2014 EAF Study Tour — BRAZIL

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Mike Strelbisky (right) presented a plaque of appreciation to Marcos Stuart (left), chief technology officer, CBMM.

The AIST Electric Steelmaking Technology Committee (ESTC) conducted its second international study tour on 15–22 November 2014. Fourteen delegates from North and South America visited three steelmaking facilities and one mining/refining operation. Unique electric arc furnace operations along with a combined BOF and EAF plant operation were toured, as well as the largest niobium mine reserve in the world.


AIST Brazil EAF study tour group.

EAF Brazilian Study Tour Trip Report

One of the main purposes of AIST, in my opinion, is to bring suppliers and producers together and promote the advancement of the steel industry through networking, teamwork and partnerships. When attending AIST functions, such as training seminars, Technology Committee meetings and AISTech, the partnership between all the different represented groups can always be felt.

This study tour was no exception — the attendees were a dynamic group of individuals that forged newfound friendships through our networking experiences. The group included representatives from three steel companies and six suppliers for a total of 14 participants.

The networking extended well beyond the group of producers and suppliers that made the trip for the tour to also include individuals from the facilities visited. This can be seen in the dialogue that has already been exchanged between producers, suppliers and tour facilities since we have returned home. For example, Steel Dynamics Inc. (SDI) has received several emails from various facilities visited discussing operational practices and equipment parameters.

On Monday, 17 November 2014, the study tour made its first plant visit at Vallourec & Sumitomo Tubos do Brazil (VSB) in Jeceaba, MG, Brazil. VSB is a relatively new facility (commissioned in 2011) and was founded jointly by the French group Vallourec and the Japanese Nippon Steel & Sumitomo Metal Corp. (NSSMC). VSB employs a large team in excess of 2,500 employees and has less than a 1% annual turnover rate. The mill currently is capable of producing 1 million metric tons per year (MMTPY).


Vallourec & Sumitomo Tubos do Brazil in Jeceaba, MG, Brazil.

During the visit, VSB emphasized the importance of its "integrated management policy" as follows:

- Promote health and safety on the job.
- Prevent accidents and occupational diseases.
- Tend to its customers by providing products that meet their expectations.
- Respect and preserve the environment and prevent pollution.
- Practice a social accountability management.
- Minimize risks.
- Optimize costs.
- Comply with legislation and applicable standards.
- Provide necessary resources for the accomplishment of those commitments and the development of the integrated management system (IMS).

VSB operates one blast furnace, a Consteel EAF, ladle furnace, a twin-tank vacuum degasser, a 5-strand round billet caster and a bar finishing line. VSB was originally designed for two blast furnaces, but has constructed only the first one so far. The hot metal is produced at 70 MT/hour and is subsequently tapped and transferred in ladles to the Consteel EAF, where it is then poured into the furnace using a hydraulically tilted ladle hot metal pourer that feeds the hot metal into the furnace at the 5 o'clock position (slag door being 6 o'clock and eccentric bottom tapping (EBT) being 12 o'clock). Hot metal is poured into the furnace at a gradual and variable rate (roughly 3 MT/minute) over a 15-minute period.

Scrap enters the 200-MT-capacity Consteel furnace at the 9 o'clock position and is melted via a 70-MVA AC (alternating current) transformer operating at a secondary voltage of 450–550 and an average current of 47 kA. The scrap and hot metal are stirred inside the furnace by four argon porous plugs located in the hearth bottom. The furnace also uses four oxygen lances, two carbon lances, and one lime lance to make further energy and foamy slag alterations to the heat. A 140-MT heat is tapped through the EBT, leaving a 60-MT hot heel. The furnace operates with a relatively high basicity foamy slag with a V-ratio of 3.2 and a B3-ratio of 2.5.

Table 1 illustrates the two charging methods employed by VSB: with and without hot metal. There are some large operational differences between the two charging methods. The major net operational savings provided by the hot metal is a decrease in electrical energy of 129.6 kWh/MT (31.6% decrease), a time savings of 13.2 minutes (22.4% decrease) and an injection carbon savings of 3.5 kg/MT (43.8% decrease). Although there are several benefits, more oxygen is required for the hot metal charge, to the tune of 7.8 Nm^3/MT (29.3% increase).

