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BEHAVIOR OF THE REFLECTION COEFFICIENTS OF TEXTOLITES UNDER LASER HEATING

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The reflection coefficients at the wavelengths 0.63, 1.15, and 10.6 μm of composite materials, heated in air by continuous CO$_2$ laser radiation, were determined experimentally.

Composite materials based on organic and glass fillers and polymer resin binders are being increasingly employed in modern technology. The most promising instruments for working these materials are the technological CO$_2$, YAG, and argon lasers, whose radiation can heat, melt, and evaporate the most heat-resistant materials.

The main parameter determining the efficiency of heat transfer from radiation to a nontransparent material with laser heating is the reflection coefficient. As a result interest in determining the reflective properties of composite materials in the spectral regions of lasing of technological lasers has increased [1-3]. Previously performed measurements of the reflection coefficients R_λ at wavelengths of 0.63, 1.15, and 10.6 μm of commercial textolites (Getinaks, textolite, glass-textolite), heated by continuous CO$_2$ laser radiation, showed that at the starting stage of irradiation irreversible thermochemical transformations (pyrolysis and charring), which decrease the reflection of short wavelength radiation (1.15 and 0.63 μm) and increase the reflectivity at the center (10.6 μm) of the IR region of the spectrum [4, 5], occur in the surface layer of the indicated materials. The temperature dependences of the reflection coefficients of cokes, forming on the surface of polymer composites under quite prolonged heating and fixed density of the incident laser flux, were obtained. However for thermophysical calculations of the heating and thermal destruction of the composite materials it is necessary to have information about the changes in the reflection coefficients and the temperature of the heated zone at the initial period of irradiation as a function of the incident flux density of the laser radiation. To this end, in this work we studied the behavior of the reflection coefficients of organic fiber plastics of the Getinaks and textolite PTK types as well as STK glass textolite as a function of the density q of the continuous CO$_2$ laser radiation flux incident on them. The textolites studied are polymer composite materials. Grade I Getinaks (GOST 2718-66) is a layered material, pressed from electrical insulation paper, permeated with phenol formaldehyde resin of the resol type. The construction textolite PTK (GOST 5-72) is prepared from cotton fabric, which, like the Getinaks, is permeated with resol resins based on phenol. The fill for the STK glass textolite (GOST 126-52), which exhibits an elevated heat resistance, consists of É glass cloth, and the binder is KO-926 silicone resin. These materials are employed for pipes, valves for chemical equipment, pinions, slide bearings, and other load-bearing components [6].

The measurements were performed on a setup which permits recording simultaneously the He–Ne and CO$_2$ laser radiation fluxes reflected from the samples and the temperature of the surface of the target in the heating zone, using the procedure described in [4]. The true temperature of the surfaces of the samples was determined from measurements of the intensity of the characteristics thermal radiation of the target and of the reflected radiation of the He–Ne laser employed as the illumination source at wavelengths of 0.63 or 1.15 μm. The errors in the temperature measurements were evaluated using the formula (2) [4] and did not

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exceed 1.5 and 2.5% for wavelengths of 0.63 and 1.15 μm, respectively, for sample temperature of 1500°K. The nonuniformity of the temperature distribution in a viewing zone 2 mm in diameter was close to its measurement error. The photoelectric system made it possible to record a minimum radiation intensity corresponding to a temperature of 800°K (at $\lambda = 1.15$ μm) or 1100° (at $\lambda = 0.63$ μm). The relative measurement error in the reflection coefficients of the material studied did not exceed 10%. The CO_2 laser radiation was focused on the surface of a 20 × 20 × 5 mm sample, placed at the center of a photometric sphere, into a spot ∿10 mm in diameter. The laser radiation flux density q at the target varied from 2 to 30 W/cm². In our case, the overall energy balance in the heating of the material included convective losses, determined by the blowing of the samples when the products of the destruction of the irradiated materials were drawn off, so as to prevent the contamination of the walls of the photometric sphere. The magnitude of the convective losses was evaluated from the measurements of the temperature of the surface of asbestos, which in the range of incident CO_2 laser radiation flux densities studied did not contaminate this sphere with gas both with and without pumping of air. It was established that owing to the airflow, the losses from the surface of the irradiated materials equalled ∿4 W/cm². All dependences on the laser radiation intensity are presented for values of the flux density obtained after subtracting the losses to cooling as a result of the airflow.

