INFLUENCE OF MACHINING WASTE UTILISATION TECHNOLOGY ON PROPERTIES OF POWDERS OBTAINED

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Abstract. Rapid growth in urbanisation and industrialisation has brought waste management to the forefront of the agenda. Industrial, municipal and medical waste management and disposal are major issues affecting the world. This study examines the methods of recycling 18X2H4MA steel waste. The metalworking industry generates a large amount of waste. When metal is processed using bladed tools such as cutters, mills, and drills, waste is generated in the form of chips. The processes of high-temperature plastic moulding of products are accompanied by the generation of waste in the form of scale. The article deals with general aspects of industrial waste utilisation by powder metallurgy. The main attention is paid to the initial operations of utilisation of machining waste on the example of scale from press and forging production. These operations include, first of all, magnetic separation, the purpose of which is to separate metal and abrasive fractions in the waste. Subsequently, the separated metal fraction is ground to obtain high-quality technological properties of powders. The particle shape, particle size distribution, bulk density, flowability, and their comparison with similar characteristics of PZhR iron powder (PZR) were investigated. An important direction in the development of industrial waste utilization is the use of resource-restoring and energy-saving technologies. The composition of the charge for the implementation of the exothermic reaction is proposed based on 18X2H4MA steel scale. The mechanical characteristics of the thermite material were investigated. The hardness of the material at different sampling depths is different, which indicates the influence of technological indicators of combustion of exothermic mixtures on the material properties.

Keywords: scale, grinding, powder, particle size distribution, properties.

Introduction

Faced with the problem of increasing waste, scientists, foundations and companies worldwide have come up with ideas and invented technologies to slow down the process. Waste sources range from industrial waste (e.g. construction and demolition materials, hazardous waste, ash) to municipal solid waste (e.g. food waste, paper, cardboard, plastic, textiles) [1-5]. A significant amount of waste is generated by metalworking, which is related to metals. In this regard, we can cite studies that consider metal waste as an alternative raw material in energy-saving technologies for the production of new products [6; 7].

Many scientists have worked on solving the problems of scale recycling [8-10]. Paper [10] describes a method of designing and degreasing the mill scale. The unique, innovative technology is based on the low-temperature treatment of oily scale with a high-speed flow of complete fuel combustion products in a vortex (cyclone) unit. In this case, oil and water are removed by sublimation when the materials are heated to a temperature of 400-450 ºC without oxygen. The coolant flow required for heat treatment is generated from the flare combustion of fuel with a minimum of excess air in the furnace. As a result, there is no free oxygen in the exhaust gases, or its concentration is minimal, which prevents the ignition of oil vapours in the reactor working space.

The technology for the utilization of oily scale was developed by S.M. Kripak [11], which consists of the following: a stage of thickening, mechanical dewatering on a belt filter with a wash layer of disposable filter material, technical degreasing in a drum furnace, mechanical activation (mixing with powdered binders), granulation, as well as a cyclic process of particle strengthening in a steaming chamber and discharging particles into storage hoppers. This technology makes it possible to recycle sludge and waste dust from rolling production. Despite all the advantages of the proposed utilization technology, no practical application of the waste briquettes produced has been found.

Foreign researchers pay considerable attention to the problems of metal-containing waste disposal [12; 13].

This work is related to the problems of utilisation of press-forging scale from the press-forging production of Kovelsilmash LLC. Fig. 1 shows an example of individual parts produced by hot plastic deformation.

a)

b)

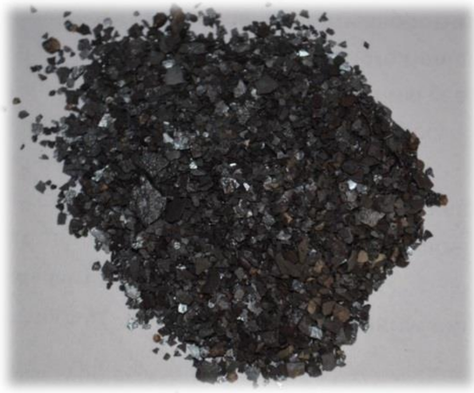

Fig. 1. **Parts produced by hot plastic deformation (a); scale particles (b)**

As a raw material, scale requires additional cleaning, separation, dehydration and grinding operations. Accordingly, the use of such waste is possible only after its preliminary preparation. Therefore, it is advisable to study the effect of scale grinding methods on dispersion and particle shape. Metal powders are characterized by chemical, physical, and technological properties, the knowledge of which allows us to create an objective picture of the totality of the huge number of particles under consideration and is necessary for the organization of technological processes in powder metallurgy production.

