Lead contamination of cast iron—some practical observations

by J. M. Greenhill

Synopsis—Contamination of iron with lead gives serious cause for concern; the presence of the element in only trace amounts can have an adverse effect on graphite form and mechanical properties of flake and nodular irons. Lead contamination in iron castings production is likely to be a continuing problem because many different types of scrap contain lead in various forms. Moreover, the increased use of electric-furnace melting can compound the problem, since such plant is unable to eliminate lead during melting and subsequent holding.

The effects of lead on the properties of cast irons are summarized here, and the foundryman is warned of the principal and some less common sources of lead contamination. In addition to the well-known effects of lead on properties, a number of practical examples of castings problems and failures are given which were associated with lead contamination. Practical data are included, relating to lead reductions during melting and holding which were experienced during surveys carried out on a number of industrial melting and holding plants.

There appears to be no satisfactory metallurgical method of avoiding problems associated with lead in flake irons, other than to ensure freedom from contamination of all charge materials.


Introduction—The problem of contamination of cast irons by lead has been known for many years; the literature contains many references dealing with practical examples of casting failures, and the results of research programmes on this topic. Contamination of irons with lead gives greatest cause for concern in flake graphite irons, since in the presence of hydrogen it can adversely affect graphite form and mechanical properties, and bring about catastrophic or premature failure of an affected casting. The presence of lead in nodular irons is rarely a problem, since its harmful effect is eliminated by the residual cerium content resulting from the treatment alloy, and there are even stages where lead can be beneficial in nodular irons. Lead has insignificant effect on malleable irons, and its presence in these irons is of no cause for concern.

With continual change in melting practices and quality of charge materials, the problem of lead contamination is becoming more prevalent and pressing in the production of flake graphite irons.

In recent years there has been a gradual increase in the use of steel and automotive scrap, and both of these materials may contain significant quantities of lead. In the production of low-grade flake irons when they are manufactured from high proportions of cast iron scrap, there is a great danger of contamination with lead, due to likely contamination of the scrap with lead compounds. The increased use of electric melting as an alternative to cupola melting, particularly when charge materials are contaminated with lead, has increased the incidence and severity of problems associated with lead contamination.

Work at BCIRA* has shown that melting dirty cylinder-block scrap, with an estimated lead content of 0·07 per cent, in the cupola, resulted in no contamination of the iron, whereas approximately 50 per cent of the lead was picked up during melting of similar scrap in a coreless induction furnace. When leaded steel containing 0·17 per cent lead was melted in a cupola, up to 10 per cent of the lead was picked up in the resultant iron.

In addition to reported casting failures due to lead contamination, and the adverse effects which lead has on mechanical properties, experience of other problems related to lead contamination has also been accumulated by BCIRA during the past decade. Italian workers have shown that lead has an adverse effect on the soundness of flake graphite iron castings, and BCIRA has considerable experience to support this view, particularly in complex castings such as cylinder blocks and heads, where the level of lead exceeds about 0·004 per cent—considered a gross level of contamination. As a result of the effects which lead can have on matrix and graphite form, problems of machinability and surface finish have been encountered in contaminated pearlitic and austenitic flake iron castings.

As a result of the regulations concerning the Control of Lead at Work, which came into force in 1981 in the UK, the control of lead in air near to electric melting-plant has assumed importance.

The lead-in-air standard has been set at 0·15 mg/m³, and action is required if the shift average concentration exceeds half the standard—0·075 mg/m³. The action requires regular air monitoring and lead-in-blood tests on employees. It is BCIRA experience that for furnaces fitted with effective ventilation, working areas adjacent to the furnaces have lead-in-air levels below half the standard.

Lead contamination of iron castings will continue to be a growing problem, since many modern steels contain lead, and there is a continuing risk of contamination from other forms of ferrous scrap. The greater use of electric furnaces for melting will compound this problem, since they are unable to eliminate lead consistently during melt-down and subsequent holding.

It is the intention of the present paper to summarize the important effects of lead on casting quality, the sources of
lead, and reductions during melting and holding, and to draw attention to the dangers of lead as a contaminant in cast irons.

