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SCRAP-BASED STEEL PRODUCTION AND RECYCLING OF STEEL

PROIZVODNJA JEKLA IZ JEKLENEGA ODPADKA

D. Janke, L. Savov, H.-J. Weddige, E. Schulz
Institute of Iron and Steel Technology, Freiberg University of Mining and Technology

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A survey is given on routes and trends of electro steelmaking which is based on statistical and experimental studies performed at the Institute of Iron and Steel Technology at Freiberg University of Mining and Technology. The report is focused on the technological features of AC and DC Electric Arc Furnaces as well as on the aspects of quantities and costs of production, material and energy sources and environmental effects.

Special emphasis is laid on the availability and quality of scrap which is closely related with the trace and tramp element problem in view of low and high alloyed steel production.

The possibilities and limits of contaminated scrap recycling and methods of scrap purification are discussed.

Key words: steel production processes, scrap quality, production costs, development of electric arc furnaces, scrap supply, scrap purification

Pregled poti in smeri razvoja pri izdelavi jekla v elektropeči na osnovi statističnih in eksperimentalnih raziskav na Institutu za tehnologijo železa in jekla pri Univerzi za rudarstvo in tehnologijo v Freibergu. Težišče poročila je v tehnoloških značilnostih AC- in CD-električni obločni peči, količinah, stroških proizvodnje, virih energije in v okoljskih vplivih.

Posebna pozornost je namenjena razpoložljivosti in kakovosti jeklenega odpadka in preostalim elementom v sledovih z upoštevanjem izdelave malo in visoko legiranih jekel. Analizirajo se možnosti in omejitve reciklaže jeklenega odpadka in metod za njegovo čiščenje.

Ključne besede: Procesi proizvodnje jekla, kakovost jeklenega odpadka, proizvodni stroški, razvoj elektroobločnih peči, oskrba z jeklenim odpadkom, čiščenje jeklenega odpadka

1 ELECTRO STEELMAKING IN THE WORLD

1.1 Steel - the Modern Material of Choice

Steel is undoubtedly the indispensable material of the modern technology driven society. Since steel encompasses a class of over 2500 different grades currently produced and used, there is a wide variety of properties leading to an even wider spread of uses. There are countless possibilities of combinations with regard to micro and macro structure, alloying elements, heat and mechanical treatment procedures, etc. Being used for thousands of years, one could expect that the scope of possible improvements is limited. However, the increasing challenges from other materials have been met by continuous product and process development ensuring the competitive edge for steel. It is fair to say that the potential of steel developments has been so far used only to a very limited extent leaving ample opportunities.

Steels can be used in a number of ways. With respect to service properties, the classification is made according to the three groups of

- base steels,
- quality steels and
- high-grade steels

One can also use the amount of alloying additives to classify

- unalloyed to medium alloyed steels and
- high alloyed steels

The second classification is sometimes more useful, since high-grade steels can be high alloyed stainless steels as well as ultra low carbon steels distinguished by a particularly low level of alloying elements and impurities.

The second method of classification is useful for electric steelmaking, since we encounter two rather distinct groups of mills with respect to their product range. On the one hand we have the producers of high alloyed steels, mainly stainless, high temperature resistant and acid-proof grades. These steels are nearly exclusively produced by electric steelmaking with tight control over temperature and composition. On the other hand, we have the production of preliminarily lower quality grade long products directed into construction industry. Here the advantages of scrap as a relatively cheap and abundantly available raw material are exploited. It has to be stated that internationally there are strong tendencies to improve the quality range and to produce flat products, too, thereby competing strongly with integrated mills.

The remainder of this chapter gives an overview of the economic issues, followed by the technological issues of electric steelmaking in the second chapter. The

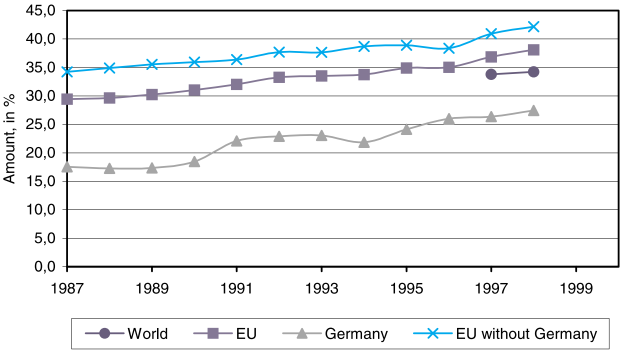

Figure 1: Development of the share of electric steelmaking [3]
Slika 1: Naraščanje deleža elektrojekla [3]

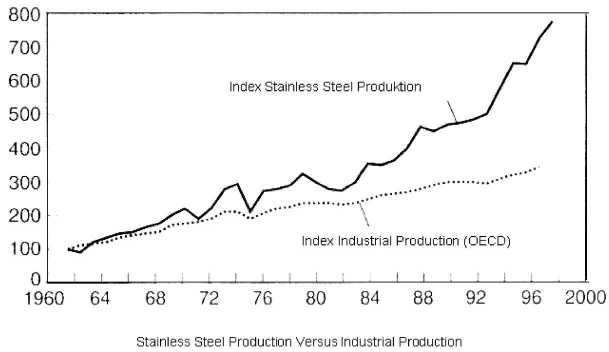

Figure 3: Growth rates of stainless steel production [4]
Slika 3: Rast proizvodnje nerjavnega jekla [4]

article is concluded by an in-depth discussion of the issues arising in connection with scrap and scrap supply.

1.2 Production Data

The total world steel production is currently around 800 million tons, of which roughly 175 million are produced in the EU and thereof 40 to 45 million tons in Germany. Slovenia produces around 405.000 tons a year which is exclusively produced by electric steelmaking [1,2].

Of this the percentage of steel produced by electric steelmaking processes is steadily increasing as shown in **Figure 1**.

The proportions differ strongly in different countries (**Figure 2**). The reasons for this difference are plentiful. Amongst others historic developments and the general scope of qualities produced nationally account for the differences. Countries with a strong tradition in integrated steel plants based on blast furnaces and oxygen steel converters aiming at high quality carbon steels have a relatively low proportion of electric arc furnaces. But there, too, the tendency goes towards an increase in their share of steel production more or less in line with the general trend but starting from a much lower level.

This considerable increase can be explained by several factors acting simultaneously. In carbon steels the amount of scrap available increases in line with increased recycling rates and a decrease of recycled scrap additions to the oxygen steel making. Process developments resulting in higher qualities allow electric steel makers to conquer bigger market shares in higher quality markets, as it happened the US market. In the high alloyed sector we find a far above average growth of production (nearly eight fold that of carbon steels) resulting in a higher electric steel production share (**Figures 3** and **4**).

1.3 Production Programmes and Costs

In general, there is a distinction between stainless and plain carbon steel production. The former is characterised by a proportion of alloying element costs and often a very wide spectrum of grades offered which

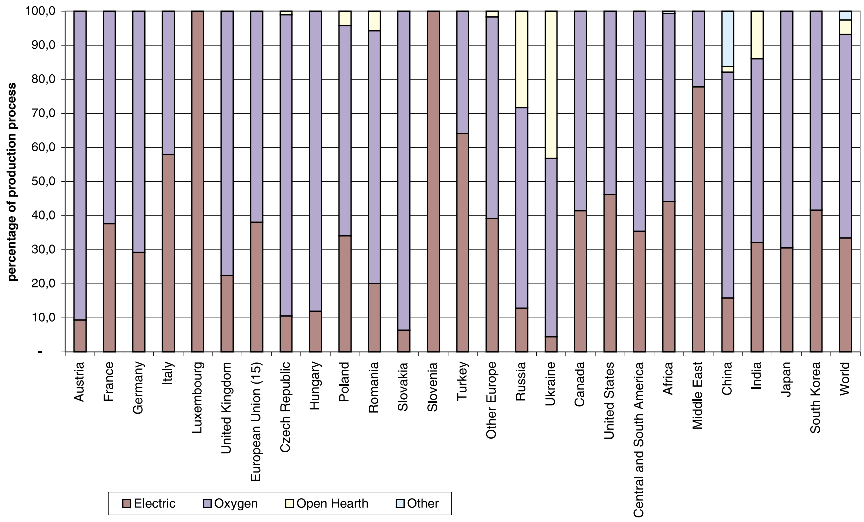

Figure 2: Share of steelmaking processes in different countries 1999 [1]
Slika 2: Delež elektrojekla v različnih državah [1]

