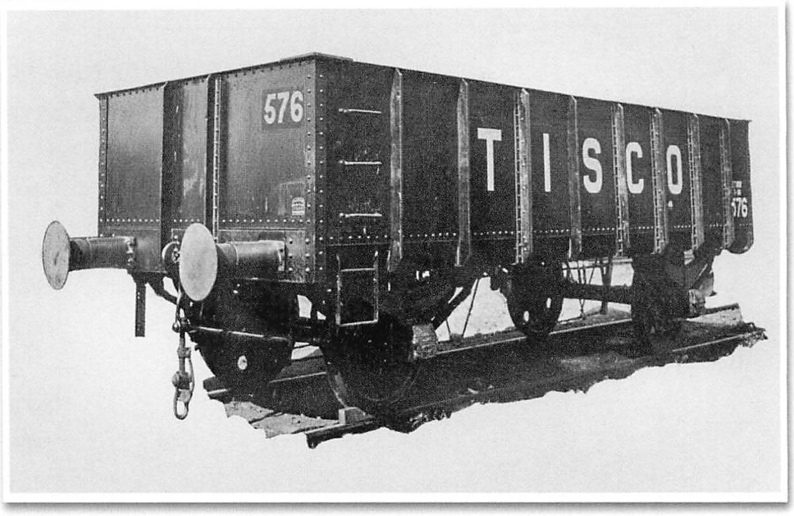
While Tiscrom and Tiscor admirably catered to the steel requirements of the civilian sector, one of Tata Steel's finest hours in creativity and innovativeness came during the Second World War. As Dr. Amit Chatterjee, points out in 1980s monograph 'Glimpses of R&D at Tata Steel':



A wagon from Tiscor steel plates

"The outbreak of World War 2 found the country dependent on Britain for the supplies of certain types of steel products, particularly those required for ordnance products. With the increased pressure on Britain for war supplies, the growing dearth of shipping, the intensification of submarine warfare and the closing of the Mediterranean route to the East, the discovery of indigenous sources of supply became essential, if India was to play her rightful role in the provision of the ammunition of war to the British armies in the East.

Naturally, the Government of India turned for such supplies to Tata Steel, which was the only commercial unit in the country having the necessary experienced personnel, equipment and research organisation, to carry out development work. During the war, as a result of elaborate R&D work, Tata Steel was able to manufacture and supply new types of alloy steel grades such as Die Steel and Bullet Proof Armour Plate."

During the five years of the war, researchers at Tata Steel managed to develop as many as 110 different varieties of steel. The most outstanding achievement was the development and production of a bullet-proof armour plate.

The first call to make this grade was made on Tata Steel in early 1940. Having no prior experience in producing such a class of ordnance steel and no sources for guidance, the company had to literally start development of the material from first principles.

To start with, the composition and class of steel to be made were selected corresponding to the facilities and equipment available in the plant. Steels that required oil and water for hardening were ruled out, as these required new large quenching and straightening installations. Efforts were therefore directed towards making air-hardening alloy steels.

After several experiments with various compositions, an air-hardening steel containing nickel, chromium and molybdenum was produced in a 34 kg Induction Furnace in the Research and Control Laboratory at Jamshedpur. After rolling into plates and normalising followed by tempering at a low temperature, the plates were subjected to severe ballistic tests.

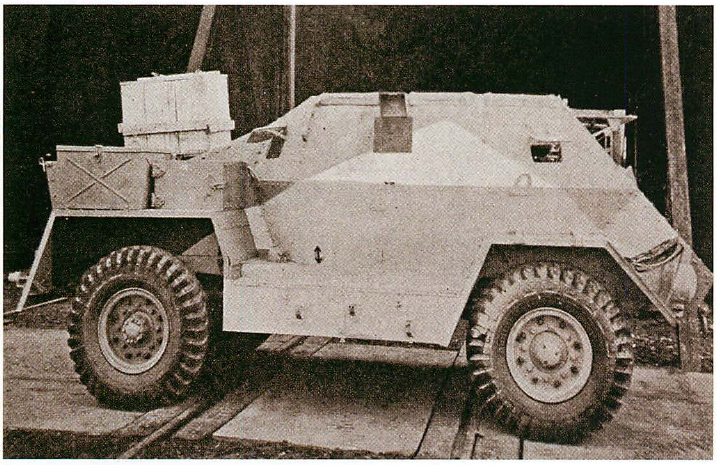
It was a tribute to the researchers at Tata Steel that the Master General of Ordnance Branch, Simla, remarked that the company's armour plate was "Excellent and up to Home Specifications". Even more creditable was the fact that this research of such magnitude and novelty was carried out in the short space of just three months.

Initially, the commercial production of this armour plate steel took place in the Electric Arc Furnace. Later, with experience gained, production was shifted to the Open Hearths. The furnaces for heat treatment were produced locally and very soon the plant was able to churn out 800 to 1,000 tons of annealed plates per month. One peculiar difficulty was this steel's extreme sensitivity to heating and cooling and its tendency to "flake". This was overcome by rigorously controlling the heating and cooling cycles at the different stages of production.

This new bullet-proof armour plate was first used for armoured vehicles that were fabricated by riveting. Special research was undertaken to also develop a bullet-proof steel for these rivets that had to be driven in hot. As it would not be possible to temper the rivets after driving, an air-hardening alloy steel was needed that retained sufficient ductility without tempering. This development was successfully accomplished by duplicating the armour plate composition with lower carbon and chromium content.

These armoured vehicles were called 'Tatanagars' and were used extensively by the British Army engaged on the North African front. A press item in the 1940's with the headline "India-made Armoured Cars Praised" mentioned:

'Safer than slit trenches during a bombing raid' was a gunnery officer's tribute to the cars during service in the 8th Army. An officer goes on to describe how a 75 mm shell burst on one side of the Tatanagar. "The metal plates were buckled but nowhere pierced. The four occupants of the car emerged unscathed. Units possessing the Tatanagar swear by them."



The Tatanagar, a light armoured vehicle built at Jamshedpur by Tata Steel using know-how developed in-house. (1940)

During the war years, researchers faced many other challenges. For example, at a crucial time during the war, nickel, an essential ingredient in armour plating steel, was in short supply. Tata Steel's researchers therefore developed a new alloy with the similar good ballistic properties but with only a third of the nickel. They also succeeded in making magnetic steel bars and high speed tool steels.

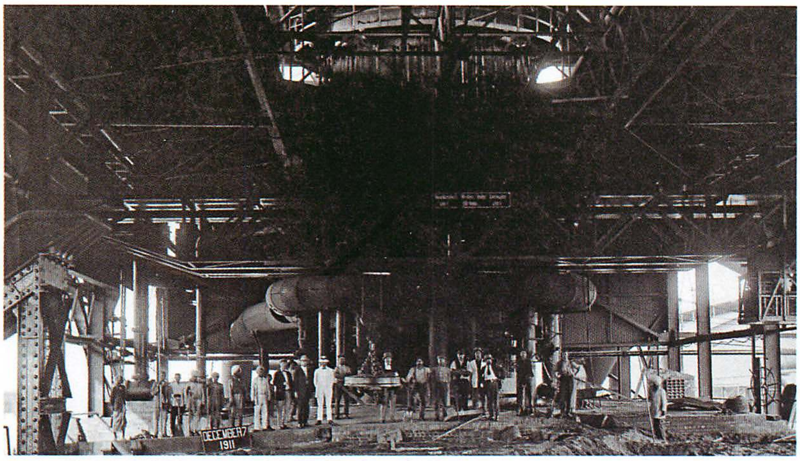
Verrier Elwin

According to Verrier Elwin in his 1958 book, "The Story of Tata Steel", the company's achievements in the production of high-speed steel faced as much opposition as the earlier battle for the acceptance of Tiscrom for the Howrah Bridge. There is a story of a responsible technical officer of the Government, at first one of TISCO's severest critics, who put the company's high - speed steel product to a series of exacting machining tests. He was amazed at the results, repeated the tests again and again and finally became an enthusiastic advocate of the TISCO steel.

Indeed, the Second World War had triggered a tremendous spurt of creativity at Tata Steel's fledgling Control & Research Laboratory. This enabled the company to make a rich variety of vitally important alloy steels for shear blades, machine tools, parachute harness and even razor blades. An interesting side-line was the production of mint die steel. In the War days, there was a great shortage of small coins and it was decided to meet this by expanding the capacity of the Bombay Mint. Since imports of steel for the dies could not be done due to unsafe seas, Tata Steel's researchers got busy and soon produced a steel which ultimately met all requirements. This may be the first attempt at the manufacture of quality tool steel in India.

The global steel industry has become highly energy and resource efficient as a result of sustained technological improvements over many decades. Tata Steel has led the way in India. Its sustained efforts in R&D and its scientific approaches to operational excellence have created world class iron making operations, despite deficiencies in the locally available raw materials.

The logic to locate the steelworks of Tata Steel at the remote tribal outpost of Sakchi, later called Jamshedpur, was the unique proximity of abundant deposits of iron ore, coal and limestone. However, the plant also had to contend with two fundamental drawbacks: a high ash content in the coking coal and a high alumina content in the iron ore. Both are detrimental to the productivity and efficiency of the blast furnaces that produce the liquid iron or 'hot metal', as it is called in the industry.



The first blast furnace (1911)

For the past 75 years, Tata Steel's researchers, scientists and their colleagues in operations have jointly fought an inspired and committed battle on a number of fronts to overcome these deficiencies. There have been a number of ups and downs, but Tata Steel has managed to achieve a high blast furnace productivity and low hot metal cost with the available domestic raw materials.

Tata Steel's researchers first turned their attention to the quality of coke, which arguably is the most important factor in a stable blast furnace operation.

There are many ways to characterise coke quality. Though all of them are relevant in some respect, the coke strength after reaction (CSR) and the ash content in the coke are amongst the decisive factors. A high ash content and a poor CSR were seen as the key reason for low blast furnace productivity in Jamshedpur.

The ash content of coal from Tata Steel's West Bokaro mine varies from 30 to 35%. This ash content is very high. However, a washing process for the as-mined coal is now able to reduce the ash content to between 12 to 15 % and yet give a clean coal yield of 35 to 40 %. This process was not achieved overnight but was perfected through extensive research and development spread over a decade.

