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CURRENT STATE AND DEVELOPMENT OF STEELMAKING PROCESSES

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During 2003 year a total world's crude steel production was 945,1 Mt, which is for 6,7 % higher than in 2002. The paper shows current state steelmaking processes (Basic Oxygen Converter and Electric Arc Furnace) including a short review of secondary metallurgy, steel casting and environmental protective as well as the development of a new steelmaking processes.

Key words: *steel production, steel scrap, secondary metallurgy, steel casting, environmental protection*

Današnje stanje i razvoj postupaka proizvodnje čelika. Tijekom 2003. godine ukupna svjetska proizvodnja sirovog čelika iznosila je 945,1 Mt, što je za 6,7 % više nego u 2002 godini. Rad prikazuje današnje stanje postupaka proizvodnje čelika (bazični kisikov konvertor i elektrolučna peć), uključujući kratki pregled sekundarne metalurgije, lijevanje čelika i zaštitu okoliša, te razvoj novih postupaka proizvodnje čelika.

Ključne riječi: *proizvodnja čelika, čelični otpad, sekundarna metalurgija, lijevanje čelika, zaštita okoliša*

INTRODUCTION

In the 20th century steel has remained the dominant engineering material. In spite of all the changes steel will be the most important metallic material in the 21st century and it will remain the basis of all future industrial development and progress. From a global viewpoint the steel production and consumption in this century will increase [1].

A key the fact in the overall acceptance of steel as the engineering material of choice is that it is the most recycled material in the world. About 45 % of the total steel production is recycled [2, 3]. It is helping to change its image from rust-colored to "green material". In this a short review current state steelmaking processes as well as the future development was discussed.

CURRENT STATE OF STEELMAKING

In 2003 total crude steel production in the world was 945,1 Mt, which is a record (Table 1.). World crude production for the 63 countries reporting to the International Iron and Steel Institute was increased by 59,5 Mt in 2003 or 6,7 % increase in compared to 2002 [4].

Three largest steelmaker countries (China, Japan and United States) products about 45 % of the total steel production in the world.

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Asian total steel production reached 427,6 Mt, which is 12,0 % higher than in 2002. China is world's largest steelmaker. Production of steel in China reached 220,1 Mt in 2003, the first time a country has produced more than 200 Mt of crude steel in a year. It is increasing by 21,2 % compared to 2002. Japan is the second largest producer in the world as well as in this region with total production of 110,5 Mt in 2003.

The European Union produced 159,7 Mt of crude steel in 2003, which is 0,8 % higher than in 2002. Germany produced 44,8 Mt of crude steel.

Total production of steel in Russia reached 61,3 Mt in 2003, a rise of 4,7 % on 2002. The Ukraine produced 36,7 Mt in 2003. This is 7,8 % higher than for 2002. Total steel production for the other European countries was 48,5 Mt in 2003, which is 7,7 % higher than for 2002. The largest producer in this region was Turkey with total production of 18,3 Mt.

Today there are two established process routes for steelmaking. The blast furnace (BF) produces hot metal for refining to steel in the basic oxygen furnace (BOF or LD), and the electric arc furnace (EAF) remelts scrap. In 2002 the share of steel production obtained by means of BOF was 60% and EAF 34 % (Figure 1). Steel production in remaining open-hearth furnaces is negligible (3,8 % share of world steel production in 2002). It is predicted that the open-hearth process will disappear completely in the next few years.

Table 1. **The largest world's steelmaking producers, Mt**
Tablica 1. **Najveći svjetski proizvođači čelika, Mt**

