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Peculiarities of Helio-Termal Treatment of Reinforced Concrete Structures in the Conditions of Extreme North

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ABSTRACT

Helio-thermal treatment is based on the principle of impact of solar radiation on hardening concrete in helioforms with translucent heat-sealing coating. Helio-thermal treatment technology efficiency is provided through the use of the natural density solar radiation flows and reaches 70 \div 100 kg of equivalent fuel per 1 cubic meter of reinforced concrete products as compared with conventional heat treatment of precast reinforced concrete structures in the cells with the use of steam, airsteam mixture, hot air, etc. Based on the analysis of approaches to the implementation of technology on helio-thermal treatment of concrete and reinforced concrete structures was disclosed the possibility of using this method in conditions of short and hot summer in the territory of the Russian Extreme North.

KEYWORDS

Helio-thermal treatment; reinforced concrete structures; helioforms with translucent heat-sealing coating; helio-thermal treatment in conditions of the Russian Extreme North. ARTICLE HISTORY Received 27 May 2016 Revised 4 November 2016 Accepted 7 December 2016

Introduction

Domestic and foreign experience of using solar energy to accelerate the hardening of concrete shows that the main direction is the use of various heliochambers (helioplants) for the two-step and one-step heat and humidity treatment of precast concrete (Dmitrieva, 1976). In the mid of 1980s. based on climatological data on radiation and temperature conditions of the southern regions of the USSR the Institute Concrete and Reinforced Concrete Research Institute of the State Construction Committee, VNIPI (All-Russian Scientific Research and Design Institute for Industrial Technology) Teploproekt on Minmontazhspetsstroya USSR and others developed methods for calculation of the duration of the seasonal period of solar power ground operation, as well as requirements for materials for concrete, and heliocovers helioforms.

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This area was investigated by M.S. Marshunova and A.A. Mishin (1988), Ye.Yu. Grigoryan (2007), A.A. Paschenko (1991), S.V. Alexandrovskiy (1979), I.I. Ulitskiy (1967), M. Singh (2002). Basic concepts and methodology for helio-thermal treatment with the definition of seasonal period of operation were developed by E.N. Malinskyi and others (1983), V.P. Rybasov and I.V. Bykova (1988), as well as by I.B. Zasedatelev, S.A. Mironov and others (1983), S.A. Shifrin and A.V. Tkachev (1985) in the Manual on helio-thermal treatment of concrete and reinforced concrete products using SVITAP coatings (for SNIP 3.09.01-85) (1987). This manual was published on the Resolution of the section of section of concrete technology of NTS Concrete and Reinforced Concrete Research Institute USSR State Committee and at the time without the consent of Concrete and Reinforced Concrete Research Institute by the decision of the USSR State Committee on Inventions and Discoveries and directives of the USSR State Construction Committee, open publication of materials on the projected and current helio plans was prohibited.

According to Clause 2.1 and 2.2 (Manual on helio-thermal treatment of concrete and reinforced concrete products using SVITAP coatings (for SNIP 3.09.01-85), 1987), the determination of the duration of the season of use of helioforms with translucent thermal proofing coating - SVITAP and acceptable products forming period during daylight hours should have been made by comparing the total amount of solar energy, reaching the unit of surface of hardening products without concrete form, as well as the heat amount emitted during hydration of the cement with the required energy consumption to ensure the required temperature requirements of concrete hardening and the amount of solar radiation coming onto the surface of the product.

Recognized in the field of concrete technology in conditions of dry hot climate are the works of Y.M. Bazhenov (1988), M.M. Dmitrieva (1976), V.P. Rybasov and I.V. Bykova (1988) and others, who investigated domestic and foreign experience.

Recent studies on the use of solar technology of concrete and reinforced concrete products with the use of innovative materials - the complex binders allowed the authors S.A. Aliev and S-A.Yu. Murtazaev (2012) recommending concrete composites of strength classes from B15 to B25, which in the conditions of a dry hot climate significantly reduce the cost of both the heat and humidity processing of products, and the purchase of expensive binders, surface active agents (SAA).

