GOSPODARKA SUROWCAMI MINERALNYMI – MINERAL RESOURCES MANAGEMENT

2018 Volume 34 Issue 4 Pages 25–50

DOI: 10.24425/122585

MARIUSZ KRZAK[1], ANDRZEJ PAULO[1]

Modern trade standards for steel raw materials

Introduction

The volume of steel production is widely considered as a basic indicator of industrial development. In terms of quantity, it exceeds that of non-ferrous metals taken in aggregate. Worldwide, actual production exceeded 1,600 million tons of crude steel and consumed a large amount of feedstock for metallurgical processes and materials necessary for the construction of furnaces as well as mining and metallurgical machines, transport equipment, etc. The great size and growth rate of the steel sector is a flywheel for the entire economy, not only for the smelting of iron and steel, but also for the production of alloy components, reducers, and fuels used in manufacturing processes, as well as refractory materials and fluxes. The introduction of new technologies and technical devices entails significant changes to the organization of this part of the raw materials market. In effect, we are witnessing dynamic changes that have not yet been presented in a comprehensive manner at the beginning of the present century. The authors have attempted to present a synthesis of the modern market for steel raw materials.

1. Steel raw materials

Batch materials include derivatives of metallic ore (concentrates, sinters, pellets) and scrap, slag-forming additives, and reducing agents, as well as carbon oxidizing and carburi-

---

✉ Corresponding Author: Mariusz Krzak, Andrzej Paulo; e-mail: krzak@agh.edu.pl; paulo@geol.agh.edu.pl

[1] AGH University of Science and Technology, Kraków, Poland; e-mail: krzak@agh.edu.pl; paulo@geol.agh.edu.pl

zing components. In addition, fossil fuel or electric energy is needed to produce a sufficiently high temperature. The following will not be discussed here: construction materials for metallurgical plants; mines, transport equipment, or other facilities involved in the processes of this sector of the economy; oxygen obtained from the atmosphere.

Depending on the technology in use, raw materials for obtaining steel include concentrates of iron ore (55–65% Fe), ore pellets (65% Fe), steel scrap, direct reduced iron (DRI), hot briquetted sinters (HBI), ferro alloys, and technical metals (i.e. not refined to a state of high purity). Steel waste products such as blast furnace dust (44–55% Fe), converter and open-hearth slag (10–24% Fe, 7–10% Mn), slag from heaters of rolling mills (45–50% Fe), and skimmings from rolling and hammer mills (about 70% Fe) are also being used with increasing frequency.

Annually, several hundred million tons of steel scrap and approximately 1400–1500 million tons of iron contained in ores are consumed in global steel production. In the first step, the ores are mostly processed into pig iron. Other metal raw materials used in these processes include manganese, chromium, nickel, molybdenum, and other alloying metals obtained from ore. In 2014, these materials were used in the iron and steel industry in the following quantities (in Mt): Mn 14–15, Cr 10, Ni 0.8, Mo 0.27 (USGS 2016).

In 2015–16, the integrated steelmaking process (blast furnace and basic oxygen furnace, BF + BOF) provided nearly 74% of total steel production, and 25–26% of electric furnaces (EAF). EAFs used DRI in an amount of less than 4%, and the share of this prospective alternative raw material has levelled off and even declined somewhat in the last decade. EAF plants pollute the environment less than integrated steel mills. Two obstacles to their fast development are a local shortage of scrap and investment costs more than double for the same production capacity (Van Wortswinkel and Nijs 2010).

Steel production consumes a great deal of energy. The most economical integrated process consumes 18 GJ/t of crude steel (including 14.6 GJ/t of fuel and 0.9 GJ/t of electrical electricity) (Worrell et al. 2008; Siitonen et al. 2010). Electric furnace technology is based on scrap metal (in several countries, on DRI) and electricity. The production of 1 ton of steel absorbs an average of 0.88 t of scrap; about 0.15 t of DRI or HBI, liquid pig iron, and other metallic raw materials; 16 kg of coal; and 64 kg of limestone (WSA 2018). According to AISI (2015), in 2003 the integrated process absorbed 25.3 GJ/t of crude steel, compared to only 6.1–7.5 GJ/t absorbed by EAF smelting; the higher figure refers to the processing of imported pig iron and DRI, the lower to the smelting of scrap.

Fuels, depending on the process used and local availability, include coke, anthracite coal, natural gas, coke oven gas, and electricity. The BF + BOF technology is characterized by a greater consumption of raw materials than EAF. The integrated process per 1 ton of crude steel for the former process consumes an average of 1.4 t of ore concentrate, 0.8 t of coal, 0.3 t of limestone, and 0.12 t of scrap. The energy expenditure on the production of 1 ton of crude steel in 2005 amounted to 18 GJ in the USA and 21.7 GJ in China (Hasanbeigi et al. 2014). Approximately half of the energy consumed globally in these processes comes from coke and coal, 35% from electricity, 5% from natural gas, and 5% from other gases (WSA 2014).

Integrated processes are associated with a much greater volume of greenhouse gas emissions into the environment than EAF. Energy consumption is three times lower in the EAF process, as iron oxides do not require reduction, which absorbs the greatest amount of energy (Arens et al. 2012). In Poland, about 60% of the energy supplied to iron and steel mills is consumed in the raw material departments (blast furnace, ore sinter and coking plants).

In recent decades, huge savings have been implemented; e.g. since 1960, energy consumption has been reduced by as much as 60% (Fig. 1). Initially, progress was mandated by competition in production costs; at present, an additional reason is the reduction of gas emissions along with a reduction in amounts of fuel. The energy cost, measured in individual countries at different times, constitutes 20–40% of the total cost of steel (Asia-Pacific Partnership 2010).

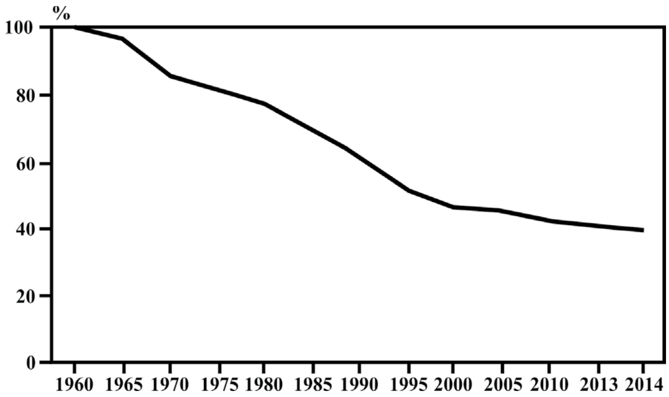

Fig. 1. Relative decrease in energy consumption per unit of steel produced in the years 1960–2014 (WSA 2018)

Rys. 1. Względny spadek zużycia energii w przeliczeniu na jednostkę wyprodukowanej stali w latach 1960–2014

On a global scale, in recent years, approximately 1,200 Mt of high-purity coal has been used to produce over 1,600 Mt of steel, i.e. approximately 15% of the total extraction of this raw material (WSA 2015). The calculation of the quantities used is complex due to the predominant use of coke, a derivative of coal. New metallurgical technologies are characterized by the more economical use of reducers. For example, in Germany, production of 1 ton of metal consumed as much as 1 ton of coke in 1950, compared to only 350 kg, plus 80 kg of coal and 80 kg of crude oil, at the end of the last century (Fig. 2). The current global coefficient of consumption of 0.75 t of coal per 1 t of steel may be subject to fluctuations as a result of changes in the share of technologies.

In integrated processes, large volumes of hot gases are created, not only in coke oven batteries but in blast furnaces and in steel tanks. These are used in new installations to provide more than 60% of the total energy, reducing the need for fuel, or serving to transfer heat and generate electricity.