For example, a new dense medium cyclone was introduced to reduce ash from the coarse coal and also a floatation process was adopted for beneficiation of coal fines. This resulted in a clean coal ash level of 17% during the 1980s. Subsequent investigations were conducted to reduce the ash further, including changes in the design of dense medium cyclones, the use of better quality dense medium magnetite, the use of a viscosity modifiers in the washeries, etc. Also the organic frother in the floatation cells was replaced with an improved synthetic frother and seam-wise treatment of coals all helped to improve yield with better control of ash. Finally, a new Tata-JK Dense Medium Cyclone was developed and is being trialled for treating fine coals.

At present, the R&D division of Tata Steel is also pursuing two very novel coal washing technologies based on chemical beneficiation. These new technologies hold the promise to produce clean coal with only 8% ash at double the present yield of clean coal. The seed for these developments was sown in 2006 when Tata Steel's management, headed by then Managing Director B Muthuraman, looked for solutions to increase the productivity of captive mines amidst rising prices and demand. If successful, the technologies will bring down the need for costly imported coal and double the usable coal output from the Tata Steel's mines in West Bokaro and Jharia.

Chemical beneficiation involves the addition of various chemicals to separate ash from the rest of the coal using multiple reactors. In 2007 researchers conducted more than 100 different experiments inside the laboratories in Jamshedpur. The purpose was to find suitable chemicals using only a few grams of coal each time. Five patents were filed based on these laboratory results. The next step was to build a small working prototype in the laboratory to determine the most effective and efficient concentration of chemicals, reaction times and other process conditions. Again five patents were filed during this stage.

From these humble beginnings the project has now grown into the largest project that is presently running at Tata Steel's R&D division. It has a team of 6 researchers and 20 support staff. Important advice and guidance is regularly solicited from visiting Scientists and contracting company.

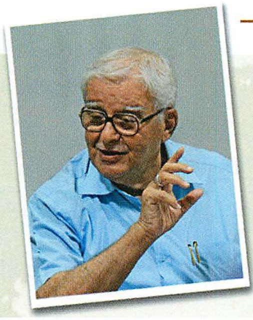
Semicontinuous pilot plant for chemical beneficiation of coal (2011)

This team has built a semi-continuous pilot plant with 500 kg batch size. It comprises of several process steps with different chemicals that selectively react with the coal. After this treatment, the coal is filtered and washed to get clean coal with low ash. This plant was commissioned in 2011 and is now operated round the clock to optimise process variables and to overcome key engineering challenges such as filtration, dewatering and regeneration of chemicals. Several unique solutions have been developed for the recycling of chemicals that have resulted in three more patents.

While chemical beneficiation is a technology that is presently still at its infancy, Tata Steel adopted another important coal technology- Stamp Charging - in the early 1980s. This technology had originally been developed in Germany and was studied, adapted and advanced in Tata Steel.

cokemaking at Tata Steel, but it was also likely to produce much better quality than the top charging process that prevails worldwide.

Based on the above findings, it was decided to progressively introduce stamp charging in the coke oven batteries at Tata Steel. The first blend used was 25% captive prime coking coal, 57.5% captive medium coking coal and 17.5% imported prime coking coal. However, this blend encountered problems with frequent hard pushes in the coke batteries. Detailed investigations in a small lab-scale coking oven concluded that the blend needed to be changed to 80% indigenous medium coking coal and 20% imported prime coking coal. This resulted in a remarkable improvement in the shrinkage behaviour of the coke mass and hard pushes were reduced considerably without adverse impact on coke quality.



" A very significant turning point in the cost of making steel in Tata Steel was the adoption of stamp charging in the coke making process."

- Dr. J J Irani, Managing Director of Tata Steel from 1992 to 2001.

Coking coal comprises only 15% of India's 200 billion tonnes of coal reserves, 80% of the coking coal reserves are of the medium coking type. During the late 1970s and early 1980s the R&D Division of Tata Steel carried out extensive tests to maximise use of domestic medium coking coal for cokemaking. They evaluated various pre-carbonisation technologies such as partial briquetting, selective crushing, pre-heating and stamp charging. A pilot plant of 600 kg capacity with state-of-the-art measurement facilities was built for carrying out studies. It was clearly demonstrated that stamp charging was not only the most appropriate pre-carbonisation technology for

Another challenge associated with stamp charging is that the stamped coal cake must have enough stability to prevent breakage during transport from the stamping machine to the coke oven chamber. Intensive studies by R&D established that it is essential to maintain a specific coal crushing fineness, moisture content and stamping energy.

During subsequent years, many further changes were made to the coal blend as part of a journey towards lower operating costs. It resulted in lowering of coke ash by 1% without impairing either the coke quality or the shrinkage characteristics of the coal cake.

Additional developments were made by incorporating lower cost non-coking coals in the blend, studying the impact on the yield of by-products such as coal tar and coke oven gas and by introducing new laboratory tests.

Pilot scale sintering facility at Tata Steel R&D

Tata Steel's strategy to adopt stamp charging for coke making in the early 1980s maximised the use of domestic coking coals and played an important role in the competitiveness of ironmaking at Jamshedpur. It has also proved to be very prescient considering today's high prices for globally traded coking coal. The impact of this technology in terms of reduction of coke rate and increase in productivity in blast furnaces has been significant and, considering the diminishing global stock of prime coking coals, we may expect that such pre-carbonisation technologies are likely to gain worldwide popularity.

When iron ore is mined it typically generates a mixture of lumpy iron ore rock and iron ore fines. Lumpy ore can be used directly in the blast furnace, while iron ore fines have to be agglomerated either in sinter plants, which fuse the fines into a single porous mass, or in pellet plants, which form small iron ore balls that are subsequently baked.

Tata Steel's association with sintermaking started in the year 1959 with the construction of India's first Sinter Plant. This plant initially produced sinter that was of such poor quality that the blast furnaces considered it as a necessary evil. The use of limestone to improve sinter quality started in 1968 and dolomite was also added in 1978. Several other developments during the mid 1980s significantly improved blast furnace productivity.

With sinter in limited supply, the proportion of sinter in the burden dropped to 30% and a need to increase the percentage of sinter was felt. However, the presence of high levels of alumina in the iron ore fines (typically 5% Al_2O_3) posed a problem to maintain the quality of sinter. When too much alumina is fed into the blast furnace, the blast furnace slag tends to become very viscous, which is detrimental to blast furnace permeability, drainage and productivity.

A vital breakthrough came in the form of 'blue dust', a material that was earlier considered to be an unusable reject. It is very fine ore that is rich in iron (67%) and low in alumina (<2%). It appeared to be ideal to be blended with high alumina iron ore fines. However, the small size of blue dust particles (35% below 0.5 mm) caused concern due its adverse impact on sinter bed permeability and productivity.

At this juncture, R&D conducted detailed pilot scale sintering experiments and concluded that up to 40% blue dust can be blended with ore fines. These results were confirmed by plant trials and, with the commissioning of the second sinter plant at Tata Steel in 1989, it was decided to use blue dust for the first time. This marked the beginning of a new era in sinter quality and, with more sinter available from both the sinter plants, the proportion of sinter in the blast furnaces increased to 50% in 1990 and 63% in 1992.

When using blue dust, the lime content in sinter had to be decreased and subsequently silica addition was also discontinued. The resulting rising sinter basicity now negatively affected the high temperature properties of the sinter. It was therefore decided to study the use of olivine, a magnesium silicate rock that was commonly used abroad. However, instead of using imported olivine these investigations concentrated on locally available dunite and pyroxenite; both are types of magnesium silicate rocks from the Dodkanya and Sukinda mines in India.

Dunite was found to be most suitable and subsequent plant scale trials at Sinter Plants #1 and #2 concluded that sinter quality and productivity were not adversely affected. Thereafter, Tata Steel completely replaced dolomite with dunite, becoming the first in India and one of the very few in the world to do so.

In the late 1990s, another special initiative titled 'P40' was undertaken in order to improve the gross sinter productivity by 50%, from 27 to 40 tons /m^2/day. As part of this project, R&D conducted several pilot scale and plant scale trials at Sinter Plant #2 to optimise the ignition intensity, to improve the granulation of sinter mix and to minimise air leakages into the sinter machine. These initiatives combined with other improvements at the sinter plant ensured that this challenging goal was met.

Keeping in line with company's environmental objectives, R&D has recently investigated ways and means to reduce solid fuel consumption and to increase the consumption of reverts and rejects during sintermaking. Pilot studies and plant trials revealed that up to 1% reduction in solid fuel usage is possible without compromising on the quality of sinter. Laboratory trials also established the technical feasibility to replace up to 20% of high quality iron ore fines by low quality and mostly unused banded hematite jasper ore.

In the same period when blue dust was adopted as a measure to reduce the alumina in sinter, various other studies were also underway to lower the

'Ultrafine beneficiation' team receiving the Tata Innovista award in the 'Promising Innovation' category (April 2010)

A recent R&D project in the field of iron ore beneficiation contributes to Tata Steel's strategy to realise complete beneficiation of all mined iron ore, and will maximise the sustainable use of iron ore deposits. This project develops a new technology to recover iron from so-called iron ore slimes; a slurry of water and ultra-fine iron particles, typically below 20 micron particle size. This slurry is presently an unused by-product of mining operations as it cannot be processed by today's beneficiation technologies. This technology won the coveted Tata Innovista award in the 'Promising Innovation' category in 2010.

alumina content of the feed ore by beneficiating the ores at the mine site. Through a series of experiments in the late 1980s and early 1990s, it was shown that the alumina content could be reduced by a combination of washing iron ore lumps and jigging iron ore fines.

The experiments conducted both at R&D and at KHD HumboldWedag in Germany showed that one percent alumina reduction with 75% iron yield was technically feasible. Based on these results, an iron ore jigging plant was installed at the Tata Steel's Noamundi ore mines. These initiatives to decrease the alumina in sinter have reduced the generation of blast furnace slag from 330 to around 280 kg/tonne of hot metal in 15 years. This has had a substantial impact on blast furnace energy efficiency and productivity.

In recent years R&D developed a novel technology to process ultra fines consists of advanced versions of a hydro cyclone, selective flocculation and flotation. After successful pilot experiments this new process is now planned to be built and commissioned at the mine site. It is expected to recover up to 50% of the ultra-fines iron ore in the form of a usable iron ore concentrate with 2% alumina.This development is part of a future trend in ironmaking technology.