The time-dependent behavior of the coefficients R_λ of the glass textolite and textolite in the first 10 sec of heating of these materials by radiation with different incident flux density is presented in Fig. 1. For low radiation intensity ($q < 2$ W/cm²) no thermochemical transformations are observed in the surface layer of the glass textolite and the numerical values of R_λ remain constant, equal to 0.2, 0.6, and 0.03 for radiation with wavelengths of 0.63, 1.15, and 10.6 μm, respectively. Irradiation with a higher flux density q causes the reflection coefficients of the glass textolite at wavelengths of 0.63 and 1.15 μm ($R_{0.63}$ and $R_{1.15}$) to drop in time, which is caused by charring of the surface in the laser action zone. At the same time, the higher the incident flux density the sharper the drop is. This is especially clearly seen for $R_{1.15}$, because the initial value of $R_{1.15}$ is three times higher than $R_{0.63}$, and they decrease to approximately the same value 0.1-0.15 (Figs. 1a and b). Burnup of the charred surface layer of the binder and exposure of the light-colored glass fibers of the fill lead to the fact that the decrease in the values of $R_{0.63}$ and $R_{1.15}$ is replaced by an increase, which for $q = 27$ W/cm² begins at the fifth second of irradiation (Figs. 1a and b). This is also observed for lower laser flux densities (beginning with $q > 10$ W/cm²), but the increase in $R_{0.63}$ and $R_{1.15}$ in this case occurs for interaction times significantly exceeding 10 sec (60-80 sec) [5].

Unlike $R_{0.63}$ and $R_{1.15}$ the reflection coefficient of glass textolite at 10.6 μm ($R_{10.6}$) increases under irradiation. The increase in the reflecting power $R_{10.6}$ in the first 10 sec of heating is virtually independent of the q in the range 5-18 W/cm². A significant increase in $R_{10.6}$ initially is observed for $q > 25$ W/cm² (Fig. 1c). It should be noted that exposure of the filler filaments reduces $R_{10.6}$ from the maximum value to 0.1 [5], but this occurs after 10 sec of irradiation.

The starting values of the reflection coefficients R_λ of textolite are practically identical to the reflection characteristics of fiber glass plastic materials and equal 0.2, 0.55, and 0.04 for radiation with wavelengths of 0.63, 1.15, and 10.6 μm, respectively. The change in the reflection coefficients as a function of time is identical for textolite and glass textolite (Fig. 1). However, the behavior of R_λ of organoplastic exhibits some peculiarities, manifested in the fact that under conditions of irradiation $R_{1.15}$ and $R_{10.6}$ reach corresponding values much more rapidly than for glass textolite (Figs. 1e and f). At the same time, after the minimum magnitude is achieved (∿0.15) the reflection coefficients $R_{0.63}$ and $R_{1.15}$ do not increase, as observed in glass textolite. These features are linked with the fact that the fill reinforcing the textolite does not contain glass filaments.

The changes in the reflection coefficients R_λ of Getinaks and textolite are qualitatively identical, and only the starting and minimum values differ somewhat quantitatively [4].

