POLITECNICO DI TORINO

Master of science program in

Automotive Engineering

(Management of Industrial

Processes)

Master's thesis:

Analysis of the current scenario of steel in automotive, with special focus on new production processes.

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Academic Year 2019/2020

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Introduction

The thesis paper presented here has as its main theme an overview on the steel industry, how it influences the automotive sector, how is the current state of the market and the possible future technological developments.

The thesis was developed in the following way:

in the first chapter, the attention is focused on the role of the steel in the automotive sector.

Steel components are the most used in the process of building a car, therefore the approach with which a company manages this resource is fundamental in each part of the strategic and the production processes. An analysis based on the information learned during my university path will show how the production of steel, the manufacturing processes involving the raw materials and the management of cost analysis related to raw materials and usage are managed in a car company.

in the second chapter, an analysis of the current market scenario is performed. The steel industry in going through an important crisis due to the trade war between the two superpowers of the world: China and USA that lead to a series of consequences. this war also involved the rest of the world and a special focus is performed for UK, Germany and Italy.

Finally, it has also been reported how the covid-19 pandemic is affecting the steel industry.

in the third chapter the future technologies are analysed.

The automotive sector requires a new type of steel to produce electric vehicles: the advanced high strength steel.

This kind of steel may be produced using the near net shape strip casting techniques. As the name suggests, the peculiarity of this technology is that the initial production of the element is very close to the final shape, reducing a lot of successive processes.

The two more advanced technique of NNSSC are Twin roll casting and horizontal single belt casting.

The first one consists in two rollers that “squeeze” the molten steel to make it a sheet and the second consists of printing liquid steel directly on a single horizontal mobile belt.

1. STEEL IN AUTOMOTIVE

a. Bill of materials

Both parts list and bill of raw materials are provided to the facilities designer by the product engineering department with each new product. These lists describe all the parts that make up a finished product.

The bill of material has a hierarchical structure, often represented as a tree diagram. The top node represents the finished product and the lower levels specify the subassemblies, the semi-finished products and the raw materials.

This list also includes part specifications as: numbers, names, quantity needed.

Bill of material shows also raw material unit costs and make or buy decisions that will be considered in later parts of the elaborate.

Considering the scope if the thesis we will focus on raw materials.

Raw material is the material usage needed to produce a part. The graph below shows that steel is the most used material by far, highlighting that steel management is a key factor in car process development.

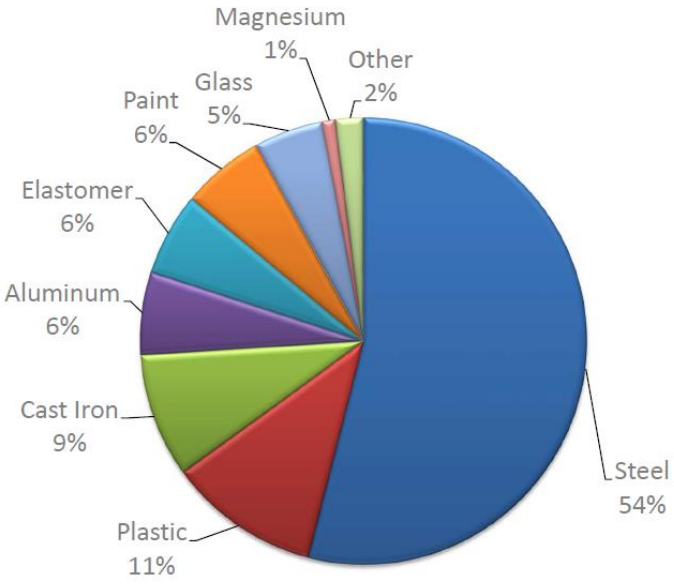

Figure 1: BOM of raw materials used to build a car.

Resilient, relatively cheap, modular in mechanical characteristics and easy to work. Steel is the most common material in average level cars.

The applications go from the car body, passing through the rims and going to the structural components of the chassis and suspensions.

b. Make or buy

The huge amount of steel needed to produce the product components, two key decisions must be considered and their outcome may heavily affect, according to the trade-offs that have to be managed, the product competitiveness:

1. carry over: use of existing components or development of new ones.

   The adoption of carry over strategy decrease the development costs, the investments related to new tooling and the risk of having poor reliability, but on the other side an excessive use of existing component on new products, especially with regard to body and interiors systems, may cause a negative effect on product personality, providing to the customer the impression of a product too much similar to the existing ones.

2. Make or buy: internal development and/or manufacturing of the components of suppliers who specializes of this kind of component.

   The use of external resources (Buy choice) for the design and manufacturing of new components may have positive impact on component quality and on the efficiency in terms of the internal effort, but if this strategy is applied for several years internal technical Know How may be damaged.

The decision to either make or buy a part is up to top management, not just the product engineering department, but the BOM is a good place to indicate that decision.

For components, the carry over and the make strategies vary according to the manufacturers and the specific factories. But if we consider the production of raw steel, nowadays, the buy strategy is by far the most applied one.

In the next chapter we will focus on the producers and on the current market scenario but here we are going to analyse the steel commercial formats in automotive:

1. Sheets (Coils, sheets): depending on the production method, such coil is classified as hot-rolled and cold-rolled.
   The differences between these two categories relates to the way these metals are processed at the mill, and not the product specification or grade.
   Hot rolled steel involves rolling the steel at high temperatures, where cold rolled steel is processed further in cold reduction mills where the material is cooled followed by annealing and/or tempers rolling.

2. Wire/bars: wire rods, bars, tubes, extruded.

In the automotive field the most used format is the sheet one and is the one that will be considered in chapter three and in the following paragraph.

c. Production process: main automotive steel process

As mentioned before, steel is the most used material in automotive for its good rate cost/quality.

In order to obtain the pre-assembly parts, steel may be worked in three different ways:

1. Sheet metal processes: set of forming and shaping operations required to transform a flat metal sheet into a desired geometry, impressing permanent deformations.

   The two main tools used are the stamping presses and the stamping dies. The press provides the force to close the stamping dies where they shape and cut the sheet metal into finished parts.

   Results of this operation are floor; body frame; doors; seat framet; dash cross member; suspensions arms…

2. Forming and bending processes: the input materials are tubes or wires. There are specific CNC machines used for plastic deformations of tubes and wires with different cross-sections.

   Results of these operation are seat frame; cross member; suspension spring…

d. Cost of raw material

Raw materials purchase price in general, includes:

- Base cost due to market drivers
- Transportation cost
- Costs for nonstandard size, format…
- Costs for quality certification
- Costs for warranty/insurance
- Mark-ups of raw material provider

It's important to underline that the costs associated with material storage, inventory carrying costs and in-plant transportation are not included in raw material cost. These costs are charged on final product cost.

Focus: **Steel Price**

The steel is a global commodity: its price is quoted on the global markets and is the sum of:

• Relatively standard costs (production);

• Fluctuating costs (worldwide availability of steel raw materials, and cost of the energy for the transformation).

The commercial availability and the price of steel is various they directly follow the trend of its raw materials (carbon coke, iron ore and crude oil).

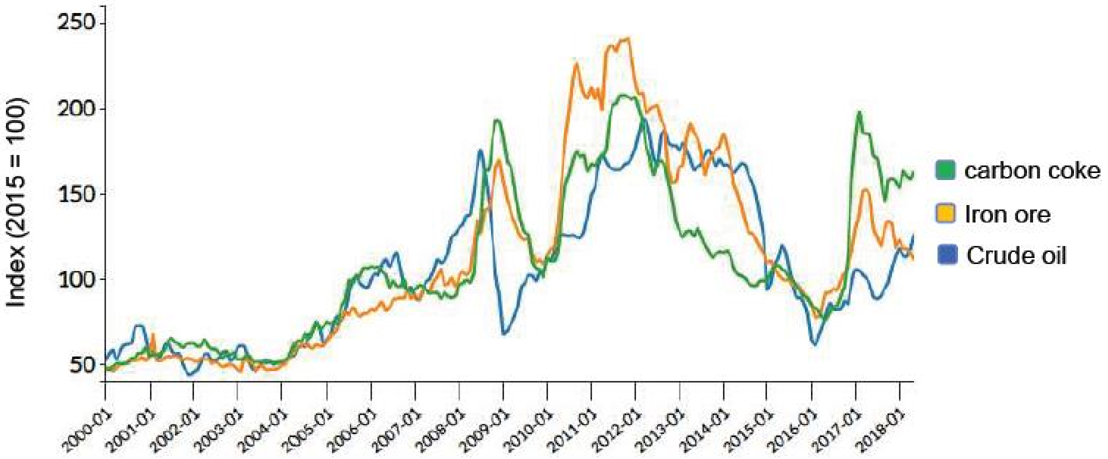

Figure 2 trends of the fluctuating costs of the raw materials used to produce steel[1]

Even if in the last years the raw materials price increased, the expectations of international bodies, banks and analyst are oriented downwards.

Specifically, iron ore, after rising 2019 and closed with average annual prices of around $90 a ton, should reach around 70-80 $ a ton in 2020 thanks to the increase in extraction capacity.

Carbon coke, on the other hand, is expected to suffer a reduction a reduction of about 10% compared to the 2019 level.[2]

[1] Pricepedia.com
[2] Data provided by the World Steel Association

Furthermore, different specifications bring to different prices. So, we can finally split the steel cost in all its components.

