STEELMAKING SLAGS ACTIVATION TO INCREASE BINDING PROPERTIES FOR NATURAL SOILS STRENGTHENING FOR ROAD BASE CONSTRUCTION[1]

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Abstract

It has been demonstrated that mainly amorphous new formations grow during the hydration and strengthening of dump ferrous slag from different metallurgical processes, with or without activators (additions of 2-3% of Portland cement) and mixed with natural soils. Their high rates of strength, and water and frost resistance render of these new materials appropriate for the construction of roads and airfield runways, levee cores, industrial and municipal dumps, building foundations, etc. In addition to their economic advantages, these materials are extremely easy to use and do not create new residues.

Key words: Dump ferrous slag; Activation of binding properties; Chemical interaction; Construction materials.

ATIVAÇÃO DAS ESCÓRIAS DE AÇO COM O OBJETIVO DE AUMENTAR AS PROPRIEDADES LIGANTES PARA FORTALECIMENTO DOS SOLOS NATURAIS COMO BASES DAS ESTRADAS

Resumo

É possível utilizar vários tipos de resíduos industriais no lugar de materiais de construção naturais (pedra britada, areia, cascalho, etc.) para a produção de bases de estradas, pistas de aeroportos, barragens e alguns tipos de fundações. Estes novos materiais são produzidos através da mistura de diferentes tipos de solos com escórias siderúrgicas sem a utilização de agentes ligantes tradicionais e sem aquecimento. Através de vários métodos modernos de investigação, ficou provado que em resultado de hidratação a mistura de solo e escória siderúrgica tem início uma dissolução parcial da parte sólida, formando um sistema de partículas coloidal (sol). Com o aumento da concentração de colóides nos poros, ocorre à formação de um gel amorfo. Este gel se solidifica devido aos vários estágios de sinérese. Após 28 dias de hidratação, este material atinge resistências à compressão de 1,1 a 2,2 MPa, em 90 dias essa resistência à compressão pode alcançar de 5 a 6,2 MPa. Com um ano, a resistência deste material dobra. Além disso, ainda é possível obter um maior aumento da resistência deste novo material, modificando as proporções iniciais da mistura. Estes novos materiais têm uma alta resistência à imersão e ao congelamento. Estradas urbanas executadas com os materiais mostraram alta performance por mais de 25 anos em diferentes regiões da Rússia, incluindo a região norte e Sibéria. A tecnologia que oferece numerosas vantagens está descrita neste trabalho. A pesquisa pode ser expandida para os resíduos industriais do Brasil com sucesso.

Palavras-chave: Escória de ferro descartada; Fortalecimento dos solos naturais; Processo sol-gel; Novos materiais de construção.

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1 INTRODUCTION

Mankind has been strengthening natural soils for construction purposes for time immemorial, using a variety of organic and inorganic binding materials for this purpose. The most commonly used organic spread materials are petroleum, bitumen, pitch, etc. Inorganic binding materials used for this purpose are Portland cement, cement kiln dust or lime,[1,2] Water glass or calcium chloride,[3] various types of ashes[4-6] etc.

The accumulation of dump ferrous slag (DFS) from different metallurgical processes is one of the most serious environmental problems in most countries that have a highly developed metallurgical industry. Even in Europe, which has the world's most stringent environmental protection legislation, 35% of the steel slag produced is still dump every year.[7] Some dumps located close to metallurgical plants contain enormous quantities of ferrous slag, i.e., up to 180 million tons (Magnitogorsk, Russia).

There is a plethora of international literature on many different ways of using metallurgical slag as cementing material.[8] The largest consumers of slag as an alternative inert material replacing crushed natural stone, gravel and sand mixtures are road constructors.[9-11] Another widespread form of using slag is in the production of Portland cement.[12,13] Then there are the well-known technologies of slag-wool production for thermal and acoustic isolation, for technical glasses, as fertilizer for agriculture purposes, for the stabilization of shores[7] etc. Some authors even propose the use of slag as coating for environmentally dangerous materials.[14]

Unfortunately, most of the reports concentrate on the use of granulated ferrous slags, which are not strictly industrial wastes, but intermediate products of Portland cement production.

The method developed [15,16] and described herein allows for the use of dump slags as binder materials for different natural soil strengthening applications.