The energy required for rendering 1 ton of steel from scrap is about 1.3 GJ. Unfortunately, a number of difficult conditions must be met to achieve maximum thermal efficiency,

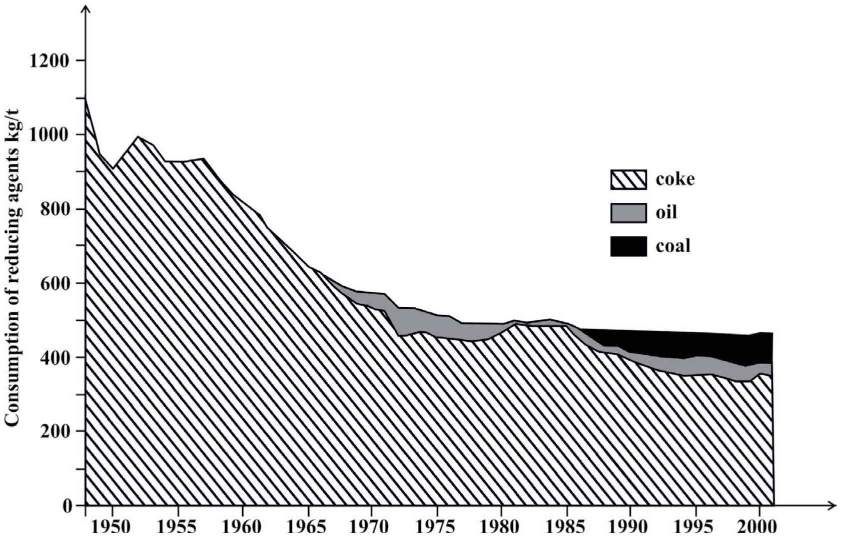

Fig. 2. Evolution in the unit consumption of reducers in the German steel industry (Birat 2014)

Rys. 2. Zużycie reduktorów w procesie produkcji stali na przykładzie Niemiec

including rapid heating and the use of waste heat (Stubbles 2000). In rolling processes, the main energy carriers are natural gas and electricity; in 2007, their unit consumption amounted to 1.24 GJ/t and 1.51 GJ/t, respectively, while consumption of coking gas amounted to an additional 0.38 GJ/t (Arens et al. 2012).

When the entire cycle of steel production is considered, it is necessary to add energy consumed at the stages of ore extraction and enrichment and the transport of raw materials. It is estimated that these processes require about 8% of the total energy needed to produce steel (LCA 2011).

Materials which form slag and lower melting temperatures include, along with limestone, metallurgical dolomite and lime. The use of fluorite has been discontinued. The proportion of these materials in charges to blast furnaces depends on their contents of silica and clay. With the increased popularity of the enrichment and use of concentrates which are increasingly rich in iron and poor in admixtures removed from slag, the consumption of fluxes has decreased drastically. This phenomenon was noted in the steel industry in Japan and the 'Asian tigers' at the beginning of the second half of the 20th century and soon spread to modernized plants in other parts of the world.

1.1. Iron ores and concentrates

The basic indicators of the usefulness of iron ore, the main metallic raw material for the production of iron and steel, are its contents of iron and beneficial and harmful admixtures;

granulation; and mechanical strength. These indicators have a decisive impact on price. The competitiveness of suppliers is affected less by the natural content of elements in the ore deposit and the cost of extraction than by the cost of its enrichment. Suppliers also cover transport costs.

In the second half of the 20th century, the quality requirements for raw materials for the production of pig iron were tightened significantly, primarily as a result of an increase in the prices of fossil fuel as a result of the energy crisis in the early 1970s. Energy costs for smelting ores with low iron content (and consequently abundant slag-forming additives that absorbed a large volume of fluxes) resulted in ores with a content of less than 55–60% Fe to being abandoned in market economy countries. However, poorer ores are still used in China, in steel centers far from ports, due to the shortage of standard raw materials. Foreign supplies elsewhere are dominated by raw materials with a content over 62% Fe. Such high concentrations in ore, rare in nature, are usually obtained by means of mechanical enrichment and, if necessary, sintering. Iron enrichment occurs primarily as a result of the separation of quartz and aluminosilicate minerals, i.e. the reduction of undesirable admixtures of SiO_2 and Al_2O_3. Currently, individual mills have differing requirements in this respect; for example, in China, of ≤ 4.0% SiO_2 and ≤ 2.5% Al_2O_3 (Table 1).

Table 1. Grade of and price adjustments for imported iron concentrates in the Chinese market (DCE 2013)

Tabela 1. Jakość i korekty cenowe importowanych koncentratów żelaza na rynku chińskim

Parameter	Standard concentrate	Substitute concentrate	
		tolerance zone	premium/discount (CNY/t)
Fe	62.0%	60.0–62.0% 62.0–65.0% > 65.0%	For each deduction of 0.1%, a discount of 1.5 For each additional 0.1%, a premium of 1.5 Pricing at 65.0%
SiO_2	≤ 4.0%	$SiO_2 + Al_2O_3 \leq 10.0$	When $SiO_2 > 4.0$, for each additional 0.1% of SiO_2, a discount of 1.0
Al_2O_3	≤ 2.5%		When $Al_2O_3 > 2.5\%$, for each additional 0.1% of Al_2O_3, a discount of 1.0
P	≤ 0.07%	0.07–0.10%	For each additional 0.01%, a discount of 1.0
S	≤ 0.05%	0.10–0.15%	For each additional 0.01%, a discount of 3.0
Pb	≤ 0.10%	Not standardized	
Zn	≤ 0.10%		
Cu	≤ 0.20%		
As	≤ 0.07%		
TiO_2	≤ 0.80%		
Cl + F	≤ 20%		
$K_2O + Na_2O$	≤ 0.30%		
Grain size	–10 mm ≥ 90% –0.15 mm < 40%	–0.075 mm ≥ 70%	No bonuses/deductions

The disadvantage of the enrichment process is the fragmentation of the ore into fines characterized by inferior metallurgical properties and lower price. If the mined ore shows the desired iron content and a tolerable level of admixtures, it qualifies for direct shipment without enrichment.

Deleterious admixtures include phosphorus (in the practice of various countries > 0.07–0.1%), sulphur (> 0.05–0.3%), K_2O + Na_2O (> 0.3%), Zn and Pb (each > 0.1%), Cu (> 0.2%). Chromium and titanium increase the temperature of melts and destroy furnace linings; thus TiO_2 content > 0.8% is not allowed. Preferred admixtures include Mn, V, and, rarely, Ni and Co.

Table 2 summarizes data from 36 large sintering plants in 9 EU countries at the beginning of the 21st century (Cores et al. 2010). The large differences in the parameters of sintered raw material are noteworthy.

Table 2. Physicochemical properties of sinters from plants of Western Europe (Cores et al. 2010)

Tabela 2. Właściwości fizykochemiczne spieków w aglomerowniach Europy Zachodniej

Parameter	Value	
	min.	max.
Coke consumption (kg/t sinter)	39	54
Productivity ($t/m^2/24$ h)	26	43
Total Fe content (%)	51	61
FeO content (%)	4.0	11.0
Al_2O_3 content (%)	0.6	1.8
MgO content (%)	0.7	2.2
Susceptibility of sinter to RDI decay (> 3 mm, %)	27	33
Tumbler index (> 6.3 mm, %)	63	79
Reducibility of sinter (%)	49	78

The characteristics of concentrates supplied by the largest producing countries are presented in Table 3.

The classification of iron raw materials on the basis of grain size is not uniform. Lumps and fines can be distinguished everywhere. In the US, the lower limit of lump size is a diameter of 4.75 mm; in most countries, 6.3 mm. Many mines increase the quality and price of their products by sintering fines into surface-hardened pellets with diameters of 10–16 mm. However, in the global supply, relatively cheap fines prevail and the steelworks see to their sintering. Desirable features of sinters include a high level of porosity and mechanical

Table 3. Chemical composition of ores and iron concentrates from major deposits (Muwanguzi et al. 2012)

Tabela 3. Skład chemiczny rud i koncentratów żelaza z ważniejszych złóż

Deposit	Country	Content (%)				
		Fe	SiO_2	Al_2O_3	S	P
Goldsworthy	Australia	63.2	4.90	1.60	n/a	0.030
Hammersley		62.7	4.20	2.73	0.016	0.059
Irvine Island		54.4	21.30	0.23	0.040	0.010
Carajas	Brazil	65.4	0.79	0.72	0.010	0.038
Itabira		68.9	0.35	0.60	0.010	0.030
Bailadila	India	64.0	2.50	2.50	0.050	0.100
Goa		57.8	2.50	6.50	0.020	0.040
Tula	Russia	52.2	10.10	1.25	0.100	0.600
Mesabi	USA	57.5	10.10	0.70	0.100	0.060

strength. These features derive from the composition of fines, not specified in contracts but optimized in the course of the thermal treatment practiced for years in the sinter plants belonging to the smelters. Therefore, they strive to ensure acquisition of all supplies from the same mine in order to maintain stable composition of feed as well as to obtain the desired sintering properties.

