Investigation of briquetting of metal waste from the bearing industry

An economical method to process the metal waste that comes from the ball-bearing industry is presented. The purpose of the study was to determine the physical-chemical properties of the material, to present the most suitable binders and identify the factors that can affect briquette strength. The mechanical strength and resistance to gravitational drop were defined for both fresh briquettes and those that had been seasoned. The briquette structure was also tested. On the basis of the results of experimental studies and laboratory trials two techniques for processing the waste from the ball-bearing industry on an industrial technological scale were developed. The economic and ecological impacts of these industrial applications were examined. The results of the investigations suggest that the briquettes might be recycled in steel-making furnaces. The reported solution to the problem of management of this type of waste appears to be universal and could also be applied by other waste-related enterprises.

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Introduction

Briquette-making is now frequently applied in the management of fine-grained production wastes that are by-products from metal industries. Briquetted waste can be used as a component of the raw material charge in electric steel furnaces and the waste material from the grinding of ball-bearings is a likely candidate for utilization in the same way (Drzymała 1993).

Before the metallurgical processing of fine-grained metal wastes can be instituted, it is necessary to carry out investigations in order to define the most beneficial processing conditions and to choose suitable parameters and equipment. Based on the requirements of the metallurgy industry, the minimum values for briquette compression strength and resistance to gravitational drop have to be specified (Drzymała & Hryniewicz 1997, Hryniewicz et al. 2003).

The aim of the present investigation was to determine the properties of the metal waste and to choose the most suitable form of mixture to be made into briquettes (Borowski 2003, Borowski & Kuczmazewski 2003) as well as to find suitable binders and examine selected factors affecting briquette strength. In addition, the mechanical strength and resistance to gravitational drop of both freshly fabricated briquettes and those that had been seasoned were determined and the structure of the briquettes was investigated.

To form briquettes a laboratory stamp press and roll press with the correct type of forming unit were used. The investigations verified the impact of relevant factors on the briquette-making process with respect to the metallurgical strength-related requirements.

The results of the investigations led to the development of two alternative designs for industrial-scale briquette making, using the metal waste from the ball-bearing industry. The first of these used natural, open-air drying of the waste whereas
the second used thermal drying. The processes appear to be very easy to implement and would have low operating costs. Due to the recent increase in scrap price, there is the prospect of a rapid return and high profitability from the capital invested. The designs presented may be modified and adjusted to specific needs and may also be applied to the utilization of other types of fine-grained wastes.

Waste description

Fine-grained waste is generated during grinding of the rolling elements and usually occurs as sludge with a water content ranging from 30 to 40%. To examine the chemical composition of the waste, it was necessary to dry the samples before they were treated by a mixture of acids (HCl, HNO_3, and HF) and digested in a CEM MBS 2000 microwave oven. ICP (inductively coupled plasma) spectrometry was used to determine the concentrations of the elements and carbon content was analysed by a Shimadzu TOC 5050 A automatic carbon analyser.

Table 1 presents the chemical composition of metal waste from the grinding of rolling bearings. The waste was characterized by a relatively low level of oily compounds. As there was a large iron content, it was considered advisable to use the waste in metallurgy. The waste did not contain a large amount of any other heavy metals. The chromium content complied with the Polish standards for steel on rolling bearings; however, scrap that is re-used to produce high-quality steels must contain smaller amounts of chromium. The re-use of the waste from the ball-bearing industry therefore depends on the type of briquettes that can form an acceptable share of the total mass of the metallurgical feeding charge.

The physical properties of the post-filtration waste before and after drying are presented in Table 2. The excess of water was removed from the post-grinding waste sludge by plate filtration presses, which are widely applied for mechanical dehydration of sludge in wastewater treatment and in galvanizing plants, tanneries and food-processing factories. The moisture of the waste reached approximately 25%, which was still too high for utilization for briquette making and so the drying needed to be continued. Further dehydration was carried out in drum driers or on sludge drying beds. It was found that the waste could be easily dried under natural conditions and it took 15 to 30 days to dry the waste, which was stored in piles (10–20 cm thick) on the sludge drying bed.

Development of the waste briquette-making method

The investigations revealed that the type of briquette-making unit used (stamp press or roll press) did not greatly matter (Borowski 2002b, 2003). The decision of press should depend on availability and the choice of the investor. The roll presses, which have become a more common part of modern technological bearing lines (Dzrymala 1993), provide numerous advantages; namely that they run continuously, have high effectiveness and consume little energy. It is crucial to select a suitable forming unit, which ensures consolidation and produces rounded briquettes (Hryniewicz 1997).