Materials and methods

Material is steel scale 18Kh2N4MA. Scale is a grey iron-containing substance in the form of sharp-edged plates. Vibratory grinding was carried out in a vibratory drum mill with an offset axis of rotation [14]. Sieve analysis of the particle size distribution was carried out in an LS-300 automatic analyser, and the Micro-optik optical software package was used to determine the morphology and structure of the materials.

Results and discussion

Crushing. The scale thickness varies from 50...200 µm, and the area is 50...5000 µm^2. It is impossible to use scale as one of the starting components in manufacturing structural or tribotechnical parts by powder metallurgy. That is why it is necessary to carry out primary processing of the scale, namely, its grinding. To determine the optimal grinding modes, a set of studies was carried out to determine the particle size distribution and shape of the crushed scale powder over different time intervals.

Grinding was carried out in a vibrating tumbling mill with a displaced axis of rotation [14]. The grinding time was 30, 60, 120, and 180 minutes. To ensure the reliability of the results, three samples were examined for each time interval. Since scale is a brittle material, the grinding process was carried out in a free-fall mode. The required drum speed was determined by the formula:

$$n_{роб} = (0.6\ldots0.8)n_{кр}, \tag{1}$$

where $n_{кр} = 42.4 \cdot D_{вн}^{-0.5}$ – critical number of drum rotations, rpm;
$D_{вн}$ – inner diameter of the drum body, cm.

The size of the grinding balls was Ø18 mm and was calculated using an empirical formula according to:

$$D_к = 4.8(\lg d_p)d_в, \tag{2}$$

where $d_в$ – initial particle diameter, mm;
d_p – particle size after grinding, mm.

The mass of the material load was determined from the ratio of the mass of balls to the mass of powder and was 0.75:1. The degree of grinding was assessed by the amount of scale powder of a particular fraction by sieve analysis by GOST 18318-94 using a vibrating sieve model 029 No. 124-85.

Fig. 2 shows an example of the particle size distribution of the scale powder when grinding for 180 minutes. In general, it was found that, regardless of the grinding time, the largest mass fraction of scale was 0.4 mm in size. With an increase in the grinding time from 30 to 60 minutes, the proportion of 1 and 0.63 mm decreases, while the proportion of 0.4 mm increases. When the grinding time is increased to 120 minutes, an increase in the 0.2 mm fraction is noticeable. However, when grinding for 180 minutes, an increase in the mass fraction of smaller fractions of 0.16, 0.1, and 0.063 mm is observed.

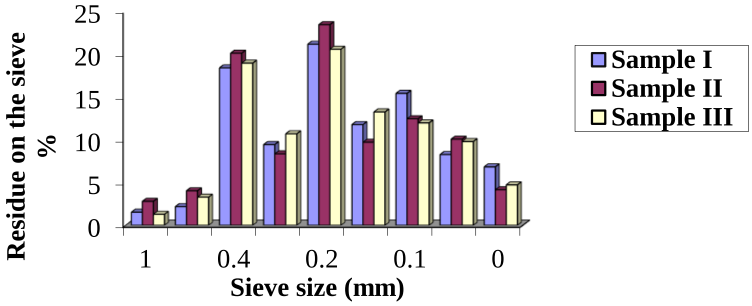

Fig. 2. **Particle size distribution of scale after grinding in a ball mill for 180 minutes**

Magnetic separation. To ensure the purity of the starting materials, the scale powder was subjected to magnetic separation. Magnetic separation was carried out to extract the non-metallic component of steel scale powder using a magnetic separator of the brand ЭСШ-100, which provides for the adjustment of the speed of movement of the separated material on the working surface. To determine the amount of non-metallic inclusions in the scale powder, eight batches weighing 1 kilogram and with fractions of 1, 0.63, 0.4, 0.315, 0.2, 0.16, 0.1, and 0.063 mm were selected, respectively. The content of non-metallic impurities for different scale fractions is shown in Fig. 3.