The sinter plants pay attention to numerous feed characteristics, the main component of which is ore fines (Wyderko-Delekta, Bolewski 1995). Blast furnaces require sinters with the following features (Paananen 2013; Mochón et al. 2014):

- chemical composition: total iron content; share of FeO, Al_2O_3, MgO, CaO, and SiO_2; minimal impurities of S, P, alkalis, Ti, Zn, and Pb; alkalinity, i.e. CaO/SiO_2 ratio; in the USA, $(CaO + MgO)/(SiO_2 + Al_2O_3)$ within the ranges 1.07–1.3 or 1.8–2.3;
- a high degree of reducibility, i.e. ability to yield oxygen;
- grain composition of the feed and produced sinter;
- mechanical resistance of sinter to impact and abrasion, i.e. tumbler index (TI);
- thermal resistance of sinter to degradation at low temperatures (LTD) and reduction at low temperatures (RDI);
- high degree of porosity of sinter;
- high melting point and low softening range.

These interrelated features determine reactions during sintering and are of significant importance for integrated processes based on ore. In practice, fines contain ≤ 10% oversized grains, with a predominant portion 1–4 mm, and 15–40% particulate grains < 0.15 mm (Umadevi et al. 2011). At the end of the 20th century, computerized control of the agglomeration process was introduced, which led to the following reductions (Wyderko-Delekta and Bolewski 1995):

- in fuel consumption by the blast furnace, thanks to the stabilization of sinter alkalinity;
- in the amount of unsintered fines (along with the stabilization of RDI);
- in labor costs, due to computer data processing and process control.

At the beginning of the 21st century in Western Europe, ore fines containing 54–67% Fe, 0.4–2.7% Al_2O_3, and (with a high degree of tolerance) shares of CaO (0.5–13.4%) and SiO_2 were used. Feed mixtures of 56–63% Fe, 0.9–1.2 Al_2O_3, and 3–4.6% SiO_2 were prepared, and, finally, sinters of 55–58% Fe, 0.9–1.4% Al_2O_3, and 5–6% SiO_2 (Cores et al. 2010). At present, the requirements for the quality of raw materials have increased, and imported ores with Fe content over 60% are preferred on the Chinese market (Table 1).

Ore fines, depending on their mineral composition, contain Fe_2O_3 and FeO, CaO and MgO, and Al_2O_3 in different proportions, which, in a complex way, affect weldability and sinter strength and reduction. The softening and melting of sinter in the blast furnace depends mainly on the sinter's alkalinity and FeO and SiO_2 contents. In the course of sintering, silica is combined with FeO and CaO, leading to a low melting point (1180–1223°C) for Fe silicates. The increased alkalinity (> 15) of a raw mixture of ore, coke, and fluxes leads to slightly higher consumption of thermal energy. Basic sinters with increased FeO content melt around 1300°C, those rich in silica and FeO at 1200–1250°C; however, the latter are brittle (Geerdes et al. 2009).

The presence of titanium in feed reduces its gas permeability. Small admixtures of TiO_2 in hematite (~0.5%) do not significantly influence the process; greater admixtures (2–5%) lower its reducibility and cause sinter decay, while exsolutions of ulvöspinel in titanomagnetite accelerate its oxidation (Paananen and Kinnunen 2007).

It has been observed that uneven grain in ore feed, moisture content, and wettability are important factors that increase the permeability of the sintered mass (Lwamba and Garbes-Craig 2008).

The susceptibility of sintered particles to decay at a relatively low temperature is measured by two indices: dynamically at 600°C (LTD) and thermally using electron microscopy, X-ray techniques, and a hardness tester at 550°C (RDI). The mechanical strength (TI) of ore, pellets, and sintered particles is measured against a standard (ASTM 1980). The reduction of hematite to magnetite occurring within this temperature range causes an approximate 4% increase in volume and structural stress. These values can be reduced by the addition of magnetite fines (Mochón et al. 2014).

1.2. Steel scrap

On the basis of origin, three main types of scrap are distinguished:

- factory (also called industrial),

- process (or home),
- old (or post-consumer).

The first, formed as waste in steelworks and foundries, is relatively clean, with a known chemical composition, and can easily be used as secondary feed. Technological advancements such as continuous casting have significantly reduced the generation of this kind of waste. The second type is internally generated in steel plants and rarely leaves their vicinity. Post-consumer scrap, which comes from used equipment, containers, vehicles, the demolition of buildings and other structures, etc., is often mixed or coated with other metals or materials, with great variations in composition and in the shape of the pieces. It must be carefully selected after disassembly of the devices.

Another kind of classification of steel scrap is based on its purpose, differentiating between alloy, batch, and non-charge scrap. Batch scrap, used in the largest amounts, is prepared for direct use in the steelmaking process, with the specific form and dimensions, chemical composition, acceptable impurities, and weight being determined by the user. The maximum weight of individual elements cannot exceed 200 kg. The scrap cannot contain non-ferrous metals, closed cans or other containers, explosive, flammable, or radioactive materials, plastics, or other non-metallics. Between ten and a dozen or so classes can be distinguished (www.silscrap.pl, http//zlom-ifo.pl, ISRI 2016).

In alloy scrap, in addition to iron and carbon, alloy additives are present, their contents ranging from approximately 5–40%. They are used to improve the physical and chemical properties of steel.

Non-chargeable scrap is not suitable for direct use in the steelmaking process, as it requires mechanical or manual processing in order to obtain the necessary dimensions, forms, and mass and to remove metallic and non-metallic contaminants in accordance with acceptable standard limits.

In view of the immense variety of available iron and steel scrap, a problem exists in relation to its inexpensive qualification for recycling, based not on costly chemical analyses but on specifications formulated by the users of this product and visual expert assessments. Suppliers of scrap metal are certified agents operating mainly in countries that use scrap. General guidelines for suppliers and specifications are formulated by the Institute of Secondary Waste Processing Industries (ISRI 2016), but individual enterprises in this industry may allow minor deviations from the recommended standards.

Iron and steel scrap is coded FS, with the addition of the year of adoption of the current standards, currently FS-2016. This is followed by three-digit codes: the range 201–228 relates to differences in form and type; the range 229–251 is allocated to EAFs and castings; the range 252–282 indicates types which have undergone the treatment required by the recipient. The basic requirement is purity. For all types, the form and size of fragments and the permissible share of non-compliant scrap is determined. Purity means the absence of coatings of dust, clods of dirt, grease, varnish, excessive rust, and non-ferrous metals (permissible contents fall below limits of 0.45% Ni, 0.1% Mo, 0.2% Cr, 1.65% Mn, and a total of 0.6% Ni + Cr + Mo). Scrap which meets these conditions is called alloy-free. Independently of this, radioactivity and mercury content are strictly limited. If a delivered batch contains trace amounts of non-class scrap, this must be so indicated in the declaration and accepted by the recipient.

The Association of American Railroads has issued separate specifications for approximately 50 types of steel scrap; other specifications are used by the large American company Cascade Steel Rolling Mills, still others by Arcelor Mittal, the supply companies Wistal, Strolz Poland, and the Polish and European standards PN-EN 10020:2002U. Thus, numerous separate scrap metal markets have been created.

There is a big difference between the methods of making stainless steel and carbon steel. Stainless steel is generally produced in small vats, with a wide spectrum of components, but there are also large devices producing alloy steel of one type. Carbon steel is more uniform and used in the same products, e.g. construction rods and profiles/fittings, in large quantities. The quality requirements for steel produced in electric furnaces are often lower than those for steel from integrated processes; this, along with cheaper raw materials, makes it possible to reduce product prices.

The most important admixture metals found in steel scrap which affect the quality of the derived steel products are non-ferrous metals: copper, zinc, and tin. The main source of copper is scrapped cars containing wires, electric engines, and air-conditioning devices. These are not always separated from the body of the car before it is cut into fragments, at which point separating them is impossible. Some copper is introduced along with construction scrap, as some grades of structural steel purposely contain up to 0.5% Cu.

The recycling of zinc-coated steel may introduce an admixture of 1–4% Zn. This hinders the melting of steel and causes the destruction of the blast furnace lining and casting ladles or intense smoking in the electric furnace; falling dust cannot be stored due to environmental regulations, nor is it profitable for processing into secondary metal. Automotive components are also an important source of zinc contamination. Other sources include brass, ceramics, rubber, and paint. The automatic evaporation of zinc during the smelting of steel scrap enables the removal of about 98% of this metal and is widely used. Another method of zinc recovery is the expensive electrolysis of process scrap in car factories.

Tin can be introduced into steel by way of scrap metal beverage cans, tins, and other food packaging. Selected wastes are pressed into bundles and delivered in this form to smelters for de-ionizing. If not for this process, molten scrap would contain about 0.3% Sn (Janke et al. 2000), i.e. well above the limit acceptable for any type of steel.