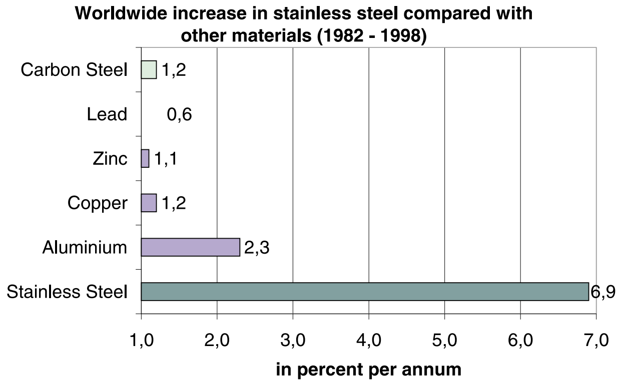

Figure 4: Annual growth rates of different metals compared to stainless steel [5]
Slika 4: Letna rast različnih kovin v primerjavi z nerjavnim jeklom [5]

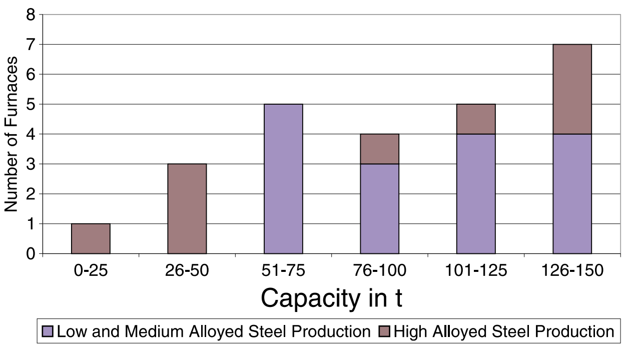

Figure 5: Capacity of furnaces in Germany 2000 [6]
Slika 5: Kapaciteta peči v Nemčiji leta 2000 [6]

are each only produced in small quantities, employing small ladles. Alternatively, large stainless steel plants exist which produce comparatively large quantities of the same grade using large ladles (**Figure 5**).

Plain carbon steel is produced nearly exclusively as long products. Quality requirements are often lower compared with integrated mills so that electric steelmaking competes on price as a result of cheaper raw

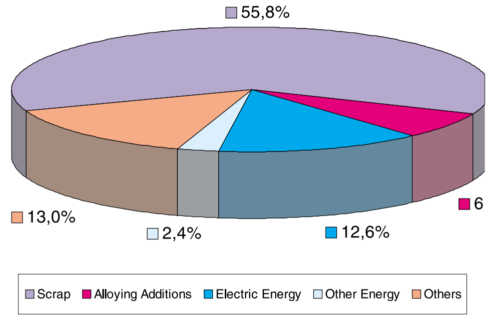

Figure 6: Split of production costs in electric steelmaking in Germany [6]
Slika 6: Proizvodni stroški za elektrojeklo v Nemčiji [6]

materials and lower energy costs as well as the absence of sophisticated secondary metallurgy.

The overall cost split for Germany is given in **Figure 6**. With nearly two-thirds accounted for by raw material and about 15% by energy these are the predominant sources of costs.

Electric energy prices fell sharply as a result of the energy deregulation in Europe with the according positive effects on electric steelmaking. This has led to increased competitiveness of European electric arc furnaces.

Scrap prices are traditionally very variable and determined independently from current steel production since they depend on the amount of scrap available. They depend strongly on quality, too.

1.4 Raw Materials

The major raw material is scrap. Scrap, as steel, encompasses a variety of different materials and qualities, most notably home scrap arising during steel making, process scrap from steel use and obsolete scrap at the end of the products' lifetime. They vary widely in quality. While carbon steel is produced from obsolete scrap, stainless steels use more home and process scrap reflecting the need for tighter alloying and tramp

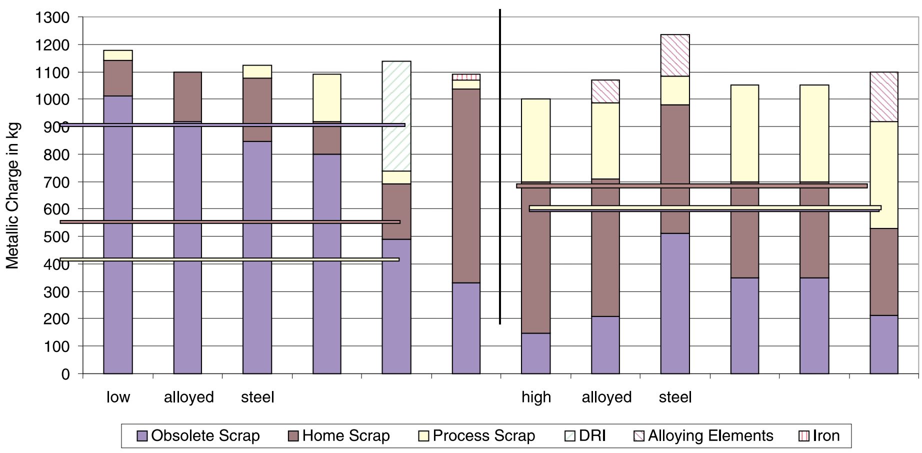

Figure 7: Raw material input in German electric steelmaking plants 2000 [6]
Slika 7: Uporaba surovin v elektrojeklarnah v Nemčiji [6]

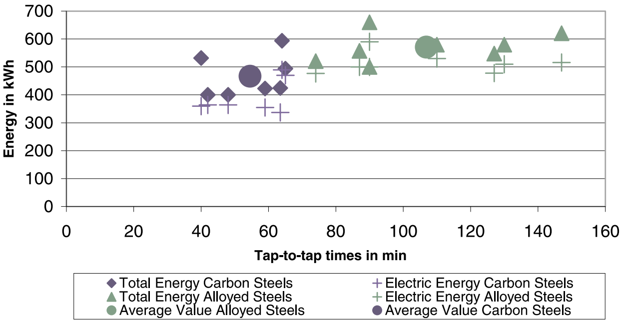

Figure 8: Energy sources in German electric steelmaking plants [6]
Slika 8: Oskrba z energijo v elektrojeklarnah v Nemčiji [6]

elements control. The relevant split for Germany is given in **Figure 7**.

The substitution of scrap by other ferrous material such as direct reduced iron (DRI) or pig iron can result in better qualities obtainable. To compete in the flat products sector this is an important consideration.

1.5 Energy and Environment

Figure 8 shows the total energy consumption per ton of steel and the proportion of electric energy versus the tap-to-tap times of the German electric arc furnaces.

It is evident that other energy sources are important, too, in particular in carbon steels, but electric energy remains the major source.

Looking at power production in the EU (**Figure 9**) it is clear that renewable energies and nuclear power account for half the power produced. This means a CO_2-free production of energy with positive results for the atmosphere concerning the greenhouse effect.

In general electric steelmaking is ecologically very beneficial since it uses energy effectively to produce valuable material from scrap and hence not only conserving energy but also reduces the waste burden by roughly 280 million tons a year world wide. Energy wise this saving comes from using just 5,7 GJ/t in electric steelmaking compared to 14,9 GJ/t in integrated plants.