To areas with favorable conditions for solar energy utilization referred the regions with dry hot climate, characterized by long hot summer, high air temperature - absolute maximum, equal to or exceeding 40° C and average maximum temperature of the hottest month, equal to or exceeding $20 \div 30^{\circ}$ C (with an average relative humidity of the hottest months of at least $50 \div 55\%$) (Rybasov & Bykova, 1988).

However, these innovative technologies can be applied also in a hot summer time conditions of the Extreme North in view of the flow of direct and diffuse radiation, sun altitudefor manufacture of monolithic and precast concrete structures and products.

Materials and Methods

Conventional heat treatment of precast concrete structures and products is carried out in the chambers of periodic or continuous action in special thermoforms, Thermal design bundles and battery moulds or under portable caps using steam,

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steam-air mixture, hot air, electric power, solar power, natural gas combustion products.

However, the wide practical application currently have helio-thermal processing technologies, the efficiency of which is ensured by the use of solar radiation flux of natural density (without the use of energy hub and the intermediate heat transfer agents) and reaches $70 \div 100$ kg of standard fuel per 1 cubic meter of concrete products.

The technology of thermal processing of products in helioforms with translucent heat-sealing coating (helio-thermal treatment using SVITAP coatings) in hot climates is an easy way to helio-thermal treatment in open workshops and yards without use of extra-redundant power sources, where a closed air layer between the fresh concrete surface and the bottom surface of the SVITAP coating allows (Manual on helio-thermal treatment of concrete and reinforced concrete products using SVITAP coatings (for SNIP 3.09.01-85), 1987):

- provision of desired system heat accumulation effect;

- obtaining qualitative surface of hardening product and maintaining of optical characteristics of translucent materials used due to lack of contact of the coating with the surface of fresh concrete;

- manifestation of the "greenhouse effect" translucent materials used due to multilayer structures;

- creation of the required conditions for concrete hardening by humidity and other.

The products harden in helioforms within $20 \div 22$ hours, while concrete warming up under SVITAP coating is performed under favorably soft mode when a temperature rise to $50 \div 70^{\circ}$ C occurs within $5 \div 7$ hours, then conventional isothermal exposure- $5 \div 7$ hours and slow cooling of the concrete at night at a temperature of $35 \div 50^{\circ}$ C at a speed of $1.5 \div 2.5^{\circ}$ C/h (depending on the concrete products massiveness and brand) (Zasedatelev et al., 1983).

Therefore, such heat treatment technology in helioforms with translucent heatinsulating coating - SVITAP (Zasedatelev et al., 1983) was recommended for concrete and concrete products of solid section with the thickness from 100 to 400 mm of heavy concrete grade M200 (class B15) and above, produced in open workshops and yards and, above all, for a variety of flat products:

- plates (slabs, road, foundation, basement, balconies, eaves, heating lines, staircases and others.);

- various panels, including internal wall; strip foundations blocks, columns, beams, frame structures, piles, bridges, etc.

It should be noted that in the case of solar energy deficiency, according to the Manual on helio-thermal treatment of concrete and reinforced concrete products using SVITAP coatings at year round grounds, approved by NIIZhB (Concrete and Reinforced Concrete Research Institute) of the State Committee for Construction of the USSR (1988), provided the use of additional resources (to compensate the deficiency of solar energy at thermal treatment of products) taking into account the expected modes for different climatic conditions.

Thus, the method of combined helio-thermal treatment of concrete products represented energy efficient method for year-round use at yards, located to the north of $45-50^{\circ}$ of north latitude, and was recommended for use in the autumnwinter-spring seasons at the sites located to the south of $45 \div 50^{\circ}$ north latitude.

I.B. Zasedatelev, S.A. Mironov and others (1983), recommended to carry out pre-cast concrete helio-thermal treatment:

- Upon occurrence of sunny weather and air temperature at 1 p.m. of not less than $20 \div 25^{\circ}C$;

- when using compounds increasing the absorption of solar energy by concrete, then at the temperature + $18 \div 20^{\circ}$ C;

- in the case of use of fast hardening cement, chemical additives or pre-heated concrete mix (including due to use of mixing water, heated by solar radiation by means of systems of engineering helio-equipment) and other technological measures that allow to intensify the concrete hardening in helioforms, then the transition. to helio-thermal treatment of products was recommended to carry out in sunny weather at air temperature at 1 p.m. of + 15°C.

