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TECHNICAL CHARACTERISTICS OF THE RECYCLING OF IRON-STEEL PRODUCTS

The iron and steel sector is an indicator of development and sophistication with the usage areas of its products and its contributions to other sectors. Steel has become an integral part of modern society with its properties such as strength and durability and its usage areas such as construction, infrastructure, machinery and automotive sectors. In this context, the iron and steel sector has strategic importance for countries. Sustainability of production in the iron and steel sector is important for the entire manufacturing industry. The use of scrap metal in production has become an integral part of modern steel production, increasing the economic vitality of the sector and reducing the environmental impact of production. In this article, a number of methods applied in contemporary times in the production process of iron-steel products, iron-steel wastes and the re-processing of these wastes have been reviewed.

Using scientific studies, articles, statistical indicators on the topic as the theoretical and methodological basis of the study, a number of methods of iron and steel production and recycling serving the purpose of zero waste were studied.

As a result of the investigations, it was understood that in order to achieve a permanent competitive advantage in the iron and steel industry, policies that design waste management and every stage of production together should be produced. Establishing a holistic approach that includes several issues when planning production, such as the efficiency of the raw materials supplied, the equipment used and the manufacturing process, and the evaluation of the products at the end of their useful life, will provide a permanent competitive power.

The result of the article is that the recycling of waste will create a competitive advantage with its environmental contributions such as reducing emissions and saving raw materials, in addition to economic savings. In this context, strategies created for the zero waste target for the iron and steel industry in the world offer new opportunities to prevent additional burdens and increase competitiveness thanks to sustainable material management. On the other hand, within the scope of sustainable manufacturing, attempts to bring waste into the economy should be carried out in accordance with the waste hierarchy. The priority includes preventing waste, if it cannot be prevented, preparing it for reuse, if these two options cannot prevent waste generation, applying other alternative solution methods such as recycling practices and recovery, and disposal as a last resort.

Key words: iron products, steel products, reproduction, production methods, production technologies.

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ТЕХНІЧНІ ХАРАКТЕРИСТИКИ ПЕРЕРОБКИ ЗАЛІЗОРУДНИХ ПРОДУКТІВ

Залізорудна та сталеливарна галузь є індикатором розвитку та вдосконалення завдяки сферам використання її продукції та внеску в інші галузі. Сталь стала невід'ємною частиною сучасного суспільства завдяки таким її властивостям, як міцність і довговічність, а також сферам використання, таким як будівництво, інфраструктура, машинобудування та автомобільна промисловість. У цьому контексті залізорудна та сталеливарна галузь має стратегічне значення для країн. Сталість виробництва в залізорудній та сталеливарній галузі важлива для всієї обробної промисловості. Використання металобрухту у виробництві стало невід'ємною частиною сучасного виробництва сталі, підвищуючи економічну життєздатність галузі та зменшуючи екологічний вплив виробництва. У цій статті було розглянуто низку методів, що застосовуються в сучасний час у виробничому процесі залізорудних продуктів, залізорудних відходів та їхньої повторної переробки. Використовуючи наукові дослідження, статті, статистичні показники з цієї теми як теоретичну та методологічну основу дослідження, було вивчено низку методів виробництва та переробки заліза та сталі, що слугують меті нульових відходів. У результаті досліджень було зрозуміло, що для досягнення стійкої конкурентної переваги в залізорудній та сталеливарній промисловості слід розробляти політику, яка б спільно проєктувала управління відходами та кожен етап виробництва. Встановлення цілісного підходу, який включає кілька питань при плануванні виробництва, таких як ефективність постачання сировини, використовуване обладнання та виробничий процес, а також оцінка продукції після закінчення терміну її служби, забезпечить постійну конкурентну перевагу. Результатом статті є те, що переробка відходів створить конкурентну перевагу завдяки її екологічним вняскам, таким як зменшення викидів та економія сировини, на додаток до економічної економії. У цьому контексті стратегії, розроблені для досягнення мети нульових відходів для залізорудної та сталеливарної промисловості у світі, пропонують нові можливості для запобігання додатковим витратам та підвищення конкурентоздатності завдяки сталому управлінню матеріалами. З іншого боку, в рамках сталого виробництва спроби залучення відходів до економіки повинні здійснюватися відповідно до ієрархії відходів. Пріоритет включає запобігання утворенню відходів, якщо запобігти неможливо, підготовку їх до повторного використання, якщо ці два варіанти не можуть запобігти утворенню відходів, застосування інших альтернативних методів вирішення, таких як практика переробки та відновлення, а утилізація – як крайній захід.