Land	2003	2002	2000	1998	1996	1994	1992
China	220,1	181,5	127,2	114,6	101,2	92,6	80,9
Japan	110,5	107,7	106,4	93,5	98,8	98,3	98,1
United States	91,4	92,4	101,5	97,7	95,5	91,2	84,3
Russia	61,3	58,6	59,1	43,8	49,3	48,8	67,0
South Korea	46,3	45,4	43,1	39,9	38,9	33,7	28,0
Germany	44,8	45,0	46,4	44,0	39,8	40,8	39,7
Ukraine	36,7	34,0	31,4	24,4	22,3	24,1	41,7
India	31,8	28,8	26,9	23,5	23,8	19,3	18,1
Brazil	31,1	29,6	27,9	25,8	25,2	25,7	23,9
Italy	26,7	25,9	26,7	25,7	23,9	26,2	24,8
France	19,8	20,5	21,0	20,1	17,6	18,0	18,0
Chinese Taipei	18,9	18,1	16,7	16,9	12,4	11,6	10,7
Turkey	18,3	16,5	14,3	14,1	13,6	12,6	10,3
Spain	16,1	16,3	15,8	14,8	12,2	13,4	12,3
Canada	15,4	16,0	16,6	15,9	14,7	13,9	13,9
Mexico	15,2	14,2	15,7	14,2	13,2	10,3	8,5
United Kingdom	12,9	11,7	15,2	17,3	18,0	17,3	16,2
Belgium	11,1	11,4	11,6	11,4	10,8	11,3	10,3
South Africa	9,5	9,1	8,4	7,5	8,0	8,5	9.1
Poland	9,0	8,3	10,5	9,9	10,4	11,1	9,9
Iran	7,8	7,3	6,6	5,6	5,4	4,5	2,9
Australia	7,5	7,5	8,5	8,9	8,4	8,4	6,8
Czech Republic	6,8	6,5	6,2	6,5	6,5	7,1	7,3
Netherlands	6,5	6,1	5,7	6,4	6,3	6,2	5,4
Austria	6,2	6,2	5,7	5,3	4,4	4,4	3,9
Sweden	5,7	5,8	5,2	5,2	4,9	5,0	4,4
Romania	5,7	5,6	4,8	6,4	6,1	5,8	5,4
Argentina	5,0	4,4	4,5	4,2	4,1	3,3	2,7
Kazakhstan	4,8	4,8	4,8	3,1	3,2	3,0	5,7
Finland	4,7	4,0	4,1	4,0	3,3	3,4	3,1
Slovakia	4,6	4,3	3,7	3,4	3,6	3,9	3,8
Egypt	4,3	4,4	2,8	2.9	2,6	2,6	2,5
Saudi Arabia	3,9	3,6	3,0	2,4	2,7	2,4	1,8
Venezuela	3,6	4,1	3,8	3,7	4,0	3,5	3,5
Luxembourg	2,6	2,7	2,6	2,5	2,5	3,1	3,1
Indonesia			3,4	2,7	4,1	3,2	2,9
Others (< 2 Mt/y)	18,5	17,4	29,4	27,7	28,3	26,6	28,8
Total in the world	945,1	885,7	847,2	775,9	750,0	725,1	719,7

Basic oxygen furnace and electric steelmaking

The oxygen converter process is vary flexible with respect to the raw materials. The BOF charge is usually consists of 70 to 75 % liquid pig iron and 25 to 30 % scrap for cooling of the melt. As an alternative to scrap there are the direct reduced iron (DRI) or hot briqueted iron (HBI) produced by reduction of iron ore by natural gas and/or coal. For feed of BOF can using hot metal obtained by smelting reduction process (Corex process) but on a smaller scale than the blast furnace. Based upon the operational experience obtained from existing Corex plants in India as well as in South Africa and Korea can be concluded that this process is a proven alternative to the conventional blast furnace technology [5].

The most important oxygen steelmaking processes are: oxygen top-blowing process (BOF or LD processes), oxygen bottom-blowing process (OBM or Q-BOP processes) and combined blowing processes. Numerous companies are invented or modified a version of the oxygen steelmaking process to suit its own situation [6]. Consequently these are many designations for fairly similar processes (LD-AC, LD-KGC, LBE, LD-OB etc.).

Over the past 25 years the use of the EAF for the production of steel has grown considerably (a share increased from 20 % to 34 % today) in account the production by open-hearth furnace (Figure 1.).

DC furnace developed to commercialization over the last 15 years and they offers any advantages over the AC furnace.

The EAF charge is primary consists of scrap but the various iron alternative can be used (hot metal, DRI/HBI products). The quality of the steel produced is directly dependent on the purity of the scrap. In the world the processes to remove unwanted elements from steel scrap are developing. In European Coal and Steel Community (ESCE) sponsored project about recycling of scrap for high quality products in order to decrease of tramp elements [7].

