AN INTRODUCTION TO THIN SLAB TECHNOLOGIES

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Mines and Metals Journals

- Comparison between Allis Chalmers and Lurgi Method of pelletizing
- An outlook in steel making and pelletizing projects in Iran
- Pelletizing- Technical and commercial outlook
- Iran pelletizing plants
- Comparison between different methods of pelletizing
- An Outlook to Iran Copper projects (Ali Bakhtiari, Elham Kordzadeh)
- Translation-Lead and Zinc, tightening up slowly
- Translation-Sentiments and fundamentals drive copper market
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Since 2011 till now

- Developing Simulator and Designer of Induration Machine (Lurgi Pelletizing Method)
- Technology Selection and Process know how
- Comparison between Lurgi and Allis Chalmers Technology
- Direct reduction and pelletizing in one plant.
- Simulation of direct reduction
- Optimizing Lurgi process using simulation

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✓ Pamidco

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7. Color Inspection, NIS (Germany) and Color Industries Research Center
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9. Welding Inspection, Iranian Technical and Professional Organization
10. Quality Control, Shahid Bahonar Semi Finished Product

Conferences papers:

- The effect of Nickel on sulphidation resistance of austenitic heat resistant alloys, 43rd annual conference of metallurgists of CIM, Hamilton, Canada, 2004
- The effect of nickel and aluminum on fracture mechanism of aluminum austenitic heat resistant steels, Steel Symposium, 2004, Yazd, Iran
- The effect of aluminum on sulphidation properties of austenitic heat resistant steels, 9^{th} National Corrosion Congress, 2004, Isfahan, Iran
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- An investigation of effective factors on fracture of heat resisting Fe-25Cr-12Ni alloy used in Copper complex converter, 8^{th} Annual Congress of Iranian Metallurgy Engineers, 2004, Isfahan, Iran

Published papers:

1. The Effect of Nickel Increasing and Aluminum Addition on Sulphidation Resistance of Fe-Ni-Cr Alloys, International Journal of Engineering, 2005
2. The Fracture Mechanisms of an Austenitic Heat Resisting Steel in Copper Converter Atmosphere, International Journal of Iron and Steel, 2008
3. Comparison between Lurgi and Allis Chalmers Process, Pardazesh Magazine, Iran, 2016, IMIDRO Portal
4. An introduction of Endless Strip Technology, Pardazesh Magazine, Iran, 2016
5. Technical Note-Arvedi Technology , Samt News, Iran, 2016
6. . An Introduction to thin slab technologies, IMIDRO Portal & Minews
7. An outlook in steel making and pelletizing projects in Iran, IMIDRO Portal

Technical Reports and Translations

1. Comparison between travelling grate and grate kiln method of pelletizing
2. 3. Pelletizing- Technical and commercial outlook
3. Iran pelletizing plants
4. Comparison between different methods of pelletizing
5. Steel making vendor list
6. Translation- Lead and Zinc, tightening up slowly, Pardazesh Magazine
7. Translation-Sentiments and fundamentals drive copper market, Pardazesh Magezine

1. INTRODUCTION

For the production of flat products, liquid steel is generally cast in form of slabs in continuous slab casting machines. These slabs are inspected, scarfed and then reheated in slab reheating furnace to the rolling temperatures before being rolled to hot rolled coils in a semi continuous or continuous hot strip mill. Development of thin slab casting and rolling (TSCR) is a step forward to reduce the number of process steps in the production of hot rolled coils (HRC). Originally TSCR technology was developed with the primary goal of reducing the production and investment costs but today it has become one of the most promising production routes to maintain steel as a leading material in technological application. But presently most of the steel grades including low, medium & high carbon, HSLA line pipe grades and steel grades for automotive application including IF grades can be cast through thin slab caster route. In fact this technology has brought paradigm shift in steel technology of casting and rolling. The thin slab casting and rolling technology was made possible because of the following improvements in casting and rolling processe:.

- Design of mould
- Hydraulic mould oscillations
- Use of electromagnetic brakes (EMBR)
- Use of high pressure descaler and roller side guide in the mill
- Dynamic liquid core reduction (LCR)
- Mould powder quality and redesigned SEN
- Water spray cooling

2. HISTORY

The implementation of TSCR concept did not achieve any success till mid-eighties due to numerous technological challenges associated with the technology. There first problem was finding a way for thin slab casting and operation with high speed. Another issue was to find a way to use the advantages of thin slab casting to overcome the limitations caused by the quality and quantity of production.

The first breakthrough in this direction was achieved in October 1985 by SMS Schloemag-Siemag when the first thin slab of 50 mm thickness was cast in a pilot plant in Kreuztal-Buschhutten. This success was achieved with a patented funnel shaped mould and an optimized submerged entry nozzle. SMS Schloemag-Siemag gave this technology the name of “Compact Strip Production (CSP)”.

The first CSP plant was ordered in late 1987 and was commissioned at Nucor Steel, Crawfordsville, Indiana in July 1989. The length of this plant was 260 m so called Compact Strip Production. Within few days of commissioning, there was a major break out in the casting machine because of inexperienced operators. This has an effect on the speedy acceptance of this technology.

Almost at the same time, the In-line Strip Production (ISP) was under intensive development by Mannesmann Demag and Arvedi group. Development of ISP started in 1988 based on an Arvedi-Mannesmann patent. In 1992, the prototype ISP plant was built by Arvedi at its Cremona works, with most development carried with the plant. In 1994-95 the prototype plant completed the first phase of its development. Later based on the ISP technology, Acciaieria Arvedi has developed a new thin slab casting/endless rolling process under the brand name Arvedi ESP.

Voest Alpine (VAI) of Austria (Now Primetals) and Danieli of Italy have also developed thin slab casting and rolling technologies. In line strip, CSP, Tippins-Samsung Process (TSP), CONROLL, QSP, ESP and fTSR are thin slab technologies developed.

