Lime slag binding agent for road concrete

K M Voronin, M B Permyakov, A M Davydova
Department of construction production, Nosov Magnitogorsk State Technical University, 38, Lenin Prospekt, Magnitogorsk 455000, Russia
E-mail: nastya2008p@mail.ru

Abstract. The article shows the comparative analysis of two compositions of cement concrete to use in road construction. In order to compare quality characteristics of the materials the method of Y.M. Butt was used that was implemented to test Portland cement samples made at Magnitogorsk cement refractory plant and cement rock on the basis of lime slag binding agent that was developed based on blast-furnace granulated slag together with Magnitogorsk Metallurgic Plant, PJSC. Computational and full-scale experiments were conducted to forecast the time changes of qualitative parameters of road surfaces with slag. It was established that its endurance to the first and second type of corrosion is higher. It was proved that lime slag concrete can be used in the production of road fine grain concrete instead of Portland cement, the presented binding agent also proved to be more economically feasible.

1. Introduction
In Russia today there are about 3% of motorways with firm concrete surface in the total of federal motorways. Motorways with cement-concrete surface are more endurable, but their cost is 10% higher than that of asphalt-concrete ones. At the same time their durability is higher and has an environmental effect [1]. In spring 2016 Russian Prime Minister Dmitry Medvedev signed an act prescribing building no less than 50% of motorways with firm cement-concrete surface by 2030.
Development and implementation of progressive concreting methods, such as additive technologies in construction allow today to reduce significantly the construction period of building high quality concrete and concrete-steel constructions [2,3].

According to the data in literature sources, the number of road accidents grows by several times when the average daily temperature falls below 8°C [4]. Snow and ice crust forms on the road surface in winter and significantly decreases adhesion properties of the surface with the wheels of a vehicle. The following requirements are essential in road construction in many countries: low freezing temperature of mortar, good melting capability, minimum environmental burden, low corrosion activity when interreacting with metallic parts of cars and road constructions, maintaining adhesion coefficient [5]. Wintertime reagents decrease adhesion properties of the road surface because of low durability of pavement surfacing to concrete corrosion. Moreover, in recent decades there has been a sharp rise in exhaust gases from vehicles.

Cement-concrete surfaces in industrial one-factory cities would be particularly pertinent. Firm surfaces with materials on the basis of local producers will improve the environmental situation, and new technologies and materials will upgrade the architectural image of one-factory cities and promote the road safety [6-8].
2. Relevance

Asphalt-concretes have low corrosion durability which leads to deformations and compromise the integrity of the road surface. The operation time of the road surface affected by mechanical stress caused by vehicles, exhaust gases, aggressive de-icing solutions significantly decreases. Moreover, every year there is a rise in the cost of road and construction materials. Economic factor brings about the search for local materials to build pavement surfacing. Many ways to increase quality and durability of road surfaces are analyzed, such as: assembled and assembly-monolith concrete surface; asphalt-concrete with polymer additives and rubber granules; production and human-made waste [9-11].

Most common local materials in regions with developed metallurgic industry are by-products of iron and non-ferrous metallurgy, namely slag [12]. The necessity to lower costs for annual maintenance and replacement of road concrete constructions determined the goal of the research, namely to obtain road concrete that would meet the requirements for lime slag binding agents [13].

3. Identification of goals

Under the present conditions, one of the priorities in road construction is improving operational durability of motorways in different seasons [14]. One of the ways to improve durability of road concrete in aggressive environments is to use binding agents that are corrosion-proof and more frost proof. Departments of Construction, Architecture and Art Institute in Magnitogorsk State Technical University have been developing lime slag binding agents on the basis of production waste for 30 years [15].

Lime slag binding agents were developed in the 20th century by Glukhovsky V.D. and have similar characteristics but are not widely used due to various technological hardening specifics. Hardening problems were solved after a thorough analysis and development of a new technology for producing binding agents. The goal of the said research is the creation and testing of road surface mortar that will allow to increase corrosion durability of cement rock without raising the primal cost of the final product, namely cement.

4. Theory

Concretes on the basis of plain Portland cement are widely used in road construction. According to [16], slag asphalt-concrete is limited for motorway surfacing III of technical category and lower. This is associated with the fact that the properties of these materials for road construction are not sufficiently researched. There are no sound experimental data that makes a quality comparison of traditional asphalt-concretes and the slag one on the road surfaces of high categories.