The EAF process and plant engineering have undergone significant improvements with time [8]. Developments of EAF have improved its efficiency (Figure 2.). Today the EAF exists in three furnace types: single-shell furnace (top charging mode), double-shell furnace (top charge mode) and continuous charging furnace. The AC furnace is widely used for single-shell design, while DC furnaces now also applied to double-shell and continuously charging furnace [9].

The twin-shell furnace is composed of two vessels which are fed by one power supply. An electrode-holder system with rotation movement is common for both vessels. While the charge material (scrap, pig iron, DRI/HBI) is molten in one shell, the first basket is charged is positioned in the other shell were the power-on phase is started.

Shaft furnace is equipped with a preheating system and delivered with either a single or double DC or AC furnaces. The shaft can hold at least 40 % of scrap charged. The remaining scrap is charged directly in the furnace before starting to melt. In the this furnace where 100 % scrap is preheated, the presence of two vessels the power-of time significantly.

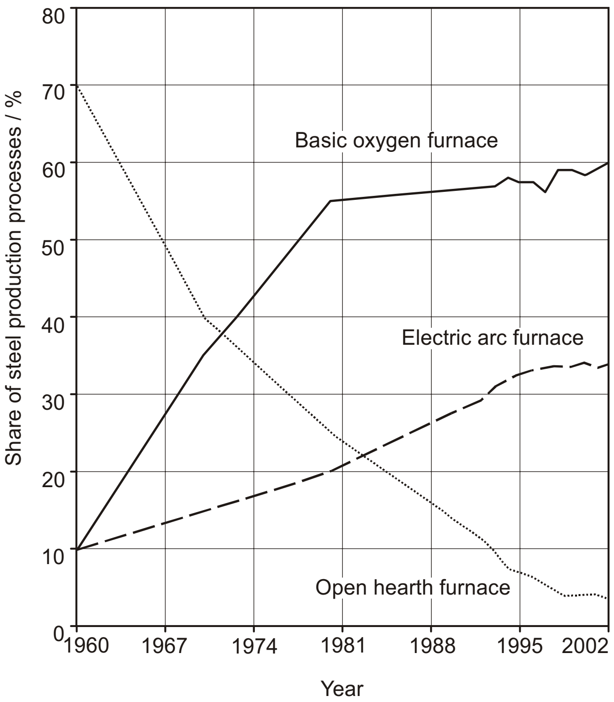

Figure 1. **Share of steel production between 1960 and 2002 years by processes**
Slika 1. **Udio proizvodnje čelika po procesima između 1960. i 2002. godine**

Conarc process presents the combination of conventional converter and electric arc furnace. This process allows a high flexibility with respect to raw materials (hot metal, DRI) as well as energy sources used. This process offers the possibility produce high grade carbon steel flat products, even ultra low carbon and stainless steels.

Fastox process is a new integrated steelmaking process combining Fastmelt iron making with BOF steelmaking. This newly integrated method of high quality steelmaking can use locally available iron ore fines and non-coking coals, coke fines or charcoal.

Continuous charge electric arc furnace

Continuous charge furnaces have following advantages: reduced electric power consumption, power utilization from 80 % to close to 100 %, very smooth electrical operation and possibility of operating in a continuous controlled environment [9 - 11].

Double electrode DC furnace or IHI process was developed in 1996. The continuous scrap charging system consists of a shaft-type preheater chamber (about 800°C) and charging unit. A two-stage scrap pusher delivers the charge into a space between the two electrodes, where the energy of the arcs is concentrated.

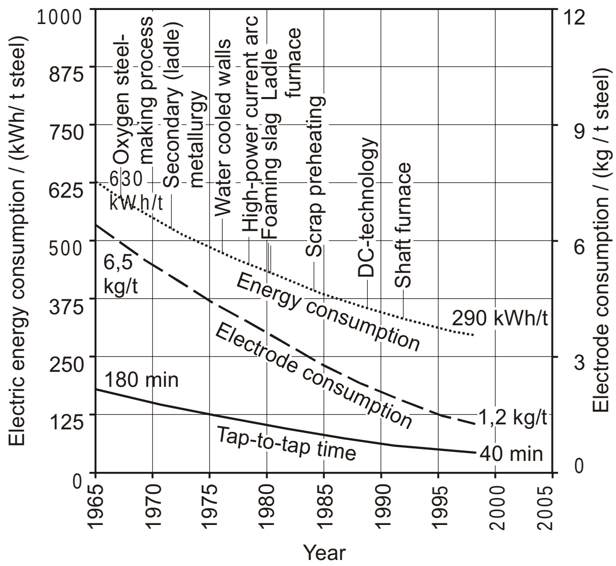

Figure 2. **Technological development in electric arc furnace steelmaking**
Slika 2. **Tehnološki razvoj izrade čelika u elektrolučnoj peći**

