrounded by a water jacket used to cool the melt and control solidification rate. To prevent arcing between the electrode and the crucible is larger than that of the electrode.
- As a result, electrode must be lowered as the melt consumes it. Control of the current cooling water, electrode gap is essential to effective control of the process and production of defect free material.
- Ideally the melt rate stays constant throughout the process cycle, but control of the process is not simple.
- This is because there is very complex heat transfer going on involving conduction, radiation, convention(within the liquid metal) and advection (caused by Lorentz force).Ensuring the consistency of the melt process in terms of pool geometry and melt

rate is pivotal in ensuring the best possible properties from alloy.



Material: Titanium, steel, maraging steels etc.

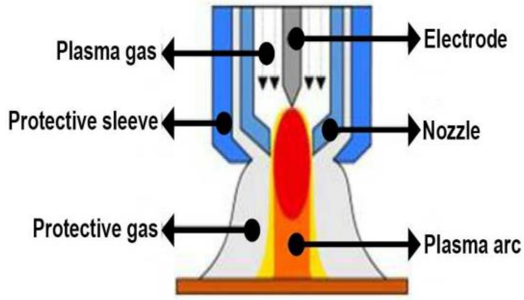
Titanium: 6al-4V; Ti-10V-Al-3Fe, Ti-5Al-5V-5Mo-3Cr.

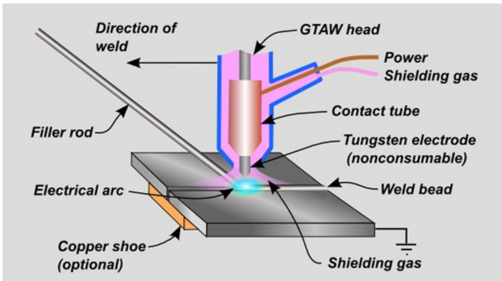
- Note that pure titanium and most titanium alloys are double or triple VAR processed.
- Nickel-based super alloys for aerospace applications are usually VAR processed.
- Zirconium and Niobium alloys used in the nuclear industry are routinely VAR processed.

Plasma Electrode Welding:

It is an arc welding process similar to gas tungsten arc welding (GTAW). The electric arc is formed between an electrode (which is usually but not always made of sintered tungsten) and the work piece. The key difference torch from GTAW is that in PAW, by positioning the electrode within the body of the torch, the plasma arc can be separated from the gas envelope. The plasma is then forced through a fine-bore copper nozzle which constricts the arc and the plasma exits the orifice at high velocities (approaching the speed of sound) and a temperature approaching 28,000°C (50,000°F) or higher. Arc plasma is the temporary state of a gas. The gas gets ionized after passage of electric current through it and it becomes a conductor of conductor of electricity. In ionized state atoms break into electron (-) and cations (+) and the system contains a mixture of ions, electrons and highly excited atoms. The degree of ionization may be between 1% and greater than 100% i.e.; double and triple degrees of ionization. Such states exist as more number of electrons is pulled from their orbits.

The energy of the plasma jet and thus the temperature is dependent upon the electrical power employed to create arc plasma. A typical value of temperature obtained in a plasma jet torch may be of the order of 28,000°C (50,000°F) against about 5500°C (10000°F) in ordinary electric welding arc. Actually all welding arcs are (partially ionized) plasmas, but the one in plasma arc welding is constricted arc plasma.





PLASMA ELECTRODE WELDING

9. TITANIUM SHOP

MIDHANI has established facilities for processing of titanium and titanium alloys from melting to mill products i.e., bars, sheets, rods and wires. It has been supplying different types of titanium and titanium alloys to numerous industries the prominent among them are space. Aviation, chemical and biomedical. At MIDHANI, Titanium alloys are classified as, Alfa-Beta and Beta alloys, according to the predominant phases present.

Titanium is one of the lightest metals and it is most commonly abundantly available. Titanium ores are rutile (TiO_2) and ($FeO\text{-}TiO_2$). Titanium is generally imported from Ukraine& Japan. Its melting point is 1660°C.It undergoes allotropic transformation at 882.5°C the grades of manufacture of in this shop are as alpha-Ti & above 1620F Bcc structure known as beta-Ti. Generally Alfa phases are pure grades (RT-12) α+β-phase grades (LT-31) etc.

