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SURFACE HEAT TREATMENT OF FACING AND OTHER MATERIALS WITH CONCENTRATED SOLAR ENERGY

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Surface treatment of building materials, ornamental ceramics, cover-coat enamels, blast-furnace and open-hearth slags, and natural stones of the basalt type has been carried out with the use of solar furnaces and their simulators for the purpose of obtaining protective-decorative vitreous and glazed coatings. The specific energy consumption and the optimum heat fluxes necessary to obtain high-quality coatings have been determined. The results of searching investigations testify to the fact that renewable environmentally safe concentrated solar energy can be utilized in industry and the national economy for surface heat treatment of different materials by melting them in the air.

One way of utilizing solar energy as an unusual environmentally safe renewable source is realization of high-temperature technological processes in solar furnaces. Searching investigations of such processes that could be realized at the present level of development of solar engineering have been conducted for some time at the Institute of Problems of Materials Science of the National Academy of Sciences (IPMS NAS) of Ukraine [1]. In the opinion of the authors, surface heat treatment of building, facing, and other materials is a promising process for the formation of vitreous coatings for protective, decorative, and other functional purposes. In this work, we present certain results of investigations in this direction, which were obtained in the last few years. For the sake of completeness, we will briefly describe the results of an earlier study of the fusion of building materials such as slag concrete and ceramic tile [2, 3].

The investigations were carried out on slag-concrete products (All-Union State Standard 6133-75) consisting of blast-furnace slag and cement. We used an SGU-6 setup of the IPMS NAS of Ukraine as the source of concentrated solar energy [2].

The rate of the process of fusion of a surface is determined by the composition, relief, and physicochemical transformations in the process of fusion and depends on the density of the radiant flux. The optimum velocity of travel of a product in the focal spot, i.e., the velocity that provides the required quality of the treated surface, depth of fusion, and moisture resistance, the absence of cracks, the required appearance, etc., was found in the course of the experiments.

The highest-quality surface is obtained with a velocity of travel of 1 mm/sec and a depth of fusion of 0.8–1.0 mm. The microstructural analysis of the metallographic cross section of a fused slag-concrete sample has shown that the upper layer is covered with a thin (to 1 mm) vitreous, not crystallized transparent dark-brown film with a refractive index ρ from 1.630 to 1.614 (this is iron- and manganese-stained glass of a complex composition).

Since solar radiation is variable, we determined the dependence of the velocity of travel of a product with an optimum state of the treated surface on the normal solar radiation. This dependence is of practical importance, since in the case of realization of processes similar to decoration, there is no need to use special means for controlling the thermal parameters of the setup, because the deviations of the normal solar radiation

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are compensated for with the corresponding changes in the rate of the process. As the comparison quantity characterizing the specific consumption of heat, the effective heat of fusion of the surface H_{ef} was determined:

$$H_{ef} = Q/(BV).$$

The effective heat of fusion of the surface of a slag-concrete product, obtained on the basis of experimental data, is about $1.36 \cdot 10^4$ kJ/m^2, which agrees well with the consumption of heat in the case of use of a plasma flow [4].

The possibility of single burning of ceramic glazed tiles with different coatings, produced at the "Keramik" Kiev Plant, was investigated. The duration of burning of ceramic samples depends on the density of the radiant heat flux and also on the chemical composition, the emissivity factor, and the thermophysical and other properties of the glaze. The dependence of the duration of burning of ceramic samples with different glaze coatings on the heat-flux density has been obtained. Visual examination has shown that the tiles have a plane (without ripples and waviness) glaze surface.

A determination of the physicomechanical characteristics of the glazed coatings obtained on samples of ceramic tiles was carried out at the "Keramik" Plant, which has supported their conformity to the requirements of the All-Union State Standards 13996-84 and 6141-91: water absorption, 11-12%; shrinkage, 3-3.5; bending strength, 25-35 MPa; heat resistance, up to 150^{o}C; Mohs's scratch hardness of the face, more than 5; frost resistance, 25 cycles of alternating freezing to a temperature of -15^o C and corresponding defreezing. The specific consumption of heat H_{ef} necessary for the attainment of the required quality of the fused surface was determined from the formula $H_{ef} = qt$. For a flux density of $q = 350$ kW/m^2, the quantity Q substantially depends on the color of the stain. For higher densities of the flux, the specific consumption of heat depends insignificantly on this parameter and averages $3 \cdot 10^4$ kJ/m^2, which is four times lower than with the available technique [3].

