Test data have been obtained on the integral emissivity of materials for various temperatures and surface states.

To perform accurate heat-engineering calculations of radiant heat transfer in power equipment one needs detailed radiative characteristics of structural materials. The present study investigates the integral directional emissivity of materials when heated in air.

The directional radiative properties of a material are described by the thermal radiative intensity

\[
I = \frac{dq(\Theta)}{dF \cos \Theta d\omega}.
\]

For a perfect black body the radiative intensity remains constant, independent of direction (Lambert's Law) \[1\]. The integral directional emissivity of the surface of a material is defined by the relation

\[
\varepsilon(\Theta) = \frac{l(\Theta)}{P}.
\]

For a given value of the product \(dF \cos \Theta d\omega\), determining the emissivity \(\varepsilon(\Theta)\) reduces to finding the ratio of the thermal radiative heat flux of the specimen to that of a perfect black body:

\[
\varepsilon(\Theta) = \frac{dq(\Theta)}{dq(\Theta)_{\text{specimen}}}.
\]

The arrangement of the working section to measure the directional emissivity (by the radiative method) is shown in Fig. 1. The angle \(\Theta\) between the normal to the specimen surface 1 and the direction of the radiation is generated by rotating the specimen along with the heating element around the point \(O_1\). Simultaneously we rotate the diaphragm 3 around the point \(O_2\) by the same angle \(\Theta\). It is rotated in order to change the visible part of the radiating area in proportion to the cosine of \(\Theta\). The cooled collimator tube 2 serves to avoid heating of the rotating diaphragm 3. The mirror 4 focuses the heat flux on the thermal column 5, located in a cooled jacket. Temperature control of the system for cooling the collimator tube and the thermal column jacket is accomplished by means of an ultrathermostat. In calibrating the equipment, besides the specimen 1 we set up a graphite high-temperature model of a perfect black body. In the calibration we do not rotate the radiating cavity of the black body, since it is known that the radiative density of a perfect black body in unit solid angle is independent of direction \[1\], but the diaphragm 3 is rotated through the angle \(\Theta\). In calibrating with the perfect black body and in measuring heat flux from the specimens we maintain equal projected areas of the apertures of diaphragm 3 in the direction \(O_1O_2\). The surface temperatures of the specimens and the perfect black body are measured with Chromel—Alumel thermocouples with a thermal electrode diameter of 0.2 mm. The thermal emf is recorded by a type VK2-20 digital voltmeter. Thus, by rotating the heated specimen, along with the heater element and the diaphragm around axes \(O_1\) and \(O_2\) by different angles relative to the optic axis of the equipment and determining the emissivity as the ratio of the measured heat flux of the specimen to the calibration radiative flux of the perfect black body, at the same temperatures and with other conditions equal, we can obtain the dependence \(\varepsilon = f(\Theta)\).

The surfaces of the materials used in the tests were isotropic. Besides the temperature the parameters governing the radiative properties of solids include the roughness and

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TABLE 1. Characteristics of the Test Specimen Surfaces

<table>
<thead>
<tr>
<th>Material</th>
<th>Surface state</th>
<th>Roughness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$R_a$, $\mu$m</td>
</tr>
<tr>
<td>19ChrMnNi</td>
<td>Ground on an emery wheel and oxidized in air at 750°C for 1 h</td>
<td>5.0</td>
</tr>
<tr>
<td>St3 steel alloy</td>
<td>Rolled sheet, oxidized in air at 850°C for 1 h</td>
<td>3.4</td>
</tr>
<tr>
<td>40Chr2Ni2MoA1</td>
<td>Rolled sheet, oxidized in air at 750°C for 1 h</td>
<td>3.0</td>
</tr>
<tr>
<td>Copper Mo3</td>
<td>Rolled sheet, oxidized in air at 850°C for 1 h</td>
<td>2.3</td>
</tr>
<tr>
<td>Aluminum alloy</td>
<td>Rolled sheet, oxidized in air at 750°C for 1 h</td>
<td>1.8</td>
</tr>
</tbody>
</table>

the presence of an oxide film. For a numerical description of specimen roughness we took the parameters $R_a$, the arithmetic average deviation of the roughness profile, and $S_m$, the average pitch of the profile roughness. The values of these parameters were measured on a type MIS-II double microscope. The surface characteristics of the material specimens investigated in terms of oxidation level and roughness are shown in Table 1. The integral directional emissivity data obtained for these specimens at specific temperatures are shown in Table 2 as a function of the angle $\theta$.

It can be seen from Table 2 that of the specimens investigated the emissivity varies most strongly as a function of the angle $\theta$ for the Al--Mn alloy. In the region of angles $\theta = 20-30^\circ$ for the Al--Mn alloy and also for Mo3 copper we observe minimal values of the directional emissivity. This may be due to the influence of roughness on the radiative properties of these specimens. For steel less deviation from Lambert's law is observed. With deep preparation of the surface the radiation becomes more diffuse. For the specimens investigated at the same temperatures the results for $\varepsilon(\theta)$ obtained after the first and repeated heating differ only within the experimental accuracy. Practically at the end of the first heating a film of oxides forms and completely determines the nature of the emissivity as a function of radiation direction.

In technological processes it is very important to know the variation of radiative properties of metals as a function of the rate of initial heating. The growth of oxide film thickness during the first heating depends on the temperature level. For steel, as can be seen from Table 3, the sharpest variation of $\varepsilon(\theta = 0)$ occurs in the temperature range 700-800°C. The variation of emissivity here is associated with the thickness of the oxide film, since the radiative power of oxides is an order higher than that of pure metals. Besides temperature, the rate of formation of the oxide film is affected by the original state of the specimen surface. As can be seen from Table 3, for St3 steel alloy preliminary