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Assessment of Reinforcement Corrosion in High-Filled Ash-Containing Concrete

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Abstract: ***Article considers ways to improve the durability and operational characteristics of reinforced concrete structures designed for railway transport by adding active mineral additives such as fuel ash and other chemical modifiers.***

Key words: high-strength concrete, mineral aggregate, crack resistance, frost resistance, water impermeability, chemical additives, fuel ash, reinforcement corrosion.

I. INTRODUCTION

A distinctive for the last few years trend of intensive transport system development in Uzbekistan, particularly in the railway sector, dictates wider use of modern high-quality construction materials while laying new and upgrading existing railway tracks. Concretes play important role in the transport systems, ensuring transportation quality and traffic safety, because they serve as a main material in the majority of railway buildings and structures. It is well known that design and operation of railway transport structures require using concretes with high strength, frost resistance, impermeability and crack resistance characteristics. These concrete properties ensure buildings and structures reliability and durability. Preparation of concrete, conforming to pre-determined requirements for high-quality operational characteristics, represents a complex, multi-phased process where each stage shapes quality of finished material. One of the most critical stages in this process is design of concrete composition. Many unsolved and disputed issues remain to this day regarding maximum allowable content of various concrete components. In the article we will attend to one of such components. As is known, concrete for railway buildings and structures transformed itself over the last years from three-component to multi-component system which mandatorily includes mineral and chemical additives.

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Fuel ash derived in heat power plants is nowadays an indispensable attribute of the modern railway concrete preparation technology. German experience shows that the use of ash, as a mineral additive in the manufacture process of concrete and reinforcement concrete structures and products, results in substantial technical and environmental advantage [1-4].

II. CHARACTERISTICS OF MATERIALS

Pozzolanic properties of the ash have a positive effect on the concrete strength. Also, hydrosilicates are formed which have a favorable influence on the concrete durability. Increased number of newly formed crystals contributes to chemical densification and lesser pores in hardened concrete.

Many top managers of Uzbek manufacturing companies are skeptical about possibility of adding HPP fuel ash to the concrete in sufficiently large volume due to the risk of disturbing the passive state of reinforcement in the concrete. In this connection, we faced the issue of studying the reinforcement steel's corrosion state in the concrete containing HPP fuel ash in the proportion up to 30% of concrete mass.

III. TESTING METHODOLOGY

Under studies corrosion state of Ст-3 reinforcement steel was analyzed in concrete samples corresponding to B30 class. Reinforcement corrosion was assessed using methodology developed by the Scientific research institute of concrete and reinforced concrete (NIIJB) [5,6]. Following was calculated according to the methodology:

- weight loss of reinforcement bars under changing sample water-air storage conditions;
- concrete carbonation depth under natural and artificial aging (at excess CO_2pressure);
- anodic polarization curves of reinforcement steel in concrete.

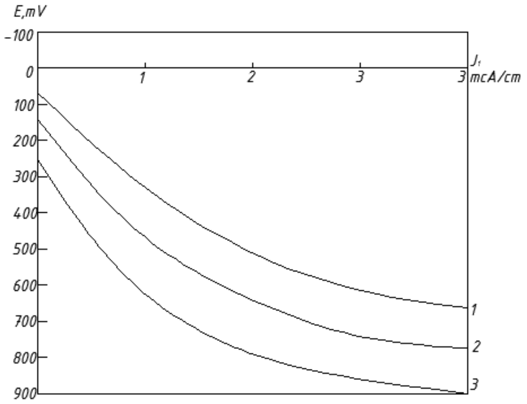
IV. RESULTS AND DISCUSSION

As is known, steel remains in a passive state, if while measuring anodic polarization curve, current density of max. 10 mcA/cm^2 corresponds to +300 mV potential.

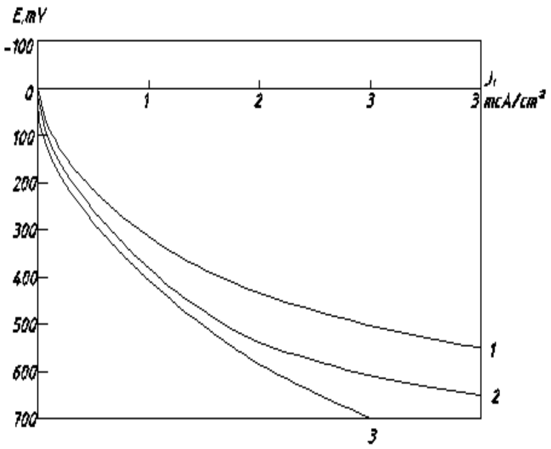
Study findings are provided in the table 1 and 2 and on the Fig. 1 and 2.