Lime slag binding agent additions to road concrete are pertinent when the load associated with exhaust gas and de-icing reagents with chlorine and nitrogen is suddenly increased. Chemical content of exhaust gases of a vehicle with the percentage for gasoline and diesel engines is shown in table 1. You can see from the established distribution of the main exhaust components that the content of exhaust gases is diverse and the majority can produce weak acids [17]. Exhaust gases are dissolved in water, or, by accumulating on snow together with de-icing reagents they produce various acids and acid salts that cause cement rock corrosion of the second type that changes to the third type corrosion. Further on, as a result of lower pH of the concrete, the high-basic calcium silicate hydrate are destroyed that form the basis of cement rock, and the percent of high-basic calcium hydrosulfoaluminate that has crystallized in pores of cement rock and causes pressure of about 80 Mpa [18] grows.

Glukhovsky V.D. developed a composition of lime slag binding agents in the 20th century. Later on, a number of studies and natural tests produced a new method of making binding agents, the problems associated with hardening were solved, and the advantages must be used in order to improve the durability of asphalt-concrete surfaces.
Table 1. Chemical content of exhaust gases of a vehicle.

| Component          | Volume ration in a gasoline engine, % | Volume ration in a diesel engine, % | Toxicity   |
|--------------------|---------------------------------------|-------------------------------------|------------|
| Nitrogen N₂        | 74–77                                 | 76–78                               | non-toxic  |
| Oxygen O₂          | 0,3–8                                 | 2–18                                | non-toxic  |
| Hydrogen H₂        | 0 – 5,0                               | -                                   | non-toxic  |
| Water steam H₂O    | 3–5,5                                 | 0,5–4                               | non-toxic  |
| Carbon dioxide CO₂ | 5–12                                  | 1–10                                | non-toxic  |
| Carbon oxide (CO)  | 0,5–12                                | 0.01–5                              | toxic      |
| Hydrocarbons       | 0.2–3                                 | 0.009–0.5                           | toxic      |
| Aldehydes          | 0–2                                   | 0.001–0.009                         | toxic      |
| Sulphur dioxide SO₂| 0–0.002                               | 0–0.03                              | toxic      |
| Soot, g/m³         | 0–0.04                                | 0.1–1.1                             | Cancer-causing chemicals |
| Benzapyrene, g/m³  | 0.01–0.02                             | 0–0.01                              | Cancer-causing chemicals |

5. Practice

The main crude material in the present research lime slag binding agent was developed on the basis of ground blast-furnace granulated slag from Magnitogorsk Metallurgic Plant, JSC and activated sodium silicate solute [19] Portlandcement from Magnitogorsk cement refractory plant was used for comparison. In order to compare quality characteristics of the samples, all the data was collected in table 2.

Table 2. Qualitative characteristics of materials for natural tests.

| Characteristic                                      | Unit of Measurement | Lime slag binding agent | Portlandcement |
|-----------------------------------------------------|---------------------|--------------------------|----------------|
| Hardening starting point                            | hour                | 0.33                     | 1.23           |
| Hardening ending point                              | hour                | 2.21                     | 2.21           |
| Normal thickness                                    |                     | 27.5                     | 24.5           |
| Stress limit on impact during hardening under normal conditions | MPa                 | 55.88                    | 51.42          |
| Stress limit on impact during hardening with heat and moisture treatment | MPa                 | 59.96                    |                |

Corrosion durability of cement rock was established using the method [20], based on which prismoidal specimens (2×2×8 cm) were made from the binding agent with optimal composition that preliminarily hardened under normal moisture conditions (NMC) for 28 days. After 28 days the samples designated for hardening in aggressive environments were transferred into the solutions, while the others were stored in NMC up till the start of testing. The hardening of samples in aggressive environments took place in special vessels with solutions covering the samples by 1-2 cm. After the completion of preliminary hardening, the prismoidal specimens were tested for prism bending. All the other samples were bent tested in differ at different time periods: 6 months and 3 years.

