Pure Titanium Slab Rolling Study & Practice on Twin-stand Hot Steckel Mill

Chen Yusheng  Shi Yaming  Su hezhou  Yan Qi  Wang Junhong
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Abstract
This article presents the industrial pure titanium coil process study and production practice on Twin-stand Steckel Mill of Kunming Iron & Steel Co., Ltd (Hereafter refer to “KISC”) carried by Yunnan Titanium Industrial Co., Ltd(Hereafter refers to “YNTY”). It analyses the different process features comparing with Continuous Hot Strip Mill. It states process study and production practice, gained experiences and achievement on how to improve the target rate and quality for Pure Titanium Coil Hot Rolling on Twin-stand Steckel Mill.

Key Word
Twin-stand Steckel Mill, Hot-rolling Titanium Coil, Process Study, Production Practice

Preface
KISCO HM started the trail rolling for industrial pure titanium coil from the year of 2007. 3~6mm×1000~1400mm titanium coils are produced on Twin-stand SM, through the acid pickling, then it was rolled on Four-high Cold Mill or 12-high Cold Mill, the final product thickness is 0.5~3mm. After few years practice, knowledge and experience have worked out for improving the titanium coiling successful rolling target on Twin-stand SM. YNTY also shares some experiences for trail rolling for titanium coils on the continues Strip Mill. It has produced large amount titanium coils with 2.6mm of Min. thickness and 98.64% of yield from May, 2009 to December, 2012.

It shares the features of shorter process flow, investment saving, time saving for construction and commissioning, flexible product, suitable product scale, etc. for Steckel Mill, but it has defectives of poor coil surface quality, sufficient method of coil shape controls. KISC imported the facilities of Twin-stand Steckel Mill and matching Reheat Furnace, Descaling System, Coiling Furnace, etc. from Tippins Inc., USA in 2000. It has been put into production on September 30, 2002 for the Project and it is the first modern Twin-stand Steckel Mill in China. The technical Data Sheet for this mill is as follows:

<table>
<thead>
<tr>
<th>Slab Size</th>
<th>200<del>230 mm × 900</del>1600 mm × 4600~10400mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Slab Weight</td>
<td>30t</td>
</tr>
<tr>
<td>Final Product Coil Size</td>
<td>1.2<del>20 mm×1000</del>1600 mm×L mm</td>
</tr>
<tr>
<td>Furnace Discharge Temperature</td>
<td>1270 °C</td>
</tr>
<tr>
<td>Slab Breakdown Temperature</td>
<td>1080~1200 °C</td>
</tr>
<tr>
<td>Coil Finish Rolling Temperature</td>
<td>800~950 °C</td>
</tr>
<tr>
<td>Main Motor Power</td>
<td>AC5224 kW (two motors for each Stand. Work Roll Driven)</td>
</tr>
<tr>
<td>Speed</td>
<td>125/300rpm</td>
</tr>
<tr>
<td>Max. Separating Force</td>
<td>35280kN</td>
</tr>
<tr>
<td>Max. Rolling Torque</td>
<td>1793kNm</td>
</tr>
<tr>
<td>Max. Roll Bending Force(on each WR Neck)</td>
<td>1930kN</td>
</tr>
<tr>
<td>WR Max. Shafting Amount(Per side)</td>
<td>100mm</td>
</tr>
<tr>
<td>Rolling Speed</td>
<td>≤763 m/min</td>
</tr>
</tbody>
</table>

1. Status and Difficulties for Titanium Hot Rolling
It is easy oxidation or generates polluted layer at surface compounded with chemical of O, N, C, Te, Si, etc. at high temperature when it was heated and rolling. It is also easy to have cracks, generate coarse grain and it is difficult to remove surface polluted layer during the rolling. Based on these facts, special heating and rolling temperature will be utilized. Furthermore, the natural of lower heat conductivity, fast temperature dropping, higher tensile ratio, fast hardening at lower temperature, etc. for titanium caused the difficulties for titanium coiling producing.

