Argon Protection Annealing Process Study & Application for Titanium Coil

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Abstract
Yunnan Titanium Industry Co., Ltd. (Hereafter referred to as “YUNTI”) utilizes the Steckel Mill and 4-high Cold Mill imported from Tippins Inc., USA. for Titanium coils hot-rolling and cold-rolling. Complete production process of Shot Blasting, Acid Pickling, Degreasing, Annealing, etc. will be carried for Titanium Coil. This article presents “Steel-Titanium” combination production process carried by YUNTI. The product property and surface quality problems have been gradually solved for cold-rolled Titanium coils through continuous study, creative and improvement for the Argon Protection Bell Annealing Process. It has been achieved for process stable, quality under controlling, commercial and batch production for cold-rolled Titanium Coil.

Key Word
Titanium Coil, Hot Rolling, Cold Rolling, Annealing, Argon Protection, Surface Cleanliness, Bonding

Preface
Most of the cold rolling titanium coils are pure titanium, the production process and technical control are relatively complicated. The titanium coils need annealing after cold rolling. However, annealing for titanium coils under high temperature has been a relatively complicated and difficult process. Because titanium is chemically active, it is easy to react with O, H, N, etc. elements in atmosphere under high temperature, it results in a contaminant coat will be generated on the surface, physics and chemical properties will get worse, plasticity and and elasticity will be decreased., the brittleness will be increased.

The present annealing process after cold rolling for titanium coils is usually under vacuum circumstance, this process is complicated, difficult to control, with high running cost. The annealing process Yunti applied is under the protection circumstance of inert gas, by electrical heating the inner bell, the titanium coils in the inner bell under inert gas protection are heated by radiation and convection, holding temperature and annealing. In order to avoid the reaction with O, H, N, etc. elements during entire annealing process, the positive pressure of argon circulation will maintain in the inner bell and the designed pressure is less than 10000Pa.

1 Production process flow chat of Yunti
1.1 Process flow chat for titanium coils production of Yunti
Yunti utilizes the Steckel Mill and 4-high Cold Mill imported from Tippins Inc., USA. for Titanium coils hot-rolling and cold-rolling from September 2007, then the independent research and developed facilities of Shot Blasting, Acid Pickling, Degreasing, Annealing, etc. has been built to formed complete Titanium Coil hot rolling and cold rolling production process. The process flow chart is as shown in Figure 1.

Figure 1

Titanium coils production of Yunti take the lead in realizing “Steel-Titanium” combination production process in China, some processing equipments are utilized KISC’s existing steel hot-rolling, cold-rolling, tempering, etc. facilities and other new equipments of EB Melting Furnace, Shot Blasting, Polish, Acid Pickling, Degreasing, Polish after Cold-rolling, Straightening and Recoiling, Slitting, etc. are specific built for titanium features.

1.2 The key processing equipments of titanium
coils annealing of Yunti

Yunti uses independent research and developed electric-heating argon-protection bell-type annealing furnace, which consists of work base, inner bell, heating bell, cooling bell, valve stand, control system, auxiliary system, etc., for Titanium coils annealing.

Figure 2 Electric-heating annealing furnace of Yunti is as shown in Figure 2.
1-Heating Bell, 2- Inner Bell, 3-Cooling Bell, 4-Work Base, 5-Convection Plate, 6-Convection Blower

1.3 The key equipments and process for titanium coils annealing of Yunti

In Yunti, the annealing process of titanium coils is as follows: put the titanium coils into annealing furnace; replace the atmosphere in furnace by inert gases, maintain the positive pressure in furnace below 10000Pa, heat inner bell at a certain heating speed till the temperature is higher than re-crystallization temperature of titanium coil and holding the temperature; then cool the titanium coil under positive pressure condition till discharging temperature and discharge the coil.

The purpose for Re-crystallization annealing of cold-rolling titanium coils is to eliminate work hardening in the rolling process and to recover the features of plasticity. These processes of recovery, re-crystallization, grain size growth will be occurred during the heating course for Cold-rolling titanium coils. These processes are occurred under certain temperature range, which varies from different material and elongation amount. As shown in Figure 3 is a typical diagram of Bell-type annealing process for titanium coils.