Alloy metals affect the melting and processing of steel and its performance properties, i.e. quality. All alloy metals cause an increase in hardness along with a simultaneous reduction in susceptibility and ductility, as is particularly evident in low-carbon steel. Sn, Sb, As, and Bi have a tendency to emerge on surfaces and at grain boundaries in the course of rolling, resulting in brittle products. This feature is intensified in alloy steels containing Mn, Ni and Cr.

Methods are available for cleaning scrap from unwanted elements before submitting it to pyro- or hydrometallurgical processes. De-tinning has been carried out electrolytically for a long time on an industrial scale, resulting in the recovery of this valuable metal and the reduction of its content in steel scrap to as little as 0.02%. This is profitable only in large plants with processing capacities over 30,000 t/year, mainly process scrap (Janke et al. 2000).

Removing copper from a Fe-Cu alloy by means of refining is not possible, so careful manual sorting and/or dilution with other material, e.g. DRI, is used.

1.3. Alloy metals

Manganese, an indispensable metal in steel metallurgy, is consumed in large amounts. Used as a deoxidizer and desulphurising additive and as a steel alloy component, it improves not only the susceptibility of steel to rolling and forging, but also many of its utilitarian properties, such as hardness, ductility, and resistance to fatigue. Carbon steel (structural) generally contains 0.6–1.2% Mn, special manganese steel 11–14% Mn. The latter, also called Hadfield steel, being extremely durable, is used for the production of railway rails, steel safes, prison bars, rifle barrels, etc.

Chromium increases the toughness of steel, but hinders its machining and welding. Chromium stainless steel contains 10.5–25% Cr. Both, manganese and chromium containing steel consumes yearly 15–20 million tons of ore concentrates. They are added in the form of ferroalloys.

The content of silicon and alloying metals such as nickel, cobalt, molybdenum, niobium, tungsten, vanadium and non-separated rare earth elements (such as so-called miszmetal) in steel is lower (0.2–5%), however for the specific purposes Ni content reaches even 10–20%.

The scale of their consumption in steel worldwide (in millions of tons in the last decade) is as follows: Si 5, Ni 1–1.5, Mo 0.2, V and W 0.08, Co and Nb 0.05–0.06, REE 0.01. They improve mechanical properties in high strength low alloy steel, and increase resistance to corrosion, fatigue at elevated temperatures (hot hardness) etc. Protective coatings have been developed for steel to prevent it from rusting and corroding, thus expanding its use. Zinc, tin, chromium and nickel are the most important of the metallic coatings for flat-rolled steel.

1.4. Metallurgical coal and coke

Primary and secondary fuels used in the steel production process include solids, liquids, and gases. Coal and coke are the main ones among them. Steelworks use both metallurgical coal and less carbonized varieties, as well as pulverized coal, which is injected into blast or rotary furnaces producing DRI, whereas fine particles of coke (1–3 mm), non-coking coal, coal tar, and gases recovered from coke plants, blast furnaces, or converters are used for pelletizing, the burning of lime, sintering of dolomite, and other accompanying operations.

Coke is a raw material processed from certain types of hard coal, usually produced in integrated metallurgical plants. Both coking coal and derived metallurgical coke must meet certain quality requirements. For coal, these include primarily low ash content (5–10%) and coking properties (volatile content, sinterability, swelling, etc.) which define the technological type, as well as sulphur, phosphorus, alkalis, and iron content (Łukaszczyk and Mianowski 2013). The utility of coal for metallurgical coke production is determined on the basis of many parameters which form a complex system. Indirect clues are provided by other commercial parameters of coal, such as humidity, volatile matter content (VM), the heat of combustion, the composition of macerals, etc. In Poland, orthocoke (35.1 and 35.2) is used for metallurgy coal production and metacoke (36) and coal mixtures of types 34–38 for the production of foundry coke. The global reference standard is Australian HCC (hard coking coals) and market supplementary SSCC (semi-soft coking coal) with PCI (pulverised coal injection). On the US market, fat coking coal is the reference standard.

Hard coking coals (HCC), especially premium HCC, are characterized by a high CSR (coke strength after reaction) index value. Semi-soft coking coal (SSCC) alone is unsuitable for coke production, but is usually used as a component of coke-forming mixtures. Pulverized coal injection (PCI), characterized by a very high level of carbonization and low content of ash, moisture, and impurities (S, P, Cl, alkalis), is used in blast furnace technology. Coking coal parameters are listed in Table 4.

Table 4. International quality standards for coking coal (MB 2016; Platts 2017)

Tabela 4. Międzynarodowe standardy jakości węgli koksowych

Parameter/ Type	Premium HCC		HCC		SSCC	PCI
	range	basis	range	basis		
CSR	≥ 67	71	≥ 57	64	–	–
VM (%)	18–25	21	1.5–27	25	34	13–15
Ash (%)	C11	9.5	≤ 11	9.5	9.25	8.5–12
S (%)	≤ 1.1	0.5	≤ 1.5	0.6	0.58	0.55
Humidity (%)	–	10	–	10	9.5	10
CSN/FSI*	≥ 7	8	≥ 6	7	5.5	–
R_0*	1.1–1.6	1.35	1–1.5	1.2	–	–

* CSN – crucible swelling number, FSI – free swelling index, R_0 – average vitrinite reflectance.

In addition to the parameters listed in Table 4, others are normalised, for HCC: fluidity ≥ 40 ddpm (basic value 500 ddpm) and grain size < 50 mm; for SSCC: fluidity = 200 ddpm, phosphorus ≤ 0.025%, and fixed carbon content ≥ 53%; for PCI: total carbon content ≥ 90.5%. Standard indicators such as CSR, VM, content of sulphur, ash, and phosphorus, humidity, and coal fluidity may slightly differ depending on the relevant region of provenance (Platts 2017).

Hard coking coals, due to their superior coking properties, command higher prices on the market. The Australian HCC price is a benchmark price for international transactions. In the statistics of some countries, SSCC and PCI coals are classified as thermal. Coal application is determined by the current economic situation and the demand reported by the relevant industry.

The production of 1 ton of coke requires approximately 1.5 t of metallurgical coal, and an average of 0.63 tons of coke enables the reduction and melting of a rich blast furnace charge calculated per 1 ton of pig iron. In other words, for the production of 1 t of pig iron, an average 0.945 t of metallurgical coal is consumed, not including other fuels.

Coke plays a threefold role in the steel production process:

- as a fuel providing heat for a series of chemical reactions and melting of the ore charge and slag;
- as a reducer and contributor to the formation of gases necessary to reduce iron oxides;
- as a permeable support enabling the vertical movement of slag and charge through the stack to the bosh, as well as facilitating gas migration to the furnace throat.

Oil, gas, and coal can be used as substitutes for the first two coke functions; however, they do not create support for the charge in the melting process. In the blast furnace, coke fills 50–70% of the usable furnace volume; one of the most difficult tasks in blast furnace melting is the establishment of the gas permeability of the feed column (Mianowski et al. 2009).

Coke quality in metallurgical applications is assessed multiparametrically. Coke properties include both chemical characteristics (Table 5) and physical properties (Table 6). These features depend on the quality parameters of the coal used for coke production. Coke with

Table 5. Composition of blast furnace coke required by European consumers (Gulyaev et al. 2012)

Tabela 5. Skład koksu wielkopiecowego wymagany przez europejskich odbiorców

Parameter (%)	Acceptable range	Standard content
Humidity	1–6	–
Volatile Content (DW)	< 1	–
Ash (DW)	8–12	< 9
Sulphur (DW)	0.5–0.9	0.7
Phosphorus (DW)	0.02–0.06	–
Alkali (DW)	< 0.3	–

DW – dry weight.

lower contents of ash and sulphur is more expensive, while coke characterised by too limited a size range is not suitable for trade or use in the blast furnace process, as it would impede gas flow through the furnace charge.

Table 6. Physical properties of blast furnace coke required by various consumers (Diez 2002; Gulyaev et al. 2012)

Tabela 6. Fizyczne właściwości koksu wielkopiecowego wymagane przez różnorodnych odbiorców

Parameter	Europe	Australia	USA	Japan
Average size (mm)	47–70	50	50	45–60
M_{40}	>78–>88	85	50	n/a
M_{10}	<5–<8	6.5	n/a	n/a
I_{40}	53–55	n/a	n/a	n/a
I_{10}	> 77.5	n/a	n/a	n/a
DI 150/15	n/a*	84.4	n/a	83–85
ASTM stability	n/a	63.6	60	n/a
Oversize particles above 80 mm (%)**	<5	n/a	<1	n/a
Fraction 30–80 mm (%)***	avg. 89	n/a	avg. 93	n/a
CSR	>60	74.1	62	50–65
CSI	20–30	17.7	23	n/a

* Not available.

