CHARGE AND BRIQUETTES PROPERTIES FOR THE PRODUCTION OF ALUMINUM-SILICON ALLOYS

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ABSTRACT

The work is devoted to the study of briquetting charge for the production of aluminum-silicon alloys especially to finding ways of partial or complete replacement of traditional binder lignosulfonate by wastes of milling industry. In industrial conditions and in laboratories of NMetAU a series of experiments were carried out to find out how amount, composition and condition of binder influence the mechanical properties as well as porosity of briquettes.

KEYWORDS: *briquetting, aluminum-silicon alloys, lignosulfonate, wastes of milling industry*

Introduction

Preparation of charge materials before feeding into the furnace is one of the most important technological operations. Properties of agglomerated charge will further determine the course of the reduction process. Briquetting small fraction of materials using binders is the most simple, affordable and low-cost way of agglomeration of valuable ore and mineral raw materials, as well as man-made waste, which in their aggregate state are unsuitable for direct use in production processes and devices metallurgical processes. Such technology allows producing durable pieces (briquettes) of identical size, shape, weight and composition which meets the requirements of the technological process assuming the use of [1, 2].

Binders are the determining factor in the creation of briquetting technology. Physicochemical and adhesive properties of binders determine the choice of briquetting process parameters and mechanical strength of briquettes. In addition to ensuring the strength of briquettes, the choice of binder is determined by its availability, the lack of a negative impact on the course of the process and the impurities that can degrade the quality of the final product [3].

However, not all types of binders are suitable for the creation of briquettes for the production of aluminum-silicon alloys. Sulfite waste liquor and lignosulfonate are the most widely used binders in this technology. This work is aimed at finding the possibility of replacing part of an expensive lignosulfonate by wastes of milling industry.

Characteristics of raw materials

Studies on briquetting were carried out under industrial conditions and in laboratories of NMetAU. The samples of the initial components, the initial charge and ready dry briquettes were taken in sufficient quantity for the research.

The components of the briquetted charge were kaolin, alumina, gas-coal. As a binder additive for the charge the lignosulfonate (based variant) and wastes of milling industry – third grade meal and brans were used.

Physical and chemical properties of the used charge components of the based version are shown in Table 1.

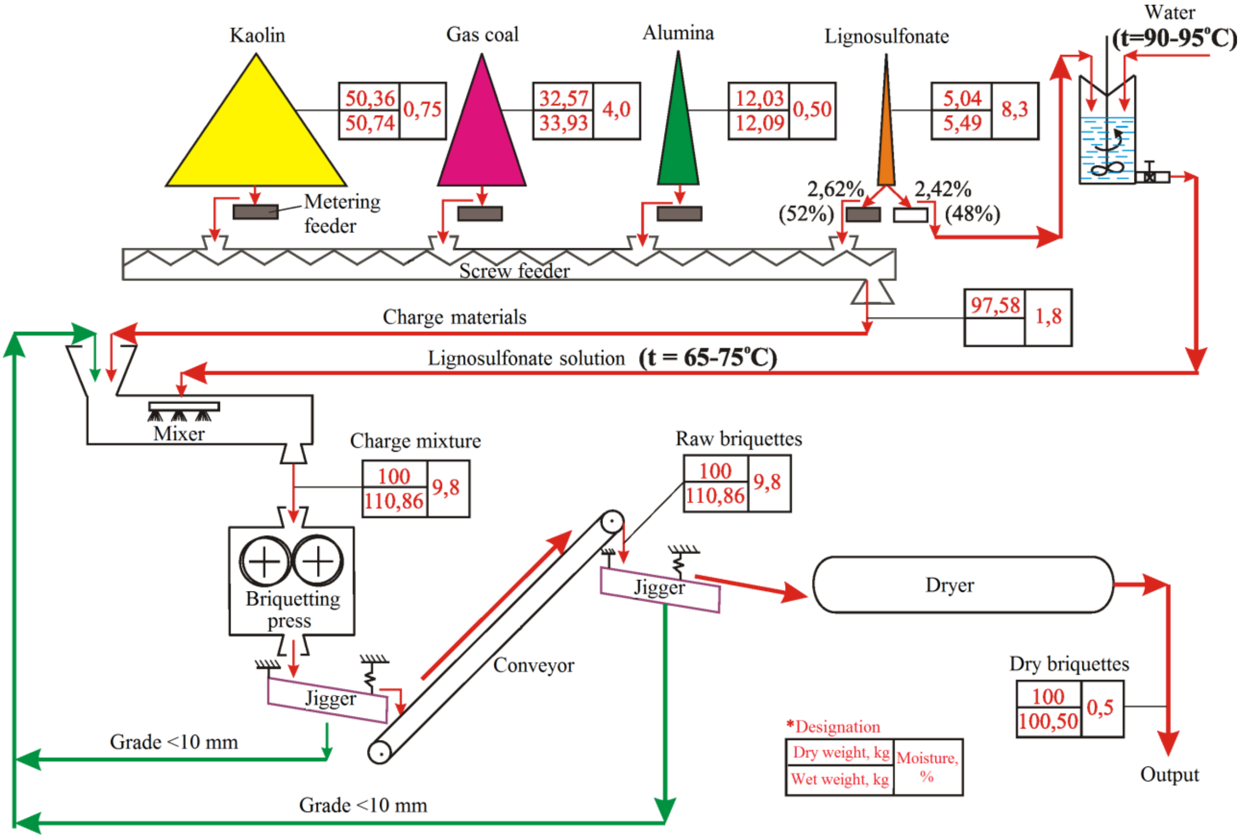
Table 1: Physical and chemical properties of the charge materials