The ladle metallurgy furnace (LMF) is a single station that operates with two ladle cars for quicker heat exchanges. The LMF uses a 26-MVA transformer for controlling temperature and uses argon porous plug bubbling to homogenize the heats. Heats are alloyed through bulk, hand and wire additions up to 5% of

VSB Consteel EAF Charge and Results

Meltshop key performance indicators	Without hot metal	With hot metal
Scrap charged (%)	62	50
Merchant pig iron (%)	38	13
Hot metal (%)	0	37
Oxygen (Nm^3/MT)	26.6	34.4
Energy (kWh/MT)	409.8	280.2
Power-on time (minutes)	58.8	45.6
Carbon injection (kg/MT)	8	4.5
Tap carbon (%)	0.1	
Tap temperature (°C/F)	1,640/2,984	

the weight of the heat, depending on the grade being produced.

VSB also processes heats through a VD (twin-tank vacuum degassing) system that utilizes mechanical pumps to draw a vacuum. Wire additions and argon stirring are both used in the treating and alloying of the heats. The goals of the VD are to lower the total dissolved gas content of the steel (hydrogen, nitrogen and oxygen), set superheat for the caster and perform inclusion modifications.

VSB operates a 5-strand billet caster capable of producing rounds in three sizes: 270, 310 and 406 mm. The billets are stored in a billet yard on-site. Roughly 60% of the billets are processed on-site through the finishing mill, and the remaining billets are sold. The finishing mill cuts and reheats the billets for piecing into seamless tube/pipe.

Figure 1 illustrates the equipment and process paths discussed at VSB.