** On the US market, oversize particles above 100 mm are normalized.

*** On the US market, a fraction of 30–100 mm is normalized.

The Nippon Steel Corporation test (ISO 18894: 2006) is commonly used for the assessment of coke quality. This test evaluates coke reactivity to carbon dioxide (CRI – coke rea- ctivity index), then determines the post-reaction strength of coke (CSR – coke strength after reaction). CSR is an indicator of the physical strength of coke relative to pressure and abrasiveness. As mentioned above, such resistance is required, since coke plays a role in the blast furnace as a support for the furnace charge above it.

The Micum/Irsid test, which supplies the parameters M_{40}, I_{40} and M_{10}, I_{10} in accordance with the mesh size of the sieves and the number of rotations, is commonly used in Europe to assess coke strength and abrasion resistance. The Japanese and US drum tests are based on similar assumptions, but differ in terms of sample weight, the number of revolutions of the drum, and screen clearance.

Coke of various quality is offered on global markets. The most important features of coke required in various producer countries are listed in Table 7.

The quality of coke currently produced in Poland meets the expectations of consumers using it in medium-volume blast furnaces, though it falls short of the requirements for large blast furnaces (Table 8). Only the best grades of coke produced in Poland meet the high requirements of consumers. Maintaining the current position of Poland as a coke exporter

Table 7. Physicochemical characteristics of coke from various suppliers (Gulyaev et al. 2012)

Tabela 7. Charakterystyka fizykochemiczna koksu od różnych dostawców

Parameter	Australia	Great Britain	US	China	Russia	Ukraine	Poland*
Ash content	12.0	10.50 (10.0–11.0)	8.25 (8.0–8.5)	13.5	11.45 (10.7–12.2)	11.5	8.5–10.0
Sulphur content	0.4	0.6 (0.5–0.7)	0.8 (0.7–0.9)	0.6	0.75 (0.4–1.1)	1.29	0.5–0.7
Yield of volatile parts	1.2	0.85 (0.7–1.0)	0.8 (0.4–1.2)	1.25 (1.0–1.5)	0.75 (0.4–1.1)	1.0	0.1–0.6**
M_{40}	85.0	83.75 (80.0–87.5)	87.0	88.0 (86.0–90.0)	69.0 (68.0–70.0)	69.0	75–82
M_{10}	6.0	6.8 (5.7–7.9)	5.8	6.0 (5.0–7.0)	8.75 (8.5–9.0)	8.6 (7.6–8.6)	6–7
CSR	> 70	> 62	> 65	> 68	> 48	< 35	57–62
CRI	< 20	< 27	< 22	< 26	< 34	> 42	28–35

* Based on Żarczyński (2015).

** Yield of volatile parts based on laboratory analyses of coal from five mines: Zofiówka, Jas-Mos, Krupiński, Pniówek, Borynia (Łukaszczyk and Mianowski 2013).

Table 8. Comparison of the average quality of coke produced in Poland and quality expectations of coke consumers (Warzecha and Jarno 2012)

Tabela 8. Porównanie średniej jakości koksu produkowanego w Polsce i oczekiwań odbiorców koksu

Parameter (%)	Consumer's expectations for:		Average parameters of coke produced in Poland
	medium-volume blast furnaces	large-volume blast furnaces	
CRI	< 28	< 25	28–35
CSR	> 62	> 65	57–62
M_{10}	6–7	5–6	6.0–7.0
M_{40}	78–82	82–90	75–82
Ash	12.5 ± 0.5	11.5 ± 0.5	8.5–10.0
Sulphur	0.7 ± 0.1	0.6 ± 0.1	0.5–0.7

in the coming years will require a series of technical and technological operations enabling the fulfilment of quality requirements on the international coke market (Kaczmarek 2013).

1.5. Gas and other energy carriers

Liquid fuels in the iron and steel industry include heating oil, diesel oil, and low-sulphur tar, used for heating and powering vehicles and supporting equipment. Gases include natural gas, liquefied gas (LPG), and acetylene, as well as gaseous by-products: coke gas, blast furnace gas, and converter gas. Characterized by calorific values of approximately 17 kJ/m^3, 3.1 kJ/m^3, and 7–10 kJ/m^3, respectively, these gases are used for cutting, welding, and sometimes for carburizing and hardening steel, as well as on a large scale in DRI plants. In the case of close proximity, a natural gas deposit is used as the basic source of furnace heat. Some gas components are, like coke, reducers.

2. Prices of raw materials for steel production

Markets of raw materials for steel production are strongly diversified and governed by different rules. The prices of iron ores and concentrates, alloyants, scrap, and energy raw materials are shaped in different ways, which, along with environmental regulations (fees, penalties for excessive emissions), influence the sector's high level of sensitivity in relation to changes in economic conditions. Regional markets have developed in response to the huge masses of transported goods and distance from ports. Regardless of the large number of suppliers, iron ore and concentrate producers from Australia and Brazil are the most significant in the market. This system is characterized by an oligopoly of producers and polypoly of consumers. A similar market model is observed for basic steel alloyants: chromium, manganese, cobalt, or vanadium. Markets for nickel, scrap, and metallurgical coal are more competitive and constitute a bilateral polypoly.

Prices of iron ores and concentrates vary over a very wide range and therefore do not constitute good material for comparisons. Their connection with steel prices is clear, although the price relationship has weakened significantly over the last decade. Iron ore and concentrate prices depend on the quality of the raw material (chemical composition and physical properties), delivery conditions, market balance of supply and demand, and the weight of the ordered cargo. These prices are usually (negotiated) contract prices, implemented according to supply conditions: FOB and CIF, and, recently, CFR.

In the period 1970–2011, prices were set in undisclosed and usually stormy negotiations between steel and mining enterprises. One-year contracts usually dominated; the reference point was the price established between the Japanese firm Nippon Steel and, later, the Chinese firm Baosteel on one hand and one of the large Australian mining companies on the other. For the sake of stability, long-term contracts of 3–5 and even 10–15 years were pursued and raw materials and conditions of delivery normalized. After 2011 (and partly since 2010), due to market disturbances and uncertainty on the part of the Chinese with respect to securing supplies and price evolution, short-term transactions (annual, quarterly, monthly) and the current 'spot' type have gained in importance. The basic settlement period is the month in which prices are determined on the basis of daily quotations of specialized trading agencies (e.g. The Steel Index). These agencies obtain price data from companies participating in the market (both sellers and buyers) and after the rejection of extreme values and the standardization of the price with respect to qualitatively different raw materials, a weighted price equivalent is set as a reference price.

In Chinese ports, new price indices have also been created, among others Platts IODEX (in Qingdao) and TSI 62% (in Tianjin). In both cases, transactions concern fine ore with a 62% Fe content (Smakowski and Szlugaj 2015). Contracts apply to a fixed schedule of amounts, and prices are renegotiated on the basis of fluctuations on the index markets: Australian–Japanese (Pacific) and Brazilian-European (Atlantic). Sample prices of iron ores and concentrates over the last twenty years are presented in Fig. 3, expressed in the ex-works mine formula and calculated on the basis of annual reports for various assortments and quality levels of ores. There is a significant spread of prices between individual mines caused by the type of raw material (lump ore, fine ore, or pellets) and supply conditions. Some prices include loading and even transport by the supplier to a specific location. Examples of current prices of various primary raw materials from major mining producers are summarized in Table 9. The average prices increased fourfold in the first decade of the current century (Fig. 3), after which they dropped nearly threefold; in the case of alloy components they fluctuated even more widely (Fig. 4).