Today, mechanised mining, sizing of iron ore and iron ore beneficiation are increasingly being used in India. A side effect is that more iron ore fines and ultra-fines are being generated. The ability to use such fines in sintermaking is limited and, for reasons of sustainability, it is therefore desirable to introduce processes to capture and agglomerate such fines. Pelletising is globally the most used process to agglomerate iron ore fines that cannot be used in sintering. In 2012, Tata Steel has commissioned a new 6 million tonnes per year pelletising plant using the latest technology from Outotec of Germany.

But, pelletising with Indian ores poses specific challenges. For example, their high alumina demands more energy during firing and also deteriorates pellet quality. R&D is therefore building a state-of-the-art pilot pelletising and pellet testing facility for future developments in agglomeration technology.

Besides dealing with problems related to raw materials, Tata Steel's R&D and Scientific Services has also contributed significantly to developments in other aspects of iron making. For example, Its researchers have used various scaled-down models of blast furnaces to experiment with new methods of burden distribution. A scaled down model of D blast furnace was first used in 1981 to design moveable throat armour and to optimise the radial distribution of the burden. Over 200 different trials were performed using 1500 tonne of materials. Similar models at a 1 to 10 scale were subsequently built. They were made of toughened glass allowing actual visualisation of the material flows.

The G blast furnace is Tata Steel's first large Blast Furnace and equipped with the Paul Würth bell-less rotating chute charging system. Before commissioning this furnace, R&D carried out studies using a full scale model of this furnace to gain

"The foundation of my career in Tata Steel was laid in the R&D/SS Division. As Senior Metallurgist Blast Furnaces, I got the real feel of the complexity of iron making! This helps even now. "

- Mr Anand Sen, VP
Total Quality Management and Shared Services

Toward Low Ash Coal

Tata Steel R&D is concurrently working on the development of two new technologies to remove ash from high-ash Indian coals. One development selectively dissolves and removes these non-energetic minerals using chemical leaching. The other development uses solvents to dissolve and separate the energy-rich carbonaceous part of coal.

In 2011, Tata Steel R&D demonstrated in the laboratory that the solvent route can reduce the ash content from 30% to 4% (or less) with a carbon yield of 80%. It more than doubles the performance of conventional physical beneficiation technology that uses crushing, sieving, washing, etc.

A chemical process would normally be substantially more costly. Reasons are the energy intensive regeneration of solvents using distillation and evaporation and the stringent environmental norms. However, the R&D team has discovered various innovative approaches to optimise the energy efficiency and reduce solvent loss, while further developments are underway to achieve zero solvent loss.

The R&D team presently operates a bench-scale pilot plant that processes 20 kg of coal at a time. It has again shown very encouraging results. The next phase is due to start in 2013. It will involve the construction of a continuous pilot plant with patented tailor-made equipments and a process control system according to in-house design.

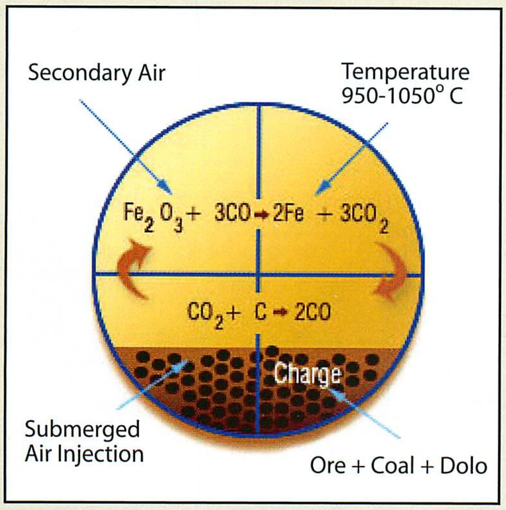
The potential of this process is not only to reduce the ash content in coke and thereby improve the efficiency and productivity of blast furnace ironmaking. The process can also be used to produce liquid fuel from coal or to create value-added carbon products, such as carbon composites, from mine tailings.

Refining evaporator and distillator in the Organo-refining pilot facility at Kolkata understanding of burden distribution and burden movement when using this new technique. Also the hearth of the G blast furnace was simulated using a scaled-down physical model. Here the impact of various hearth and taphole parameters on the drainage was established. Several of these works were complemented by mathematical models derived from first principles.

Proper charging is an essential element of stable blast furnace operation at high productivity and efficiency. On 10th December 2010, a team from R&D in Jamshedpur and Tata Steel Europe also successfully deployed an advanced trajectory probe to measure path of burden materials when being charged in the blast furnace. This new probe, an invention by researchers in Tata Steel Europe, can be regularly used even during short stops and is a clear improvement over previous measurement systems, which could only be used once during the start-up of a blast furnace.

The search for better iron making is an ongoing process. Future challenges for researchers lie in such areas as reducing the carbon footprint, smelting reduction, use of non-coking coal, full process automation, etc. Tata Steel's R & D division is gearing up to meet these new objectives.

Probing the Blast Furnace using an advanced material trajectory probe (2010)



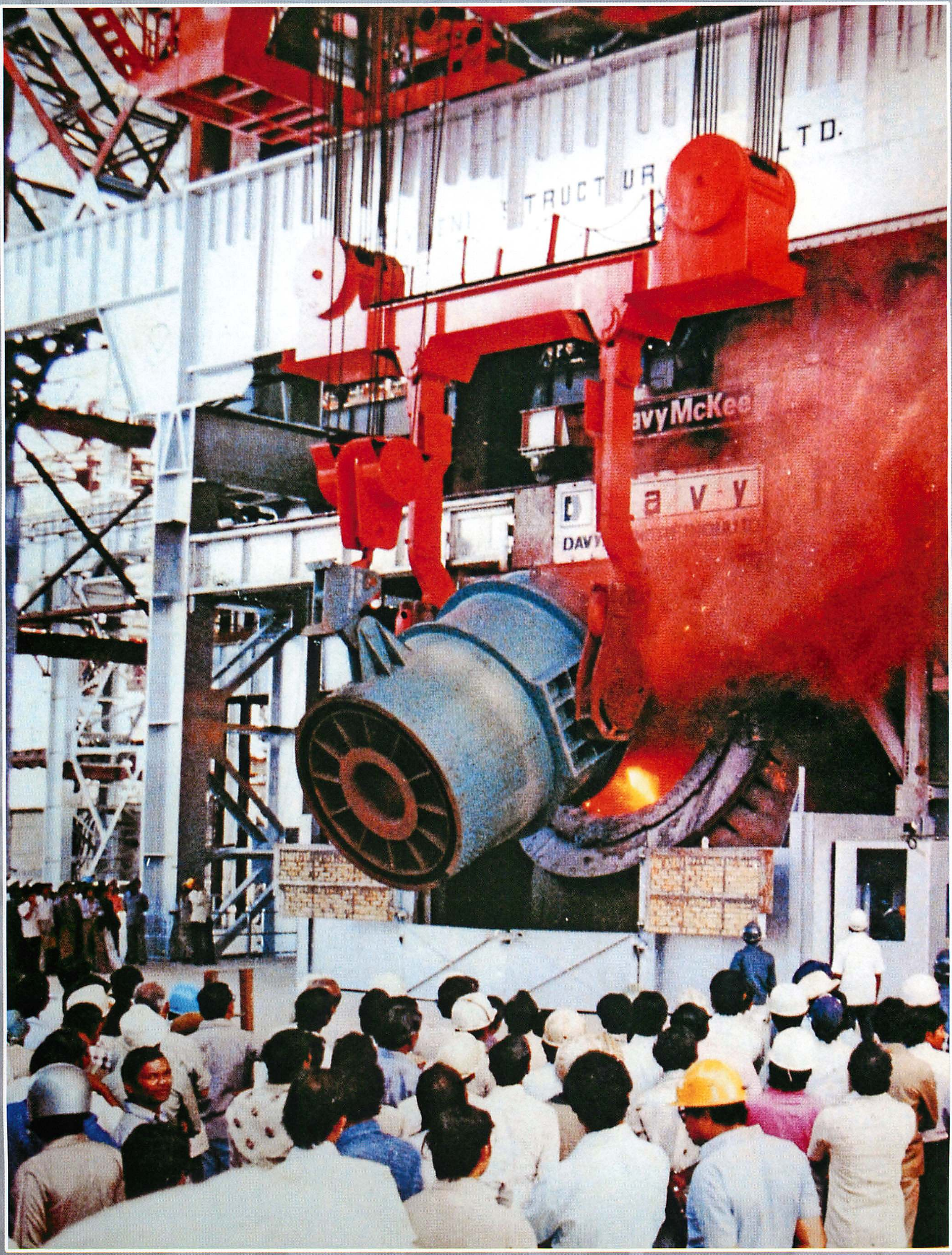
Cross-section of Rotary Kiln

TISCO Direct Reduction (TDR) Technology

In early Seventies, the mini steel plant route was envisaged to quickly escalate steel production capacity in India. Tata Steel R&D took an active interest in developing a coal-based direct reduced iron (DRI) process. The process uses an inclined rotary kiln reactor. The rotation of the kiln, coupled with the inclination, imparts a forward motion to the charge towards the discharge end. The charge, consisting of iron ore and non coking coal, while traversing the kiln length at high temperature, undergoes two simultaneous reactions, viz., gasification of the coal and reduction of the oxide ore. The oxide ore thus gradually gets converted to the lower oxides and finally, to the metallised product, DRI (90 - 95% iron). However, the hot product from the kiln also contains coal char and ash and these being nonmagnetic, are separated from the product DRI (magnetic) by magnetic separation. Before magnetic separation, the hot kiln-discharge product is cooled to about 100°C, usually in a rotary cooler, indirectly cooled by water.

Based on fundamental modelling studies, the R&D Division of Tata Steel put up a pilot plant of 10 tonnes per day of DRI. Extensive trials were conducted to optimise the process conditions and to determine the various operational issues related to the technology. All these concerted efforts led to the development of the TISCO Direct Reduction (TDR) process. Subsequently, the process was commercialized in IPITATA Sponge Iron Ltd.'s plant with 300 tpd capacity in the Keonjhar district of Orissa in 1982. The company was set up as joint venture between Tata Steel and the Industrial Promotion and Investment Corporation of Orissa (IPICOL). It became an associate company of Tata Steel in 1991 and was renamed as Tata Sponge Iron Ltd. The process won for Tata Steel, the Technology and Innovation award from the Confederation of Indian Industry in 1984 and awards galore for Dr. Amit Chatterjee, who was leading this technology development program at R&D Tata Steel.