The effects of lead on structure and properties
In commercially produced irons, lead content may vary between 0.001 and 0.01 per cent, depending on the quality of charge materials and the particular melting practice used. The major effects of varying degrees of contamination in the more commonly produced types of iron are outlined.

Flake graphite irons—The most important and striking effect which lead has upon the structure of flake graphite irons is on graphite, since a variety of abnormal forms of graphite may be associated with varying degrees of lead contamination. These abnormal forms are frequently referred to as "sooty" or "spiky" and are illustrated in Figs. 1 & 2.

Examination of such graphite at high magnification may reveal a Widmanstätten form, as illustrated in Figs. 3 & 4, which sometimes is clearly visible at low magnification also. Scanning electron micrographs of such structures are shown in Figs. 5 & 6. Widmanstätten graphite structures were observed in the 1930s, but it was not until the 1950s that several workers linked the presence of lead with the formation of Widmanstätten graphite in flake graphite irons.

In 1955 Simonsen & Brown reported that small amounts of lead were responsible for the formation of Widmanstätten graphite and other abnormal forms of graphite in heavy castings, which resulted in a serious reduction in mechanical properties. In 1956 Morton reported a series of observations concerning unusual failures in a range of heavy engineering castings, all of which contained lead, and some castings tellurium also. He concluded that the failures were due to abnormal graphite structures which both elements could produce, although the conditions for lead to produce the structures appeared to be more critical than for tellurium. Morton also showed that the presence of lead and abnormal graphite forms could reduce tensile strength by 50 per cent.

From a considerable number of analytical and metallographic observations at BCIRA in the 1950s and 1960s, it was apparent that the formation of Widmanstätten graphite was not solely due to the presence of lead. Peleg's work in the 1960s on the effect of lead in flake graphite irons confirmed these observations, since he was unable to produce Widmanstätten graphite in his melts and it was obvious that there were other factors in addition to lead which controlled the formation of this form of graphite. In 1964 Hughes & Harrison clearly showed that in grey and austenitic flake
Irons containing lead, Widmanstätten forms of graphite were only observed when hydrogen was present in above-normal levels. They also confirmed previous work, that there was a greater tendency for such graphite to be present in heavy, rather than light, sections. At times one may encounter castings which have high levels of lead contamination (above 0.002 per cent) and show no evidence of abnormal graphite forms; yet, on the other hand, extremely poor graphite may be seen in castings with as little as 0.0004 per cent lead present.

The moulding method has a critical role in the formation of abnormal forms of graphite; green sand moulds are more likely than dried or chemically bonded sands to give rise to more hydrogen pick-up by the metal. It is possible therefore that contaminated irons may be cast into dried moulds and the resultant castings exhibit no evidence of abnormal forms of graphite. Equally, an iron with only a trace of lead may exhibit significant evidence of abnormal graphite if cast into a very wet mould.

It should be borne in mind that the first metal from a freshly lined furnace may have an abnormally high hydrogen content, and this material would therefore be prone to the detrimental effects of only small amounts of lead. The presence of aluminium increases hydrogen pick-up, and together with lead can have a serious effect on graphite form.

The degree of degeneration of graphite is generally greatest in castings of heavy section, or in those areas in light castings which cool slowly. Extensive evidence of Widmanstätten graphite may often be seen in extremely heavy sections even with low levels of lead, which in light sections would result in normal structures.

In addition to its effect on the graphite form, lead affects the matrix of both grey and austenitic irons. Unpublished work at BCIRA11 has shown that, in 30 mm bars, the ferrite content was suppressed to below 5 per cent by the addition of 0.003 per cent lead, whereas at less than 0.0002 per cent lead there was about 20 per cent ferrite present, and a corresponding reduction in hardness from 180 to 155 HB 10/3000. Figs. 7a & 7b illustrate matrix structures without and with lead additions. It was also observed that
further increases in lead, above that required to produce a fully pearlitic matrix, resulted in further increases in hardness.

