OVERVIEW OF STEEL INDUSTRY AND WELDING RESEARCH IN KOREA

Chang Hee Rhee
Pohang University of Science and Technology-POSTECH-MSE

Abstract

From virtually no steel production after the Koran war, steel industry in Korea had a phenomenal growth to reach crude steel production of 40 million tons level in 1997 and became the 6th largest steel producer in the world. The growth owes to steel technologies developed elsewhere over centuries and decisive management decisions to adopt new technologies as quickly as possible. Steel technologies are reviewed and brief overviews of welding research in Korea are presented.

1. Iron and steel production

Although 'Iron Age' lasted many centuries, the production capacity was rather limited to a few kilograms at the beginning and grew to a few tons much later. It is hard to imagine that the world pig iron production matched in 1700 the daily production of a single large modern blast furnace; 10000tons. United Kingdom, then the leading iron producer, made 20000tons of pig iron in 1720. An annual output of one million tons in UK was achieved for the first time in 1835 and the iron production in UK grew till 1872 to reach 6.75 million tons. The growth rate slowed down over next 20 years to have about 8 million tons level. The leading role in iron and steel industry shifted to continental Europe and the United States, making pig iron production of the world from 13.6 in 1875 to 30.2 million tons in 1895.

Ever since Bessemer Process was introduced by Sir Henry in 1856 for mass production of steel, we are living in 'Steel Age,' preceded by 'Iron Age,' 'Bronze Age' and 'Stone Age.'

Once tonnage steel was feasible, the production rate increased reaps and bounds with other steelmaking processes; Open Hearth Process, Thomas Process and Electric Arc Furnace Process, which dominated the first half of 20th century to produce 189million tons of crude steel in 1950.

The second half of 20th century had another jump of steel production with introduction of Basic Oxygen Process and large Electric Arc Furnace Process. World crude steel production reached 700million tons in 1973, and the world wide growth rate slowed down markedly due to oil shocks. Crude steel production remained below 800million tons level till the end of the century. Korean production grew steadily from 1 million in 1973 to over 40 million tons in 1997 and then leveled off.

2. Current Status of Iron and Steelmaking Technologies

Present steel technologies have been developed over a long period; some over hundreds years and some over 50 years. Although technologies keep on developing, a typical integrated steel works nowadays consists of plants to process raw materials to steel products in major divisions of Ironmaking, Steelmaking, Continuous Casting, Hot- and Cold Rolling, Heat treatment, Surface treatment, etc.

Steel technologies had a few revolutions and many steps of evolutions. Improvement of product quality, reduction of production cost and less pollution are major themes of new technologies. Technologies to increase productivity and yield and to save raw materials, energy and manpower are for the cost reduction. Technologies to improve steel properties such as strength, ductility, formability, weldability with less quality deviation have been developed and yet better ones are still being developed.

As each plant in Steel Works consists of huge, expensive facilities, an accurate process control is required for a smooth operation without interruption. Introduction of computer aided control centers in the seventies and further upgrading of the central control system improved the efficiency of the Steel Works.

2.1 Ironmaking

Ironmaking is the extraction process of iron from iron; usually by smelting in a Blast Furnace to produce hot metal or by Direct Reduction Processes to make direct-reduced iron(DRI). Modern Blast Furnace Ironmaking technology has been developed over thousands years, more by evolution than revolution. Methods to supply combustion air had a few revolutions such as water wheel, steam engine and turbo-blower. To preheat the combustion air and application of coke instead of charcoal introduced in 1709 are other revolutions. Growth in size of Blast Furnace was a slow gradual process from a few cubic meters in 15C to hundreds cubic meters at the end of 19C. The pace of growth took off in the last century to thousands cubic meters. The furnace size is directly associated with a daily production from a few tons at the beginning to 10 thousand tons with a furnace of 5000 m3 inner volume. Improvements in burden preparation, higher blast temperature and better furnace control resulted in reduction of fuel rate from 8-9 to 0.5.

Less expensive iron ore (Goethite) is introduced and sintering operation is optimized to increase productivity and reducing emissions.

The campaign life of a Blast Furnace has been extended to 20years due to various measures, such as reducing shaft overheating and hearth refractory erosion by a better operational control. The earliest 'blast furnace' had to be relined after every campaign lasting a few days and even in the nineteen seventies just before the all out efforts to extend the furnace life were initiated, the period was about 3 years in the average. At one time a blast furnace was a black box as the inside profiles could not be monitored. Recent development in monitoring system makes a reliable temperature profile, shape of cohesive zone, hearth liquid level and raceway penetration depth available for a better diagnosis and control of operation. Pulverized Coal Injection(PCI) is to replace coke with less expensive coal and reached about 40% of fuel rate. High efficiency PCI lance is being developed to increase the flame temperature. Injection of waste polymers into the blast furnaces has been tried for recycling of wastes and environmental protection.