2 MAIN RESEARCH PURPOSES

1. Study amorphous new formations of DFS with and without small (2-3%) additions of Portland cement as activators of the hardening processes;
2. Study the processing of amorphous new formations in the hardening mixtures of activated DFS with different natural soils and the main properties of new construction materials;
3. Develop some applications for the materials with amorphous new formations that cause these properties.

3 RESEARCH METHODS

A wide range of traditional and novel methods of mutually complementary research were used to study the initial slag and soils compositions and temporal changes during hydration. These methods included the definition of the limit strength under uniaxial compression, temporal changes of moisture and of linear deformation, water and frost resistance, XRD analyses by the powder method, the amount of bonded water and carbonate content, using TGA and DTA, scanning electron microscopy and chemical analysis (free CaO, SiO_2, Fe_2O_3, Al_2O_3, non-bonded SO_3, pH and others), infra-red spectroscopy, X-ray-spectral analysis by "Cameca", "Edax" and "Link-System", and laser micro-mass analysis by "LAMMA-1000". Presenting the results of all these methods here would be impossible owing to space limitations; nonetheless, they have been taken into consideration in the description of the materials strengthening process.

Samples of the materials were compacted for 1 min under a 10 MPa pressure in a cylindrical mold with a 5 cm diameter and height under conditions of optimal humidity (10-12%). The hardening occurred under a condition of 98% humidity.

4 RESEARCH OBJECTS

The most typical ferrous metallurgy dump slags (blast furnace, open-hearth, converter and electric steel smelting) were studied here for the reinforcement of a variety of natural soils (light and heavy loams, fine and medium sands, loess and loess-like loam). The main components of the chemical composition of these materials are given in Table 1.
The significant differences in the chemical compositions of the slags under study (Table 1) are explained by the substantially divergent metallurgical processes and applications for the final metal produced. The greatest difference is found between the compositions of blast furnace (BF) and converter (CON) slags, especially insofar as the content of SiO_2, CaO, Al_2O_3, MnO, $FeO+Fe_2O_3$, and common S are concerned. Open heart (OH) and electrical steel (ES) slag compositions, on the other hand, are more similar to each other (except the amount of Al_2O_3 and FeO $+Fe_2O_3$) and are intermediate between the first two slags.
These divergent chemical compositions of slags lead to different values of modulus of alkalinity, Ma, which is one of the most important indicators of the binding properties of inorganic materials. Converter slag has the best Ma while furnace slag has the worst. Maximal SiO_2 content occurs naturally in all types of natural soils, but especially in medium sand (item 9 of Table 1).

Table 1. Main components of the chemical composition (%) of DFS and natural soils under study.

№	Slags & Soils	SiO_2	MgO	CaO	Al_2O_3	MnO	FeO - Fe_2O_3	SO_3 comm	M_a
1	blast furnace	35.2	3.5	36.1	10.6	2.0	4.0	3.7	0.69
2	open hearth	17.5	18.1	26.7	6.1	2.0	22.1	0.2	1.85
3	converter	19.5	1.8	56.1	2.1	6.7	11.0	0.1	2.67
4	electric steel	18.4	16.5	29.6	10.9	4.2	16.2	0.5	1.57
5	light loam	73.2	2.3	3.7	8.8	0	3.2	0.0	-
6	heavy loam	59.1	2.2	8.0	13.4	0	4.6	0.2	-
7	loess-like	56.7	2.1	17.4	14.3	0.1	4.4	0.5	-
8	loess	59.1	1.9	6.8	14.5	0	5.8	0	-
9	medium sand	92.7	0.1	0.2	2.3	0	4.1	0	-

Where: Modulus of alkalinity (M_a) = $\frac{CaO + MgO}{SiO_2 + Al_2O_3}$

Small amounts (2-3%) of Portland cement were used to activate the slags' binding properties and accelerate the chemical interaction of slag-soil mixtures.