Material		Weight ratio of the moisture, %	Weight ratio, %									
			SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	Na_2O	LOI	C original (in LOI)	V^r (in LOI)	A^C
Kaolin	mid	0.75	42.72	39.57	0.82	0.90	0.68	–	14.47	–	–	–
	min–max	0.60–0.91	40.26–45.87	37.83-42.47	0.59-1.02	0.85-0.95	0.56-0.85	–	14.23-14.34	–	–	–
Alumina	mid	0.50	0.041	96.74	0.11	–	–	0.53	2.66	–	–	–
	min–max	0.43–0.72	0.02–0.068	95.07-98.6	0.014-0.20	–	–	0.45-0.60	0.9-4.42	–	–	–
Gas-coal	mid	4.0 hydrated	–	–	–	–	–	–	96.47	54.66	37.96	7.03
	min–max	3.42–4.50	–	–	–	–	–	–	94.7-97.9	51.83-57.42	31.46-39.0	4.55–9.51
Gas-coal ash	mid	–	36.7	32.1	14.7	0.72	14.5	–	–	–	–	–
	min–max	–	34.0–39.5	12.0–42.2	8.7–15.8	0.53–1.1	5.9–21.0	–	–	–	–	–
Ligno-sulfonate	mid	8.3	–	–	–	–	7.1	–	–	–	63.7	14.2
	min–max	4.90–9.40	–	–	–	–	6.4–8.0	–	–	–	–	13.7–15.1

Dosing of lignosulfonate was carried out into the charge in the dry form 52% (relative) and as a solution 48% (relative). The density of the solution was 1.12-1.20 g/cm^3 with a solution temperature of 60-80°C. Contents of the components in the charge (excluding the binder additives) were calculated from the chemical composition of the components which insure of receiving the alloy (Silumin) containing 38-40% silica and 60–62% alumina. Carbonaceous reducing agent injected into the charge with the small (1–1.5% relative) lack for guarantee of the stoichiometric reactions of oxygen selection from the SiO_2 and Al_2O_3 compounds.

All trails on alternative binder additives were carried out at a constant ratio of kaolin, gas-coal and alumina.

Technological flowsheet and composition of the charge base version are shown in Figure 1.



*The calculation was performed for 100 kg of dry charge, excluding irretrievable losses of the charge materials.

Figure 1: Technological flowsheet of briquetting area

Chemical composition and physical-mechanical properties of the initial charge shown in table 2 and table 3.