For example, the **FCA best practice** for Steel Coils Price Construction is:[3]

$$
\begin{aligned}
&\mathit{Steel\ specific\ Cost}\\
&\qquad = \mathit{Steel\ base\ cost}: \mathit{by\ production\ technology}\\
&\qquad + \mathit{Extra\ for\ surface\ quality} + \mathit{Extra\ for\ format\ cutting}\\
&\qquad + \mathit{Extra\ for\ surface\ coating}
\end{aligned}
$$

Where the base price tendency is[4]:

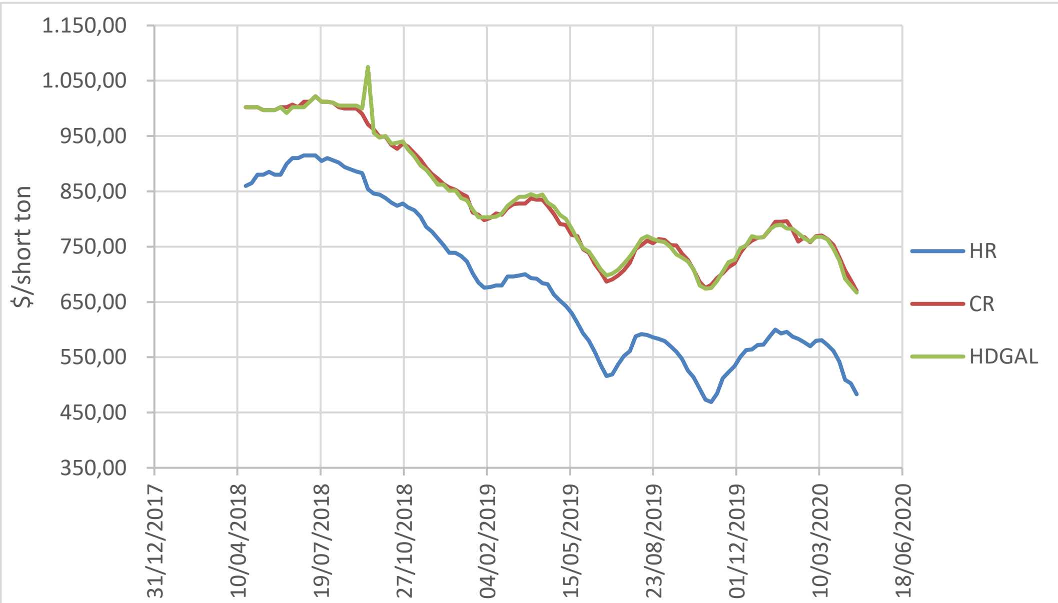

Figure 3 USA Steel base prices – Midwest. According to Phoenix Steel service, inc.

[3] Knowledge learned during master's course: project management and cost/value analysis.
[4] phoenixsteelservice.com

e. Material usage

It is always necessary to calculate gross and net material usage to calculate material costs.

Gross material usage is directly linked to:

- Material type (eg: metallic, chemical, fabric…);
- Material commercial availability;
- Production process used for the material transformation.

While net material use is linker to

- Raw material gross usage
- Material Cost Calculation: General Rule
- The material cost is defined by the raw material price, the gross and the net material usage.

For metallic stamped components, gross weight utilization is the main driver for material cost. The strategy is to arrange parts in order to maximize the metal sheet saturation.

BUT material gross reduction is limited by constrains of stamping process and material

characteristics such as formability and thinning.

Nonetheless, it is possible to recycle scraps and subtract the resale material cost from the gross material cost.

Infact, according to rockawayrecycling.com, the current price of steel scraps is $ 0.02 - $0.035 /lb.[5]

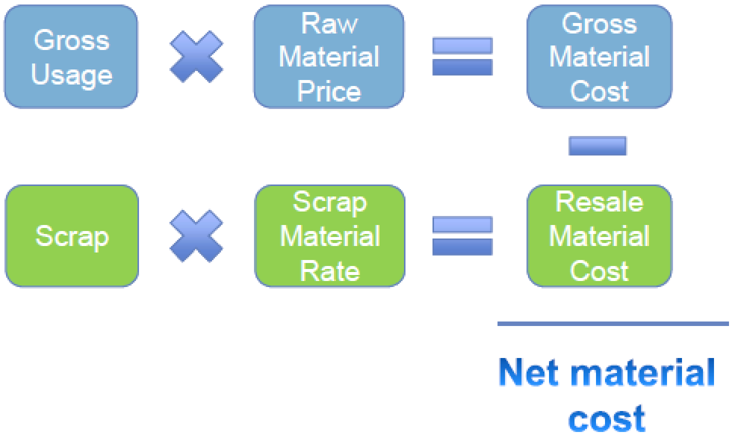

Figure 4 Net material cost calculation

[5] rockawayrecycling.com

2. MARKET AND CURRENT SCENARIO

To have a complete overview of the steel industry and its main influencing factors, it is fundamental to understand the historical period and the resulting market contest.

In this chapter we will understand where the steel industry is going, who are the main characters, and which are the most criticalities of the sector.

a. Trade war between USA and China

March 2017, the American stock exchange Nasdaq published an article in which tired to analyse the new USA's president program to reinforce his national manufacturing industries and forecast the future evolution of the steel market.

The article said: "In addition to strong domestic demand growth, U.S. steel producers could see an easier competitive environment as the new administration focuses its sights on steel imports." [6]

Furthermore, the article asserts that the high average age of light vehicles in the United States (11.5 years) will result in a great demand for replacement, both of cars and related spare parts, and all the steel industries can do is to earn money from it.

This kind of enthusiasm and optimism would not last long and it is easy to understand that this forecast was before the start of the trade war between USA and China.

[6] These Steel Stocks Are Some Of The Top Stocks Of 2017 – Nasdaq.com. 7/march/2017

In order to have a clear idea of the current steel market situation, the chronology of the political actions will be highlighted.

8 March 2018, Donald Trump announced additional customs duties of 25% on steel imports to reduce American trade deficit. It will exempt several countries from this tariff rate, but not China.

Two weeks later (22 March) the US president declares a trade war opened against Beijing, denouncing "China's economic aggression" and threatening to impose punitive duties on $60 billion in imports of Chinese products.

Between 6 July and 24 Semptember 2018, Washington imposed customs duties by 25% on 34, then 16 and then 200 billion dollars of imports of Chinese goods. Each time, Beijing responds with similar values.

After a brief period of truce, where China promises to buy a significant amount of American products, on 10 May 2019 America raises taxes on $200 billion of Chinese product from 10 to 25%, claiming that China did not keep its commitments.

As response, Beihing raises taxes on US $60 bilion in imports and plans a blacklist of "unreliable" foreign companies.

On August 2019, vitually all $660 billion in annual trade between the world's tw largest economies will be subject to tariffs.

Furthermore, Washington formally accuses Beijing of dropping the yuan below 7.0 units against the dollar for the first time in 11 years to support its exports and Donald Trump announces preliminary dumping on some Chinese structural steels.

On 13 December 2019, the two countries announce a preliminary commercial agreement "phase 1". [7]

Unlike other trade agreements, the US–China Phase One agreement did not rely on arbitration through an intergovernmental organization like the World Trade Organization, but rather through a bilateral mechanism.[8]

[7] Dazi, ecco le tappe principali della guerra tra Usa e Cina – lastampa.it. 17/01/2020
[8] China – United states trade war – Wikipedia.

b. Effects of the trade war

The effects of this war on the steel industries are explained by the same "optimistic" Nasdaq, highlighting three major themes:

1. "Waning steel demand poses problems for steel producers. A slowing Chinese economy amid lingering trade conflict with the United States has triggered a slowdown in steel demand in China, the world's top consumer.

   The trade war has taken a huge toll on China as reflected by its tepid economic indicators. Signs of weakness across the country's major steel end-use markets — construction and automotive — as reflected by a slowdown in real-estate investment growth and falling car sales have clouded steel the demand outlook.

2. The industry continues to reel under the effects of sustained oversupply of steel in the market, exacerbated by continued growth in production in China. Notwithstanding the U.S.-China trade tensions, China's steel mills continue to crank up output. A glut of cheap Chinese steel has put downward pressure on both Chinese and global steel prices.

3. The 25% tariff on steel imports, which the Trump administration levied last year, drove up production capacity of U.S. steel producers. Improved capacity also provided a boost to U.S. steel production. However, higher production, partly driven by restarted mills, has contributed to the sharp decline in U.S. steel prices this year. In fact, after rallying to multi-year highs on the back of the Trump administration's imposition of tariffs, U.S. steel prices have now fallen back to the levels seen prior to the tariff announcement. Sliding steel prices, softening demand across major domestic end-markets and trade tensions have weighed on U.S. steel producers this year. While some of these producers have recently taken steps to reduce capacity in the wake of declining domestic steel prices, the move is not expected to result in a significant recovery in prices anytime soon

given the oversupply in the market and weak domestic steel demand."[9]

Even the international news organization Reuters reports that the manufacturing sector, in December 2019, fell into its deepest slump in more than a decade and asserts that: "The manufacturing sector had been under pressure for much of the second half of 2019, as tit-for-tat tariffs by the United States and China slowed the flow of goods between the world's two largest economies and contributed to a cooling in the pace of global economic growth". [10]

The article reports the words of Timothy Fiore, chair of Institute for Supply Management's manufacturing Business Survey Committee: "Global trade remains the most significant cross-industry issue, but there are signs that several industry sectors will improve as a result of the Phase 1 trade agreement".[11]

[9] Near-term Outlook Appears Bleak for Steel Producers' Stocks – Nasdaq.com. 3/9/2019.
[10] U.S. factory sector in deepest slump in more than 10 years – Reuters.com. 3/1/2020.
[11] ivi

c. Global steel productors

To understand these points of view we can simply show the main actors in the production of steel worldwide.