Ключові слова: залізорудні вироби, сталеві вироби, відтворення, методи виробництва, технології виробництва.

INTRODUCTİON

The iron and steel industry in the world is one of the sectors that has shown great progress in production and capacity increases. Iron and steel producers in the global market have developed some strategies to cope with these negativities, such as company mergers, concentration in production and transformation into high value-added production. Although the strategies followed offer short-term solutions to manufacturers, the contraction in demand, especially in developing countries, and the increasing global idle capacity have led to low profitability rates in the sector.

In addition, most of the supply of coke and iron ore, which are important raw material sources of the sector, is under the control of a few countries. Scrap supply, another important raw material of the sector, is naturally located in developed countries.

Increasing iron and steel production and capacity due to intense demand in developed countries after the 2000s has led to great increases in raw material need and trade. As a result of the raw material supply not being able to meet the production amount, there were large increases in raw material prices. This situation has caused the cost pressure on businesses to increase.

In summary, in addition to the supply and demand-related problems, the competitiveness and profitability of the iron and steel industry have been negatively affected by pressures such as global economic recession, harsh environmental standards, idle capacity and high input costs. In addition to these negativities, the disposal or storage of waste generated in production creates additional costs. Economic developments and the decrease in profitability in the iron and steel sector attract the attention of investors and make it difficult to make new investments in the sector.

It is thought that waste management in the iron and steel industry will increase competitiveness and profitability and restructure production profitably within the framework of the concept of sustainability. In this context, the industrial ecology approach will help businesses pay attention to resource efficiency in a versatile way and increase their competitiveness levels to the maximum level by encouraging production system thinking with closed-loop system opportunities and environmental design opportunities that include material balance.

PRODUCTİON PROCESS İN THE IRON AND STEEL INDUSTRY

The term steel refers to an iron alloy that can act flexibly in some temperature ranges and contains manganese, carbon and some other alloying elements. According to Javaid and Essadighi, there are more than 3,500 different steels with very different physical, chemical and environmental properties, approximately 75% of which have been discovered in recent years [5].

These alloys, known as steel grades, are developed to produce various combinations of strength, ductility, hardness, toughness, magnetic permeability and corrosion resistance that modern consumers need. During crude steel production, these metals are added as elements or ferro alloys. The effects of some important alloying elements on steel according to their desired properties are listed in Table 1.

Table 1.

Effects of Alloying Elements on Steel Structure

Effects	Alloying elements											
	Al	**Cr**	**Co**	**Cu**	**Mn**	**Mo**	**Ni**	**P**	**Si**	**W**	**V**	**S**
Deoxidant								0				0
Austenite stabilizer	0	0	1	1	1	0	1	0	0	0	0	0
Ferrite stabilizer	1	1	0	0	0	1	0	0	1	1	1	0
Carbide growers	0	1	0	0	1	1	0	0	11	1	1	0
Graphite makers	1	0	1	0	0	0	1	0	1	0	0	0
Hardenability	0	1	0	0	1	1	0	0	0	1	1	0
Resistance	0	1	1	1	1	1	1	1	1	1	1	0
Impact resistance	-1	-1	-1	0	0	1	1	-1	1-	-	-1	-1
Wear resistance	0	1	1	0	1	1	-1	0	-1	1	1	0
Corrosion resistance	1	1	0	1	0	0	0	0	0	0	0	-1
Machinability	0	0	0	0	-1	-1	-1	-1	-1	-1	0	1

(0) - Ineffective;
(1) - Positive effect
(-1) - Has a negative effect
Al-Aluminium, Cr - Chromium, Co - Cobalt, Cu - Copper, Mn - Manganese, Mo - Molybdenum, Ni -Nickel,
P - Phosphorus, Si - Silicon, W - Tugsten, V - Vanadium, S – Sulfur

Source: 17, p. 660.

Steel materials have a profound impact on the development of society. Properties such as strength and durability make steel the ideal material for the construction and automotive industries. At the same time, it is widely used in many types of packaging and other areas of use due to its other properties. Modern steel production is carried out by two dominant processes: Basic Oxygen Furnace and Electric Arc Furnace. Iron ore and scrap are the basic raw materials of production, and production methods are determined according to the use of raw materials.