The conventional way in China is to produce single piece of titanium sheet on Two-high or Four-high Mill. While it cannot produce the titanium coil using this technology and results in lower production efficiency, lower yield, limited product length and width, poor flatness and surface quality. High production capacity for Continuous Hot Strip Mill(HSM) with thousands to more than ten thousand tons of steel production each campaign, while small quantity of titanium batch will be leading more energy consumption for titanium rolling on HSM. Therefore, it is the continuously
research and develop target for titanium coil rolling to adapt the hot rolling process with flexible product mix and small batch of titanium coil producing. It is preferable for wider titanium coil with better flatness, superior surface quality, improved the strength and plasticity, it is needed to automatically develop the rolling process per various material and target product parameters in order that the produced titanium coil can reach the reference value of target parameter.

2. Advantage and Disadvantage for Titanium Coil Rolling on Twin-stand SM

2.1 Advantage for Twin-Stand SM

(1) Industrial pure titanium rolling on Twin-stand SM can produce various product size and grade with small quantity, even less than one hundred ton to hundreds of tons. It has the feature of diversify product mix with small batch.

(2) The Coiling Furnaces at entry/exit of Mill Stands can significant reduce the titanium strip temperature drop during the coiling passes and remain higher temperature at end rolling. It will be beneficial for improving the evenly elongation, reducing the camber and obtaining superior flatness.

(3) Due to compact Twin-stand tandem configuration, there are two drafts for each pass, the rolling duration will be half of the time comparing with Single-stand Four-high Mill, it will reduce the temperature drop and oxidation due to expose to the air for titanium strip.

(4) Titanium coil rolling on Twin-stand SM, it can achieve satisfied flatness for wider product, enhance the strength and plasticity for titanium coil, it also can automatically generate the rolling process for different material and target product parameters and result in increasing the productivity, lowering the energy consumption and improving the product quality.

2.2 Disadvantage for Twin-Stand SM

(1) Due to reversing rolling, there are processes of threading, acceleration, constant speed, deceleration, holding, reversing, etc. The duration time in the Coiling Furnace for tail and head are only half of the middle of trip, in addition, the head will wrap on the water cooling drums shafts. The tail and head temperature will lower and there is temperature differential and uneven with strip middle due to these two factors.

(2) Tail and head with lower and uneven temperature thread for several reversing passes, the rolling force are higher during the threading and the rolling piece is easy to run cross offset, the threading process is not stable.

(3) There is no flying shears at the mill entry/exit, the irregular head and tail for titanium strip cannot be cut before finish passes (coiling passes). The sharp edges for tail and head are easy to hit with table/apron and bend, it may result in the tail and head lead in the gap between the table/apron, the possibility of threading failure and cobble will be increased.

2.3 Target Rate for Titanium Coil Rolling on Twin-stand SM

The ideal deforming temperature is 700℃ ~ 880℃ for industrial pure titanium and it will not form surface oxidation and polluted layer at this temperature states in some documentation. Even the Twin-stand SM has reduced the half of rolling time, it is still difficult to finish 7 passes of reversing rolling within 180℃ temperature fluctuation. The actual end rolling temperature is near 550℃, the titanium strip surface are getting dark and almost no brightness.

Rolling under this temperature, it is difficult to control the turn up/down after it comes out from #2 Stand of first pass. It will heavily impact the roller table and apron. At most case, the threading will be failure and cobble at initial 5 passes due to turn up/down and stopped by table/apron and even worse it may damage the apron or other equipments. Sometimes, even it completes the target thickness rolling, due to relatively lower the heat capacity ratio, fast cooling and end rolling temperature is below 600℃, the last pass deforming is not even and result in bigger camber, poor flatness, even worst the threading failure.