Data from worldesteel.com shows a huge step forward the production of steel by China during the last years.

Rank (2018)	Country/Region	2018[8][9]	2017[1][10]	2016[1][11]	2015[12]	2014[13]	2013[14]	2012	2011	2010	2009	2008
—	World	1808.6	1674.8	1606.3	1620.4	1670.1	1649.3	1552.9	1490.1	1413.6	1219.7	1326.5
1	People's Republic of China	928.3	831.7	786.9	803.8	822.7	779.0	724.7	683.3	626.7	573.6	500.3
—	*European Union*[15]	168.2	168.7	162.3	166.2	169.3	166.4	168.6	177.7	172.8	139.3	198.2
2	India	109.3	101.5	95.5	89.6	87.3	81.2	77.3	72.2	68.3	62.8	57.8
3	Japan	104.3	104.7	104.8	105.2	110.7	110.6	107.2	107.6	109.6	87.5	118.7
4	United States	86.7	81.6	78.5	78.9	88.2	87.0	88.6	86.2	80.6	58.2	91.4
5	South Korea	72.5	71.1	68.6	69.7	71.5	66.0	69.3	68.5	58.5	48.6	53.6
6	Russia	71.7	71.3	70.5	71.1	71.5	69.4	70.6	68.7	66.9	60.0	68.5
7	Germany	42.4	43.6	42.1	42.7	42.9	42.6	42.7	44.3	43.8	32.7	45.8
8	Turkey	37.3	37.5	33.2	31.5	34.0	34.7	35.9	34.1	29.0	25.3	26.8
9	Brazil	34.7	34.4	30.2	33.3	33.9	34.2	34.7	35.2	32.8	26.5	33.7
10	Iran	25	21.8	17.9	16.1	16.3	15.4	14.5	13.0	12.0	10.9	10.0
11	Italy	24.5	24.0	23.3	22.0	23.7	24.1	27.2	28.7	25.8	19.7	30.6

Figure 5 List of counties by steel production, million metric tons [12]

This table shows the production trend until 2018. Even by neglecting 2019 we can see that China is the world first steel producer and had a huge increase in steel production during Trump's presidency, even higher than the increase during the period of the two Obama mandates.

Then, if we consider also the 2019, the whole picture becomes clearer even without the help of the previous articles.

Statistics provided by worldsteel.org show that China's crude steel production in 2019 reached 996.3 Mt, up by 8.3% on 2018. China's share of global crude steel production increased from 50.9% in 2018 to 53.3% in 2019.

While the US produced 87.9 Mt of crude steel, up just by 1.5% on 2018.13

[12] List of countries by steel production – Wikipedia.
[13] Graphs by worldsteel.org

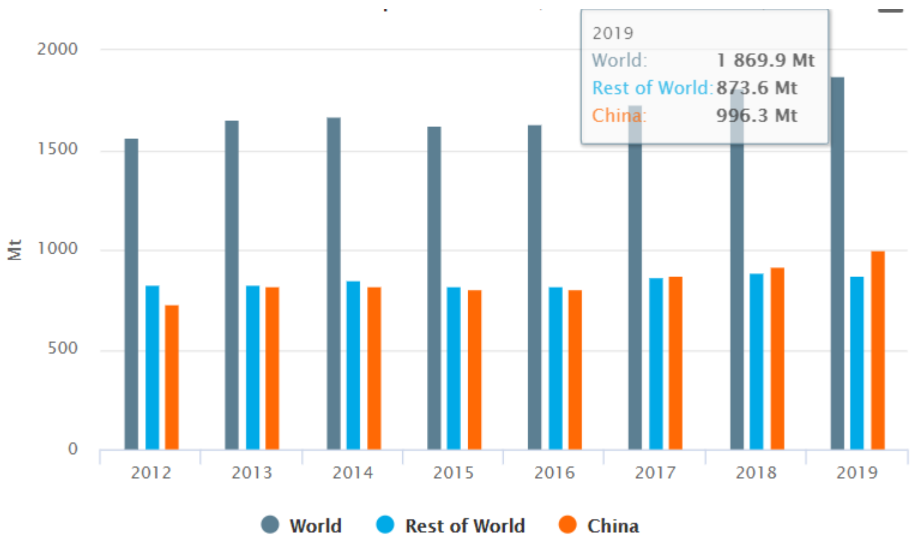

Figure 6 Annual crude steel production (in million tonnes)

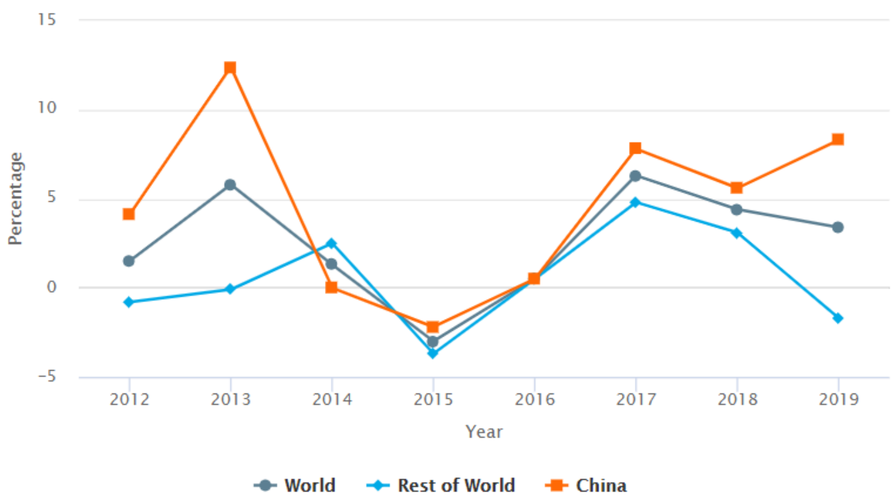

Figure 7 Crude steel production annual growth trend

Overcapacity

The issue that aggravates the global crisis is the overcapacity. There is too much production capacity compared to demand, too many plants that produce steel.

In this sector fixed costs are high; the production is in a continuous cycle and so this means that it is not possible to stop and restart a steel plant without having to bear inefficiencies and additional costs.[14]

[14] ArcelorMittal e Ilva: nella crisi dell'acciaio l'Italia paga il prezzo più alto – ilsole24ore.com. 8/11/2019.

d. Europe

If the Trump policy has not been so effective towards China, the same cannot be said for Europe.

Washington announced additional customs duties of 25% on steel imports, starting from the 8th of February 2020, even for some European countries.

The measures were taken based on controversial "national security" reasons in order to protect – including from allies – a domestic industrial base defined as "essential for defence and critical infrastructure".

If compromises have emerged with China, a potential hardening of Trump's position with Europe is likely. [15]

Referring to the worldsteel.org data previously analyzed, The EU produced 159.4 Mt of crude steel in 2019, a decrease of 4.9% compared to 2018, in particular:

- Germany (the 1st European steel producer) produced 39.7 Mt of crude steel in 2019, a decrease of 6.5% on 2018.
- Italy (the 2nd) produced 23.2 Mt in 2019, down by 5.2% on 2018.

Then France produced 14.5 Mt of crude steel, a decrease of 6.1% on 2018 and Spain produced 13.6 Mt of crude steel in 2019, a decrease of 5.2% on 2018.[16]

This shows that Europe is far weaker than China and does not have the strength to fight a trade war against the US.

The main reason is that China floods the steel market at bargain prices thanks to the state subsidies provided to its companies while the EU forbids them.

So, Trump's policies have encouraged China to bring its low-cost products to the European market. This led to a drop in the average price and therefore difficulties for European producers.

Other factors add to this situation: the increase in the price of raw materials, the increase in the price of raw material, the rising costs of the CO2 emissions allowances foreseen by the European carbon market and, above all, the crisis in the sectors where there is more demand for steel, like automotive.[17]

In fact, British Steel has ended up in controlled administration, ThyssenKrupp has announced 6.000 redundancies and ArcelorMittal cuts operations in many countries.

[15] Usa, dazi su acciaio e alluminio. La Ue non è nella lista degli esentati – ilsole24ore.com. 26/1/20202
[16] Worldsteel.org
[17] Acciaio, anno di crisi per tutti i player europei: produzione giù, migliaia di lavoratori a rischio tra Spagna, Francia, Germania, Polonia e UK – ilfattoquotidioano.it. 9/11/2019

In the following paragraphs the worsts cases will be analysed.

UK

The UK steel production is in constant decline for years, it has fallen to the fifth place in Europe and from 1960 till now the steel industry has lost 60% of its turnover, having in 2016 the worst year.

The biggest national steel productor, British Steel, is on the verge of collapse and attributed the cause to alleged customer uncertainties related to Brexit.

The group was in crisis even before Brexit but the drop of the pound after the 2016 referendum made matters worse.

Nowadays the labour party is trying in every way to save the society and prevent thousands of workers from becoming unemployed, so the company ended up in controlled administration.[18]

Germany

Germany is the leading European steel producer, but this was not enough to make it immune from the continental crisis. In addition, the major German carmakers have been involved in a scandal involving the steel industry.

BMW, Volkswagen and Daimler will have to pay a fine of € 100 million for forming a cartel dedicated to modulating the prices for the purchase of steel in their favor in the period between 2004 and 2013. This is the German antitrust sentence, accusing the three Teutonic giants of anti-competitive behaviour.

The companies have accepted the fine also because in the shareholding of the same there are good slices of state ownership. Therefore, part of the money will go out and enter from the same pockets, as already happened in the past for other sanctions raised on the builders in question.

