PROSPECTS OF INDUCTION SORTING OF AUTOMOTIVE SCRAP

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Abstract - Recovery and recycling of metals from wastes have a major role in the economy because of the scarcity of raw materials and the problem of environmental pollution. In this article the necessity of using electrodynamics (eddy current) separators for extraction of non-ferrous metals from crushed automotive scrap and sorting of non-ferrous metals by types and grades of alloys is shown. The results of studies of an experimental separator based on a three-phase linear inductor are presented.

Keywords - automotive scrap, aluminium alloys, technological problems, electrodynamic separator, research results.

I. INTRODUCTION

The development of secondary non-ferrous metallurgy refers to strategic directions of economic development [1]. Recycling of metals makes it possible to reduce the consumption of natural resources the cost of which is constantly increasing due to depletion of primary raw materials and increasing transport costs. On the other hand, when using secondary raw materials for the production of alloys, the energy intensity of metallurgical processes is significantly reduced, and their environmental performance is improved. For these reasons, the production of secondary metals is continuously growing and becomes commensurate with the production of metals from minerals.

This is illustrated by the data in Table 1 [1].

Table 1

The share of recycling in the production of metals and the level of energy savings when using recycled materials (estimated for year 2012),%

Useful component	US	EC	Saving energy
Steel	58	42	62-74
Aluminium	36	39	95
Copper	35	32	85
Zinc	53	20	60
Lead	83	74	60

It’s important to note that in our country the share of secondary raw materials in the production of metals is still insignificant (for example, according to [2] in 2012, the share of recycling in aluminium production in Russia was only 11%). This is explained by the fact that a significant part of the amortization scrap falling into the mixed solid waste of production and consumption is irretrievably lost due to the absence of waste processing plants, as well as the lack of domestic technologies and equipment for collecting and processing of non-ferrous metal scrap, and the technological backwardness of the sub-sector in general [2-3]. One of the problems of secondary non-ferrous metallurgy is the low quality of alloys obtained from recycled materials. This is due to the fact that, as a rule, such raw materials come for processing as a mixed unsorted scrap. In particular, for aluminum, the main pollutants are iron, silicon, manganese, zinc. For example, the concentration of iron in wrought aluminum alloys should not exceed 0.5-0.8% [4]; and in 10 out of 13 groups of secondary aluminum alloys in accordance with GOST1639-2009, the content of zinc is limited by fractions of a percent (not more than 0.1-0.3%) [5]. Taking into account what has been said in our country, dilution of melts with primary aluminum remains the main method for obtaining high-quality alloys from secondary aluminum raw materials [3]. In this article, these problems and the possibilities for their solution are considered in the example of automotive scrap.

II. SOLVED TECHNOLOGICAL PROBLEMS

Automotive scrap is one of the fast growing multi-tonnage types of solid waste, which occupy an increasingly significant share in the scrap market. Disposal and landfills of such wastes due to lack of their industrial processing leads to negative environmental consequences and loss of metals. Therefore, the problems of utilization of end-of-life vehicles require increased attention [6-7]. Effective utilization of end-of-life vehicles established in many developed countries. According to the data [6], there are more than 700 factories in the world for the utilization of end-of-life vehicles, which have shredder units for fragmentation and crushing of cars (more than 300 of them in Europe). Most of materials are used as secondary source. Currently, the recycling rate in Europe averages about 85% of the mass of the car, and the utilization rate is 95%. In our country, the number of shredding plants can be counted on the fingers of one hand. In this situation, there is a unique opportunity to create in Russia a new efficient auto-recycling industry based on the best practices of developed countries and using advanced domestic developments.