Titanium & Titanium Alloys

Commercially Pure grades:

Novient Grades:

RT-12=Ti (99.8)

BT-6=Ti, 6AL, 5V

RT-15=Ti (99.7)

BT-9=Ti, 6.5AL, 3.3Mo, 1 Zr, 0.3Si

RT-18=Ti (99.6)

BT 5-1=Ti=5.6 Al, 2.6 Sn

RT-20=Ti (99.5)

BT 9=Ti, 6.5AL, 2.5Mo, 1.5Cr

RT-Ps =Ti, 0.2 Pd

OT 4.1 =Ti, 1.5AL, 1 Mn

Alloy Steels:

LT-21 = Ti, 5 Al, 2.5 Sn

LT-22 = Ti, 8 Al, 1 Mo, 1V

LT-24 = Ti, 6 Al, 2 Sn, 4 Zr, 2 Mo

LT-25 = Ti, 2.5 Cu

LT-26 = Ti, 6 Al, 3 Si, 5Zr, 1 Mo

LT-31 = Ti, 6 Al, 4 V

LT-32 = Ti, 7Al, 4 Mo

LT-33 = Ti, 6 Al, 6 V, 2 Sn

LT-34 = Ti. 4 Al, 2 Sn, 4 Mo

LT-41 = Ti, 3 Al, 11Cr, 13 V

Half alloy =Ti, 3 Al, 2.5 V

PROCESS OF Ti PRODUCTION IN Ti SHOP:

1. Visual inspection
2. Mixing
3. Compact pressing
4. Plasma arc welding
5. Dehumidification
6. Vacuum arc melting
7. Ingot turning

Raw material used for production of titanium and titanium alloys

1. Titanium sponge
2. Mater alloys, Viz. Al-V, Al-Mo-Ti etc.
3. Titanium scrap
4. Zirconium sponge
5. TiO_2 Powder

1. Visual Inspection

Visual inspection involves separation of any unwanted waste material present in the Ti sponge. The charge is passed through a magnetic separator to remove Fe bearing Particles. After this inspection it is send to mixing.

2. Mixing :The Ti sponge and the alloying element are mixed in this mixer according to their quantities and alloys percentage. After mixing the material these are sent to compact pressing.
3. Compact pressing:The mixed material is compacted at a pressure if 3000 tones. The material is placed in the die and ram is releasing to make compacts 620 X 170 mm^3.
4. Plasma Electrode Welding:The Compact are arranged in the jig. The jog is placed in a plasma-welding chamber having argon atmosphere. The compacts are welded together to have sufficient mechanical strength and electrical continuity to enable primary melting into a first melt or primary ingot. The welding automatically cycled through the entire welding process by programmable controller
5. De-Humidification:It is for removing of moisture contents, which trapped between gaps of the compacts. This process is carried out in vacuum and electrode is heated up to 200°C.
6. Vacuum Arc Remelting:

Capacity: 8 Tons steel, 4 Tons Titanium.

Diameter of Ingot produced: 860 mm Ø

Vacuum created: 1 X 10^{-3}

Melt Voltage: 20-35 V

The welded compacts from plasma electrode welding are melted in VAR furnace, to change sponge Ti and other alloys into a uniform solid solution these process is done. The main principle in this furnace is when a high amperage low voltage direct current is employed for striking an arc between the electrode and a pad of Ti scrap is placed in the bottom of the copper mould. The air gap is automatically maintained. The metal is progressively melted from the lower end of the electrode forming an ingot in the mould. The air gap maintained for Ti is 30-25 mm and for steel is 23-20 mm. The maximum current level range depends on diameter.

7. Ingot Turning Lathe: The ingot that are produced in VAR furnace are turning lathe to remove the outer oxidized layer and to

obtain better surface finish. After turning, ingots are subjected for further processing like forge shop etc.

Other furnaces in Ti shop are:

Vacuum annealing Furnace: Annealing is some in this furnace to relieve internal stresses and also to soften the material. Vacuum is created up to less than 1µ.Annealing is done in vacuum because Ti is very reactive and forms other compounds .Annealing temperature of Ti is 700

Vacuum arc Furnace: (capacity: 150 kgs)-It is similar to VAR furnace in principle and operation. But it is limited to fewer capacities. During process a skill is formed adjacent to the furnace wall by this crucible is protected from melting.