Innovation efforts in the iron and steel industry continue to produce new types of steel, many of which are thinner but can meet the necessary strength requirements. These new products, called Advanced and Ultra High Strength Steels, allow their customers, especially automotive manufacturers, to reduce vehicle weight by 17% to 25% while maintaining safety standards. Vehicles are becoming lighter due to the use of thinner but stronger steel. Today, more than 50 percent of steel parts in vehicles consist of new high-strength steels. By reducing the need for materials, emissions that will arise from both steel production and use due to the lightness of the vehicles are reduced [14, p. 1].

Many items made of steel can be easily reused. For example, paperclips are used over and over again in homes and offices around the world. While the normal lifespan of barrels is six months, this period can be extended to five years thanks to the use of steel. It is the durability feature of steel that enables these products to be reused, and in this way, steel offers environmentally friendly solutions by reducing the need for products [14, p. 2].

Based on unprocessed iron ore, steel can be produced by first reducing iron oxide to liquid metal (pig iron) in the Blast Furnace (BF) and then purifying it in Basic Oxygen Furnaces and converting it into steel. This method is defined as primary steel production. Extra heat is produced due to the processes taking place during the purification process, and this extra heat is removed by the addition of steel scrap. According to the data of the World Steel Association [16], the rate of ore-based production has increased since the 2000s and in 2012, 69 percent of world steel production was produced on ore-based basis.

Based on preliminary Census Bureau data, the American Iron and Steel Institute (AISI) reported today that the U.S. imported a total of 2,547,000 net tons (NT) of steel in January 2024, including 1,914,000 net tons (NT) of finished steel (up 21.7% and 18.0%, respectively, vs. December 2023). Total and finished steel imports are down 2.4% and 4.4%, respectively, vs. January 2023. Over the 12-month period February 2023 to January 2024, total and finished steel imports are down 7.6% and 13.5%, respectively, vs. the prior 12-month period. Finished steel import market share was an estimated 22% in January 2024 [10]. Coke combustion is provided by hot gases (carbon monoxide (CO), hydrogen (H_2), carbon dioxide (CO_2), water (H_2O), nitrogen (N_2), oxygen (O_2)) and fuels. As these gases move upward, they pass through the layers and cause the temperature to increase [8, p. 90]. The reactions taking place in YF are as follows:

$$F2O3 + CO \rightarrow 2\ FeO + CO2$$
$$FeO + CO \rightarrow Fe + CO2$$

Liquid iron drips downward and accumulates at the bottom of the blast furnace. This liquid iron is taken at regular intervals. Limestone combines with polluting elements such as silica (SO_2), sulfur (S), alumina (Al_2O_3) and forms molten slag on liquid iron.

Pig iron taken from the blast furnace contains more than 4% carbon and additive elements and requires additional purification for the production of cast iron and steel. In order for the steels to have the desired qualities, chemical compositions need to be adjusted at much more precise levels. Therefore, polluting elements must be at very low levels.

The pig iron in the molten state is taken from the blast furnace and loaded into the Basic Oxygen Furnace along with scrap iron-steel and lime. After loading, pure oxygen (O_2) is blown through the pipe at high speed. This process leads to combustion and heating on the surface of the molten pool. Excess carbon is burned and removed from liquid steel. Impurities such as silicon (Si), manganese (Mn) and phosphorus (P) are also oxidized and collected in slag thanks to lime. Reactions that take place at Basic Oxygen Furnaces [8, p. 91]:

$$2\ C + O2 \rightarrow 2\ CO \text{ (some CO2)}$$
$$Si + O \rightarrow SiO2$$
$$2\ Mn + O2 \rightarrow 2\ MnO$$
$$4\ P + 5\ O2 \rightarrow 2\ P2O5$$

During the process, the carbon content decreases linearly over time, which allows for better control of the carbon level in steel. After the purification is completed, alloying elements and some additions are added to the molten steel according to the product requirements, and finally steel production is completed by taking slag.