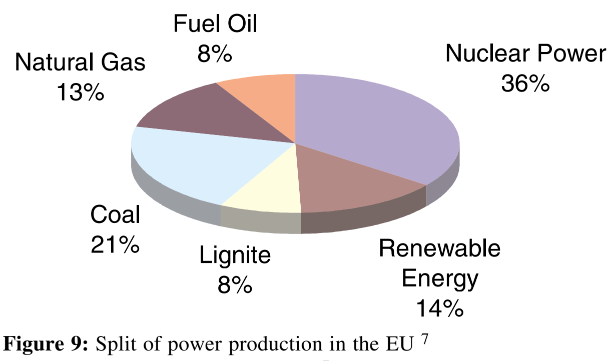

Figure 9: Split of power production in the EU [7]
Slika 9: Proizvodnja energije v EU [7]

Figure 10: Locations of electric steelmaking plants in Germany [3]
Slika 10: Lokacija elektrojeklarn v Nemčiji [3]

1.6 Plant locations in Germany

Figure 10 shows the locations of the major German electric steelmaking plants. In contrast to the integrated mills these are rather evenly split making use of regional scrap supplies and delivering to local markets. Of those shown several are former integrated mills converted to electric steelmaking plants, such as Georgsmarienhütte, Peine, Brandenburg or Unterwellenborn. In particular in the East there are several newly built plants as a consequence of the restructuring efforts in the wake of German re-unification.

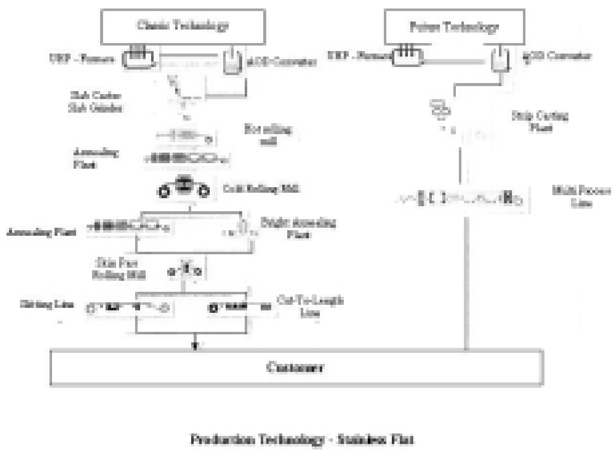

Figure 11: Production technologies of stainless steel flat products [5]
Slika 11: Proizvodne tehnologije za ploščate proizvode iz nerjavnega jekla [5]

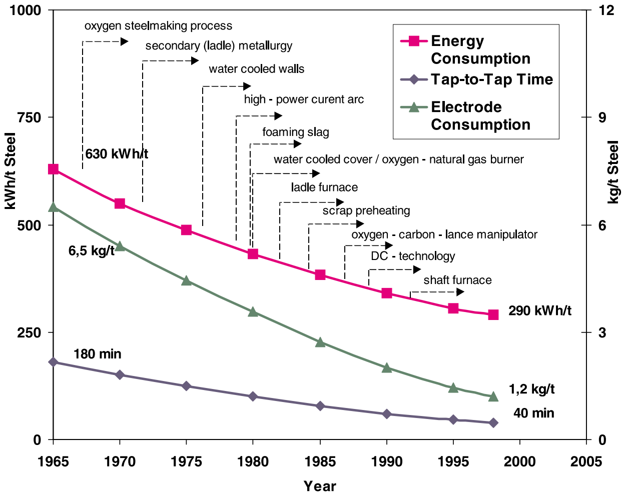

Figure 12: Technological developments in electric steelmaking [8]
Slika 12: Tehnološki razvoj pri proizvodnji elektrojekla [8]

2 SCRAP-BASED MELTING TECHNOLOGIES

2.1 Process Routes and Technology

Steel making has to be seen as part of a chain which leads from raw materials to semi-fabricated products. The classical process route for electric steelmaking is

- scrap charging
- melting down
- tapping
- secondary metallurgy
- slab casting
- hot rolling
- cold rolling
- treatments
- delivery

While there are several innovations concerning the actual steel making it also has to be pointed out that the subsequent steps are undergoing reconsideration and innovation, too, as shown in **Figure 11** for stainless steel flat products.

It can be claimed that in the area of carbon steels the success of the electric arc furnace is linked to its joint

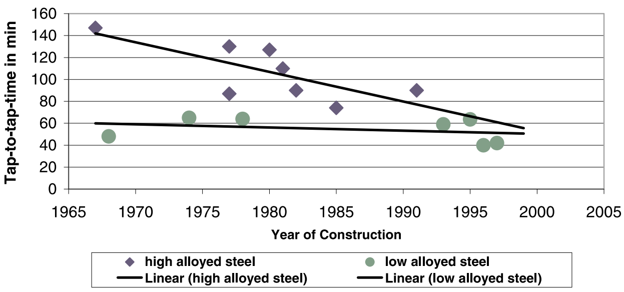

Figure 13: Reduction of tap-to-tap-times in German electric steel-making mills [6]
Slika 13: Zmanjšanja "tap-to-tap" časa v elektrojeklarnah v Nemčiji [6]

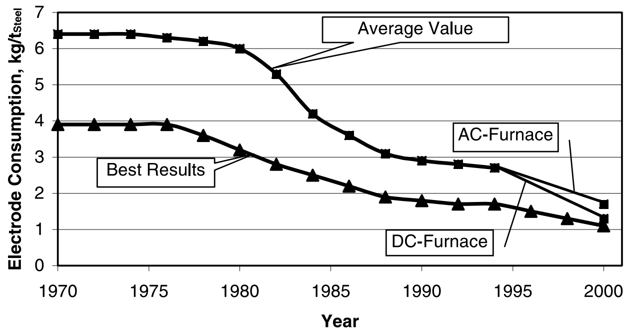

Figure 14: Reduction of electrode consumption since 1970 [9]
Slika 14: Zmanjšanje porabe elektrod od leta 1970 [9]

operation with thin strip casters to construct the classical Mini Mill concept.

2.2 Measures to increase productivity

Productivity increase in the electric steel making process can be taken as a reduction of the tap-to-tap times and the consumption of energy and other materials. **Figure 12** links their reduction to technological improvements carried out over the last 35 years.

With the introduction of the oxygen steel converter and the replacement of the open hearth furnace there was an increased demand for an effective metallurgical process to handle the scrap which was rightly believed to be the electric arc furnace. Improving its melting capacity and productivity were major achievements resulting from a variety of technological alterations.

As of now there is no end of this development in sight. Furthermore there are additional solutions proposed not only to improve its role as a melting vessel but also to improve the qualities producible and hence challenging the oxygen steel converter in the high quality segment, too.

This development can be demonstrated for the German electric arc furnaces as shown in **Figure 13**. The reduction of tap-to-tap times for stainless steel production is stronger than for carbon steels which might be explained by increased furnace power and better use of secondary equipment.

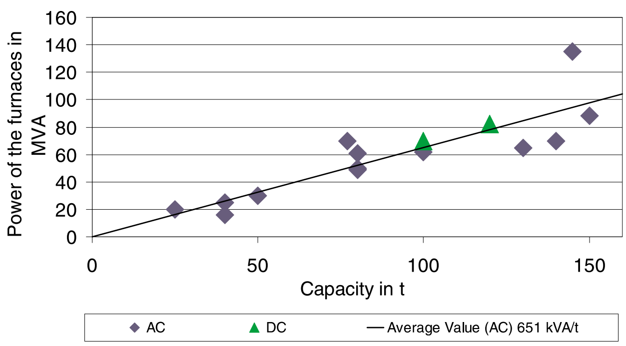

Figure 15: Furnace power in relation to furnace capacity in Germany [6]
Slika 15: Razmerje med močjo in kapaciteto peči v Nemčiji [6]

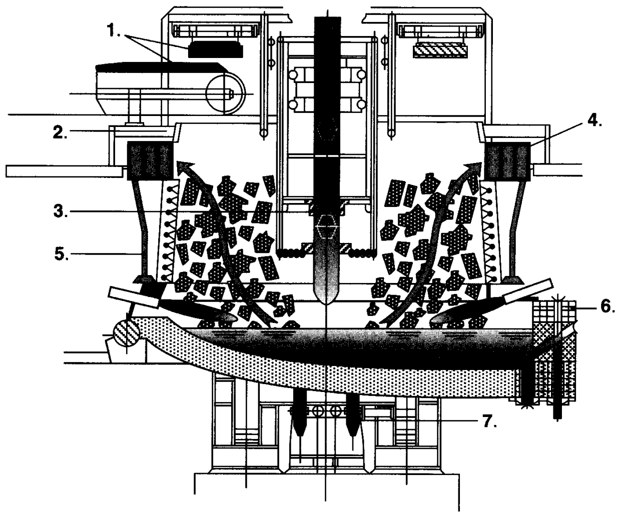

Figure 16: Schematic representation of the CONTIARC-Technology [10]
Slika 16: Shema tehnologije CONTIARC [10]

The general improvement and reduction of inputs can be clearly shown for the electrode consumption (**Figure 14**). The drastic decrease can be assigned to the use of foaming slags and improved electrode construction.