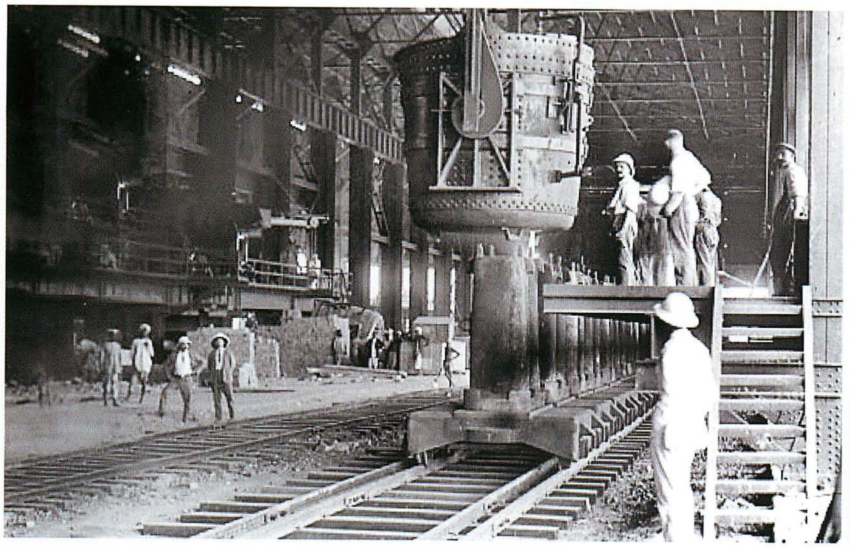
DSIR award for 'R&D efforts in Industry' in the Processing Industries Category for the TDR technology (1990)



The first LD Oxygen Steelmaking Plant in Jamshedpur (1983)

During the past 100 years of its existence, Tata Steel used a wide variety of processes for refining liquid iron into steel; and several different processes for casting Every change in process represented a major challenge, but the operations personnel succeeded in mastering the technology with the syncopated support of colleagues from the Research & Development and Scientific Services Division.

Tata Steel started its steelmaking journey with four 40 tonne stationary open hearth furnaces served by a 300 tonne hot metal mixer. In February 1912, the first steel was tapped. This enabled the company to make light rails, fishplates, rounds and flats, light angles, channels and beams.



First ingot casting steel from ladle into ingot mould, (2nd December, 1911)

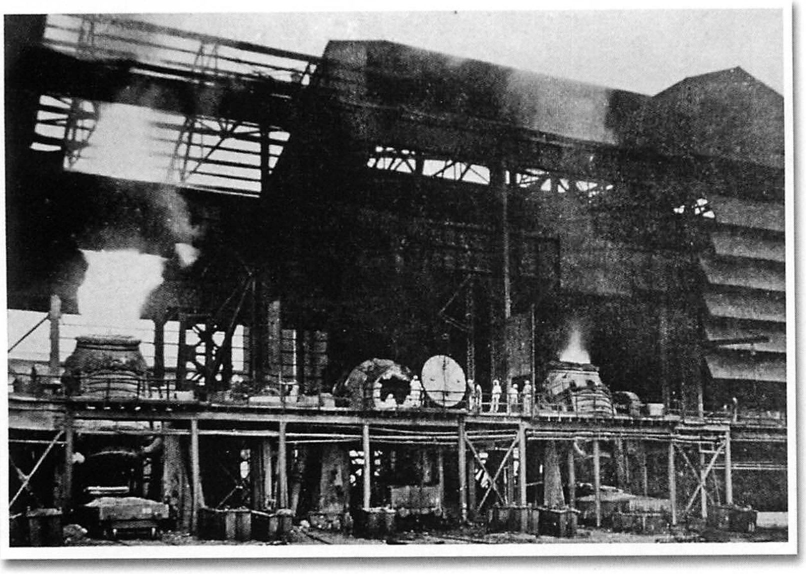
The new steel plant reached full capacity just when the First World War broke out. It caused a sudden increase in demand for steel and immediately plans were made to increase annual production to half a million tonnes of ingot steel. The company also decided for a major change in its steelmaking process.

Reports had come in of remarkable achievements by some American steel plants using a new combination of technologies. This Duplex process combined blowing hot metal in a Bessemer converter and then refining the blown metal in an open hearth furnace. While a single open hearth furnace took 10 hours for a heat of steel, this new process could do the same in just three hours.

Tata Steel decided to make the switch and adopted the Duplex process in the early 1920s. The steel grades produced with this process included medium manganese rail steel, high carbon steel, deep drawing quality steel, high tensile steel and high silicon steel.

During the early 1940s, Tata Steel's attention was drawn to the possibilities of the Perrin Process that was operated successfully by Ugine in France. It involved pouring partially refined steel into a highly oxidising basic slag and enabled rapid steel production at lower cost. Large scale experiments indicated that after some modifications the process could be employed under local Indian conditions. Steel Melting Shop 3 was designed accordingly and commissioned in 1958.

Around the same time, the Second World War broke out in Europe. It constrained imports of steel and Tata Steel was urged to produce wheels, tyres and axles to meet the requirements of the Indian Railways. The Perrin process was therefore modified to produce different steels needed for these products. The modified process was called a Triplex



A group of three Bassemer Converters at Duplex Plant (1928)

Process and involved a combination of an acid Bessemer process, a basic open hearth process and acid open hearth process. This endeavour turned out to be an outright success at the time. However, later experimentation and developments could prove that the basic open hearth process was also able to produce steels suitable for railway wheels and axles. The Triplex process was therefore abandoned in the 1950s.

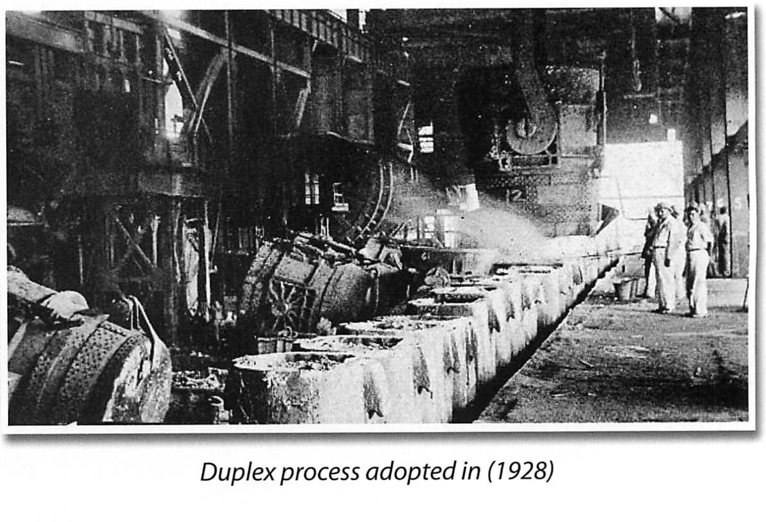
The period of the Second World War at Tata Steel was characterised by the development of a wide variety of ordnance materials and special steels for defence purposes. The central Control & Research Laboratory played a major role in these immense efforts. Today, samples of such ordnance materials can still be found in the basement of the R&D building in Jamshedpur.

This demand for urgent product diversification during the war years represented a big challenge for a Laboratory that had been established only a few years back. However, successful development projects and the investment in two small electric arc furnaces and a 500 kg high-frequency induction furnace allowed the company to produce new products, such as armour plates, alloy steels, tool steels, special steels and bars of stainless steel.

By 1956, the independent government of India launched a major industrialisation drive with its second Five Year Plan. Tata Steel was permitted to expand its annual capacity to 2 million tonnes of steel ingots. At the time, Tata Steel's management faced a major dilemma whether or not to invest in the new Linz-Donawitz (LD) oxygen steel making process, which originated from Austria. It was becoming the new technology of choice in Europe and seemed very attractive because of the lower equipment costs.

However, after actual trials at Linz in Austria, Tata Steel concluded that the process would be uneconomical in India. A key reason was that the locally available refractory materials were not expected to last long enough under the severe process conditions. Another deterrent were the specifics of Indian raw materials that result in a high phosphorous content in the liquid iron and require specific operating practices during steelmaking.

Management at Tata Steel therefore decided to continue with the Duplex process. It was a hard decision for a company that was fully aware of the technological and competitive potential of oxygen



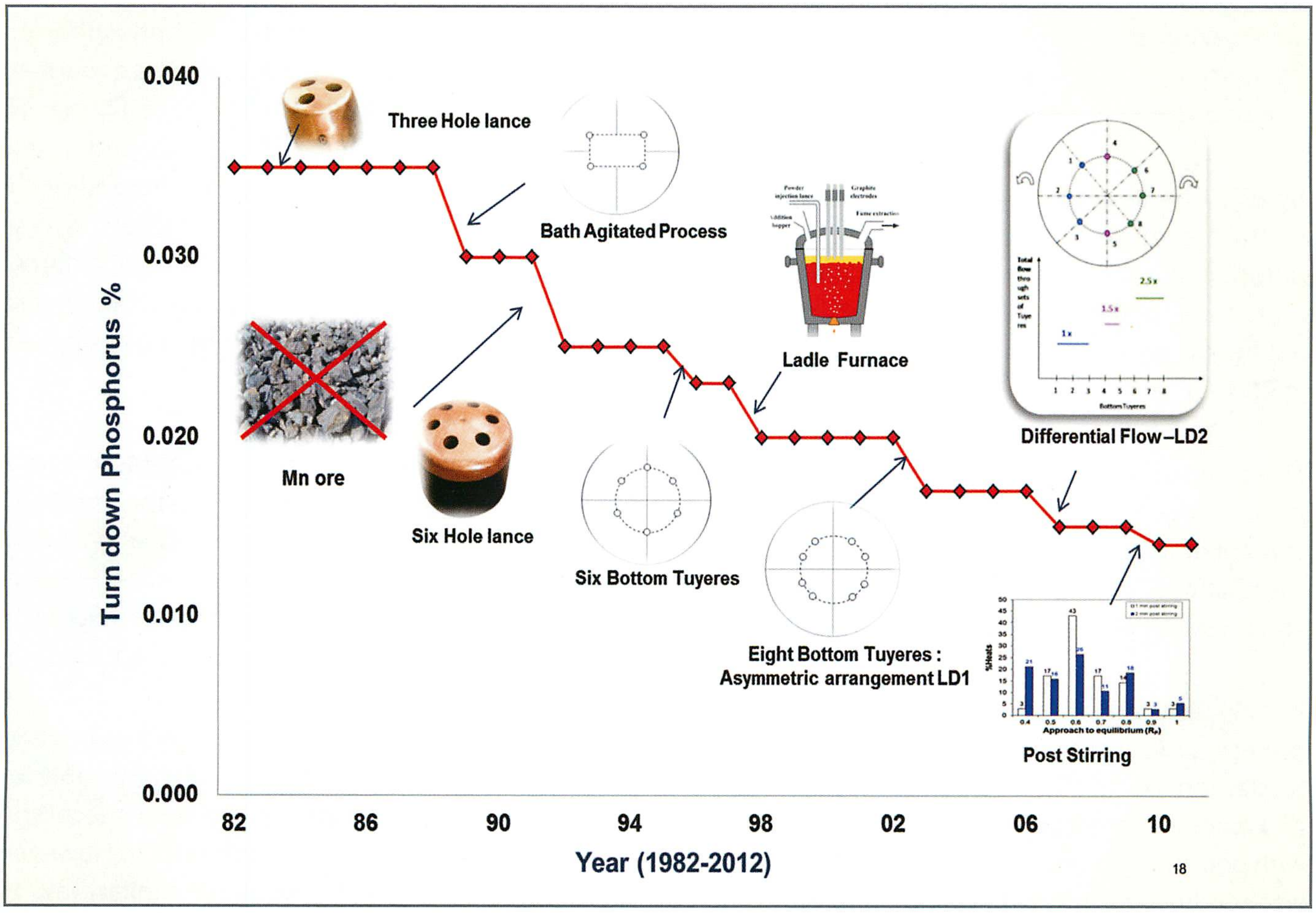
Duplex process adopted in (1928)