To improve the above mentioned situation, the heating temperature will be increased by 40℃, but it still cannot avoid the rolling piece seriously turn up/down after first pass, it even gets worse and more difficult to control. The turn down head can take out the apron after it comes out from #2 stand of first pass and the turn up head can reach the height to Edger Separator after it comes out from #2 stand of second pass. Due to frequently cobble for initial two passes, it is hardly to go ahead. At this case, the target rate for Titanium Coil Rolling on Twin-stand SM is only around 60%. The seriously turn up/down shapes are illuminated as following sketch:
The essential reason for rolling piece turn up/down is due to the elongation difference for top and bottom surface metal during the hot plastic deforming. It will bend to another side for the side, which has better plasticity and larger elongation and form the turn up/down. The temperature will be the directly factor to affect the rolling titanium piece plasticity. From the crystallography feature of pure titanium, it has to been taken into consider for the effect of plasticity at high temperature.

From the point of crystallography, the plastic deformation for metal is caused by combination of crystal slip and twinning. The slip means partial of crystals are relatively moved along with certain crystal direction and plane and it is the major and common deformation appearance. There are two allotropes of $a$ and $\beta$ for pure titanium. It is $a - Ti$ and h.c.p (close-packed hexagonal structure) under 882 $^\circ$C. It is $\beta - Ti$ and body-centered-cubic (BCC) structure from 882 $^\circ$C to melting point of 1678$^\circ$C. The structures are illuminated as following sketch:

[Chart1 Close-packed Hexagonal Structure]
[Chart2 Body-centered-cubic (BCC) Structure]

There are 6 $\{110\}$ slipping planes and two slipping directions of each slipping plane for Body-centered-cubic (BCC) Structure, so total is 6X2=12 slipping systems. There are one $\{0001\}$ bottom slipping plane and 3 diagonal slipping directions of the slipping plane for Close-packed Hexagonal Structure, so total is 1X3=3 slipping systems. Due to the number of slipping system are 4 times difference for two crystals. For pure titanium, the plasticity of Body-centered-cubic (BCC) Structure $\beta - Ti$ is much better than Close-packed Hexagonal Structure $a - Ti$. For actual deformation, although the $a - Ti$ is Close-packed Hexagonal structure (h.c.p), but its $\{0001\}$ crystal plane is not solely slipping plane, the other planes, such as $10\bar{1}1$, $10\bar{1}0$ planes are also can join the slip. So the plasticity for pure titanium is better than other h.c.p structure, which solely have $\{0001\}$ slipping plane, such as magnesium, zinc, etc. therefore, it is states the hot rolling temperature is from 700$^\circ$C to 882$^\circ$C for titanium plate in some documentation.

In case the temperature is increased by 40$^\circ$C, it may get to Body-centered-cubic (BCC) Structure of $\beta - Ti$. For reheat furnace that width is more than 10m, it may have 40$^\circ$C temperature difference for top and bottom surface of slab. It will cause one side is Body-centered-cubic (BCC) Structure and another side is Close-packed Hexagonal Structure for top and bottom, the plasticity for top and bottom will be significantly difference due to different crystal structure and related plasticity. This will result in bigger elongation difference for top and bottom at first and second rolling passes and serious turn up/down will happen and cobble may occur.

Therefore, it is needed to appropriately control the reheating and start rolling temperature. After increasing the rolling temperature to 950 $^\circ$C and reducing the temperature difference within 20$^\circ$C for top and bottom surface, make rough passes (initial two passes) rolling for thick titanium slab shall be at $\beta$ phase to avoid serious turn up/down and cobble, which caused by top and bottom surface at different $a$ and $\beta$ phase, make the plastic elongation $\Omega$ are difference for top/bottom surface for initial two passes with thicker slab and heavier draft rolling.