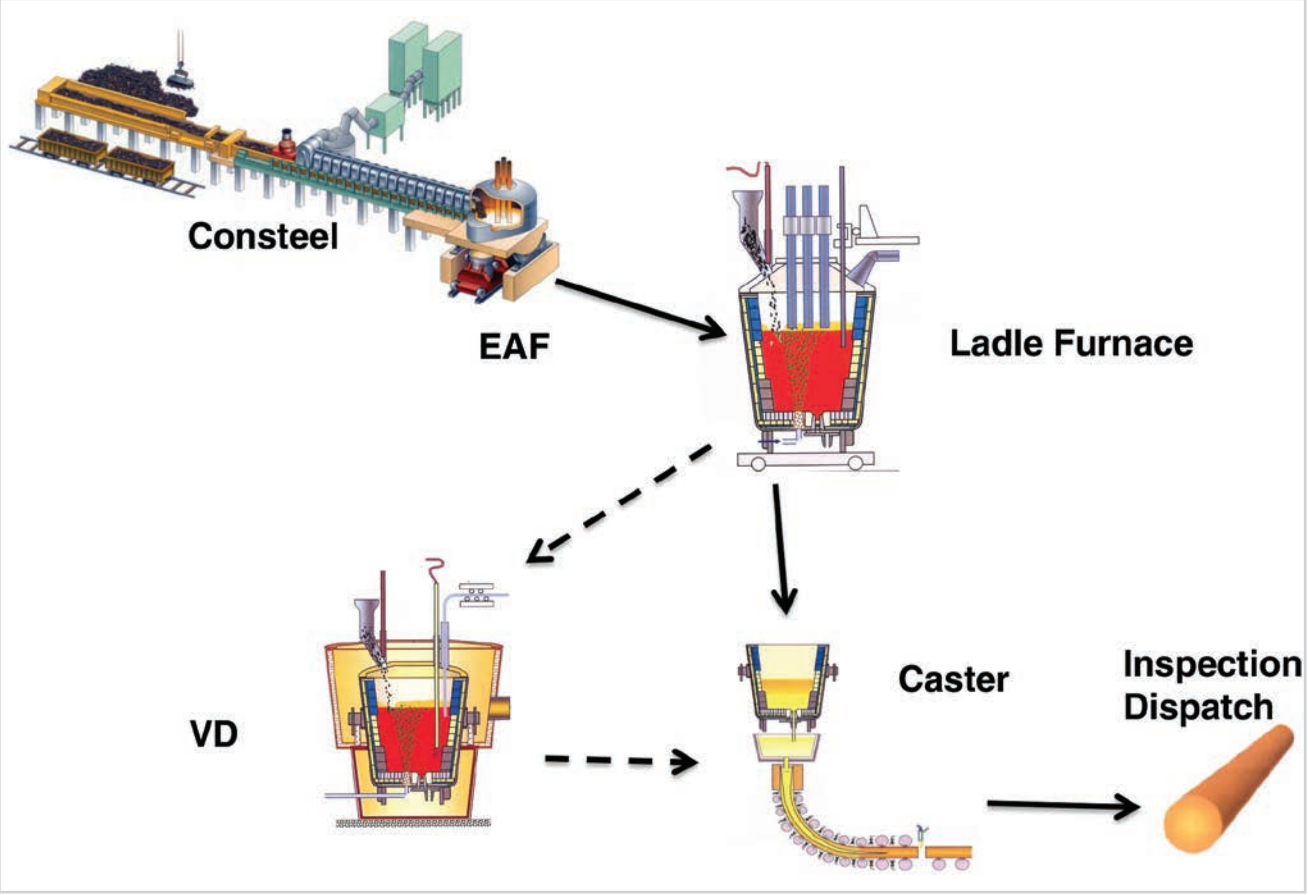


Figure 1: VSB hot side processing equipment.

AIST Brazil EAF study group at VSB.

The study tour group visited Companhia Brasileira de Metalurgia e Mineração (CBMM) on the second day of the tour. CBMM is located just outside of Araxá. Minas Gerais, Brazil, and is a privately held Brazilian company founded in 1955. CBMM retains roughly 80% of the world's niobium market and is the only supplier present in all of the niobium market segments.

Ferroniobium, which CBMM produces, is used in the steel industry primarily as a grain-refining, microalloying element. When added to steel, niobium combines with carbon and nitrogen to form niobium carbide and niobium nitrides. The grain-refining characteristics of niobium hinders recrystallization and improves precipitation hardening of steels. Microalloyed steel grades that utilize niobium can be found in steel used to generate pipe, car bodies and structural steels.

CBMM currently produces 70,000 metric tons per year (MTPY), with the estimated capacity to produce 90,000 MTPY if the market required it. The company also maintains a large inventory (40,000 MT) around the world to meet fluctuating customer demand in a timely manner. It is estimated that the current world market demand for niobium is between 80,000 and 90,000 MT, so the inventory carried by CBMM could supply the world's demand for almost six months if there were ever any supply chain hiccups.

CBMM is a technology company that produces and markets niobium through mining and refining processes with a team of nearly 2,000 employees.

Niobium is generally found as ore with tantalum and takes some form of $Nb_2O_5 + Ta_2O_5$, but there are also usually trace amounts of thorium (ThO_2) and uranium (U_3O_8) along with the deposits. The slightly higher-than-background radiation at a mine is how the niobium deposit was discovered. Geologists were searching for uranium deposits and found the niobium deposit. At the time of the discovery, niobium was not used or valued as it is today, and the mine was developed later as uses for the microalloying element grew.

The area from which CBMM mines its ore is an underground volcanic deposit that is roughly 5 miles in diameter and has already been excavated as deep as a half-mile. There is an abundance of niobium, with nearly 300 known ore deposits worldwide, but the fact that only four of them are actively mined makes the alloy a prized commodity. According to CBMM, the secret is not sourcing the ore itself, but the methods used to mine, concentrate, refine and process that generate high barriers of entry for would-be competitors.

CBMM processes 750 MT of ore per hour through the concentration processes. The ore ranges in

CBMM mine and processing facility.

niobium concentrations across the mine from 1 to 5%. Through planned mining and ore mixing prior to processing, the average level of Nb_2O_5 contained within the ore entering the concentrating facility is 3.5%. CBMM use a ball-grinding mill as a first processing step to prepare the ore for downstream processing. CBMM then employs a water flotation separation practice, where the Nb_2O_5 literally sticks to air bubbles passing through the agitated water ore slurry. The bubbles and Nb_2O_5 passengers float to the top of the tank, where they are skimmed off the surface, and this process is repeated multiple times, concentrating the level of Nb_2O_5 each time.

