Study of Factors Affecting the Strength of Briquettes Made of Aluminum and Nickel-Containing Slags

Falah Mustafa Al- Saraireh

Department of Mechanical Engineering, Faculty of Engineering, Mutah University, Jordan
Email: f_saraireh@mutah.edu.jo

Abstract: This study investigated a technique for pressing slags containing aluminum and nickel to create briquettes using a polymer binder. It examines how the pressing pressure and the proportion of nickel to carbon in the slags affects the strength of the briquettes that are produced. Some of the issues that currently plague the metallurgical sector and environmental ecology can be resolved by employing briquette slags from the secondary processing of aluminum (slags containing aluminum). In the smelting of ferrous metals, their usage as slag thinners enables the exclusion of expensive and scarce natural raw materials like bauxites and fluorspar, which has a favorable impact on the price of steel produced. The study indicated that pressing pressures between 130 and 230 MPa can produce sufficiently strong briquettes, enabling the combined use of these wastes in the metallurgical industry. The ratio of the nickel and carbon contents in the charge significantly impacts the briquettes' strength. The nickel content that is 1.5 times greater than carbon is ideal from this vantage point.

Keywords: briquettes, metallurgical industry, solid wastes, slags containing aluminum, ferrous metals, ferrous slag.

1. Introduction

A range of industries produces solid wastes, some of which are slags from the pyro-metallurgical production of metals and non-metals [1]. Metals are extracted from ore to create slag, a glassy mixture of silicon dioxide, metal oxides, and sulfides. Slag is a secondary source of metals since it includes significant metals [2]. Processing of slags is required due to environmental concerns since depending on the source of the slag, it may potentially contain heavy and dangerous metals. It is also a rich supply of metal, which is recovered by recycling utilizing various techniques.

For the cleanup of contaminants, especially heavy metals, a variety of solutions are in use., and industrial pollution is currently a severe issue that needs to be handled to avoid negative effects [3]. Slags can be treated to recover metal, or they can be put to use for other things. Because it contains valuable materials, ferrous slag can be used in buildings. To build railroad tracks, roads, and roof shingles, some slags that are thought to be chemically inert are combined with cement [4]. Road construction uses steel slag (45%), interim storage uses 17%, internal recycling uses 14%, and fertilizer, hydraulic engineering, and cement manufacturing use 3% each [5]. In leaching facilities, copper is used as a solution to copper sulfate.

Reusing aluminum garbage is among the most significant issues that contemporary civilization is dealing with. Its large energy supply economy is the main reason for this. To produce aluminum, for example, the energy required is about 190 MJ/kg for primary aluminum production, but only 20 MJ/kg for secondary aluminum.

According to expert calculations, secondary metal liquefaction activities alone generate 5 million tons of waste annually from aluminum companies worldwide [7]. Expert opinion is that the Russian Federation [6] produces about 100,000 tons of Al-containing salt slags yearly during the production of raw aluminum and aluminum-based goods.

The production of glasses based on calcium aluminate [8] and other construction materials for civil and transportation engineering [9] are two uses for recycling products made from slag.

In the process of producing refractory materials, an isolated nonmetallic product with an alumina content greater than 80% may be needed, and aluminum hydroxide, which is extracted from salt slags, can be used to raise the molecular ratio of aluminum to chlorine in the aluminum oxychloride solution, which is subsequently used as a coagulant to purify water [10]. Ammonium hydrocarbon, which is helpful for manufacturing fertilizers, is produced by dissolving aluminum salt slags [11].

Some slags have remarkably high levels of dangerous or heavy metal content. The emission of heavy metals seriously threatens all living things. Comparatively speaking, the potential for non-ferrous slags to affect the environment is higher than that of ferrous slags [12]. Slag disposal necessitates a sizable amount of land, and because heavy metals may seep from the waste, it also poses a risk of water pollution. The contaminating effects of industrial slag leachate on soil and water sources are also connected to a variety of ailments. According to reports, consuming chromium-contaminated water frequently might lead to anemia and stomach cancer [13]. Hemochromatosis (iron buildup in tissues that harms them) is caused by a high iron intake [14]. Lead, mercury, and other dangerous heavy metals are also present in steel, zinc, copper, and tin slags.

