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RECYCLING OF STEEL CHIPS

RECIKLIRANJE JEKLENIH OSTRUŽKOV

Matjaž Torkar, Martin Lamut, Agron Millaku

Institute of Metals and Technology, Lepi pot 11, SI-1000 Ljubljana, Slovenia
matjaz.torkar@imt.si

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The recycling of waste metallic materials and the use of scrap are important for the economic production of a steelworks. Here, we investigate the technology of remelting steel chips. It was confirmed that the main problems with using chips in an electric arc furnace were the chips' large specific surface and the high losses due to the chips' oxidation. To overcome both problems the compaction and remelting of the chips were tested. The investigation revealed that a major problem for the recycling ecology of steel chips was the safe removal of cutting fluids and oils from the chips' surface. The chemical analysis of the remelted chips confirmed that stainless-steel chips can be an acceptable source of the alloying elements chromium, nickel and molybdenum.

Key words: steel chips, magnetic separation, cold compaction, remelting

Recikliranje odpadnih kovinskih materialov in uporaba starega železa sta pomembna za ekonomiko železarne. Tehnologija proizvodnje jekla s pretaljevanjem starega železa v elektro obločni peči je primerna tudi za jeklene ostružke. Preizkušena je bila tehnologija pretaljevanja jeklenih ostružkov. Glavni ugotovljeni problemi pri uporabi ostružkov v elektro obločni peči so velika specifična površina in velike talilne izgube zaradi oksidacije ostružkov. Zato je bilo preizkušeno stiskanje ostružkov in njihovo pretaljevanje. Predstavljeni so rezultati teh preizkusov. Ti so pokazali, da je bila glavna težava pri ekološkem recikliranju jeklenih ostružkov odstranitev rezilne tekočine in olj z njihove površine brez kontaminacije zraka. Kemijska analiza pretaljenih ostružkov je potrdila, da so ostružki nerjavnega jekla koristen vir legirnih elementov, kot so krom, nikelj in molibden.

Ključne besede: jekleni ostružki, magnetno ločevanje, hladno stiskanje, pretaljevanje

1 INTRODUCTION

Wastes that were traditionally discarded from industrial production are nowadays recycled.[1] The discarding of waste materials has a negative environmental impact and is a waste of time and money for the manufacturer of steel or machine parts.[2] Steel chips are a by-product of the mechanical working of steel parts in the metal industry and their quantity is considerable. The quantities of steel chips recorded by years in Slovenia are shown in **Table 1**.

Table 1: Quantity of steel chips in Slovenia
Tabela 1: Količina ostružkov železa v Sloveniji

Year Leto	Clasification number/Klasifikacijska številka: 120101 Quantitiy of filings and turnings of steel/ Količina opilkov in ostružkov železa (t)
2002	58 120
2003	33 111
2004	48 828
2005	43 991
2006	53 180
2007	93 381

Source: Statistical Office of the Republic of Slovenia

Steel production in the Republic of Slovenia is based on the remelting of scrap. From the data in **Table 1** it is evident that steel chips could be an important source of iron and other elements for steel producers.

With the prices of nickel and chromium currently high, and on the rise in recent years, the production of steel is becoming increasingly more expensive, and with the prices rising, the recycling of steel chips is beginning to look more appealing for steel companies.[2,3,4,5] For better productivity during metal working the cutting tools are cooled and lubricated with special cooling liquids consisting of lubrication, cooling and anti-corrosion agents. However, the chips are contaminated with these substances and need to be cleaned before any further processing. It is important to note that discarded coolants from the manufacturing of steel have a more harmful impact on the environment than dry chip processing.[4] This means that the coolants have to be removed in order to obtain more environmentally friendly waste from the chips generated in the processing of the steel. The discarding of metallic chips is harmful to the environment, regardless of whether they are contaminated or not, and these chips should not end up in landfills, thereby losing their potential for reuse. In the near future the recycling of these chips will actually cost less than disposing of them in a landfill.

The first step during the recycling of chips is usually the separation of the cooling liquid and the oil with a centrifuge.[3,4] It is also possible to remove the lubricant by washing them in an organic solvent that dissolves the organic contaminants from the chips' surface. The latter possibility is less acceptable because most organic solvents are carcinogenic and harmful to the environment, and their use and removal are regulated by the law.

Vacuum separation[2] is also used, by heating the chips in a vacuum chamber up to 270 °C. The low pressure in the chamber accelerates the evaporation of volatile components that are pumped out, cooled in a condenser at appropriate temperatures and the oils and water are separated. After regeneration, the oil is reused for machining.