Heating speed, holding temperature and holding time should be mainly controlled in the annealing process. Among them, the most critical point is to control the temperature and atmosphere inside the furnace so that the product could meet the requirement of property and surface quality.

2 Analysis on main problems and Countermeasures for annealing process of cold-rolling titanium coils

Pure titanium has feature of chemically active and significant deformation strengthening effect after cold working and annealing will be needed after hot-rolling and cold-rolling. Annealing temperature should be higher than re-crystallization temperature. Because of its chemically active feature, titanium is easy to react with some elements, such as O, H and N, in the air under high temperature. The reaction leads to form oxidation film, which makes physical and chemical properties getting worse, not only the hardness and brittleness increasing, but also the plasticity and elasticity decreasing. Particular, the strong absorbability of industrial pure titanium under high temperature will cause surface black marks after annealing by absorbing cold-rolling residues, carbide and dust in the heating atmosphere in the surface of titanium. These black marks have strong influence on the surface quality of annealing product. Besides, the bonding problem between layers will happen during titanium annealing in coil condition.

Consequently, according to the feature of cold-rolling titanium coils and bell-type annealing process, the critical points for improving and controlling surface quality will be surface cleanliness and bonding defects control. It became the technical difficulty about how to control the surface quality for titanium coil annealing process after cold rolling, and the main subject of the study on annealing is to continuously optimize the annealing process and improve surface condition after cold-rolling.
2.1 Study and Improvement on the Surface Cleanliness after annealing for Cold Rolling Titanium Coil

The key to improve the surface quality of titanium coils after annealing is to study and optimize the annealing process. With the increasing annealing temperature, moisture, residual oil, dust and debris taken into furnace with work base, inside wall of inner bell, pipelines of work base and surface of titanium coils begin to volatilize and then form carbides and compounds when annealing at the protected atmosphere by inert gases. These volatiles, carbides, and compounds have a serious influence on the surface quality for titanium coils.

A large amount of practical research shows that different temperature schedules and atmosphere regular will effect on the generation of black marks and black stripes on the Titanium surface. The adjustment for the annealing process will significantly improve the surface condition for reducing black marks and black stripes. After a large number of experimental study, it proves the carbonation and oxidization reaction with titanium base can be effectively avoided by maintain the volatilizing components in residual coolant to volatilize at lower annealing temperature. The study on volatility of cold-rolling coolant greasing additives shows that coolant residue can effective volatilize at around 350°C. In this case, holding under this temperature for a period of time can effectively reduce the appearance of black marks, and the longer holding time, the more improvement, while the improvement will not be significant over 6 hours holding. Therefore, the temperature schedule of annealing process will be determined by temperature holding 2~6 hours for volatilization. The large flow argon purging of 100~120m3/h at initial stage and 16~24m3/h flow at the warm up stage are utilized for atmosphere purging schedule, so as to rapidly and effectively clean up the surface reside after degreasing for titanium coils.

2.2 Stabilize the Utilities Conditions and Enhance the Equipments Maintenance to Reduce the Furnace Shutdown

The study on annealing process shows that there are much more black marks and stripes appearance in case the furnace are unscheduled shut down during the heating process and resume the operation comparing with normal annealing. The unscheduled shutdown will change pre-set heating-up speed and corresponding purging atmosphere for cleaning. Besides, the longer duration time of shutdown, the more temperature drop than expected, it will cause shrinkage rapidly between layers of titanium coils and lead to bonding finally. Thus, it will be helpful for enhancing the maintenance and inspection of equipments to reduce failure and shutdown for the furnace.

2.3 Reduce the Surface Residues of Cold-rolling Titanium Coils

As what has mentioned above, the residues of rolling coolant except ash content shall be volatile as much possible during the annealing process. Due to the conflict feature of rolling lubrication of rolling coolant and annealing cleanliness, annealing volatility will be taken into consideration subject to rolling lubrication.