5 EXPERIMENTAL RESULTS

The fastest and most constant increase in strengthening was displayed by hydrated converter slag samples, whose strength reached 40 MPa up to one year of age. This finding was expected due to its chemical composition: large content of CaO – 56.1% and 1.8% of MgO and relatively small amounts of SiO_2 - 19.5% and Al_2O_3 - 2.1%, which resulted in a value of Ma = 2.67. Electric steel slag showed the best strength on the 28th day (3.9 MPa), but the worst (16.2 MPa) after 6 years. The strength of blast furnace and open heart steel showed highly diverse values in every stage of hardening, but practically the same values at the end of the 6th year, i.e., approximately 20 MPa.

5.1 Strength of DFS after Activation

S mall amount of cement (2%) was used simply to increase the normal alkalinity of the hydrated slags, since this amount is insufficient to function as an independent binding material.

Figure 1 shows the alterations in the hardness of DFS from different processes, activated by 2% of Portland cement. A comparison of the strengthening of the same slags without activator reveals a significant increase in the hardening rate as result of activation, especially in the first year.

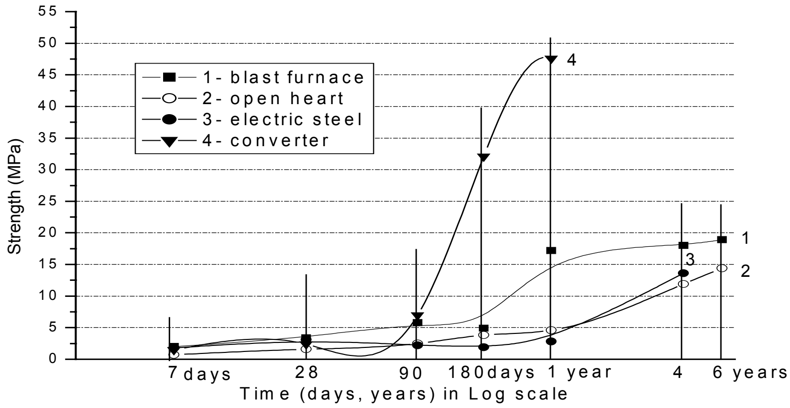

Figure 1. Strengthening of hydrated DFS of different metallurgical processes activated by 2% of Portland Cement: 1 – Blast Furnace, 2 – Open Heart, 3 – Electric Steel, 4 – Converter.

The only exception to this rule is open hearth slag, whose strength decreased almost twofold (from 7.2 to 3.8 MPa) on the 180th day as a result of activation and almost threefold (from 11.1 to 4.6 MPa) after one year. This difference between activated and non-activated slag decreased in the 4th year (13.8 versus 11.9), but it increased again in the 5th year (19.3 versus 9.3 MPa), and again slightly in the 6th year (19.4 versus 14.4 MPa).

Blast furnace slag displayed the best results for activation during the first 90 days. On the 28th day, the strength of activated blast furnace slag was 3.4 MPa (versus 0.5 for non-activated slag, i.e., 6.8 times higher) and on the 90th day it was 5.8 versus 1.4 MPa (i.e., 4.2 times higher). However, after 6 years, this advantage in the strength of activated over non-activated slag was practically inexistent.

The strengthening effect of converter slag activation was negative after 90 days (6.96 versus 11.58 MPa), but very positive after 180 days and 6 years, i.e., 32.1 and 47.6 MPa for activated versus 17.92 and 39.89 MPa for non-activated slag, respectively. Only electric steel slag consistently demonstrated the advantage of activation in every stage of hardening.

5.2 Effect of Dump Ferrous Slag Activation on Water and Frost Resistance

The water and frost resistance of all the types of ferrous slag under study are shown in Table 2. The requirements of the Russian standards for road base materials derived from natural soils strengthened with industrial wastes after 90 days of hydration (Rw) are 6-4 MPa, 4-2 MPa, 2-1 MPa, which correspond to class I, II and III roads. The coefficient of frost-resistance, Cf, of the materials must be no less than 0.75, 0.70 and 0.65, respectively, for the three classes of road.

This means that the strength of water-saturated converter slag, Rw, far exceeds (more than twice) the highest requirements of this standard. The Rw of open hearth and electric steel slags conform to class II of the standards, but the frost resistance coefficient, Cf, of the latter falls short of the standards' requirements. Its low water and frost resistance values preclude the use of blast furnace slag without special activation of its binding properties, limiting its use to regions with mild climatic conditions.

Table 2. The effect of dumped ferrous slag activation by 2 % of Portland cement.