To study the dependence of the extremal values of the reflection coefficients R_λ (minimum $R_{0.63}^{\min}$, $R_{1.15}^{\min}$ and maximum $R_{10.6}^{\max}$) of the materials indicated on the incident CO_2 laser radiation flux density the measurements were performed with a heating duration of greater than 10 sec. It was established that the time over which extremal values of R_λ are reached for given irradiation density decreases sharply as q increases and is virtually independent of the type of

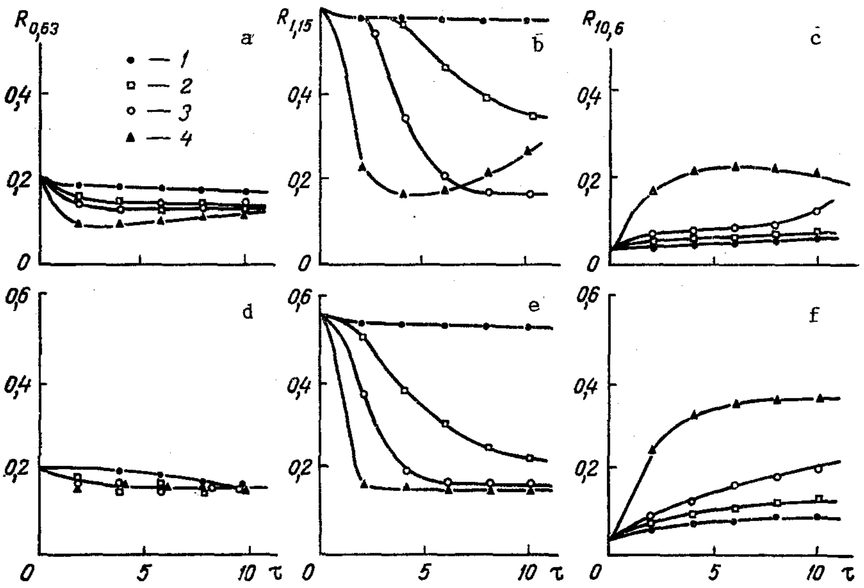

Fig. 1. Variation of the reflection coefficients at wavelengths of 0.63 (a, d), 1.15 (b, e) and 10.6 μm (c, f) for glass textolite (a-c) and textolite (d-f) surfaces heated with CO_2 laser radiation, whose flux density equals 5 (1), 13 (2), 18 (3), and 27 W/cm² (4). τ, sec.

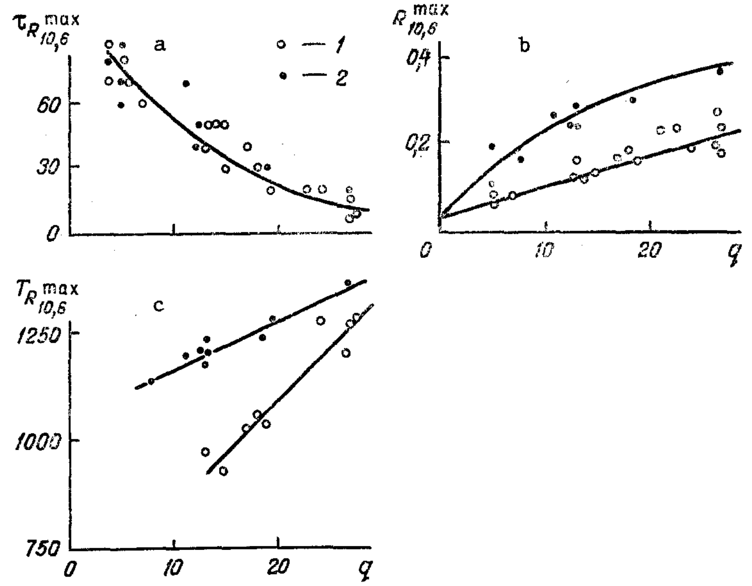

Fig. 2. Times for achieving the maximum value of the reflection coefficient at 10.6 μm (a) and values of this coefficient $R^{max}_{10.6}$ (b) and of the temperature, corresponding to $R^{max}_{10.6}$ (c), versus the CO_2 laser radiation flux density incident on the composite material: 1) glass textolite; 2) textolite. $\tau_{R^{max}_{10.6}}$, sec; $T_{R^{max}_{10.6}}$, K; q, W/cm².