steel making. In the event, they proved to be right. The public sector Rourkela Steel Plant did adopt the LD steelmaking process in the 1960s, but faced enormous problems for the next 20 years, particularly regarding the life of the refractory lining of LD converters.

Ultimately, in its third expansion phase, Tata Steel did switch to oxygen steelmaking. Its first LD oxygen steelmaking plant (LD1) was commissioned in 1983 and had two LD converters of 130 tonnes capacity. LD2 was commissioned ten year later with the installation of two 130 tonne converters. One more converter was added later on.

Initially, the converters at LD1 only had an oxygen lancing facility whereby oxygen is blown from the top through a lance with a three-hole tip. This was not very suitable for the local raw materials and the resulting metal and slag. There were many problems such as higher phosphorus content in the steel (0.035 %), a higher slag volume, higher turndown temperatures, lower lining life, etc.

The Steelmaking Research Group of the R&D Division played a major role in tackling these problems. A large research programme was launched in 1990 using a water model of the LD converter. These investigations concentrated on the effects of various process parameters on the mixing and mass transfer in the converter. Researchers studied various bottom purging arrangements, such as Bath Agitated Process (BAP) and Thyssen Blowing Metallurgy (TBM), and studied their impact on productivity and steel quality. They also developed a new top lance with different holes in the lance tip. These experiments showed a need to make changes in the design of the converter and its operating practice. Two



The decades of reducing Phosphorus in liquid steel examples were the replacement of the old three-hole lance tip by a new six-hole lance and the asymmetric location of eight tuyeres at the bottom of BOF vessel at LD1.

The result was dramatic improvement. For example, the life of the converter lining in LD1 increased more that sevenfold; from 160 heats in 1983 to 1211 in 1997 and more than 2000 heats in 2002. This was a world-beating achievement for a lining made with tar bonded dolomite bricks.

At the time, conventional wisdom dictated that a highly basic steelmaking slag with 7 % MgO should be formed to protect the lining. By studying the fundamental kinetics and thermodynamics of the converter process, R&D discovered a different approach using a slag of less than 2% MgO. This new operating strategy eliminated the use of dolomite and manganese ore fluxes during steelmaking, thereby reducing production cost and creating more stable and reproducible operating conditions.

By 2005, the life of the dolomite lining life was raised further to more than 2300 heats as a result of introducing other tactics. Today the lining survives more than 5000 heats following the changeover to a different type of lining using Mag-carbon bricks in 2006.

Most Indian iron ores contain elevated levels of phosphorous. This increases the phosphorous content of liquid iron. It represents an extra challenge since phosphorous needs to be removed during steelmaking to create high quality ductile steels.

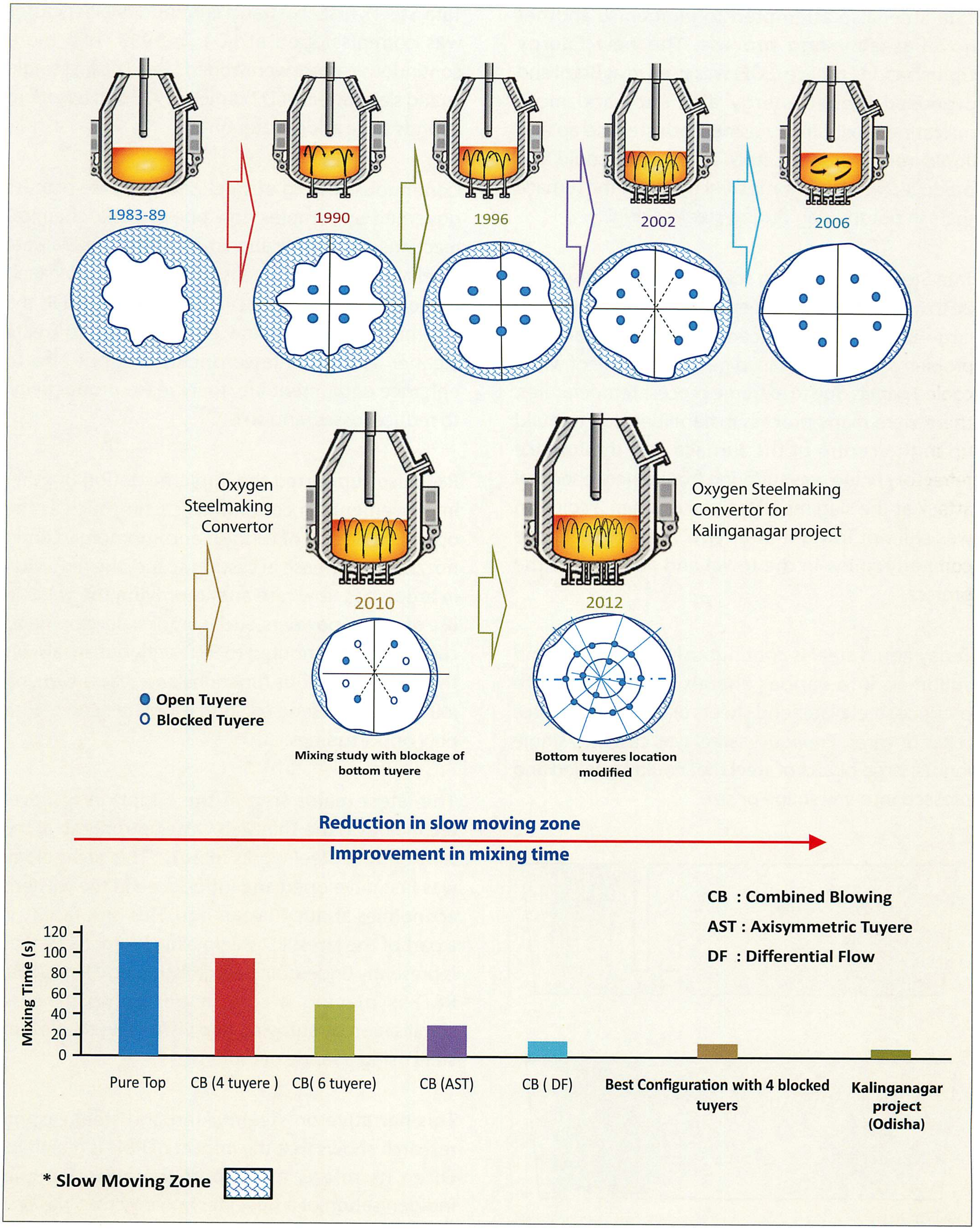
In 2004, R&D launched a new strategic development project to lower the phosphorus in steel. Its aim was to demonstrate the production of steel with a phosphorus content of below 0.015% from hot metal with phosphorus content of up to 0.22%. This project was conducted jointly with various foreign institutes and involved many colleagues in operations for conducting plant trials. New initiatives included the development and application of advanced knowledge of slag formation and the development of a novel approach for the injection of argon gas into the converter to improve the mixing of steel.

This new approach was called Differential Flow and uses non-uniform flow from eight injection points located in a symmetric pattern in the bottom of converters at LD2. A water model study showed that the differential flow of argon reduced mixing time by about 35% and increased mass transfer by 30% compared to conventional uniform flow. When implemented at the last part of a heat, differential flow also results in reduction of phosphorus content and saves consumption of costly argon gas.

Data analysis also showed that actual phosphorus partition in the LD converter is much lower than the thermodynamic equilibrium. This means that the reactions that allow the transfer of phosphorous from the steel into the slag are not fast enough to complete this task within the given time. To overcome this problem, R&D developed a new design of lance tip using water modelling in combination with computer models. These computer models allow the simulation of different process conditions and were developed by in-house specialists in advanced computational fluid dynamics.

The new lance tip has a central hole to create a subsonic oxygen jet that impinges on the steel bath. Its purpose is increase steel droplet formation during oxygen blowing to create intimate mixing of steel and slag. These new lance tips are currently undergoing trials at the LD plants in Jamshedpur.

Clearly, adoption of LD steelmaking technology and subsequent developments to make it amenable for Indian raw materials proved to be a successful indigenisation of a foreign technology. However, not all such ventures turn out in a similar way. In the mid-1980s, before putting up the LD2 steel plant,

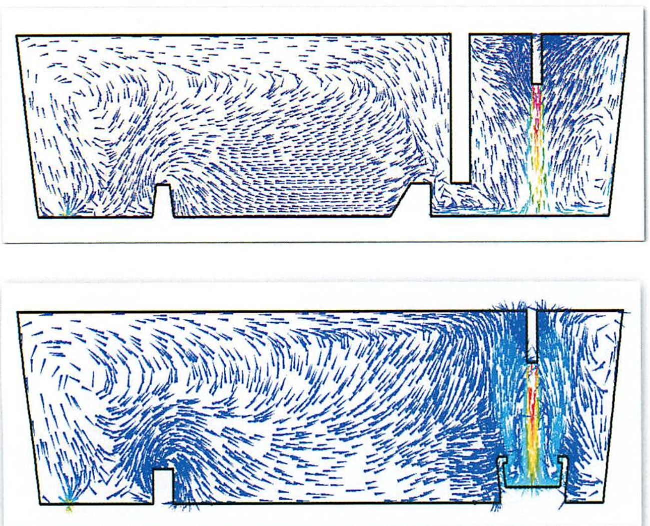


Reducing mixing time in LD Steelmaking using different bottom tuyere arrangements

Tata Steel also attempted to indigenise another novel steelmaking process. The new Energy Optimisation Furnace (EOF) was used in at Brazil and promised higher energy efficiency and more operating flexibility by using both steel scrap and liquid iron to produce steel. The furnace could also produce low phosphorus steel by tilting the furnace to flush out the slag during steelmaking.

