Some Metallurgical Aspects of Incinerator Construction

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Abstract

Some metallurgical factors influencing the performance of incinerator components are reviewed. Data are presented covering creep, growth, adherence of non-ferrous metals, scaling and distortion due to temperature gradients of the common ferrous constructional metals.

Introduction

Incinerator service can, from a metallurgical standpoint, be classed as high temperature service. Although normal operating temperatures of the metal parts are not excessively high, under 800°F, the possibility of local, or general occasional overheating cannot be ignored. This point is important, for temperatures in the order of 600-800°F are in the area of a drastic change in the properties of the common ferrous constructional metals. Below this temperature area room temperature properties apply. Above 600-800°F the elastic modulus of these metals decreases and they start to behave like viscous liquids. The exact temperature and rate of change depends on the individual metal or alloy.

Creep

The decrease in elastic modulus is evidenced by the property known as creep. The change from a fixed elastic modulus is not abrupt, but very gradual. Temperature and time are major factors of high temperature metal properties. Temperatures exceeding 800°F are required in many cases to cause enough change for measurement by normal procedures. A measurable change at 800°F can be expected to occur at a lower rate at 700°F, and at a still lower rate at 600°F. There is no such thing as constant deformation for infinite time at temperatures exceeding 600-800°F. These higher temperatures need not be continuous. They may be accidental. Also, creep is irreversible and additive.

There is a shape factor in creep that is not generally appreciated. Practically all published creep data have been determined in tension. Much of these creep data are reported as per cent extension per 1000, 10,000, or 100,000 hours at a given temperature. If the part is a beam, especially one whose span is measured in feet simple geometry shows what seems like insignificant extensions in tension can cause significant beam deflections. The illustration of Fig. 1 shows that deflection of a 10 ft span of 1/2 in. can occur with an extension of the tension face of the beam of only 0.0033 per cent. It would require only a hundred, or so degrees higher grate temperature than now considered normal incinerator operating temperatures to increase creep and deflection of long beams by several degrees of magnitude.

Fig. 1 Relation between deflection (SAG) in bending and extension of tension face.

\[
0.002 = 0.0033 \times \text{extension of tension face}
\]

\[
\text{extension of tension face according to } \frac{0.002}{0.0033} = 60.002
\]
Creep may be said to occur in three stages. In the first stage the rate of extension is relatively high in the first few hundred hours of high temperature, with the rate diminishing with time. In the second stage the rate is lower and is constant. If the metal is badly overheated, or overloaded a third stage of creep is encountered when extension, or deformation increases with time to final rupture. This third stage is rarely encountered in service.

Figs. 2 present creep and deflection data determined in the Illinois Stoker Laboratory in an endeavor to obtain experimentally determined creep data under transverse loading. It should be emphasized that the testing procedures do not conform with ASTM standards. They were planned not to conform, but to test under different conditions. One-half inch diameter test specimens with 12 in. spans were loaded as simple beams with a concentrated load at the center of the span. Temperatures were allowed to fluctuate plus and minus 50°F from the mean to obtain data under conditions simulating to some degree alternate heating and cooling.

One point frequently overlooked was accentuated by these tests. While standard creep data report the second stage of creep, these transverse tests emphasize the importance of the first stage. If small rates of creep are significant, as they seem to be with long beams, the first stage of creep cannot be ignored. Therefore, the deflections given in Figs. 2 include the first as well as the second stage. The curves of Figs. 2 can be extrapolated to 10,000, or 100,000 hours (as has usually been done with most creep data) if desired. It may be pointed out that creep data in the literature of 0.01 per cent, or less per 10,000 hours are rare.

Figs. 2 show that low alloy steel deflects the least at all temperatures. Carbon steel is next, followed by unalloyed nodular iron. Gray iron shows the highest deflections. The difference in deflection between these metals increases as the temperature and stress increase.
Another facet of high temperature metal properties is growth. The ferrous alloys containing graphite, particularly gray iron, show permanent growth especially when alternately heated and cooled. Measurable growth of gray iron occurs below 900°F and growth becomes visible after just a few hours at red heat. Growth, like creep, is irreversible and additive. Occasional heating to above 800°F, even for short periods of time will cause measurable growth if repeated often enough, even though each heating causes an almost imperceptible change.