EAF Study Tour Tree — CBMM plants a tree for every visitor to their plant.

After the water concentration has reached its maximum potential, the ore slurry is transferred to a balling facility. In this facility, the concentrated ore is mixed with binders and fluxes before entering a rotary balling mill. The pellets are then loaded into a sintering furnace, where they are dried and ready to be charged as a raw material into the EAF.

The EAF melts the charged Nb_2O_5 pellets as one of the final refining processes. Aluminum is added into the furnace to cause an exothermic aluminothermic reduction reaction, converting Nb_2O_5 into Nb, by the following reaction:

$$Nb_2O_{5(s)} + \frac{10}{3}Al_{(s,l)} = 2Nb_{(s)} + \frac{5}{3}Al_2O_{3(s)}$$

(Eq. 1)

The slag generated in the furnace due to the aluminothermic reduction method used is primarily Al_2O_3, which is not reused in their process. When the melting and reduction steps have concluded, the furnace is tapped out a runner block into 5-ton pots. These pots are on a rail system that pulls them under the tap stream as the furnace is drained. The heat observed during tapping filled three pots.

Then, the niobium is converted into specific product types, such as ferroniobium, various niobium oxides, vacuum-grade alloys and pure niobium metal. Finally, the material is packaged to customer specifications, stored and shipped to the end user.

Every new tree planted is accompanied with a plaque of recognition.

The third facility visited by the study tour was Villares Metals Brazil, which has been producing steel for more than 60 years and is located in Jardim Volobueff (Nova Veneza), Sumaré, São Paulo, Brazil. Villares is also the largest non-flat high-alloy steel producer in Latin America and follows multiple melting and casting methods to produce its products. In 2010, Villares produced 88,000 MT of final goods, and of that, 59,000 was consumed domestically in Brazil. Villares employs roughly 1,500 team members throughout its organization.

Villares Metals produces steel to enter the following markets:

- High-speed steels.
- Tool steels.
- Stainless steels.
- Valve steels.
- Specialty alloys.
- Forged parts.

Villares melts steel by both conventional EAF processing as well as some more unconventional methods, such as vacuum induction melting (VIM), electroslag remelting (ESR) and vacuum arc remelting (VAR). Two EAFs are operated in independent production cells — cell 1 is the newer of the two furnaces and melts 12 heats per day, whereas cell 2 operates an older furnace and produces eight heats per day.

Cell 1 is a spout-style AC furnace that taps 35–40 MT heats and runs only a 1- to 2-ton hot heel. The furnace operates with an average power of 13.6 MW, max secondary voltage of 531 V and 24 kA max secondary current. The average power-on time for a heat is 90 minutes with a corresponding tap-to-tap time of roughly 145 minutes. The furnace is charged multiple times from an 8-ton-capacity scrap bucket, and the scrap mix is comprised of bundles, bush and plate & structure steels. This furnace also operates with one argon porous plug in the hearth. Cell 1 primarily produces low-alloy steels, engineering steels, high-speed steels and tool steels. Cell 1 accounts for roughly 60% of the steel melted at Villares.

Cell 2 operates similarly to Cell 1, utilizing an AC spout furnace commissioned in 1960. Heats out of this cell are between 25 and 28 MT and are produced at a 3-hour tap-to-tap time. The furnace has an average active power of 9.5 MW, has a max secondary voltage of 490 V, a max secondary current of 23.2 kA and an average power-on time of


The BOF Study Tour visited CBMM in 2011. Pictured is their tree with the following participants (L-R): Ernesto Rheinboldt, Mike Strelbisky, Giyas Mohammed and Steve Jansto.


EAF tapping at Villares Metals.

100 minutes per heat. The only injection point in this furnace is though the door with a manipulated lance. Generally, high-alloy steels are produced out of this cell.