Table 2: Chemical composition of the initial charge and briquettes

Name	Weight ratio, %												
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	P_2O_5	S	LOI	CO_2 in LOI	$C_{orig.}$ in LOI
Sample #1 (initial charge)	21.04	29.38	0.71	1.43	0.54	0.20	1.45	0.46	0.034	0.938	44.19	0.56	29.30
Sample #2 (trade briquette)	20.82	29.73	0.71	1.29	0.54	0.17	1.40	0.42	0.034	0.887	44.55	0.54	29.42

Table 3: Physical and mechanical properties of the initial charge and briquettes

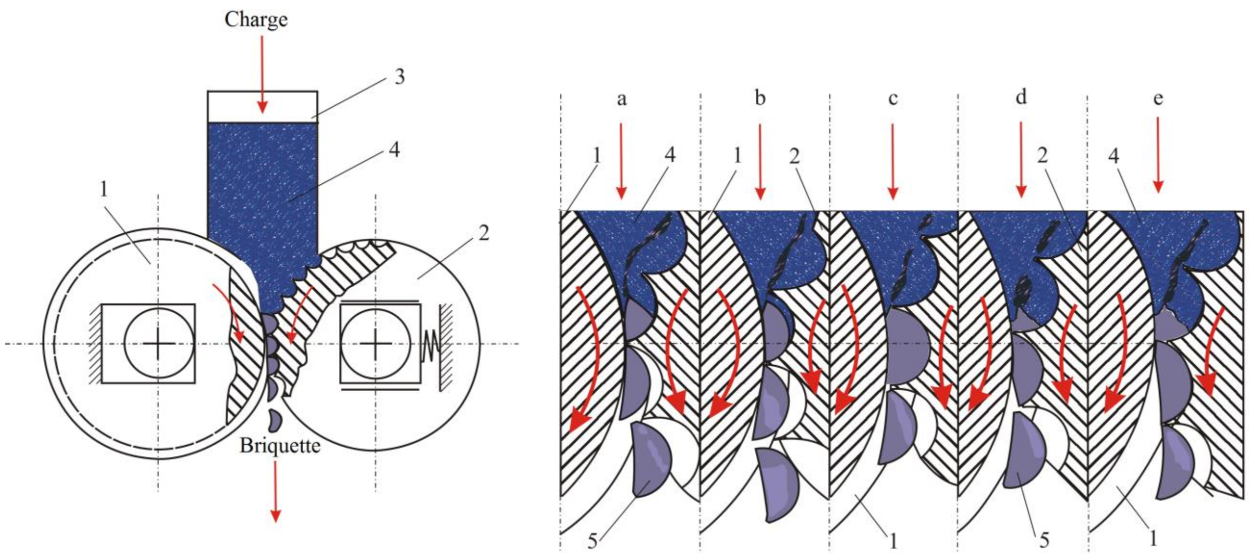
Name	Moisture weight ratio, %	Bulk density, kg/m^3·10^3	True density, kg/m^3·10^3	Porosity, %	Dropping, times	Compressive strength, kg/briquette	Resistance, %				Moisture steam resistance om fraction more than 5 mm
							The impact on the fraction of more than 5 mm	Crushing in fractions more than 0.5 mm and less than 5 mm	Abrasion on fraction 5 mm		
Sample #1 (initial charge)	2.60	0.918–1.11	1.93	–	–	–	–	–	–	–	
Sample #2:											
Wet briquette	9.80	1 briquette 75.2–80.1 g	-	–	>15	15.0	–	–	–	–	
Trade briquette	0.50	1 briquette 69.2–-74.0 g	1.96	28.1	>15	140	64.5	23.1	12.4	95.4	

Research of briquetting process using various binder additives

Briquetting of the complex charge was carried out on the press, which has toothed channeled shape of the working surface of the rollers.