Vacuum arc Furnace: (capacity: 250 kgs)-It is similar to VAR furnace in principle and operations. But it is limited to fewer capacities. It is used for making new products in Ti One single compact can be used as an electrode in this furnace.

Crucible Cleaner: It is used for clean the crucibles.

Chip breaking Machine: It is used for breaking large chips into small chips.

TITANIUM SPONGE

Processing of Titanium-31 alloy:

- This alloy consist of 6% Al and 4% V remaining titanium.

Raw Material:

- The material required for pure titanium is titanium sponge, for pure aluminum and vanadium master alloy Al-V is used which contains 50% each Al and V.
- TiO_2 powder is also added to improve the oxygen content which should be around 0.16%.The O_2 content should not be more than 1600 ppm as per requirement.

Mixing:

All these raw materials along with 0.04-0.06 % of iron powder are added into a double mixer.

Compact Press:

- This powder is passed into the compacting press which gives a compact of 510 kg weight.
- In order to prepare a 4T weight electrode we prepare 510 kg weight 8 segments of compacts.

Charge calculations:

- Each of 510 kg weigh segment is again divided into 9 parts which are the products from compacting press.
- These 9 parts are arranged in the following manner after charge calculation.
- The compacting press works on hydraulics press principle which has 300 kg/cm^2 pressure in order to have a good compact of Ti alloy.
- These compacts are arranged in Jig for the welding process.
- The electrode that is welded is kept in VAR furnace which has a pressure of 5 $x10^{-3}$ mbar pressure.
- The primary melting occurs in 750Ø crucible in VAR-I. The maximum leakage in VAR should be 10 microns.
- In the vacuum arc remelting furnace, the electrode at the bottom melts into liquid drops and solidifies which also has a water jacket in the furnace.
- Gradually liquid drops of metal of the electrode solidify up to the top of the electrode.
- This remelting process is done for 3-4 hours.
- In the secondary melting process it occurs at 2800°C.
- In the secondary melting process it occurs at 2800°C in VAR-II. Keeping the electrode upside.
- This happens in 860Ø crucible for 4-5 hours.
- In VAR-I, the melting occurs at 500 kg/hr and in VAR-II the melting occurs at 700 kg/hr.
- The final ingot is of length 4960 mm weighing 4T.

- The ingot is turned in order to remove the oxide layers as in turning 3-4 mm of material is removed and a shiny surface of titanium ingot is produced.
- This ingot is sent to stage control lab in order to test the percentage of alloying metals like Al, V in the ingot.
- Each process in manufacturing of these alloys takes 2 days, while VAR-I and VAR II takes one day each.
- In stage control lab, the material is tested in gas burner emission spectrometer, which has O_2, H_2, N_2 gases; the emission of different wavelength gives the percentages pf alloys in the materials.
- After inspection in SCL, the forge shops receive this as its starting material final products being sheets, strips, bars etc.

10. Processing of Titanium alloy bars:

- The ingot from titanium shop is sent into the forge shop.
- Forging is done to improve.
    - To increase the material strength.
    - To reduce the elastic limit, which is heated to upper critical temperature around 1200°C where plastic deformation occurs finally resulting in fine grain structure.
- In the open die forging, the saw material process is followed.
- The ingot of 830Ø is heated in bogie hearth furnace.
- The ingot is heated up to a temperature of 1150°C in the furnace and then forging is done.
- The forging is done by 6000T, weight equipment.
- For 550Ø ingot, the material is heated at 950°C and them beta (β) solution heat treatment is done.
- For bars, the forging is done until the area of cross-section is 100^2 mm^2.
- Thus these bars are finally sent to hot rolling mill. For bar mill to produce rods.

11. Hot Rolling Procedure

Deformation of square bars of 100^2 mm^2 cross section into 50Ø round bars using hot rolling bar mills of 3 high -3stands.