Anodic polarization curves of reinforcement steel in the non-filled concrete

a)



b)

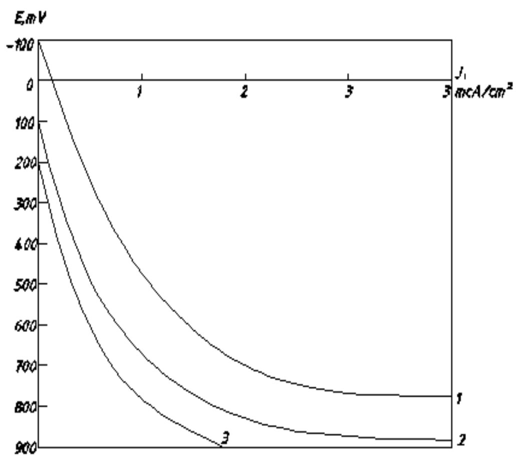


a) **normal-cured concrete, b) concrete after steam treatment**

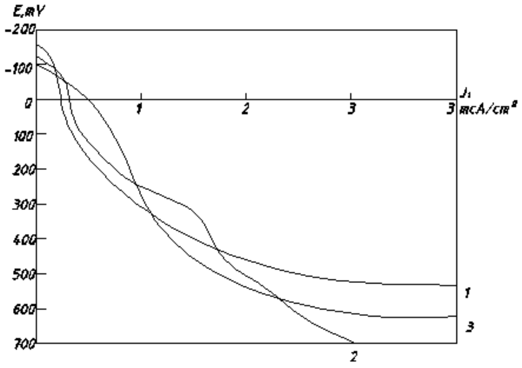
1,2,3 – at accelerated tests after 1, 3, 6 months respectively

Fig. 1. Anodic polarization curves of reinforcement steel in the non-filled concrete

a)



b)



a) **normally hardened concrete, b) concrete after steam treatment 1,2,3 – at accelerated tests after 1, 3, 6 months respectively**

Fig. 2. Anodic polarization curves of reinforcement steel in the filled concrete

Fascinating data were obtained when concrete carbonation was studied under natural and artificial aging. Steam treatment resulted in a more intensive carbonation process in artificially aged samples compared with naturally aged samples, which is consistent and attributable to higher post-treatment concrete structure imperfections. Different scene is observed in the samples of more optimally filled concrete composition. Carbonation depth of these samples was, in each case, lower than in those of reference composition.

Table 1 Kinetics of Cт-3 reinforcement steel weight loss in the concrete under changing water-air storage settings

Composition	Conditions of hardening	Weight loss 10^{-3}g			Weight loss per 1 m^2 of surface, g/m^2		
		1 month	3 months	6 months	1 month	3 months	6 months
Reference sample	Normal storage	0,37	0,40	0,50	0,29	0,32	0,39
Reference sample	After steam treatment	0,12	1,25	1,40	0,09	0,99	1,11
Optimally filled	Normal storage	0,50	0,65	0,70	0,39	0,51	0,56
Optimally filled	After steam treatment	0,65	1,60	2,35	0,51	1,27	1,87

Table 2 Concrete carbonation depth

Composition	Conditions of hardening	Carbonation depth, mm					
		Under normal storage			At excess CO_2 pressure		
		1 month	3 months	6 months	8 hours	24 hours	72 hours
Reference sample	Normal storage	2,5	3,0	4,0	3,0	5,0	10,0
Reference sample	After steam treatment	3,5	4,5	5,0	4,5	6,5	12,0
Optimally filled	Normal storage	2,0	2,0	3,0	2,0	4,5	8,0
Optimally filled	After steam treatment	3,5	4,0	4,0	3,0	4,5	8,0

Moreover, steam treatment mode did not significantly impact gas permeability of concrete, and in consequence, carbonation depth of normal and steamed concrete were almost identical. This is apparently attributable to denser concrete structure formed due to reduction of water-cement ratio and additional number of de-novo syntheses formed due to interreaction of $Ca(OH)_2$ with active acidic ash oxides, especially in the steam treatment mode. Both factors have a positive influence on concrete structure with general reduction trend observed in concrete gas permeability and porosity imperfections as a result of stream treatment.

Figures 1 and 2 show anodic polarization curves of samples measured after 1-6 months of varied storage. Following regularities were revealed:

- in each case stable condition of steel reinforcement is observed, because current density at E=300mV doesn't exceed 1-2 mcA/cm^2;

- passivation interval in each case exceeds 500 mV;
- in all the samples, except for those made of optimal concrete composition, increased passivating influence of concrete on reinforcement is observed after steam treatment, as evidenced by decreasing current density and increasing passivation interval as samples storage period increases. Exceptions are samples of optimal composition after steam treatment, which show typical stable E values regardless of storage period;
- normal-cured concrete has a more intensive passivating influence on the reinforcement than steam-cured concrete, which is attributable to difference in $Ca(OH)_2$ concentration of concrete in both modes. The last-mentioned fact correlates well with pH indicators of water extract;
- normal-cured reference concrete, pH is within 12.28 to 13.02;
- steam-cured reference concrete, pH is within 12.08 to 12.47;
- normal-cured optimal concrete composition, pH is within 12.09 to 12.81;
- steam-cured optimal concrete composition, pH is within 11.90 to 12.20;

Studies show that the ordinary Cт-3 isn't exposed to corrosion process in the concrete that contains fuel ash in the proportion up to 30% of concrete weight.

Study findings suggest the need to review many concepts of fuel ash applications in the concrete composition. Particularly, it seems expedient to revise generally accepted formula [7,8] determining the minimum allowed cement concentration in ash-containing concrete by adding the factor K_T to take into account the concrete preparation technology. With K_T factor introduction, formula will be as follows:

$$Ц = K_T \cdot (0.4 + 0.004 \cdot A) \cdot P,$$

where A – content of unburnt coal particles in the ash, %;
P – amount of ash, kg/m3.
K_T is suggested to be adopted equal to:
1.00 – for traditional concrete preparation methodology and
0.9 – for separate methodology.
K_T factor is to be more accurately defined in the future studies to take into consideration the technological parameters of concrete preparation.

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