When the titanium piece become thinner and enters into finish passes, the cross section temperature for thinner piece will be even and it can be rolled under $a + \beta$ two phases,
the absolute drafts will be significant reduced, although the plastic elongation for top/bottom surface are still difference, the actual elongation length are also restricted by internal metal stress on entire titanium length. The influence for tail and head turn up/down is no longer sensitive and it is not easy to happen for serious turn up/down and cobble. At the same time, the produce flatness and camber will also significantly improved due to higher end rolling temperature result in evenly deformation for last pass, the threading failure will also be reduced.

After improving the hot rolling process temperature as per mentioned above for Titanium Coil Rolling at Twin-stand SM, it has significantly reduced for turn up/down at rough passes and threading failure at last passes.

Bogie hearth electrical heating furnace will be used for reheating the industrial pure titanium. During the rolling, the stable and best condition rolls will be selected for Mill Stand. It will be rolled shifting between the steel and titanium and fast to change the rolling model in order to significantly improve the yield and quality, the target rate has increased to 96.67%, furthermore, there is no longer serious oxidation and polluted layer, surface cracks at surface, worse microstructure and mechanical property. The flow chart for shifting rolling between the steel and titanium is shown as chart #3. The pictures #4 & #5 are shown the titanium charging for rolling and final hot rolled coil.

While, some differences are appearance for Microstructure, the Grain Size is getting course and un-even after increased the start rolling temperature. The surface oxidation extend has appeared minor difference for Ti-slab under 900℃ and 860℃ of start rolling temperature as shown at chart 6 &7, the surface getting course due to oxidation under 900℃ of start rolling temperature. The differences are also appearance for longitudinal Microstructure for Ti-slab under 900℃ and 860℃ of start rolling temperature as shown at chart 8 &9, the Grain Size is getting more course and un-even for 900℃ than 860℃ of start rolling temperature.
3. Advantage and Disadvantage for Titanium Coil Rolling on Continuous Hot Strip Mill

3.1 Advantage for HSM

(1) For 5 reversing rough passes, the titanium slab is thicker (42~48mm) and the rolling temperature is higher, reversing strip threading is less and the rolling force is appropriate, it will be helpful to improve the work piece off center and it is easier to thread and rolling is stable.

(2) The finish passes will be one direction rolling on the 7-stand finish mill, it is only have threading, mill acceleration and deceleration, etc process. The rolling speed for every stand is relatively constant, thread and mill acceleration is stable, the speed is high for acceleration rolling and the temperature drop is less for whole work piece.

(3) Titanium strip temperature drop and differential is small. Along with the strip length, the tail is rolled at the end and temperature drop is more. The temperature is graduate drop from head, middle body to tail of strip. The temperature at head is highest, the temperature is continuously and slowly drop along with the strip length and there is no suddenly temperature change. The deformation is relatively evenly and easier to control the thickness accuracy and flatness.

(4) There is flying shear located at the entry of finish mill, it can cut the irregular and black mark titanium head and it can avoid the sharp thin head at the following rolling. The higher temperature and regular head will be benefit for strip threading and it can avoid the threading failure. It can significant improve the threading stable and target rate. While the yield will be lower due to the flying shear cut the head and tail.

(5) There is sufficient technical measures to control the thickness variation at width direction and flatness for titanium rolling on the HSM, it can achieve satisfied flatness for wider product and it can improve the strength and elasticity for titanium coil. It can automatic control based on different product data and target data in order to improve the productivity and product quality.

(6) It can achieve superior surface finish for the titanium coil rolling on the 7-stand finish mill and work roll of last stand.

3.2 Disadvantage for HSM

(1) The duration of tail of the titanium strip exposed to the air is longer and the temperature drop is higher. The lower temperature of the tail, the more un-even for rolling deformation and result in strip will be off the mill center line.
and easy to cause camber for the tail.

2. The capacity of the HSM is big and it can be more than ten thousand tons of products per day and the productivity is higher. For the titanium coil product, it will be small batch with more or less one hundred tons. It takes long time to prepare the small batch production and it is lower efficiency and consumption is increased.