A stamp press, such as the PH-20 stamp hydraulic press, which has been produced for briquette-making using metal waste from the bearing industry produces cylinder-shaped briquettes (Figure 1), whereas the roll press (1 PW 450 type), produces saddle-shaped briquettes (Figure 2).

The waste for briquettes was prepared by mixing the components and drying the mixture in a laboratory Z-type mixer.

Fig. 1: Cylinder-shaped briquettes from the stamp press.
with a heating jacket. Samples of material with a humidity range of 2.6–6.7% were prepared.

Different values of the stamp parameters were used; these depended on the type of briquette-making unit that was used.

- Stamp press: stamp unit pressure $p = 20$ MPa; stamp diameter $d = 30$ mm; stamp displacement $l = 200$ mm; Pressing time $t = 10$ s.
- Roll press: tangential velocity of rollers $v = 0.2$ m s$^{-1}$; roller expansion gap $a = 1.5$ mm; unit pressure range $p = 40$–110 MPa.

The most favourable briquette-making conditions, the briquette quality as well as the impact of binding agent, the humidity of the waste material and the seasoning were assessed during strength tests. The ZWICK Z100 testing machine was used to continuously register the thrust and translocations of the stamp, and the data were saved in a computer. The examination comprised about 100 briquettes, made with eight different types of binders and with their content ranging from 5 to 10%. In addition, control samples with no binder were tested. All samples were compressed between flat surfaces with a preliminary force of 100 N. Some of the binding agents proved beneficial whereas others were not beneficial in comparison with binder-free briquettes.

Further investigations verified briquette resistance to damage caused by gravitational drop. The samples were dropped three times from a height of 2 m onto a steel plate, 20 mm thick. The briquettes that were made using a high pressing strength were found to be very resistant to the drop. The results of the investigations are shown in Table 3.

High mechanical strength of briquettes can be achieved by using a suitable binder. Briquettes that had been manufactured using various binder types as well as binder-free briquettes were tested. It was confirmed that briquettes with no binder would not be suitable for metallurgical industry application.

A suitable binder should be cheap, easily available, of organic origin, and should not contaminate the environment during combustion. All the requirements mentioned above are met by molasses, a waste product of sugar refinery. The addition of molasses made it possible to obtain briquettes with good mechanical properties. The amount of molasses added to the mass to be briquetted was approximately 8%. The pressing force and the resistance to gravitational drop were assessed, for both ‘fresh’ and for briquettes that had been seasoned for at least 5 days. Seasoning of briquettes to which molasses had been added proved to be beneficial, as their mechanical properties continued to improve (Table 3).

The briquettes obtained would be completely acceptable for metallurgical recycling. The trials confirmed the possibility of their metallurgical use. On the basis of the results obtained, two concepts for large-scale industrial briquette-making using metal waste from the bearing industry were developed. The first concept is based on ‘natural’ air drying of the wastes, and the second concept is based on thermal drying. Both schemes assume that a roll press (fitted with a forming unit that will allow the production of saddle-shaped briquettes) would be used. In addition to the briquette-making machine some other tools to prepare the waste mixture, and also to relocate and gather raw materials and products were used. Figure 3

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Table 3: Mechanical properties of roll pressed briquettes, both fresh and seasoned for 120 h.

<table>
<thead>
<tr>
<th>No</th>
<th>Humidity (%)</th>
<th>Unit pressure (MPa)</th>
<th>Briquette destructive force (N)</th>
<th>Briquette resistance to the gravitational drop (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>fresh</td>
<td>seasoned</td>
</tr>
<tr>
<td>1</td>
<td>2.60</td>
<td>110.0</td>
<td>723</td>
<td>1080</td>
</tr>
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<td>2</td>
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<td>6.72</td>
<td>41.4</td>
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</tr>
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</table>
Fig. 3: Concept for the briquette-making process line with natural air-drying of the wastes: 1, tank for post-grinding sludge; 2, filtration press; 3, sludge drying bed; 4, molasses tank; 5, mixer [ worm conveyor ]; 6, bucket conveyor; 7, cylindrical briquetting machine; 8, separator; 9, bucket conveyor to turn back mesh fraction; 10, belt conveyor to collect the briquettes; 11, tank for the briquettes.