Slags	R_w	C_w	R_f	C_f
blast furnace	0.39		0	0
blast furnace + 2% P.C.	6.24	0.28	5.07	0.81
		1.08		
open hearth	2.69		2.59	0.96
open hearth + 2% P.C.	2.61	1.15	2.06	0.79
		1.05		
electric steel	2.60		9.00	0.48
electric steel + 2% P.C.	7.66	1.21	5.72	0.78
		1.05		
converter	12.22		1.24	0.74
converter + 2% P.C.	6.97	1.06	8.85	1.27
		0.93		

where: $C_w = \frac{Rw}{Ra}$ and $C_f = \frac{Rf}{Rw}$,

C_w and C_f - coefficients of water and frost resistance, R_w - strength of 90-days samples saved in air-humid conditions (94-96% humidity) after water saturation during 24 h, R_a– strength of 90-days samples saved in air-humid conditions (94-96% humidity), R_f - strength of water saturated sample after 25 cycles of freezing and thawing (-25 °C and + 20 °C in water with room temperature), each cycle - 16 h.

The results presented in Table 2 and Figure 2 confirm these conclusions, which are illustrated by the values of modulus of alkalinity, Ma, given in Table 1: converter slag shows the best structural properties (mechanical strength, water and frost resistance).

Activation with a 2% content of cement (Table 2) had different effects on different slags, with blast furnace slag showing the most visible improvement in water and frost resistance properties. The results of activation met the highest requirements of the Russian standards.

The least positive results were obtained from the same test on open hearth dump slag, which showed a decrease of all the parameters, particularly of frost resistance. It can, however, be used as an independent material without activation. Open hearth slag contains less SiO_2 and CaO, the two main components in its chemical composition, than the slags deriving from other metallurgical processes (Table 1).

Electric steel slag displayed low Cw and Rf, but considerably high Rw and Cf , allowing it to be used as a construction material.

Converter slag showed low Ra and Cw, but significantly high frost resistance parameters, Rf and Cf. The rather rare effect of the Cf value surpassing 1.0 (i.e., 1.47) can be explained by the 50 thermal shocks, with a thermal difference of 45°C (from –25°C in the freezer to +20°C in water and vice-versa), to which the material was subjected for several seconds in each cycle. Such shocks probably destroy the surface of slag grains, thereby increasing the surface area (and the quantity) of synthesis of new formations. During 22 days of frost resistance tests, the number and density of new formations displayed significant increases of Rf in comparison with Rw.

5.3 Strengthening of Natural Soils by Non-activated and by Activated DFS

The mechanical properties of slag-soil materials depend mainly on the properties of their chemical components (Table 1) and their ratios, dissolution and interaction in alkaline pore solutions. Most non-activated soil-slag materials showed very low water resistance values (Table 3), and all of them failed the frost resistance tests. Only the samples of mixture 7, Table 3 (medium sand + open hearth slag) did not show spontaneous decomposition by the end of the frost resistance tests. The aforementioned lack of SiO_2 in the chemical composition of open hearth slag was compensated for by the addition of medium sand, which may explain the significant improvement of the slag-soil samples' properties. However, its Cf value (0.42) allows this material to be used only as road base substratum for Russia's climatic conditions.

Table 3. Water and frost resistance effect of natural soils strengthening by DFS, activated with Portland cement.

Item	Materials composition	R_a	C_w	R_f	C_f
1	Light loam + blast furnace slag	0.57	0.44	0	0
2	....+2% P.C.	2.48	0.96	2.08	0.84
3	Heavy loam + blast furnace slag	0.09	0.37	0	0
4	....+2% P.C.	2.91	0.96	2.30	0.79
5	Light loam + open hearth slag	0.06	0.24	0	0
6	....+3% P.C.	1.74	0.93	1.50	0,86
7	Medium sand + open hearth slag	1.30	1.71	0.72	0.42
8	....+3% P.C.	3.37	1.04	4.08	1.16
9	Loess like loam +electric steel slag	3.66	0.97	0	0
10	....+2% P.C.	9.57	1.16	7.96	0.83
11	Loess + electric steel slag	3.37	0.84	0	0
12	....+2% P.C.	13.98	1.14	11.06	0.81
13	Heavy loam +converter slag	3.12	0.93	0	0
14	....+2% P.C.	4.26	1.14	3.32	0.78