3.3 The Target Rate for Pure Titanium Rolling on the HSM

The rolling speed is higher and temperature drop is lower for HSM. The head temperature of work piece is higher and the shape is regular and threading is stable. The reheating temperature for pure titanium slab can control to range of 880~920℃, it can be discharged under temperature of 870~890℃ and start rolling below 880℃ to ensure the finish rolling temperature ≥650℃. It can totally avoid the rolling is under α+β phase, which will cause the plastically elongation deferential for α and β phase. Especially for initial two passes with bigger draft, it can effectively avoid elongation deferential for top and bottom surface caused by α and β phase crystal structure and avoid the cobble due to head turn up/down. It improved the rolling stability and the rolling successful rate is achieved to 99.78%. At the same time, the uniformity of plastic elongation for last pass is improved due to higher finish rolling temperature and the flatness for titanium coil is significantly improved. Due to lower reheating temperature and the function of finish stand and work roll of last stand, the surface roughness is better and surface quality is significant improved for TA2 pure titanium coil rolled by HSM comprising with SM. Refer to the following Chart 10, 11, 12, 13.

Chart 11 Scanning microscopeX500,TA2 surface rolled by SM, Start Rolling Temp. 900℃

Chart 12 Scanning microscopeX100,TA2 surface rolled by HSM, Start Rolling Temp.860℃

Chart 13 Scanning microscopeX500,TA2 surface rolled by HSM, Start Rolling Temp.860℃.

4 Conclusion

4.1 When the industrial pure titanium is heated and start rolling at temperature near 882℃, it is easy to under α+β phase in case the control is not accurate. The pure titanium will be α—Ti phase and Close-packed Hexagonal Structure when the rolling temperature in below 882℃, while it will be β—Ti phase and Body-centered-cubic (BCC) Structure when the rolling temperature is above 882℃. There are significant differences for the elongation and
deformation properties when they are being plastic deformation due to different crystallization features for two phases and this will cause serious turn up/down during the rough passes for titanium coil rolling at Twin-stand SM.

4.2 Increase the heating and start rolling temperature to 950 °C and reduce the temperature differential within 20°C, the initial 2 passes rough rolling will be at β phase for thicker titanium slab. In this case, the it can be avoided for serious turn up/down and result in cobbles, the thread failure will be also significantly reduced and the target rate increased.

4.3 The titanium coil rolling will alternate with steel rolling during one campaign and it can improve the pure titanium rolling stability, target rate and flatness. It has features of practicability and economy for alternative rolling between steel and titanium.

4.4 Based on above mentioned method to improve the reheating and rolling process temperature for titanium coil rolling, there is no serious surface oxidation layer and polluted layer, surface cracks, worse microstructure and inferior mechanical property.

3-4mm titanium coil rolled after the Twin-stand Steckel Mill, it will be annealing and surface treatment at YNTY, then cold rolling. The batch and commercial production has been achieved for bigger ratio of width to thickness for 0.5mmX1380mm titanium coiling cold rolling. It has been produced large amount of 3.0mm-6.0mm thickness hot rolling titanium coil and large amount of 0.5mm-2.0mm thickness cold rolling wider titanium coil in 2011. The product has been widely used for welding piping, plate heat exchanger. It also acknowledged and widely used for varies industrial areas. It has gained good social and economic benefits in China.