To get better surface cleanliness after annealing, firstly try to remove the coolant on the coil surface at the cold-rolling mill. Thus, the coolant purging system of cold-rolling mill was improved for titanium coils rolling. It adopted continuous higher pressure and larger flow rate for purge system to achieve the min. residual coolant, the residues will be cleaned to a maximum limit by degreasing line. Secondly aiming at rolling coolant technical characteristic, adjust coolant application parameters and source the optimum mixing ratio by technical test and comparison to satisfy both lubrication and surface quality requirement for different rolling product sizes.

<table>
<thead>
<tr>
<th>Total Draft</th>
<th>Product Thickness (mm)</th>
<th>50~55%</th>
<th>60~70%</th>
<th>70~75%</th>
<th>75~80%</th>
<th>Before 80%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.80≤h&lt;3.00</td>
<td>1.9~2.1%</td>
<td>2.1~2.5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00≤h&lt;1.60</td>
<td>2.1~2.5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.60≤h&lt;0.90</td>
<td>2.5~2.7%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h&lt;0.50</td>
<td>2.5~2.7%</td>
<td>2.6~2.9%</td>
<td>2.9~</td>
<td>3.4%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.4 The Surface Topography Improvements for Cold-rolling Titanium Coils

At earlier stage for the production of titanium coils, the finished surface Work Rolls with roughness around Ra
0.4 μm are used for cold-rolling. The gaps between layers of rolling titanium coils are smaller and it is not beneficial for contacts between Titanium basis and not to facilitate the volatilization of residues on the surface of titanium coils.

After Continuous studying and developing, the textured surface Work Rolls with 1.2~2.0 μm roughness machined on laser texturing machine have been adapted for cold-rolling by KISC. The surface cleanliness has been significantly improved and the bonding has been largely reduced after annealing for coils comparing with the application of Ra 0.4 μm surface Work Roll. Therefore, the Work Roll surface roughness application standards are generated at Yunti for different rolling mill and product sizes of titanium coil.

3 Bonding Prevention and Control for Cold Rolling & Annealing
Bonding is always a quality problem along with annealing process of titanium coils and it is a specific defect when coil annealing by bell-type furnace. It is strain stripe with curve shape and mostly appears crescent shape. It is easy to generate tearing deformation and protruding during uncoiling and lead to crescent, horseshoe or arc shape. Gravure are occurred after tempering. Mostly, the scrapped or inferior quality product have been produced due to work hardening lower plasticity and worse punching performance at the bonding areas for titanium coils.

3.1 The Main Reasons for Bonding Occurrence
Titanium has feature of chemically active and strong absorption and it will be more chemically active under high temperature when annealing with coiled titanium. Bonding between layers will be easily occurred under the effects of high temperature and stress and result in surface damage of titanium coils during uncoiling and even failure for uncoiling. During cooling procedure for the bell-type annealing process, very high radial heat compressive stress will be applied between layers and it makes layers press against each other after few hours of temperature over 500 °C. Then, bonding generates under the variable radial heat compressive stress.

Serious bonding of titanium coils is showed in Figure 4 and Figure 5.

The temperature varies from coil to coil for different location in the bell-type annealing furnace as well as the temperature also varies for same coil at different areas. However, there is always a highest point and a lowest point of temperature called hot point and cold point during heating and cooling stages for each heat. Usually, hot point is located at the edge of coil while cold point at the inner part of coil's center zone. Because every stage of annealing process is proceeded under certain temperature range, the temperature difference between hot point and cold point (usually ΔT) should be controlled in a certain temperature range during the annealing process in order to control annealing process, bonding and the final properties of products.