Following industrial reports of machining difficulties in austenitic flake irons, Kemp\textsuperscript{12} examined the effect of lead contamination and found that as the lead content was raised there was a gradual increase in the quantity of carbides present. The structural changes observed by Kemp in flake austenitic irons resulted in an increase in hardness from 108 HV at less than 0.0004 per cent lead to 132 HV with 0.045 per cent present, and there was also a significant reduction in elongation due to the carbides, while a gradual increase in the amount of Widmanstätten graphite reduced tensile strength from 238 to 192 N/mm\(^2\).

In heavy-sectioned grey iron castings with compositions similar to ingot moulds, Evans\textsuperscript{13} reported highly significant reductions in mechanical properties when there was lead contamination and Widmanstätten graphite. Examples of lead contamination on the properties of ingot mould and Grade 220 irons are given in Table 1.

<table>
<thead>
<tr>
<th>Property</th>
<th>Uncontaminated iron</th>
<th>Iron contaminated with lead</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Large ingot mould</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensile strength, N/mm(^2)</td>
<td>90 – 120</td>
<td>45</td>
</tr>
<tr>
<td>Modulus of elasticity (E(_o)), GN/m(^2)</td>
<td>85 – 105</td>
<td>55</td>
</tr>
<tr>
<td>Impact value (ASTM A 327-88), J</td>
<td>58</td>
<td>23</td>
</tr>
<tr>
<td><strong>Grade 220 Iron</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensile strength, N/mm(^2)</td>
<td>215 – 245</td>
<td>45 – 155</td>
</tr>
</tbody>
</table>

Gilbert\textsuperscript{14} compared the stress-strain properties of normal flake graphite irons, having tensile properties about 100 N/mm\(^2\), with irons containing Widmanstätten graphite, having strengths as low as 40 N/mm\(^2\). With these irons the modulus of elasticity had fallen from 90 GN/m\(^2\) to 55 GN/m\(^2\), and Poisson’s ratio from 0.24 to 0.18, respectively.

**Nodular irons**—As early as 1955 Morroghi\textsuperscript{15} demonstrated that small quantities of lead prevented the production of nodular graphite structures by magnesium additions, but the harmful effect could be eliminated by the addition of 0.005 per cent of cerium. Figs. 8 & 9, respectively, illustrate a well-formed nodular graphite structure in the absence of lead, and a form of flake graphite in the presence of 0.015 per cent lead. In modern nodular irons the residual cerium level is normally maintained at about 0.01 per cent, by either the addition of mischmetal or the use of a cerium-bearing magnesium treatment alloy, and so problems associated with lead contamination are rarely encountered unless high levels of lead, say 0.01 per cent or more and in combination with other subservient elements, are present. Fig. 10 illustrates flake graphite present in a nodular iron containing 0.02 per cent cerium, 0.02 per cent lead, and 0.1 per cent antimony.

In very heavy nodular iron sections two undesirable graphite forms, namely ‘chunky’, and poorly shaped nodules, can occur, owing to the combination of high-purity materials and the presence of cerium. Work at BCIRA has shown that under such circumstances, an addition of about 0.007 per cent lead is effective in overcoming the formation of chunky graphite and improving graphite nodule shape.

Morroghi\textsuperscript{15} demonstrated the drastic reduction in tensile strength and elongation in nodular irons with lead additions, and that these properties could be easily restored with a 0.02 per cent addition of cerium. Gilbert\textsuperscript{16} recently studied the effect of lead on a range of properties in irons without cerium, and the results are summarized in Fig. 11. It can be seen that with as little as 0.01 per cent lead present, the properties are below an acceptably useful level.

**Malleable irons**—Since both blackheart and whiteheart malleable irons are frequently produced from charges of high steel content, lead is an element likely to be present in the resultant material in significant amounts. There is considerable documented evidence on the effect of trace quantities of carbide and pearlite-stabilizing elements, but few data on the effect of lead. Rynsz & Mikkola\textsuperscript{17} reported work on the effect of lead on pearlite stability in ferritic...
malleable iron, which was prompted by occasional periods of higher-than-normal retained pearlite, thought to be due to lead contamination. Their work demonstrated that lead levels up to 0.01 per cent, which is a very high level of contamination for a commercially produced material, had no effect on secondary graphitization.