Therefore, in the absence of sunny weather in summer for products warming up was recommended to use an additional source of energy (steam, electricity) or to increase the duration of product staying under the SVITAP coating due to diffuse radiation.

For the southern republics of the former USSR such combined helio-thermal treatment allowed (Manual on helio-thermal treatment of concrete and reinforced concrete products using SVITAP coatings at year round grounds, approved by NIIZhB (Concrete and Reinforced Concrete Research Institute) of the State Committee for Construction of the USSR, 1988):

- all year-round operation of solar power grounds;

- expansion of areas and climatic conditions for solar power grounds functioning and development of manufacture of precast concrete with low positive and negative temperatures of external air;

- savings of traditional forms of energy during heat treatment of products in the warm period of the year up to 100%, and in the autumn-winter-spring periods - up to 30-40%;

- implementation for solar power grounds of 2-shift operation;

- increase in forms turnover (more than one turnover per day);

- increase in concrete strength after helio-thermal treatment (stripping, transfer or transport);

- increase in the range of products manufactured according to solar technology at the grounds due to manufacturing of: massive product with the thickness exceeding 400 mm; thin-walled products with the thickness of up to 100 mm, products of complex shape with voids etc., three-layer sandwich wall panels; prestressed structures of varying massiveness; components and structures from lightweight concrete with porous aggregates; products from heavy concrete of brand M100 (class B7,5) and above, as well as products prepared with different cements, including pozzolanic, etc.;

- significant reduction of environmental pollution with combustion products, etc. as compared with conventional methods of concrete steaming.

During helio-thermal treatment should be monitored following concrete strengths: stripping, transport and at design age.

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Therefore, it should be considered that products helio-thermal treatment with he use of SVITAP coating is carried out during 20-22 h., and during this time the strength of concrete products, manufactured on the basis of Portland cement, approximately reaches the grade strength of the age of 28 days (Manual on heliothermal treatment of concrete and reinforced concrete products using SVITAP coatings (for SNIP 3.09.01-85), 1987):

- for concrete g	grade M200 (class B15)	45 –	55	%;
- same	M300 (class B25)	55 –	65	%;

Stripping strength of the concrete is a compressive strength, at which are provided stripping (form removal) and safe intrashop (intraplant) transportation of products without damaging them, the value of which is set by technological production regulations for each type of the product by the manufacturer. Therefore, appropriate temperature and humidity conditions for achieving at the subsequent handling and storage handling the transportation strength by the time of shipment of products from the manufacturer and the design strength within prescribed time limit must be provided.

Thus, manufacture of products using helioforms with SVITAP coatings enables the daily forms turnover, as the concrete gains strength within 20-22 h , the magnitude of which is sufficient for products demoulding. The use of helio-thermal treatment when manufacturing concrete products at the grounds in areas with a hot climate allows you to completely abandon the traditional steaming tin the springsummer-autumn periods of the year and to ensure (Manual on helio-thermal treatment of concrete and reinforced concrete products using SVITAP coatings (for SNIP 3.09.01-85), 1987):

- obtaining high quality concrete with its daily strength in products reaching 45-70% R28 (and, consequently, at daily cycle of forms turnover);

- saving fuel and energy resources, reaching 70-100 kg fuel equivalent per 1 $m^{\scriptscriptstyle 3}$ of concrete and concrete products

- reduction in operational labor costs through eliminating the part of the staff (employees of boiler and auxiliary services, steamers et al.);

- reduction in water consumption for technological needs (more than 0.5 t / $m^{\rm 3}$ of products);

- increase in durability of metal forms that do not suffer corrosion processes due to lack of steam environment;

- maneuverability when using ground production facilities due to abandoning fixed positions for the thermal treatment of products (steaming chambers, etc.), in some cases, exclusion of heat transfer agent supply communications;

- reducing in construction and installation work cost (20-30%) at construction of new ground due to refusal from construction of boilers with ancillary facilities, communications for the heat transfer agent supply, steaming chambers, sewage, etc.;

- reduction of precast concrete cost at the grounds operated by 3-6 rubles per 1 m3 of products (in 1991 prices).