Figure 2 illustrates a method of briquetting by grinder rollers. Two rollers with alternating toothed combs and channels on them, the distance between which is calculates in the way that the pass in 1-2 mm arises between them, rotating at the same peripheral speed. Material intended for briquetting is fed on top of the rollers, which suck in this material into the slot where the material is compacted and formed into briquettes.

Forces generated during compaction and molding transmitted to the rollers and the roller press support frame. There are toothed combs and channels on the surfaces of the rollers which define the form of briquettes.



1 –fixed roller; 2 - movable roller; 3 - charge bunker;
4 - briquetted charge; 5 - briquette

Figure 2: The principle of the briquetting and phase of briquette formation on a roller press

Briquetting process characterized by three phases, namely:

- Feeding of the material between the rollers;
- Compaction and forming of the briquettes;
- Removal of the briquettes.

The behavior of the material between the rollers at retraction depends on the diameter and surface configuration of the rollers, physical and kinetic properties of the briquetted material, the circumferential rotation speed of the rollers, the initial pressure during the feeding of the material between the rollers.

The friction between the rollers and the material depends on the circumferential rollers speed and determined by the suck in angle, on which the suction speed of the material between the rollers depends.

Uniform loading and suck into the briquetted gap ensures proper seal (thickening) of the material. To improve the feeding conditions and sucking of the material between the rollers, a mechanical device should be used for prepressing of the feed materials, which is very important for bulk materials with a low bulk density and high porosity.

Phase of material sealing between the rollers starts with the sucking of the material between the rollers and ends by the forming of briquettes. Briquette forming process is illustrated in Fig. 2. Forming of briquettes begins from the moment when the bottom edges of the form are converged and formed briquette cut down – “a”.

Then the mold is opened from the bottom, and in the bottom part the formation of the briquette continues - "b".

In “b” and “c’ mold position sliding of the briquettes has not been observed, but briquetted material is sucked down into the soft core of the briquette.

Described phenomenon contributes to the appearance of cracks on the bottom edges of the briquette. These cracks in the fitted briquetting process are the only one drawback of the briquettes. Briquette starts to slip out of the mold in the position “a”, and in the position “e” falls from the mold.

At high pressures certain materials tend to stick to the walls of the mold that greatly hinders unloading briquettes from the mold.

Adhesion may be due to capillary phenomena, surface tension, electrostatic or magnetic forces, local material melts during the hot briquetting and other factors. Briquettes unloading from the mold can be improved by the choice of mold form, its size, depending on the briquetted material properties. Suitable chosen form causes slipping of the briquette out from the mold that is caused by the action of the vertical force component during briquetting. The profiled surfaces of the rollers, i.e. the size and type of the mold is essential for the quality of briquettes, the nature of the load press, as well as the strength of briquetting devices.

It was already mentioned about the influence of shape on the process of condensation and mold of the briquettes. Type of mold closing influences the size and quality of the briquettes on the perimeter of the roller. The denser the mold closed, the higher quality of the briquettes. During the smallest curve of the surface and increasing the roller diameter the allowable size of briquettes increases around the perimeter of the roller.

Irregular shape may hinder unloading of the briquettes. The remainder of the unloaded briquettes causes significant overload for the presses. With the passage of profiles filled with compressed material, the pressure in the gap of briquetting increases very quickly. The reason of the overload of the rollers may be accidental caught with the material metal objects or stones received for briquetting. Overload of the rollers can also be due to “dead” surfaces between neighbor molds.

To ensure continuous operation of the roller press modern presses are equipped with at least one movable roller pressing with the help of elastic device, such as springs system or hydraulic cylinders operating with a gas accumulator. A significant advantage of roller presses is an effective use of briquetting equipment, low frictional force of the material on the wall of the mold in the process of sealing and forming of briquettes.

The relevant form can have a beneficial effect on the durability of the briquetting devices. Teardrop shape is very suitable for briquetting since radially extending upper edge of the mold captures and suck material without slipping, and the bottom flat part of the mold is too low frictional resistance during the unloading of the briquettes.

Duration of operation of the briquetting equipment depends on the circumferential speed of the rollers. In order to eliminate slippage between the briquetted materials and mold the roll speed should be high.