The relationship of furnace power to furnace capacity in Germany gives an average value of 651 kVA/t (**Figure 15**) which demonstrates the capability of these equipments.

2.3 Furnace Developments

A confusing variety of electric arc furnace developments at several stages exist with complicated licensing agreements and mergers of companies adding to the confusion.

The following lists major achievement which appears to have a chance of economic breakthrough in addition to being technologically reliable:

- scrap preheating to ensure even more efficient energy use (part of nearly all concepts)
- continuous steel producing concepts to better align with casters and rolling mills
- inclusion of blowing processes known from oxygen steel converters
- reduction of tap-to-tap times by using two shells

These processes can be primarily characterised as either continuous or discontinuous. **Continuous processes** try to smoothen the change from batch process steel making to continuous following steps (caster, rolling mills). Their main drawback is the loss of flexibility with respect to the steel grades produced.

The **Contiarc** process (**Figure 16**) is based on a circular vessel where scrap is continuously charged and preheated and then dissolved in the shallow metal bath. This concept is advantageous with respect to low emissions and energy losses, but might be prone to maintenance problems.

The **Consteel** process is the first commercially used process for continuous preheating, charging and melting, organised in a counter-current exhaust gas stream to treat the burden. Scrap is melted by the molten pool which is heated by the electric arc hence no scrap pile is occurs. Six furnaces are in operation, four others are being built.

The **Contimet** process (**Figures 17** and **18**) combines the classical electric arc concept with advantages of the oxygen steel converter. Scrap, either pre-heated or not, is

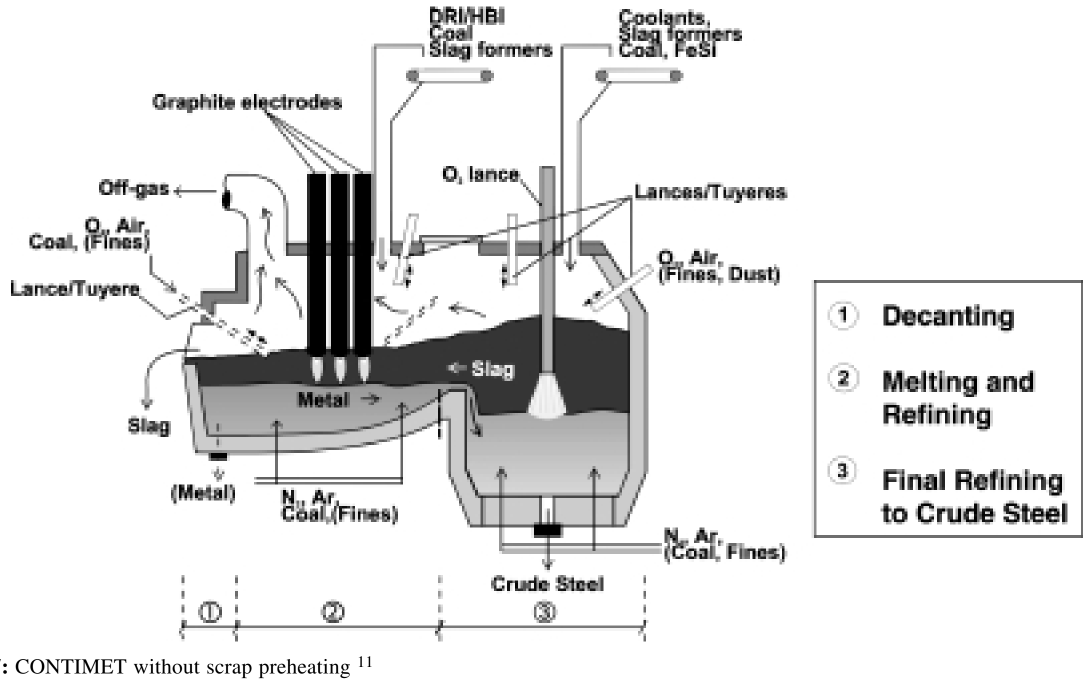

Figure 17: CONTIMET without scrap preheating [11]
Slika 17: CONTIMET brez predgrevanja vložka [11]

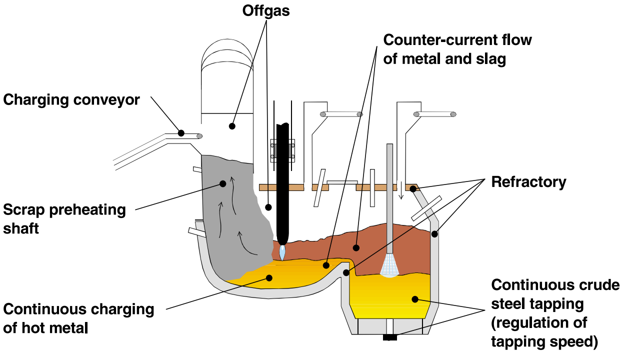

Figure 18: CONTIMET with scrap preheating [11]
Slika 18: CONTIMET s pregrevanjem vložka [11]

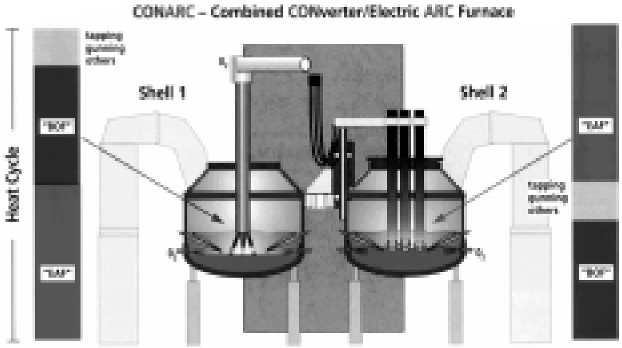

Figure 19: CONARC-Process [12]
Slika 19: Postopek CONARC [12]

continuously melted by an electric arc to produce a melt overflowing into the converter section where it is blown with oxygen to the desired composition before being tapped. This process is very flexible with respect to the raw materials which are processable, but might experience draw-backs in terms of permanent refractory wear and very sophisticated process control requirements.

There are improvements of the **discontinuous processes**, too. Their advantage is a greater flexibility with respect to the different charge compositions and steel grades to be produced.

Twin Electrode DC concepts try to improve the cost advantages of DC furnaces by using cheaper and more robust electrodes than those used in AC furnaces. At present, however, there appear to be problems with the melting of scrap while this system works with DRI feed.

Twin shell furnace concepts exploit the fact that the electrodes are only used during part of the process, so that one set of electrodes can serve two shells.

This concept is developed further in the **Conarc** process where one shell is operated as an electric arc furnace while the other is operated with an oxygen lance rather as an oxygen converter (**Figure 19**). This allows a high flexibility with respect to raw materials as well as energy sources used. World wide there are currently 12 units in operation, but none in Germany.

2.4 Injection Equipment

In addition to the charging of pieces into the electric arc furnace the injection of gases or pulverised material has become particularly important since it allows the delivery of material exactly where it is required.

Concerning the equipment used, there are automatic systems, so-called lance manipulators, and manually operated lances. With respect to the injected material one can distinguish between oxygen, carbon and dust injections.