The solutions MgSO₄ of the 3rd concentration, Na₂SO₄ of the 5th concentration and FeSO₄ of the 5th concentration are used as aggressive environments. Portlandcement corrosion durability data for the said aggressive environments are cited for comparison in table 3.
Table 3. Corrosion durability of samples with slag binding agents in sulphate environments.

| Test period, months | Stretching strength when bent, MPa | in water | in Na2SO4, 5% solution | in MgSO4, 3% solution | in FeSO4, 5% solution |
|---------------------|----------------------------------|----------|------------------------|----------------------|----------------------|
| 6                   | 12.10                            | -        | -                      | -                    | -                    |
| 12                  | 13.21                            | 17.55    | 12.46                  | 12.15                | -                    |
| 18                  | 13.82                            | 15.98    | 12.74                  | 12.93                | 12.32                |
| 24                  | 14.04                            | 14.32    | 11.85                  | 11.94                | -                    |
| 36                  | 14.06                            | 13.88    | 11.13                  | 11.41                | -                    |
| a) lime slag binding agent | Before the aggressive environment | 10.68 | 11.79 | 10.43 | 10.02 |
| 6                   | 10.72                            | 9.97     | 9.21                   | 9.10                 | -                    |
| 12                  | 10.87                            | 9.36     | 8.69                   | 8.50                 | -                    |
| 18                  | 9.75                             | 8.73     | 8.11                   | 8.07                 | -                    |
| 24                  | 9.33                             | 8.01     | 7.53                   | 7.23                 | -                    |
| 36                  | 9.33                             |          |                        |                      |                      |
| b) Portlandcement   | Before the aggressive environment |          |                        |                      |                      |

The results presented in table 3 show that the binding agents of lime slag and Portland cement after 6 months of being stored in sodium sulfate become stronger, as cement rock CaSO42H2O that formed as a result of an exchange reaction between calcium hydroxide and sodium sulfate solidifies. In case of other salts, this process does not occur because of the parallel process of calcium silicate hydrate destruction by iron and magnesium ions.

Further on the destruction of Portland cement accelerates as a high-basic calcium hydrosulfoaluminate is formed that exerts pressure on the walls of pores. There is almost no such thing in case of the lime slag binding agent as there is no hexaqua calcium hydroaluminate, and lower durability is caused by exchange reactions resulting in iron and magnesium hydroxides that after long storage can increase their volume. Mechanic characteristics of lime slag binding agent are studied also using new approaches within the degradation theory [21, 22, 23, 24].

Economic effect from using lime slag binding agent in concretes can be seen in the example of fine grain concrete in comparison with fine grain concrete with Portland cement. It will be ensured by the difference in the cost of these concretes that is provided for by the difference in the cost of the binding agent and the change in the composition of the concrete mix. Binding agent consumption by a durability unit in concretes with lime slag binding agent is by 51.6% lower than in Portland cement concrete. Economic effect of substituting traditional cement PC 400 with lime slag binding agents: 994.73 rubles/m3 with similar operational qualities.

6. Conclusion
Finally, we can say once again that adhesion qualities of road surface are the most important element in strengthening the traffic safety. The number of road accidents in winter is 4.2-4.6 times higher than on dry surfaces [25]. The main method of fighting icing on road surfaces is chemical reagents in cold seasons.

Reagents then lower the adhesion between a wheel in a vehicle and the road surface. The degree of reduction depends on the properties of the reagents being used, weather conditions, abrasion and adhesion of the road network. The existing asphalt-concrete composition when exposed to aggressive de-icing reagents together with toxic components of exhaust gases from vehicles rapidly lead to quality deterioration of the road surface. This trend can be observed in many Russian regions with the main consequence of low durability of the initial material being frequent maintenance works and complete replacement of road surfaces.
Lime slag binding agent that has higher corrosion durability to the second and third corrosion types instead of Portland cement in road concretes allows not only to extend the period without maintenance but also to increase economic benefits.

