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Recycling Scrap for Steelmaking

The case of the Danish Steel Rolling Mill

Jørgen Burchardt

Steel scrap is one of the most recycled materials. It uses approximately 35 percent less energy and reduces emissions of greenhouse gases up to 87 percent. The use of scrap is not unproblematic, however, and the accumulation of quality-compromising tramp elements has become an increasing threat to its use and viability as a "raw material" for steel. As a steelworks in a country without iron ore, the Danish Steel Rolling Mill and its history between 1943 and 2002 provide a good case study for looking at these facets in the nature of scrap. The successful recycling of scrap at the mill required a well-organized collection regime, while quality control at the mill ensured that industries such as the Danish shipyards could remain competitive.

Around eight percent of fossil fuel–based CO_2 emissions worldwide are derived from the steel industry. The level of CO_2 emissions is almost double the amount of steel created. In 2020, 1.86 billion tons of steel were created, which equates to about 2.6 billion tons of direct CO_2 emissions.[1] Most CO_2 comes from pig iron production, where blast furnaces use coal to melt the ore.

Iron is one of the most recycled materials. It uses approximately 35 percent less energy and simultaneously reduces emissions of greenhouse gases. Research has suggested a CO_2 reduction of up to 87 percent with steel produced by scrap compared to iron ore in a blast furnace.[2] In 2019, iron ore accounted for about 68 percent of new steel, while recycled steel scrap accounted for 32 percent.[3] As will be explained later, this small share is due to increasing steel consumption and delayed recycling.

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Iron products typically contain carbon. From melted ore, blast furnaces create so-called pig iron with a portion of four to five percent carbon. Pig iron turns into steel through a reduction of the content of coal. While the Bessemer converter initially handled the pig iron, the Basic Oxygen Process has taken over production for the past sixty years. Cast iron has a share of carbon that ranges from 2.5 to 4.5 percent. It has been used for centuries due to its low melting point of ca. 1,150–1,250 degrees centigrade. Cast iron is still used, but because of its hardness and fragility, steel has mostly replaced it. Today, only a small percentage of the total iron trade is cast iron, so it will not be mentioned further.

Steel has a low share of carbon of 0.5–2.0 percent. This small share gives it a higher melting point of ca. 1,250–1,535 degrees centigrade, and only special expensive furnaces can accommodate this high temperature.

Many alloyed steel qualities can also be found in scrap. Stainless steel with standard 21 percent chromium and seven percent nickel is one of the many steel qualities used on the market. As such, when these steels are returned for recycling, the collecting companies have to sort them, keeping the special alloys together so that the qualities and alloy percentages remain consistent. As will later be explained, it is not possible to remove all unwanted materials, however.

Sorting of scrap

The scrap originating from a steelworks, called "home scrap," is mostly of high purity and value. The steelworks know the content beforehand, and the scrap has no foreign elements added to it. It does not need pre-treatment except for cutting to size. The same scrap quality is often obtained from the later manufacturing processes at factories. Recycling this "process scrap" can be economically beneficial, so long as efficient collecting is organized.

Old scrap, known as "obsolete scrap," does not have a comparable quality, and is often processed through shredding. This obsolete scrap originates from products discarded after the end of their service life. It is a mix of old passenger cars, electrical appliances, steel cans and other items. The metal is often part of a complex product mixed or coated with other materials such as zinc or plastics. As such, the chemical composition fluctuates widely and the content of the different elements is unknown beforehand, calling for an analysis of the melted scrap in order to find out and be able to alter its composition.

The circulation of iron over time

The lifespan of steel products varies between categories. Home scrap can be used immediately. Processing scrap can be recycled after a few months. Then we have the scrap from consumer products ("end-of-life scrap"). While it is complicated to measure the lifespan of this scrap, on average it lasts around forty years. Transport, including private cars, has a mean lifespan of twenty years; steel in machinery lasts approximately thirty years, and steel in construction has a lifespan of 75 years.[4]

Steel production is rising sharply at the moment. Therefore, the increase of end-of-life scrap will continue for forty years after the current upsurge has ended. Some studies have predicted that the share of steel made by ore will fall while steel made by scrap will expand. Primary steel production may peak before 2030 and decline afterwards, whereas secondary steel production based on scrap may surpass primary production between 2050 and 2060.[5]