A small addition (2-3%) of Portland cement drastically changed the mechanical properties of slag-soil materials. The strength (Fig. 2) of the 90-day-old materials varied from 2 MPa (curve 3) to 12 MPa (curve 6). The water and frost resistance of all the slag-soil materials tested (Table 3) also improved considerably in response to activation and, by the 90th day, the value of Rw ranged from 1.7 to 14.0 MPa, the Cw varied from 0.93 to 1.16, the Rf from 1,5 to 11.1 MPa, and the Cf from 0.78 to 1.16. After their activation, all these materials can be recommended as road base materials, in accordance with the aforementioned Russian construction standards.

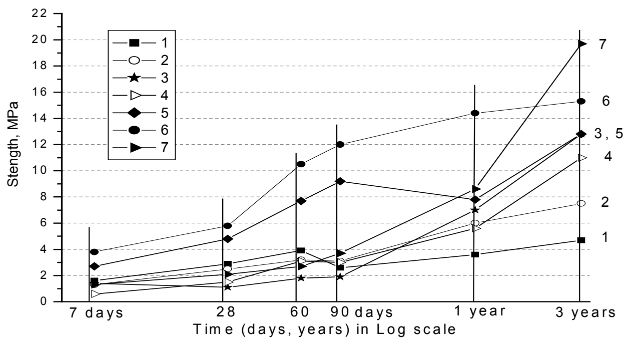

Figure 2. Resistance changes of natural soils strengthened by activated DFS, where 1 - light loam + blast furnace slag, 2 - heavy loam + blast furnace, 3 - light loam + open hearth, 4 – medium sand + open hearth, 5 – loess-like loam + electric steel, 6 – loess + electric steel, 7 - heavy loam + converter slag.

5.3 Structure Formation of Activated Slag-soil Materials

The hardening processes of the natural soil-dump ferrous slag-activator mixtures were studied with every possible instrumental detail, in accordance with paragraph 4 of the "Research Methods." Table 4 presents the main physicochemical strengthening parameters obtained for the "heavy loam-blast furnace slag-2% Portland cement" system.

Similar data were also obtained for all the compositions, see Table 3, but are not given here due to space limitations.

Table 4 indicates the following: The fastest increase in the system's values occurred during the first 7 days. There was a clearly defined synchronization between the samples' changes in compressive strength and bonded water losses over the 3-year period under study. These changes coincided with the value of pH up to the 60th day and thereafter overlapped up to the 3rd year. The values of the coefficient of linear deformation and the CO_2 and SiO_2 content increased steadily throughout the period under study, but in the first 60 days (i.e., 5.5% of this 3-year period) they rose to 61.7%, 54.6 and 39%, respectively, of their final values.

The XRD images showed no new peaks of newly formed crystals during the entire period. SEM (Fig. 3), however, revealed many gel-like new formations that completely covered the sample's surface. All the above data can be explained by the corrosion (leaching) of the solid surfaces of soil and slags by alkaline (pH=10.90) pore solution, which causes all the ions of the dissolved parts to be carried into this solution, and the gradual transformation of sol solutions into a more dense gel.

Part of the alkaline Ca and Mg ions are bonded in very different complex compounds of new formations and part are bonded by the CO_2 of air in the carbonates. However, the carbonization process takes place very gradually (Table 4 – CO_2 quantity, and Fig. 5- endothermic peak 810^0C), reaching the value 2.3% of $CaCO_3$ with the conversion of CO_2 content on the 60th day, 3.0% at 1 year and 4.2% at 3 years. Such small amounts of all carbonate forms (calcite, dolomite, siderite, etc.) are hardly sufficient for their peaks to be fixed by powder XRD method (sensitivity close to 3-5%).

Table 4. Changing of the indices of heavy loam strengthen by activated blast furnace slag.