In cars that are currently being recycled, from 60 to 80% of the mass is accounted for by steel knots and parts. Therefore, steel scrap is the main product of auto-recycling. At the same time, there is a tendency in the automotive industry to increase the share of light alloys (primarily aluminium) in the design of machines. For example, in cars produced by JSC AvtoVAZ up to 2010, the share of aluminum units and parts does not exceed 5% (by weight) [6]. By this time, in the cars of the world's leading automobile companies, the share of aluminium has already reached 15-20% and its subsequent growth is projected to reach 30% [8-10]. The replacement of steel assemblies with aluminium is caused by the need to reduce the mass of cars, which leads to improved dynamic performance, a significant reduction in fuel consumption and improved environmental performance. For example, according to [9], for every 10% reduction in vehicle weight, fuel savings of 5-7% can be achieved. Correspondingly, emissions of carbon dioxide and other combustion products of fuel are reduced.

The growth in the share of aluminium is accompanied by the expansion of the list of aluminium alloys used in the automotive industry. For the manufacture of parts for motors, transmission housings, etc., casting aluminium alloys are traditionally widely used (ISO 209-1: A359, A356, A361, A413, etc.). To them are added wrought alloys of aluminum (AA6060, AA6061, AA6063, AA6016, AA3003, AA5754, etc.) to create such elements of the structure as: frame of the case, carcasses of seats, trim of saloon and doors, bumpers, heat exchangers, etc. [8-10]. The aluminum scrap that is recovered as mixed fractions that contain various alloys and other materials cannot be used to produce alloys contained in these products.

Increasing the share of aluminium in car scrap requires a new approach to auto-recycling technologies. Traditionally, the separation of aluminum from a mixture of nonmetals obtained after crushing and magnetic separation (separation of the ferromagnetic fraction) is carried out at the shredder plants. In foreign practice for the extraction of non-ferrous metals from shredder residues, separation in heavy media and electrodynamic (eddy current) separation is most often used. In this case, the main useful product is aluminium scrap, used as a raw material for the production of casting alloys, mainly returned to the automotive industry. As shown in [9], taking into account the increase in the share of aluminium in cars, the volumes of secondary aluminium raw materials obtained at shredder plants begin to exceed the requirements of the industry in casting alloys. At the same time, it is impossible to obtain high-quality wrought alloys from mixed aluminium scrap. An exit from the emerging situation may be the development of auto-recycling technologies in the direction of obtaining selective concentrates of non-ferrous metals. At the same time, it seems expedient to solve three consecutive technological problems:

- separation of non-ferrous metals from the bulk of non-metallic materials after shredding and magnetic separation;
- separation of scrap of non-ferrous metals by types of alloys (aluminium, copper, zinc);
- separation of aluminium scrap by groups and grades of alloys.

III. RESULTS OF THE RESEARCH AND THEIR ANALYSIS

The possibility of solving these technological problems has been studied in recent years at the Department of Electrical Engineering and Electrotechnological Systems of the Ural Federal University during the development of electrodynamic separators with a traveling magnetic field for various applications [11]. The department has created mathematical models and methods for calculating electrodynamic separators, which differ both in the way they excite the traveling magnetic field and in the ways they feed and divert the separated materials. The prototypes of separators of various designs and capacities are made, on which experimental studies are performed and various technological tasks are tested.

At the first stage of the research, electromagnetic forces acting in the electrodynamic separator were evaluated for samples of different alloys contained in car scrap. An example of comparison of the experimental and calculated characteristics of the electrodynamic separator based on the linear induction machine (LIM) with two-sided inductor is shown in Fig. 1.

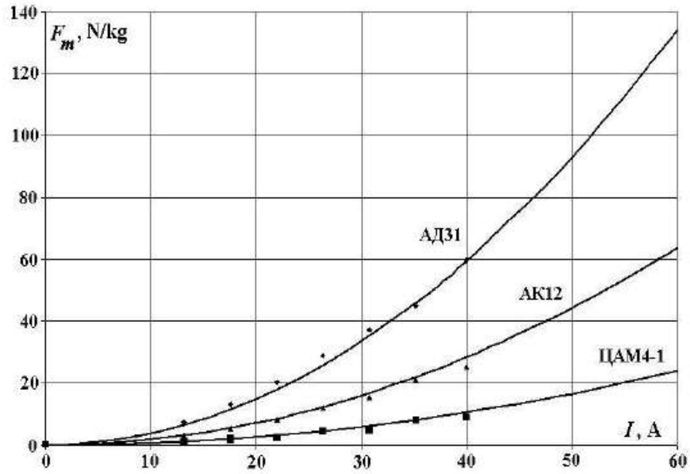

Fig. 1. The dependence of the specific electromagnetic force on the LIM current: calculated (lines) and experimental (points)