Work by Kawano & others, however, showed lead to increase second-stage graphitization, where Sanchez & others claimed that lead retarded second-stage graphitization unless the S/Mn balance was at least 1:1. Work at BCIRA has clearly shown that lead contents up to 0.005 per cent have no significant effect on the structure or tensile properties of either blackheart or whiteheart malleable irons, both with balanced and excess sulphur content. Furthermore, such levels of lead contamination did not adversely affect the annealability under commercial conditions. Average properties for both types of iron with and without lead are given in Table 2.

### Some sources of lead contamination

The iron foundry industry uses a wide range of ferrous scrap, and unless its source can be guaranteed there is always a chance that lead contamination of the iron may occur. Some common sources of lead contamination for which the foundrymen should always be vigilant are as follows.

#### Steel scrap—Free-cutting bar stock has traditionally contained lead, but many forging-quality steels, particularly those used in the automotive industry, have been modified to improve machinability and may contain up to 0.3 per cent lead, and resulting scrap may therefore arise as boring, scrap components or off-cuts.

Terne-plate is a lead-coated sheet steel which is commonly used in the automotive industry for fuel tanks and certain under-body pressings. It is a dangerous source of lead contamination, and may frequently arise in the form of baled steel scrap. The proportion of lead in the coating can represent as much as 3 per cent by weight of the plate, and instances have been experienced where foundries have purchased baled scrap sheet steel which has been contaminated with terne-plate, direct from an automotive press shop. It is vital therefore that the source of baled steel should be known, and if there is a possibility of terne-plate being baled it should be segregated at source and not mixed with steel destined for iron foundry use.

Automotive wheels are often baled or flame-cut into suitable sizes, and unless lead balance-weights are removed this material is a source of lead contamination.

Lead-painted structural-steel scrap can be a significant source of lead contamination, since steel from old buildings, bridges or mechanical plant is often heavily coated with layers of lead-based paints, and it is not uncommon to find some layers of paint as much as 1 mm in thickness present on such steel scrap. Whilst this form of scrap may at times appear financially attractive, it is dangerous for grey iron castings production.

#### Cast iron scrap—General light and machinery cast iron scrap which is frequently used as a charge component in the production of low-grade irons is a potential source of lead contamination. Some common sources in this form of scrap include heavily painted components, lead inserts for balancing, in weights and flywheels, and cast iron window-frames with retained putty (which contains lead carbonate). All of these forms of scrap have been known to give problems in resultant castings.

In light-castings foundries producing vitreous-enamel ware, the recycling of scrap enamelled parts always poses a problem of lead contamination, since the enamel can be a source of lead; likewise, this form of scrap is also dangerous when present in general engineering scrap. Evans & McWebster related the incidence of cracking in bath castings to the amount of enamelled cast iron scrap in the cupola charge. They showed that the excessive use of this
form of scrap resulted in high levels of lead, boron and antimony. They concluded that in order to minimize the dangers of these elements, a maximum of 5 per cent enamelled cast iron scrap should be stipulated for the cupola charge.

Automotive scrap is widely used in the production of high-grade low-phosphorus iron castings and is generally regarded as a reliable source of cast iron scrap, since its base composition lies within close limits and the material has guaranteed low-phosphorus levels. There are possible hazards, however, since most petrol engines use lead-containing petrols which deposit lead compounds in the engine throughout its life. The deposits may be dry compounds in the cylinder head or exhaust manifold and upper parts of the cylinder bore, others may be in the oil sludges adhering to the crankcase and oil galleries in the block. For a small petrol engine having a total weight of 70 kg, it has been estimated that approximately 70 grammes of lead could be present at the end of its useful life, in the head, manifold and block, or about 0.01 per cent of the total weight. This form of scrap does therefore pose a significant threat of contamination. A further source of lead contamination from cylinder blocks and heads is lead-containing bearings, which must therefore be removed prior to melting.