FINEX Process is being developed as an alternative ironmaking process. It is a combination of COREX Process with a fluidized bed technology for fine ore reduction. COREX-2000 is in operation at Pohang Works since 1995 to produce hot metal at a rate of 2000 tons a day.

2.2 Steelmaking

Steelmaking is the refining of hot metal produced in a blast furnace or similar process, usually in a Basic Oxygen Furnace(BOF) removing carbon by oxidation with oxygen to carbon monoxide (CO) and other elements such as silicon, manganese, phosphorous and sulfur are transferred to a slag phase. Furnace size and productivity of BOF had dramatic increase in 50 years of oxygen steelmaking history from 30 to 300 tons and the productivity from 30 tons/hr to 600 tons/hr as the tap-to-tap time dropped from 1 hour to 30 minutes.

Another major steelmaking process is utilizing electric power to melt scrap or DRI and remove impurities from molten steel in an electric arc furnace (EAF). Technologies of EAF operation advanced significantly during its one hundred year history. Until ultra high power (UHP) technique was introduce in 1964 EAF steelmaking was rather limited to produce alloy steels due to higher energy cost. Availability of cheap scrap, increased furnace size, utilization of oxygen, advanced power supply system allowed EAF steelmaking process to share up to 40 percent of crude steel production worldwide.

2.2.1 Secondary Refining

After treating the molten steel in BOF or in EAF it is further refined in the ladle. This is commonly called secondary refining or ladle metallurgy. The processes include decarburization, deoxidation and vacuum degassing. A new RH-POSB has been recently developed for economical production of ultra-low carbon steels. Extra oxygen lances installed at the side wall of RH vessel accelerated decarburization with minimum temperature drop resulting in higher productivity.

For stainless steelmaking the liquid iron-chromium-nickel treated in EAF is refined either in an argon-oxygen decarburization vessel (AOD) or a vacuum oxygen decarburization vessel (VOD).

2.2.2 Casting

Efforts to reduce the processing time resulted in introduction of Basic Oxygen Furnaces for steelmaking and Continuous Casting of steel to replace processes of Ingot Casting, Soaking Pit, Primary Mills for slabs or blooms as well as Billet Mills. Since liquid steel is directly cast into slabs, blooms or billets, operations of ingot mold preparation, of stripping station, of soaking pit, of primary mills with associated ingot handling are short cut to save manpower, energy and processing time. Due to elimination of losses at casting station such as spillage and partial ingot, of scale loss at during soaking and rolling as well as crop loss of ingot a CC process has a much higher yield than an IC process.

Two innovative technologies are being developed in the area of near net shape steel casting. Thin slab casting makes about 80mm thick slab instead of the conventional 250mm thick ones to by pass the roughing mills in Hot Strip Mill. It has been successful in commercial scale in a few EAF steel plants, and the next step would be installation at integrated steel works. Strip Casting is the ultimate goal of continuous casting, since it will allow to shut down the whole Hot Strip Mill.

2.3 Steel grades

Steels with higher strength, in general, tend to have a lower ductility and poorer formability as well as less weldability. In order to counteract this tendency, super clean steels with fine grains have been developed. The cleanliness is secured at steelmaking and casting processes while grain size is controlled in the rolling stage via 'Thermo-mechanical control process" (TMCP). It is a new technology to have a simultaneous heat treatment of steels during hot rolling; if steels with micro alloying (such as niobium) are subject to control rolling and control cooling, about 1/2 size grains of conventional steels may be obtained. Since the carbon equivalent can be reduced in TMCP steels, weldability and toughness are significantly improved and they are widely used in shipbuilding, construction and pipe lines thanks to their improved formability and weldability.

2.4 Application of Steel Products

Construction industry is the largest consumer of steel products with about 50% of total steel demands, the other half being shared by manufacturing industries; general machinery, automotive industry and shipbuilding industry, in the order of demand tonnage. By steel grades, structural steels lead in demand for construction, automobiles, oil industry, shipbuilding, machinery and appliance industry. Other grades, such as stainless steels, silicon steels and various coated steels(tin, zinc, polymer) have special applications in industries.

2.4.1 Construction Industry

Construction of highways, railroads and infrastructure of metropolis and building construction demanded tonnage steels demands re-bars and other construction materials in 1970s, while harbor system, off-shore structures, high rise buildings in 1980s had a high demand on beams and large section steels. Steel housing project was successful to increase the demand on sheet steels by replacing two-by-fours in 1990s. Demands on maintenance-free steels and stainless steels are increasing.

2.4.2 Automotive Industry

Oil shocks in the past forced to reduce car sizes for fuel efficiency followed by more stringent pollution control. As the world economy recovered from the shock, weight of car increased a little bit for comfort and safety. Steel weight of a car remained (973/979 kg/car), while total weight increased slightly (1168/1204) in 1994/1999 in the United States. Automobile industry is the major consumer of cold strips. Interstitial-free(IF) steels have been developed for extra deep drawing quality to be used as car body. Molten steel must be treated in vacuum to reduce nitrogen and carbon to minimum(a few tens ppm range), and these remaining interstitial elements are precipitated as Ti or Nb compounds. IF steels make Continuous Annealing feasible after cold rolling, replacing conventional Batch Annealing; processing time dropped to mere 10 minutes from 3 days for Batch Annealing.