Feeding of the press with briquetted material under pressure can provide operation without slipping at the increased circumferential speed.

To determine the possibility of dissolution and a method of supplying new binder additives, the possibility of obtaining free-running binding solutions was investigated which contain different amounts of low-grade flour, bran and lignosulfonate providing technological strength of raw briquettes and compliance with requirements of ferroalloy production on chemical composition and physical and mechanical properties of dry briquettes. Binder additives were dissolved in water according to developed technology for lignosulfonate (base variant) in various quantities and ratios by dry weight. These studies were necessitated by the high cost and scarcity of lignosulfonate. It should also be noted that the lignosulfonate ash contains CaO. This compound is highly undesirable in the smelting of the silica-aluminum because it can lead to the emergence of low-melting eutectic in the system CaO-SiO_2-Al_2O_3 from which it is not possible to reduce Si and Al. At the same time the technical and economic indicators decrease.

Analyzing the results of the studies, it is necessary to note that the free-running solution with the use of flour as a binder additive is observed upon administration of 8-9% by dry weight. Dissolution of more than 10% four by steaming method leads to receiving of the paste solution that makes it difficult to feed it into the charge and effective distribution in the charge during its mixing. Low content of binder additives in the solution does not allow inputting into the charge 4-5% of the flour without waterlogging of the charge before briquetting. Moisture content of the charge should be 9.5-9.8%, as waterlogging of the charge lead to the sticking of the briquettes in cells of the briquetting presses, receiving of the plastic briquettes that stick together, lose their shape during transport causing insurmountable difficulties during heat treatment.

Therefore, the briquetted process of the charge should exclude the input of solution in quantities that are greater than the optimum weight fraction of the moisture in the charge, which is 9.5-9.8% for the developed technology. At such moisture 0.8 - 1.4% of binder additives can be input into the charge (flour, bran) depending on the mass fraction of the moisture in the initial charge components. Adding of the small amounts of lignosulfonate to the flour and bran makes it possible to improve the fluidity of the solution that will increase the solids content of the components in solution up to 10-12%, including 1.5-2.0% of lignosulfonate.

For all experiments, solutions were prepared similarly to the industrial one - by method of steaming the binder additives with water at 90-95°C temperature and extensive mixing.

In the first series of experiments solutions in which the solid phase was 8% were obtained, that ensure the input into the charge from 0.8 to 1.4% of the binder additive. Such an amount of binder additives (flour, bran) in the charge at given physical and chemical properties of the briquetted charge did not provide sufficient strength of wet and dry briquettes.

In the second series of the experiments, in order to increase the mechanical strength of wet and dry briquettes, the binder additives were input into the charge in dry form and as a solution, bringing the content of the binder additive on the solid weight for 3.4 and 5%. In this case, the weight fraction of moisture in the charge before the briquetting was optimal and amounted to 9.5–9.8%.

In the third series of experiments, binding additives were uploaded into the charge in a dry form. Then the moisturization of the charge till optimum was carried out. In this case, the optimum moisture content educed a little and amounted to 9,2–9,4%. The amount of binder additives in the charge and the type of its feed are given in Table 4.

Table 4: Mechanical characteristics of dry briquettes using various binder additives