Both cells feed steel to an LMF station that treats and alloys the steel for casting. Both cells also feed a vacuum degassing station that can draw a vacuum down to 2 or 3 mbar. This allows hydrogen levels at the caster to be less than 1 ppm and an average nitrogen level at cast of 60 ppm.

Villares also produces steel for specialty casting through alternative melting practices. It operates two VIM furnaces which use an electrical current field to melt metals under a drawn vacuum environment. They also operate three ESR melting furnaces that use an already-cast ingot as, in essence, an electrode, where it is submerged in molten bath of a specially engineered slag and the ingot is slowly converted to a liquid from contact with the slag and induction heating. The molten metal then sinks to the bottom of the vessel based on a density difference from the slag, where it is then solidified on a water-cooled copper base. VAR melting is a practice where an ingot already formed through a process like VIM is required to act as an electrode much like in the ESR process. A vacuum is drawn and the ingot is lowered within very close proximity to the bottom of the crucible (generally formed out of copper and is water-cooled), which will act as an anode in the melting process. Current is passed from the crucible (anode) to the tip of the ingot, which is consumed and must be continuously lowered to maintain the close proximity to the bottom of the crucible. The metal melted from the ingot in this process can be solidified at a controlled rate in the bottom of the crucible.

The majority of the metals melted using the alternative methods go into specialized applications. Many of these applications are for aerospace, aircraft and military equipment and can make their way into the nuclear industry.

Steel from either of these two cells goes to either ingot casting or to a single-strand continuous billet caster.

Mike Strelbisky (right), study tour chair, presented Bruno Pessoa Ramos (left), meltshop manager, Villares, with a plaque of appreciation.

Several different sized ingots are produced at Villares, but the majority of the steel produced from cell 1 is cast into either 20- or 45-MT ingots. The bulk of cell 2 production feeds smaller ingot molds ranging from 800 kg to 2 tons. All of the ingots are produced through a bottom fill method that is critical for the production of quality, clean steel. The smaller ingots are cast up to four at a time.

The continuous billet casting machine produces a bar 145 mm square. The caster uses a 4-MT tundish and averages two heats per sequence. The caster runs between 1.3 and 1.4 m/minute at 120°C above liquidus. A heat normally takes 2 hours to cast.

After the steel has been cast, Villares has several finishing operations that take the billets and ingots and preform value-added processes to them. The company operates a 5,000-ton forging press. Villares currently produces forged rounds from 160 to 900 mm in diameter. Villares also operates a rolling mill capable of producing wire from 6 to 22.22 mm and bars from 13 to 152.4 mm. There are also multiple heat-treating furnaces utilized at the facility. Villares Metals has the capacity to produce a total of 140,000 MTPY of finished goods.

The final mill visited on the tour was Companhia Siderúrgica Nacional (CSN), which started production on 1 October 1946 and brought about a new age of flat steel production to Brazil. CSN is a publicly traded company that employees a team in excess of 20,000. It operates a colossal integrated and electric steelmaking facility located in Volta Redonda, RJ, Brazil. CSN is capable of producing 5.7 MMTPY of hot metal for


Villares 5,000-ton forging press

conversion in its basic oxygen furnaces (BOFs) at this facility.

CSN is a vertically integrated company operating many of its upstream and downstream processes. CSN operates a jointly owned mine that contains an estimated 1.6 billion MT of magnetite. CSN uses this ore internally for hot metal production, and ore is sold on the seaborne iron ore market. In 2013, 45 million metric tons (MMT) of iron ore was mined from its ore reserves and used internally and sold abroad. Future plans for the mine include expanding production to 50 MMTPY. A significant portion of the material shipped abroad plays a large part in the production of alternative iron units, such as direct reduced iron (DRI) and hot briquetted iron (HBI) around the world.

CSN also operates a mine processing both dolomite and limestone to be used as fluxes in its steelmaking operations, as well as additives in its cement producing facilities. The cement plant operated by CSN has the capacity to produce 2.4 MMT per year. CSN also operates a tin mine and refining facility for use in the production of tinplate through a subsidiary company. CSN, being a large consumer of electrical energy in Brazil, has made steady investments in the local electrical market. It now owns stakes in a majority of the local power generation to ensure future operations.