The amount of the fine, however, will not weight so much in the financial statements of these multinationals, some of which have already had to pay billions to end the polluting emission scandal.

It is not fully clear how much these companies have spared in nearly a decade of steel supplies below the true market value.[19]

[18] Acciaio inglese vittima di brexit. British Steel sull'orlo del collasso, a rischio 25mila posti – ilsole24ore.com. 21/5/2020.

[19] Cartello dell'acciaio, in Germania multa da 100 milioni per Bmw, Daimler e Volkswagen – ilfattoquotidiano.it. 12/11/2019.

Italy

Italy is the second largest steel production power on a continental level but outside the top ten of the world ranking, overtaken by Iran.20

This last fact is mainly due to the situation of ex-ILVA factory in Taranto, for which no one has yet been found a solution, but which alone constitutes 20% of the national production capacity.

Ilva plant

The Ilva plant in Taranto is the largest industrial center in southern Italy. The great crisis began in 2012: the company was defined by the judges as a "factory of disease and death" due to excessive emissions harmful to humans.

To protect workers and production, Mario Monti's government decides not to close the factory entirely.

Subsequently, the owner family (Riva), accused of not having made the necessary investments for environmental protection, leaves the board of directors and the government decides to commission the company.

During the 2016 and 2018 two-year period, the French Indian multinational Arcelor Mittal wins a public tender and assumes honors and charges to relaunch the Ilva.

A fundamental condition of the agreement is the "penal shield" for which the company can take advantage of penal immunity regarding past damage.

So, despite the thousands of deaths on the shoulders, a new start becomes possible for the plant.

In July 2018, the Minister for Economic Development Luigi Di Maio asked to launch an investigation into the legitimacy of the tender for the allocation of the Ilva and subsequently, in May 2019, suggests the hypothesis of eliminating the penal shield in order to put in AncelorMittal the charges to take responsibility for the deaths.[21]

On November 5, 2019 Arcelor Mittal communicates its intention to withdraw from the transfer contract, returning it to Ilva, in extraordinary administration, within 30 days.

This announcement begins a long battle between the company, the unions and the government, which has not yet ended.

Nowadays Ilva returns to the commissioner management, under the protection of the penal shield. [22]

The products related to the heavy manufacturing industry, such as the automotive

[20] List of countries by steel production – Wikipedia.
[21] Ilva di Taranto, la storia infinita di un pasticcio all'italiana – Panorama.it. 6/11/2019.
[22] Ilva (company) – Wikipedia.

supply chain, are the specialty of Ilva and a single other operator in Italy (the Arvedi group).

The disappearance of an internal supply source of this type cannot fail to impact on most of the Italian production chains, with repercussions on the level of stock and prices. For this reason, the story of the former Ilva is an industrial policy problem that affects all of Italy.[23]

[23] ArcelorMittal e Ilva: nella crisi dell'acciaio l'Italia paga il prezzo più alto – ilsole24ore.com. 8/11/2019.

e. Covid-19

The global health crisis due to the covid-19 pandemic had a relevant effect also on economy, trades and production of almost all goods, steel included.

Data reported by the World Steel Association shows a decreased of crude steel production in March 2020 of 6% compared to March 2019.[24]

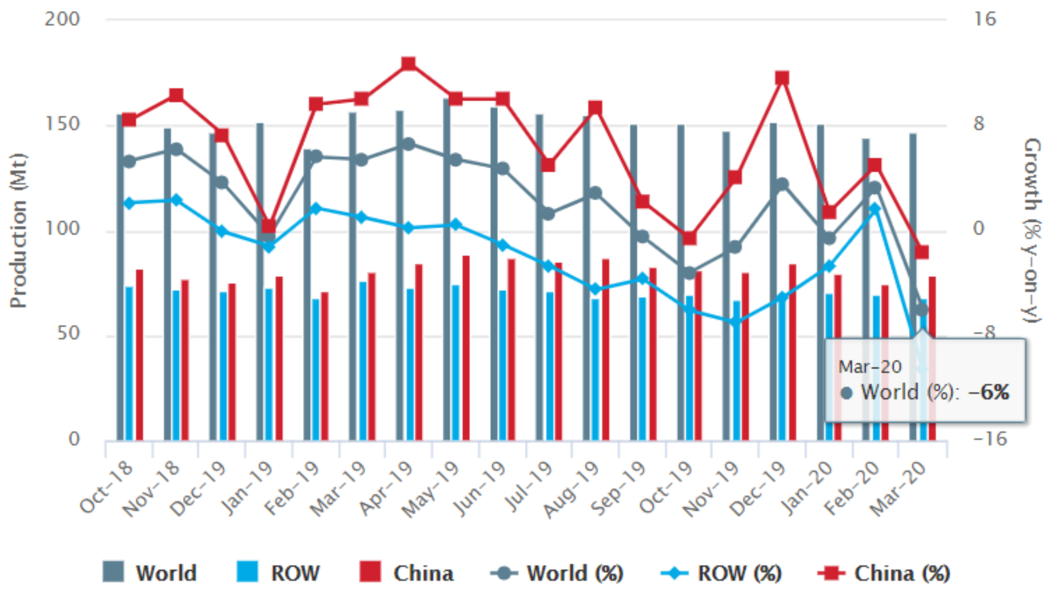

Figure 8 crude steel production

A special report published by the American business and financial service company "Moody's" on April 7 of 2020 shows that the pandemic, projected to bring about a global recession, exacerbates the already challenging environment of steel industries.[25]

In fact, not only the plants are closed but even the demand for steel will be further drive down and so, the steel price probably will drop more and more.

For what concerns Europe, the lock down of steel industries is not applied on all the nations.

Massimiliano Burelli, Ceo of ThyssenKrupp Italy, gives an example: "My Finnish and Belgian competitors work at full capacity. Outokumpu, in Finland, has been declared a strategic company and forced to work" and " in all the plants of the Materials Service, the division to which we belong, we are the only ones blocked. Personally, I do not think that, given the situation, Germany will make a lockdown by decree. Maybe some plants will be stopped if the automotive industry stops. I repeat, for April we have customers who expect the volume. Let us see what the government will tell us. We are the only Italian

[24] Data provided by worldsteel.org.

[25] Covid-19 further dampens global steel sector – thestar.com. 18/4/2020.

manufacturer of flat rolled stainless steels in Italy. If I start not providing customers, we will be in trouble".[26]

From these statements we can understand what Moody's means by saying that a recovery can only be seen later this year if the economic stimulus programmes imposed by various governments show impacts.27

So, the governments play a fundamental role in the recovery from the virus effects.

If in Europe most of the countries have weak governances and there are difficulties to dialogue as a united continent by making unanimous decisions, the situation between USA and China is even worse.

The trade truce is at risk again because the two superpowers are through a propagandistic war based on corona virus: on one side Trump's strategy is to accuse China of not only provoked the pandemic ("the Chinese virus") but that it has hidden its existence in the first crucial months, in which it could be contained and neutralized.

Xi Jinping's strategy is to continuously exalt the victory of the nation against the virus and to focus on the willingness to cooperate with everyone (USA included) and provide them with medical and healthcare materials.[28]

The situation is continuously evolving and, considering the imminent presidential election in USA, the tones will tighten.

These tensions can only worsen the relation between these two nations and the whole world will be involved.

[26] Burelli, Ceo Thyssenkrupp Italia: "Ci dicano se siamo un'azienda strategica o no" – ilmessaggero.it. 1/4/2020.
[27] Covid-19 further dampens global steel sector – thestar.com. 18/4/2020.
[28] Vi spiego la guerra sanitaria fra Cina e Usa. L'analisi di Jean – startmag.it. 29/3/2020

3. THE FUTURE OF STEEL

Even if the steel industry is going through a period of crisis, the industry of automotive in changing radically and will be completely different if few years.

In particular, the shift from combustion engine to electric one is inevitable, and the previsions show that by 2025 will cover a quarter of new registrations.

This revolution will also involve a change in the steel role on future vehicles.

Some years ago, a common thought was that electric cars, due to the high weight of batteries, should be composed of low-density materials such as aluminium and carbon fibre.

Instead, the improvements made to the battery technology, together with the new types of high strength steels, have made steel the main material again.[29]

a. AHSS (advanced high strength steel)

The new type of steel that will be protagonist of the future is the AHSS: advanced high strength steel.

They are highly resistant, characterized by a tensile strength greater than 500 MPa and by complex multi-phase microstructures containing bainite (an extremely fine mixture of ferrite and cementite), martensite and residual austenite. Among others, TRIP (Transformation induced plasticity) and TWIP (Twinning induced plasticity) steels belong to this category.

1. <u>TRIP</u> are characterized by the fact that their plasticity properties change during the plastic deformation process: compared to the other AHSS steels, in fact they show a further increase in breaking deformation, and therefore in ductility, with the same tensile strength.

   They are characterized by a complex structure, essentially consisting of a ferritic matrix containing at least 5-10% of residual, unprocessed and metastable austenite.

   During the plastic deformation process for forming, this can turn into martensite for plastic deformation (TRIP effect). This results in high values of tensile strength and plastic deformation. In addition to manganese (1.5-2.1%) these steels have unusual silicon contents (1.5-1.7%).

   Both elements increase the stability of the residual austenite, delaying the precipitation of carbides during the bainitic transformation; manganese also promotes the transformation of austenite into martensite by plastic deformation.