References:
[1] Permyakov M B et al 2013 Relevant Problems of Construction Industry (Magnitogorsk: Magnitogorsk state technical University.UN-TA im. G. I. Nosova) p 139
[2] Permyakov M B, Krasnova T V and Dorofeev AV 2018 Actual problems of modern science, technology and education Additive technologies in construction and design of architectural environment: present and future 9(2) 2–5
[3] Permyakov M B, Krasnova T V and Dorofeev A V 2018 In the collection: Creative education space Collection of materials of intra-University (part-time) scientific and practical conference Application of additive technologies in architecture, construction and design (Magnitogorsk: Nosov Magnitogorsk State Technical) pp 170–6
[4] Samodurova T V 2003 Operational management of winter road maintenance (Voronezh: Voronezh State University Press) p 168
[5] GOST 450-77 1977 Technical Calcium Chloride 1-2
[6] Permyakov M B and Krasnova T V 2018 Conceptual design of russian modern monotowns' architectural space IOP Conference Series Materials Science and Engineering electronic edition pp 012153
[7] Krasnova T V and Permyakov M B 2019 Creative approaches to the image of the urban environment of architecture and design Sovremennye naukomekie tekhnologii 2 89–93
[8] Krasnova T V and Permyakov M B 2019 In the collection: Innovations in science ways of development materials X all-Russian scientific-practical conference (Cheboksary 26.12.2018) Creation of comfortable environment of Ural cities by means of landscape architecture pp 18–21
[9] Veselov A V, Permyakov M B and Davydova A M 2015 Reconstruction of roads using precast concrete elements Internet-zhurnal Naukov,denije 5(30) 118
[10] Ilin A N, Chernyshova E P, Permyakov M B, Andreev V M, Krishan A L and Sabirov R R 2016 Polymer-modified cement as a new level of electric insulation in electrical engineering systems Journal of Engineering and Applied Sciences 11(1) 13–6
[11] Permyakov M B, Pivovarova K A and Domnin V YU 2016 The processes of obtaining rubber crumb and its application in the system of road fencing Vestnik nauki i obrazovaniya 9(21) 28–31
[12] Andreev A V 2005 Determination of transport and operational parameters of roads with asphalt concrete coatings based on slag materials (Voronezh: dissertation and abstract VAK 05.23.11)
[13] Veselov A V, Permyakov M B, Davydova A M and Pivovarova K A 2015 Possible directions for improving domestic roads Tekhnicheskie regulirovanie v transportnom stroitel'stve 5(13) 25–33
[14] Voronin K M 2009 The Scientific Research, Innovations in Construction and Engineering Communications in the Third Millennium Bulletin of the Nosov Magnitogorsk State Technical University 2 49–50
[15] Permyakov M B and Permyakova A M 2013 Scientific directions of the departments of the Faculty of Architecture and Civil Engineering Arhitektura. Stroitel'stvo. Obrazovanie 2 10–7
[16] GOST 9128-2013 2013 Mixtures of asphalt concrete, polymer-asphalt concrete, asphalt concrete, polymer-asphalt concrete for roads and airfields. Mezhgosudarstvennyj standart Tekhnicheskie usloviya
[17] Vyatkina M F and Kuimova M V 2015 On the effect of exhaust gases on a car on human health Molodoj uchenyj 10 87–8
[18] Gluhovskij V D and Pahomov V A 1978 *Slag-alkali cements and concrete* (Kiev: Izdatel'stvo "Budivel'nik") p 184

[19] Artamonova A V 2016 *Slag alkali binder and concretes based on electric steelmaking slags of centrifugal impact grinding* (Magnitogorsk: dissertation and abstract VAK 05.23.05) p 173

[20] Butt Y M, Sychev M M and Timashev V V 1973 *Workshop on the chemical technology of binders* (Moscow: Vysshaya shkola Press) p 504

[21] Varlamov A A, Rimshin V I and Tverskoi S Y 2018 Durability of buildings in urban environment *Materials Science Forum* 931 MSF pp 340–5

[22] Varlamov A A, Rimshin V I and Tverskoi S Y 2018 The General theory of degradation *IOP Conference Series: Materials Science and Engineering* 463(2) 022–8

[23] Varlamov A A, Rimshin V I and Tverskoi S Y 2018 The modulus of elasticity in the theory of degradation *IOP Conference Series: Materials Science and Engineering* 463(2) 022–9

[24] Varlamov A A and Rimshin V I 2019 *Models the Behavior of Concrete. The General Theory of Degradation* (Moscow: INFRA-M Press) p 436

[25] Vetrova V V 2006 *Influence of anti-icing reagents on road conditions and traffic safety on highways* (Moscow: dissertation and abstract VAK 05.23.11)