Today a three strand TSCR plant based on CSP technology has been installed at ESSAR Gujarat, India.

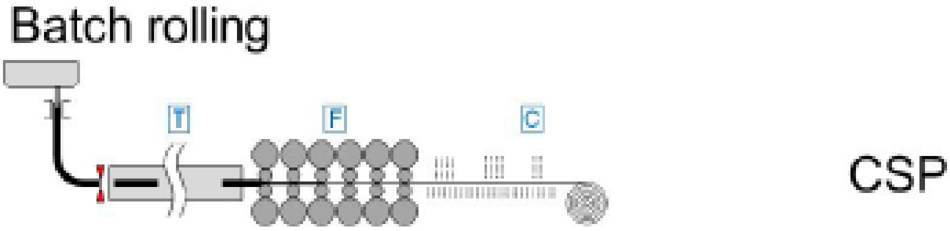

Figure 1. Schematic of strip production in Compact Strip Production (CSP)

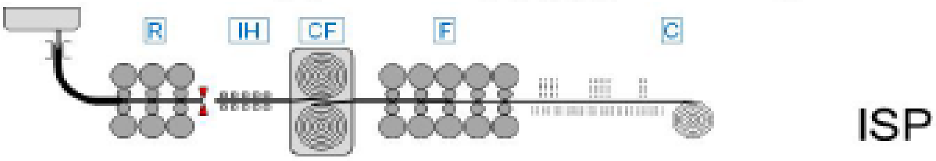

Figure 2. Schematic of In line Strip Process (ISP)

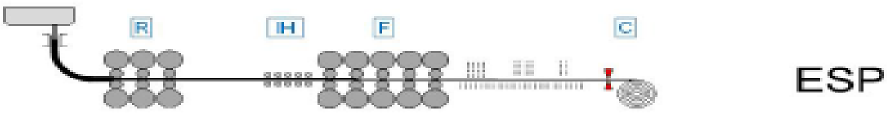

Figure 3. Schematic of Endless Strip Process (ESP)

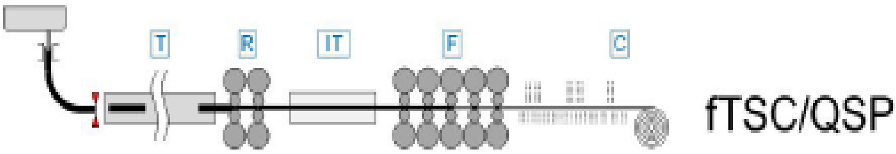

Figure 4. Schematics of Flexible Thin Slab Casting (fTSC)

3. NECESSITIES OF USING ALTERNATIVE TECHNOLOGIES

From an engineering perspective, the ideal scenario is to meet the needs of engineering simultaneous to reach the physical and chemical properties of steel. To make such a change which would be technically and economically attractive, two conditions must be met. Steel producers have to be ensured that their benefit is not reduced and the consumers must be given a qualified product with lower prices.

The cost of micro-alloyed steels decreased by two innovations in technology. Over the past decade, the use of electric arc furnaces (EAF) increased sharply by about 40 per cent of world steel production. In the second phase, thin slab casting technology, effected on coiled flat products.

The ability of production flat hot rolled products directly from molten steel represents a fundamental step to reduce steel production costs.

4. METALLURGICAL CONSIDERATION OF THIN SLAB CASTING

Some of the metallurgical aspects of this technology include:

- Rapid solidification of thin slab compared to conventional products
- Correction in dendritic structure and help to more homogenous structure
- Help to isotropic properties during rolling
- High temperature before rolling causes added micro alloys remains solved and prevents early precipitation of dissolved elements.
- High temperature of slab, prevents the formation of transverse cracks in bending time.
- Direct transfer of slab to rolling mill is the most important factor in reducing energy consumption.

5. Thin slab casting and rolling system design and control:

Thin slab production requires precise control of casting area to provide a high quality slab for hot rolling. A narrower mould than for conventional caster moulds magnifies any casting problem and there is a need for strict control of casting parameters. The design of thin slab caster must allow for the following:

- Reliable control of casting speed in excess of 3 m/min, variable casting speed and sequence of casting
- Excellent control of liquid steel supply into a narrow mould
- High surface and internal quality of thin slab is critical as slabs are directly hot rolled not allowing any remedial scarfing.
- Uniform temperature distribution over the cross section of slab before and after reheating furnace.

Solidification time is about 22.5 m/min for a conventional with 250 mm thickness, but for a thin slab with a thickness of 80 mm is 2.5 m/min and for 50 mm thin slab it is 1.5 m/min.

Faster solidification, provides more uniform finer structures. Fine secondary dendrite arm spacing (SDAS), achieved due to rapid solidification in casting, and promotes a more homogenous structure with less micro-separation structure than the conventional casting.

Micro-segregation is segregation between the dendritic arms where minimum solute concentration is at the center of the dendrite arms and the maximum solute concentration is between the arms. In fact SDAS is a measure of the non-homogeneity in slab continuous casting.

In thin slab casting, Liquid core reduction (LCR) system is used. More tendency to thin slab technology made use of LCR technology. Liquid core reduction allows for the thickness of strand bellow the mould to be reduced while the core is still in liquid phase. Usually the first segment in the strand guiding system can be adjusted to obtain the desire reduction in thickness of strand.

The plant technologist, SMS Schloemann-Siemag AG has created two alternative designs for this system. In the first alternative, strand thickness is controlled by hydraulic cylinders. In the second alternative, a more complex position controlled hydraulic cylinder system is used that allows infinitely variable adjustment to the strand thickness.

Danieli's LCR system allows the strand thickness to be adjusted at any time.

Thin strip is more easily achieved when a thinner slab is cast because there is less reduction required.

Improvement in surface quality and internal quality is largely due to greater mould dimensions that can be used when using LCR. Increased mould dimensions, improve surface and internal quality due to greater stability at the meniscus, less turbulence, longer mould length and lower flow velocity.