Indices	Time of hardening								
	Initial	Days					Years		
		7	28	60	90	180	1	2	3
Compression resistance, MPa	-	1.30	2.50	3.20	3.10	4.40	6.00	5.70	7.50
Coefficient of lineal deformation, %	-	0.74	1.04	1.13	1.22	1.37	1.35	1.70	1.83
Common losses of weight, (TG), %	-	10.3	10.7	11.5	11.3	11.5	11.7	11.7	13.8
Contain of CO_2 (TG), %	-	1.00	1.00	1.00	1.33	1.33	1.34	1.52	1.83
Losses of bounded water, (TG), %	-	9.33	9.73	10.5	10.0	10.1	10.3	10.2	12.0
pH	10.90	8.41	8.25	8.21	8.34	8.45	8.31	8.02	7.70
Content of mobile SiO_2, %	0.23	0.60	0.62	0.62	0.65	0.70	0.70	1.15	1.40

A x 1000	B x 1000	C x 1500

Figure 3. SEM image of the mixture of Blast Furnace Slag with clay particles of heavy loam: A – before hydration, B – after 60 days and C – after 90 days of hydration; syneresis-related cracks.

The density of the pore solution is rather low at the beginning of the hydration process, but it increases over time. Moreover, it appears that the density of the new formations around the solid surfaces of the slag after the first year becomes sufficiently high to prevent future strong erosion of the slag's particles by alkaline pore solutions.

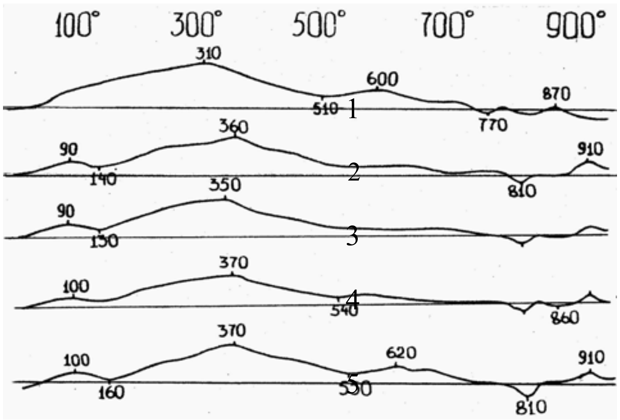

Figure 4. The changing of DTA curves during the process of heavy loam - blast furnace slag – 2% of Portland Cement mixture strengthening after: 1 – 1 day, 2 – 60 days, 3 – 90 days, 4 – 1 year, 5 – 3 years.

Due to these cracks caused by gel syneresis, the liquid phase of the alkaline pore solution approaches the surface of solid slag particles and starts leaching them out once more. During the 90 to 180-day period, the cracks are closed by more freshly generated amorphous gel new formations.

The amorphous nature of the new formations are confirmed by:

1. The absence of new peaks on the XRD until the samples reach the age of 6 years, except for very small carbonate peaks; 2. The aforementioned absence of crystal-like forms in SEM (Fig. 4-B, C) and the presence of large amounts of specific amorphous-like new formations without any similarity to crystal bodies, and by the presence of syneresis-related cracks (Fig. 4-C) and their eventual filling up and closing by new portions of gel; 3. The presence of wide exothermic areas ranging from 50° to 750°C on the DTA curves of all ages (Fig. 5); 4. The results of laser micro-mass analysis (LAMMA, Fig. 6 A, B and C). All the LAMMA-specters of the chemical compositions of new formations obtained at points as close as possible (as in Fig. 4-C) reveal quite different combinations and quantities of isotopes (intensity of the peaks). Similar results were obtained by X-ray spectral analysis using the "Edax" and "Link-System" (Fig. 4-C and Table 5).

The phenomenon of the amorphous structure of new formations agrees with Groth-Fedorow's crystal-chemical law on the growth of crystal structures from solutions.

According to this law, the crystal structure system (syngony) tends to decrease as the complexity of the chemical solution increases. From the point of view of Groth-Fedorow's law, no crystal bodies are expected to grow in solutions as complex as mixtures of DFS with natural soils and Portland cement; hence, they can only be amorphous. These amorphous formations can be very stable, occurring in amorphous minerals (e.g., hisingerite, limonite, etc.) or in sedimentary rocks such as flint, opoka, tripolite, etc., that have existed in amorphous form over geological epochs.