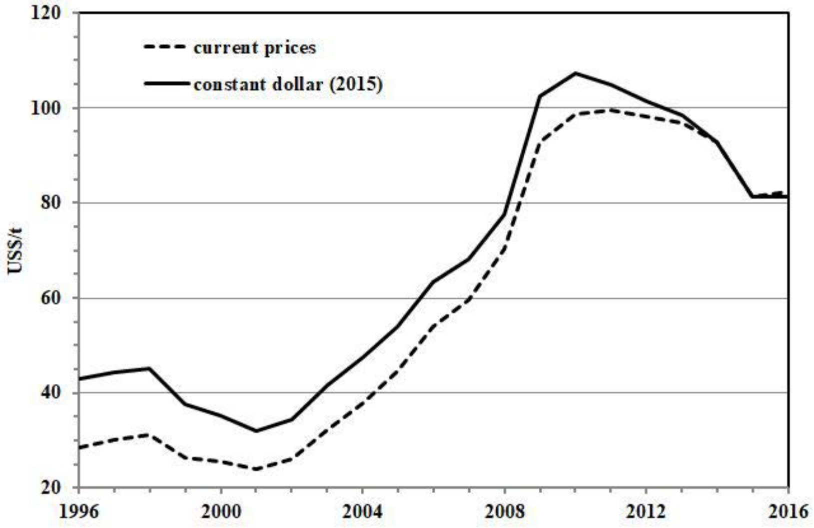

Fig. 3. Average prices of iron ore mine products in the US (ex-works) (USGS 2016)

Rys. 3. Średnie ceny produktów sprzedażnych kopalń rud żelaza w USA

Table 9. Average primary iron raw materials
(according to USGS, Smakowski and Szlugaj 2015; www.indexmundi.com; www.vale.com)

Tabela 9. Średnie ceny pierwotnych surowców żelaza

Raw material	1980	1990	2000	2010
Iron ore – lumps, 51.5% Fe, EXW Mesabi, USA	28.50	29.56	–	–
Iron ore – lumps, Brazil, 65% Fe, CIF Western Europe	–	26.50	–	–
Pellets 64% Fe, EXW Mesabi, USA	46.40	45.76	–	–
Pellets, Brazil, 64.5% Fe, FOB Tubarão	47.05	51.60	49.24	–
Pellets, Vale S.A. (former CVRD) (ex-works)	–	–	49.20	110.31
Fine ore, Brazil, 64.5% Fe, FOB Tubarão	28.10	30.80	27.67	–
Fine ore, Carajas, 64.5% Fe, CIF Japan, CIF Rotterdam	–	–	25.40 28.80	–
Fine ore, Hammersley, 64.3% Fe, CIF Japan, CIF Rotterdam	–	–	27.80 36.50	–

	2010	2011	2012	2013	2014	2015	2016
Fine ore, Vale, 62% Fe, spot CFR Tianjin	147.72	168.79	128.53	135.36	96.84	55.21	57.71

It is worth noting the significant differences between the Asian and European markets in the price of the same raw materials at the same point in time.

The most important steel alloyants are quoted using contract prices; nickel and cobalt are quoted on the LME exchange (Fig. 4).

Since November 2015, steel scrap has been the subject of LME quotations (LME Steel Scrap) (Fig. 5). Transactions include only forward contracts with a period up to 15 months; the lot size is 10 tons. The final settlement price is determined based on the average monthly index of TSI HMS 1 and 2 (80:20), CFR ports of Turkey. The price index reflects the mass import of steel scrap to Turkey. The import destinations cover a wide spectrum of suppliers, from the US, Great Britain, Western Europe, Russia, and the countries of South America to the CIS states. HMS 1 scrap does not include galvanized or blackened steel, while HMS 2 scrap tolerates its presence; the proportions of both types (ISRI codes 200–206) in the index valuation are 80:20. In the materials being traded, the sizes of the elements which, depending on the type of scrap, do not exceed the required volumes are normalized. For example, HMS 1 ISRI 200 is scrap with pieces smaller than 1.5 × 0.6 m.

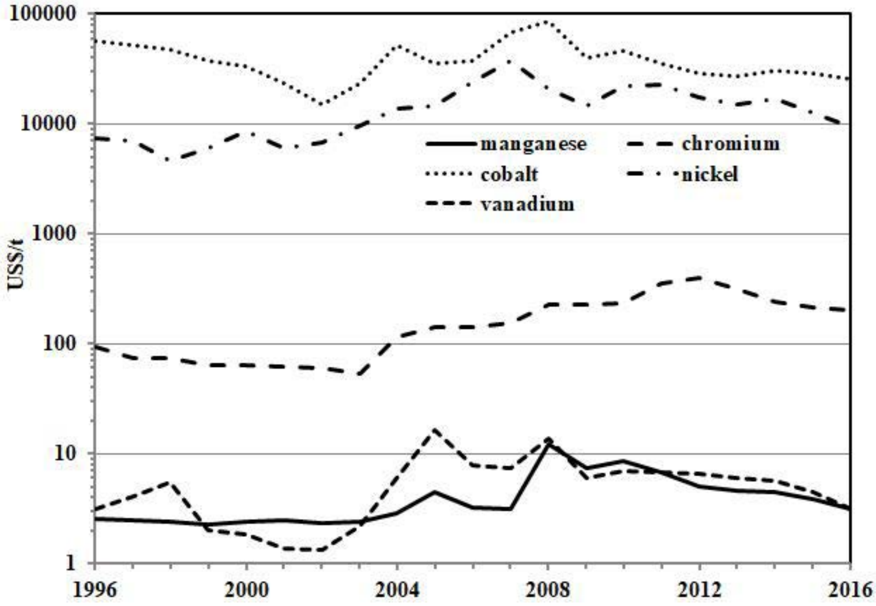

Fig. 4. Current annual prices of selected steel alloyants (logarithmic scale):
manganese – unit price for 1% of manganese, CIF US ports; vanadium – unit price for ton V_2O_5;
chrome – price for metallurgical chromite, nickel and cobalt – LME price

Rys. 4. Średnioroczne, bieżące ceny wybranych uszlachetniaczy stali (skala logarytmiczna);
mangan – cena za 1% Mn w rudzie surowej cif porty USA, wanad – cena za tonę V_2O_5,
chrom – cena rudy, nikiel i kobalt – ceny LME

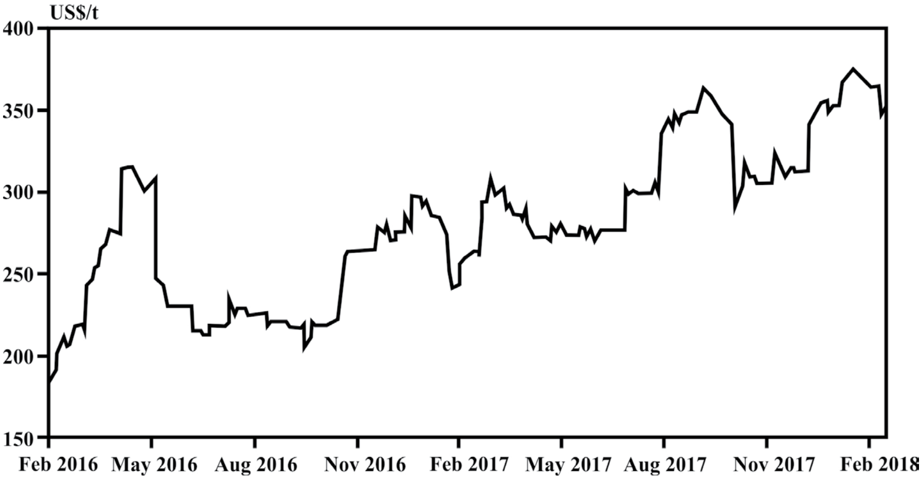

Fig. 5. Monthly quotations of steel scrap on LME (www.lme.com)

Rys. 5. Miesięczne notowania złomu stalowego na LME

The metallurgical coal market reacts to changes in demand and supply in a flexible manner. It is common practice in the metallurgical coal trade to conclude contract agreements which are usually valid for a year. Producers of the highest-quality coal sell over 90% of their production in this way (Ozga-Blaschke 2010). In cases of underestimated consumption, steel plants acquire the required quantities in the physical spot market. Coking coal markets are subject to dynamic short-term changes in the following areas: coal quality, valuation methods, and sea freight. The reference price is still based on the price of Australian coal, differing by 50–100% depending on coal type and current availability, and is subject to strong cyclical fluctuations (Figs. 6, 7).