The best quality of regenerated oil is obtained with a treatment involving supercritical CO_2 gas at a pressure of 100 bar.[2] However, when compared to other methods, this method is too expensive for the cleaning of chips.

After the chips of structural steel are cleaned they are separated from the chips of stainless steel using magnetic separation.[6]

Steel chips have a high specific volume and a low density that makes the remelting more difficult and with a low yield. For this reason, compacting with a cold press or briquetting, which increase the density of the chips, makes possible a more effective melting process.

The content of chromium in stainless steel is greater than that of nickel, but the price of nickel makes it more costly overall than chromium in the production of stainless steel.

The cost of nickel is so high that the price of stainless steel is directly related to the price of nickel, which has increased six fold from 2002 to 2006.[3] The price of ferrochrome has more than doubled in the past four years (2002 to 2005)[3], but the increase in the chromium price is still lower than the increase in the nickel price. For this reason, any source of chromium and nickel is cost attractive for stainless-steel producers.

For the producer of stainless steel in Slovenia an evaluation of the mixture of chips with respect to the content of chromium, nickel and molybdenum, as a possible additional source of alloying elements, was made.

2 EXPERIMENTAL

Magnetic tests showed the chips, declared as stainless-steel chips, were in reality a mixture of carbon steel and stainless steel. After the magnetic separation, however, only the stainless-steel chips were processed further.

Two methods of degreasing the chips were tested: heating in a laboratory furnace up to 400 °C and burning the volatile gases, and washing the chips in a waste organic solvent, trichloroethylene. Using both methods, dry and clean chips were obtained.

The degreased chips were cold pressed into cylindrical compacts, more suitable for remelting because of their higher density and lower volume. For the cold pressing a manually driven screw press was applied. The chips were charged in a hollow, slightly conical tool and repeatedly added and pressed until the tool was full. The pressed chips were then pressed out of the tool from the opposite site.

The compacts were then melted in a 20-kg induction-melting furnace using a premelt of known composition. The compacted chips were added to the primary melt and after remelting a sample of the melt was submitted to chemical analysis and the contents of nickel, chromium and molybdenum in the chips were calculated. The chemical analysis was performed with optical emission spectrometry ARL and controlled with

Figure 1: Mixture of steel chips
Slika 1: Mešanica jeklenih ostružkov

Figure 2: Separated stainles steel chips and compacted, cold pressed chips
Slika 2: Ločeni ostružki nerjavnega jekla, hladno stisnjeni ostružki

Figure 3: Compacts of stainless steel chips after cold pressing
Slika 3: Stisnjeni ostružki nerjavnega jekla po hladnem stiskanju

Figure 4: Charging of compact into melt
Slika 4: Dodajanje stisnjencev v talino

Figure 6: Ingots composed of basic steel and added compacts
Slika 6: Ingota, sestavljena iz osnovnega jekla in dodanih stisnjencev

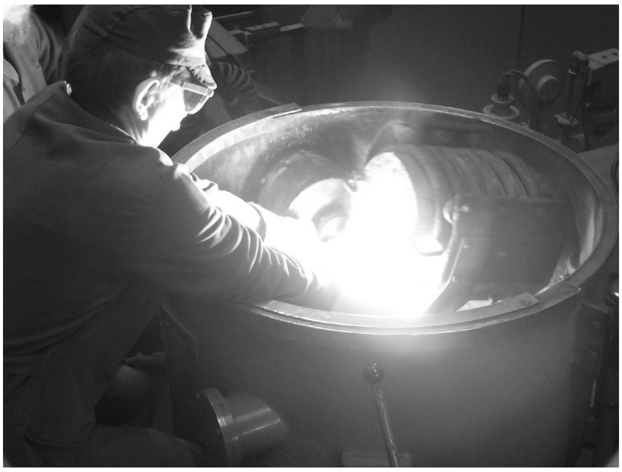

Figure 5: Casting of sample for chemical analysis
Slika 5: Ulivanje vzorca za kemijsko analizo

wet chemical analysis. The quantity and composition of the slag were not taken into account.

3 RESULTS AND DISCUSSION

The magnetic separation revealed that the investigated sample consisted of a mixture of 1/3 of stainless steel and 2/3 of carbon steels, but for further processing only the chips of stainless steel were used.