Carbon or **coke** is injected (**Figure 20**) to increase the melt-down efficiency by supplying additional energy from the combustion process aided by oxygen injection and to form foaming slag with CO produced from the carbon combustion to cover the electric arc and hence reduce energy losses by radiation.

Oxygen is injected by manipulators (**Figure 21**) to aid the formation of foaming slag in combination with carbon injections or to achieve a blowing process similar to that of the oxygen steelmaking process. Manual lances are used to clear the deslagging gate, residual scrap or

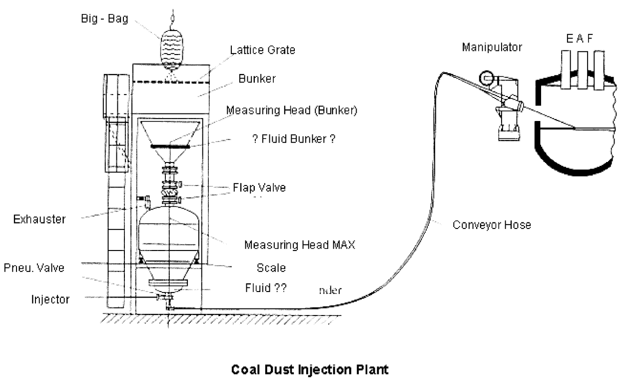

Figure 20: Coal dust injection plant [9]
Slika 20: Peč z vpihavanjem premogovega prahu [9]

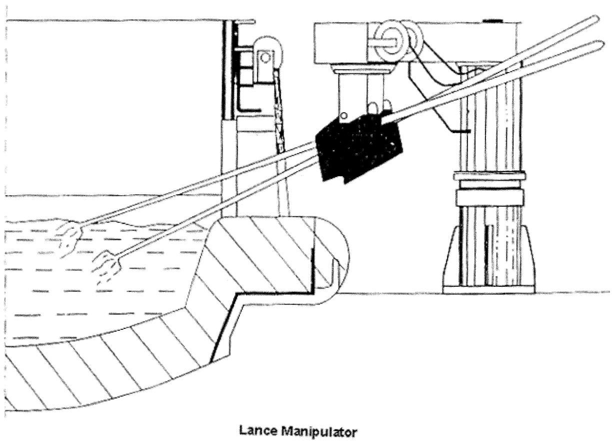

Figure 21: Lance manipulator [9]
Slika 21: Manipulator kopja [9]

blocked tap holes as well as to intensify the melt down of the charge.

Residual metallurgical dusts from off-gas cleaning systems bearing Fe, Zn or Pb can be injected to concentrate the non-ferrous materials in the dust and to recover the iron. The dust enriched with Zn and Pb can then be processed further for the recovery of secondary heavy metals in the non-ferrous metals industry. For the injection of such dust special hollow electrode systems have been developed.

2.5 Scrap Preheating

The energy requirement in the electric steelmaking process is for melting down the scrap. Hence it is an obviously good idea to reduce this energy requirement by preheating the scrap which additionally reduces the tap-to-tap times and increases the overall productivity. Further benefits are a reduction in the electrode consumption and the refractory wear. Metallurgically the preheating results in dry feed and therefore a decreased hydrogen content in the steel.

Care has to be taken if organic contaminations are present to avoid the formation of dioxin and other undesired products.

The heat required can be either provided by external energy sources such as fossil fuels which adds to the total energy balance. Alternatively the furnace off-gases can be used to heat the next feed. This adds to an overall energy saving by recuperation of the heat content of gases.

There are several constructional solutions to integrate preheating in the charging system. The BBC-Pruza process uses a rotary kiln. The Consteel process uses a counter-current flow principle in which the escaping off gases heat the burden being conveyed on a horizontal belt to the electric arc furnace. The shaft furnace originally designed by Fuchs uses the head room above the electric arc furnace to install a shaft in which the next feed is heated by the escaping off-gases. This system can be employed with a variety of electric arc furnace concepts using batch processes.

2.6 Dust and Emissions

During melting dust is produced in the electric arc furnace and carried away in the off-gases which contains mainly iron, but also valuable non-ferrous metals such as zinc or lead. So not only ecological considerations, but also economy require the collection of the off-gases and their dedusting to recover valuable material.

There are three main collection types for off-gases as shown in **Figure 22**. Dust from within the furnace vessel can be collected through a fourth hole in the top. This collects only dust from the actual melting process. A suction system collects additionally and at least partially the dust originating from tapping and charging. A complete housing of the furnace improves on this by collecting nearly all dust and preventing any escaping to the outside. An additional benefit is that it also protects against noise emissions which are a considerable source of environmental concern in the running of an electric steel making plant.

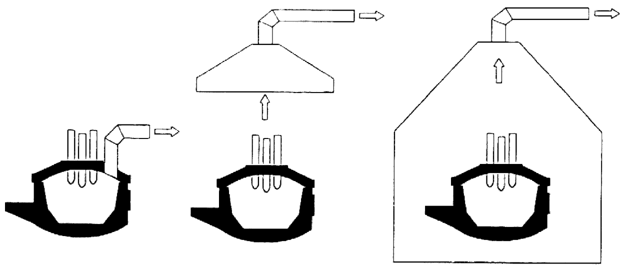

Figure 22: Dust and emission collection systems [13]
Slika 22: Sistem za zlivanje praha in emisij [13]

Dust and noise also originate from handling scrap on the scrap yard which also leads to increased housing of scrap yards. This is particularly important if the plant is close to a residential area. Whether it improves the feed quality is doubtful.

3 SCRAP SUPPLY

3.1 Scrap qualities

Generally, steel scrap can be divided into three categories:

A) home scrap (plant scrap)
B) process scrap (prompt scrap)
C) obsolete scrap (capital scrap)

A) Home scrap is generated in steel mills during the production of steel. It is relatively pure and its chemical composition is known, so it can be easily recycled.

B) Process scrap is generated in the manufacturing of products made from steel. This scrap occurs during production of both industrial and consumer end products.

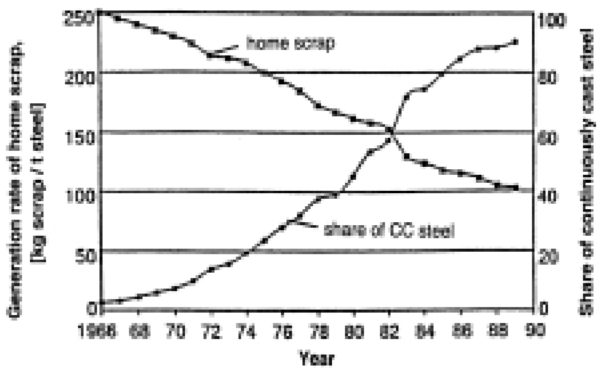

Figure 23: Development of the home scrap generation rate as a function of the implementation of continuous casting technology (Germany, 1966-1989) [17]
Slika 23: Odvisnost med količino domačega jeklenega odpadka v odvisnosti od implementacije kontinuirnega litja (Nemčija, 1966-1989) [17]

Process scrap is available for recycling in relatively short time after its generation. However, scrap preparation and classification are essential before melting. The rate of process scrap generation will be decreasing due to the better steel utilisation in steel processing.

C) Obsolete scrap consists of iron or steel products discarded after the end of their service life. Post-consumer steel products include old passenger cars, steel cans, electric appliances and other items. Obsolete scrap is often mixed or coated with other materials, such as copper, zinc, tin, glass and plastics. For this reason the content of tramp elements in obsolete scrap is usually high. Moreover, the chemical composition of obsolete scrap fluctuates widely depending on its origin and degree of processing. Obsolete scrap, especially the one originating from old passenger cars, is usually processed by shredding.