Tramp elements: a threat to future recycling

"As a permanent material which can be recycled over and over again without losing its properties, steel is fundamental to a successful circular economy."[6] These encouraging words from the World Steel Association, one of the leading international organizations in the field, are also backed by the American Iron and Steel Institute. They state that "once produced, steel can be continually recycled into new steel products"[7] and that "Steel is 100 percent recyclable, which means it can be recycled into the same material of the same quality again and again."[8] However, those viewpoints are not correct for two reasons. Firstly there is the issue of disappearing steel – steel that does not re-enter circulation – which some research has estimated to be at a rate of at least twelve percent of steel produced, probably higher.[9] Secondly, a worse reason is that some unwanted elements in steel cannot be easily removed by current smelting processes and can compromise the metal's material qualities. Such impurities are known as tramp elements.[10]

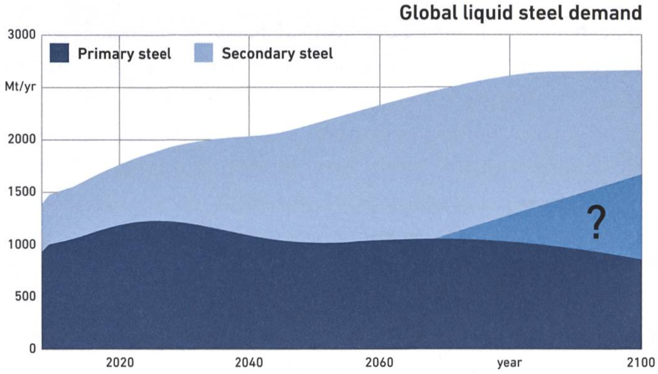
Copper is, as mentioned, the most pervasive material in scrap. The increased use of electrical wires in the current generation of cars for contacts, sensors and perhaps fifty small servomotors can elevate the level of copper in a shredded product once the car has been scrapped. Separation with a magnet, to retrieve the ferrous part, cannot separate 100 percent of the iron.[11]

Today, the trade has developed rather strict standards to divide the types of scrap in terms of chemical composition of metals, level of impure elements, physical size, shape and homogeneity. Even manual sorting and better separation techniques cannot remove all the copper. As a result, this contamination with copper will accumulate over time.[12]

Copper is helpful in some products. It can give steel a mild resistance to corrosion at 0.25 percent copper, and structural steels can contain up to 0.4–0.5 percent copper. However, in other circumstances, a concentration of copper over 0.1 percent is a danger when making products with hot rolling and forming techniques. For some products, the limit of tolerance is less than 0.06 percent.[13]

With the refinery loss, recovery loss and the accumulation of tramp elements, after 100 years more than forty percent of the best steel for flat rolling will have almost disappeared, and the rest will only be useful in products where the high content of copper does not cause problems for machines and construction.[14] Indeed, the

1 The 1922 steel rolling mill purchased by the Danish Steel Rolling Mill after World War II is still in operation today.



2 Forecasts for the use of scrap and iron ore around 2050. It is unclear, however, how much scrap will be rendered useless by tramp elements.

situation may become even worse, and the dilution of low-purity scrap with high-purity resources might only allow the utilization of all scrap until 2040. Hereafter, some scrap cannot be reused anymore. Therefore (at least with present technology), while in 2050 scrap in theory could be the source of 75 percent of crude steel production, more than 45 percent of that crude steel would need to be made from steel from primary sources, such as home and process scrap, due to impurities.[15]

The Danish Steel Rolling Mill

The Danish Steel Rolling Mill's history illustrates how the above factors have an effect in practice, shaping the realities and decisions that developed an industrial scrap-to-steel production center. Denmark has no iron ore deposits, but the steelworks could exist by utilizing the country's increasing amounts of scrap. As with any scrap recycling factory plant, a particular but simple setup was required: a scrap yard, a couple of kilns, and rolling mills. However, the dimensions are enormous, as will be shown through a description of the Danish Steel Rolling Mill. The story is based on a research project at the National Museum of Science and Technology published in the monograph 'Mænd af stål. Det danske Stålvalseværk 1940-1962' and some articles.[16]