   The characteristics of high strength and deformability make TRIP steels suitable for application in the automotive field, especially in components designed to ensure safety conditions.[30]

[29] L'auto elettrica avrà "fame" d'acciaio – meccanicanews.com. 7/3/2019.
[30] Transformation-Induced Plasticity (TRIP) Steel – worldautosteel.org.

2. TWIP: on the other hand, are extremely resistant materials with induced plasticity characterized by a high manganese content (17-24%) and carbon contents up to 0.7%, as well as by a completely austenitic microstructure even at ambient temperature.

   During plastic deformation, a twinning process takes place in the grains, that is, the creation of defects originating from the modification of the overlapping sequence of the planes with greater atomic density, with the formation of two specular crystals with respect to the twinning plane.

   The formation of the geminates determines an effect like that of a refinement of the size of the crystalline grains, hindering the movement of the dislocations with a mechanism such as that of the grain edges.

   TWIP steels are therefore characterized by high values of tensile strength (even higher than 1600 MPa) and ductility (deformation at break can even reach 60%), and also show a high impact toughness, even for very high temperatures low and for high deformation speeds (conditions that for many steels may imply a transition from a ductile type breakage to a brittle type, with a strong reduction of the energy required to break the metal).

   This feature makes TWIP very interesting for many applications, in the transport sector, considering that the high mechanical strengths allow a strong reduction of the resistant sections of the manufactured articles, with consequent lightening of the same. In addition, the high resistance to dynamic stresses allows a net increase in the products' ability to absorb energy during impacts, promoting an increase in safety.[31]

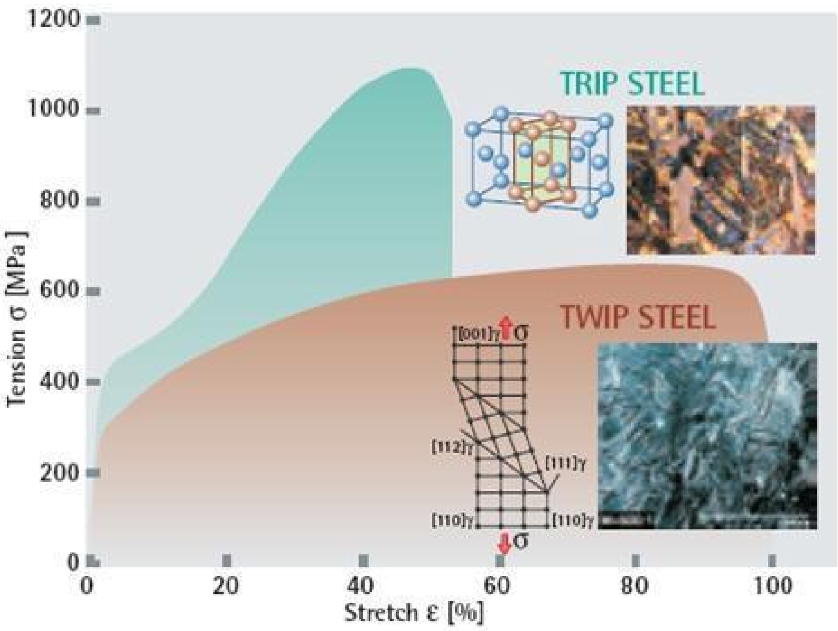

Figure 9: σ-ε diagram of the trip and twip steels with details of the lattice composition attached

[31] Multi phse Twinning-Induced Plasticity (TWIP) Steel – totalmateria.com.

b. Near Net Shape Strip Casting

Near Net Shape Casting is an industrial production technique. The name implies that the initial production of the element is very close to the final shape, reducing the need for surface finishes.

Reducing the traditional finish, such as hot rolling, eliminates more than two thirds of manufacturing costs in some industries.

The steel industry is very interested in the development of these techniques. Near Net Shape Strip Casting steels have very important characteristics: compact size, low energy and production costs and lower CO2 carbon dioxide emissions.

The sheets produced with reduced thickness have dimensions very similar to those requested by the buyers (e.g. automotive sector), as they need very little subsequent processing.[32]

For these reasons, many studies are working on designing systems capable of guaranteeing Near Net Shape Casting.
The two most advanced studies are:

1. Twin roll casting (TRC):

the original idea was to pour molten steel between two water-cooled rollers that "squeezed" the metal to make it a sheet.

There are several prototypes using a "twin roll" process, the most important are:

<u>Castrip</u>: is already employed by the Nucor company (large American steel plant). Started in the 80s and survived the commercialization, it is chosen as an example to demonstrate the various, important, characteristics of a TRC system.

<u>Mainstrip</u>: conceived by the Swiss company MTAG Marti-Technologie AG, it has brought many new features to simplify and potentially improve the TRC process.[33]

2. Horizontal Single belt casting (HSBC):

More recent method, still in the testing phase, has not yet been commercialized. It consists of printing liquid steel directly on a single horizontal mobile belt.

Salzgitter, a German steel producer, opened the first single belt casting commercial plant in Peine (near Hanover) in 2012. He began by producing structural steel and then progressed by making more special steels. This plant is used to produce AHSS. The whole process extends for 60m, 11 of which are used for molding. The ladle has a capacity of 80 tons and produces 1m wide slabs with an average of 30m / min.

[32] Near-Net-Shape Casting – Washington State university.
[33] The Economist, p.63. 11/3/2017.

Roderick Guthrie of McGill University in Canada, one of the pioneers of technology, is working with several companies, including a large car maker, on the development of the project.

While twin-roll is constrained by practical limitations, such as the size of the rollers, the single-belt has less (says Guthrie).34

i. Twin-Roll Casting (TRC)

Machines layout:

CASTRIP: the process is divided in three phases.

1. The conventional 110-ton ladle is supported by an overhead crane. During casting, the molten metal contained in the ladle is made to flow through a nozzle into a waste container and immediately after, through a protection tube, into a molten steel distributor. The distributor is a large box made of refractory material (such as magnesium oxide) and has a series of longitudinal openings on its lower part that allow the molten metal to flow into the dispensing nozzle located below. The dispensing nozzle is also made of refractory material (such as alumina graphite) and has an elongated conical shape that allows to direct the flow of molten metal between the rollers to form the first foil.

2. After passing the rollers, the sheet enters a controlled atmosphere chamber located below. This chamber has an oxygen content of less than 100 ppm and is filled with a non-oxidizing gas (e.g. 99.99% nitrogen or argon), alternatively the atmosphere of the chamber is weakly reduced (e.g. nitrogen with 2/10% hydrogen) . These changes in the atmosphere serve to prevent surface oxidation of the steel plates (passing at a temperature of 1300/1400 ° C). In addition to the chemical composition, the temperature is also kept under control: between 950 ° C and 1200 ° C, suitable for steel flow.

3. After eaving the controlled atmosphere chamber, the sheet passes through a series of hot rolling processes and typically reduces its thickness by 10/15%. Subsequently the hot foil passes to a cooling table where it is quickly cooled by a spray of water. After cooling the sheet is rolled up by winders.

[34] The Economist, p.63. 11/3/2017.

The final thickness of the slab is typically 0.9 / 1.5mm.

The rollers used by the CASTRIP process are approximately 500mm in diameter and 2,000mm in length, so the steel plates can extend for 2m. The rotation speed of the rollers is 60/100 m / s, the discussion will be resumed later.

The cooling of the rollers is done internally with a series of internal longitudinal ducts through which water passes.[35]

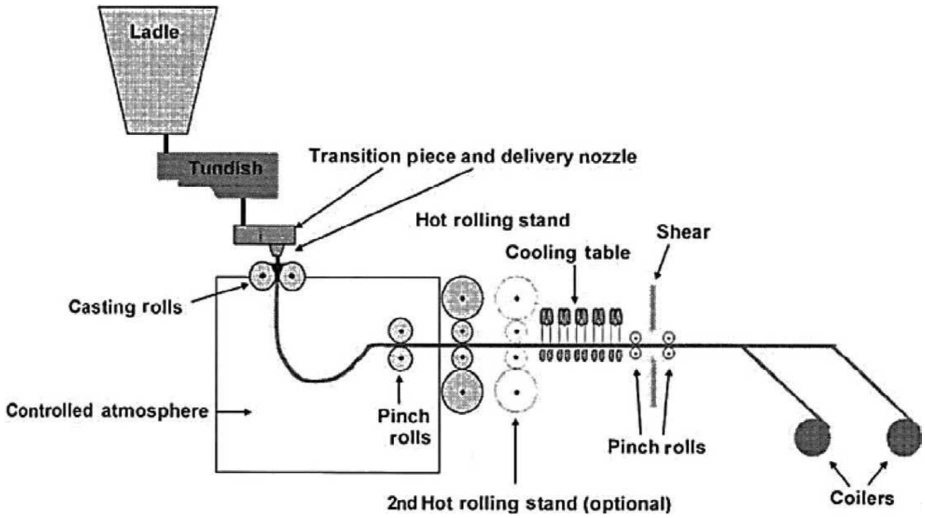

Figure 10: CASTRIP process outline

MAINSTRIP: Use a mobile drive system. It allows the two rollers to work on a single mobile unit, to make the maintenance of the rollers quicker and easier. It is also possible to adjust the distance between the rollers without having to physically detach them from the assembly.[36]

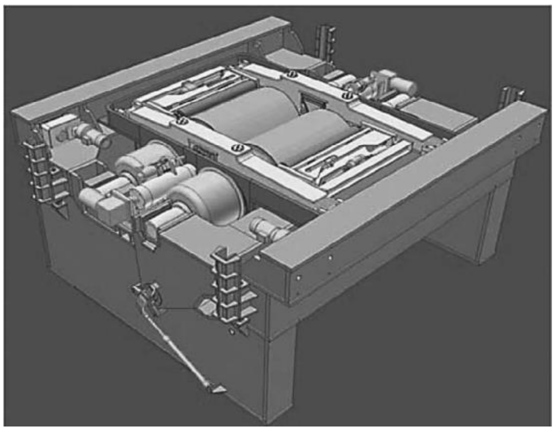

Figure 11: a diagram of the MAINSTRIP "moving head"

[35] Progress in Strip Casting Technologies for Steel; technical Developments – Sa GE, Mihaiela ISAC and Roderick Ian Lawrence GUTHRIE. 19/2/2013.
[36] Ivi.