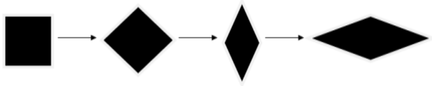
- Though the required diameter is 50mm, the final product of this mill is around 52-53mm of diameter.
- The deformation takes place in number of states using the 3 stand of bar mill.
- The bar mill is fed with 100^2 mm^2 area of bars into the first stand which are heated to a temperature above its re-crystallization temperature i.e., 950°C.
- The deformation of bar in 1st stand takes place in the following ma

$$100^2 \longrightarrow 94^2 \text{ (in first pass)}$$

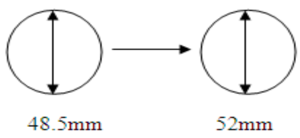
$$94^2 \rightarrow 87^2 \rightarrow 80^2 \rightarrow 72^2 \rightarrow 65^2 \rightarrow 59^2$$

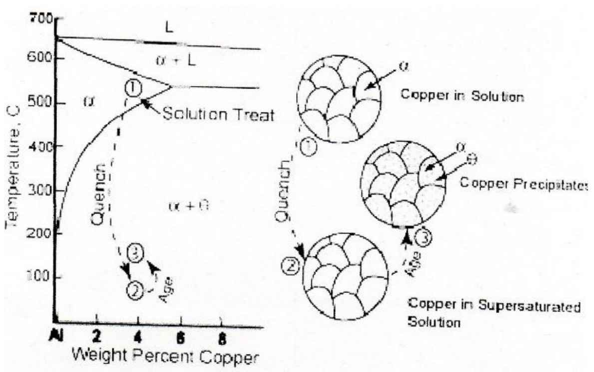
After 59^2 area is obtained is it's passed into a diamond pass. Thus we get a square shape of 59^2areas in the next pass.

- Gradually from 59^2 area of square bar is again passed through a diamond pass of 56^2 area.
- Finally a bar of square shape and 56^2 area of cross-section is obtained from the first stand.
- This square bar in second stand is made into a diamond shaped box.



- In the third stand we obtain the final product with diameter 52mm and round shape.
- The bar from second stand is passed into a oval guide in 3rd stand which is between the first two rolls of this stand.
- This oval shaped bar obtained will be of diameter around 48.5mm or above.
- This bar is passed through circular entry guide placed between the next two rolls of 3rd stand.
- Thus the final round bar of diameter 5mm is obtained.





12. QUALITY CONTROLLABORATORY

Quality control can be defined as the regulatory process through which we measure actual quality performance, compare it with standards and act on the difference. The quality performance is the conformance to be specification on testing the product or sample.

This department consists of the following main divisions:

1. Mechanical testing.
2. Raw material inspection cell (RMIC)
3. Quality control workshop

1. Mechanical testing:

In mechanical testing, test is done on the specimens obtained from the quality control workshop. The various types of tests that are mostly performed are:

1. Hardness measurement
2. Impact testing
3. Tensile strength testing
4. Fracture toughness
5. Fatigue failure testing

1. Hardness measurement:

Harness can be defined as the property of a metal by nature of which it resist scratch, wear, abrasion or indentation. In the hardness testing section there are four testing machines.

2. Impact testing:

The classical strength of material procedure calculate the load carrying capacity of a part on the basis of some percentage of the gross static yield stress as measured by a smooth uniaxial tension specimen.

3. Tensile strength testing:

It is done to determine the yield strength. Ultimate Tensile strength, % reduction in areas and % elongation in length. Ultimate tensile strength testing machine is used for this. Three machines of capacity 10 tons, 20 tons and 25 tons are used for determining yield strength. Extensometers are required for determining the % elongations. The 20 ton Universal testing machine (UTM) is attached to a computer. High temperature tests have been carried out in the 25 ton UTM. Temperature ranges from 175-1000 centigrade.

4. Fracture toughness test:

The aim of the test is to obtain reproducible values for the lower limiting critical toughness of a material. The specimen for testing is made from the recommended design.

A sharp crack is introduced at the tip of the stress concentrator. For this purpose fatigue cracking is employed. This process is called pre-cracking. The specimen is then loaded and load displacement curves are drawn until the specimen fractures. The value of the lower critical toughness is calculated from tables.