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Pure Titanium Slab Rolling Study & Practice on Twin-stand Hot Steckel Mill

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Section chief & Senior Engineer of rolling process
YUNTi (Yunnan Titanium Industrial Co., Ltd of KISC )

October 7-10, 2012, Atlanta, Georgia, USA
Pure Titanium Slab Rolling Study & Practice on Twin-stand Hot Steckel

1. Status and Difficulties for Titanium Hot Rolling
2. Advantage and Disadvantage for Titanium Coiling on Twin-stand SM
   2.1 Advantage for Twin-stand SM
   2.2 Disadvantage for Twin-stand SM
   2.3 Target Rate for Titanium Coil Rolling on Twin-stand SM
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Each slipping plane and slipping direction at this plane for crystal will be a slipping system. The more slipping system in the crystal, the more possibility for slipping occurrence and better plasticity. The slipping plane and slipping direction for close-packed hexagonal (h.c.p) structure and body-centered-cubic (BCC) structure are illuminated as following sketch:
• There are 6 \{110\} slipping planes and two slipping directions of each slipping plane for Body-centered-cubic (BCC) structure, so total is 6 \times 2 = 12\ slipping systems. There are one \{0001\} bottom slipping plane and 3 diagonal slipping directions of the slipping plane for Close-packed Hexagonal (h.c.p) Structure, so total is 1 \times 3 = 3\ slipping systems. Due to the number of slipping system are 4 times difference for two crystals. For pure titanium, the plasticity of Body-centered-cubic (BCC) Structure\(\beta\)—Ti is much better than Close-packed Hexagonal (h.c.p) Structure\(\alpha\)—Ti.
For actual deformation, although thea—Ti is h.c.p structure, but its \(\{0001\}\) crystal plane is not solely slipping plane, the other planes, such as \(\{10\bar{1}1\}\), \(\{10\bar{1}0\}\) planes are also can join the slip. So the plasticity for pure titanium is better than other h.c.p structure, which solely have \(\{0001\}\) slipping plane, such as magnesium, zinc, etc. therefore, it is states the hot rolling temperature is from 700°C to 882°C for titanium plate in some documentation.
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Crystallography Feature and Plasticity at High Temperature for Pure Titanium

• In case the temperature is increased by 40°C, it may get to Body-centered-cubic (BCC) Structure of β—Ti. For reheat furnace that length is more than 10m, it may have 40°C temperature difference for top and bottom surface of slab. It will cause one side is BCC Structure and another side is h.c.p. Structure for top and bottom, the plasticity for top and bottom will be significantly difference due to different crystal structure and related plasticity. This will result in bigger elongation difference for top and bottom at first and second rolling passes and serious turn up/turn down will happen and cobble may occur.
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When the titanium piece become thinner and enters into finish passes, the cross section temperature for thinner piece will be even and it can be rolled under α+β two phases, the absolute drafts will be significant reduced, although the plastic elongation for top/bottom surface are still difference, the actual elongation length are also restricted by internal metal stress on entire titanium length. The influence for tail and head turn up/down is no longer sensitive and it is not easy to happen for serious turn up/down and cobble. At the same time, the produce flatness and camber will also significantly improved due to higher end rolling temperature result in evenly deformation for last pass, the threading failure will also be reduced.
2.3 Target Rate for Titanium Coil Rolling on Twin-stand SM

- After improving the hot rolling process temperature as per mentioned above for Titanium Coil Rolling at Twin-stand SM, it has significantly reduced for turn up/down at rough passes and threading failure at last passes.

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2.3 Target Rate for Titanium Coil Rolling on Twin-stand SM

- Bogie hearth electrical heating furnace will be used for reheating the industrial pure titanium. During the rolling, the stable and best condition rolls will be selected for Mill Stand. It will be rolled shifting between the steel and titanium and fast to change the rolling model in order to significantly improve the yield and quality, the target rate has increased to 96.67%, furthermore, there is no longer serious oxidation and polluted layer, surface cracks at surface, worse microstructure and mechanical property. The flow chart for shifting rolling between the steel and titanium is shown as chart #3. The pictures #4 & #5 are shown the titanium charging for rolling and final hot rolled.
2.3 Target Rate for Titanium Coil Rolling on Twin-stand SM