Microstructure and mechanical properties:

In terms of the chemical composition of steel, it has been observed that the control of Mn and Si within certain limits (Mn> 0.55% and 0.15% <Si <0.35%) makes it possible to cast plates of more than 60m / min without incurring substantial defects.

This composition was chosen to ensure the oxidation products (MnO and SiO2) remain liquid during the casting, to avoid "clogging" and increase the degree of surface heat exchange.

There is an inverse correlation between the degree of heat reduction and the size of the austenite grains, therefore of resistance.

In addition, the combined effect of the degree of heat reduction and the degree of cooling (the spray of water after hot rolling) plays an important role in determining the strength of the steel sheets:

- For small heat reductions (less than 15%):
    1. rapid cooling determines the prevalence of acicular ferrite with a yield strength of 340/410 MPa;
    2. slower cooling determines a mix between acicular ferrite and intergranular columnar ferrite with yield strength of 275/340 MPa.
- For more heat reductions (more than 25%):
    1. Rapid cooling determines the presence of grains of intergranular acicular ferrite and ferrite at the edges with yield strength of 310/380 MPa;
    2. Slower cooling determines the presence of equiaxial ferrite with a yield strength of 240/310 MPa.

To increase the strength of steel, binders' materials are also used:

• By increasing the Mn content (from 0.6% to 0.8%) there is an increase of 35/70 MPa in the yield strength.

• Adding the Niobium (Nb) to about 0.084% (with: 0.03% C, 0.85% Mn and 0.2% Si) there is a 20/30% increase in the yield strength. This increase is since with the introduction of Nb there is the promotion of benite and acicular ferrite during the austenitic transformation and the formation of Nb-N clusters.

In TSC, the steel used must not contain more than 0.15% Cu and 0.015% of Sn, in order to avoid the formation of surface cracks. This threshold can be increased by 3.5 and 10 with 0.55% of Cu and 0.16% of Sn, in the case of TRC.[37]

[37] Progress in Strip Casting Technologies for Steel; technical Developments – Sa GE, Mihaiela ISAC and Roderick Ian Lawrence GUTHRIE. 19/2/2013.

Defects

During the TRC three types of surface defects can occur: the "chatter", the "" crocodile-skin "and non-metallic inclusions due to cooling.[38]

<u>Chatters</u>: the defect occurs in the meniscus, the starting point of solidification. It depends on the rotation speed of the rollers.

- Low speeds: premature cooling occurs in the upper meniscus; a weak superficial shell is formed and deforms as it continues.
- High speeds: the protective shell forms "too late", there is an accumulation of liquid above the shell. The liquid that arrives at the meniscus is unable to keep up with the rotation of the rollers and therefore there is a slip between the liquid metal and the roller at the meniscus, this leads to the phenomenon of the beam.[39]

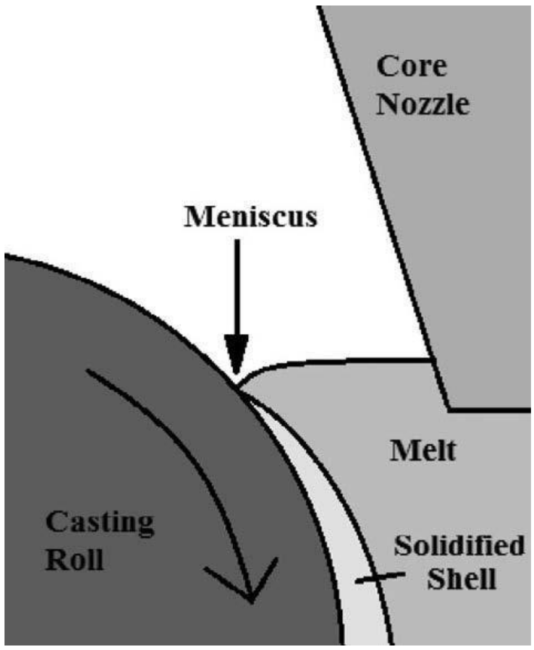

Figure 12 Detection of the meniscus during the process

[38] Progress in Strip Casting Technologies for Steel; technical Developments – Sa GE, Mihaiela ISAC and Roderick Ian Lawrence GUTHRIE. 19/2/2013.

[39] Personal notes of "tecnologia dei materiali metallici" by prof. Giorgio Scavino. From academic year 2015/2016.

Crocodile skin: the defect occurs during the solidification phase, when the Feδ (austenite) and Feγ (ferrite) phases solidify simultaneously, causing localized heat flows. The two phases have different characteristics of heat resistance therefore the flux variations cause distortions localized in the solidification shell.

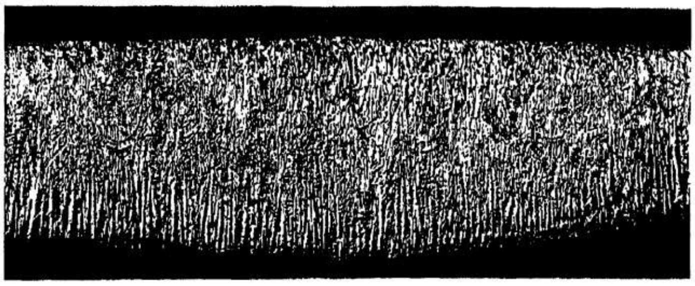

Figure 13 impression of an x-ray plate of a steel which has the defect of the crocodile skin

Non-metallic inclusions: occur in the sheet coming out of the rollers. Given the high degree of cooling, especially the meniscus (heat flow around 23 MW / m2), the steel sheet has a high susceptibility to the formation of cracks caused by stress in the surface shell. They cause internal defects such as porosity and cracks formed in the middle of the columnar and equiassic structures of steel.

The size of these inclusions is typically 0.5 / 5µm. The TRC, having a lower degree of rolling of the rollers (compared to conventional processes), and has not very elongated and elliptical inclusions in the direction of the rollers.[40]

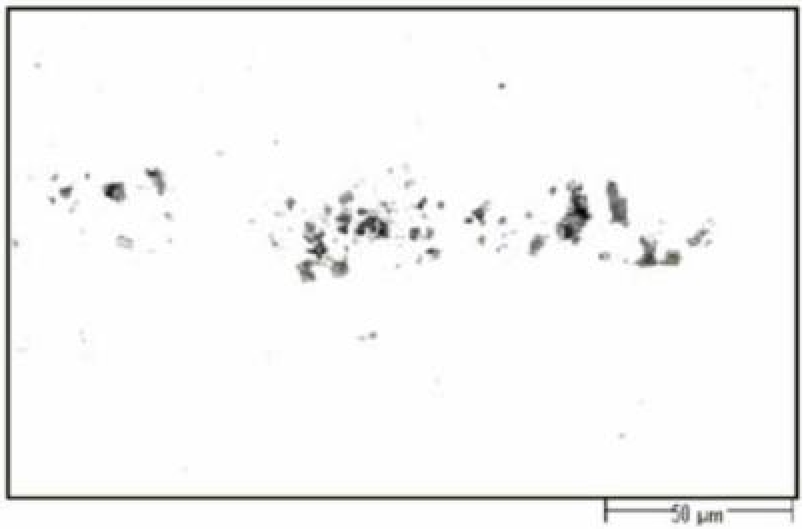

Figure 14 Micrograph of non-metallic inclusions in a steel strip

[40] Personal notes of "tecnologia dei materiali metallici" by prof. Giorgio Scavino. From academic year 2015/2016.

How to avoid defects

A small oxide deposit with a lower melting point of the metal is placed on the rollers, it ensures a more uniform heat flow during solidification.

During casting, the oxide layer melts when the molten steel reaches the meniscus.

A thin liquid layer of interface is created between the surface of the rollers and the steel that is cooling, this liquid intensifies the heat flows by uniforming them.

Despite this, an excessive amount of oxide is harmful as the oxide can re-solidify and, given its high thickness, does not melt anymore thus decreasing heat flows.

This problem can be avoided with a uniform and periodic cleaning of the rollers to keep the oxide thickness within certain limits (usefulness of the MAINSTRIP method).

Other methods of preventing defects are given by the surface texture of the rollers: experimental research by McGill University has revealed that surface roughness has an instantaneous effect on the degrees of heat transmission during casting:

- Sandblasting on the roller surfaces: The desired surface is obtained by sandblasting and subsequently applying a protective layer (eg: copper) or just sandblasting.

  The peaks of the discrete projections formed by sandblasting have an area of 100/400 µm2 and a distribution of 5/200 peaks / mm2.

- Chemical electrodeposition: a layer is deposited on another substrate using chemicals.

  Two suitable binders have been found: HASTALLOY C (Ni, Cr and Mo) and T800 (Ni, Mo and Co).[41]

[41] Progress in Strip Casting Technologies for Steel; technical Developments – Sa GE, Mihaiela ISAC and Roderick Ian Lawrence GUTHRIE. 19/2/2013.

ii. Horizontal single-belt casting (HSBC)

Machine layout

HSBC was conceived in 1988 by Professor Guthrie. Unlike TRC, it is a technology not yet on the market.