Tata Steel attempted to scale up this process from 20 to 80 tonnes of steel per heat. Unfortunately, the large 80 tonne EOF faced too many intractable problems. Operators faced frequent failure of water cooled panels due to extreme process temperatures, there were many process instabilities due to build up in the centre of the furnace and the furnace refractory lining was suffering from severe chemical attack at the slag metal interface. When a solution was still not in sight after two years of trials, the company threw in the towel and abandoned the project.

Today liquid steel is continuously cast, cooled and solidified into various shapes, such as slabs to produce steel plates and sheets or billets to produce rebar or wires. Previously steel was cast into single ingots; large blocks of steel that could be rolled and pressed into any shape or size.



Numerical modelling of fluid flow in LD3 tundish with different flow configurations

Tata Steel's first six strand continuous billet caster was commissioned at LD1 in 1983. Two more continuous casters were added later. The first single strand slab caster at LD2 came in 1992 and two more strands were added later on.

Continuous casting of steel is an intricate process governed by complex flow phenomena, chemical reactions and solidification mechanisms. R&D at Tata Steel has carried out extensive studies to understand and optimise these processes. These included the optimisation of steel flow characteristics to create cleaner steel with fewer inclusions, but also to enhance equipment life, to increase productivity, to reduce losses, and so on.

R&D also supported the implementation of other improvements in continuous casting such as the optimum design of tundish and submerged entry nozzle, the increase in casting speed, the reduction in argon gas flow rate and improving the value in use of mould powders. Such complex developments can never be attributed to R&D only, but are always the result of various functions and teams working jointly to overcome existing problems and realise new opportunities.

The latest major step in the adoption of novel technology is the Thin Slab Caster introduced at the Jamshedpur steel works in 2012. This technology was first developed and introduced in the western economies about 10 years ago. This new facility is a part of the latest LD steelmaking plant (LD3) that is presently undergoing commissioning. Here again, R&D is playing a role in hastening process stabilisation by studying and visualising the flow of steel using a range of models.

This narrative on steelmaking and steel casting research shows that the impact of R&D is manifold. Often its role is to support the adoption and indigenisation of a novel technology that was first piloted outside India. Even then, the technical challenges are huge. Over the years, the steelmaking and casting research group of the R&D division has developed very strong modelling capabilities, both in physical water models and virtual models in the form of computational fluid dynamics. Also the chemical reactions can be predicted effectively using various types of software. With the development of ever more advanced computational models and the adoption of more accurate measuring techniques, we can expect new breakthroughs and see researchers thrive in this complex and exciting field of steelmaking.

Scaled down water model of the billet caster tundish at Tata Steel

Energy efficient ingots

Trapezoidal shaped pig iron ingot

Small and medium-sized steel foundries that have no access to captive ores are dependent on pig iron ingots that are mainly produced in mini blast furnaces. These foundries use cupola and induction furnaces to melt iron ingots. Mini blast furnaces are the main source of foundry grade ingots. Ingots that cool fast during manufacturing and melt faster in furnaces are desirable for higher productivity and help the customer to save energy. In 2010, Tata Steel R&D and Tata Metaliks, a leading company in the Indian pig iron industry with 16% market share, jointly launched a project to develop a new design of ingot that meets these requirements.

Researchers from Tata Steel R&D first used computer simulations to optimise the shape of the ingot. Through resistance network modelling and heat transfer analysis, a trapezoidal shaped ingot was found to take 25% lesser melting time than other conventional shapes. Experiments with wax ingots revealed that the new ingot design had the best packing density and a better distributed voidage compared to earlier ingot designs.

Use of this innovated ingot in an induction furnace can result in 13 minutes less melting time compare to a standard ingot, thereby substantially saving in electrical energy. In addition, product consistency at Tata Metaliks improved and spillage scrap was reduced. By re-designing the ingot, Tata Steel R&D helped Tata Metaliks to establish a new and differentiated product titled Tata eFee in a market that would otherwise driven by price alone.

In its infancy itself, Tata Steel had to focus its energies on providing a product - rails for the Indian Railways – which had never been made in India. The endeavour sowed the seeds of industrial research in the company. This interplay between meeting new market demands and R&D efforts. That has kept Tata Steel in the vanguard of steel product innovation in India.

Wire rod manufacturing at the Tata Steel Wire Rod Mill

Right from its inception, Tata Steel's primary goal was to create products that meet the requirements of customers in the Indian market. In the beginning, the nature of these products was largely dictated by the British colonial regime. In those days, being the only integrated steel plant in the East of the British Empire came with onerous expectations.

This particularly concerned steel products for the nascent Indian industry and the country's requirements for infrastructure, such as roads, bridges and railways. In fact, back in 1912 the very first products to roll out of the new steel plant were rails for the country's rapidly expanding railway network. Also the First and Second World Wars triggered a strong demand for steel. The earlier chapters in this book have already related this story in detail.

From the mid 1950s, India saw rapid and pervasive development of its infrastructure. These initiatives were led by the independent Government of India and particularly focused on the construction of dams as well as all-round industrialisation. Central themes in the government policies for Industry and Trade were technological self-reliance and import substitution dictated by the shortage of foreign exchange.

In 1960s, the Joint Plant Committee (JPC), an autonomous body constituted by the Government of India, governed the policies for pricing and distribution of steels produced in India. Unfortunately, the prices fixed by the JPC were so low that Tata Steel could barely generate enough profits to maintain its outdated equipment. Fortunately, special steels and alloy steels were kept outside the purview of JPC and their prices were determined only by market trends. This was an opportunity for an innovative company like Tata Steel, which by then had a well-established capability for research and development.

Management therefore initiated the development of new products to increase Tata Steel's profitability. This meant gradually changing the product mix to those steels with highest profit margin and also developing new special steels and low alloy steels that were not governed by JPC policies. These new developments included rimming steels with low residuals for the manufacture of wire rods for welding electrodes and also cold rolled steel strip and tubes for boiler applications. Also, various steels were identified that could still be produced with a good profit margin, despite being under the purview of JPC. Amongst these were LPG sheets, weldable steel plates, high strength billets and gothic section bars for the production of seamless tubes.

During the early 1970s, Tata Steel decided to diversify into special steel products for the engineering industry. The production facilities available then were basically suited for manufacture of mild steel grades. Several in plant operations therefore have to be modified. Examples are the augmentation of the bottom pouring facility, judicious use of hot tops, capacity expansion for controlled cooling and heat treatment, use of roller guides instead of friction guides in rolling bars and many more. New control practices were also introduced, such as rapid analysis centres at the steel melting shops. The use of the latest analytical techniques, including X-ray fluorescence, led to effective control of bath slag composition, steel de-oxidation and consistent steel quality. These laboratories are still part of the R&D and Scientific Services Division and continue to offer state of the art analyses for accurate quality control.

Under the government policy to stimulate import substitution, Tata Steel's R&D designed many new steel products and supported their successful commercialisation. The two decades from 1970 till 1990 saw a wide range of product introductions.

Low-Alloy High-Strength Structural Steels were developed and produced by quench and temper techniques using indigenously available ferroalloys. A pressure quench pilot plant was designed and built by R&D as a part of this programme. High strength steels in the range of 550 to 700 MPa with satisfactory ductility, weldability and notch toughness could be obtained using this technique.

During the mid 1970's micro-alloyed plates, sheets, strips and structural products were produced by refining the grain size of low carbon ferrite-pearlite steels with the use of small amounts of niobium and/or vanadium. Ferro-titanium, which was available in the country, was also used extensively to replace conventional imported ferroalloys. During the mid 1980s further modifications were made in the steelmaking operations, particularly the de-oxidation technology, in order to reduce the production cost of these micro-alloyed steels.

Steel tubes manufacturing at the Tata Steel Tubes Division

Extra deep drawing quality sheets were developed by treating low carbon steel with boron and titanium in order to improve formability and strain ageing characteristics. Also, cold drawn seamless tubes were developed for defence purposes. The specific process parameters were determined in close liaison with the research wings of defence establishments and about 1500 tonne of tubes were supplied.

Tata Steel also developed wear-resistant plates and closed die forged blanks. A new product called 'Tiscral' was sold in the form of plates and was the first wear-resistant steel produced in India. Close die forged blanks were designed specifically to Inter Steel Plant Standards. Tata Steel also met the requirement of the Indian Ministry of Defence for turret rings for the Vijayanta Tanks.

In addition, Tata Steel developed a wide variety of plain carbon and low alloy steel strip with a high degree of cleanliness. They were commercialised for a range of applications, such as hack saws, razor blades, springs, chains, etc. This almost completely substituted imported medium and high carbon steel strip. Other new steel products included extra low carbon steel in the form of plates and strip for applications in galvanising pots and magnetic relays.

During the 1980s, Tata Steel also attempted to develop an inexpensive lamination-grade silicon-free steel for fractional horse power motors. The steel was made with deliberate addition of manganese and phosphorus to increase electrical sensitivity. Boron was also added in order to reduce the detrimental effect of mobile nitrogen. However, because of inadequacy of the sheet and strip mills of Tata Steel, this grade could not be commercialised.