Cast iron borings, which may or may not be briquetted, are frequently used in cupola and electric melting. Unless borings are carefully selected at source, contamination with leaded steels or non-ferrous materials may occur.

It is advisable where such material is being used in bulk that strict control by means of analysis is adopted, to prevent contamination with lead and other undesirable metals such as aluminium.

Copper additions—Copper is often added to flake and nodular graphite irons to promote pearlite and improve strength, and in flake iron additions of up to 2.0 per cent are sometimes made. Copper scrap is normally used, but it is essential that the high-purity/high-conductivity grade material is employed; some forms of copper may contain up to 1 per cent lead, and instances have been known where the use of such material as an alloying element has resulted in serious lead contamination. Richter\(^2\) reports that the rejection of large hydraulic cylinders was due to abnormalities on machined surfaces, and porous areas, arising from contamination due to the use of copper containing 0.5 per cent lead.

Monel scrap—Monel scrap, which contains 65–70 per cent nickel and 30–35 per cent copper, is a useful charge material in the production of certain austenitic irons. As mentioned earlier, lead contamination of flake graphite austenitic irons reduces strength, promotes carbides and impairs machinability, and recent work at BCIRA\(^4\) has demonstrated that several types of Monel scrap when melted in induction furnaces are potential sources of lead and aluminium contamination. Such scrap should therefore be carefully selected to avoid soldered or lead-castulked sections and K Monel, since this latter alloy contains 2 per cent aluminium. It must of course be appreciated that if any scrap is also contaminated with aluminium the dangers of lead will be increased, since aluminium enhances the tendency for hydrogen pick-up to occur, and hydrogen must be present for lead to have its adverse effect on graphite form.

Some problems associated with lead contamination

Failures

Pressure cylinder—A pressure cylinder weighing approximately 1 tonne which was produced in Grade 260 grey iron failed during pressure-testing. Based on the composition, the expected strength in the wall section was 185 N/mm\(^2\), but tensile specimens machined from the casting resulted in very low strengths—between 52 and 80 N/mm\(^2\)—substantially below half of the predicted strength. Metallographic examination of the casting revealed mesh-type and Widmanstätten graphite, and analysis indicated 0.025 per cent lead was present.

The material had been alloyed with copper, and although positive evidence was not obtained, it was suspected that the copper was contaminated with lead.

Spontaneous cracking of balance-weight castings—Several instances of spontaneous cracking in heavy balance-weights, of up to 7 tonnes, have been associated with severe contamination with lead and poor graphite structures. Frequently such castings are manufactured in low-grade irons such as Grade 180 or 220, which are normally adequate for their applications since very little stress is applied in service. Spontaneous fracture of these large balance-weights, often up to 30 cm in section, is basically due to the release of internal stress, which may be high if the castings are removed from the mould before cooling to about 250 °C. Experience at BCIRA has been that when such a failure has occurred, the strength of the material has been drastically reduced by the presence of lead and Widmanstätten graphite. Fig. 12 illustrates the graphite form in a balance weight.

---

\(^1\) Monel is a trade name of Henry Wiggins & Co. Ltd.

Fig. 12 Abnormal graphite present in a large balance-weight containing 0.02% lead, which failed during service. Etched in 4% picral. \(\times 500\)
contaminated with 0.02 per cent lead and which failed during service.

**Machining problems**

It has been shown that lead increases hardness of grey and austenitic irons. Dawson\(^1\) demonstrated that increasing lead contents suppressed ferrite in grey irons, and Kemp\(^2\) related increased hardness in austenitic irons to an increase in carbide and a phosphide/carbide complex.

An example of machining difficulties due to lead contamination was experienced when a foundry converted from cupola to electric melting. For many years the foundry had supplied a range of automotive castings to machine shops, which had machined satisfactorily, but immediately after converting to electric melting there were machining difficulties with iron of the same basic composition as that produced from the cupola. It was however noticed that the electrically melted iron had higher hardness and tensile values, and the machinability was restored by raising carbon and silicon levels.