Therefore, the following characteristics are, for the moment, applied on pilot plants and may require some modifications before they are fully marketed.

At the McGill Metal Processing Center, in development since 1999, there is a pilot plant with an induction furnace of 600lb.

The plant consists of three main areas:

1. Zone used only for melting: the metal is melted and tied in a furnace.
2. Primary cooling zone: the furnace is physically transported.

   Here the molten steel is directed into special distribution tanks, made of refractory material, thanks to a piston that regulates the flow out of the furnace.

   The tanks act as a means of transporting the spindle in mobile steel belts. Subsequently the steel solidifies in the form of sheets having a thickness of 6/20 mm.
3. Homogenisation zone: after primary cooling, the substantially solidified slab passes into the homogenisation zone.

   It is an area with a controlled atmosphere for temperature control and relieving voltages.

   It consists of a thermally insulated round table; the plate maintains the same temperature. Leaving this area, the slab has a thickness of 1 / 10mm.

The final line of the process typically consists of three lamination rollers and, subsequently, another cooling zone where the sheet is cooled enough to start winding.

The distribution tank is divided into three parts:

1. Entrance chamber: A slag barrier is placed before the entrance chamber so that any incoming slag can be removed.
2. Control chamber: the liquid metal passes a dam before entering the control tank to reduce turbulent movements.

3. Exit chamber: the exit chamber is connected to the belt by means of a nozzle, the characteristics of the nozzle are still in the planning stage as it must be considered: spindle stability, uniformity of casting, clogging of the nozzle, maximum passage speed etc.

The whole system is previously heated by a resistive network. The induction furnace containing the molten metal heats the system, while it is positioned in the molding area.[42]

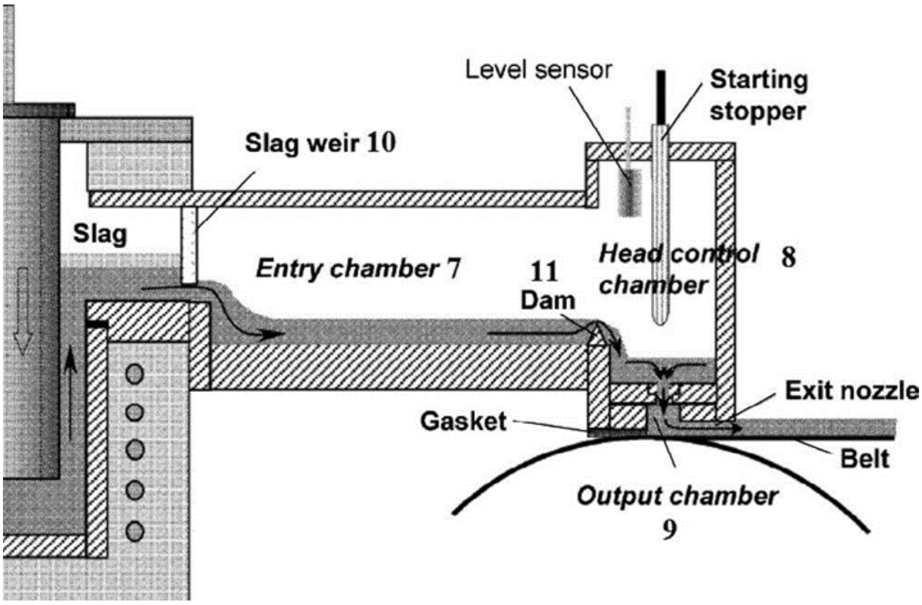

Figure 15 process outline

The figure shows a scheme of the whole: on the left there is the regulating piston that allows the spindle to enter the distribution tank while, on the right, the distribution tank.

42 Progress in Strip Casting Technologies for Steel; technical Developments – Sa GE, Mihaiela ISAC and Roderick Ian Lawrence GUTHRIE. 19/2/2013.

Characteristics of the belt:

- It is made of steel; a layer of graphite can be applied on the surface of the belt which is cooled by water below.
- It is supported by magnetic support cylinders near the initial contact area between the molten metal and the belt.

  This measure eliminates belt oscillations (bulging).
- It is kept in a controlled atmosphere with a pressure of about 0.7 atm, to reduce distortions.

  Instead, the molten metal on the belt is protected by an inert gas that prevents the formation of oxides.
- The edge of the belt is cooled to compensate for the internal expansion.
- The surface texture of the belt plays an important role about the transmission of heat and the quality of solidification.

  It has been shown that a 5/10-fold increase in surface heat exchange can be achieved by reducing roughness peaks from 40μm to 4.5μm.[43]

Lateral containment system:

The lateral containment system is required to prevent the spindle from dripping on the sides of the belt.

The McGill-Hazelett system consists in the addition of two lateral dams, which move together with the belt, in which refractory segments enter which tend to come out from the edges.

Supports are installed, suitable to ensure the stability of the dams.

McGill's experiments show that the lateral containment system is necessary for slabs of thickness equal to 3-8 mm. For slabs with a thickness greater than 7mm, however, the lateral dam was not necessary.[44]

Slab uniformity in width:

During advancement, it is important to keep the distribution of molten steel uniform over the width of the belt, to ensure uniformity of the thickness of the sheet.

This was made possible by using a series of transversely distributed jets of Argon gas having the opposite direction to the casting.

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[43] Progress in Strip Casting Technologies for Steel; technical Developments – Sa GE, Mihaiela ISAC and Roderick Ian Lawrence GUTHRIE. 19/2/2013.

[44] “”

Figure 16 lateral containing system of McGill-Hazelett's system

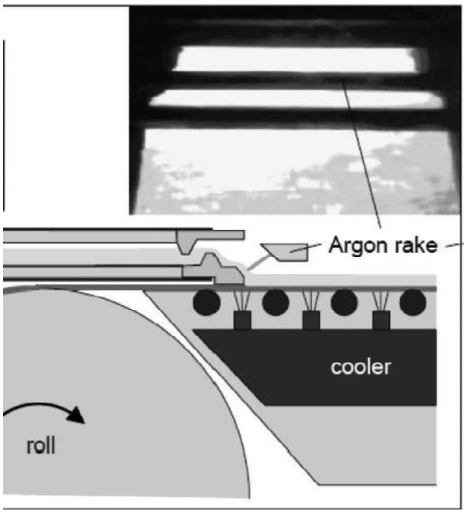

Figure 17 detail that highlights the atmosphere of argon

The relative speed of the steel with respect to the belt must be minimized to ensure uniform solidification.

In order to do this, a powerful magnetic field is used which moves synchronously with the belt. It is generated by a linear inductor called the Electromagnetic Flow Synchronization System (EFSS), installed behind the Argon jets.

Furthermore, when the molten metal meets the belt, it is possible to develop swellings (caused by high heat exchange) and the subsequent non-uniform expansion of the belt. To prevent this, it is possible to:

- Insert strong neodymium magnets that hold the belt down.
- Pretension the belt which will meet the spindle by cooling the edges.[45]

[45] Progress in Strip Casting Technologies for Steel; technical Developments – Sa GE, Mihaiela ISAC and Roderick Ian Lawrence GUTHRIE. 19/2/2013.

Defects

The solidification of the molten steel during primary cooling takes place in a protective argon atmosphere to prevent oxidation from compromising the surface quality of the slabs.

However, in an atmosphere of pure argon, the melt has low emissions. As a result, heat removal and solidification are prevalent on the side of the belt, therefore porosities will occur in the central part.

This unwanted effect can be avoided by adding percentages of CO2 together with argon. CO2 slightly decarburises the top layer of the sheet by raising its cooling temperature.

The resulting liquid leads to heterogeneous nucleation of a thin layer of surface steel.

This thin layer increases the surface emissivity of the sheet, in this way the degree of solidification of the surface increases over the entire width of the sheet. So, there are less micro-porosities that will be sealed during subsequent hot laminations.

The HSBC system used for the TU Clausthal is designed so that pure argon is first applied. CO2 is only mixed after the surface calms down.[46]

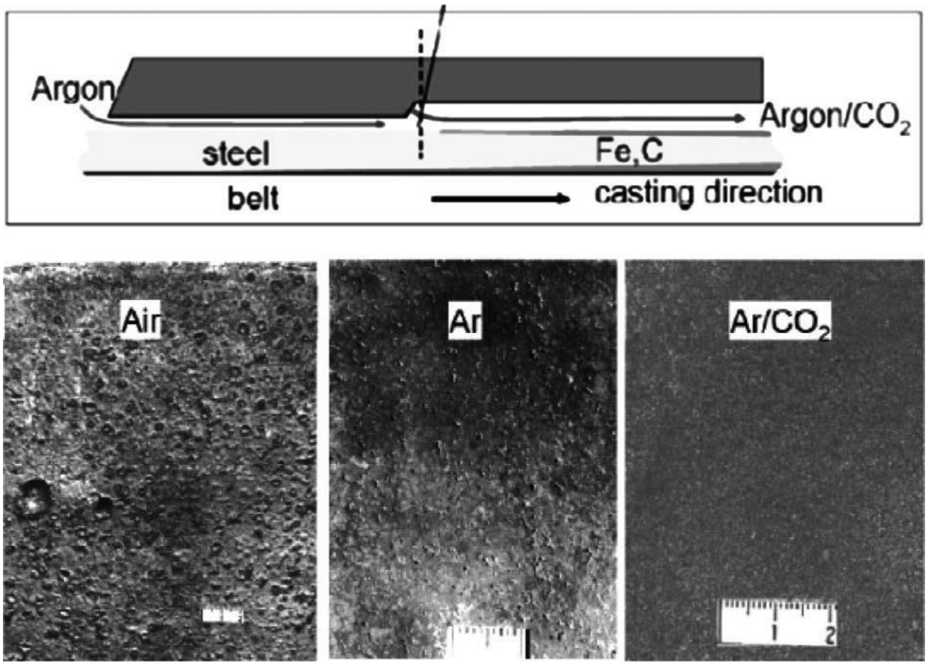

Figure 18 comparison of the surface quality in different protective atmospheres

[46] Progress in Strip Casting Technologies for Steel; technical Developments – Sa GE, Mihaiela ISAC and Roderick Ian Lawrence GUTHRIE. 19/2/2013.

c. Characteristic and advantages of strip casting

i. Simplification of the molding process:

One of the most important innovations of strip casting technology is the drastic simplification of process operations.