CSN's integrated steelmaking process runs much like its domestic counterparts in the States. A process map of its operations can be found in Figure 2.

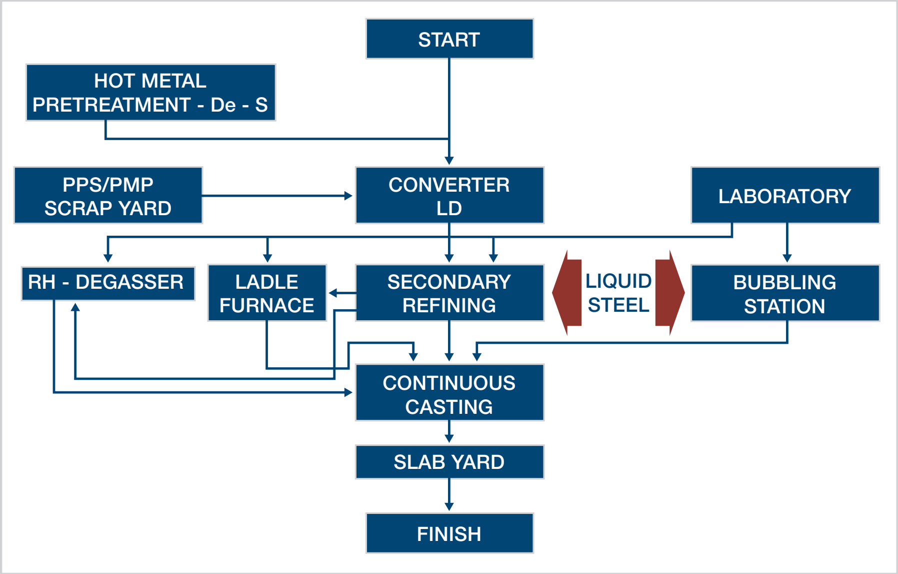


Figure 2: CSN integrated hot side processing flow diagram.

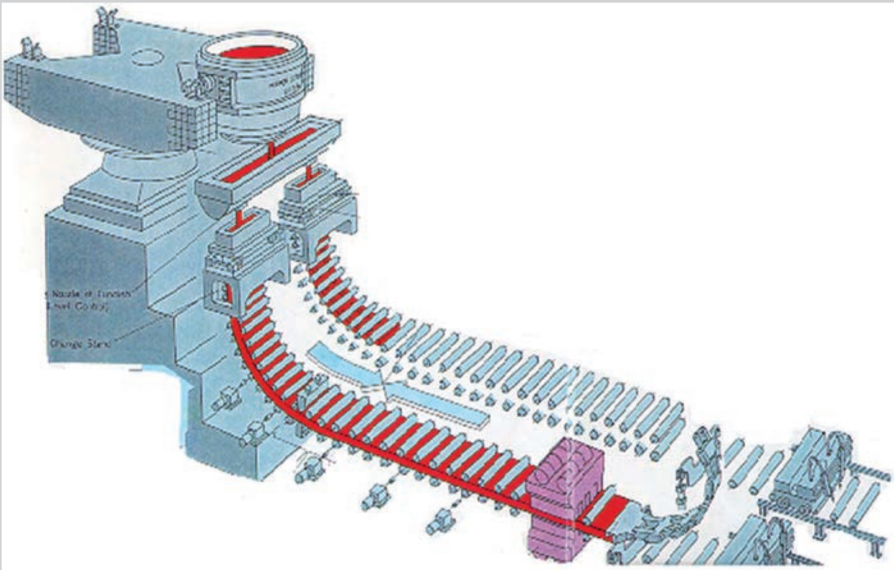


Figure 3: CSN Caster 4 general configuration.

CSN operates three converters when running at full capacity, producing heats of 230 MT. The three converters are capable of processing 5.4 MMTPY. They are charged with 210 MT of hot metal, 44 MT of scrap, 8 MT of lime and 4 MT of dolomitic lime. The output of this charge is the 230 MT of steel and 20 tons of slag with a typical chemistry of:

- CaO: 45%.
- SiO_2: 12%.
- FeO: 25%.