Experimental studies found that there is close relationship for coil surface roughness and annealing schedule with bonding: bonding is more occurrence with smaller surface roughness, higher annealing temperature, longer annealing temperature and faster cooling speed. Aiming at this feature, cooling with heating bell is carried on after heating stage finished, achieving
slow cooling to prevent bonding. The duration of slow cooling is related to the coil charging amount and usually it is about 2 hours, then use normal cooling to discharging temperature with cooling bell. Inert gases are used during entire process of slow cooling and normal cooling with cooling bell to protect titanium coils. Open the inner bell till the temperature cooled down to below 80°C and discharge the titanium coil. Prolong cooling time as much as possible to avoid bonding caused by radial thermal comprehensive stress because of too rapid cooling.

Besides, thickness and shape deviation (flatness) of cold rolling titanium coils will lead to stress concentration between layers of titanium coils caused by coiling tension and partial higher concentration of radial thermal comprehensive stress, which will result in locally bonding. Thus, in order to achieve higher thickness accuracy and better strip flatness to reduce bonding occurrence, it has been cautiously optimized for profile of cold-rolling rolls, cold-rolling process and lubricating process.

Therefore, corresponding measures have been developed according to internal and external factors for titanium coil bonding occurrence:

1) The external factors and measures to reduce annealing bonding:
   a) Control roll surface roughness to achieve as much as possible coarse titanium coils surface by laser texturing the surface of rolls;
   b) Get the minimum deviation of cross profile accuracy and flatness for titanium coils by roll profile and rolling process controlling;
   c) Take as small as possible coiling tension for titanium coils before annealing.

2) The internal factors and measures to reduce annealing bonding:
   a) Lower annealing temperature as much as possible;
   b) Prolong cooling time as much as possible;
   c) Stabilize the running of equipments to avoid failure and furnace shut down during in the annealing process.

The feature of the bell-type furnace is that the temperature of coils in the furnace is nonuniformity for different areas. Temperature uniformity will be improved by prolong the cooling time and the chance of bonding occurrence will be less. While it is also pursuit goal to shorten annealing time, improve the output, reduce the energy consumption and lower costs. Therefore, it is the principle to determine the cold-rolling and annealing process for shortening annealing time, improving the output, reducing energy consumption as much as possible subject to guarantee the product properties uniformity and preventing bonding occurrence.

4 The Results after Cold-rolling & Annealing
4.1 Mechanical property chart before and after annealing

<table>
<thead>
<tr>
<th>Sample Condition</th>
<th>Sampling Direction</th>
<th>R0.2 / Rp0.2 MPa</th>
<th>Rm MPa</th>
<th>A %</th>
<th>Yield-Strength ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>After cold Rolled</td>
<td>Longitudinal</td>
<td>565</td>
<td>613</td>
<td>17.6</td>
<td>1.08</td>
</tr>
<tr>
<td></td>
<td>Transverse</td>
<td>565</td>
<td>636</td>
<td>9.4</td>
<td>1.13</td>
</tr>
<tr>
<td>After Cold Rolled &amp; Annealing</td>
<td>Longitudinal</td>
<td>300</td>
<td>390</td>
<td>30</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>Transverse</td>
<td>355</td>
<td>400</td>
<td>28</td>
<td>1.13</td>
</tr>
</tbody>
</table>

Cold-rolling and annealing process of YUNTI has accommodated the production of cold-rolling titanium coils gradually by the improvement of technology and process. Appearance quality has significant improvement, and black spots rate is descending obviously(from 80.95% to about 2%) and reflectivity of most titanium coils reaches above 75%. Besides, there are no marks of azotization and oxidation and hydrogen embrittlement as well as bonding.

Steckel Mill and 4-high Cold Rolling Mill for steel-rolling are used for titanium coils hot rolling and cold rolling at Yunti, the annealing process technology and facilities have being continuously improved. The quality of the titanium coils can satisfy the requirement of market, 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.

The cold rolled titanium coils and plates produced by EB melting and the unique original creative processing technologies of Steckel mill for hot rolling, 4-high Cold Mill for cold rolling and annealing shares the superior quality and lower costs in Yunti. Most of the titanium plates in the near future will be replaced by titanium coils. Titanium will have higher performance-to-price ratio and its substitution
effect to other materials will be more obvious, which will promote the titanium market, extend the field of application and increase the titanium consumption.