Two methods for removal of the cooling fluid were tested. First, degreasing in trichloroethylene, which is an effective solvent for greases and a variety of organic materials. Its use is harmful because it is carcinogenic and it is suitable only for applications in laboratory-controlled conditions, whereas it is not suitable for industrial processing.

The second method was heating the chips to 400 °C in an electric furnace, when the water and oil evaporated, and clean and dry chips were obtained. The heating smoke was burned to CO_2 and H_2O by introducing it into a flame.

On an industrial level, it is also possible to charge oil-contaminated chips with scrap directly. In this case the organic impurities would be burned out at high temperatures and the formed gases would escape through the filters for furnace exhaust gases. In the case of a too low temperature, the evaporation of oils and their collection in filters may reduce the filters' efficiency.

3.1 Compacting the chips

The direct melting of the chips in the 20-kg induction furnace was not possible. Because of the low density, the chips in the furnace would only be heated to a temperature below the melting point. For the melting it was necessary to prepare chips in a compacted form and for this reason, the chips were cold pressed into a cylindrical form with a pressure of 1765.8 kPa. For comparison the pressing of contaminated and degreased chips was tested. In both cases the product was compacted into a round, cylindrical form with a diameter of 55 mm and length of 120 mm, and with a density of between 3 kg/dm^3 and 4 kg/dm^3. The pressed forms were of round section and had a diameter of 55 mm and a length of 120 mm. The size of the forms was limited by the dimensions and the height of the pressing-tool cavity.

3.2 Remelting the chips

An induction-melting furnace requires a minimal density of charge, and the density of the compacts was still too low for direct melting in an induction furnace. The compacts were only heated and their temperature did not reach the melting point. To master the melting a primary melt with known composition was prepared and then the compacts were charged into the molten steel. First, 7 kg of mild steel was melted in the 20-kg induction furnace and its chemical composition was determined. The mass of the molten steel was reduced by 765 g to 6 235 g, 13 000 g of compacts added and a total melt mass of 19 235 g was achieved. The slag was

Table 2: Chemical composition of primary melt, after the addition of chips and calculated composition of chips. All in mass fractions, *w*/%
Tabela 2: Kemijska sestava primarne taline, po dodatku ostružkov in izračunana sestava ostružkov. Vse v mas. deležih, *w*/%

Chemical composition		**C**	**Si**	**Mn**	**Ni**	**Cr**	**Mo**	**Cu**	Fe
Primary melt *w*/%		0.14	0.25	0.19	0.04	0.03	0.05	0.11	99.30
Weight (g)	6235	8.73	15.59	11.85	2.49	1.87	3.12	6.86	6191.36
Mixture *w*/%		0.24	0.35	0.89	4.30	8.80	0.60	0.34	84.82
Weight (g)	19235	46.16	67.32	171.19	827.11	1692.68	115.41	65.40	16315.13
Chips *w*/%		0.29	0.40	1.23	6.34	13.01	0.86	0.45	77.88
Weight (g)	13000	37.44	51.74	159.35	824.61	1690.81	112.29	58.54	10065.23

removed from the melt and a sample for chemical analysis was taken. The rest of the melt was cast into ingots with a square cross-section. The weight of the as-cast sample for the chemical analysis and ingots together was 18 150 g. The difference between 1 085 g and 19 235 g is the material loss (slag, drops, remains in the melting furnace).

3.3 Determination of the composition of the chips

The basis for the calculation of the content of elements in the stainless-steel chips was the total mass of 19 235 g. This represents 13 000 g of chips of unknown composition diluted within 6 235 g of mild steel with known composition. A programme was prepared in Excel for the calculation of the chemical composition of the premelt, of the ingots and of the content of the individual elements in the chips. From the chemical composition of the premelt and of the composition of the ingot the content of elements in the chips in **Table 2** was calculated.

4 CONCLUSIONS

The recycling of steel chips with remelting in an induction-melting furnace was investigated. Based on the experimental results, the following conclusions can be drawn:

Tests with magnets revealed that the investigated chips were a mixture of 1/3 of non-magnetic fraction (stainless steel) and 2/3 of magnetic fraction (structural steel). Both fractions of chips were successfully separated with magnetic separation and the following composition of the investigated chips was obtained: 13.01 % Cr, 6.34 % Ni, 0.86 % Mo and 0.45 % Cu.

The higher carbon content and the lower chromium content in the chips are probably due to the inaccuracy of magnetic separation method or the incomplete elimination during the burning of the oil contamination.

The investigations confirmed that the compaction of the chips is necessary for a better yield of material in the melting process and that stainless steel is a valuable source of alloying elements.

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