With new facilities available in Tata Steel, an array of new products was added to the basket of existing

The development of wire rod for CO_2 welding

MIG/MAG steel wire

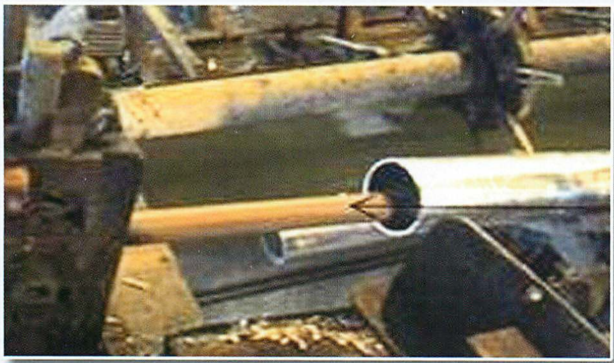
A typical example of a recent successful product development by Tata Steel R&D is the development of wire rods for direct drawing into CO_2 welding wire. At present more than 72,000 tonnes of this product is sold and this technology is protected through a patent that was granted in 2008.

The salient feature of this development was the design of a new steel with low carbon (0.07- 0.09%), high manganese (1.4 -1.8%) and a restricted nitrogen content (<50 ppm). The objective was to obtain a predominantly ferrite microstructure with suitable mechanical properties after processing through Tata Steel's wire rod mill in Jamshedpur. This chemistry enabled direct drawing from the wire rod to the final wire size without the occurrence of significant strain ageing.

Wire rod mill processing parameters like mill speed, laying-head temperature and Stelmor conveyor speed were determined by thermo-mechanical simulation experiments and deployed to attain the desired microstructure in the commercial product. The ferrite grain size was maintained at around 10 µm to meet the yield and tensile properties. Wire rods of 5.5 mm diameter were successfully drawn to 0.8 mm diameter without any intermediate operations of annealing and pickling, marking a major advancement in wire processing technology in India and resulting in lower cost and reduced environmental impact.

This example shows how a high level of expertise in steel metallurgy, lab experiments and plant trials come together to create a successful new steel product.

Reduction of zinc consumption in tube galvanising



Novel tube inner wiping system to remove excess zinc

The Tubes Division of Tata Steel manufactures high quality galvanised steel tubes whereby steel tubes are pre-treated and then dipped into a hot zinc bath. These tubes have a superior resistance against corrosion and are used in plumbing applications.

In 2010 it was noticed that the gross zinc consumption in tube galvanising was much above the benchmark value. This can be caused by non-uniform inner coating, excess dust loss or zinc dross formation. Excess consumption of zinc means a loss of a valuable raw material and results in higher costs.

A study was carried out to develop detailed understanding on zinc solidification in an industrial tube galvanising line. The entire process was simulated using computational fluid dynamics to predict zinc flow, heat transfer and the formation of a surface wave on the liquid zinc layer.

It was coneluded that zinc on the tube inner surface has already solidified along one third of the tube length before steam is blown through the tubes to remove excess zinc. The wavy coating profile that develops during steam jet blowing was also predicted and matched well with the measured profiles on actual tubes.

A solution was developed and implemented in the form of a new internal wiping system to remove excess zinc from the inner tube surface. This has generated a smoother inner tube surface and has decreased the gross zinc consumption by reducing zinc dust and zinc dross formation. The reduced zinc consumption now generates considerable cost savings each year.

products. Spring steel flats for automobiles, rolled-forged rings for the bearing industry, deep drawing quality steels in the form of strips for the cold rolling industry and the automobile industry, low alloy clean forging quality steels for crank shafts, gears and forged products for the engineering industry are some examples.

Through intensive research and very long periods of testing, creep resistant steel for use in boilers was developed and commercialised. Meanwhile, to meet the demands of railway axles in the country, the Railways had set up a Wheel and Axle plant in Bangalore. In a short span of four years, Tata Steel developed and supplied for 70% of the demand of low hydrogen steel for axles made in that unit. Tata Steel also supplied over 5000 tonnes of seamless bars to discerning customers like Bharat Heavy Electricals for the production of seamless tubes for boilers and other applications.

During these years, the product offerings from Tata Steel grew richer and richer as more and more market segments were identified. Corrosion resistant rebars, long and cross members for medium and heavy commercial vehicles, steel for automobile wheels, clean steels for the bearing industry were some relevant examples.

However, this rampant diversification of Tata Steel's product portfolio came to an abrupt end. In 1991 India was bailed out from a foreign exchange crisis and the International Monetry Fund and World Bank forced the Indian Government to open up the economy and remove a host of industrial and trade restrictions.

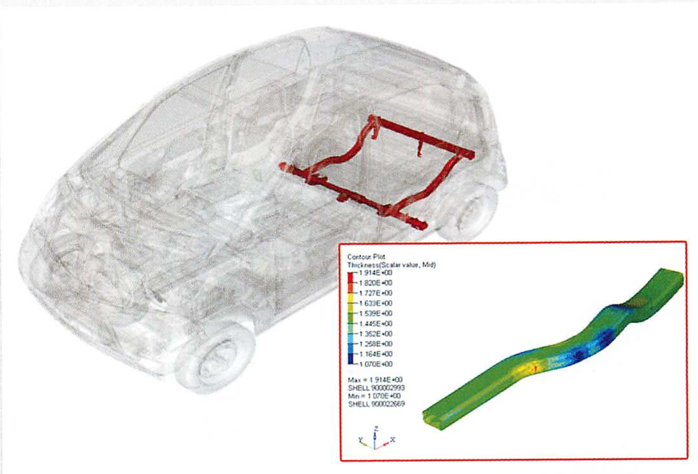
Import substitution was no longer a holy cow. For a private company like Tata Steel these new freedoms were a welcome relief in operational terms, but also a fresh challenge as it had to stand up and compete with imports from top international steelmakers. At the same time, the Government's own steel plants had become well-established and were in a position to compete keenly. All this meant that Tata Steel had to deploy new competitive strategies including a rationalisation of its wide product portfolio and a focus on core competencies in selected markets.

Changing rules for foreign direct investment resulted in the advent of multinational manufacturing giants into India, particularly in area of automobiles, auto components, electrical engineering, electronics and domestic appliances. This gave a boost to economic growth resulting in a growing population of middle class consumers with demands for the latest consumer goods.

One such newcomer was the Suzuki Motor Corporation, a major Japanese carmaker. During the 1980s it established a modern car manufacturing plant near Delhi in a joint venture enterprise with Maruti Udyog Ltd. and the Government of India. Initially, Maruti had to source steel from Japan as the Indian steel industry could not meet the quality requirements. Indian steel mills had not yet mastered the technology to make the light alloy high strength steels that the Japanese manufacturers preferred for their lightweight and energy efficient cars.

As the leading alloy and special steel producer in India, Tata Steel took up the challenge to meet

Reducing the weight of Tata Nano with hydroforming technology



One of the primary challenges in automobile design is to reduce the vehicle weight with improved structural performance, thereby improving both fuel economy and crash safety. Tube hydroforming is an advanced technology to form complex components that are structurally stiff, strong and lightweight. These are can be used in the structural parts of a vehicle body.

The process involves the use of a specialised type of die whereby high pressure hydraulic fluids are injected inside a steel tube to shape it into the desired form. It can produce complex components in one processing step, thereby preventing stamping and welding of multiple components.

However, a hydroforming component needs to be designed by specialists in order to take full advantage of the process. When Tata Motors took up a challenge to develop and produce the Tata Nano, the world's most affordable car, Tata Steel supported this initiative through design, development and manufacturing of a hydroformed engine cradle component. The design made by the joint team resulted in 26% weight reduction and 22% cost reduction compared to a cradle produced through conventional means. Tata Steel R&D now offers these hydroforming design solutions to premier automotive customers.

Maruti's needs. By then, Tata Steel had already geared up new production facilities like oxygen steel making, continuous casting and a hot strip mill that could provide the required quality of steel. It was also in the process of setting up a modern cold rolling and galvanising mill in collaboration with Nippon Steel, a major Japanese steelmaker.

While Tata Steel's R&D was investigating how to consistently produce the required steels, its sales engineers were working with Maruti's indigenisation team and provided quick and valuable feedback on the performance of the new products provided by Tata Steel. In the end Tata Steel was able to meet Maruti's needs of special steels and also that of its own sister concern, Tata Motors that had just started producing cars too.

By the time that Korean, German and American car manufacturers entered with automobile plants in India, most of their steel needs could be met by Tata Steel and a few other Indian steel producers. This successful localisation of steel supplies in an important factor creating a globally competitive car industry in India.

DSIR National award for 'R&D efforts in Industry' in the New Materials category for developing high strength steel for auto body (awarded to Tata Steel 2001)

This drive was also extended to the Indian two-wheeler and three-wheeler sectors. For example, Indian two wheeler manufacturers used to make petrol tanks with imported materials such as Terne coated and electro-galvanised steel sheets. In 2003, Tata Steel developed a corrosion resistance chromate coating on galvannealed steel sheet and replaced the above products with superior performance.

In another such instance, low carbon low alloy steel strip has been developed for Bajaj Auto. Compared to conventional grades this steel possesses more than 50% higher yield strength and 35% more tensile strength, both in welded and normalised conditions. Because of its higher strength, thinner gauge strip can be used for making tubes, which reduces tube weight by 20% and also creates superior dent and crash resistance.

Another product that was recently developed is a cold rolled batch annealed bake hardening steel. This grade undergoes a 25% increase in yield strength during commercial baking of the paint in automotive body shops. It allows a 20% decrease in thickness of car body panels, making cars lighter and more fuel efficient.

The development of such greener steel products is a strong and ongoing trend. India, as it industrialises further, has entered in the most energy-intensive phase of economic growth. This will continue to bring investments in industrial equipment, infrastructure and transportation methods for raw materials, goods, energy and people.

The steel industry in India is expanding to meet the resulting growing demand for steel. The average steel use per capita in India of 50 kg per year is presently well below international average and is set to rise substantially in the forthcoming decades. At the same time, it may be expected that Indian steel use will never rise to the consumption patterns as presently seen in some developed economies (500 kg per capita per year). Reasons being the development of new types of advanced high-strength steels that enable lighter manufacturing and construction.

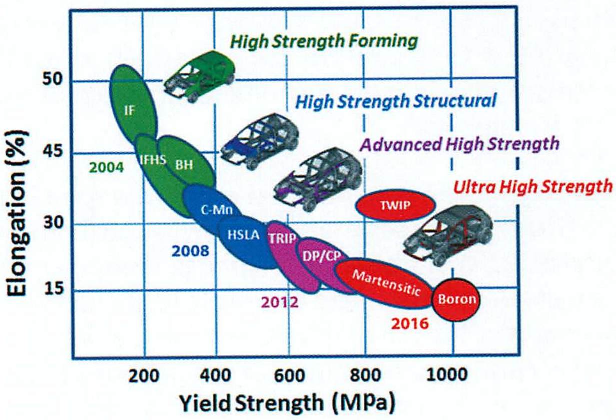
This trend is particularly evident in the development of new steels for lighter and safer car bodies; similar trends exist in light-weighting packaging, engineered equipment, buildings, etc. Tata Steel is technologically leading such trends in India and is thereby supporting India to emerge as the worldwide manufacturing hub for the ultra small and fuel efficient cars.