5. Fatigue testing: Fatigue is a property by which the material fails at a relatively low value of stress when that stress is repeatedly applied. Of all the type of repeated stress that could be applied, the totally reversed bending stress is the most severe one. Hence fatigue strength of metals is generally determined under completely reversed bending conditions.

The fatigue-testing machine applies a bending moment to a circular specimen which is simply supported at its ends in chucks or collects while it is rotated at a specimen speed. The number of cycles and the load applied are noted for each specimen before it breaks. The maximum load for which the specimen does not break even after one million revolutions is taken as the endurance strength of the material.

Creep laboratories: In the creep laboratories three types of tests are carried out:

1. Creep test.
2. Creep rupture test
3. Stress rupture test.

1. Creep test: It is the time dependent strain that occurs after the application of a load, which is there after maintained constant. A creep test has the objective of measuring creep and during the time of testing. Since the maximum deformation is small, a sensitive extensometer is required.

2. Creep rupture test: It is one in which progressive specimen deformation and the time for rupture is measured. In general, deformation is much larger than that developed during a creep test.

Material Tested:

1. Titanium alloys for aeronautical industry.
2. Special steels for aeronautical industry.
3. Super alloys for aeronautical, nuclear and chemical industry.

Raw materials inspection cell (RMIC): The inspection is done mainly to check the chemical composition. The presence of trace elements, which are low melting element and are not suitable for high temperature applications are studied here. All tests are carried out using solutions only. A sample is a one, which is prepared accurately to the required conditions. For analyzing the samples, double bam atomic absorption spectrophotometer and double beam UV-VIS spectrophotometer are used.

The atomic absorption spectrophotometer makes us of a hollow cathode lamp. Different lamps are used for the analysis of different element such that the lamp emits the same radiation as that of the element analyzed. Two beams are produced, one passing through the sample and the other passing through the reference solution. Depending upon the concentration of the element, radiation will be absorbed. The difference in absorption between the sample and reference solutions is given out as a reading.

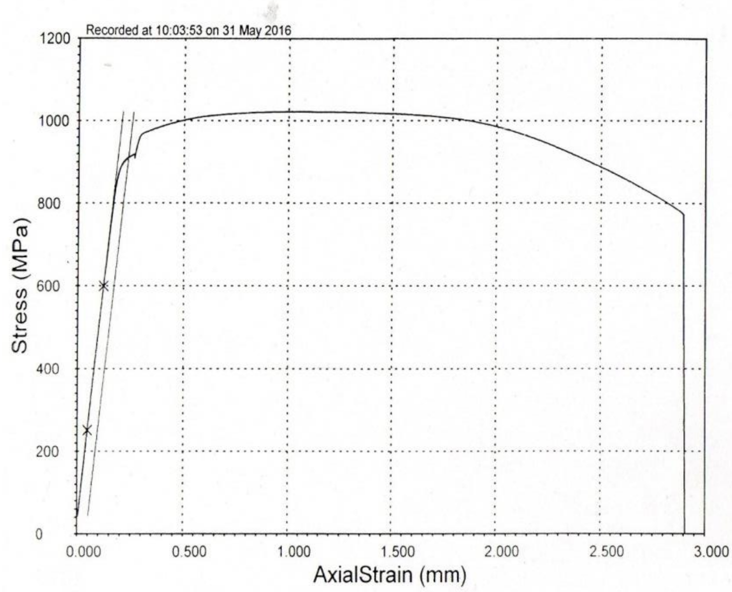
The UV-VIS spectrophotometer makes use of a tungsten lamp, which emits radiations ranging from light yellow to dark blue.

Quality Control workshop: In the quality control workshop, samples are brought in from the various other shops, which are then machined into specific shapes prescribed for testing. Test-specimens for fatigue, tensile, stress rupture, impact creep and various other tests are made in this workshop. For this purpose there are a variety of machines from a simple band saw to a CNC controlled high precision lathe. This shop also has metrology sections, which checks the test-specimens for dimension and tolerances. The machines used in this shop are:

1. Bi-metallic band saw, 2nos, with HSS teeth and medium carbon steel body.
2. Center lathe, 4 nos.
3. CNC controlled high precision lathe
4. Milling machines, 3 no's
5. Center grinders, 2nos
6. Tool & cutter grinder
7. Abrasion cutting saw, no's
8. Shaping machine
9. Broaching machine.
10. Wire electric discharge machine, 2nos

The input material to the quality control workshop comes from various shops in various shapes and sizes, ranging from 3mm wire to 180 mm diameter ingot slices. These are properly cut to required sizes and then machined to produce a standard test specimen conforming to the ASTM or ISI standards.