REFERENCE

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Argon Protection Annealing Process Study & Application for Titanium Coil

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Booth #C
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1 Production process flow chart of Yunti
2 Analysis & Countermeasures for annealing process
3 Bonding Prevention and Control for Cold Rolling & Annealing
4 The Results after Cold-Rolling & Annealing
Preface

Most of the cold rolling titanium coils are pure titanium, the production process are very complex. Normally, the titanium coils need annealing after cold rolling. However, annealing for titanium coils under high temperature has been a very complex and difficult issue. Because titanium is very active, it will react with O,H,N in atmosphere very easily when it is under high temperature, there will be a contaminant coat on its surface, physics and chemical performance will be bad, plastic behavior and degree of elasticity will reduce, the brittleness will increase.
The present annealing process after cold rolling is mostly under vacuum. The annealing process Yunti applied is under the protection of inert gas, by heating the internal bell to heat, keep worm, cooling and annealing, in order to protect the reaction with O, H, N, during annealing process, there is argon circulation with a little bit positive pressure and the designed pressure is less than 10000Pa inside the bell.
1. Production process flow chat of Yunti

1.1 Process flow chat for titanium coils production
Yunti utilizes the Twin Steckel Mill and 4-high Cold Mill imported from Tippins Inc., USA. for Titanium coils hot-rolling and cold-rolling from September 2007, then the self-research machine for Shot Blasting, Acid Pickling, Degreasing, Annealing, etc. will be carried for Titanium Coil.
Titanium coils production of Yunti is the first one to realize “Steel-Titanium” combination production process in China, part of processing equipment using KISC’s existing steel Hot-rolling mill, Cold-rolling mill, Temper rolling mill, etc. and others using new equipment for the particularity of Titanium.
1. Production process flow chart of Yunti

Titanium and titanium alloys coil/sheet production process:

- Titanium Sponge → EB furnace → Slab → Electrically heated furnace → Twin Steckel hot rolling mill → Bell annealing furnace → Shot blasting & grinding → Pickling
- Cold rolling mill → Degreasing → Bell annealing furnace → Temper mill → Straightening → Slitting → Re-coil → Cutting to length → Sheet → Welded pipe
Titanium Hot Rolling in Operating
Reversion Cold Rolling Mill
Shot Blasting & Grinding Line
Picking Line

钛酸洗机组
功能：用化学方法去除金属表面的氧化层和富氧层，为金属进入冷轧工序进行最终酸洗的提供清洁、抗氧化层的表面光洁。
能力：年处理钛矿25000吨，线处理酸洗槽：直径6mm，宽度3mm，宽度1400mm，径宽350mm。

创新点：
1) 无循环式酸洗磷化化学反应法连续处理钛酸洗酸洗槽工艺；
2) 两段式酸洗表面清洗-洗涤工艺；
3) 工业用零污染热酸工艺。
水平：是国内自主研发、设计生产线上采用湿法化学反应法连续处理酸洗的生产线，属国内领先，国际水平。
Polish & Picking Line
Straightening & Recoiling

拉矫机组

功能：用于细镀带的线状退火，中间退火等不良板型的矫正矫正。
技术参数：拉矫机直线变形 1Kw-1.3Kw（厚度0.2-0.6mm）
创新点：首次利用拉矫弯边矫正机的原理，弯边使用矫正板长从达到屈服模
模型目的。
水平：国内第一条专门用于钛卷板弯边矫正的生产线，能够实现钛卷板的连续矫
正，具有国内领先，国际先进水平。

云南钛业股份有限公司
功能：
用于卷带的切断与分条，达到客户要求的尺寸要求。

剪切技术性能：
剪切成品带材宽度：≥75mm
剪切条数：厚度为0.2mm~0.8mm ≤16条
厚度为0.8mm~1.5mm ≤12条
厚度为1.5mm~2.0mm ≤8条
切边宽度：5~20mm
Argon Protection Annealing Furnace
Titanium Coil Annealing In Operating
1.2 The key equipment of titanium coils annealing of Yunti