Reheating of slab is done by tunnel furnace or induction furnace for the aim of achieving to a homogenous temperature and reheating to the proper temperature for rolling. However in tunnel furnace, natural gas control and in induction furnace the electric current flow are of importance.

The short resident time in the furnace, limits grain growth, scale formation and dissolution of precipitates.

Some steel grades such as peritectic carbon grade and Nb bearing steels are prone to the formation of surface detects and this limits production of them by thin slab casting route.

In conventional slab casting, surface defects is removed from the surface due to the removal of the surface layer. That is why this category of steels are sensitive to traverse cracks and make their casting difficult.

To achieve the desired microstructure and mechanical properties, speed cooling control after rolling and temperature control during coiling is required. This technique increases the mechanical properties by precipitation strengthening in ferrite.

6. THIN SLAB TECHNOLOGIES

6.1. COMPACT STRIP PRODUCTION (CSP)

This technology produces slabs with a thickness of 50-90 mm. High casting speed of 6 meters per minute for plain carbon steels and 3.5 meters per minute to other grades is used. The small mould cavity was a limitations of this technology for using this system for cast steels with high quality in the past. To overcome this problem, the funnel form and immersed nozzle system was designed. The larger length more than conventional, 1100 mm, were used for quality improvement.

The casting machine has a vertical design. The slab is directly sent to furnace which prevents scales formation. The roughing mill is no longer needed and the energy requirement is reduced by the direct rolling of the thin slab without intermediate cooling and reheating.

Today, the product range covers all of the steel grades demanded by the market. In particular, these include low carbon IF and mild steel grades, medium and high carbon steels, HSLA, API pipe steels, stainless, acid and heat resistant special steels, as well as Si-alloyed electrical steel grades.

Ternium México (formerly Hylsa) has been producing finished strip in gauges less than 1.0mm since 1995.

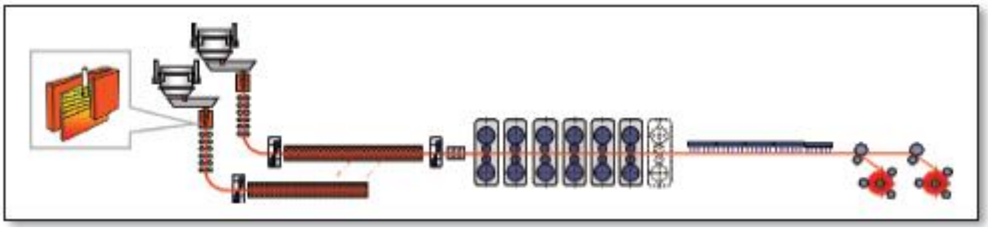

Figure 5. Thin slab technology with Compact Strip Production (CSP)

Since 1989, twenty nine plants were installed based on this technology and from 2000, 10 plants which used this technology were modernized. Over the past years some changes happened in technology design and a newer technology called CSP flux were invented.

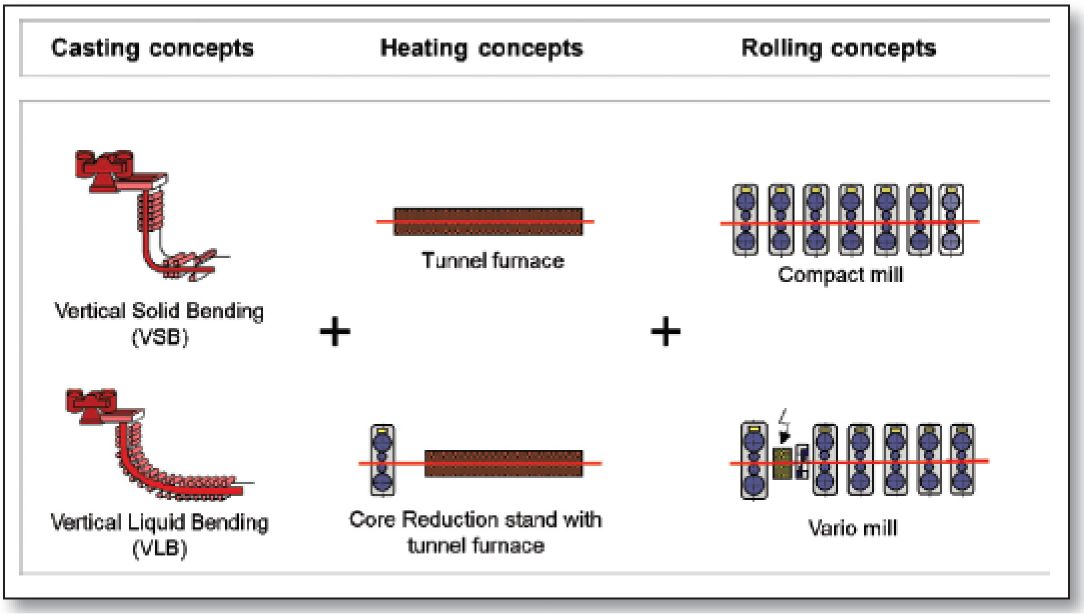

Figure 6. Modular components of the CSP® flex concept

As can be seen in figure 6, CSP technology is vertical casting with a solid core in the bending zone. This part has been changed to a liquid core in the bending and straightening area in CSP flex.