Bauxites and fluorspar, two expensive and in-demand natural raw materials, can be excluded from the technological process by using them as slag thinner in smelting ferrous metals [15]. This has a favorable impact on the price of the steel that is produced. Large regions will be cleared and the ecology will be better off thanks to the utilization of slag from dumps [16].

By combining aluminum-containing slags with other bulk wastes, such as galvanic slags that include nickel, the range of these slags can be expanded [17]. The liquefaction of slags and the alloying of steel with nickel will benefit from using briquette raw materials derived from these wastes in ferrous metallurgy. Studying the conditions for pressing briquettes from slags containing aluminum and nickel is the goal of this study. Slags from the secondary processing of aluminum and those containing nickel are materials of various fractions based on their physical characteristics [18]. Slags ranging in particle size from 0.92 mm to 1.8 mm, as well as one of every of all four nickel-containing slag mixtures (Table 2) and combinations of slags including aluminum (Table 1), were tested.

Steelmaking applies waste products from the processing of foundry slag [19]. A lime and aluminum-based slag mixture has been created for the out-of-furnace desulfurization of steel. 60% Al_2O_3-containing slag. Open-hearth steel is desulfurized to a level of 30%; steel is desulfurized to a level of 50%. Its costs don't go over 0.6% of the price of steel at a mixture flow rate of 10 kg/t. The primary slag-forming material utilized in the production of steel in oxygen converters, open-hearth furnaces, and electric arc furnaces is waste aluminum production, which contains up to 30% Al_2O_3.[20] This shortens the lowering duration, speeds up the desulfurization of steel, and removes white slag quickly [21].

The oxidation of aluminum releases heat, which can be used to heat the slag [22], lower the melting point of the slag increase its liquid mobility under the influence of Al_2O_3, and speed up the absorption of slag lime due to an increase in slag temperature and a decrease in viscosity, which is also accompanied by an improvement in desulfurization. The scrap's melting length increases as sulfur removal conditions get better [23]. The utilization of waste from the manufacturing of secondary aluminum is particularly cost-effective since it decreases the use of other additives that create slag (for instance, bauxite).

Briquettes made from aluminum slag discharge shorten the time spent treating slag and removing it from the furnace [24].

Steel lowers the need for lime, aluminum metal lowers the need for energy, and non-resistant stabilizes the performance of desulfurization. Using these briquettes may extend the life of a ladle's slag belt lining and cut down on the number of ladle refractories you need [25].

The use of man-made waste from the secondary aluminum smelting process in the steelmaking industry as a means of recycling secondary resources is a significant reserve for improving the efficiency of metallurgical production and enabling the resolution of several environmental, economic, medical, and social problems [26].

The use of bauxites and fluorspar as slag thinners allows for the exclusion of these pricey and in-demand natural raw materials from the technical process of smelting ferrous metals. This is advantageous for the cost of steel production. Large regions will be cleared and the ecology will be better due to the utilization of slag from dumps [27].

2. Materials and methods

Samples of slag containing aluminum and slag containing nickel were collected from the waste of the National Aluminum Factories Company in Jordan Figure 1.and Figure 2.