Heats are converted in 35 minutes using 11,000 Nm^3 of oxygen flowing through the lance at 700 Nm^3/minute and a velocity of Mach 3.1. From there, steel is transferred to secondary metallurgy facilities.

CSN operates a RH (recirculation degasser) that utilizes a four-stage steam ejector vacuum pump and is capable or circulating 160 MT/minute. The RH degasser is capable of producing steel with C ≤30 ppm and H ≤1.5 ppm. The RH process operates at a pressure of 1 mbar and generally takes 38 minutes to treat a heat. Roughly 25% of the steel generated at CSN is treated at the RH degasser. Applications for the steel treated in the RH degasser include exposed automotive, home appliances, steel cans and motor lamination steels.

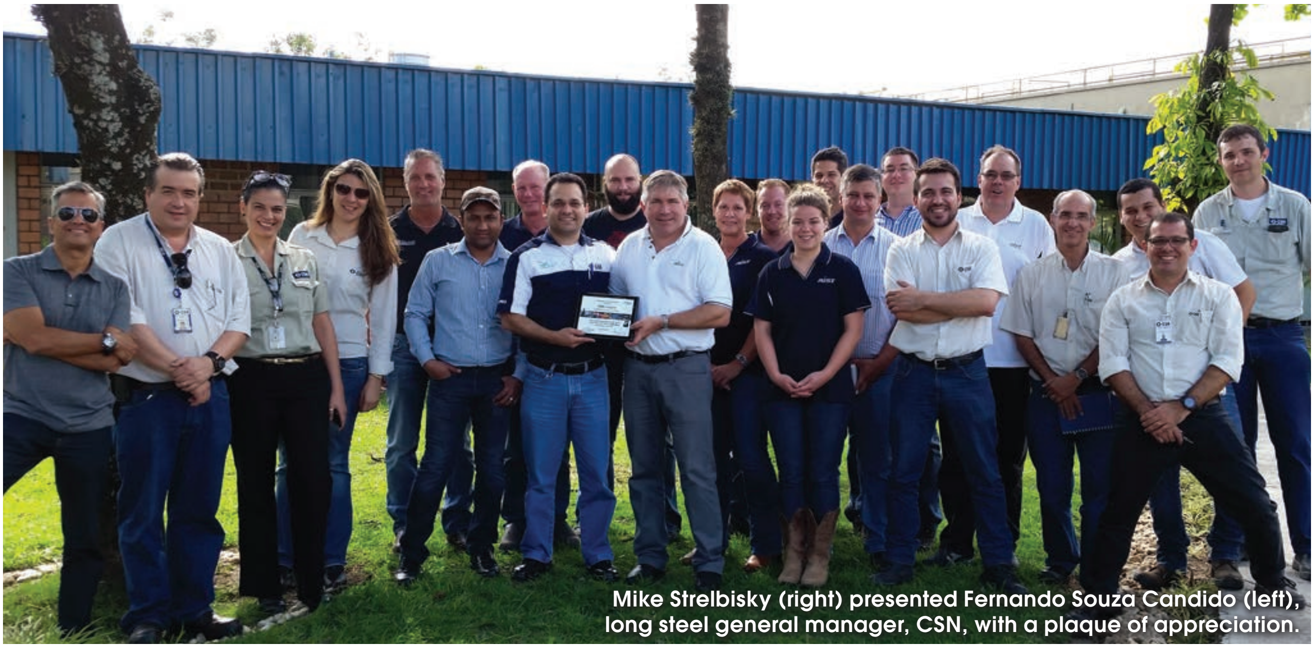
The ladle furnace uses a 38-MVA transformer for controlling steel temperature, which can be raised at 4.2°C/minute. The LMF reduces sulfur to ≤20 ppm and also incorporates wire and powder lance injection for alloy additions. The LMF treats a heat in 50 minutes and accounts for only about 10% of the final goods produced by CSN. The steel produced through the LMF is used in wheels for cars, pipe, building materials and agricultural implements.