The only economically way to provide the greater metallurgical length thus required for the caster is to use a Vertical Liquid Bending (VLB) which increases the production to 2 mt/y for each strand. (Figure 7)

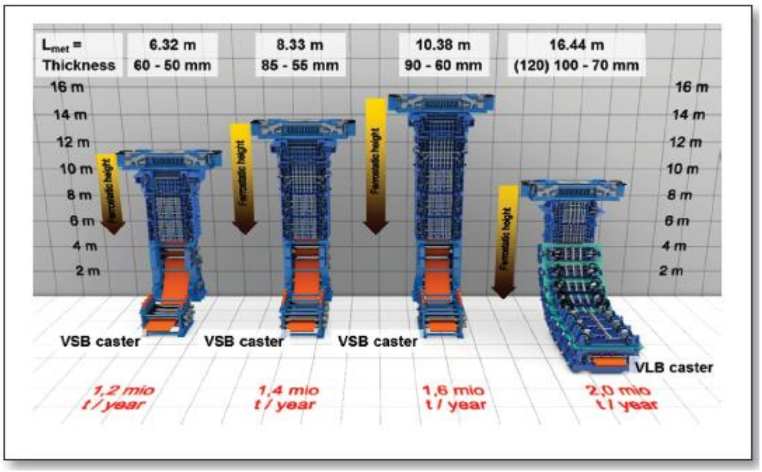

Figure 7. Range of CSP® casters

In reheating area, for equalize slab temperature, tunnel furnace is used for CPS technology while a LCR system is added before tunnel furnace in CSP Flex technology.

It comprises a strong medium stand M1 with two single drives, arranged upstream from the first finishing stand F1 at a distance that is ideal for process conditions. In this space of approximately 11m between M1 and F1, there is space for a pre-leveller for levelling the intermediate strip head end and for an induction heating system.

The temperature and the retention time between M1 and F1 are so adjusted that a complete recrystallisation takes place without micro-alloying elements being precipitated prematurely or excessive grain growth taking place.

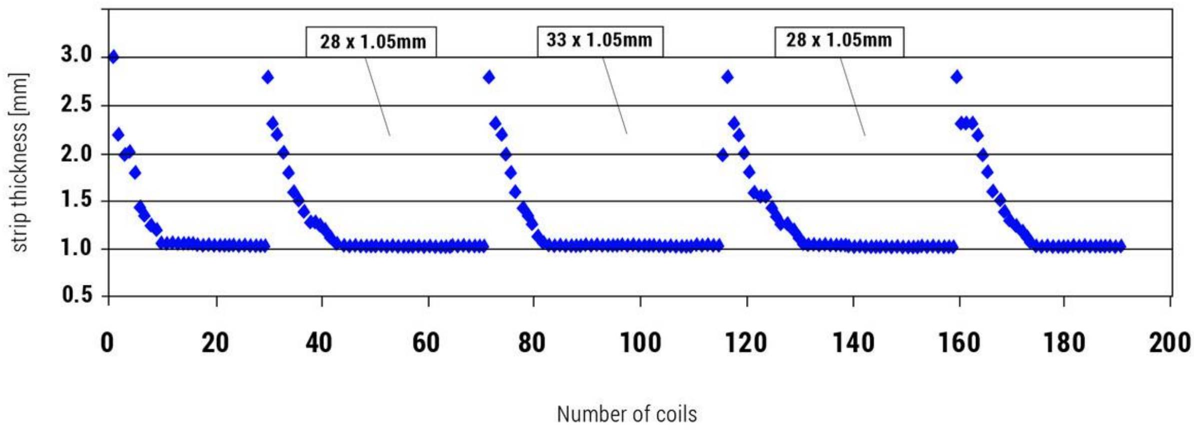

Figure 8. Process stability and performance for ultra-thin gauges

Row	Plant Name	Place	Product Grades	Product Width	Thickness	Capacity
1	Big River Steel	America	Carbon grades, HSLA grades, pipe grades (X70/ X80) Si-grades (GO and NGO)	1200-1930 mm	1.55-24.5 mm	3 mt/y
2	Wuhan Iron & Steel	China	Carbon steels, dual-phase steels (DP), HSLA steel, Silicon steel (NGO), pipe grades	900-1600 mm	0.8-12.7 mm	2.5 mt/y
3	Tata Steel	India	Carbon steels, Si steel, pipe grades, dual-phase steels (DP)	950-1680 mm	1-20mm	2.4 mt/y
4	Nucor Steel	America	Carbon steels, dual-phase steels (DP), HSLA steel, Silicon steel (NGO), pipe grades	900-1600 mm	0.8-12.7 mm	2.5 mt/y

Table 1. Some of reference list

6.2. IN LINE STRIP PROCESS (ISP)

This technology is invented by Mannessmann Demag and pipe and tube producer, Arvedi. The first plant was built in Cremona in 1993.

Figure 9. Thin Slab Production with ISP Technology

Casting with liquid core reduction system allows slab thickness to be reduced while its core is still liquid. Cast slabs has a thickness of 60 to 80 mm. After leaving the casting machine, slab enters into a three stands rolling which reduces its thickness to 15-25 mm. Cutted strip then enters to reheating furnace which equalized its temperature to rolling temperature. The belt then enters in a furnace called Cremona for coiling. This coiled strip is sent to finishing mill. The finishing mill has four stands that can reduce the slab thickness to 1.5 mm. This technology is a compact plant and its length is 180 m. The process time of 15 to 30 min is one of the advantages of this technology.

The mould is vertical-curved design and maximum strip width is 1,300 mm. The maximum casting speed is 6 meters per minute. This method produces a variety of steel grades includes deep drawing, structural steel and alloy steels, austenitic-ferritic steels, HSLA and stainless steels.

Plant	Place	Capacity	Produced grades	Product Width	Thickness
Arvedi ISP	Italy	1.2 mt/y	Structural alloy and non-alloyed steel, HSLA steel and Ferritic-Austenitic stainless steel	1300 mm	1-12 mm

Table 2. Some Reference List

6.3. CONROLL TECHNOLOGY

The thin slab casting and hot direct rolling technology coined “Conroll” was developed by Voest Alpine IndustrieanLagendau (VAI). The Conroll process produces 70-80 mm thick slab through a straight mould with parallel sides but does not perform strand thickness reductions. High casting speeds of 2-4 m/min and width of 800 to 1600 mm is possible. The caster is connected to rolling mill via a roller hearth reheating furnace that equalize slab temperature to 1120^{O}C.The rolling mill can include four, five or six finishing strand depending on product mix and required finishing gauge. The rolling mill consist of a hydraulic shear mechanism, high pressure water descaler, laminar strip cooling system and a downcoiler. Final strip thickness is between 1.8 to 20 mm. The Conroll technology was installed in April 1995 at Armco’s Mansfield. Armco adopted this technology because it was designed specifically for stainless steel. Steel grades produced includes carbon steel, 409, 430 stainless steel as well as a small percentage of HSLA, high alloyed and Silicon steels.