Growth and resulting binding can at least be suspected as the cause of breakage of gray iron parts in incinerator service. Table I summarizes available data on growth of gray iron. Most of the data has been taken from the Gray Iron Handbook [1].
Malleable and nodular (ductile) iron show less growth than does gray iron. Temperatures exceeding 1000 F are required to obtain measurable growth under test with these metals. An initial growth of 1/8 in. in 77 in. has been recorded for nodular iron after two heatings for a period of six hours at 1252 F [2]. No further growth occurred at this temperature. Growth of nodular iron was quite rapid at 1600 F, 0.006 in./ft/hr, a grate temperature perhaps unlikely in normal incinerator operation, but one that may occur due to accidental or local overheating.

As steel contains no graphitic carbon it should not show growth at any temperature. No growth in 77 in. steel grid test castings for blast furnace sintering machine pallets has been experienced with temperatures up to 1650 F [2].

**Adherence of Nonferrous Metals**

A problem that seems unique to incineration is the build up of low melting point metals on the grates. The problem seems so unique that no data can be found in published metallurgical literature. Some work along this line has been done in the Illinois Stoker Laboratory. The mechanisms of adherence of solder, Babbitt metal, tin, lead and brass were investigated. These metals showed similar adhering characteristics to the irons and to steel.

True metallurgical bonding never occurred unless the surface was chemically clean. It was not possible to bond any of the metals studied to the usual cast, or machined surface. This merely confirms generations of experience in soldering and brazing.

Even if the surface were chemically clean the possible build up by metallurgical bonding is remote. In order to adhere by bonding, the nonferrous metals must be heated appreciably above their liquidus temperatures. At these temperatures the metals studied were as fluid, or more fluid than water. It was found impossible to build up more than 1/32 in. by metallurgical bonding. Unless the additional metal was mechanically trapped, it simply ran off.

Rapid build up was experienced with solder, Babbitt metal, tin, lead and brass at temperatures near the solidus temperatures, when the metal solidified on contact with the colder iron, or steel. At these temperatures there was no metallurgical bonding. Adherence was mechanical. No adherence to any degree was experienced to flat or rounded surfaces. Strong adherence was obtained at corners if the surface was rough and at re-entrant angles regardless of the surface. Adherence in these instances was mechanical due to thermal contraction locking the deposit to the angle or corner.

Combinations of metallurgical and mechanical bonding gave even less overall adherence. When the surface was tinned by metallurgical adherence the smoother surface caused less mechanical adherence and therefore less overall adherence. No difference between adherence to iron and steel was found. Steel surfaces were more easily cleaned for metallurgical adherence. The more important mechanical adherence was dependent on shape and surface, independent of the type of metal. Aluminum and zinc oxidized, or volatilized so rapidly that it was quite difficult to obtain metallurgical or mechanical adherence. Extreme precautions were necessary to obtain coherent deposits with these metals. These experiments indicate that nonferrous metal build-up is a great degree a design problem. Sharp corners, especially re-entrant angles, should be avoided.

**Corrosion**

Corrosion, stress corrosion cracking, corrosion fatigue, or combinations of these factors do not seem important in incinerator operation. None of the common ferrous constructional metals can be considered corrosion resistant. The irons, particularly gray iron are significantly more resistant to mild atmospheric and normal soil corrosion than carbon steel.

The addition of small percentages of copper, in the order of one per cent, either alone, or in conjunction with small amounts of chromium and nickel will appreciably increase the resistance of the irons and steels to many types of mild corrosion. The next step is usually

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**TABLE I**

<table>
<thead>
<tr>
<th>Temperature Degrees F</th>
<th>Chromium Content</th>
<th>Growth In./Ft</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>930</td>
<td>nil</td>
<td>1/64 to 1/32 in 1000 hr</td>
<td>Continuous Heating</td>
</tr>
<tr>
<td>1250</td>
<td>nil</td>
<td>1/16 in 120 hr</td>
<td>Cyclic Heating</td>
</tr>
<tr>
<td>1472</td>
<td>nil</td>
<td>3/8 in 500 hr</td>
<td>Cyclic Heating</td>
</tr>
<tr>
<td>1472</td>
<td>0.5 %</td>
<td>1/8 in 500 hr</td>
<td>Cyclic Heating</td>
</tr>
<tr>
<td>1472</td>
<td>1.0 %</td>
<td>1/16 in 500 hr</td>
<td>Cyclic Heating</td>
</tr>
<tr>
<td>1650</td>
<td>nil</td>
<td>7/16 in 20 hr</td>
<td>Cyclic Heating</td>
</tr>
</tbody>
</table>

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*Figure numbers and additional details have been removed for clarity.*
the high alloy stainless irons and steels at a relatively great increase in cost.