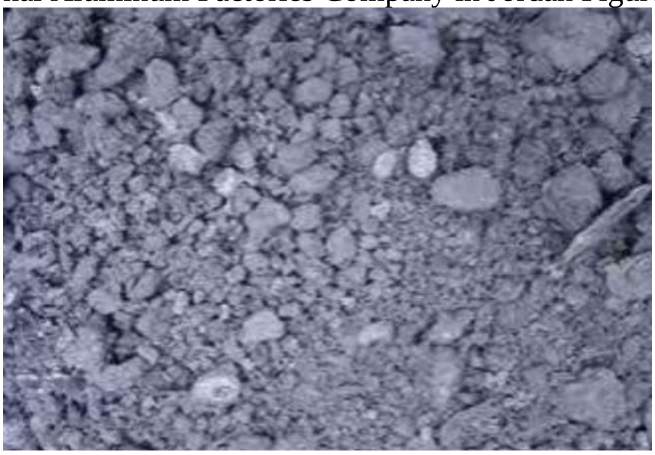

Figure .1. *Sample of slag containing aluminum.*

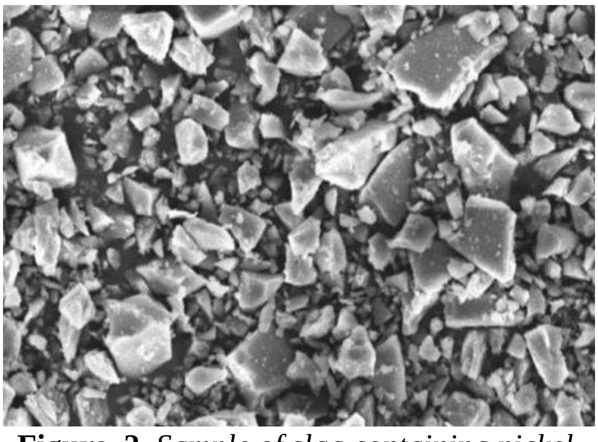

Figure. 2. *Sample of slag containing nickel.*

The range of these slags can be expanded by combining aluminum-containing slags with other bulk wastes, such as galvanic slags that include nickel. The liquefaction of slags and the alloying of steel with nickel will benefit from using briquette raw materials derived from these wastes in ferrous metallurgy [28]. Studying the conditions for pressing briquettes from slags containing aluminum and nickel is the goal of this effort. Slags from the secondary processing of aluminum and those containing nickel are materials of various fractions based on their physical characteristics [29]. Pressing was done on slags with a particle size range of 0.92 mm to 1.8 mm aluminum-containing slag was used as the analyzed charge composition (Table 1). and a combination of four different compositions of nickel-containing slags (Table 2)

The samples were analyzed by (SEM-EDX, FEL, Model: Quanta 600) device

Table 1. *Chemical composition of aluminum-containing slag*

AL	AL_2O_3	MgO	KCl	NaCl	SiO_2	S	P	Fe_2O_3	Others
11,1	57.0	5.0	0.21	3,4	7,2	0,05	0,01	4.8	11.24

Table 2. *Chemical composition of nickel-containing slag*

N0	Ni, %	Fe, %	C,%	Moisture %	Ni/C
1	8,4	10.8	41.8	19.3	0.2
2	18.6	7.5	21.2	3.4	0.89
3	21.4	7.5	13.6	9.5	1,57
4	22.2	6.1	24.8	11.0	0.89

A polymeric binder solution was utilized to produce fracture-resistant briquettes [30], which strengthen interparticle bonding. Heating the charge in the mixer at a temperature of 100°C for 30 minutes sped up the polymerization process. It eliminated extra moisture from the briquettes YKHD 650 hydraulic aluminum briquetting press with 55 kwt power was used for the pressing (figure 3.).

Figure. 3. *YKHD 650 hydraulic aluminum briquetting press*

. Specimens with a 20 mm diameter and a 15–20 mm height were created throughout the deformation process (Figure 4).

Figure 4. *Aluminum slag briquette.*

Once the briquettes were pressed, they were dried for 40 minutes at 200°C in an oven to speed up the fastener's polymerization and remove any moisture.

3. Results and discussion

Pressures of 86, 130, 180, and 230 MPa were used during pressing. At a temperature of 150°C, the resulting briquettes were dried to a consistent weight. The compressive strength of the briquettes was measured using the LT-60-VFD (Forney) universal testing machine (figure 5) and the axial compression method by ISO 1924-2:2008 to measure the compression stress for specimens.

Figure. 5. *LT-60-VFD (Forney) universal testing machine.*

As a consequence of the measurements, Fig. 6 illustrates how the briquette strength depends on the pressing pressure.

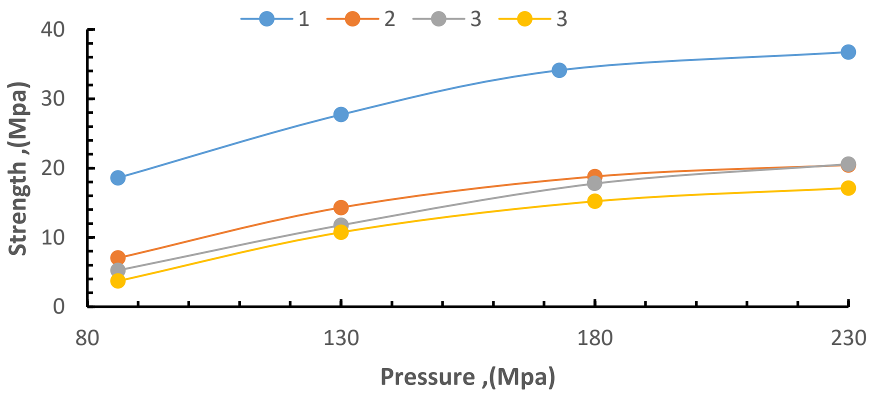

Figure 6. *Dependence of the strength of the briquette on the pressure of pressing for different compositions:1, 2, 3. 4 - composition of slags by the table. 2*