The steel industry has always aimed at a higher steel yield through rationalisation of equipment and technology. Consequently, the rate of home scrap generation has been gradually decreasing. The sharpest decrease ever was achieved with the introduction of continuous casting, which decreased the amount of home scrap. **Figure 23** shows the decrease in home scrap quantity due to the gradual introduction of continuous casting technology in Germany for the period 1966-1989. During this period the home scrap generation rate fell from 250 to 100 kg scrap/t of produced steel, while the share of continuously cast steel reached 90% of the total steel production [14]. No great changes in the quantity of home scrap will occur because the steel yield in state-of-the-art steel mills has already been maximised. However, local differences have to be considered. While western industrialised countries have successfully implemented continuous casting technology, other steelmakers are lagging behind. The share of continuously cast steel in the total output of some major steel producers such as China, Russia and India is still below 50% [15]. In order to be competitive in an increasingly globalising economy, these countries will have to implement the continuous casting technology. As consequence, the generation rate of home scrap is expected to decrease sharply in some regions of the world.

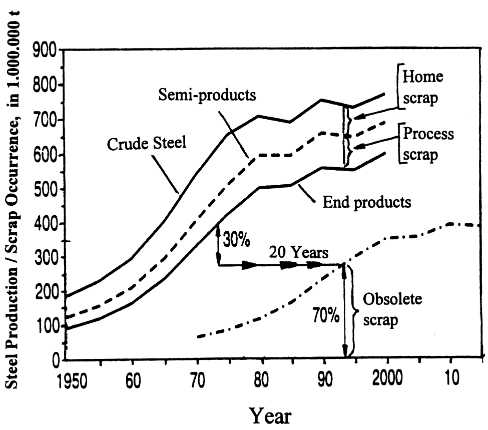

Figure 24: Interrelations between world steel production, steel consumption and scrap generation [19]

Slika 24: Odvisnost med svetovno proizvodnjo in porabo jekla ter izvirom jeklenega odpadka [19]

It is assumed that the occurrence of home scrap and process scrap are simple functions of crude steel production and semi-products manufacturing, respectively (**Figure 24**). However, the occurrence of obsolete scrap depends on previous manufacturing numbers for steel end products. It was found that on the average 70% of the tonnage of steel end products is returned into the materials cycle 20 years after the manufacturing took place. The rest of 30% is lost mainly by rusting of steel. For example, the world occurrence of obsolete scrap in 1994 was 272 million tons which represents 70% of the amount of manufactured steel end products in 1974 [16].

There are however consumer goods which are recycled very quickly after being manufactured, e. g. the life cycle of steel cans is 6-12 months, compared to 12 years for cars and electric household appliances, and 25 years for the steel used in construction [17]. Certainly there exists an interdependence between the rate of obsolete scrap generation, scrap quality and the life cycle of the common consumer goods made of steel. The complex nature of these interrelations has not yet been investigated sufficiently.

Another problem which is in the early stage of investigation is the evaluation of the average chemical composition of scrap coming from a given group of consumer goods (e. g. small cars, washing machines, electric stoves) or the analysis of the chemistry of given components of consumer goods. The aim of such investigations is to gain the information necessary for the prediction of the chemical composition of obsolete scrap and to determine proper measures to reduce the impurity content of scrap by dismantling single components of post-consumer goods which are particularly harmful for scrap purity. For example, it was found that by selective dismantling of auto-parts the Cu content of shredder scrap can be reduced from 0,27 to 0,12% [18].

3.2 Scrap impurities

Table 1 shows the desired limits for tramp element contents in most contaminated scrap qualities as defined in the European Scrap Quality List which went into effect on 1.07.1995. The processing of scrap using currently available methods of scrap preparation ensures that the tramp element content is kept below these limits.

There are basically three different modes of existence of harmful tramp elements in scrap:

1. Tramp elements in pure state coexisting with pieces of steel scrap. The impurities are mixed with the ferrous portion of the scrap and are mechanically

separable. Example: discarded electric motors (iron and copper coexist in pure state)
2. Tramp elements used as coating material for steel products. Iron and the non-ferrous metal of the coating build a series of layers consisting of different phases. Example: galvanised steel (zinc-rich layers on steel sheet)
3. Tramp elements used as alloying additions in certain steel grades. The impurity elements are dissolved in the bulk steel scrap and are separable only after scrap melt down. Example: Ni, Cr, Mo as alloying elements in steel.

Table 1: An excerpt from the European scrap quality list showing the limits for tramp element contents in different scrap qualities

Tabela 1: Povzetek Evropske kakovostne liste za jekleni odpadek z mejami vsebnosti preostalih elementov pri različnih kakovostnih razredih jeklenega odpadka

Type of scrap	Specification code	Impurity content in %		
		Cu	Sn	Cr, Ni, Mo
Obsolete scrap	E 3	≤ 0,250	≤ 0,010	Σ ≤ 0,250
	E 1	≤ 0,400	≤ 0,020	Σ ≤ 0,300
Home scrap with low content of tramp elements, free from coated steel	E 2	Σ ≤ 0,300		
	E 8	Σ ≤ 0,300		
	E 6	Σ ≤ 0,300		
Shredded scrap	E 40	≤ 0,250	≤ 0,020	
Steel turnings	E 5 H	subject of additional specification		
	E 5 M	≤ 0,400	≤ 0,030	Σ ≤ 1,0
Scrap with high content of tramp elements	EHRB	≤ 0,450	≤ 0,030	Σ ≤ 0,350
	EHRM	≤ 0,400	≤ 0,030	Σ ≤ 1,0
Shredded scrap from municipal waste incinerators	E 46	≤ 0,500	≤ 0,070	

Following this basic classification, the occurrence of the most important tramp elements in steel scrap (Cu, Zn and Sn) will be discussed. The main source of Cu in steel is the obsolete scrap which is obtained from discarded cars. Cu in old cars is present mainly in the form of wires, electric motors and cooling elements. At present, 40-50 electric motors are installed in a passenger car. The tendency is to supply vehicles featuring even more parts which contain copper. If these parts are not dismantled prior to scrap shredding, they are shredded with the bulk auto-body and copper is mixed with steel scrap. The subsequent magnetic separation is not able to divide completely the non-ferrous fraction of the scrap from the ferrous share. Moreover, industrialised countries are characterised with high labour costs which hinder to a great extent the dismantling of old cars and the manual sorting of shredded scrap. There is a growing tendency to increase the portion of non-ferrous metals used in car production. Furthermore, many auto-parts containing copper are reduced in size in contemporary designs which makes the removal of the copper fraction from the bulk iron fraction difficult using existing

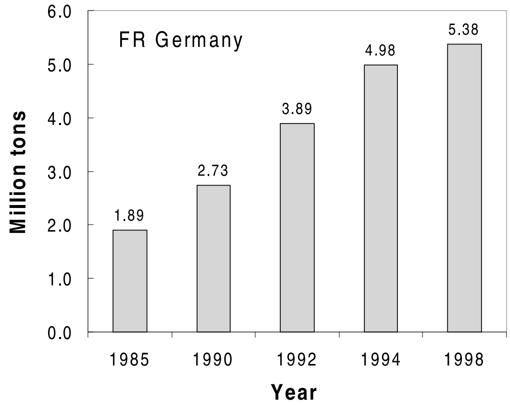

Figure 25: Development of the production of galvanised steel in Germany [20]

Slika 25: Rast proizvodnje galvaniziranih trakov v Nemčiji [20]

shredding technology. Cu is also introduced into steel melts by the smelting of scrap which originates from steel grades containing an increased amount of copper. For example, structural steels can contain up to 0,5% Cu. Copper is also used as an alloying element which gives some steels a mild resistance to corrosion (e.g. up to 0,25% Cu). The recycling of scrap originating from such steel grades is an additional source of contamination with Cu.