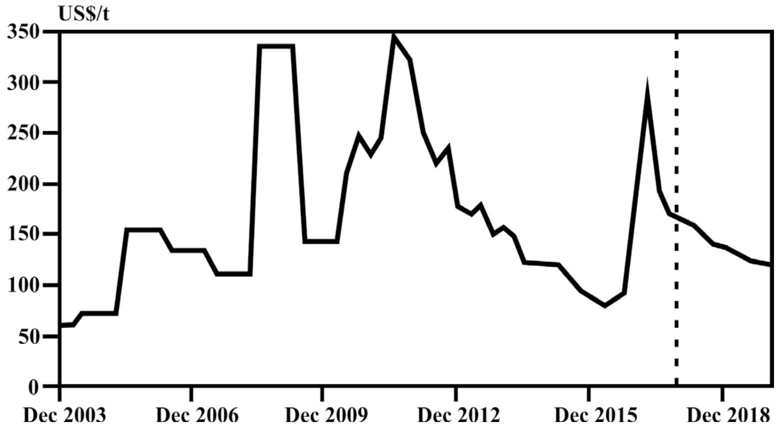

Fig. 6. Contract reference prices of Australian metallurgical coal and their forecasted levels

Rys. 6. Kontraktowe ceny odniesienia australijskiego węgla metalurgicznego i ich prognoza cenowa

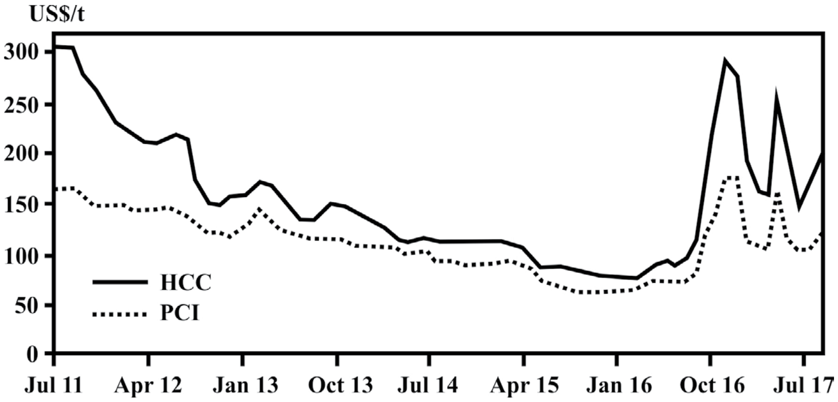

Fig. 7. Monthly prices of Australian hard coke (HCC) and pulverized coal (PCI)

Rys. 7. Porównanie miesięcznych cen australijskiego węgla koksowego typu HCC i PCI

Three price indices for metallurgical coal have been introduced (Energy Publishing 2010):

- the Coking Coal Queensland Index (CCQ),
- the Coking Coal Hampton Roads Index, Low Volatile (CCH-LOW),
- the Coking Coal Hampton Roads Index, High Volatile (CCH-HIGH).

Transactions carried out on the market are included in the index calculation if:

- vessel loading is scheduled within 90 days of data submission,
- payment is due shortly after vessel loading,
- the coal quality is within the quality ranges specified,
- the price has been adjusted by the index compiler to account for deviations in quality, the applicable loading port, and/or standard commercial terms.

The commercial types of metallurgical coal demanded standardization; therefore, since August 2013, the price indexes of CCQ, CCH-LOW, and CCH-HIGH have been unified and combined with IHS McCloskey, and a homogeneous valuation methodology has been introduced (IHS 2014). Price indexes published by IHS refer to trade centers in Australia, the USA, Europe, and China.

Summary

Steel production has become concentrated in Asia, while the market for steel and its raw materials has become globalized. The production of steel strongly affects the associated raw material industries involving ores and concentrates, alloyant metals, metallurgical coal, fluxes, and others, as well as shipment and its organization. It is estimated that the global trade in these commodities is huge, reaching 3.5 Gt annually. Mining follows the development of the steel market in a more or less flexible manner by supplying the necessary raw materials.

The technological lines of metallurgical plants are characterized by a high degree of sensitivity to the quality of batch materials. Standards of composition and the product range of raw materials change along with the economic optimization of related industries. Quality requirements have become very strict and have enforced significant changes in processing. Rarely does the quality of mine output enable it to find a buyer; it is usually necessary to process it in order to meet the growing demands of consumers. Due to changes in transport conditions, some characteristics of feedstock are shaped in metallurgical plants, in branches such as coking plants and agglomerations. The raw material on offer usually has strictly defined parameters (e.g. in the case of metallurgical coals it must be characterized by an appropriate chemical composition, strength and granulation). The use of steel scrap, sorted into batch and non-charge scrap, is increasing. The former is characterized by dimensions, forms, and a chemical composition that allows it to be directly loaded into furnaces, while the latter must be subjected to thermal or mechanical treatment aimed at obtaining the required dimensions and forms.

The method of setting freight and commodity prices has also changed. Previously, long-term contracts prevailed, whereas currently short-term contracts and spot transactions are more common. Steel was introduced briefly onto the LME market, and forward quotations for rebar and scrap can be noted at present. Certain other raw materials are quoted on the commodity exchange, which permits the disclosure of a reference price in both international and domestic trade. Commodity exchange quotations also enable the application of hedging transactions.

The steel raw materials market is largely competitive and operates in conditions of a mutual polypoly, although the key segment of iron ore and concentrate supply shows features of an oligopoly involving the producers, with a wide dispersion of consumers. The steel producers' market is competitive, and investments in installations of electric arc furnaces, which are inherently smaller than plants based on blast furnaces, favor even greater competition.

The attempt undertaken in this article at a synthetic presentation of the evolution of the steel sector and the characteristics of contemporary requirements for its raw materials, along with a price review, has not been supplemented with forecasts due to the strong development and market dynamics which would prove any forecast to be weakly grounded. Experts generally point to good prospects for the development of the industry, resulting from an increased demand for steel products, especially in developing countries characterized by dynamic population growth. Increased demand may be reflected in a slight reduction of quality requirements.

The paper was prepared as a part of the statutory research project AGH No. 11.11.140.626.

REFERENCES

AISI 2015. *US steel shipments by market classification. Profile 2015*. Washington: American Iron and Steel Institute, 40 s.

Arens et al. 2012 – Arens, M., Worrell, E. and Schleich, J. 2012. Energy intensity development of the German iron and steel industry between 1991 and 2007. *Energy* 45(1), pp. 786–797.

Asia Pacific Partnership 2010. *The State-of-the-Art Clean Technologies (SOACT) for Steelmaking Handbook, 2nd Edition*. Berkeley: Asia Pacific Partnership for Clean Development and Climate, 138 pp.

ASTM 2001. *Standard Test Method for Determination of Abrasion Resistance of Iron Ore Pellets and Sinter by the Tumbler Test*. ASTM International, 3 p.

Birat, J-P. 2014. Steel industry: culture and futures [In:] *8th European Continuous Casting Conference*. Graz 23–25 June, pp. 1–24.

Cores et al. 2010 – Cores, A., Babich, A., Muñiz, M., Ferreira, S. and Mochón, J. 2010. The influence of different iron ores mixtures composition on the quality of sinter. *ISIJ International* 50(8), pp. 1089–1098.

DCE 2013. *Dalian commodity exchange iron ore futures trading manual*. Dalian: Dalian Commodity Exchange, 36 p.

Díez et al. 2002 – Díez, M.A., Alvarez, R. and Barriocanal, C. 2002. Coal for metallurgical coke production: predictions of coke quality and future requirements for coke-making. *International Journal of Coal Geology* 50, pp. 389– 412.

Energy Publishing 2010. *Coking Coal Queensland Index (CCQ) and Coking Coal Hampton Roads Index (CCH)*. September 9, Version 15, 12 pp.

Geerdens et al. 2009 – Geerdens, M., Toxopeus, H. and van der Vliet, C. 2009. *Modern blast furnace ironmaking, an introduction*. 2nd ed. Amsterdam: IOS Press, Delft. 176 pp.

Gulyaev et al. 2012 – Gulyaev, V.M., Barskii V.D. and Rudnitskii A.G. 2012. European Quality Requirements on Blast Furnace Coke. *Coke and Chemistry* 55(10), pp. 372–376.

Hasanbeigi et al. 2014 – Hasanbeigi, A., Price, L., Aden, N., Chunxia, Z., Xiuping, L. and Fangqin, S. 2014. Comparison of iron and steel production energy use and energy intensity in China and the U.S. *Journal of Cleaner Production*, 65, pp. 108–119.

IHS Energy, 2014. *Coking coal market price methodology and specifications*, July, 7 p.

Janke et al. 2000 – Janke, D., Savov, L., Weddige H.-J. and Schulz, E. 2000. *Scrap-based steel production and recycling of steel.* Materiali in Tehnologije, 34(6), pp. 387–399.

Kaczmarek, W. 2013. ArcelorMittal Poland SA development policy in the light of the current situation in the global coke and steel market (*Polityka rozwojowa ArcelorMittal Poland SA w świetle obecnej sytuacji na światowym rynku koksu i stali*). *Karbo*, Konferencja „Koksownictwo 2013” Szczyrk, 02–04.10.2013 (*in Polish*).

LCA 2011. *Methodology report Life cycle inventory study for steel products*. Brussels: World Steel Association, 95 pp.

Lwamba, E. and Garbers-Craig, A.M. 2008. Control of the grain size distribution of the raw material mixture in the production of iron sinter. *Journal of The Southern African Institute of Mining and Metallurgy* 108, pp. 293–300.