Yunti uses self-researched argon-protected annealing furnace for Titanium coils.
Electric –heated annealing furnace

1-Heating Bell, 2- Inner Cover, 3-Cooling Bell, 4-Work Base, 5-Convection Plate, 6-Convection Blower
1.3 Annealing Process of Titanium Coils In Yunti

In Yunti, the process of annealing is: firstly titanium coils should be put into anneal furnace; secondly, the gases in furnace should be replaced by argon, the pressure in furnace should be kept positive and less than 10000Pa, then heat titanium coils until the temperature is higher than recrystallization at a certain heating rate of titanium coils and make thermal insulation; finally, under positive pressure condition, discharge titanium coils after they are cooled until tapping temperature.
Cold-rolling titanium coils in heating will have three different stages: recovery, recrystallization and grain growth.
Annealing Process of Titanium Coils In Yunti

Improvement and adjustment on annealing process

Diagram showing the annealing process with various stages including:
- Heating start
- 1.5 hours
- 2-5 hours
- Slow cooling ~2 hours
- Cooling start
- Heating platform ~650°C
- Heating stage ~400°C
- Vacuum
- Hydrogen sweep
- Time
- Atmosphere
1. Production process flow chat of Yunti

Heating rate, holding temperature and holding time should be mainly controlled in the annealing process.
2. Analysis & Countermeasures for annealing process

The bonding problem between layers might also happen during annealing the piles of titanium coils.
According to the feature of cold-rolling titanium coils and Bell-type annealing process, we should focus on the control of surface cleanliness and bonding defect to ensure surface quality.
2. Analysis & Countermeasures for annealing process

When annealing in the inert gas atmosphere, the volatileless have enormous influence on the surface quality with the annealing temperature increased.
2. Analysis & Countermeasures for annealing process

It was found by a large numbers of experiment, that trying to volatilize components in residual emulsion at lower temperature as much as possible can prevent oxidization reaction between volatiles and titanium at higher temperature.
2. Analysis & Countermeasures for annealing process

2.2 Reduce the Surface Residues of Cold-rolling Titanium Coils

As mentioned above, the contaminant of emulsion residue except ash should volatile as possible in the annealing process. But because rolling lubrication of rolled oil and annealing detergency conflict with each other, getting better annealing volatility should be on the premise of rolling lubrication.
To get better annealing surface cleanliness, try to clean on the cold-rolling mill as much as possible to have the least residue which will be cleaned to a maximum limit by degreasing. Besides, then the best ratio need to be found based on rolling oil technical characteristic. The specification of 4-high Cold Mill for cold rolling as following.
## 2. Analysis & Countermeasures for annealing process

### Coolant concentration and Rolling Product Size Correspondence

<table>
<thead>
<tr>
<th>Deformation rate(%)</th>
<th>Product gauge(mm)</th>
<th>50~55%</th>
<th>60~70%</th>
<th>70~75%</th>
<th>75~80%</th>
<th>Over 80%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.80≤h≤3.00</td>
<td>1.00≤h≤1.60</td>
<td>1.9~2.1%</td>
<td>2.1~2.5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00≤h≤1.60</td>
<td>0.60≤h≤0.90</td>
<td>2.1~2.5%</td>
<td></td>
<td>2.5~2.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.60≤h≤0.90</td>
<td>h≤0.50</td>
<td></td>
<td></td>
<td></td>
<td>2.6~2.9%</td>
<td>2.9~3.4%</td>
</tr>
</tbody>
</table>
2. Analysis & Countermeasures for annealing process

2.3 Make sure Maintenance of Equipment to Reduce faults

The study on annealing process showed that discontinuous annealing interrupted by blowing out in heating process would produce more black plots and black tapes compared with normal annealing. Blowing out will change scheduled heating-up rate.
2. Analysis & Countermeasures for annealing process

Besides, longer time of blowing out could increase cooling rate, which causes shrinkage rapidly between layers of titanium coils and leads to bonding finally. So, we should strengthen examination and maintenance of equipment and reduce fault and blowing out.
2.4 The Improvement of Surface Topography of Cold-rolling Titanium Coil