Contiarc process consists of DC arc-heated shaft furnace and scrap is fed continuously with an appropriate system in the upper part of the annular shaft. This process have advantages with respect to low emission and energy losses, but might be prove to maintenance problems.

Comelt process consists of tiltable melting vessel and a fixed shaft that are connected by a movable shaft ring. Scrap is charged into the furnace by a conveyer belt that extends to the charging door of the shaft. This process has many economical and ecological advantages.

Consteel process was developed in 1987. This process consists of automatically continuous charging and preheating (countercurrently) of charge (scrap, HBI etc.) to the EAF (AC or DC) by means of a conveying system. One of particularly significant at latest installation of this process unit in China is coupled with simultaneous continuous feeding of hot metal (40 %) and preheated of scrap (60 %).

The K-ES process is modified AC EAF furnace developed in 1986. The K-ES process can uses hot metal efficiently and employes bottom injection of oxygen. This process uses pulverized or lumpy coal as a source of primary energy.

The Danarc process is similar K-ES process but has optimized furnace electrics supply. The preheating of single scrap bucket was carried out to a mean temperature of 600°C. In this process presented a high degree utilization of chemical energy (injection of oxygen and carbon, post combustion of CO gas by oxygen).

The BNF process is combined furnace system composed of two independent vessels. The first vessel is a conventional EAF. In the second vessel the main source of energy is of the carbon oxidation reaction and with burners (O_2/carbon injection lances). On this way the steel similar to that one produced by converter can be obtained.

The Fasteel process consists of Fastmelt and Consteel processes. This process using 30 % hot metal and 70 % preheated scrap from Consteel process to produce high quality steel. Looking ahead in the future the process seems to be one of most economically and environmentally viable alternatives, especially for an integrated producer of steels.

SECONDARY METALLURGY AND STEEL CASTING

The growth in secondary steelmaking was one of the most important features of steelmaking development in recent time, and particularly during the past 25 years [12]. For improved caster utilization future investment in secondary metallurgy appears to be of highest priority.

The last years the development in secondary steelmaking facilities is contining in the trend towards to metallurgical station that are capable of carried out multiple treatments at one site. Consistent control of the procedures is maintained through investment in extensive computing facilities and with the use of computer models of the plant operations. Many such models help to guide the operator to achive optimum processing performance in terms of time, temperature and composition.

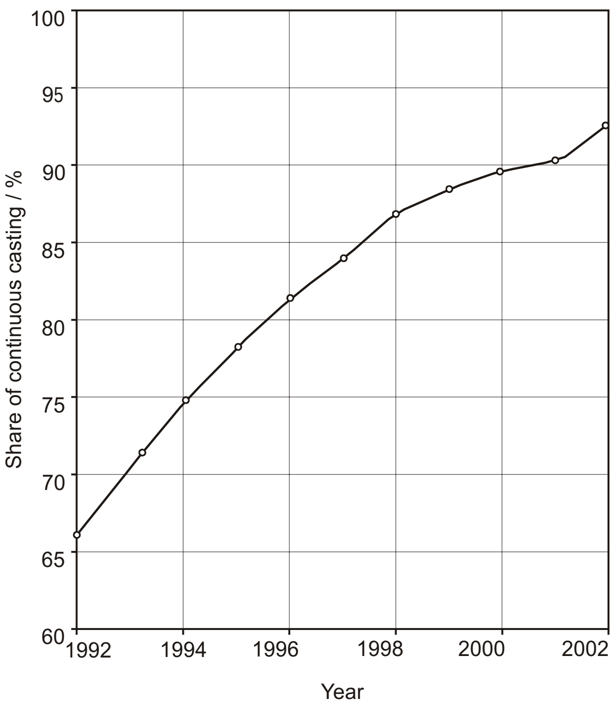

Figure 3. **Share of steel produced by continuous casting**
Slika 3. **Udio čelika dobivenog kontinuiranim lijevanje**

The conventional casting of steel is losing its significant. However, ingot casting will continue to be used where large weights are required e.g. for forging. Since 1960s continuous casting has steadly displaced ingot casting.