Łukaszczyk, Z. and Mianowski, A. 2013. Quality of coke produced from Carboniferous coking coal (*Jakość koksu otrzymanego z karbońskich węgli ortokoksowych*). *Przemysł Chemiczny* 92(6), pp. 950–956 (*in Polish*).

MB 2016. *Metal Bulletin – Coking Coal Index Guide*. August 2016, London.

Mianowski et al. 2009 – Mianowski, A., Radko, T. and Koszorek, A. 2009. Assessment of the high-quality blast furnace coke by using the reactivity and strength integrated Nippon Steel Corporation test (*Ocena jakości wysokogatunkowego koksu wielkopiecowego w skali zintegrowanego testu reakcyjności i wytrzymałości NSC*). *Przemysł Chemiczny* 88(6), pp. 692–698 (*in Polish*).

Mochón et al. 2014 – Mochón, J., Cores, A., Ruiz-Bustinza, I., Verdeja, L.F., Robla, J.I. and Garcia-Carcedo F. 2014. Iron ore sintering, Part 2. Quality indices and productivity, *DYNA* 81(183), pp. 168–177.

Muwanguzi et al. 2012 – Muwanguzi, A.J.B., Karasev, A.V., Byaruhanga, J.K. and Jönsson P.G. 2012. Characterization of chemical composition and microstructure of natural iron ore from Muko deposits. *ISRN Materials Science,* pp. 1–9.

Ozga-Blaschke, U. 2010. *Coking coal eceonomy* (*Gospodarka węglem koksowym*). Kraków: Wyd. IGSMiE PAN, 69 pp. (*in Polish*).

Paananen, T. 2013. *The effect of minor oxide components on reduction of iron ore agglomerates*. Doctoral thesis, University of Oulu.

Paananen, T. and Kinnunen, K. 2007. The effect of titanium on reduction degradation of iron ore agglomerates. *Proceedings Iron Ore Conference*, Australia, Perth: pp. 361–367.

Platts 2017. *Methodology and specifications guide. Metallurgical coal*. October 2017. [Online] www.platts.com [Accessed: 2018-05-5].

Siitonen, S., Tuomaala, M. and Ahtila, P. 2010. Variables affecting energy efficiency and CO_2 emissions in the steel industry. *Energy Policy* 38, pp. 2477–2485.

Smakowski, T. and Szlugaj, J. 2015. *Iron and steel* (*Żelazo i stal*) [In:] Smakowski, T., Galos, K. i Lewicka, E. ed. *Balance of Economy hith Mineral Resources of Poland and the world of* (*Bilans gospodarki surowcami mineralnymi Polski i świata*). Warszawa: PIG-PIB oraz IGSMiE PAN Kraków, pp. 1123–1148 (*in Polish*).

Stubbles, J. 2000. *Energy use in the U.S. steel industry: An historical perspective and future opportunities*. Energetics, Inc. Columbia, MD.

USGS 2016. *2014 Minerals Yearbook*. Washington: U.S. Geological Survey.

Van Wortswinkel, L. and Nijs, W. 2010. *Iron and Steel. IEA ETSAP – Technology Brief I02*, pp. 1–6. [Online] www.etsap.org [Accessed: 2018-05-5].

Warzecha, A. and Jarno, M. 2012. Światowy handel węglem koksowym i koksem. *Seminarium SITPH*, 11–13 maja, Karpacz (*in Polish*).

Worrell et al. 2008 – Worrell, E., Neelis, M., Price, L., Galitsky, C. and Zhou, N. 2008. *World best practice energy intensity values for selected industrial sectors*. Lawrence Berkeley National Laboratory, Berkeley, CA, 51 pp.

WSA 2014. *Energy intensity project report and energy intensity system*. Brussels: World Steel Association, 125 pp.

WSA 2015. *Steelmaking Raw Materials & Sea Freight Outlook.* Brussels: World Steel Association, 27 pp.

WSA 2018. *Energy use in the steel industry. Fact sheet*. Brussels: World Steel Association, 3 pp.

Wyderko-Delekta, M. and Bolewski, A. 1995. *Mineralogia spieków i grudek rudnych*. Kraków: Wydawnictwa AGH, 280 pp. (*in Polish*).

Żarczyński, P. 2015. *Technologiczna i ekonomiczna ocena zastosowania operacji podsuszania wsadu w warunkach Koksowni Zdzieszowice*, praca doktorska AGH w Krakowie (*in Polish*).

[Online] https://zlom.info.pl/klasyfikacja-zlomu/443/zlom-info-pl-zlom-stalowy-wsadowy.html [Accessed: 2018-05-5].

[Online] www.silscrap.pl [Accessed: 2018-05-5].

[Online] www.indexmundi.com [Accessed: 2018-05-5].

[Online] www.vale.com [Accessed: 2018-05-5].

MODERN TRADE STANDARDS FOR STEEL RAW MATERIALS

Keywords

steel, iron ores and concentrates, alloy additives, coke, steel scrap, prices

Abstract

Steel and cast-iron products, due to their low price and beneficial properties, are the most widely used among metals; their consumption has become an indicator of the economic development of countries. The characteristics of iron raw materials, in relation to current metallurgical requirements, are presented in the present this article. The globalization of the trade and development of steelmaking technologies have caused significant changes in the quality of raw materials in the last half-century, forcing improvements in processing technologies. In many countries, standard concentrates (at least 60% Fe) are almost twice as rich as those processed in the mid-20th century. Methods of quality assessment have been improved and quality standards tightened.

The quality requirements for the most important raw materials – iron ores and concentrates, steel scrap, major alloy metals, coking coal, and coke, as well as gas and other energy media – are reviewed in the present paper. Particular attention is paid to the quality testing methodology. The quality of many raw materials is evaluated multi-parametrically: both chemical and physical characteristics are important. Lower-quality parameters in raw materials equate to significantly lower prices obtained by suppliers in the market.

The markets for these raw materials are diversified and governed by separate sets of newly introduced rules. Price benchmarks (e.g. for standard Australian metallurgical coal) or indices (for iron concentrates) apply. Some raw materials are quoted within the framework of the commodity market system (certain alloying components and steel scrap). The abandonment of the long-established system of multi-annual contracts has led to wide fluctuations in prices, which have reached a scale similar to that of other metals.

STANDARDY HANDLOWE WSPÓŁCZESNYCH SUROWCÓW STALI

Słowa kluczowe

ceny, stal, rudy i koncentraty żelaza, koks, złom stalowy

Streszczenie

Wyroby stalowe i żeliwne ze względu na niską cenę i korzystne właściwości znajdują najszersze zastosowanie wśród metali w gospodarce, a ich zużycie stało się wskaźnikiem rozwoju gospodarczego. W artykule przedstawiono charakterystykę surowców żelaza w odniesieniu do obecnych wymagań hutnictwa. Globalizacja handlu i rozwój technologii wytwarzania stali w ostatnim półwieczu spowodowały istotne zmiany w jakości wsadowych surowców mineralnych. Wymusiło to usprawnienie technologii przeróbczych przez zakłady górnicze. Przedmiotem światowego handlu są obecnie standardowe koncentraty o zawartości żelaza ponad 60%, tj. niemal dwukrotnie bogatsze niż rudy przetwarzane w połowie XX wieku w wielu krajach. Udoskonalone zostały sposoby oceny jakości surowców wsadowych i zaostrzono normy jakości.

W publikacji dokonano przeglądu wymagań jakościowych najbardziej istotnych surowców: rud i koncentratów żelaza, złomu stalowego, głównych metali stopowych, węgla koksowego i koksu oraz gazu i innych nośników energii. Zwrócono szczególną uwagę na metodykę badania jakości surowców oraz standaryzację surowców wsadowych. Jakość surowców oceniana jest wieloparametrycznie; istotne są zarówno cechy chemiczne, jak i fizyczne. Gorsze parametry jakościowe surowców wsadowych skutkują niższymi cenami uzyskiwanymi przez dostawców w obrocie.

Rynki tych surowców są zróżnicowane, kierowane odrębnymi i częściowo nowymi regułami. W obrocie handlowym funkcjonują standardy odniesień cenowych (np. ceny węgla metalurgicznego w Australii czy indeksy cenowe koncentratów żelaza). Część surowców kwotowana jest w systemie giełdowym (niektóre składniki stopowe i złom stalowy). Rezygnacja z powszechnych dawniej kontraktów wieloletnich doprowadziła do dużych wahań cen, które osiągnęły podobną skalę jak inne metale.