Figure 7 illustrates how the briquettes' strength grows with increased pressure. So, from 8.5 MPa (compression pressure 86 MPa) to 19 MPa, the strength of briquettes made from slag composition 1 increased (compression pressure 230 MPa). Slag briquettes with compositions 2 and 4 have slightly greater strength values. Briquettes made from slag composition 3 had the largest improvement in strength, going from 19.8 MPa (compression pressure of 86 MPa) to 33

MPa (compression pressure of 230 MPa). The fact that there is such a big difference in strength values can be clarified by the observation that the carbon content in the slag with composition 3 is quite low and the nickel content is fairly high.

Therefore, the ratio of the quantity of nickel to the amount of carbon (Ni/C) contained in the slag was computed to assess the extent of influence of the concentration of these chemical elements on the strength of the resulting briquettes (Table 2). Based on the results, a plot showing the strength of the briquette's dependence on the Ni/C ratio in slags of compositions 1-4 at various pressing pressures was created, as seen in Fig. 7. This demonstrates that when the amount of nickel grows. The carbon concentration in the charge composition decreases, and the briquettes' strength increases as well. The range of Ni/C values is where the curve shows the most growth. As demonstrated in Fig. 7, the strength of the briquettes increases as the nickel content and carbon percentage in the composition of the charge decrease. The Ni/C ratio ranges from 0.9 to 1.6, where the curve is seen to rise the fastest. Briquettes with a Ni/C ratio of 159 had the highest strength of 33 MPa.

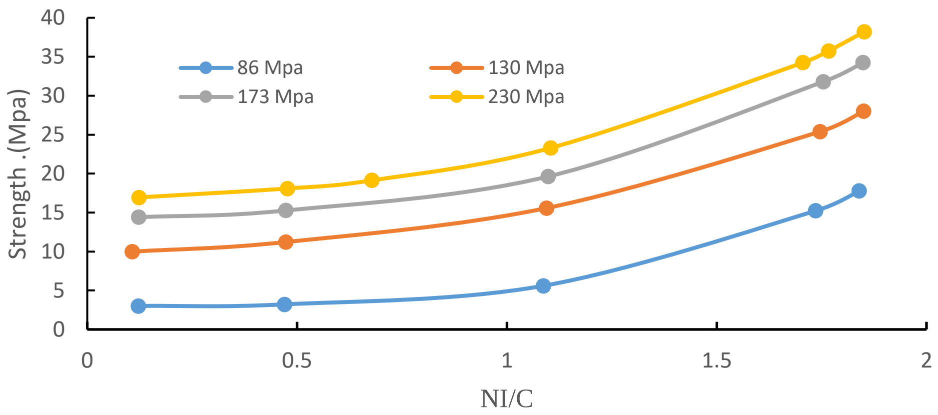

Figure 7. *Dependence of the briquette strength on the Ni/C ratio in slags at different pressing pressures*

pressing pressures equal to 80, 130, 180, and 230 MPa, respectively. Thus, the quantity of nickel and carbon in the charge significantly impacts the joint briquetting of aluminum- and nickel-containing slags. The measurements were carried out to determine the briquette strength's dependency on pressing force at various binder concentrations, as seen in Fig.8. Binder content of 10, 12, and 20% in the slag combination.

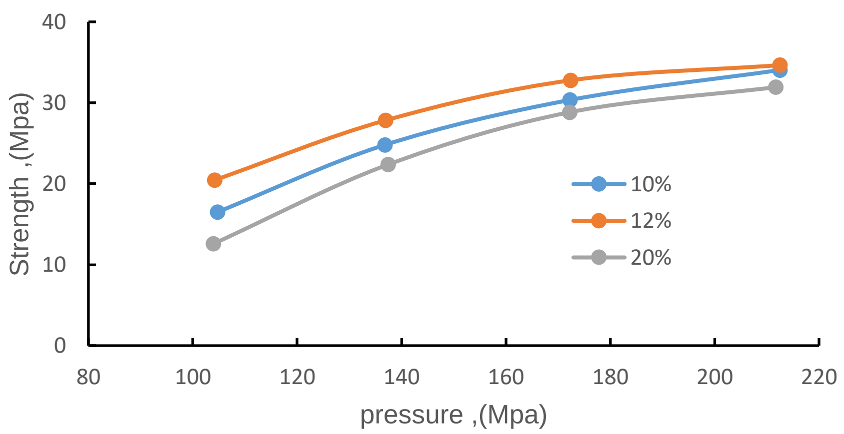

Figure 8. *Dependence of the strength of the briquette on the pressure of pressing for different binder concentrations.*