material. At the same time the quantities $R^{min}_{0.63}$ and $R^{min}_{1.15}$ are established more rapidly than the reflection coefficient at 10.6 μm reaches its maximum value $R^{max}_{10.6}$. In the studied range of radiation flux densities heating the composite materials of interest, the minimum values of the reflection coefficients at 0.63 and 1.15 μm do not depend on q and equal 0.1-0.15. At the same time the reflection coefficient $R^{max}_{10.6}$ increases as q increases (Fig. 2b). It should be noted that for one and the same incident radiation flux density for organoplastics both $R^{max}_{10.6}$ and the surface temperature $T_{R^{max}_{10.6}}$ corresponding to this value of $R^{max}_{10.6}$ are higher than for glass textolite (Fig. 2b, c). This difference in the behavior of $R^{max}_{10.6}$ and $T_{R^{max}_{10.6}}$ of textolite and glass textolite is determined by the different composition of the indicated materials. Thus if polymer resin is employed as the binder in organoplastics and fiberglass plastic materials, then their fills have substantially different thermophysical properties. Heating of composite materials up to 550-560°K gives rise to pyrolysis of the organic binder [7, 8]. In textolite the pyrolysis process encompasses the organic fill also. As a result of further heating in the surface zone of irradiation of organoplastics (textolite, Getinaks) at a temperature 1000-1100°K [8] the formation of coke, whose thermal conductivity is obviously lower than the thermal conductivity of the products of pyrolysis on the surface of the fiberglass, is completed. This leads to the fact that for one and the same incident flux density the temperature of the textolite surface in the heating zone is higher than for the fiberglass plastic material, though the relative fraction of the absorbed energy in the latter case is higher (Figs. 2b and c). The time required for thermochemical transformations in the surface layer of both organoplastics and fiberglass materials is obviously the same, and for this reason the times for reaching the values $R^{max}_{10.6}$ are the same for them (Fig. 2a).

The difference in the composition of the products of thermal destruction on the surface of organoplastics and fiberglass plastic materials is manifested not only in the thermophysical but also in the optical properties. Thus for all three materials the dependence of the coefficients R_λ on the temperature of the surface of the samples in the irradiation zone was constructed taking into account the rate of heating $\Delta T/\Delta\tau$, which determines the rate of pyrolysis [7] in the surface layer of the composite materials and depends largely on the CO_2 laser radiation flux density incident on the sample. It was established that for all materials studied in the range 800-1000°K the values of the reflection coefficients R_λ are uniquely related with the temperature and their temperature dependences are determined by the rate of heating of the samples. This is manifested especially for the reflection coefficient at 1.15 μm, since it changes the most. Above 1000°K the temperature dependence of R_λ on the coke residue on the surface of the organoplastics and glass textolite differs significantly. Thus the reflection coefficients of the coke, forming on the surface of organoplastics, in the spectral regions 0.63 and 1.15 μm are identical and independent of the temperature for all experimentally realized rates of heating from 50 to 95 K/sec, constituting 0.15 for textolie and 0.1 for Getinaks. Under the same conditions the reflection coefficient at 10.6 μm is determined uniquely by the temperature and increases from 0.1 to 0.35 on heating from 1000 to 1450 K (broken line in Fig. 3b). This behavior of the reflection power of coke on the surface of organoplastics indicates that the thermochemical transformations in their surface layer are completed when a temperature of ∿1000°K is reached, and on further heating the charred layer behaves like a chemically stable material.

The temperature dependence of the reflection coefficients R_λ of coke on the surface of glass textolite is determined substantially by the rate of heating at temperatures above 1000°K also (Fig. 3). One can see that like for organoplastics the pyrolysis of the resin binding the glass fibers reduces the reflection coefficients $R_{0.63}$ and $R_{1.15}$ and increases $R_{10.6}$. Then there occurs a range of temperatures in which the reflection coefficients $R_{0.63}$ and $R_{1.15}$ of the coke formed do not depend on the temperature, while $R_{10.6}$ increases linearly with heating. Later the products of pyrolysis of the resin burn up from the surface layer of the fiberglass plastic and the glass fibers are exposed, which increases the reflection coefficients in the short wavelength (0.63 and 1.15 μm) and decreases them in the long wavelength (10.6 μm) regions of the spectrum. It should be noted that the temperature at which burnup of the binder leads to the fact that the surface of the fiberglass plastic is formed completely by the filler material is also determined by the rate of heating. For a heating rate of 55 K/sec the glass fibers of the fill are exposed at 1000°K, while the same process begins at 1300°K for a heating rate of 95 K/sec (Fig. 3). And since pyrolysis and thermal destruction of the resin are completed at a temperature of ∿1000°K [8], increasing the rate of heating of the glass textolite increases the temperature range within which $R_{0.63}$ and $R_{1.15}$ are constant, while the reflection coefficient $R_{10.6}$ increases linearly as the temperature increases (Fig. 3).