Plans for a steelworks

In the first part of the twentieth century, plans to establish a Danish steelworks to secure steel for national industries were reconfigured from time to time. During World War I, there were concrete plans, but the project did not materialize until the war ended; thus Denmark only developed a few small steel foundries.[17]

In the 1930s, the need for Danish production became relevant again. At one time Danish shipyards had built up to nine percent of the world's tonnage, but the industry became difficult. In part, this was due to problems obtaining raw materials. The chief factor, however, was the impact of the arms race, and by 1937 German and English steelworks had formed cartel agreements to protect their countries' shipyards. This situation led a circle of businesspeople to found the Stålvalseværket (The Danish Steel Rolling Mill) in 1940, which started with bar steel production of 40,000 tons a year in 1943. About fifty Danish companies were owners, together with the state, which actively backed the initiative.[18]

Knowledge about building a steelworks was not available in Denmark. Therefore, the company sent engineers to Germany to conduct industrial espionage.

Knowledge about building a steelworks was not available in Denmark during this period. Therefore, the company sent engineers to Germany to conduct industrial espionage at a German steelworks. Knowledge about operating a steel rolling mill was also lacking, so

3 The Danish Steel Rolling Mill, Frederiksværk. The oldest part of the steelworks is in the middle. Built on the landfill from the furnaces is a rolling mill for long products (right), and the 1975 electric arc furnace from 1975 (left).

experts from abroad were employed, and the company used Swedish engineers at both the highest and middle management levels.[19]

Scrap-based plant with Siemens-Martin ovens

The steelworks was built in record time, housing two thirty-ton Siemens-Martin type furnaces, and as such, Denmark's largest recycling company was created. The furnace type was a well-developed technology, introduced around 1867, and was based on two inventions that made it highly suited for turning scrap into valuable steel. The first of these made the furnace capable of heating up to high temperatures to melt steel. To reach above, 1,600 degrees centigrade, the furnace had two identical chambers filled with stones. In one, the combustion air was passed through, heating the stones. After half an hour, the chambers changed function, with fresh air passing through the heated chamber for preheating while the second chamber was heated again. The second invention was flames on the surface of the flat bin for reducing the carbon content. As a result, the material was heated without adding coal, which was the case in blast furnaces. The workers simultaneously added limestone to remove unwanted substances, ending in the slag for landfill.

The technical facilities and process

The Siemens-Martin furnaces had large but not very deep bins, and both of the furnaces stood in a large hall with a platform, served with materials by a narrow-gauge tipper train. The locomotive would drive small dump trucks, collecting a few hundred kilos of scrap at a time. The workers would then fill the furnaces with scrap through doors above the floor level of the platform, and in total it took six to eight hours for the full furnace (a charge) to be melted.

While the Siemens-Martin furnaces at the Danish Steel Rolling Mill mainly melted scrap, testing of the scrap's composition also meant the addition of a certain proportion of raw materials, so that the end product would have the desired composition. Usually this meant the addition of pig iron, a lot of which came from Ålborg, where a Cement-Iron Consortium set up production in connection with a cement plant. The raw materials used in their rotary cement kilns were largely scrap but often of a quality that the Danish Steel Rolling Mill itself could not process, such as contaminated shavings from the metal industry.

The casting process, meanwhile, took place on the opposite side of the furnaces. Each bin had a drain hole in the bottom. When a charge was complete, a hole was punched or blasted to remove the plug in the draining hole. First out was the steel, which would flow down into casting spoons, and finally, the so-called "slag" with all the impurities, which would be diverted into a slag container and be removed. Initially at Det danske Stålvalseværk, this process was powered by two small gas plants. However, after the war, the plant switched to procure heat by oil burners. This post-war development also included upgrades to three 130-ton furnaces and a smaller one for seventy tons of steel, through which 500,000 tons could be cast annually with continuous production.[20]

4 The yard of one of Denmark's largest scrap companies in the mid-1920s. Even then, the scrap had to be sorted carefully. For example, the pile on the left consists exclusively of horseshoes.