From (Figure 8). The strength of the briquettes decreased with an increase in binder percentage to 20%. This is because the binder intensely flows out of the briquette through the tool's gaps when there is a high binder concentration and increased pressing forces. The result of this is a decline in the briquette's strength due to a drop in the percentage of binder.

Consequently, fig.8 (20% binder) shows a notable drop in the amount of briquette binder following pressing, which subsequently causes a fall in the binder content of the briquette.

4. Conclusions

1. By incorporating nickel-containing slags into the secondary aluminum processing slags, it is possible to produce sufficiently robust briquettes at pressing pressures between 130 and 230 MPa, allowing for the joint use of these wastes in the metallurgical industry.
2. The strength of the briquettes is substantially influenced by the charge's ratio of nickel and carbon content. From this perspective, the nickel concentration that is 1.5 times higher than carbon is the most ideal.
3. The strength of the briquettes decreases when the percentage of binder in the briquette after pressing is increased to 20% in the slag mixture.

Since the use of slag as a waste material is no longer feasible for environmental and economic reasons, a study of a new utilization for nickel smelting slags in the production of synthetic ore may be of great interest. Both of these considerations are important for future developments in the utilization of industrial slags and were strongly influential in the choice of high-aluminum and high-nickel slags as raw materials for the present study. there were some limitations during the study such as getting a briquetting pressing machine, and getting slags from different places.

References

1. Li Y, et al., Current status of the technology for utilizing difficult-to-treat dust and sludge produced from the steel industry. Journal of Cleaner Production. 2022 Jun 28:132909. http://dx.doi.org/10.1016/j.jclepro.2022.132909 .
2. Mikoda B, et al., Bacterial leaching of critical metal values from Polish copper metallurgical slags using Acidithiobacillus thiooxidans. Journal of environmental management. 2019 Apr 15; 236:436-45. https://doi.org/10.1016/j.jenvman.2019.02.032 .
3. Vardhan KH, et al. A review on heavy metal pollution, toxicity, and remedial measures: Current trends and future perspectives. Journal of Molecular Liquids. 2019 Sep 15;290:111197. https://doi.org/10.1016/j.molliq.2019.111197 .
4. Guo J, et al. Steel slag in China: Treatment, recycling, and management. Waste management. 2018 Aug 1;78:318-30. https://doi.org/10.1016/j.wasman.2018.04.045 .
5. Hussain A,and Hussaini SK. Use of steel slag as railway ballast: A review. Transportation Geotechnics. 2022 May 10:100779. https://doi.org/10.1016/j.trgeo.2022.100779 .
6. Yang J, et al. Pyrometallurgical processing of ferrous slag “co-product” zero waste full utilization: A critical review. Resources, Conservation and Recycling. 2022 Mar 1;178:106021. http://dx.doi.org/10.1520/C0071-12R18 .
7. Mollo VM. Evaluation of Heavy Metal Pollution and Its Ecological Risk in Water from the Sasolburg Region. University of Johannesburg (South Africa); 2021.