6.4. TSP TECHNOLOGY

Tippins Incorporated (American) teamed up with caster builder Samsung Heavy Industries of South Korea to develop TSP technology. This technology is suitable for low carbon to high carbon grades of steels, stainless, HSLA, Silicon, API and drawing quality steel. One of the strength of the mill is its versatility, it can produce coil or discrete plates enabling a wide range of width and gauges to be produced. The casting of intermediate thickness slabs has some advantages. The slab is thin enough to eliminate the need for a separate roughing mill and thick enough to maintain good quality. The intermediate thickness allows for greater slab width, reduced reheating time and hence reduced scale formation compared to 50 mm thin slabs.

After casting, slabs are sent to directly to reheating furnace to equalize the slab to the correct rolling temperature. The typical holding time to heat a slab to 1250ºC is 12-13 min. Once the strip has been reduced to 20-25 mm, it is coiled to in the coiling furnace to retain strip temperature. The strip is then reversed back and forth through the rolling mill. A total of three flat roughing passes and six coiling finishing passes are generally required to finish gauges to 1.5 mm thickness.

6.5. DANIELI THIN SLAB TACHNOLGIES

In the past 20 years, Danieli has developed a group of solutions for thin slab casting. These solutions increase the production from 0.8 million tons in 1989 to more than 2 million ton in 2010 in Posco with 8 m/min casting speed and average daily speed of 7 m/min.

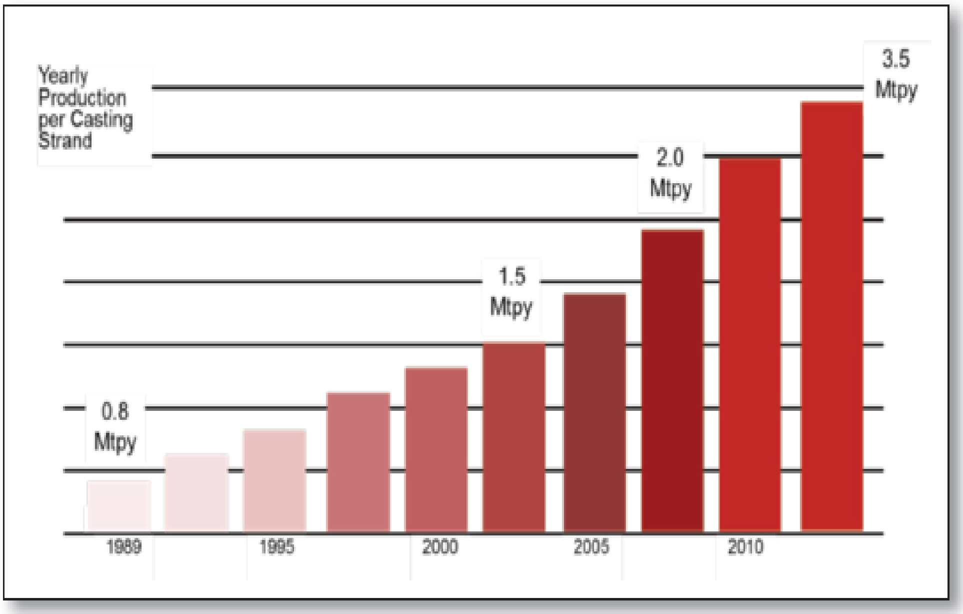

Figure 10. Annual Thin Slab Production per Strand

Nowadays, the producing of all flat products becomes possible with thin slab casting.