In Manual on helio-thermal treatment of concrete and reinforced concrete products using SVITAP coatings (for SNIP 3.09.01-85) (1987) the following solar power grounds types are recommended:

- solar power grounds on existing reinforced concrete products plant: seasonal solar power grounds at the plant; year-round solar power grounds at the plant; outrigger, freestanding (seasonal or year-round);

- new year-round solar power grounds as part of the newly designed enterprises of precast concrete with application for the cold season of additional back-up energy source: steam in the presence of the boiler or CHP (with an excess of steam), electricity or other heat transmitting agent (in the absence of steam);

- mobile seasonal and year-round solar power grounds.

It is important to note that mobile solar power grounds are recommended for the construction of linear structures (canals, highways, energy routes, and others.), as well as for underdeveloped and hard-to-reach areas (mountains, islands, etc.) that do not require a permanent base of construction industry and, usually, designed with a minimal amount of long-line process equipment with placing near the water source and near existing excavating plant.

Therefore, in our country since the mid-70s to mid-80s of the twentieth century for the separate application of thermal treatment of concrete and reinforced concrete products were developed:

- for heat treatment - Manual on the thermal treatment of concrete and reinforced concrete products (1974);

- for helio-thermal treatment - Manual on helio-thermal treatment of concrete and reinforced concrete products using SVITAP coatings (for SNIP 3.09.01-85) (1987) and Manual on helio-thermal treatment of concrete and reinforced concrete products using SVITAP coatings at year round grounds, approved by NIIZhB (Concrete and Reinforced Concrete Research Institute) of the State Committee for Construction of the USSR (1988);

- for the use of electric power - "Guidelines for electro-thermal treatment of concrete."

Results and Discussion

At the present stage the research on the use of solar technology of concrete and reinforced concrete products is associated with the use of innovative materials - the complex binders, which allowed the authors S.A. Aliev and S-A.Yu. Murtazaev (2012), to recommend concrete composites of strength classes from B15 to B25 in conditions of a dry hot climate, which greatly reduces the cost of both heat and humidity treatment of concrete products, and for the purchase of expensive binders, surface active agents (surfactants). Complex binders formulation was obtained by mixing cement with mill ground fillers with surfactant additives, as well as through co-grinding of cement, filler and surfactant additives in the research center of the collective use "Nanotechnologies and nanomaterials" GGNTU named after academician M. D. Millionshikov. As raw materials for the implementation of pilot studies were used ground mixtures of Portland cement and pre-crushed bottom-ash mixture from CHP Grozny or fine sands, modified with an active mineral additive "Bio-NM" (Bazhenov, 1988; Aliev & Murtazaev, 2012; Marshunova & Mishin, 1988; Murtazaev et al., 2015a; 2015b; Kuladzhi et al., 2015).

The Russian Federation is located in the four climate zones - arctic, subarctic, temperate and sub-tropical, and therefore all over the territory of the country there is a big difference in the seasonal entry of solar heat, which depends on the variation of the angle of incidence of sunlight on the seasons and on the sunshine duration time (Fig. 1). The amount of solar energy reaching the earth's surface at

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the North of the European part of the country is as follows: in the winter - less than 0.8 kWh/m² per day, and in the summer - more than 4 kWh/m² per day. According to Atlas of the energy balance of the North Pole region (1992), the amount of solar energy supply from the 4 to 4.5 kWh/m² per day is also observed in the regions: Krasnodar Krai, North Caucasus, Rostov Region, south end of Volga river basin, the southern regions of Novosibirsk, Irkutsk region, Buryatia, Tyva, Khakassia, Primorsky and Khabarovsk Territory, the Amur region, Sakhalin Island and in vast areas from the Krasnoyarsk Territory to Magadan, Severnaya Zemlya, North-East of Yamalo-Nenets Autonomous District.



Figure 1. Map of climatic zonation (Research and Application guide to the Russian climate (Arctic region): Solar radiation, 1997).

Arctic Circle is a territory to the North of polar circle (66°33' n.l.) is in the arctic and subarctic climates and consists of four climatic zones: The central part of the Arctic Basin, Atlantic, Siberian, Pacific. Above the Arctic mainland in July the average monthly air temperature at the Polar Circle latitude is 13°C, on the coast 11°C, in the north of the Taimyr and in the southern parts of the Laptev Sea and East Siberian - 3 °C. Isotherm of 0 °C coincide with the boundary of multi-year ice to the north of 85 ° N, where the average air temperature in July is 2°C, and the frequent changes of air masses lead to the day to day variability in air temperature.