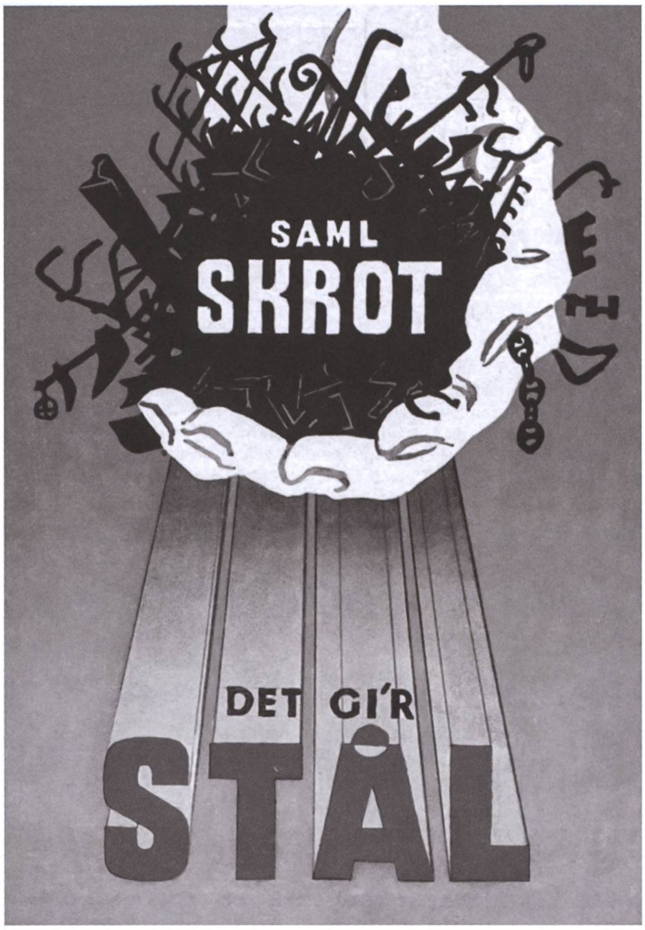
After the war, Danish shipyards could not buy enough steel sheets from foreign steelworks, so it was decided at Det danske Stålvalseværk to acquire a second-hand sheet metal mill from the United States. In 1949 a sheet metal mill, originally constructed in 1922, began service at the plant. In the first years, only bar steel was manufactured, which did not have strict requirements regarding the quality. That changed when the company began to produce plates, which were required to have both a high and a uniform quality. Shipyards bought many of the plates, and a certification body such as Det Norske Veritas (DNV) or Lloyds, who also insured the ships they were made of, was required to approve them.

However, significant problems arose for the Danish Steel Rolling Mill that threatened its existence, as with this expansion to its productive capacity the company had expanded without securing deliveries, and without a view to potential fluctuations in the availability of scrap.

The steelworks almost stopped by scrap shortage

During World War II and for several years afterwards, the steelworks had been in receipt of an abundant scrap supply. The need for scrap had increased, and the industry responded, as they had a good and fast buyer in Det danske Stålvalseværk. Supply had been reaching as much as 25,000 tons of scrap annually. These were good years, when obsolete machinery in industry was being replaced by new devices. At the same time, traders found large quantities of used steel in the military areas left by the German army.

This glut was not endless, however, and production demand soon began to outstrip what the scrap industry could supply. In response to this, the Danish Steel Rolling Mill established nationwide campaigns in the early 1950s, including one together with the National Association for the Fight Against Unemployment, LAB, giving the unemployed work collecting scrap.[21] As an advertisement, the Danish Steel Rolling Mill produced a film to demonstrate its importance, so that people would help gather scrap metal together. Though the film was only completed after the scrap shortage was no longer so acute, it was still shown around the country for a few years to encourage continued recycling. An employee from the plant drove around with a film projector, visiting local cinemas and town halls, usually in collaboration with the local scrap dealer. In all, about 18,000 people watched the film. The trip around the country took so long that the steelworks had been rebuilt in the meantime, and parts of the film had to be updated so it would not appear obsolete.[22]



5 "Collect scrap – it makes steel," was the message on posters distributed nationwide in the 1950s when the steelworks' scrapyard was almost empty.