The main source of scrap contamination with Zn is the recycling of zinc-coated steel. The zinc content of galvanised steel products is in the range 1-4%. About 50% of the zinc which is used for coating of steel in the EU is consumed for sheet galvanising. Zinc coated steel sheets feature an average zinc content of 2,74%. The consumption of zinc for zinc-coated steel in the EU was 940 000 tons in 1994 [19]. The production of zinc-coated steel in Europe has increased from 6,3 million tons in 1985 to 13,0 million tons in 1994. A significant increase was registered in Germany as can be seen in **Figure 25**. The reason is the automotive industry which is increasingly employing zinc-coated sheets for the newest car models. The average life of a car in Germany was

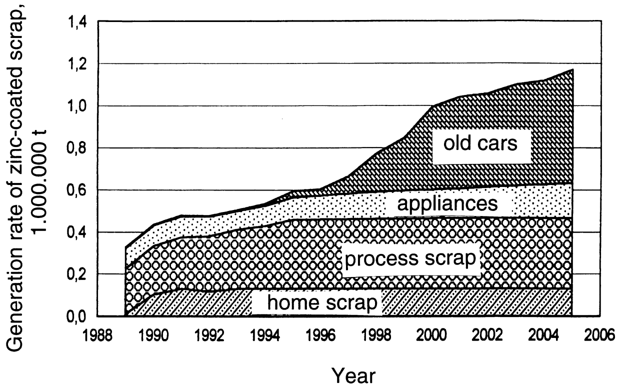

Figure 26: Development of the generation rate of zinc-containing scrap in Germany [20]

Slika 26: Rast količine jeklenega odpadka, ki vsebuje cink [20] estimated to be about 10 years. This means that the quantity of obsolete scrap originating from zinc-coated steel will continue to increase in the future. **Figure 26** shows the development of the generation rate of scrap from zinc-coated steel in Germany and the break down in Terms of various consumer goods in it [17].

Zinc used as an alloying element forms the second largest group of applications of this metal surpassed only by its use in coatings. The predominant use is with copper to form a series of brasses. This suggests that steel scrap which is mixed with brass is contaminated with Zn. Zinc is also present in the form of zinc compounds in rubber, ceramics and paints, which can be an additional source of zinc in steel scrap.

About a third of all tin produced today goes to make tinplate for food and beverage steel cans and other packaging. The amount of tinplate produced in the EU was almost unchanged in the last few years and fluctuated around 4,1 million tons per year [19]. Tinplate production in Germany remained constant at a level of 0,9 million t. The main source of tin in steel is the recycling of post-consumer tinplate packaging. The discarded tin cans are retrieved from the municipal solid waste by magnetic separation which is carried out either before or after incineration. At present one of the world's highest recycling rates of tinplate cans is achieved in Germany (81% in 1998), and German law requires that a minimum of 70% are recycled [20]. Tinplate scrap is pressed in bales and transported to the steel mills where it is recycled. Over the last ten years, the thickness of the walls of a typical steel can has been reduced by 20%. The thickness of the average tin coating has also been progressively reduced by 20% over the same period and currently amounts to 5 g Sn/m^2 sheet [17]. Thus, the supplied packing volume per unit of tin increased considerably. However, the present level of tin used for steel coating is unsatisfactory in view of the recycling of tinplate scrap. If tinplate is smelted without previous detinning, the scrap melt contains approximately 0,3% Sn. This is an unacceptably high level of tin for every steel grade.

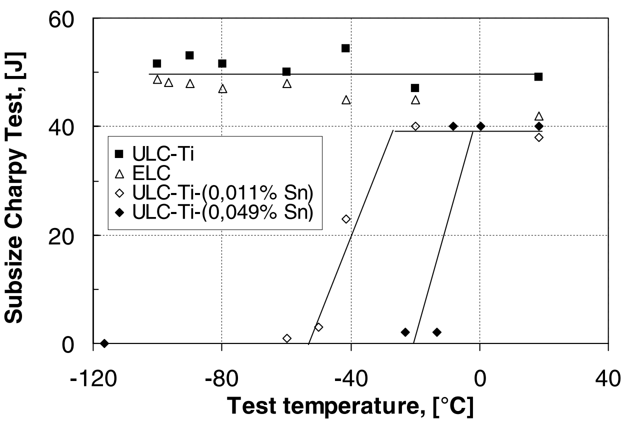

Figure 27: Effect of Sn content on the toughness of IF-Ti hot strips [25]
Slika 27: Vpliv kositra na žilavost vročih trakov IF-Ti [25]

3.3 Influence of impurities on steel processing and service properties

Tramp elements influence steel quality in two different ways. First, they can influence the processing conditions of steel, from ladle treatment through casting to final annealing, thus indirectly affecting the quality of steel. Second, as constituents of steel they can directly influence the mechanical properties of steel products.

Basically, all tramp elements contribute to an increase in strength associated with a ductility loss and a decrease in the drawing properties. These effects are more pronounced for low carbon clean steels (low carbon, extra low carbon and ULC-IF steel grades) than for medium and high carbon steel grades.

Copper is the key element related to surface defects of steel caused by a loss of ductility in the temperature range 1050-1200 °C (hot shortness). Surface defects can appear along the whole hot processing line, during casting or during hot rolling. Hot shortness is due to surface scaling and the low solubility of Cu in austenite, resulting in the formation of a liquid copper-rich phase under the scale. This phase penetrates along grain boundaries and leads to loss of ductility in the critical temperature range due to intergranular fracture. Alloying and tramp elements in steel modify the negative effect of Cu. Some of them amplify, while others neutralise the negative effect of copper. The interactions are illustrated by empirical expressions for the so called "copper equivalent". For example, the expression "%Cu+10x%Sb+5x%Sn+2x%As-%Ni" shows that Sb, Sn and As when present in steel increase, each of them to a different extent, the negative effect of copper, while the presence of Ni reduces it [21].

The tramp elements Sn, Sb, As and Bi tend to segregate at surfaces, grain boundaries or other interfaces. Segregation occurs during cooling and coiling in the hot strip mill, or during final annealing after cold rolling. The segregation reduces grain cohesion and makes fracture more likely, thus causing embrittlement. An example for the negative effect of Sn on the toughness of low carbon steels is shown in **Figure 27** [22]. It can be seen that steels containing tin become brittle in the temperature range -30 °C - 0 °C while tin-free steels preserved their toughness at much lower temperatures. Tramp elements are more likely to cause embrittlement in alloyed steels than in plain carbon steels. Furthermore, the lower the carbon content of the steel, the greater the segregation of tramp elements on grain boundaries. Ni, Mn and Cr enhance the segregation of tramp elements, while Mo, Ti and rare earths can combat it. Some formulae have been proposed which link embrittlement to the alloying and tramp element level in steel [21]. One of the most common expressions is:

$$\text{Embrittlement} \propto (10x\%P+5x\%Sb+4x\%Sn+As) \qquad (1)$$

In the field of cold rolled and annealed sheet, the major part of the product mix is low carbon or ULC steels. The properties of these steels are tailoredfor very demanding applications. Consequently, these steel grades are very sensitive to the content of tramp elements. It has been shown that Sn, Cu, Ni and Cr increase the tensile strength of ULC-Ti steel grades and decrease their ductility expressed in terms of elongation. Drawing properties are also dependent on the tramp element content in steel. Sn, As, Cu, Ni, Cr and Mo have adverse effects on drawability, decreasing the r-value and, to some extent, the ductility of ULC-IF and ELC grades.

Recent investigations have shown that increasing the zinc content of steel has no harmful effect on its mechanical properties [19]. However, zinc has a negative effect on the steelmaking process. Increasing the share of galvanized scrap in the charge increases the amount of dust generated per tonne of crude steel. Moreover dust emissions contain higher levels of zinc and other heavy metals contained in the zinc coating. EAF dusts cannot be dumped because of environmental regulations and dust processing increases steel production costs. The zinc content of EAF dusts is not sufficient to ensure economically viable recovery of zinc. On the other hand, increased levels of zinc in the BOF dust make its usual recycling route via the sinter plant/blast furnace problematic because of the harmful effects of zinc in the blast furnace. Moreover the BOF scrubber discharge water usually requires treatment to lower its zinc content. In the last years public concerns about the acceptable zinc levels in water have risen dramatically, hence even stricter regulations are expected. Apart from the smelting stage, problems may appear during casting of steel melts featuring higher Zn contents. Possible effects are corrosion of the casting mould and emanating zinc vapours which are harmful to the personnel at the continuous caster. Blisters due to evaporating Zn have also been observed.