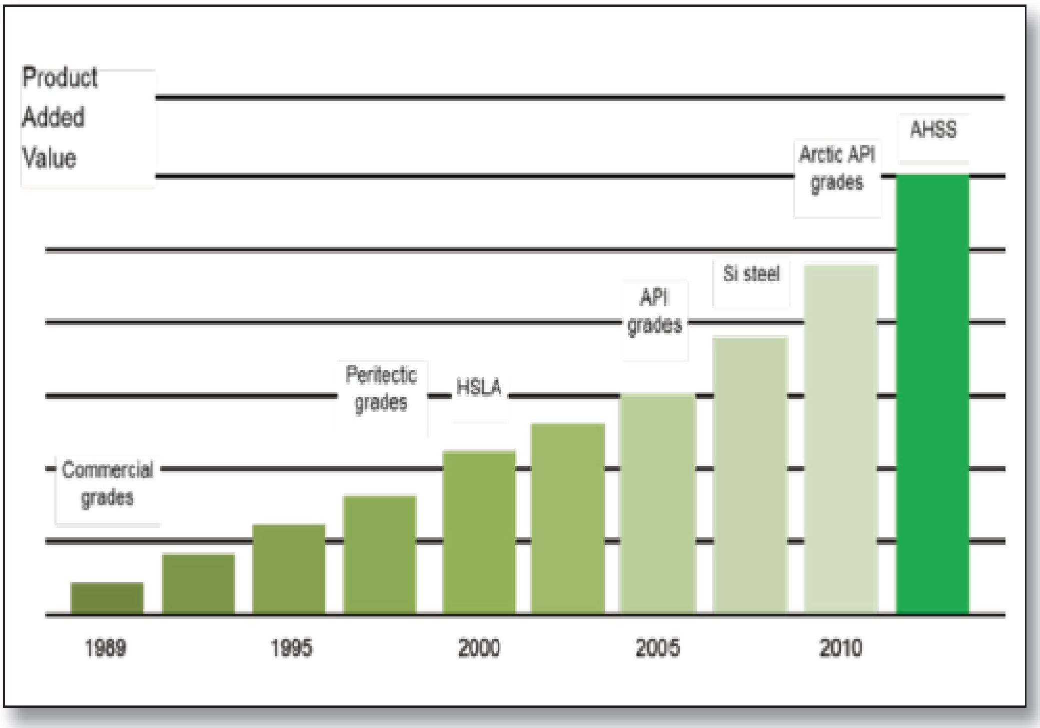

Figure 11. Produced Grades with Danieli Thin Slab Technology

In 1997, Essar Algoma plant, Canada became the first plant in the world to produce Pritectic grades with thin slab casting and rolling technology. This plant developed its production to HSLA steel grades with 700 MPa yield strength.

Bensky Iron and Steel Company successfully produced electrical steels with high Si content more than 3.2 percent and Russia's OMK uses this technology for the production of high quality grades such as API X70 and X80 pipe.

In the field of thin slab casting and rolling, Danieli has developed three technologies that include:

QSP (Quality Strip Production), fTSR (Flexible Thin Slab Rolling) and ETR (Extra Thin rolling)

The product grade consists of almost all steel grades used for the application of flat products. The grades includes Pritectic steels, Micro alloy steels and Silicon alloyed steel for applications such as automotive and pipe production lines and applications for ultra-thin strips. Thin slab casting a vertical curved design that uses dynamic soft reduction process. This process provides the possibility for choosing slab thickness.

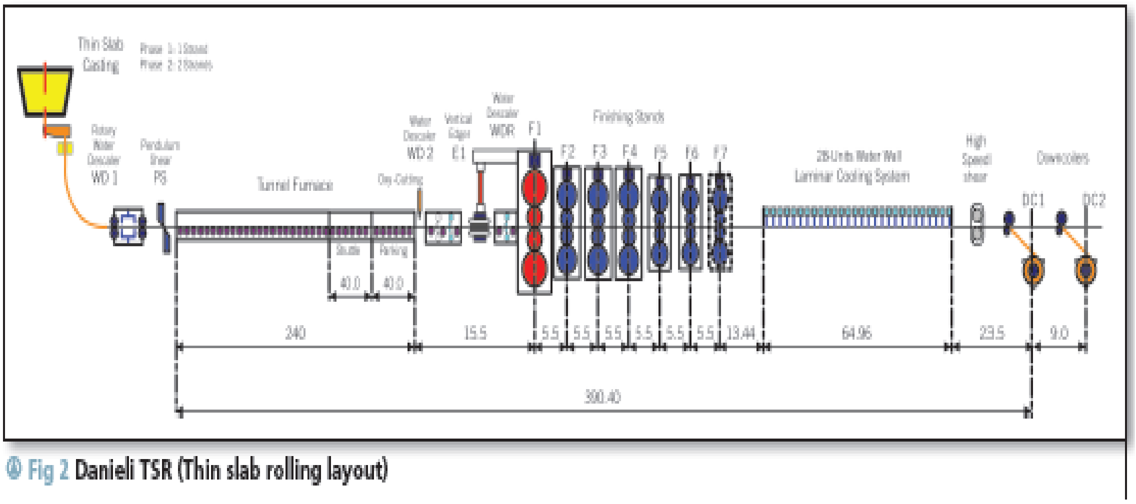

Figure 12. TSR Technology

6.6. QSP TECHNOLOGY

QSP technology is used for production more than 3 million tons per year capacity, where internal quality and dimensional accurate of slab has to be considered. This technology is designed for the plants produce thicker slabs (up to 100 mm) and with only one strand casting want to reach to 2 million per year capacity. For higher-grade, this technology uses a two-stage and thermo-mechanical rolling. The use of slab with 100 mm thickness and temperature control allows the installation of eight strands in this technology

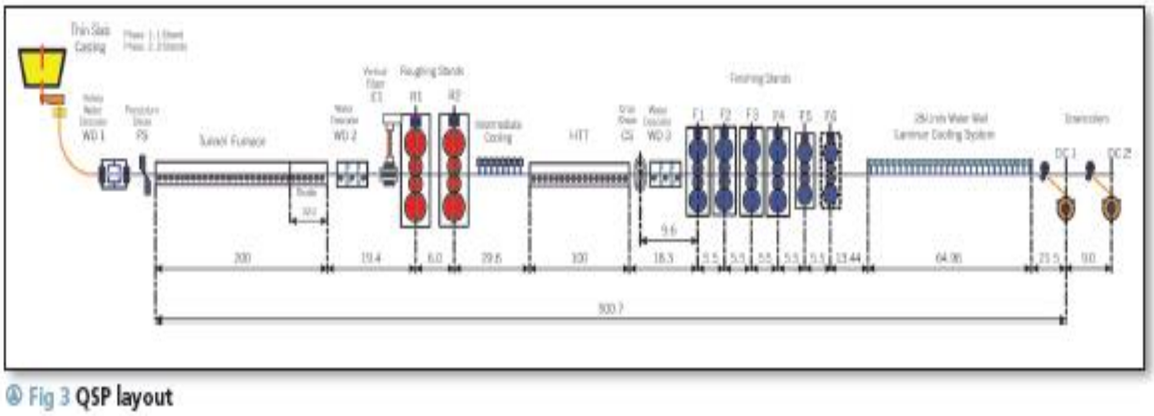

Figure 13. QSP Technology

Plant	Place	Product grades	Product width
Dongbu Steel	2.6 mt/y	ULC, LC, MC, HC, Peritectic, HSLA for automobile and pipe applications.	800-1650 mm
POSCO	1.8 mt/y	HR coil	1600 mm
MMK-Atakas	2.4 mt/y		800-1570 mm
OMK	1.2 mt/y	LC, MC, PE, HSLA, API grades (up to X70 for arctic applications and K52 for sour service	850-1850 mm

Table 3. Some Reference List

6.7. fTSR TECHNOLOGY

fTSR technology is more compact version of QSP. In this way, the investment cost is reduced. This technology is shorter than the QSP. In this plant roughing and finishing mill coupled to each other. fTSR gives the benefits QSP is in a more compact layout. This method has limitation for producing specific grades such as grade API X70-X80 used in very cold areas and there is a special thermo-mechanical process needed for its production. In this technology thickness is lower than QSP thickness, usually 70-85 mm. Due to the compression plant it is capable of producing semi-final products, 0.8 mm ultra-light in seven strands.