With the aim of extending the possibility of utilizing concentrated solar energy, we have conducted experiments on the production of ornamental ceramics with application of a pattern by the method of decalcomania. This method is most commonly used for decorative designing of ceramic products, whose basis is the transfer of a pattern made by the method of printing arts from paper to the surface of a ceramic product with subsequent heat treatment. The investigations were carried out with the use of a "Uran-1" optical furnace with xenon lamps whose radiation is close to solar radiation in spectral composition. As the initial samples, we used ceramic tiles produced at the "Keramik" Kiev Plant and decals of the Kiev Porcelain Works. The transfer of decals to the ceramic samples was carried out according to a conventional technique. The regime of burning of products depends on their color, which is determined by the composition of ceramic paints. The most usual range of burning temperatures is 770–850^{o}C. The temperature on the setup was controlled by defocusing and changing the current in the discharge lamp. The burning time was determined by the value of the heat flux and by the physicochemical and thermophysical characteristics of the paints and the ceramic base. In the investigations, the burning time was about 15 min for fluxes of 70–100 W/cm^2. So as to prevent the cracking of the ceramic base, the process of preliminary heating and cooling of the sample must be gradual and uniform. The most demanding period of heat treatment was the regime of increase in the temperature within 600–850^{o}C. As this takes place, the flux in the paints begins to fuse and the glaze begins to soften. A very important stage in the production of ornamental ceramics is cooling in the temperature range 520–600^{o}C, in which the softened glassy mass changes in the process of solidification to a solid, colored, vitreous coating keyed well to the glaze. The obligatory cooling of samples was 2 min for a radiant flux of ≈ 30 W/cm^2. Visual examination and comparison of the samples produced to industrial products testify that their quality is sufficiently high.

The experiments on production of enamel coatings on a metal base were carried out on a "Uran-1" artificial-radiation setup. Samples of size $\approx 20 \times 20$ mm were produced at the Novomoskovsk Tube Plant according to a standard technique. A ground-coat enamel providing a tight linkage with the metal and the cover-coat enamel was applied on billets of sheet, cold-rolled, low-carbon steel (All-Union State Standard 9045-80), which were annealed at a temperature of 600–650°C for removal of the lubricant, pickled in acids, washed in a soda solution, and dried. The thickness of the ground coating was 0.18 mm. After drying and burning, the samples were covered with a cover-coat enamel. The slip of the cover-coat enamel was somewhat different from the slip of the ground-coat enamel. The thickness of the ground-coat and the cover-coat layers together was 0.6 mm.

In the experiments, we used cover-coat enamels of four colors: the white enamel contained a titanium whitener, the gray enamel contained a titanium whitener with addition of an opacifier, the brown enamel contained salts of manganese, iron, and chromium, and the red enamel contained a selenium-cadmium pigment. So as to prevent the cracking of the enamel in burning, the samples must be heated gradually and uniformly. This regime was realized through progressive movement of a sample to the focal spot for 4–5 min with subsequent keeping in a heat flux of 55–65 W/cm^2 for 4–5 min depending on the color. For the white and gray enamels, the heat flux was somewhat increased in the process of fusion. The temperature of burning of the cover-coat enamels was 830–860°C. The process of cooling of an enamel is very important. Both the cooling and heating of the burned products must be carried out in a strictly verified regime, especially in the temperature range 520–600°C, in which the softened glassy mass changes to a solid colored coating. Under our conditions, the process of cooling was carried out through gradual removal of the samples from the focal spot for 2–3 min. Visual examination of the samples and comparison of them to industrial products have shown that the coatings produced are of a sufficiently high quality and have the required color, resistance to heat, and mechanical strength.

The possibility of obtaining vitreous coatings on natural stones of the basalt type under the conditions of radiant heating has been evaluated. Basalt is used as a building material that is not subjected to heat treatment as a rule. A fused basalt surface has a beautiful glossy appearance of different shades of black (depending on the chemical composition). The melting temperature of basalt is $\sim$ 1640 K. The fusion of billets was carried out on SGU-4 and SGU-9 setups by the method of scanning and double passage of the fused surface through the focal spot. A stable vitreous layer is formed in the process of heating and fusion. The thickness of this layer depends on the exposure time and the heat flux supplied. After the fusion, the surface becomes glossy black with individual optical inhomogeneities that are due to the microbubbles of gases released in the process of heating, glass sags, and a different degree of overheating of individual structural elements of the melt. Both the crude surfaces of the basalt samples and the surfaces leveled in advance by cutting with a diamond tool were subjected to fusion. In both cases, the process of formation of a glazed coating is stable; at the end of the process, the difference is only in the relief of the surface.