- **Steel/Titanium Coil Shafting Rolling Flow Chart**

Steel Slab ➔ Walkbeam Reheat Furnace ➔ Reversing Flat Rolling on SM ➔ Reversing Steckel Rolling on SM ➔ Steel/Titanium Coil ➔ Coiling on the Upcoiler

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2.3 Target Rate for Titanium Coil Rolling on Twin-stand SM

Chart 4 Single Ti-Slab Discharging from Electrical Furnace

Chart 5 3.0mm Hot Rolled Ti-Coil

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While, some differences are appearance for Microstructure, the Grain Size is getting course and un-even after increased the start rolling temperature. The surface oxidation extend has appeared minor difference for Ti-slab under 900°C and 860°C of start rolling temperature as shown at chart 6 &7, the surface getting course due to oxidation under 900°C of start rolling temperature. The differences are also appearance for longitudinal Microstructure for Ti-slab under 900°C and 860°C of start rolling temperature as shown at chart 8 &9, the Grain Size is getting more course and un-even for 900°C than 860°C of start rolling temperature.
2.3 Target Rate for Titanium Coil Rolling on Twin-stand SM

TA2, Edge Longitudinal Microstructure, Start Rolling Temperature 900°C

TA2, Middle Longitudinal Microstructure, Start Rolling Temperature 900°C

TA2, Edge Longitudinal Microstructure, Start Rolling Temperature 860°C

TA2, Middle Longitudinal Microstructure, Start Rolling Temperature 860°C
3. Advantage and Disadvantage for Titanium Coil Rolling on Continuous Hot Strip Mill

3. 1. Advantage for HSM.

• (1) For 5 reversing rough passes, the titanium slab is thicker (42~48mm) and the rolling temperature is higher, reversing strip threading is less and the rolling force is appropriate, it will be helpful to improve the workpiece off center and it is easier to thread and rolling is stable.

• (2) The finish passes will be one direction rolling on the 7-stand finish mill, it is only have threading, mill acceleration and deceleration, etc process. The rolling speed for every stand is relatively constant, thread and mill acceleration is stable, the speed is high for acceleration rolling and the temperature drop is less for whole workpiece.

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Advantage and Disadvantage for Titanium Coil Rolling on Continuous Hot Strip Mill

3. 1  Advantage for HSM

(3) Titanium strip temperature drop and differential is small. Along with the strip length, the tail is rolled at the end and temperature drop is more. The temperature is graduate drop from head, middle body to tail of strip. The temperature at head is highest, the temperature is continuously and slowly drop along with the strip length and there is no suddenly temperature change. The deformation is relatively evenly and easier to control the thickness accuracy and flatness.

(4) There is flying shear located at the entry of finish mill, it can cut the irregular and black mark titanium head and it can avoid the sharp thin head at the following rolling. The higher temperature and regular head will be benefit for strip threading and it can avoid the threading failure. It can significant improve the threading stable and target rate. While the yield will be lower due to the flying shear cut the head and tail.
Pure Titanium Slab Rolling Study & Practice on Twin-stand Hot Steckel

3. Advantage and Disadvantage for Titanium Coil Rolling on Continuous Hot Strip Mill

3.1 Advantage for HSM

(5) There is sufficient technical measures to control the thickness variation at width direction and flatness for titanium rolling on the HSM, it can achieve satisfied flatness for wider product and it can improve the strength and elasticity for titanium coil. It can automatic control based on different product data and target data in order to improve the productivity and product quality.

(6) It can achieve superior surface finish for the titanium coil rolling on the 7-stand finish mill and work roll of last stand.

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3. Disadvantage for HSM

(1) The duration of tail of the titanium strip exposed to the air is longer and the temperature drop is higher. The lower temperature of the tail, the more uneven for rolling deformation and result in strip will be off the mill center line and easy to cause camber for the tail.

(2) The capacity of the HSM is big and it can be more than ten thousand tons of products per day and the productivity is higher. For the titanium coil product, it will be small batch with more or less one hundred tons. It takes long time to prepare the small batch production and it is lower efficiency and consumption is increased.