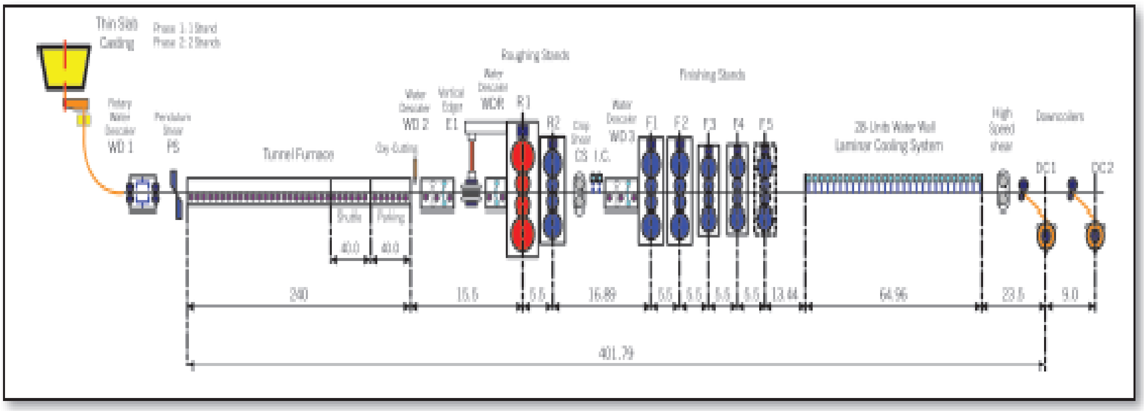

Fig 7 fTSR layout

Figure 14. fTSR Technology

Plant	Place	Product grades	Product width	Capacity
MMK Metalurji	Turkey	ULC, LC, MC, HC, Peritectic, HSLA for automobile and pipe applications.	800-1570 mm	2.3 mt/y
DongBu	Korea			2.5 mt/y
Tong Hua, Benxi & Bao Steel	China			
Severstal Lucchini	Italy		1829 mm	1.7 mt/y

Table 4. Some Reference List

6.8. ETR TECHNOLOGY

This compact technology allows ultra-thin slab production with up to 0.8 mm thickness. If the slab thickness considered 80 mm with casting speed of 7 meters per minute, production capacity will be more than 2 million tons per year. This technology is suitable for thin and ultra-thin slab up to 0.8 mm.

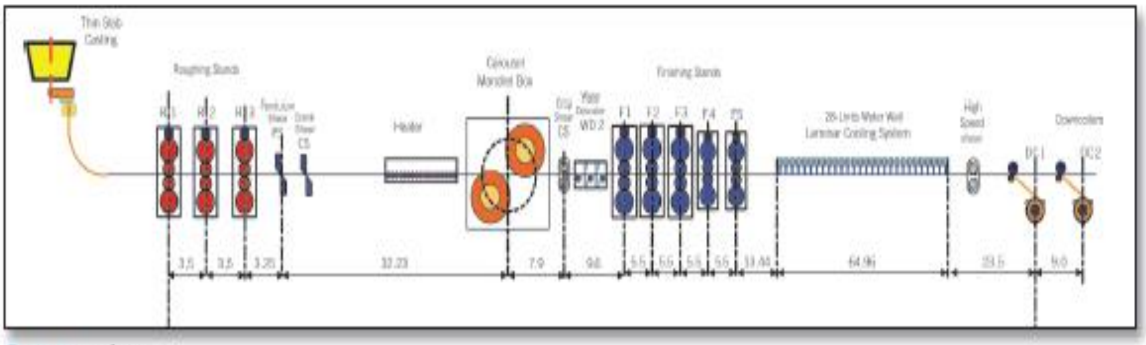

Fig 8 ETR layout

Figure 15. ETR Technology

Plant Name	Place	Capacity	Product Grades	Product width	Casting Speed
POSCO	Korea	1.8 mt/y	ULC, LC, MC, HC, Peritectic, HSLA for automobile and pipe applications.	1300 mm	More than 7 m/min

Table 5. Some reference list

6.9. ESP TECHNOLOGY

The first plant with ESP technology was established in Italy with 2.3 million tons per year capacity. The range of product is 1570 mm and thickness up to 0.8 mm. The plant is able to produce carbon steel, high-strength low alloy steels (HSLA), API grades, duplex steels and silicon grades.