Scrap purification methods

Many tramp elements dissolved in steel melts, e.g. Cu, Sn, Sb and Pb, are not oxidised in the presence of iron due to their low affinity for oxygen. This means that these elements cannot be removed from a steel scrap melt by a common pyrometallurgical process, as is the case with Si, Mn and Al which are oxidised and dissolved in slag. In order to remove tramp elements, scrap can be pre-treated at lower temperatures while it remains in the solid state. Pre-treatment of scrap in solid state has often the advantage that the tramp elements are present in pure state, either mingled with the ferrous portion of the scrap or existing at scrap surfaces, a fact which should facilitate their removal.

Detinning. The electrolytic detinning of tinplate scrap has been a commercialised process for a long time. Tinplate scrap is pressed into bundles with a density of about 1,5 t/m^3. The bundles which serve as anodes in the electrolytic process are immersed in a caustic soda bath at a temperature of 85 °C. Tin is deposited on a steel cathode as a sponge material which is then scraped off, pressed into large pills and sold to the tin industry. After detinning a residual tin content in the scrap as low as 0,02% can be achieved. Electrolytic detinning is economically efficient only for installations with an annual capacity higher than 30 000 t scrap [18]. Furthermore, electrolytic detinning is suitable for prompt scrap, but is problematic for obsolete scrap. Thus 47% of the prompt tinplate scrap which was recycled in the steel industry had been electrolytically detinned but only about 10% of the obsolete tinplate scrap was detinned [18]. The tin coating on tinplate cannot be removed by mechanical treatment (e.g. by shredding). In the temperature range 400-550 °C the sulphidation of the coating with reactive gases featuring a sulphur potential and its subsequent removal as a brittle sulphide phase was applied successfully on a laboratory scale [23]. At present it is impossible to remove tin from steel scrap melts under industrial conditions. On the laboratory scale tin was successfully removed by treatment with Ca-containing slags under reducing conditions [24] as well as by vacuum treatment of steel melts at a pressure of 0.1 mbar [25].

Decopperization. Copper cannot be removed from scrap-based iron melts by a conventional refining method. Several approaches to reduce the Cu content of steel have been proposed, namely, improvement of scrap sorting, dilution of contaminated charges by directly reduced iron as well as mechanical or chemical scrap pre-treatment aiming at impurity removal. Significant research efforts have been made to develop pyrometallurgical decopperisation techniques. It was confirmed on a laboratory scale that copper can be removed by treatment with sulphide fluxes but a more promising method is the treatment of iron melts at reduced pressure of the gas phase. This method which consists of the selective vaporisation of copper has been successfully tested on the laboratory scale [25]. At present, investigations are carried out to optimise the shredder operation with respect to the Cu content of the shredder scrap. Preliminary results show that the Cu content can be controlled by varying the degree of the shredder's grid opening [26]. With respect to sorting of scrap, it was found that copper is most effectively removed my manual hand picking [18].

Dezincing. Due to its high vapour pressure (70 bar at 1600°C) most of the zinc evaporates during the steelmaking process. A Zn balance for an EAF furnace shows that 97,9% of the zinc input escaped with the fumes, with only 2% remaining dissolved in steel and 0,1% in the slag [19]. Although the removal of zinc at the scrap smelting stage is not problematic, it is supposed that dezincing at a scrap pre-treatment stage would avoid the problems associated with recycling large amounts of galvanised scrap. A continuous process for the electrolytic dezincing of process scrap from automotive industry was developed by Hoogovens (Holland) and a pilot plant has been operated in France. Galvanised scrap is immersed in a hot caustic solution where zinc dissolves while steel remains unaffected. After leaving the dissolution reactor the dezinced scrap is washed and compacted. The zinc-enriched solution is circulated to electrolysis cells where the zinc is recovered electrolytically by deposition on cathode plates [17]. The high processing costs of 75 DM/t scrap and the additional transport costs are disadvantages of the process. However, particularly for niche markets determined by a regional combination of a large supply of zinc-coated process scrap and a demand for reliable foundry feedstock, this dezincing process offers a real direct recycling solution. Several other methods of dezincing the scrap have been investigated recently, too. These include thermal treatment, treatment with Cl_2-O_2 gas mixtures and mechanical post-treatment after thermal treatment [26].

4 REFERENCES

[1] Jahrbuch Stahl 2000, Band 1, VDEh/Wirtschaftsvereinigung Stahl, Verlag Stahleisen, Düsseldorf, 1999

[2] IISI, Internet (www.steelworld.org), 2000

[3] VDEh/WVS: Statistisches Jahrbuch der Stahlindustrie 2000, Verlag Stahleisen, Düsseldorf 1999

[4] H.-U. Lindenberg, O. Kazmicrski, A. Otto; Stahl und Eisen, 120 (**2000**), 6, 37-42

[5] Thyssen Krupp Steel Information 6/2000

[6] E. Schulz: Technologische, wirtschaftliche und umweltrelevante Aspekte der modernen Elektrostahlerzeugung, TU Bergakademie Freiberg, Diplomarbeit, 2000

[7] Bundesministerium für Wirtschaft und Technologie: Energiedaten 1999, BMWi, Bonn, 1999

[8] K.-H. Klein: Development of the EAF Technology during the last decade & the future evolution, IISI, Mexico City, 1999

[9] K.-H. Heinen: Elektrostahlerzeugung, Verlag Stahleisen, Düsseldorf, 1997

[10] W. Reichelt: Contiarc - A new scrap melting technology, Iron and Steel Engineer, July 1998

[11] R. J. Fruehan (Ed.): The Making, Shaping and Treatment of Steel - Steelmaking and Refining Volume (11th edition), AISE Foundation, 1998

[12] G.-H. Feldmann, H. Smith, G. p. Dawson, J. Lemke: Commissioning of the new CONARC process at Saldanha Steel, 6th European Steelmaking Conference, METEC Congress 99, Düsseldorf, 1999

[13] C. Roederer, L. Gourtsoyannis: Coordinated Study "Steel Environment", DGXII-EUR 16955 EN; Brussels, 1996

[14] J. Lee: Kupferproblematik beim Schrottschmelzen, Shaker Verlag, Aachen, 1996, ISBN 3-8265-2320-2

[15] L. Savov and D. Janke: Metall, 52 (**1998**) 6, 374-383

[16] R. Willeke, R. Ewers and H.W. Kreuzer: Stahl und Eisen, 114 (**1994**) 4, 83-88

[17] A. Ender: "Recycling von oberflächenverdeltem Stahlschrott"; VDEh Kontakstudium Metallurgie, Teil IV: "Recycling", Freiberg, 26-28.05.1997

[18] C. Marique (Ed.): Recycling of Scrap for High Quality Products, 1996 Report of the ECSC Research Project 7210-CB, Brussels, 1997

[19] R. Tomellini (Ed.): Third ECSC workshop on steelmaking: Recycling of zinc-coated steel scrap, 4.12.1996, Brussels (**1997**), ISBN 92-828-0844-0

[20] Prospect material of Informations-Zentrum Weissblech e. V., Kasernenstr. 36, 40213 Düsseldorf, Germany.

[21] Effects of Tramp Elements in Flat and Long Products, ECSC Final Report, Contract No. 7210-ZZ/555+ZZ/564, Brussels, 1995, ISSN 1018-5593.

[22] J. C. Herman and V. Leroy: Iron and Steelmaker, 23 (**1996**) 12, 35-43

[23] S. Tu, L. Savov and D. Janke: to be published in Proceedings 2001 TMS Annual Meeting, Materials Processing Fundamentals.

[24] M. Breitzmann, H-J. Engell and D. Janke: Steel Research 59 (**1988**) 7, 289-294

[25] L. Savov and D. Janke: ISIJ Intl. 40 (**2000**) 2, 95-104

[26] Ongoing research project of ECSC: Mechanical and metallurgical study and modelling fragmentizing end of life goods in a scrap shredder, Technical Report No. 1 (1999)