The annual amounts of the radiation balance in the Arctic vary from 85-100 MJ/cm² in polar region to 850-1050 MJ / cm2 at the latitude of the Arctic Circle. In mainland of Arctic at the west and east 35-40% of the radiation balance goes for air heating, in the north of Siberia - 15-20%. The annual amount of solar radiation is determined by the place latitude and cloudage alteration, so at the same latitude on the west of Barents Sea it is 2300 mJ/cm², and in Eastern Siberia it increases to 3350, and then decreases to 3150 MJ/cm² in Chukchi Sea region. In the temperate zone due to the length from north to south, the total solar radiation varies from 293 to 544 kJ/cm² per year from the northern to the southern part. Comparative characteristics of the total solar radiation per year in the north and the south of Russia shows that in the Pechora river Basin (Nenets Autonomous District) total annual solar radiation reaches 2700 mJ/m², in the South - 4800-5050 mJ/m², in the Caspian lowland (115-120 kcal/cm²) (Aliev, 2011).

Analysis of climatic conditions of the Extreme North of Russia makes it possible to recommend for the conditions of the Extreme North hot and dry summer climate application of innovative concrete composites for the production of reinforced concrete structures, which at application of complex binders are cheaper material than similar concrete on cement, and their application to accelerate the concrete hardening of concrete at helio-thermal treatment reduces their cost (Aliev & Murtazaev, 2012; Gairabekov et al., 2015; Murtazaev et al., 2015b; Mazhiev & Betilgiriev, 2012; Krutov, 2007).

Indicators by cold-resisting quality and waterproofing qualities of concrete composites manufactured on the cement and complex binders are given in Table 1(Aliev, 2011).

Concrete type	Mass, kg		Water absorption capacity, %		Δ٧,	Brand by cold-	Brand by waterproofin				
	Initial	Saturated	By mass	By volume	cm ³	resisting quality F	g qualities W				
A. Helio-thermal treatment with the use of SVITAP coating											
Concrete composite on CB	2.17	2.24	3.21	6.53	0.35	300	12				
Concrete on PC	2.02	2.14	5.90	12.32	0.95	150	8				
B. Steam treatment in steam-curing chamber											
Concrete composite on CB	2.14	2.25	5.30	11.31	0.65	200	10				
Concrete on PC	2.01	2.14	6.17	12.23	0.95	100	6				
C. Hardening in humidity chamber											
Concrete composite on CB	2.15	2.21	2.70	5.91	0.30	300	12				
Concrete on PC	2.03	2.17	6.03	12.24	1.0	150	8				
D. Maturing without cure											
Concrete composite on CB	2.10	2210	5.22	10.95	1.95	100	8				
Concrete on PC	1.98	2.15	11.21	22.10	2.78	50	6				

 Table 1. Cold-resisting quality and waterproofing qualities of concrete composites, hardened in different conditions (Aliev, 2011)

It should be noted that the manufacture and use of concrete composites on the basis of complex binders in a dry hot climate of the Extreme North, can allow to simultaneously perform the following tasks:

- Improving the environmental situation in the northern settlements through the use of bottom-ash and slag waste of boilerhouses;

- reduction of concrete composites production costs;

- reduction of cost for thermal and wet treatment of concrete composites products.

Conclusions

1. At the bottom of helio-thermal treatment is placed the principle of influence of solar radiation of varying flux density on the hardening concrete, and for the combined helio-thermal treatment - selection of an optimal combination of controlled thermal energy supply from the additional-redundant sources to provide daily technological cycle in the presence of deficit of solar radiation in summer: rain, clouds, fog.

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2. In conditions of short but hot summer of the Extreme North it is recommended to implement helio-thermal treatment technology for monolithic concrete and reinforced concrete, which requires relevant research in the Extreme North conditions, and relevant studies on the use of concrete composites, as cheaper materials than similar concrete on cement (Murtazaev et al., 2015a).

Disclosure statement

No potential conflict of interest was reported by the authors.

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