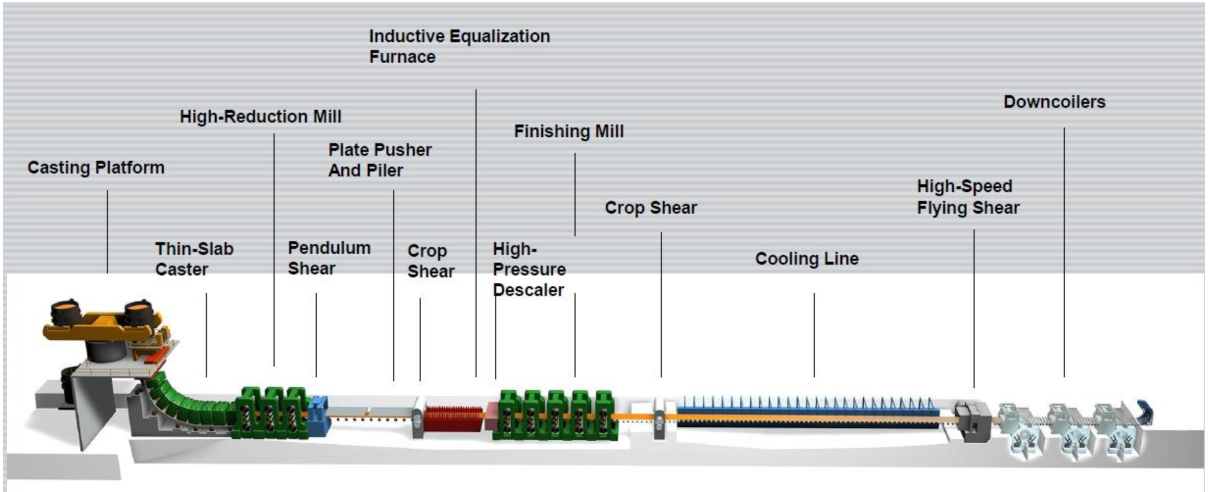

Figure 16. Arvedi ESP Technology

The Chinese producer Rizhao Steel ordered a total of five Arvedi ESP lines from the former Siemens VAI (now Primetals) in 2013 and 2014. The first Chinese plant consists of three lines, each with an annual capacity of 2.55 million tons per year of ultra-thin heating belt with a width ranging from 900 to 1600 mm. Lines 4 and 5, with about 900 to 1,300 mm width will be replace with existing plant. The thickness of strip is minimum 0.8 mm. The liquid steel is cast to slab and after mould its thickness reduces with LCR system. Then rolled at high temperature and its thickness is reduced to an average thickness. A pendulum cutting system separate dummy bar from slab. This section consists of three or four stands.

In this technology induction furnace is used instead of tunnel furnace. Its advantages is reducing the length and consumption of natural gas but the electrical energy consumption is higher than other technologies and more complex repairs is needed. After re-heating to the right temperature slabs were guided to finishing mill and coiled.

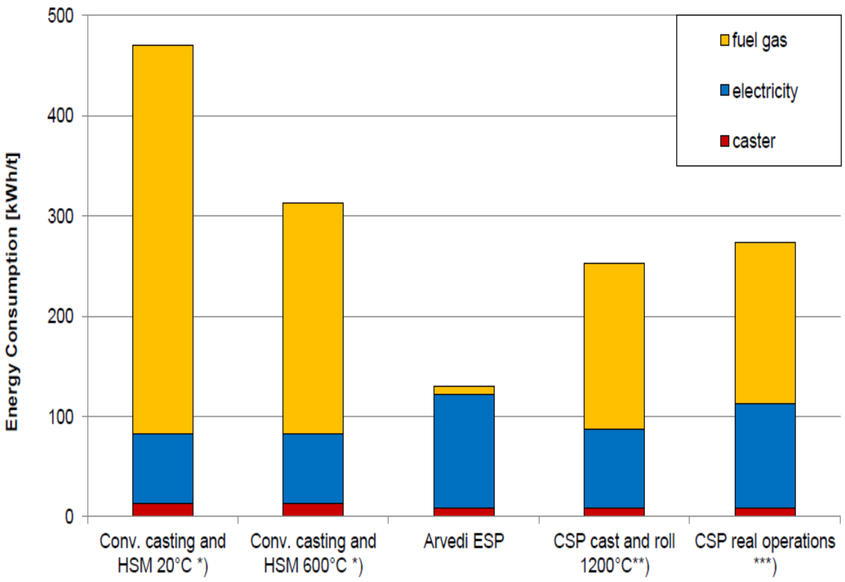

Figure 17. Comparison between Energy Consumption for Various Hot Rolled Coil Technologies

Plant name	Place	Product grades	Product width	Thickness	Capacity
Arvedi ESP	Italy	Carbon steels, high-strength low alloyed (HSLA)grades, API grades, dual phase steels and silicon grades	1570	0.8-12 mm	2.3 mt/y
RIZHAO 1	China	Carbon steels, high-strength low alloyed (HSLA) grades, API grades, dual phase steels and silicon grades.	1600 mm	>0.8 mm	2.55 mt/y
RIZHAO 2	China	Carbon steels, high-strength low alloyed (HSLA) grades, API grades, dual phase steels and silicon grades.	1600 mm	>0.8 mm	2.55 mt/y
RIZHAO 3	China	Carbon steels, high-strength low alloyed (HSLA) grades, API grades, dual phase steels and silicon grades.	1600 mm	>0.8 mm	2.55 mt/y
RIZHAO 4	China	Carbon steels and high-strength low alloyed (HSLA) grades	1300 mm	>0.8 mm	1.7 mt/y
RIZHAO 5	China	Carbon steels and high-strength low alloyed (HSLA) grade	1300 mm	>0.8 mm	1.7 mt/y

Table 6. Some Reference list

7. CONCLUSION:

In choosing appropriate technology for a given plant, it is important to consider the following points:

- Plant Capacity (Is this technology proper for low capacity or high capacity)
- Type of Products
- Electrical Energy Consumption (Due to high cost of energy in Iran , it is important to consider the operating cost and which technology consumes less energy)
- Fuel Consumption (Which technology has less fuel consumption and whether this decrease in fuel can compensate increasing in electrical energy or not)
- Water Consumption (With regard to water scarcity, water-saving technologies will be of more interest)
- Infrastructural facilities
- The Standby Lines
- Plant Availability
- Maintenance and Repairs Costs
- Production Costs
- Investment Costs
- Environmental Aspects (Which of the technologies produce fewer emissions? Related to process NO_x, CO_2 and SO_x is more important)
- Space Needed
- Steel Structure Weight
- Maintenance Methods

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