This indicates that aside from the thermal condition for burnup of the binder the residence time of the material in the heated state is also significant. Surface radiant heating gives rise to gradual burnup of resin until the filling fibers are completely exposed. In the course of this process, with a higher rate of heating a higher temperature is also reached by the time the surface layer of binder is burned up.

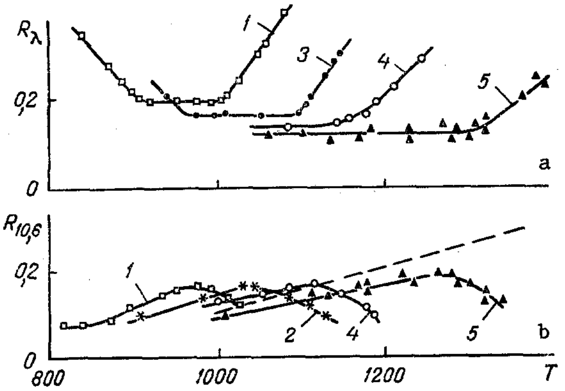

Fig. 3. Reflection coefficients at 0.63, 1.15, and 10.6 μm as a function of the temperature of the surface of glass textolite, heated at a rate of 55 (1), 60 (2), 70 (3), 80 (4) and 95 K/sec (5); a) $R_{0.63}$ (4, 5); $R_{1.15}$ (1, 3); b) $R_{10.6}$. The broken line shows $R_{10.6}$ for textolite. T, °K.

The maximum values of the reflection coefficient R_λ reached as a result of burnup of the products of pyrolysis from the surface of glass textolite are equal to one another for 0.63 and 1.15 μm, and depend on the incident CO_2 laser radiation flux density, constituting ~0.5 (0.63 and 1.15 μm) and 0.1 (10.6 μm) in the range 10-15 W/cm². For heating radiation flux densities higher than 15 W/cm², when the temperature of the irradiated surface exceeds 1250 K, a silica fiber softens and a film of melted glass forms with particles of the destroyed coke residue distributed in it [7, 8]. This reduces $R_{0.63}$ and $R_{0.15}$ to 0.3, while $R_{10.6}$ remains at the level 0.1, as in the case when there is no melt. After the formation of the melt the reflection coefficients R_λ are no longer dependent on the incident CO_2 laser radiation flux density and are correspondingly independent of the surface temperature of the glass textolite for heating right up to 1500°K by radiation with a density of 30 W/cm².

NOTATION

λ, wavelength at which the measurements are performed; R_λ, spectral reflection coefficients; $R_{0.63}$, $R_{1.15}$, $R_{10.6}$, reflection coefficients for radiation with wavelength of 0.63, 1.15, and 10.6 μm; $R_{0.63}^{\min}$, $R_{1.15}^{\min}$, minimum experimentally achievable values of the reflection coefficients at 0.63 and 1.15 μm; $R_{10.6}^{\max}$, maximum values of the reflection coefficients at 10.6 μm; q, flux density of the CO_2 laser radiation incident on the sample, T, true temperature of the surface; $T_{R_{10.6}^{\max}}$, true temperature of the surface of the sample at which $R_{10.6}$ assumes the maximum value; $\tau_{R_{10.6}^{\max}}$, time over which the reflection coefficient at 10.6 μm reaches the maximum value; and $\Delta T/\Delta\tau$, rate of heating of the surface.

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