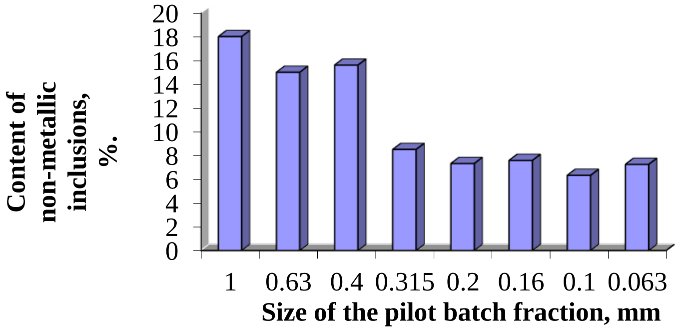

Fig. 3. **Content of non-metallic inclusions in different fractions of scale powder**

As it can be seen from Fig. 3, the largest amount of non-metallic impurities is in batches with a fraction of more than 0.4 mm, which is explained by the fact that the impurities present in the primary raw material are less capable of grinding.

Characteristics of the properties of 18H2N4MA steel scale powder

Chemical properties. The content of the base metal, impurities, various mechanical contaminants, and gases assess the chemical composition of the powder. The chemical composition of the powder obtained from the press and forging waste depends on the machining temperature, the workpiece material, and the method and time of storage of the scale before processing.

The chemical and spectral analysis of the powders was carried out in the I.M. Frantsevich Institute of Materials Science laboratory of the National Academy of Sciences of Ukraine.

Steel 18X2H4MA contains 1.35-1.65% chromium, 0.30-0.40% molybdenum, 0.17-0.37% silicon, 0.30% copper, 0.25-0.55% manganese, 4.00-4.40% nickel, 0.025% phosphorus, 0.025% sulfur as alloying elements. Hot deformation of this steel produces scale with the following chemical composition: 58-59% iron oxide, 40-48% iron (ferrite), and 1.5-2.0% oxides of alloying elements, namely chromium, molybdenum, and silicon. The process of hot working the steel, which results in scale formation, is short-lived, and ferrite did not undergo internal oxidation.

Particle shape. The shape of the powder particles depends on the method of its production and significantly affects the technological properties of the powder, as well as the density, strength and uniformity of the properties of the powder blanks. The shape of the powder particles was determined by optical microscopy.

During grinding, the change in the shape of the scale powder particles was analysed. Fig. 4 shows the general appearance of the scale after 1 hour of grinding. Figure 5 shows the general appearance of the scale after 2 hours of grinding.

Fig. 4. **Appearance of scale samples after 1 hour of grinding (x 50):** a – scale with a fraction of 1-1.2 mm; b – scale with a fraction of 0.4-0.315 mm; c – scale with a fraction of 0.2-0.16 mm

Fig. 5. **Appearance of scale samples after 2 hours of grinding (x 50):** a – scale with a fraction of 1-1.2 mm; b – scale with a fraction of 0.4-0.315 mm; c – scale with a fraction of 0.2-0.16 mm

Fig. 4. and Fig. 5. show that after both one and two hours of grinding, the shape of the particles practically does not change. The scale particles have a plate-like shape with a thickness of 100-200 µm and sharp edges. This particle shape leads to an increase in inter-particle friction and reduces the bulk density. When combining a powder of this shape with a powder of a smaller dispersion, the bulk density and degree of mixing increase. This is due to the distribution of smaller particles among the larger ones.