Fig. 4: Concept for the briquette-making process line with thermal drying of the wastes: 1, tank for post-grinding sludge; 2, filtration press; 3, molasses tank; 4, mixer; 5, drier; 6, bucket conveyor; 7, cylindrical briquetting machine; 8, separator; 9, bucket conveyor to turn back mesh fraction; 10, belt conveyor to collect the briquettes; 11, tank for the briquettes.

shows the proposed scheme for a large-scale, industrial process with the wastes being air-dried on a sludge drying bed.

This variant of the process is economical but time-consuming. The wastes should be stored under cover for 2 to 4 weeks, depending on the thickness of the storage layer, although, due to the high effectiveness of the briquette-making machine, the wastes could be processed after a few days.

The other proposition was to install a mixing drum drier in the industrial process line, especially where there is little storage space for waste (Figure 4). Thermal drying of waste increases the cost of the process but it is more effective. The briquetting of waste is continuous and more waste material can be processed.

Investigations on briquette structure

The investigation of briquette structure included the following measurements:

- shape and size of waste grains before agglomeration;
- grain packing in the briquette after agglomeration;
- location and structure of a binder in a briquette profile; and
Economic and ecological aspects of the implementation of waste briquetting technology

The application of waste briquetting using either of the two concepts presented above requires purchasing of the necessary equipment and covering the cost of its operation. Among the different types of equipment available, it is suggested that the PW 500-type roll press should be used to briquette the waste material, and the PFH-630 plate filtration press to remove any excess of water. In Poland, their net cost is approximately €135,000, and the total payment for the process line has been assessed at €200,000.

Once the metal waste has been formed into briquettes, they can be used in the metallurgical industry. The nearest steel plant, located about 50 km from the waste producer (ball-bearing industry), is equipped with electric arc furnaces to recycle ferrous scrap. The price of the scrap in Poland is now approximately €125 per tonne, including transport charges. The waste under investigation, produced in one company only, may generate 800 tonnes of briquettes per year, which is equivalent to an annual revenue of up to €100,000.

The sale of briquettes is likely to generate a high income and lead to a rapid repayment of the capital invested in the process line. The analysis of investment effectiveness (Borowski 2002a) confirmed a high profitability and economic remuneration for waste briquette-making.

As the recommended technology complies with the EU directives, according to which all waste that otherwise may contaminate the environment, should be re-used, there are also ecological benefits. Due to the fact that the waste is being recycled in steel-making furnaces, the toxic and hazardous compounds it may contain are eliminated. Such substances are thermally destroyed and broken down into non-hazardous and non-toxic compounds that no longer contaminate the natural environment.

Results

Briquetting appears to be an effective method to manage the metal waste that comes from the ball-bearing industry. It produces a homogenous agglomeration of briquettes that have a desirable shape, size and mechanical strength.
So far the process to form metal waste into briquettes that are recycled in steel-making furnaces has not been implemented in Poland. Finding a solution to this problem required investigations focused on the determination of suitable process parameters. The metal waste used in this study came from the production of ball-bearings. In addition to the analysis of chemical composition and physical properties of the metal waste, suitable binders and processing equipment were also tested and selected to produce the required briquette strength.

The investigation revealed that good quality briquettes need molasses as a binder. It was found that the briquetting mixture can be dried under both natural conditions and with a drier. The briquettes obtained during laboratory trials were seasoned, appeared to be durable and strong, and met the requirements of the metallurgical industry for feeding into steel furnaces. Briquette structure was homogeneous and no clear defects such as air-holes and cracks were observed.

The results of the reported investigations made it possible to design two concepts for the industrial application of briquette-making, using the waste from the ball-bearing industry. If the suggested process line is implemented, both economic and ecological benefits can be expected. The capital invested would be quickly repaid by high revenue.

Conclusions
The conclusions are presented in the following paragraphs.

References

Briquetting technology is recommended to be applied to production process and recover metal waste from the ball-bearing industry, which can be recycled as feeding material for the furnaces of metallurgical industries.

The briquettes can meet the requirements of metallurgical industry, if a suitable binder is added and the waste mixture is properly dried. It was found that the best briquettes were obtained when molasses added in an amount of approximately 8% of the briquetted mass and the moisture of the briquetting mixture ranged between 4.5 and 6.5%.

Mechanical strength of briquettes to which molasses had been added improved during seasoning.

The results of laboratory tests and metallurgical trials made it possible to develop a large-scale industrial application of briquet making that used metal wastes.

The implementation of the recycling technology suggested is of economical advantage, as now the demand for scrap in metallurgical industry is high.

The suggested technology is ecologically justified as it does not contaminate natural environment.

The successful introduction of this new recycling technique may be an inspiration for other enterprises dealing with by-products such as highly crumbled metal wastes.

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