The route of administration of the binder additives	Name of indicators	Initial variant	Trails types*					
			1	2	3	4	5	6
Feed of the additives binder in solution	Mass fraction in briquette (dry weight) %:							
	flour	-	0.58	1.3	0.65	0.77	-	-
	bran	-	0.30	-	-	-	1.47	1.18
	lignosulfonate	5.05	5.25	-	0.65	0.53	-	0.29
	Total	**5.05**	**6.13**	**1.30**	**1.30**	**1.30**	**1.47**	**1.47**
	The strength of dry briquettes, kg/briquette:							
	cold one	211	470	507	598	1391	292	270
	hot one	78	29	20	23	30	201	58
Feed of the additive binder in solution 50% in dry form 50%	Mass fraction in briquette (dry weight) %:							
	flour	-	-	10.4	9.95	0.45	-	-
	bran			-	-	-	9.09	1.4
	lignosulfonate			-	0.45	9.95	-	9.3
	Total	**-**	**-**	**10.4**	**10.4**	**10.4**	**9.09**	**10.7**
	The strength of dry briquettes, kg/briquette:							
	cold one	-	-	378	607	170	393	201
	hot one	-	-	203	161	162	92	61
Feed of the additive binder in dry form	Mass fraction in briquette (dry weight) %:							
	flour	-	-	9.09	16.6	8.3		
	bran						8.3	13.3
	lignosulfonate					8.3	8.3	6.7
	Total	**-**	**-**	**9.09**	**16.6**	**16.3**	**16.6**	**20.0**