The scrap crisis also encouraged efficiency at the steelworks. It often only took a few hours before "home scrap" – liquid steel dropped on the floor or taken from knives used for cleaning the rollers – was returned to the furnace. At the start of the Danish Steel Rolling Mill, this had accounted for well over thirty percent of the scrap. The proportion decreased over the years as people became more skilled at managing the processes. The efficiency drive continued after the scrap crisis, with a most considerable reduction in "home scrap" use happening after the company acquired a continuous casting plant in the mid-1970s.[23]

The steelworks: one of the EEC's strongest supporters

Some of the country's most prominent supporters of the EEC were in Frederiksværk, the site of the Mill. It was essential to the Danish Steel Rolling Mill that Denmark entered the European community. This membership happened after a referendum in 1972, and significant changes soon followed at the plant, as the company could obtain extremely cheap loans to build private homes and pay for expansions.

However, EEC membership also had consequences not wanted by the Danish Steel Rolling Mill. At the founding of the Mill, the Danish state had introduced an export ban on scrap, meaning the Danish scrap industry could only sell to the Danish Steel Rolling Mill. Initially, this had ensured that the plant had a steady supply of scrap, set at a price that, to a certain extent, followed that of the world market, as the Ministry of Trade did not want to receive too many complaints from scrap dealers. This had meant that the plant was almost obliged to purchase the scrap, because otherwise there was a clause that allowed scrap dealers to export. As such, the plant sometimes had to receive scrap that it did not actually need but was at risk of being exported. Large stocks were occasionally collected in Frederiksværk, so the company had to find alternative storage sites elsewhere in the country.[24]

Following Denmark's accession to the EEC, however, the rule on export bans was lifted over several years, thus opening up access to buy on the world market. The price of steel scrap fluctuated to the point where the cost could triple or fall by half in a short period. One of the explanations behind this is that blast furnace–based steelworks can also use the scrap as a raw material. Thus, if a strike broke out among miners in one of the significant ore-exporting countries, the scrap price inevitably rose immediately, impacting upon the economy of the Danish Steel Rolling Mill.

New, faster and larger furnaces

The day after Denmark joined the EEC, the construction of a new steelworks was initiated. The company was then able to apply for a loan from the EEC to use the latest technology, a so-called electric arc furnace. An arc is created with extremely high temperatures of 8,000–10,000 degrees centigrade by sending a strong current through three-ball electrodes. The new kilns, each with a capacity of 100 tons of steel, were completed in 1975. The previous kilns had to be filled 160 times for a batch, and the new kilns only needed to be served three times (later reduced to twice). Where as it took the old ovens six to eight hours for a charge from "tap to tap," the time was reduced to one hour. Thanks to conversions and improvements, the charger time was later reduced to about half an hour. Therefore, the old Siemens-Martin furnaces manufactured their last steel in 1980 and were demolished.

Improved laboratories essential

The plant could only use the new high-speed furnaces because the technology on the laboratory side for the analysis and control of quality had evolved too. Initially, steel analysis was a slow process. When the people at the Siemens-Martin furnaces reckoned that the steel was almost finished, they fetched a sample of the steel with a small container on a long rod, which was then poured into a mold. The mold was cooled, and the workers sent the small-molded sample to the laboratory via a tube post. Technicians then took a number of shavings and analyzed them through chemical processes. The analysis showed which substances the steel was missing, and then the workers at the furnace were told what quantities of additives, such as aluminum, coal, silicon and manganese, should be thrown into the kiln, so that the metal would be at the desired composition. This process took a long time, which did not mean much, as the ovens were slow.

New analysis methods could determine the composition of a charge in a short time. The analysis was no longer done by a chemical process but by a so-called electro-spectrometer, which analyzed the composition of the emitted light from an arc lit between a sample of the steel and a platinum electrode. Whereas the old chemical analysis took twenty minutes, the spectrometer needed only twenty seconds.

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Improved laboratories meant improved products, which was necessary for the DDS, as by the 1980s the requirements for steel quality had risen considerably. For instance, plates for offshore use became a large part of the market. Drilling platforms in the North Sea were built at great water depths and in extremely violent waters compared to the seas in which oil was otherwise traditionally extracted. The use of robots and other automated fabrication therefore placed new demands on the high and uniform quality of steel, and therefore the testing of the raw materials for its production.