Below is a comparison of sheet metal molding technologies: continuous casting system (CCC), Thin-slab casting (TSC), Twin roll casting (TRC) and Horizontal single belt casting (HSBC).[47]

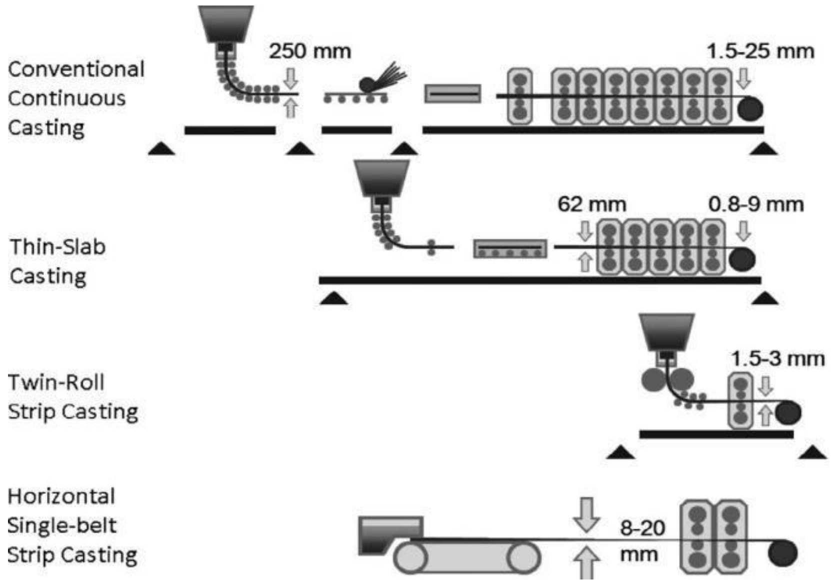

Figure 19 comparison between processes outline.

Process variable	CCC	TSC	TRC	HSBC
Product thickness (mm)	150 – 300	20 – 60	0.7 – 5	5 – 20
Total solidification time (s)	600 – 1 100	40 – 60	0.15 – <1.0	~6
Casting speed (m/min)	1.0 – 2.5	4 – 6	30 – 150	12 – 60
Avg. mould heat flux (MW/m^2)	1 – 3	2 – 3	6 – 15	~ 11 – 13*
Weight of melt in caster (kg)	> 5 000	~ 900	< 400	~ 120
Avg. shell cooling rate (°C/s)	~ 12	~ 50	~ 1 700	400 – 500
Scale loss (kg/m^2)	–	7.8	< 0.2	–
Plant capacity (Mt/yr)	4 – 10	2	0.4 – 0.6	Up to 3

Figure 20 comparison between different results of the main molding technologies.

[47] Progress in Strip Casting Technologies for Steel; technical Developments – Sa GE, Mihaiela ISAC and Roderick Ian Lawrence GUTHRIE. 19/2/2013.

ii. Economic benefits

Strip casting allows the production of thin sheets from the melt and eliminates most of the hot rolling after stamping.

This decrease in processes reduces capital investment by four to ten times. An estimate has been made that reports a 40% decrease in costs for each ton of steel compared to conventional methods.

The Eurostrip company has declared a 68% reduction in capital investments and a 40% reduction on used spaces, compared to TSC.[48]

The trend of investment costs compared to the annual capacity produced by the plant for known molding technologies is shown below.

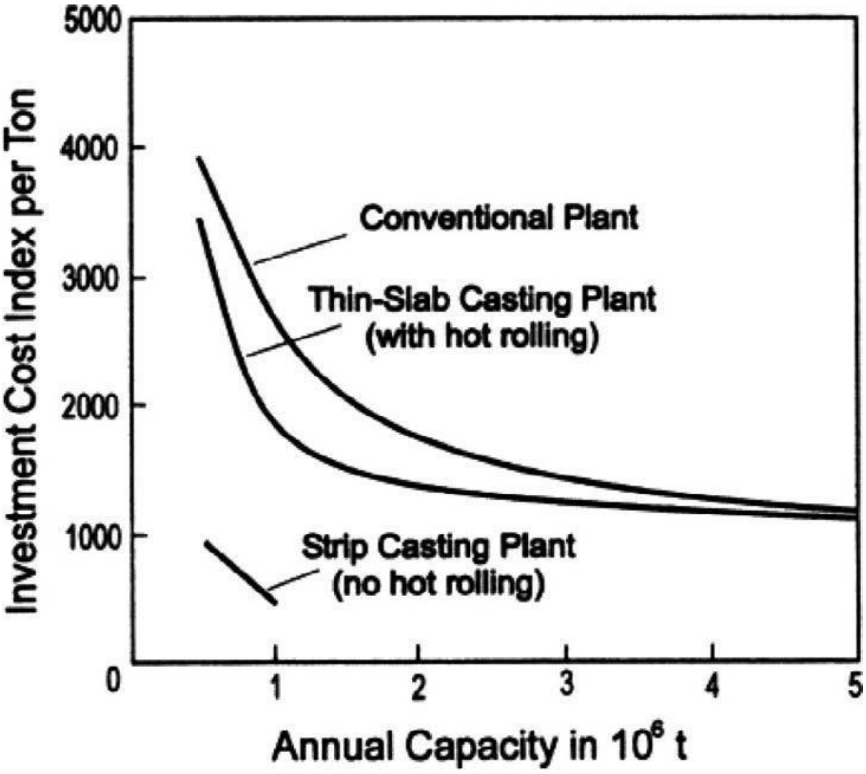

Figure 21 Trend of investemts cost compared to the annual capacity.

[48] Toshiaki MIZOGUCHanId & Ken-ichi MIYAZAWA: "Formation of 18Cr of 8Ni Solidification Structure Stainless Steel in Twin Roll Casting Process" (1995);

iii. Environment impact

In addition to the economic advantages, strip casting offers the steel industries a great reduction of energy for each ton of steel produced with a consequent decrease in emissions and environmental impact.

It is important to note that although energy savings are significant, its contribution to overall cost savings is modest since energy costs are only a small part of the operating cost.

Studies have estimated that Strip Casting plants are able to reduce energy consumption by up to 90% and greenhouse gas emissions by 80% compared to CCC.

CASTRIP reports that overall the energy consumption was 81-89% lower, compared to a traditional process, and that greenhouse gas emissions were reduced by 71-80%.

As for the HSBC process, due to the need for a greater degree of hot rolling, the possible energy savings are somewhat lower, by about 75% compared to the CCC. However, since the HSBC process has yet to be industrialized, it is reasonable to think that consumption and emissions may decrease further in the future, at a level comparable to TRC technology.

An aspect that influences energy consumption is identified in the fact that recycled steel from electric arc furnaces (EAF) can be used instead of virgin steel made using the classic oxygen-based furnace (BOF). In fact, EAF steel production consumes 60% less energy than BOF steel (7.5 GJ vs 19.2 GJ per tonne).[49]

In addition, Strip Casting products have a higher area-volume ratio due to their reduced thickness. This allows a more efficient heat transfer to the environment, which therefore makes cooling / heating faster. This allows the mold to be re-heated if necessary, reducing energy consumption and processing time.

Although the current environmental and energy benefits are not proportional to the economic benefits, with oil prices rising and widespread implementation of the increase in coal taxes worldwide, it is believed that the potential cost savings will further improve.

For example, in Canada (in July 2012), the British Columbia carbon dioxide emissions tax on industries was increased by $ 30 per tonne of CO2 produced.

The ability to reduce emissions in strip casting (calculated using data from CASTRIP) is 0.16 tons of CO2 per ton of steel compared to the CCC process, which would result in approximately $ 5 savings per ton of steel.[50]

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[49] Progress in Strip Casting Technologies for Steel; technical Developments – Sa GE, Mihaiela ISAC and Roderick Ian Lawrence GUTHRIE. 19/2/2013.

[50] Ivi.

Conclusions

Based on the topics covered in the thesis we can understand that the steel sector is in crisis.

This is really an issue because steel, as one of the most consumed material, anticipates the market tendencies of all the other goods.

The trade conflicts between China and USA, probably will not have an end until the American presidential election in November 2020 and European's nationalist governments struggle to collaborate with each other to find new solutions.

The political crisis can only be overcome by scientific innovation.

So, innovation is no more an option but is a necessity for the whole system.

The new technologies analysed in the thesis underline that strip casting will be extensively implemented globally in the coming decades, revolutionising the way steel strips are made, and delivering significant saving for the global steel industry.

Lastly, our hope is that the steel industry of the future must be based on sustainability and innovation, achievable by integrating quality rigor, attention to organization and economic logic with wisdom, courage and creativity of the human being.

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