Today liquid steel destined for subsequent rolling is generally continuously cast. The share of steel production accounted for by continuous casting in the EU is now more than 96 %. In the world continuously cast steel has reached 87 % (Figure 3.). Today a high casting speeds are readily achieved (up to 6 m/min.).

Thin-slab casting technology was initially only applied in the case of mini mills operating on a scrap basis. In the meantime, thin-slab casters have also become an integral part of the material flow in these integrated mills. Introduction of cast-rolling means that integrated steel mills are able to produce hot strip in thickness from 0,8 to 1 mm by the direct route. Examples for the application of thin-strip casting systems in integrated steel works include compact strip production (CSP) and direct strip production (DSP) plants.

A total of 25 CSP casting machine including 40 strands have so far been solid. The installed capacity amounts to more than 40 Mt/year [13]. Direct strip casting so-called Eurostrip project was set in 1999 to commercialize European developments in strip casting [14]. Nucor corporation in USA now operated on the EAF/thin slab casting route as well as strip casting technology (Castrip process) for production of hot-rolled steel in thickness range less than of 1 mm.

ENVIRONMENTAL PROTECTION

Former the brown fumes indicated that the steelmaking plant was in operation. Today as result of modern dedusting technology the operation of the steelmaking processes can only be detected by flare stack. In 1987 the world commission on Environment and Development first defined the idea of sustainable development. In the 1990s in the world the integrated environmental protection concept has implemented.

Today steel industry produces besides of steel also by-products (solid waste, sludge) and gases (CO, CO_2, NO_x, SO_x, VOCs, dioxins, furans, etc.). The fact is that scrap usage is a very effective way of controlling greenhouse emission of the steel industry [15]. The slope of the curve shows how effective scrap use is in reducing emissions of CO_2 (Figure 4.).

By-products can be used either reuse within the steelmaking process or as sources for the other industries. The slag is the most important by-product in steelmaking (more than 80 % of the by-products are slags). In standard steelmaking generated from 100 to 150 kg slag/t of steel produced. A degree of utilization of BOF slag is about 75-80 %. The rate of recycling of EAF slag in Germany nearly reached 100 %.

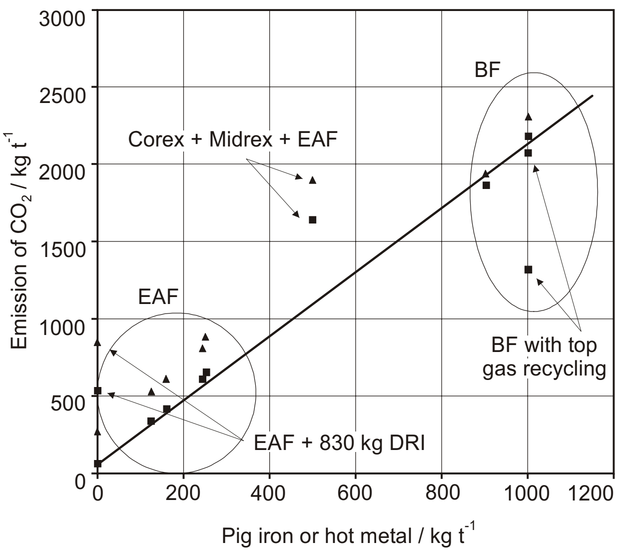

Figure 4. **Effect of steelmaking routes on emission of CO_2**
Slika 4. **Utjecaj načina proizvodnje čelika na emisiju CO_2**

The dust generated during steelmaking contains considerable amounts of valiable elements, especially zinc, lead and iron. Companies were developed new dedusting systems including wet and dry-type technologies. Approximately 90 % of all offgas cleaning system installed for steelmaking converters using a wet-type technology (content of dust is less than 50 mg/m^3). The dust content less than 10 mg/m^3 can be achieved with electrostatic dry-type dedusting technology.