TENSILE TEST



Specimen Identifier:	S1413-B-L1
HEAT NO.:	S1413-B
GRADE:	Titan 31
PRODUCT:	45 DIA
BATCH NO.:	90680
ROUTE CARD NO.:	16349
CONDITION:	ANN
HEAT TREATMENT:	-
CUSTOMER:	SBC
TEST DONE BY:	A.NANDINI
Test Date:	31 May 2016
Start Time:	10:03:53
End Time:	10:08:06
Geometry:	Round
Diameter:	6.21 mm
Axial Strain Gauge Length:	25.00 mm
Area:	30.29 sq mm

Analysis Results

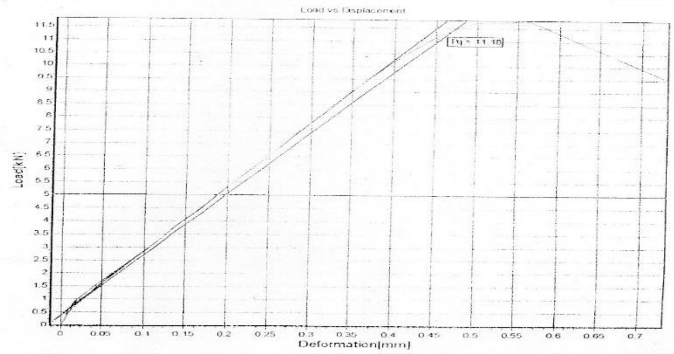
Manual Elongation at Break	
Elongation	16.20 %
Initial Gauge Length	25.00 mm
Final Gauge Length	29.05 mm
Maximum Load	
Load	30.94 kN
Maximum Stress	
Maximum Stress	1021.36 MPa
Modulus of Elasticity	
Modulus	118624.89 MP
Reduction of Area	
Reduction	43.931 %
Final Diameter	4.65 mm
Yield by Offset (Load)	
Yield	27.58 kN
Offset	0.200 %
Yield by Offset (Stress)	
Yield	910.47 MPa
Offset	0.200 %

K1C DATA SHEET (ASTM E399)

Customer:	VSSC	Testdate:	28.05.2016
Specimen ID:	S1360ACR	Operator:	MURTHY.GVSSN
Material:	TITAN-31	Remarks:	S1360A:887X855X145.5RING BNO;90678
Sampleform:	C(T)		
Starter Notch:	Narrow Notch		Ti-31:RC:16312

PARTICULARS	DATA	REF.
Crack Plane Orientation	ACR	3.1.3
Yield Strength [MPa]	931	7.1.1
Thickness, B [mm]	12.49	8.2.1
Width, W [mm]	25.08	8.2.2
FATIGUE PRECRACKING	**DATA**	**REF.**
Max Stress Intens. [Mpa-m1/2]	20.00	
Total Cycles	25000	
Terminal Kmin [Mpa-m1/2]	10.00	
Terminal Kmax [Mpa-m1/2]	18.00	

FRACTURE TEST	DATA	REF
Crack Lengths		8.2.3
Center of Crack Front (a1) [mm]	12.83	
Right of Center(a2) [mm]	12.88	
Left of Center (a3) [mm]	12.76	
Right of Surface (a4) [mm]	12.36	
Left of Surface (a5) [mm]	12.14	
Loading Rate [mm/s]	0.50	8.3
Test Temperature [°C]	21	
Relative Humidity [%/rel]	13	
CALCULATIONS	**DATA**	**REF.**
Validity Requirements according to ASTM E399	valid	next page
Kq [Mpa-m½]	56.533	
Result of Validation	Kq is Qualified as KIc	
Valid Kic [Mpa-m½]	56.533	



13. RESULTS

We have deformed the titanium grade metal by hot rolling technique and it was successful we have the bar from furnace and pass through the hot roll mills of three high stands and hence the deformation is seen in the sheets of the titanium

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