Since the preparation of regularly shaped basalt products requires certain efforts and expenditures, we have made an attempt to obtain samples of the tile type by fusing broken stones in a poured layer of thickness of about 10 mm. When such a mass is heated, not only is the surface fused, but also the space between individual elements is filled with a melt to the extent of individual through meltings. As a result, a rather monolithic and beautiful product is formed; however, to retain its integrity, a special regime of cooling characteristic of all glass products must be observed. In our case, the heating was carried out by scanning the surface, and such cooling would require a substantial complication of the experiment with the use of additional heating sources, which was beyond the scope of the searching investigations. Therefore, through cracks were formed in the samples subjected to cooling, and the strength of the products obtained was evidently insufficient. The monolithic basalt, conversely, was absolutely thermal-shock proof and withstood well the regime of scanning surface heat treatment within the limits of the experiments.

We have conducted experiments on fusion of the surface of ceramic tiles of the slag of the Pobuzh Nickel Plant (Kirovograd region) and the foamed metallurgical slag of the Mariupol’ Metallurgical Plant. The samples of both types of materials were manufactured according to the techniques developed at the IPMS NAS of Ukraine. The fusion of their surface results in a decrease in hygroscopicity, an increase in the resistance to corrosion media and minus temperatures, an increase in mechanical strength, and an improvement in the aesthetic appearance. The experiments were carried out in a "Uran-1" optical furnace by scanning the surface. After the fusion, the surface of the samples of ferronickel slag became glossy black with dark-brown free designs. In the case of the samples of foamed metallurgical slag, the fused surface became beautifully greenish. The technology of production of these materials allows one to change their porosity in a wide range, which makes it possible to somewhat influence the color and the relief of the surface subjected to fusion. Independently of the porosity, the material of the samples was strengthened due to the formation of a vitrified surface. Moreover, such a treatment makes it possible to "heal" too large pores and individual defects.

We have conducted searching experiments on evaluation of the possibility of using the blast-furnace and open-hearth slags of the Krivoi-Rog Metallurgical Plant, in particular, as a stain for the fused surfaces of products of slag concrete. The fusion of the slags in poured form has shown that the melt has a high viscosity, the slag-concrete surface has a low wettability, and the mass of the melt cracks in cooling. Both melts were dirty-gray. For the purpose of decreasing the viscosity of the melt and searching for acceptable color schemes, we prepared mixtures of slag, sand, and glass and fused them by radiant heating. Blast-furnace slag with additions of glass, subjected to fusion, becomes greenish, while open-hearth slag acquires a deeper color. A mixture of blast-furnace slag with sand and glass gives a fairly attractive light-blue melt. Thus, cheap mixtures obtained from industrial and domestic wastes and river sand can be used for staining slag concrete and other materials of metallurgical slags by fusion of their surface.

The results of these searching investigations show that, in the opinion of the authors, there is a possibility of using solar furnaces in industry and the national economy for surface treatment of different materials, especially in regions that are at a large distance from the sources of conventional types of energy and have a high potential of solar energy. They show promise for private small enterprises. A characteristic example is the present situation with a French solar furnace of power 70 kW in Mont-Louis [5]. After the destruction of its heliostat by a powerful hurricane in 1977, the furnace was significantly modernized and the "Four Solaire Development" Enterprise was created on its basis. This enterprise produces and sells souvenirs, mainly of ceramics. The enterprise also popularizes the utilization of solar energy by demonstrating to numerous tourists the action of the solar furnace and a number of units powered by solar energy and also the displays of the store museum with samples of "solar" products.

We also note in conclusion that the obtained results on heat treatment of the surface of basalts and materials based on the wastes of metallurgical production are of special scientific and practical informational value independently of the problem of utilization of solar energy.

NOTATION

B, width of the fused zone, m; H_{ef}, specific consumption of heat, kJ/m^2; Q, supplied heat flux, kJ/sec; V, velocity of travel of a sample in the focal spot, m/sec; ρ, refractive index; q, density of the heat flux, kW/m^2; t, duration of heating, sec.

REFERENCES

1. V. V. Pasichnyi (Pasichny), in: *Proc. World Renewable Energy Congr. V*, September 20–25, 1997, Florence, Pergamon (1998), pp. 2114–2117.
2. V. V. Pasichnyi, V. Ya. Berezhetskaya, and G. G. Frolov, *Geliotekhnika*, No. 3, 30–33 (1986).
3. V. V. Pasichnyi, V. Ya. Berezhetskaya, Yu. I. Chop, et al., *Steklo Keram.*, No. 8, 5–6 (1986).
4. G. G. Zolokitin, T. O. Romanyuk, and N. K. Skripnikova, in: *Ext. Abstr. of Papers presented at IXth All-Union Conf. on Generators of Low-Temperature Plasma*, 1983, Frunze (1983), pp. 284–285.
5. F. Tromb, in: V. A. Baum (ed.), *Solar High-Temperature Furnaces* [in Russian], Moscow (1960), pp. 44–58.