Production based on steel scrap obtained by melting the scrap in an Electric Arc Furnace is a secondary steel production method. High alloy steel varieties such as stainless steel and tool steels are usually produced based on scrap. The type of scrap used affects the material properties as well as alloying elements such as chromium and nickel. Scrap-based Electric Arc January production also accounted for 29 percent of the world's steel production in 2012. Although its share in total steel production has decreased due to Basic Oxygen Furnace investments, which have increased greatly since the 2000s, the amount of production is increasing.

The January January 2013 American Iron and Steel Institute summarizes steel production by Electric Arc Furnace as follows; Electric Arc Furnace works as a batch smelting process. Scrap iron-steel loaded into the furnace is heated by means of an arc created by arc electrodes of alloying elements and limestone, resulting in molten metal. January January Deceleration Electric Arc Furnace activities are expressed as successive melting or heating cycles and consist of charging the furnace, melting the metal, purification, separation of slag, transfer of molten metal and return to the furnace.

Scraps collected from expired products and other sources are collected by the scrap industry and prepared for re-melting. Scrapping is needed in both steel production methods. The Electric Arc Furnace is mainly based on scrap, while Basic Oxygen Furnaces allow the use of scrap in January to remove excess heat in production (scrap up to 8.5% of its ore can be used) [15].

Although the final products of the two production methods are steel, they differ in terms of material flows and the qualities and quantities of waste they create. In Basic Oxygen Furnaces, oxygen is blown into the molten iron to remove impurities such as carbon, phosphorus and so on. At the end of this operation, various waste materials such as gas, dust and slag are formed. In the Electric Arc Furnace, where secondary production is made based on scrap, steel undergoes physical and chemical processing to achieve certain properties. The steel can then be cast and rolled. All processes carried out until the final product create separate waste materials such as mill shavings or oily sludge. Crude steel production with an Electric Arc Furnace produces certain materials, especially powders and gases, but also slag [6, p. 179].

For both production methods, studies have been carried out to reduce waste and efficient raw material management. While these studies reduce the amount of waste, they also provide savings and competitive advantage as they reduce the amount of raw materials needed in production. While in the 1970s and 1980s, modern steel facilities had to consume an average of 144 kg of raw materials to produce 100 kg of liquid steel, today, with the investments in research, technology development and good planning, the iron and steel industry uses only 115 kg of raw materials to produce 100 kg of liquid steel. This development means a savings of over 20 percent in raw material needs [14, p. 1].

The primary production method is more polluting than secondary production due to environmental impacts resulting from chemical reactions, mining and combustion that occur during crude steel production. According to the data of the International Bureau of Recycling [2013], by recycling 1 ton of steel, 1.1 tons of iron ore, 0.6 tons of coal and 55 kg of limestone are saved. Through the use of scrap, CO_2 emissions are reduced by 58 percent. Recycling 1 ton of steel saves 642 kWh of electrical energy, 287 liters of oil, 11.5 GJ of coal energy and 2.3 m^3 of storage space. Steel recycling creates 74 percent less energy, 90 percent less raw material and 40 percent less water usage, as well as 76 percent less water pollution, 86 percent less air pollution and 97 percent less mineral waste.

Despite all its environmental and economic advantages, it is not possible to meet the steel need with secondary steel production alone. Separating or removing a particular residual element from scrap becomes more expensive than primary production. It is not possible to remove some contaminants that damage steel properties and production, both economically and metallurgically. For this reason, secondary production is insufficient to meet the demands, especially those requiring high purity. Therefore, as a country, we need to produce policies that take this situation into consideration.

Yellishetty [17, p. 660] investigated various studies on the effects of special alloying elements and residues on the recycling process, the mechanisms of separating them from the metal, and the relationships between cost and competition.

Studies have shown that metal is constantly recyclable, and each time the density of the residue increases and it becomes more difficult to process it. In these studies, residues that are important for steel recycling were tried to be identified. Residues are (i) copper, tin, nickel and molybdenum; It is divided into three categories: (ii) chromium, manganese, zinc and lead and (iii) aluminium, silicon and titanium. According to this category, the first group is very difficult to separate from scrap and poses a big problem in terms of metallurgical processes.

Their concentrations increase during each subsequent recycling cycle. The second group can be separated by metallurgical processes, although there may be deficiencies depending on the purification process. The third group does not cause a problem because it is completely removed during the purification process. As a result, the primary production method is preferred when there is a need for purer material.