Tata Steel's R&D has already invented some interesting possibilities for new advanced grades, such as a high strength interstitial free steel using solid solution strengthening elements such as manganese and phosphorus, a high strength non-microalloyed galvannealed steel using carbon and manganese as strengthening elements and a new precipitation-hardened high strength hot rolled sheet with a ferrite matrix and nanometre-sized precipitates. The latter also has a high fatigue resistance and is being developed for long members of a future range of trucks produced by Tata Motors.

It is not just the automobile industry that R&D targets for its new product developments. For example, low carbon steel using boron to cause lower work hardening by causing coarse grain ferrite micro-structures developed for making ERW tubes for town water transport and replaces the more expensive FM tubes. New coatings are being developed for steel which employ polymers and nanoparticles of silica, titania and alumina to replace expensive zinc and harmful hexavalent chromium.

Developing advanced high-strength steels

Developments in automobiles are driven by four key factors: fuel efficiency, eco-friendliness, safety and cost. To meet these trends, research is underway to develop advanced steel grades with a combination of high strength and high ductility. Components made from such steels are light, strong and stiff, with a high capability to absorb energy in the event of a crash.



Development of advanced high-strength steel grades requires novel steel chemistries and very specific processing parameters so that the optimum combination of properties is achieved without adding very expensive alloying elements.

Tata Steel's R&D has defined a technology development roadmap until 2012. This plan includes the development of a high strength steel for automotive applications with a strength of 1000 MPa and 50 % elongation. Today no steel manufacturer as is able to meet this target.

As part of this development programme, R&D has already developed hot rolled steels of 600 MPa and 800 MPa strength, which have been commercialised. Further efforts are underway to develop a family of new generation high strength steels such as high strength 1200 MPa bainitic steel grade with high ductility, a ultra-high strength TRIP assisted steel for crash and structural components and several nano-precipitate strengthened steel grades with a combination of high strength, high ductility and superior weldability. Alongside, Tata Steel R&D also works on the development of durable hybrid joining techniques, so that complex car components can be formed out of multiple steel grades.

75 years of microscopy

The microscopic characteristics of steels and its raw materials, such as ore and coal, determine their macroscopic physical and chemical properties. Optical Microscopes and other microscopy systems have therefore always been important tools for material characterisation in the R&D and Scientific Services Division. Throughout its 75 years, the Division has continuously augmented its capability in this field. We hereby recall the developments in the past 20 years.

In the late 1990s there were several investments to improve the materials characterisation laboratories. An ISI 40 scanning electron microscopy system was acquired and the optical microscopy systems were enhanced with an image analyser attached with 36 mm photographic facility. These facilities provided black & white high resolution imaging, manual phase analysis and grain size measurement. Later a Zeiss Axio Plan optical microscope was also added with more sophisticated capabilities and digital image analysis. This microscope was subsequently upgraded to a system for polarized optical microscopy to identify the mineral phases present in raw materials.

Next, the old SEM was replaced with a new scanning electron microscope attached with an energy dispersive spectrometer for phase composition analysis. A manual micro-hardness tester had also been added. These facilities allowed the identification and accurate quantification of the various phases present in raw materials, sinter, refractory and steel. It allowed the operator to precisely identify the microstructure, to measure the hardness of individual phases and to digitally store images.

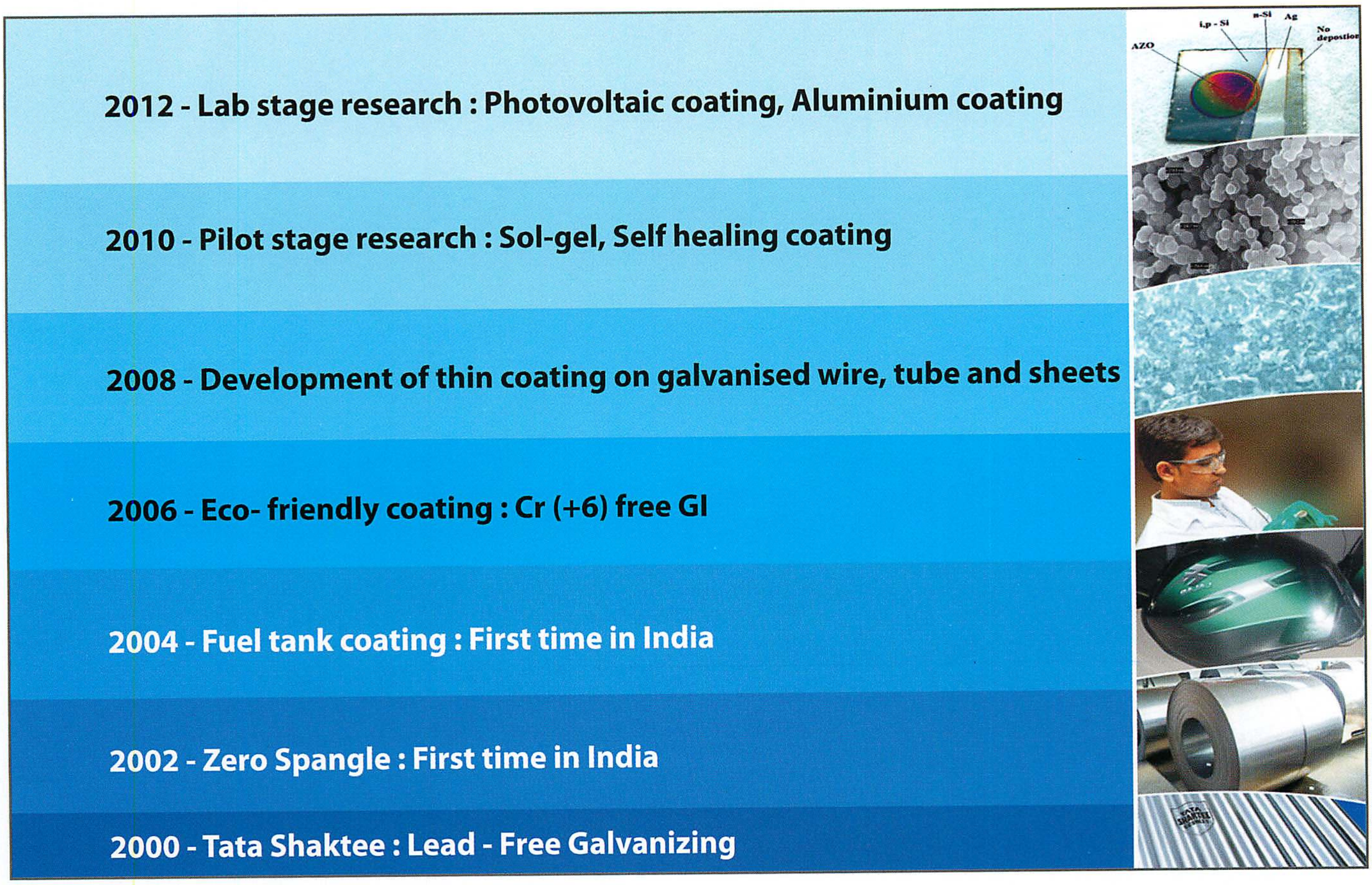
In 1999 a system for Electron Back Scatter Diffraction (EBSD) was added; a technique used to examine the crystallographic orientation of materials. It allows the researcher to predict steel properties prior to plant experiments and helps the determination of grain orientation of different phases in the steel. However, by this time the performance of the old scanning electron microscope had deteriorated and fine precipitates and microstructures could no longer be observed.

The year 2006 saw the next step-change in the metallographic laboratory. A state-of-the-art (QEMSCAN) Quantitative Evaluation of Minerals by Scanning Electron Microscopy was acquired. This automated mineralogy and petrography system, the first in India, was installed to augment raw material characterisation and support the development of raw materials beneficiation processes. Other investments included a new Field Emission Scanning Electron Microscope (FESEM) attached with facilities for both EBSD and for Energy-Dispersive X-ray spectroscopy (EDX) for the analysis of a sample. Also two X-ray diffraction facilities (XRD) were acquired (one powder XRD and another dedicated to material research) and a fully automatic optical microscopy system with image analysis software to analyse inclusions in steel. Several new equipments for sample preparation were introduced alongside.

Microstructure imaging beyond one thousand times magnification and up to 100 thousand times is now possible. It allows the observation of nano-sized precipitates in steel. In fact FESEM coupled with EBSD has generated orientation data of very small sample areas. With the help of XRD, one can now obtain information on the volumetric proportion of phases, the bulk textural relationship, the high-temperature effect on phases and also a stress analysis can now be obtained.

Using QEMSCAN and XRD, researchers are able to characterize raw materials comprehensively and generate information on phase identification, modal phase percentage, grain size distribution and liberation effectiveness during beneficiation. This information is crucial to increase the pace of developing new process flowsheets for raw materials beneficiation.

Future investment plans include a new scanning electron microscope and an advanced optical microscopy system for raw material studies to meet the growing needs stemming both from operating divisions, mine developments and R&D projects.



Development of new coatings at Tata Steel R&D

An environment-friendly coating for MIG welding wire electrodes was also developed recently. It reduces spatter and smoke during welding, resulting in a safer work environment. Thin organic coating formulations developed for galvanised products and double its corrosion resistance. This novel coating is only several microns thick and was already commercialised for superior quality steel wires and plans are in place to apply the same to steel tubes and steel sheets.

Several other advanced coatings are under development at R&D. These include a photovoltaic coating to generate solar electricity to be used on steel roofing products, and also a self-healing protective coating that has the ability to heal from scratches just like a cut in a living skin.

As India continues on its path of development an industrialisation, it will be attracting more and more high-tech industries such as wind power, solar photovoltaics, marine structures, oil gas and nuclear power. Steel in its countless avatars remains the king of all structural and construction materials. Tata Steel looks forward to meet the needs of these new customers. It will be a contest of innovation and competition. Knowing its history, we can conclude that Tata Steel with its R&D and Scientific Services Division is capable to face up to this challenge.