	The strength of dry briquettes, kg/briquette:							
	cold one	-	-	632	1493	281	1028	500
	hot one	-	-	241	389	409	181	67

* For all experiments, the content of the charge materials corresponds to industrial one, given in technological scheme

The density of the solution with the use of lignosulfonate (base variant) was 1.18–1.20 $kg/m^3 \cdot 10^3$. Density of solutions with the use of flour and bran lower was around 0.95–1.05 $kg/m^3 \cdot 10^3$. The charge in the laboratory conditions was mixed extensively and the briquettes were formed in special molds under the pressure with 40 mm diameter and 15 mm height. Then all produced briquettes were dried under industrial conditions in a furnace according to the technological regime. Heat treatment of the briquettes is given in table 5.

Table 5: Regime of heat treatment of the experienced briquettes

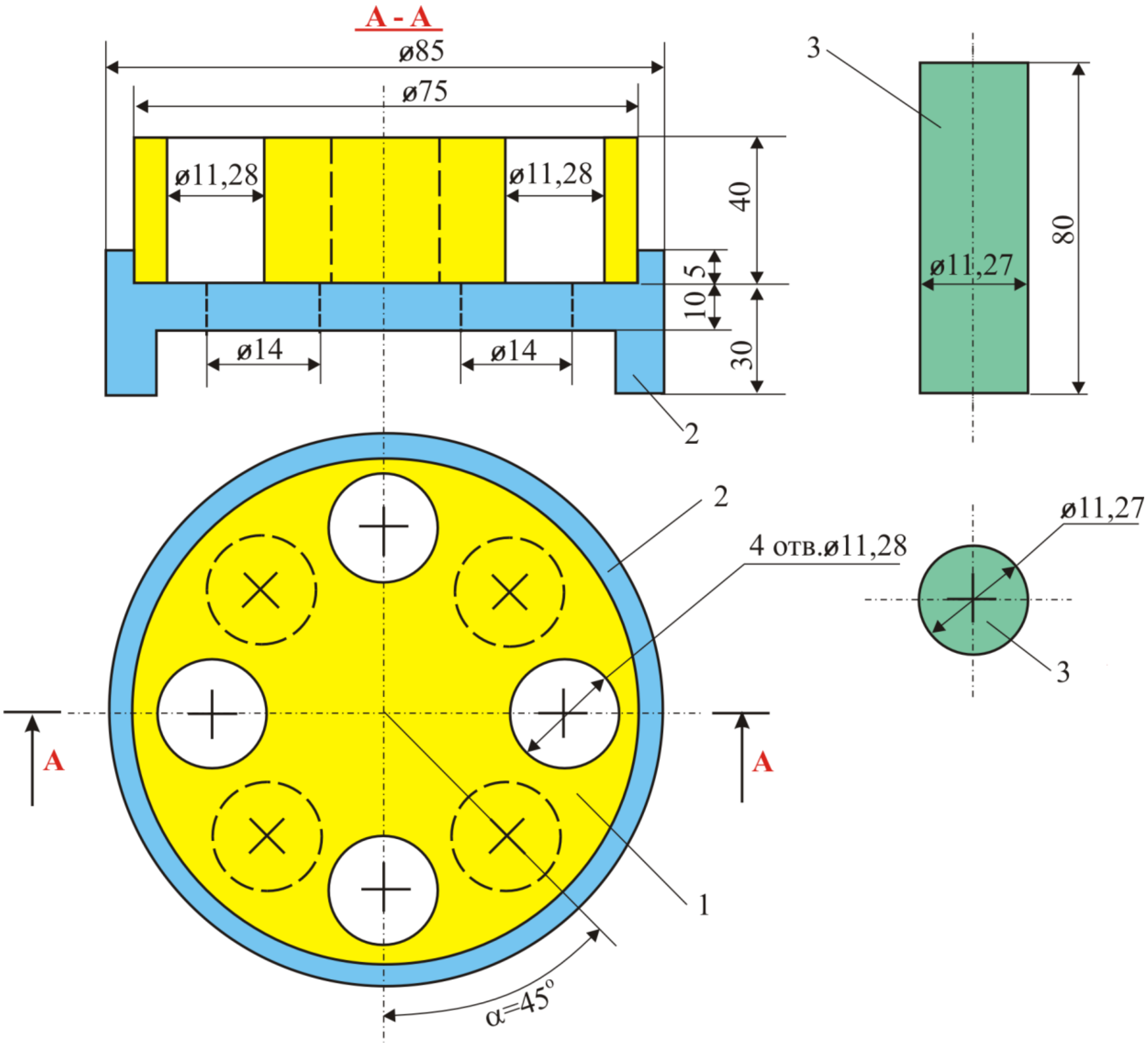
Inicator	Zones of drying unit															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Actual temperature in zones, °C	235	190	110	240	240	250	250	240	235	200	190	160	60	35	35	40