The well-known gel-forming property, SiO_2, was the main reason for the strong effect of enhanced mechanical properties after open hearth slag was mixed with medium sand. This mixture became equally frost resistant with and without the addition of the activator (Table 3, item 7 and 8). After 90 days, the strength, water and frost resistance of all slag-soil materials met the standards' requirements for the second (2-4 MPa) and third (1-2 MPa) grades of reinforced soils.

Further increases of the materials' resistance from 4.4 to 6.0 MPa in the period of 180 days to 1 year can, in our opinion, be explained by the synthesis of the gel of new formations at the bottom of the cracks produced by gel syneresis. The increase of new gel augments the amount of bonded water from 10.12 to 10.33%. The alkaline corrosion of the slag's fresh surfaces at the bottom of the cracks causes the quantity of all ions to increase, including alkaline Ca and Mg, raising the pH. But the changes in pH value are not clearly synchronous with the resistance and bonded water content.

The same simultaneous oscillation was observed in the periods of 1-2 and 2-3 years, with the total growth of these two parameters. This is ascribed to the total increase of gel formation with no significant linear deformation of the samples, due to the equal growth of this gel density. Such gluing of solid slag and soil grains by gel formation accompanied by the growth in density explains the effect of equal increases in the samples' strength and other mechanical properties, such as water and frost resistance.

6 APPLICATIONS OF THE MATERIALS

Leaching tests of the materials in acid, alkaline and neutral solutions were conducted by two independent and competent groups of medical and sanitary experts. The value of leachability was found to be well below the requirements of Russian standards [17].

The results of the leaching tests and the high value of the main mechanical properties of slag-soil activated materials permit their recommendation as road base construction materials to replace crushed stone, gravel, sand, etc.

The first constructions of experimental stretches of roads of different technical categories using these slag-soil materials demonstrated their excellent cost efficiency and exploitation properties, even in the extremely harsh climatic conditions of northern Russia and Siberia. Subsequently, almost 300 km of road were built with different structures. A comparison of traditional and proposed road structures is given in Fig. 7. Two layers (crushed stone and sand) are replaced by one layer of the new activated slag-soil mixture.

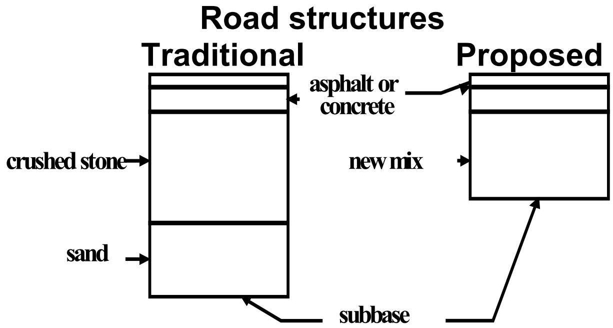

Figure 7. The comparison of the simplest schemes of traditional and proposed road structures.

These road base layers were built by mixing natural local soils with DFS, activator and water directly on the road (*in situ*). The mixture can also be prepared in stationary mixers.

7 CONCLUSIONS

1. Dump ferrous slags from all the metallurgical processes under study (blast furnace, open-hearth, converter and electric steel) have clearly defined binding properties. However, the development of these properties is so slow that only open hearth slag can be used as an independent material without the addition of Portland cement activators.

2. The binding properties of slag can be accelerated easily by the addition of 2-3% of Portland cement.

3. The strengthening process of all the types of ferrous slags under study is triggered by the synthesis of new amorphous formations. Very small amounts of carbonates are formed as crystal structures, but they cannot be the cause of the samples' strengthening up to 47 MPa at one year of age.

The strengthening of the "slag-natural soil-activator" system has the same amorphous nature. But because natural soils adsorb a substantial part of the alkaline ions Ca and Mg, the alkaline excitement of the solid parts of slag takes place at a very low intensity, resulting in the weaker synthesis of amorphous new formations. As a result, the highest strength of this system at 1 year is only 14.4 MPa.

4. Activated slag-soil materials can be used for the construction of road bases, airfields, municipal and industrial dumps, as dam core, etc. Almost 300 km of roads have been built with such bases in different regions of Russia, including regions with rigorous climates in northern regions of Russia and Siberia. These roads have all displayed many advantages, evidenced by their high indices of cost effectiveness, and technological and ecological efficiency compared to the traditional forms of road construction around the world.

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