Cooling-rates and heat losses in ironfoundry ladles

Cooling-rates should be kept as low as possible, to avoid loss of heat in transit and pouring. Benefits of reduced cooling-rates are:
1. Less risk of misrun castings from the last metal poured.
2. Use of lower superheating temperatures—saving fuel in melting.

Cooling conditions
Whatever the shape, size or condition of the ladle, the cooling of the metal passes through two distinct stages:
1. Fast initial cooling, as the metal filling the ladle heats the refractory materials in the ladle to its own temperature.
2. Cooling at a steady rate, as heat is lost by radiation from the metal surface and by conduction through the ladle.

<table>
<thead>
<tr>
<th>Ladle capacity, kg</th>
<th>Lining thickness, cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>2.5-5.0</td>
</tr>
<tr>
<td>500-5000</td>
<td>5.0-7.5</td>
</tr>
<tr>
<td>5000</td>
<td>7.5-15.0</td>
</tr>
</tbody>
</table>

Table 1 Minimum lining thickness.

![Graph showing cooling rates and heat losses](image)

Fig. 1 Typical cooling-curve for metal in a ladle.

This rate depends on the ratio of surface area to weight of metal in the ladle, and on whether the upper surface is exposed or covered. Lining thickness, if it complies with Table 1, has negligible effect.

Fig. 1 is a typical cooling-curve for metal in a ladle.

What determines cooling-rate?
Loss of metal temperature owing to fast initial cooling is relatively small in ladles exceeding 500 kg capacity, but increases as amount of metal held in ladles decreases. In smaller ladles this loss is reduced by thoroughly preheating the ladles, and is minimized when a ladle is in continuous use. Excess metal should always be emptied from the ladle before refilling.

After the high initial temperature loss, cooling occurs at a steady rate of 1 to 6 °C/min in filled ladles exceeding 500 kg capacity, but rates increase rapidly—as ladle capacity decreases—to exceed 30 °C/min in those of less than 50 kg capacity.

In these steady cooling conditions most heat is lost by radiation from the metal surface, and rates of loss of metal temperature are reduced by:
1. Use of ladle covers during transit and pouring—which if properly fitted can halve the cooling-rate.
2. Use of narrow, deep ladles—reducing surface area.
3. Filling ladles as full as is practicable.
4. Using ladles of as large a capacity as possible.

Fig. 2 shows the effect of reducing the ratio of surface-area to weight, by the use of larger or narrow deep ladles, and by the use of covers.

Heat losses through the refractory and ladle wall are of secondary importance, and provided that an adequate refractory lining thickness—of not less than 2.5 cm in small
Table 2  Approximate cooling-times for uncovered ladles in good condition.

<table>
<thead>
<tr>
<th>Weight of metal in full ladle, kg:</th>
<th>50</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
<th>1000</th>
<th>5000</th>
<th>25 000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ladle diameter at metal surface, cm:</td>
<td>25</td>
<td>28</td>
<td>31</td>
<td>33</td>
<td>38</td>
<td>43</td>
<td>48</td>
<td>65</td>
<td>108</td>
<td>170</td>
</tr>
<tr>
<td>Time (minutes) for the following temperature loss:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300 °C</td>
<td>13</td>
<td>21</td>
<td>26</td>
<td>31</td>
<td>35</td>
<td>36</td>
<td>36</td>
<td>40</td>
<td>72</td>
<td>146</td>
</tr>
<tr>
<td>250 °C</td>
<td>11</td>
<td>18</td>
<td>22</td>
<td>26</td>
<td>29</td>
<td>30</td>
<td>30</td>
<td>33</td>
<td>60</td>
<td>122</td>
</tr>
<tr>
<td>200 °C</td>
<td>9-0</td>
<td>14</td>
<td>17</td>
<td>20</td>
<td>23</td>
<td>24</td>
<td>24</td>
<td>27</td>
<td>48</td>
<td>97</td>
</tr>
<tr>
<td>150 °C</td>
<td>8-8</td>
<td>11</td>
<td>13</td>
<td>15</td>
<td>17</td>
<td>18</td>
<td>18</td>
<td>20</td>
<td>36</td>
<td>73</td>
</tr>
<tr>
<td>100 °C</td>
<td>4-5</td>
<td>7-2</td>
<td>8-8</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>12</td>
<td>13</td>
<td>24</td>
<td>49</td>
</tr>
<tr>
<td>50 °C</td>
<td>2-3</td>
<td>3-6</td>
<td>4-4</td>
<td>5-2</td>
<td>5-9</td>
<td>6-1</td>
<td>6-1</td>
<td>6-7</td>
<td>12</td>
<td>24</td>
</tr>
</tbody>
</table>

Ladles—maintenance, there is little advantage gained from further increasing lining thickness.

Prediction of cooling-rate

The rate of cooling in bucket-shaped ladles, after initial rapid heat losses during filling, may be predicted—to provide:

1 Estimates of how much time is available for the transport and pouring of the metal.
2 Comparison of cooling-rates measured on ladles in use, to assess whether they are higher than necessary.

The steady-state cooling-rate (quickly reached by well-preheated ladles) can be predicted for these full, bucket-shaped ladles as follows:

1 For uncovered ladles:
   
   Cooling-rate, °C/min
   
   \[= 2.256 \times \frac{\text{metal top-surface area, cm}^2}{\text{metal weight, kg}}\]

2 For covered ladles:
   
   Cooling-rate, °C/min
   
   \[= 1.124 \times \frac{\text{metal top-surface area, cm}^2}{\text{metal weight, kg}}\]

If steady-state cooling-rates are much greater than those predicted, the ladle or cover insulation probably needs repair or modification, or the ladle is of unusual design. Drum ladles may give higher cooling-rates, even though metal is enclosed within them. This is due to radiation losses through the openings for pouring and filling, and also to the large surface area in relation to the weight of metal contained.

Ladle covers

The upper surface of the metal may be insulated by one of two methods:

1 A steel lid, hinged or loose-fitting, lined with a refractory such as gannister or castable alumina.
2 Insulating board, which may be of fibrous aluminosilicate (asbestos substitute).

Comparing production ladles for cooling

Steady-state cooling of well-lined, full, uncovered ladles is related to capacity roughly as follows:

<table>
<thead>
<tr>
<th>Weight</th>
<th>25 kg</th>
<th>500 kg</th>
<th>30 000 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C/min</td>
<td>5 °C/min</td>
<td>under 2 °C/min</td>
<td></td>
</tr>
</tbody>
</table>

The performance of full production ladles can be compared, with the values here or with each other’s, allowance being made for any difference in capacity. Cooling-curves (like the one in Fig. 1) should be prepared, with a digital pyrometer in the molten metal and a stop-watch—measurements being taken at frequent intervals over a wide range of temperature, and the steady-state cooling-rate determined.

Guide to cooling-times for ladles

Table 2 is a guide to the cooling-times which may be expected when uncovered ladles are in good condition—well-lined and well-maintained, and in continuous use or very well preheated.

Where an improvement of 25–30 per cent is still required, it is usually available from an insulating cover for the metal, as described above.

Other diameters of ladle—As an approximate guide, a departure of 10 per cent from a diameter shown in Table 2 has twice the percentage effect on cooling-time; e.g. a 33cm ladle filled with 200 kg of metal cools through 300 °C in 31 minutes (as shown), but a 10 per cent wider ladle filled with the same amount of metal would cool through 300 °C in about 20 per cent less time—25 minutes.

Recommended further reading


Available only to BCIRA Members.