The heat treatment time was 1 hour and 35 minutes at unit capacity of 4.4–4.5t/h.

After drying, the trailed briquettes were studied on strength in cold and hot conditions (see Table 4). Analyzing this figure, it can be noted that the flour as the binder additive can effectively be used in briquetting process.

Experiments (see Table 4) with a high content of binder additives were designed to study the effect of physical and mechanical properties of the charge on the roller presses operation.

Flowability, adhesion, plastic strength predetermines the speed of displacement of the gas phase from the powder blend layer during the continuous rolling, i.e. briquetting. In order to prove the effect of the gas phase on the properties of the molded material, and to determine the acceptable range of rolling speed for fine-grained charge, the studies on laboratory briquetting device were carried out, as shown in Fig. 3. Briquetting was performed with molding force between 300 and 1000 kg/cm^3 with a different speed of the punch.

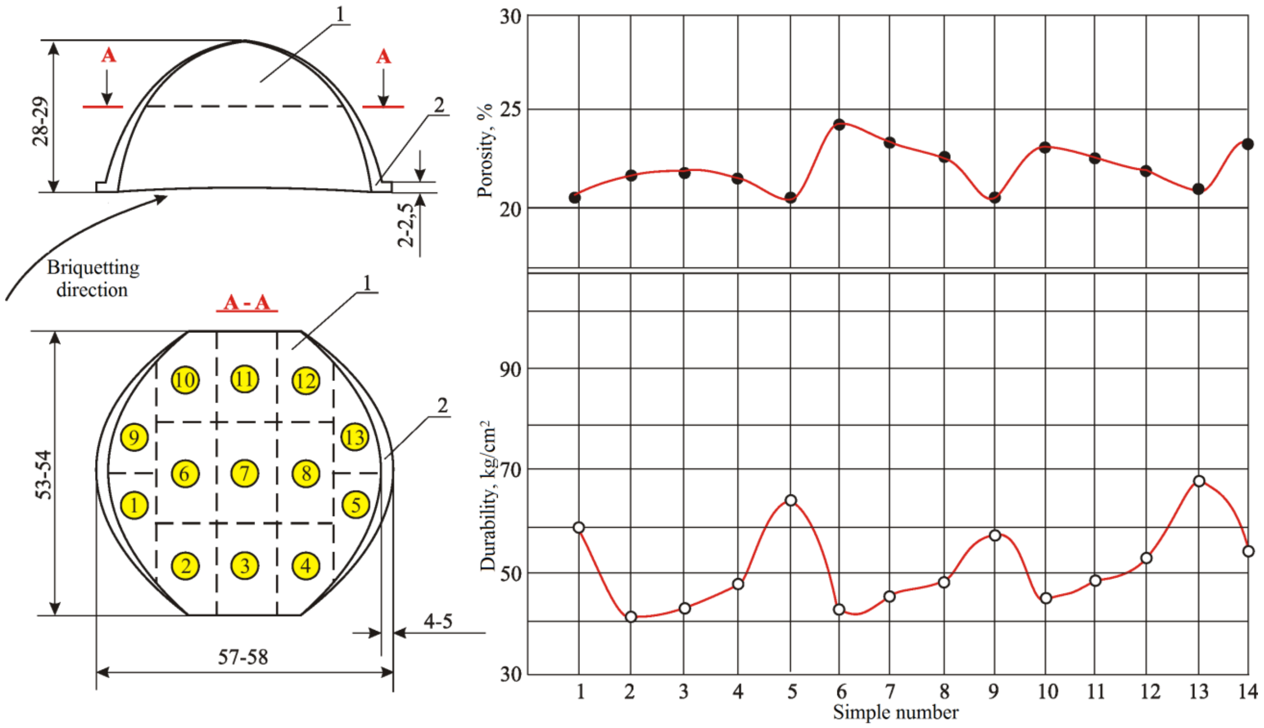


1 –matrix with 4 holes; 2 - Stand with 4 holes; 3 - punch

Figure 3: Sketch of laboratory briquetting unit

During extrusion of the finished briquettes from the matrix the effect of moisture content and binder additives on the force was determined, which is required for the removal, because the clutch of the charge with the surface of the matrix, and in an industrial environment with the surface of the roller press determines the efficiency of the process of briquetting. The dependency between the porosity of dry briquettes (at optimum moisture content of the charge) and the molding pressure was also established, that helped to determine approximately the efforts that develop during briquetting process on a roller press.

While investigating industrial briquettes chemical and physical properties (see Table 2) and a porosity by volume of the briquette were determined. In order to investigate the porosity and bulk density by volume of the briquettes, the sector in 10 mm was cut, which, in its turn, was cut into samples. Analysis of the results showed (Figure 4 and Table 6) that porosity along the periphery is by 1.4–1.6 times lower than in the middle, which is the reason for different pressing forces.



1 - briquette; 2 - bridge between briquettes

Figure 5: Briquette size and numbering of tested samples by the section A-A

Table 6: Physical properties of samples by briquette volume

Indicator	Sample No.														Avg. value
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Apparent* density, $kg/m^3 \cdot 10^3$	1.55	1.53	1.53	1.50	1.51	1.49	1.52	1.53	1.49	1.46	1.31	1.48	1.46	1.50	1.49
Total porosity, %	20.9	21.9	21.9	21.0	20.3	24.1	23.4	23.0	20.5	23.2	23.0	22.7	20.6	23.0	22.1
Compressive strength, kg/briquette	60	40	42	44	64	42	45	48	59	45	49	54	68	55	51.1

*True density for all samples was $1.96 \cdot 10^3$ kg/m^3

CONCLUSIONS

1. The possibility of partial or complete replacement of lignosulfonate by low grade flour in the process of briquette production was established. The optimum content of the binder additives in the charge should be 4.8-5.0% that will ensure receiving of durable wet briquettes and high metallurgical properties of heat-treated briquettes.
2. In order to optimize the usage of binder additives and operation mode of briquetted press to conduct industrial trials on the production of briquettes with replacement of lignosulfonate by low grade flour at 50%, 90% and 100% were carried out. The total content of binders additives in the charge should be 4.8%, 5.0% and 5.2% by dry weight, respectively.
3. Using the results of research to develop a facility for molding of the charge during feeding it to the rollers that will allow to reduce the amount of spillage by 20-30% and to increase the hourly productivity of the press by 15-25%.

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