The dust collected in the systems can be hydrometallurgy or pyrometallurgy treated [16].

FUTURE DEVELOPMENT OF STEELMAKING PROCESSES

New technologies must are developing in according to available cost, quality and environmental protection.

The blast furnace and oxygen converter route will remain the future process leader for the production of high grade steels, especially for flat products. In addition to the scrap problems a further reason is the 4-6 times higher decarburization rate in the oxygen converters as compared to the EAF with the same inner diameter of the unit.

From a global perspective EAF production may approximate that in the oxygen converter, however, it will not replace it. No new technology is in sight that will replace the oxygen converter technology. Despite it is necessary that this technology is further improved from an economic and ecological perspective.

In recent years others process have been developed or proposed such as the energy optimizing furnace (EOF), the AISI continuous process, iron carbide continuous process and Ifcon.

The evaluation indicated that the Irsid continuous steelmaking process may be an attractive to a traditional BOF or EAF could be an attractive option when high scrap levels (50 %) are required [6]. The cyclone converter furnace (CCF) process could be a promising process for use in the EU [17].

In Japan the BOF is using only for decarburization of hot metal. However a new refining process is proposed, by which hot metal is dephosphorized and decarburized continuously in the same basic oxygen furnace, with intermediate deslagging folowed dephoshorization. After decarburization slag is kept inside the furnace and reused to dephosphorize the next charge so to minimaze the quality of slag discarge [18].

Many new processes for steelmaking using EAF are now commercialized (Consteel, K-ES, EOF, etc.). Common for all these processes is the energy from the waste offgas is used to preheat of scrap.

At new technologies scrap will remain the predominant raw material for the EAF. The scrap recycling rate will from present average of 45 % today to 55 %. Continuous charging of scrap is expected to rise to 10 %. Scrap preheating is anticipated to increase from 10 % to 30 % in newly built furnaces. Shaft preheating is seen as the major method of preheating 50 % and twin shell preheating Consteel process is seen as an important alternative method. In terms of savings can be concluded that of existing systems shaft furnaces (Fuchs and IHI) and Consteel process have the best results. Similar characteristics shows Comelt and Contiarc processes.

The DC furnaces will continue to be interest for high efficiency melting operations. The additional space available on the furnace roof due to a single electrode operation will allow much greater automation. The production of steel by DC EAF using twin electrodes is expected to increase to 10 % as result of high DRI charging rates.

CONCLUSION

The blast furnace is expected to remain a major source of hot metal followed by Corex and new smelting reduction processes. The production of steel by BOF will increase at 1 % per year. The share of EAF steelmaking is expected to rise at 2 % per year from the current 34 to 40 % in 2010. The EAF will acts like BOF using fossil fuel and it will also using more non-scrap iron such as DRI/HBI products and hot metal.

During the next two decades it is anticipated that at least 50 to 60 % of crude steel will be produced in the EU by the BF-BOF route, while the rest will be obtained from the EAF route. New steelmaking process are not expected. Due to high production levels using these two production routes very small changes improvements in the technologies used can already result in substantial advances in primary materials and energy savings, productivity improvements and cost reduction.

Today main routes of steel production processes (BOF and EAF) will be fully integrated with the secondary metallurgy and casting techniques within a flexible operating environment. Development in secondary steelmaking facilities will be continue in the towards to metallurgical station that are capable of carried out multiple treatments at one site. Treatment of steels will increase, particular the use of ladle furnace and vacuum degassing.

Development new casting technologies will including thin slab casting and direct strip casting for improve productivity and quality of final steel products. Thin slab casting will gradually completely replace conventional casting of thick slabs. On the other hand this slab casting of commercial qualities will be completely transformed to strip casting.

The sensitivities to CO_2 emissions should not be forgotten although steelmaking contributes just 7 % of total emission in EU (for example the transport has impact of 23 %). In the future the most important emission will be of CO_2, dust, dioxins and NO_x. The use of the EAF is the best way to reducing CO_2 emissions due to the lower energy needed to melt scrap than to smelt iron ore. Mercury is believed to become on issue in the future as well as NO_x.

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