Surface roughness of smooth cold rolling rollers is about Ra 0.4μm. Since the gap between layers of rolling titanium coils is very small. It is not easy for titanium coils matrix to contact argon and volatilization of residue on the surface of titanium coils.
Continuous study showed that using the cold rolling rollers textured by KISC laser texturing machine (their roughness is 1.2~2.0μm) would improve cleanliness and reduce bonding.
3. Bonding Prevention and Control for Cold Rolling & Annealing

It is easy to form bonding between layers of titanium coil under the effect of temperature stress and cause surface damage of titanium coils and even not to uncoil. During cooling procedure in the cover-type annealing process, very high radial heat compressive stress might occur between layers. It would generate bonding
3. Bonding Prevention and Control for Cold Rolling & Annealing

Serious bonding of titanium coils is shown in below Figures.
3. Bonding Prevention and Control for Cold Rolling & Annealing

3.1 The Main Reasons for Bonding Occurrence

The temperature at different positions of coils is different. The temperature difference (called $\Delta T$) between hot point and cold point should be controlled in order to control bonding.
3. Bonding Prevention and Control for Cold Rolling & Annealing

Experimental studies found that the bonding has a close relationship with coils' surface roughness, and annealing schedules. It is easier to generate bonding with higher annealing temperature, longer annealing time, faster cooling rate and smaller surface roughness.
Besides, the deviation of thickness and flatness of cold rolling titanium coils would cause partial concentration too big leading to local bonding. Thus, the thickness accuracy and flatness should be optimized to reduce bonding.
3. Bonding Prevention and Control for Cold Rolling & Annealing

Therefore, corresponding measures are taken to prevent bonding from coming into being:

The external factors and measures to reduce annealing bonding:

a. control surface roughness by laser texturing the surface of rolls;
b. get the minimum thickness deviation and flatness;
c. take small tension of coils.
3. Bonding Prevention and Control for Cold Rolling & Annealing

The internal factors and measures to reduce annealing bonding:

a. low annealing temperature;
b. long cooling time;
c. steady function of equipment to avoid fault and blowing out in annealing process.
## 4. The Results after Cold-Rolling & Annealing

### 4.1 Mechanical property chart before and after annealing

<table>
<thead>
<tr>
<th>Sample Condition</th>
<th>Sampling Direction</th>
<th>$R_{p0.2}$ (MPa)</th>
<th>$R_m$ (MPa)</th>
<th>$A_{50}$ (%)</th>
<th>Yield Strength Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>After cold Rolled</td>
<td>Longitudinal</td>
<td>565</td>
<td>613</td>
<td>17.6</td>
<td>1.08</td>
</tr>
<tr>
<td></td>
<td>Transverse</td>
<td>565</td>
<td>636</td>
<td>9.4</td>
<td>1.13</td>
</tr>
<tr>
<td>After Annealing</td>
<td>Longitudinal</td>
<td>300</td>
<td>390</td>
<td>30.0</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>Transverse</td>
<td>355</td>
<td>400</td>
<td>28.0</td>
<td>1.13</td>
</tr>
</tbody>
</table>
4. The Results after Cold-Rolling & Annealing

YUNTI has accommodated the production of cold-rolling titanium coils gradually by the improvement of technology and process. There are no marks of oxidation and hydrogen embrittlement or bonding. Therefore, the quality meet the requirement of customer.

By EB melting and the original processing technologies of twin steckel mill of hot rolling, cold rolling and annealing in Yunti, the products-cold rolled titanium coils have good quality and low cost.
Titanium Coil After Cold Rolled & Annealing
Titanium Coil After Cold Rolled & Annealing
4. The Results after Cold-Rolling & Annealing

By improving the annealing process and equipment, the quality of Yunti titanium coil satisfy the requirement of market, the products have been used on the welding pipe for desalination equipment, electrochemical industry, plate heat exchanger industry, Yunti has been widely recognized by customer.
Thank You