CSN also operates two argon bubbling stations that perform 60% of the secondary metallurgy processes. Argon is blown in from a top lance, and wire alloy additions are utilized. The blowing stations also have a chill scrap addition system for quickly getting heats to the proper superheat for casting. The bubbling station processes steel that is later converted into coiled sheet steel, gas cylinders, bottle caps, paint cans and metallic furniture, just to name a few applications.

CSN currently operates three slab casters in the integrated portion of the facility. Casters 2 and 3, respectively commissioned in June 1982 and 1983, are identical DEMAG machines, and caster 4 is the newest (voestalpine) addition to the fleet. Casters 2 and 3 are a curved design, each operating two strands with a 27-MT tundish. Secondary water cooling is provided by a spray water system, and both machines are equipped with mold level control and breakout detection software. Both casters produce slabs at 250 mm thick and ranging in width from 830 to 1,660 mm at an average rate of 1.4 m/minute. Casters 2 and 3 are both capable of producing 1.6 MMTPY.

Caster 4, seen in Figure 3, was commissioned in December 1998 and is a straight caster that uses multi-point bending and unbending. A 60-MT tundish is used to supply this 2-strand machine. This caster also uses breakout prevention software, but has air mist cooling for a secondary cooling source. Caster 4 was designed with the ability to cast in two thicknesses, 200 and 250 mm, but only the 250-mm narrowfaces are currently being utilized. The width ranges on caster 4 also exceed those of casters 2 and 3, with a width range of 830–1,800 mm. Cast speed also surpasses casters 2 and 3 at 1.8 m/minute, netting an annual capacity of 2.4 MMTPY.

An interesting piece of equipment that CSN operates is a slab torcher that longitudinally cuts slabs. This converts the slabs into billets that are 250 x 250 mm. These billets are used in later rolling sections of the mill, in conjunction with billets sent from the EAF operation.



Mike Strelbisky (right) presented Fernando Souza Candido (left), long steel general manager, CSN, with a plaque of appreciation.

CSN also operates an electric steel, long products mini-mill on-site that is independent of the integrated production facility. In December 2013, CSN commissioned the EAF, LMF, billet caster and bar rolling mill, which have an estimated annual capacity of 500,000 MT. The meltshop is located in a sound-insulated building, and the EAF is further acoustically insulated with a sound-deadening structure built over the furnace. These noise reduction measures had to be taken due to the mill's proximity to the populous city.

The furnace has a 56-MT capacity and produces 50-MT heats. The AC EAF is charged with 70% scrap and 30% pig iron, and requires 35 kg/MT of fluxes. The furnace has a manipulated door lance with oxygen and carbon injection. The furnace also utilizes oxy-fuel burners with carbon injection and lancing oxygen. Metallurgical coke is utilized as the injection carbon. The EAF does not currently use hot metal from any of the blast furnaces on-site. There are future plans to incorporate a method of using hot metal at the EAF, but nothing has been implemented as of yet.

The EAF feeds a conventional LMF station that utilizes bulk, wire and hand additions. The LMF controls chemistry, superheat and inclusion modifications for casting. Steel is shipped from the LMF to the caster via ladles. The caster is a 3-strand billet caster producing 150- x 150-mm square pieces that are later rolled in the on-site bar finishing mill.

Conclusion

The AIST study tour was a great success. As a group, we had the opportunity to network, benchmark and exchange information with a whole new group of steelmakers and suppliers. At each of the facilities visited, we conducted a technical exchange, which included a presentation from each of the producer companies in attendance, as well as a benchmarking session in which the local producers and producers from the tour group shared meltshop key performance indicators. This information is extremely useful, when used correctly, to let you know how your company is performing against fellow steelmakers. We also held a roundtable discussion at each facility, in which we shared issues and got advice from one another. It is always amazing to hear that we all experience similar issues, and it is interesting to learn the different approaches everyone has used to overcome them.

From what I have experienced in my brief involvement with the steel industry, I have learned that it is a collaborative group of men and women who all work together to make the best quality steel in the safest way possible.

In the end, it is not the equipment that makes the difference; it is the people who operate and optimize it. We have to work together to grow our collective experience and knowledge by pushing the boundaries of what steel can do to ensure its presence in future society. ✦

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