Scrap quality testing and preparation still essential

Improved laboratory testing of samples from the liquid metal did not diminish the need for thorough scrap processing before it was put in the furnaces. Earlier on at the works, ammunition lodged in wartime scrap had been a clear and present danger to workers. Though this problem diminished with time, the risk of explosions did not, as closed containers could still be hidden in the scrap heaps. If such containers were placed in thousand-degree hot steel, air would quickly heat up, and the container would act like a grenade. Although the valve in a gas cylinder would be removed, there was not enough of a hole for the air to escape quickly enough. All objects of that type had to be cut into pieces. Water was even worse, and hidden ice was a particular problem in winter.

Unfortunately, there were quite a few explosions at the furnaces. The company has tried to trace the cause of the accidents, which caused both permanent injuries and several deaths. Often, the scrap collectors were not careful enough, and the subsequent inspection by workers at the plant was not sufficiently effective either. Sometimes the blame did not lie with the scrap itself but with the molds, as some were possibly not fully dried before the workers poured the hot steel into them.

Despite the high standards for steels, there were – oddly enough – no international standards for scrap grades for a long time. Thus, DDS never set out its own specifications. One explanation may be that each steelworks had different wishes for the scrap, for instance its mechanical dimensions. The Siemens-Martin furnaces had a small kiln mouth, and therefore the scrap had to be very small. After the plant obtained electric arc furnaces with larger kilns, the scrap pieces could be larger.[25]

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Thin sheets and long strips were cumbersome to handle. The plant, therefore, required them to be compressed into "packages," so that the workers could easily put them in the kilns. In processing the scrap this way, certain employees at De Danske Stålvalseværk became very good at spotting what scrap dealers occasionally overlooked: for

6 Samples are taken from the electric arc furnace, 1990.

example, a gasket or faucet made out of copper. The most skilled could supplement their annual income with almost a month's extra wages because they were paid the value of the copper collected.[26] However, a lot of the copper could not be removed. The Danish Steel Rolling Mill even had to ban scrap companies from supplying used rebar – which the company itself had manufactured, so that it would not "poison" the new steel with copper. In the end, it was not possible to continue hand-sorting the scrap in this manner. When the increasing volumes of cars from the 1960s had to be scrapped, new techniques were developed at the scrap companies, such as shredders, which disassembled cars into small parts that could subsequently be finely sorted via magnets or liquids. Some undesirable substances, such as lead or zinc, could not be sorted easily with this method. While they disappeared from the steel through evaporation, therefore not affecting the metal quality, they nonetheless presented a health hazard for workers, as air filters contained large amounts of heavy metal. This especially began to increase as a problem with the use of galvanized metal in cars. Another health hazard came from the widespread use of radioactive substances in hospitals and industry, which meant scrap collectors and steelworks, and also the Danish Steel Rolling Mill, were required to install radioactivity detectors.[27]

From buying scrap to selling

In 2002, the Danish Steel Rolling Mill went bankrupt, like many other steelworks from that time. In the end it was not the flow of raw materials to the company, or the quality of the product through tramp elements that brought an end to its business, but environmental legislation. Global competition had become too fierce for the plant to remain profitable and also coexist with some of the world's strictest environmental laws, while other countries still supported the industry at the expense of the environment. Though the furnaces no longer burn, the rolling department for plates continues today at Dansteel. The company receives semi-finished products from Russia in the form of slabs and rolls them into the desired steel plates. In 2006, Duferco Danish Steel took over the rolling mill for long products. While scrap is no longer purchased and processed on the site that was initially built for that purpose, Dansteel and Duferco Danish Steel have now become producers and exporters of scrap, shipping many thousands of tons to Chinese steelworks.

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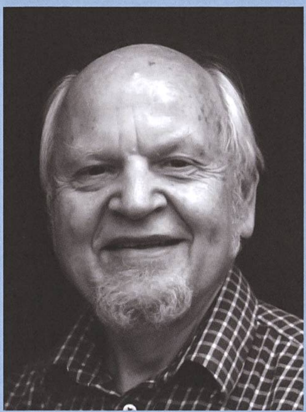

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1 Jørgen Burchardt.

2 Stefan Pauliuk, Rachel L. Milford, Daniel B. Müller, and Julian Allwood.

3 Stålvalseværket, Frederiksværk, Denmark.

4 H.I. Hansen.

5 Stålvalseværket, Frederiksværk, Denmark.

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