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3.3 The Target Rate for Pure Titanium Rolling on the HSM

The rolling speed is higher and temperature drop is lower for HSM. The head temperature of work piece is higher and the shape is regular and threading is stable. The reheating temperature for pure titanium slab can control to range of $880 \sim 920^\circ C$, it can be discharged under temperature of $870 \sim 890^\circ C$ and start rolling below $880^\circ C$ to ensure the finish rolling temperature $\geq 650^\circ C$. It can totally avoid the rolling is under $\alpha + \beta$ phase, which will cause the plastically elongation deferential for $\alpha$ and $\beta$ phase. Especially for initial two passes with bigger draft, it can effectively avoid elongation deferential for top and bottom surface caused by $\alpha$ and $\beta$ phase crystal structure and avoid the cobble due to head turn up/down.

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3.3 The Target Rate for Pure Titanium Rolling on the HSM

It improved the rolling stability and the rolling successful rate is achieved to 99.78%. At the same time, the uniformity of plastic elongation for last pass is improved due to higher finish rolling temperature and the flatness for titanium coil is significantly improved. Due to lower reheating temperature and the function of finish stand and work roll of last stand, the surface roughness is better and surface quality is significant improved for TA2 pure titanium coil rolled by HSM comprising with SM.

Refer to the following Chart 10, 11, 12, 13.
3.3 The Target Rate for Pure Titanium Rolling on the HSM

Scanning microscope X100, TA2 surface rolled by SM, Start Rolling Temp. 900°C

Scanning microscope X500, TA2 surface rolled by SM, Start Rolling Temp. 900°C

Scanning microscope X100, TA2 surface rolled by HSM, Start Rolling Temp. 860°C

Scanning microscope X500, TA2 surface rolled by HSM, Start Rolling Temp. 860°C
4 Conclusion

4.1 When the industrial pure titanium is heated and start rolling at temperature near 882°C, it is easy to under α+β phase in case the control is not accurate. The pure titanium will be α—Ti phase and Close-packed Hexagonal (h.c.p) Structure when the rolling temperature is below 882°C, while it will be β—Ti phase and Body-centered-cubic (BCC) Structure when the rolling temperature is above 882°C. There are significant differences for the elongation and deformation properties when they are being plastic deformation due to different crystallization features for two phases and this will cause serious turn up/down during the rough passes for titanium coil rolling at Twin-stand SM.

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4  Conclusion

4.2 Increase the heating and start rolling temperature to 950°C and reduce the temperature differential within 20°C, the initial 2 passes rough rolling will be at β phase for thicker titanium slab. In this case, the it can be avoided for serious turn up/down and result in cobble, the thread failure will be also significantly reduced and the target rate increased.

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4 Conclusion

4.3 The titanium coil rolling will alternate with steel rolling during one campaign and it can improve the pure titanium rolling stability, target rate and flatness. It has features of practicability and economy for alternative rolling between steel and titanium.

4.4 Based on above mentioned method to improve the reheating and rolling process temperature for titanium coil rolling, there is no serious surface oxidation layer and polluted layer, surface cracks, worse microstructure and inferior mechanical property.
4. Conclusion

3-4mm titanium coil rolled after the Twin-stand Steckel Mill, it will be annealing and surface treatment at YUNTi, then cold rolling. The batch and commercial production has been achieved for bigger ratio of width to thickness for 0.5mm×1380mm titanium coiling cold rolling. It has been produced large amount of 3.0mm-6.0mm thickness hot rolling titanium coil and large amount of 0.5mm-2.0mm thickness cold rolling wider titanium coil in 2011. The product has been widely used for welding piping, plate heat exchanger. It also acknowledged and widely used for varies industrial areas. It has gained good social and economic benefits in China.
THANKS FOR YOUR ATTENTIONS! 10.8.2012

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