Moreover, according to Birat [2006] ve Matsuno [2007], most of the steel produced remains in use for a very long time (15-19 years on average), so it cannot be used for recycling immediately. This shows that there is not enough available recycled steel to meet the increasing demand for steel worldwide and that the demand cannot be met by secondary steel production alone. Therefore, steel demand is met by the combined use of primary and secondary production routes [17, p. 656].

WASTES GENERATED İN THE IRON AND STEEL INDUSTRY

In iron and steel production, various basic and by-products are produced at various stages such as mining, sinter plant, coking, iron reduction, steel production, lime making, washing and rolling. As can be seen in Table 2, there are main products and other products that are desired to be obtained at each stage of the primary processing process.

Table 2.

BY-PRODUCTS FORMED İN IRON AND STEEL PRODUCTİON

Production process	Main product	Other products
Coal Mining	Coal	Methane
Coal Washing	Clean Coal	Medium Quality Coal
Coke Oven	Coke	Coke Oven Gas
		BTX
		Naphthalene
		Tar
		Ammonium sulfa
sinter plant	Sinter	sinter residue
Blast furnace	Eriyik demir	Blast Furnace Slag
		Blast Furnace Gas
		Blast Furnace Powder
		Dark Mud (Viscous)
Slab casting	steel plate	Tundish* Skeleton
		scraps
		Rolling Shavings
rolling mill	rolled steel	Cut Steel Pieces
		Rolling Shavings
sheet metal mill	tin plate	Oil
		Pickling Solution
* - A wide and shallow container used to control the flow when pouring liquid metal into a mold.		

Source: 2, p. 1.

Hazardous wastes arising from the sector are examined under three main classes: wastes specific to the production process, wastes resulting from side processes and non-production process wastes. Apart from iron and steel production and pyrolytic processing of coal, processes such as painting, physical and chemical surface treatments can also be applied. Therefore, the wastes that may arise from these side processes should be included under the wastes from the iron and steel industry.

In the iron and steel industry, solid wastes such as Blast Furnace slag, steel slag, dust and coal ash are generated during the production process. Disposal of these wastes causes environmental problems such as soil pollution, surface water pollution and groundwater pollution. How to combat these wastes is defined as one of the biggest problems of the iron and steel industry. While the recycling of solid waste generated in the iron and steel industry is considered, scrap generated in other sectors and generated by domestic consumption is not included [3, p. 33-34].

The waste and by-products generated in iron and steel production consist of 90% slag, dust and sludge. In the production of 1 ton of liquid steel, approximately 180 kg of waste and by-products containing slag, dust, mud and other materials are generated in the secondary production with the Electric Arc Furnace, and approximately 445 kg in the primary production with the Blast Furnace and Basic Oxygen Furnace [13, p. 1].

In primary liquid steel production, approximately 275 kg of YF slag, 126 kg of Basic Oxygen Furnace slag, 20 kg of Blast Furnace dust and sludge, and 23 kg of BOF dust and sludge are produced for 1 ton of production. In secondary liquid steel production, approximately 169 kg of Electric Arc Furnace slag and 12 kg of Electric Arc Furnace dust and mud are produced for 1 ton of production [9, p. 936].

One of the approaches used to deal with problems arising from solid waste is recycling. Many methods are applied to recycle this type of solid waste. Despite this, it is still debated whether recycling is the best method and which of the applied methods is most appropriate. Combating solid waste generated in the manufacturing industry is defined as a multidimensional problem because it depends on many environmental, economic, technical and social components.

RESULT

Recycling waste will create a competitive advantage with its environmental contributions such as reducing emissions and saving raw materials, as well as economic savings. In this context, strategies created for the zero waste target for the iron and steel industry in the world offer new opportunities to prevent additional burdens and increase competitiveness thanks to sustainable material management.

On the other hand, within the scope of sustainable manufacturing, attempts to bring waste into the economy should be carried out in accordance with the waste hierarchy. The priority includes preventing waste, if it cannot be prevented, preparing it for reuse, if these two options cannot prevent waste generation, applying other alternative solution methods such as recycling practices and recovery, and disposal as a last resort.

According to the research results, the recycling industry is a sector that can be invested at low costs and create employment. Recycling is important for sectors whose input and energy needs depend on imports, due to the potential raw material supply to be provided through waste management. In the iron and steel industry, where

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profitability is low, it is also important to prevent additional costs arising from waste generation and environmental impacts.

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