The investigated electrodynamic separator has a pole pitch of the inductor τ = 180 mm and an air gap δ = 60 mm and is a prototype of the industrial device. The characteristics were obtained for three samples of autjmotive scrap supplied by the customer enterprise (russian classification): wrought aluminium alloy АД31 (profiles from which the car's supporting structures are made), casting aluminium alloy АК12 (scrap engine) and zinc alloy ЦАМ4-1 (the sample is cut from the carburetor case). Mechanized processing after crushing and magnetic separation receives materials with a particle size of less than 60-65 mm. Therefore, metal particles ranging in size from 20 to 60 mm were used in the studies. The results shown in Fig. 1 were obtained for samples in the form of square plates with sides a = b = 40 mm and thickness d = 2-3 mm. The indicated dimensions correspond to the middle of the investigated range of size of particles.

It can be noted that the calculated and experimental dependences are in good agreement. In experiments, the currents of the LIM separator were limited by the capabilities of the research laboratory (up to 40 A). The calculations are carried out to the values of the LIM current I = 60 A, which corresponds to the current load achieved in an industrial device with forced air cooling of inductors. According to

Fig. 1 it is not difficult to see that the specific electromagnetic forces (the ratio of the electromagnetic forces to the mass of metal particles - F_m, N/kg or m/s^2), which determine the maximum possible acceleration of metal particles in the separator, differ significantly for different alloys. Studies show that, depending on the design and performance of electrodynamic separators, the specific forces required for separation are 10-20 N/kg. As can be seen in Fig. 1, at LIM currents of the investigated separator 50-60 A, such forces are achievable for all alloys. The obtained results confirm the possibility of induction sorting of non-ferrous metal alloys contained in automotive scrap.

One of the features of electrodynamic separators is the dependence of the specific electromagnetic forces on the dimensions of metal particles, as well as their shape and orientation in a traveling magnetic field. To assess this effect, experimental studies were carried out on the separator described above with a two-sided LIM when feeding the separated materials along an inclined plane. The final path deflections of the metal particles from the feed line B at the outlet of the installation (at the end of the inclined plane) were measured, depending on the distance from the input edge of the linear inductor to the initial point (L_0). For the convenience of measurements, the experiments were performed with a reduced current (17 A). Some results of such studies are shown in Fig. 2 and 3.

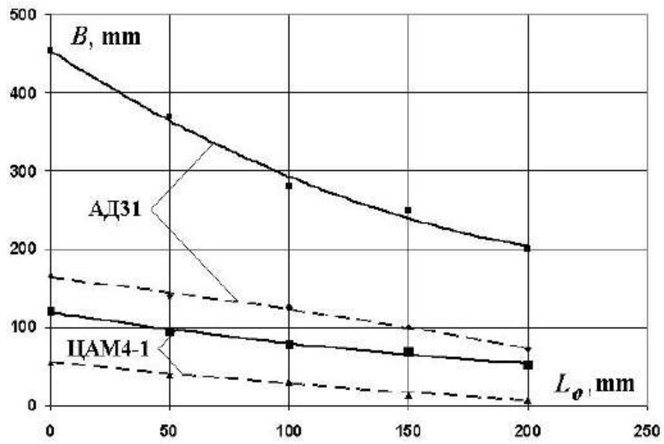

Fig. 2. Path deflections of particles of different alloys from the feed line, depending on the distance from the input edge of the inductor to the starting point: 40 × 40 mm - solid lines, 20 × 20 mm - dashed lines