8. Hua NP, et al, Regional analysis of aluminum and steel flows into the American automotive industry. Journal of Industrial Ecology. 2022 Mar 24. https://doi.org/10.1111/jiec.13268 .
9. Abramowicz A, et al. Environmental management and landscape transformation on self-heating coal-waste dumps in the Upper Silesian Coal Basin. Land. 2020 Dec 29;10(1):23. https://doi.org/10.3390/land10010023 .
10. Gao W, et al, Investigation into the semi-dynamic leaching characteristics of arsenic and antimony from solidified/stabilized tailings using metallurgical slag-based binders. Journal of hazardous materials. 2020 Jan 5;381:120992. https://doi.org/10.1016/j.jhazmat.2019.120992 .
11. Katarzyna, et al. Value-added strategies for the sustainable handling, disposal, or value-added use of copper smelter and refinery wastes. Journal of Hazardous Materials, 2021, 403: 123602. https://doi.org/10.1016/j.jhazmat.2020.123602.
12. Brückner L, et al. Industrial recycling of lithium-ion batteries—A critical review of metallurgical process routes. Metals. 2020 Aug 18;10(8):1107. https://doi.org/10.3390/met10081107 .
13. Zhang X, et al, the potential utilization of slag generated from iron-and steelmaking industries: a review. Environmental geochemistry and health. 2020 May;42(5):1321-34.
14. Kudyba A, et al. Aluminothermic reduction of manganese oxide from selected MnO-containing slags. Materials. 2021 Jan 13;14(2):356. https://doi.org/10.3390/ma14020356.
15. Brough D, and Jouhara H. The aluminum industry: A review on state-of-the-art technologies, environmental impacts and possibilities for waste heat recovery. International Journal of Thermofluids. 2020 Feb 1;1:100007. https://doi.org/10.1016/j.ijft.2019.100007 .
16. Chen J, et al. Application of iron and steel slags in mitigating greenhouse gas emissions: A review. Science of The Total Environment. 2022 Jul 6:157041. https://doi.org/10.1016/j.scitotenv.2022.157041 .
17. Daehn KE, et al. Finding the most efficient way to remove residual copper from steel scrap. Metallurgical and Materials Transactions B. 2019 Jun;50(3):1225-40. https://doi.org/10.1007/s11663-019-01537-9 .
18. Varanasi SS, et al.Recycling ladle furnace slag as flux in steelmaking: A review. Journal of Sustainable Metallurgy. 2019 Dec;5(4):449-62. https://doi.org/10.1007/s40831-019-00243-9 .
19. Korostelev AA, et al. Increase in EAF lining life with the use of hot-briquetted iron in a charge. Refractories and Industrial Ceramics. 2018 Jul;59(2):107-14.
20. Daehn K, et al. Innovations to decarbonize materials industries. Nature Reviews Materials. 2022 Apr;7(4):275-94. http://dx.doi.org/10.1038/s41578-021-00376-y .
21. Song Q, et al. Use of steel slag as sustainable construction materials: A review of accelerated carbonation treatment. Resources, Conservation And Recycling. 2021 Oct 1;173:105740. http://dx.doi.org/10.1016/j.resconrec.2021.105740 .
22. Tsakiridis, P. E. Aluminium salt slag characterization and utilization–A review. Journal of hazardous materials, 2012, 217: 1-10. http://dx.doi.org/10.1016/j.jhazmat.2012.03.052 .
23. LI, Yun, et al. Cleaner extraction of lead from complex lead-containing wastes by reductive sulfur-fixing smelting with low SO2 emission. Minerals, 2019, 9.2: 119. https://doi.org/10.3390/min9020119.
24. Dippenaar, R. Industrial uses of slag (the use and re-use of iron and steelmaking slags). Ironmaking & steelmaking, 2005, 32.1: 35-46. http://dx.doi.org/10.1179/174328105X15805.

25. ROY, S. K. C., et al. Development of Siliceous Slinging Material for Ladle Lining. Transactions of the Indian Ceramic Society, 1982, 41.2: 40-44.
26. Izydorczyk Grzegorz, et al. Potential environmental pollution from copper metallurgy and methods of management. Environmental Research, 2021, 197: 111050. https://doi.org/10.1016/j.envres.2021.111050.
27. Piatak, et al. Characteristics and environmental aspects of slag: A review. Applied Geochemistry, 2015, 57: 236-266. http://dx.doi.org/10.1016/j.apgeochem.2014.04.009.
28. Ferigita, et al. Corrosion behavior of new oxo-pyrimidine derivatives on mild steel in acidic media: Experimental, surface characterization, theoretical, and Monte Carlo studies. Applied Surface Science Advances, 2022, 7: 100200. https://doi.org/10.1016/j.apsadv.2021.100200.
29. Shen, et al. An overview of recovery of metals from slags. Waste management, 2003, 23.10: 933-949. https://doi.org/10.1016/s0956-053x(02)00164-2.
30. Zhang, et al. Review of briquette binders and briquetting mechanism. Renewable and Sustainable Energy Reviews, 2018, 82: 477-487. http://dx.doi.org/10.1016/j.rser.2017.09.072.