Bake hardened(BH) steels are popular as materials with easier stamping and higher dent resistance in the 400MPa strength range. For automotive parts requiring ultra high strength like wheels and members, truck frames, etc Transformation induced plasticity (TRIP) steels with 800MPa have been developed. For durability of cars over 80% of steel parts are made of surface treated steels. IISI is leading the Ultra-Light Steel Auto Body (ULSAB) program, working with 30 steel companies. The objective of the program is to prove that a reduction of 25% car weight is feasible with higher strength steels.

3. Welding Research in Korea

Recent industrial needs in welding related field are similar to other industry; cost reduction without sacrifice of quality. To meet the needs of industry it is necessary to increase productivity, to apply automation more widely to better control quality. For the development of welding technologies and materials following items have to be pursued; high efficiency and quality, new welding/joining processes, high performance welding materials and environment-friendly process.

As the leading steel producer POSCO plays the major role in the steel welding research in Korea. For technical services for customers such as car makers, ship builders and other manufacturers, POSCO evaluates the weldability of steels and helps customers in their trouble shooting of welding related problems. Some topics of recent research projects in the category of customer services are as follows ;

(1) Weld toughness of TMCP plates for shipbuilding, (2) Weldability of 409L stainless steel for fin tube in heat exchanger, (3) ERW melting mechanism for defect-free ERW pipes, (4) Analysis of weld defects in spiral pipe SAW joint.

During pipe making with electric resistance welding(ERW) penetrator defects may appear along the bond line. These defects are caused by oxides of Si and Mn formed at the weld joints. Close examination of defects indicated that formations of defects were related to the width of heating zone, showing periodic occurrence. The variation of heating zone width is caused by 'arcing and bridging', affected by such factors as welding speed, heat input, contact angle etc. By monitoring these factors and feedback to control the welding process penetrator defects could be minimized.

For development and modification of welding technologies and materials research work is carried out at POSCO on such subjects as high heat input welding, reducing weld cracking susceptibility, high performance welding consumables, extending of welding application and simulation of welding phenomena.

Among topics studied so far, a few are highlighted below:

- High nitrogen TiN steel for high heat input welding

For welding of thick plates used for large structures it is necessary to apply high heat input welding to have a higher welding productivity. With high heat input welding, however, austenite grain coarsening at Heat Affected Zone (HAZ), resulting in poor toughness, is unavoidable. For a normal HAZ toughness with high heat input welding, prevention of austenite grain growth is mandatory.

Hinted by stabilization effects of fine TiN precipitates, nitrogen addition was tried. With a higher nitrogen content in steel TiN precipitates became fine and stable at high temperature to prevent austenite grain growth and accelerated ferrite formation upon cooling. When high nitrogen steel had super high heat input welding(500kJ/cm), HAZ had much finer grains compared to normal nitrogen steel.

- Solid Wire for Low Spatter in CO2 Welding

CO2 welding has a dubious distinction of most frequent spatter producer among welding methods. Spatter is basically due to unstable arcing, which is affected by many factors such as welding conditions, power source, composition and surface conditions of welding consumables.

With conventional wire arcing was rather unstable with irregular short circuit between droplet and weld pool. By controlling chemistry of wire and improving the surface quality more stable arcing could be achieved reducing spatter in CO2 welding.

- Laser Welding for High Efficiency

Laser welding research is divided to application for sheet and plate. For butt joint of sheet Twin Beam Laser welding is investigated to minimize defects at HAZ and to maximize the welding productivity. Application of Twin Beam is studied along with Parallel beam, Sequential beam and Beam rotation.

In order to extend the application of Laser welding to plates, possibility of Hybrid Laser-arc welding is also explored.

- Automobile / Laser Welding

Auto industry is the leader in laser welding in Korea by applying in the fields;

- Tailor Welded Blank
- Car body welding
- Tube welding for hydroforming

TWB production system in Korea operates both In-house and Outsourcing. Among 14 lines 12 are with laser welding. Application of laser welding is expected to expand to high strength steels and coated steels as well as joining of different grades and different thickness in the future. Research and development in the field of laser welding have bright future.

4. Final Remarks

In spite of world wide slow down, Korean steel industry advanced steadily ever since the inauguration of the integral steel works in 1973, thanks to wise decisions to adopt most advanced technologies at right time and further development of steel technologies by dedicated scientists and engineers. Welding research is no exception and progress in this area is being made; first as technical services to customers and playing more active roles in development and modification of welding technologies and welding materials as well as weldability of steels.