From Fig. 2 that the final path deflections of the particles from the feed line decrease with decreasing their dimensions. The scatter in the deflections of particles from different alloys from the feed line when the particle size was changed from 20 to 40 mm, obtained in experiments, is shown in Fig. 2 in the form of regions (segments). It is easy to see that the segments corresponding to the alloys АД31 and ЦАМ4-1 do not intersect, which indicates the possibility of obtaining during the separation of selective concentrates of these alloys in the specified range of particle size. In the figure it can also be seen that the range of final deflection of particles increases with decreasing distance L_0, which determines the position of the material feed point on the inclined plane of the separator. In practice, the choice of the values of L_0 is limited. It depends on the departure of the end parts of the windings of the inductor and the method of feeding the separated materials. For example, for industrial realization of the investigated electrodynamic separator the distance L_0 can not be less than 100 mm.

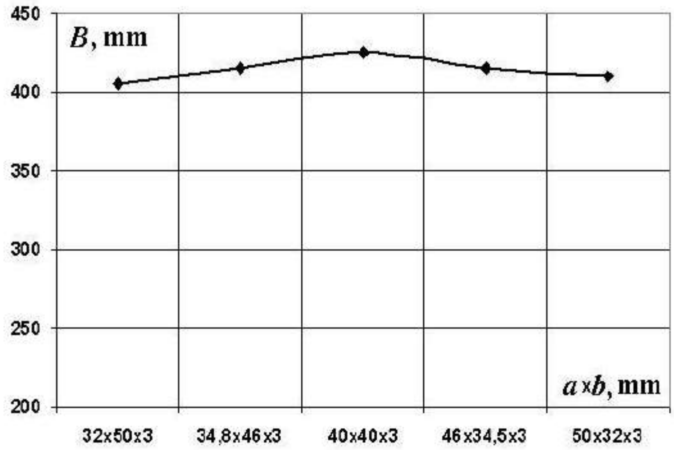

Fig. 3. Influence of the shape of metal particles and their orientation in a traveling magnetic field on the final path deflections

The shape of the non-ferrous metal particles entering the separation is a random factor, so its impact on the sorting result is difficult to assess. The studies are performed on the example of plates of rectangular shape. In Fig. 3 shows the final path deflections of the separated metal samples from the feed line when the shape of the particles changes and their orientation in the traveling magnetic field, obtained experimentally on the experimental electrodynamic separator described above. Samples of plates were cut from the deformable aluminum alloy AMг3. The plate size in the direction of motion of the traveling magnetic field is *b*, in the transverse direction - *a*. The surface area of the plates remained unchanged. It can be seen that the final path deflections of the shape of the plates from the square and the change in their orientation in the field reduce the deflections achieved in the separator, which leads to a decrease in the stock by the selectivity of the sorting. At the same time, it can be seen that for sufficiently large distortions of the particle shape, the decrease in the deviations of the particles from the feed line does not exceed 10%. Another positive factor is that the final deflections of the plates of rectangular shape depend little on their orientation in the traveling magnetic field.

IV. CONCLUSION

The analysis of the literature sources performed by the authors made it possible to identify trends in the growth of the share of aluminium in car designs and an increase in the nomenclature of used aluminium alloys, both casting and wrought. With this in mind, industrial recycling of car scrap is advisable not only to extract non-ferrous metals from shredder waste, but also to sort non-ferrous metals by types, groups and grades of alloys. The carried out theoretical and experimental studies have shown the possibility of using electrodynamic separators with a traveling magnetic field for induction sorting of automobile scrap. In the course of research, the possibility of separating non-ferrous metals from a bulk of crushed shredded waste that has undergone magnetic separation, as well as the possibility of selective separation of zinc alloys from aluminium, was confirmed. The third of the previously formulated technological problems (sorting of automobile aluminium by groups and alloy grades) is more complex and requires additional research. In particular, it is necessary to analyze ways of increasing the selectivity of induction sorting of aluminium alloys in a wide range of sizes of recoverable metal particles (ideally from 5 to 60 mm).

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