The bulk density depends on the size and shape of the powder particles. It is higher the larger and more regular the powder particles are. The presence of protrusions and irregularities on the surface of the particles, as well as an increase in their surface due to a decrease in size, increase inter-particle friction, which makes it difficult for them to move relative to each other and leads to a decrease in bulk density. In addition, the powder after magnetic separation has high magnetic properties, reducing its bulk density. The powder that is purified by electromagnetic separation must be demagnetised at special facilities. The bulk density of 18X2H4MA steel scale is shown in Table 1.

Table 1

Bulk density of scale, g·cm^{-3}

No of sample	1.2-1.0 mm	0.63-0.40 mm	0.400-0.315 mm	0.315-0.200 mm
1	1.06	1.39	1.51	1.5
2	0.59	1.13	1.29	1.23
3	1.11	1.54	1.72	1.74
4	0.75	1.14	1.23	1.32
5	1.31	1.42	1.68	1.66
6	0.81	1.25	1.43	1.38

The resulting powder from 18X2H4MA steel scale was used to implement exothermic technology. An important application area for thermite is metal welding and the production of thermite high-speed steels. The combustible metals in thermite mixtures can be metals with a high heat of oxide formation, such as aluminum, magnesium, and silicon (especially amorphous silicon). The source of oxygen in thermite mixtures is metal oxides with a relatively low calorific value, such as iron, manganese, nickel, and copper oxides. Iron scale is usually used as a source of oxygen in welding thermites, which roughly corresponds in chemical composition to iron oxide-oxide, FeO, Fe_2O_3, Fe_3O_4 [15]. The quality of thermite steel directly depends on the composition of the charge. It is known that the aluminium content of 0.15-0.20% in thermite steel leads to a deterioration in its plastic and mechanical properties. To deoxidize and improve the mechanical properties of thermite steel, ferromanganese, and ferrosilicon are added to the exothermic charge. Adding 3-5% copper to the charge results in a uniform reaction increases the combustion temperature by 100-150 ºC. In addition, copper increases the pyrophoricity of the charge and promotes better separation of liquid metal from slag. It was found that the oxygen balance of 18X2H4MA steel scale from forging and stamping production is 22.5-25% O_2, which is lower than that required for a stable reaction and complete combustion of the charge. The addition of 5-7% potassium nitrate powder to the exothermic charge ensures stable combustion due to the uniform distribution of the oxygen balance of the charge. In addition, adding potassium nitrate reduces the ignition temperature of the charge and increases its calorific value. Based on the analysis of patent search data and literature sources and based on the operational and mechanical characteristics required for the proposed thermite material, the following composition of the exothermic charge was selected [16] – Table 2.

Table 2

Mass fraction of components of the exothermic charge, wt.%:

Steel scale 18X2H4MA	68-72
Aluminium powder ПА-3 of GOST 6058-73	16-20
Copper powder ПМС-1 GOST 4960-75	3-5
Potassium nitrate GOST 19790-74	7-9
Ferromanganese ФМн75А	0.5-0.8
Ferrosilicon ФС45	1.5-2.2

The particle size distribution of the exothermic mixture in mm: iron-aluminium thermite, namely, scale 0.3-0.5, aluminium powder 0.3, copper powder 0.1, potassium nitrate powder 0.4-0.5, ferrosilicon and ferromanganese powder 0.1. The exothermic reaction resulted in a monolithic material. The ratio of metal to slag is 63:37.

Conclusions

A technology for the utilisation of scale has been developed that allows the production of metal powders of 18Kh2N4MA steel. It has been proved that the obtained powders, due to their chemical, physical and technological properties, are expedient to use in exothermic processes of manufacturing parts for structural and tribotechnical purposes.

Author contributions

Conceptualization, V.R., methodology, V.R. and L.S., software, O.R. and N.R., validation, N.R. and N.T., investigation, V.R., L.S., O.R. and N.T., data curation, O.R. and N.R., writing – original draft preparation, L.S., writing – review and editing, O.R. and N.R., visualization, L.S., N.R. and N.T. All authors have read and agreed to the published version of the manuscript.

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