Oxidation Resistance

Although the metals under discussion are not considered heat resistant, these metals are occasionally subjected to accidental overheating. Such overheatings are almost always accidental and there usually is no record of the temperature and time of overheating. Two points are important under these circumstances.

1) Is there any significant difference in the oxidation and scaling characteristics of the common constructional metals, gray iron, nodular iron, carbon and low alloy steel?

2) Is it possible to determine the approximate time and temperature of heating from the metal loss, or scale thickness?

Figs. 3 and 4 summarize the loss in weight and loss from one surface in inches of the four metals at 1250, 1500 and 1750°F when heated from 3 to 200 hours in air. There is little difference in loss in weight, or in inches between the four metals. The differences shown in Figs. 3 and 4 for a given temperature are minor and may be experimental error.

It should be possible to estimate the time and temperature of heating above 1250°F by loss due to scaling. For example, metal loss in excess of 0.01 in. would indicate heating above 1250°F for long periods of time, or above about 1400°F for time intervals in the order of 24 hours. Metal losses over 0.02 in. would indicate heating to over 1500°F for periods of time totaling 24 hours or more. Metal losses exceeding 0.03 in. indicate serious overheating in the range 1600-1700°F.

If the part cannot be measured, or weighed and scale is available for measurement, scale thickness will average twice the metal loss. The ratio between scale thickness and metal loss varied from 1.7 to 2.5 depending on time and temperature. The thicker scales will average quite close to 2.0 times the metal loss. Although there was a significant difference in adherence of scale to the various metals, this difference in adherence did not affect metal loss, or scale thickness. Gray iron showed the most adherent scale, carbon steel the least adherent. Nodular iron and WC6 chromium-molybdenum steel showed intermediate adherence.

Distortion

One possibly important facet of elevated temperature properties is that of distortion due to thermal gradients.
This phase has received practically no attention. It is theoretically possible (subject to experimental proof) that the relative merits of the various ferrous metals will be reversed if distortion due to thermal gradients is important. This point may explain some divergent opinions as to the merits of the ferrous metals at elevated temperatures.

Conclusions

Available data on creep, growth, resistance to shock and breakage indicate the following sequence of metals in order of decreasing serviceability at elevated temperatures: low alloy steel; carbon steel; low alloy malleable iron and nodular iron; unalloyed malleable and nodular iron; low alloy gray iron; and unalloyed gray iron.

If the part is subject to thermal gradients, especially if heat is applied to one face, thermal distortion is possible. The amount of distortion at a given rate of heat transfer and a given geometry will increase with decreased thermal conductivity, increased modulus of elasticity. Expansion of the heated face of a relatively massive part can only be compensated by the metal upsetting in the heated face. High tensile stress occurs on cooling. Buckling may then occur. The degree of buckling will increase with each heating and cooling. Heat checking occurs when the temperature gradients are high.

High carbon, low strength gray iron, under 30,000 psi tensile strength should theoretically be the most resistant to thermal buckling of the metals under discussion. Contrary to most published data these irons show appreciably higher thermal conductivity than the other ferrous metals, even higher strength gray iron [3]. Such irons also exhibit relatively low moduli of elasticity and, therefore will not build up stress in the heated face to the degree if the modulus of elasticity is higher.

If other properties are necessary to the point that high carbon irons are not satisfactory, a solution to the problem of thermal distortion seems possible by design. Subject to experimental confirmation, any design to break up the continuity of the heated face so that upsetting on heating, or tensile stress on cooling are decreased, distortion should decrease due to thermal gradients with any metal.

Serviceability of metals at elevated temperatures is dependent on the same combination of design and metallurgy as it is at lower temperatures. Many times the design is as influential, or more influential on the properties of the metal when shaped into a usable part than the metal itself.

References