Spectrographic and chemical analysis subsequently established the presence of up to 0.01 per cent lead in the electrically melted material, which was suppressing the formation of ferrite and thus increasing hardness. This industrial example of the effects of lead contamination on matrix structure, hardness and tensile values was later confirmed by Dawson,\(^1\) who also showed that in a pearlitic structure further additions of lead continue to increase hardness.

From time to time machining difficulties are encountered in austenitic irons, and again these have frequently been associated with lead contamination from the use of lead-contaminated Monel scrap components.

**Abnormal white iron formation**

Changes in machinability due to lead contamination are usually associated with increased pearlite and hardness levels, but occasional instances have been experienced of abnormal eutectic carbide or white iron formation. Fig. 13 illustrates a chevron formation of white iron in a wedge-test specimen of grey iron composition, which occurred for a very limited period during production in an automotive foundry and was found to occur in iron containing a high level of lead—at 0.002 per cent.

A similar occurrence of abnormal white iron formation associated with lead was experienced in various chilled-iron tappets, illustrated in Fig. 14. The chilled iron tappets illustrated were found to contain 0.001–0.002 per cent lead, and in those tappets with normal low levels of lead such white iron formation was not present. It was interesting to note that in this particular instance, only two ladles of metal from a 6-tonne furnace melt produced the abnormal white iron form. It was concluded that metal from these two ladles had a higher-than-normal hydrogen content, due to patching of the ladle lining. However, such abnormal white iron patterns have only been observed in the presence of high lead contents, and it is possible that hydrogen is also an essential element. The unusual presence of white iron in the non-chilled positions on the tappets would promote severe machining difficulties, and damage to the cutting tools.

Barbero & Fortino\(^5\) also observed this chevron or 'chill banding' in wedge specimens which they produced in their work, and attributed its presence to lead only. Recent work at BCIRA laboratories has also demonstrated the increased 'chilling' tendency of lead-contaminated iron when cast into wedge and plate-with-fin castings.

Practical observations indicated that the formation of this form of white iron banding is affected by casting geometry, or production which results in rapid solidification—wedge shapes or, as in the case of the chilled tappet, one face being deliberately chilled. An interesting feature of the abnormal white iron in the tappets is that it formed some distance away from the chilled face. Japanese Patent\(^25\) 82-130754.

**Fig. 14** Chilled iron tappets exhibiting white iron bands on unchilled surfaces, the occurrence of which was associated with high levels of lead contamination.

**Fig. 13** Chevron formation of white iron in a wedge test piece, which contained 0.004% lead.

July 1985
Toyota Motor Company, relates to a process that enables a white iron layer to be produced on a grey iron casting, without the use of chillers. This Patent claims that the formation of the white iron layer is effected by increasing the lead content of the iron to between 0.015 and 0.05 per cent, in combination with a nitrogen content of 0.015 – 0.03 per cent. It is however of interest to note from the details given in the patent that together with the increase

15a Satisfactory honed finish (Cylinder A) containing less than 0.0002% lead.

15c Graphite structure in Cylinder A. Etched in 4% picral. x 200

15b Unsatisfactory honed finish (Cylinder B) exhibiting 'plucking' due to presence of 0.002% lead.

15d 'Spiky' graphite in Cylinder B. Etched in 4% picral. x 200

Fig. 15 Honed surfaces of two grey iron cylinders, showing severe 'plucking' of Cylinder B.
in nitrogen content there was also a simultaneous increase in the hydrogen content.

**Effect on machined finish**

Where high degrees of surface finish are required, for example in hydraulic control valves, compressors and vacuum components, the presence of abnormal graphite structures due to lead contamination can lead to plucking at the machined surface, giving an 'open grain' appearance. The author has on several occasions investigated outbreaks of deterioration of surface finish in grey iron components which have been found to be related to sporadic increases in lead content. Fig. 15 illustrates the surface graphite structures of two honed cylinders, where in one cylinder casting severe plucking is associated with spiky graphite due to the presence of $0.002$ per cent lead, whereas the acceptable surface had a normal flake graphite with a $0.0002$ per cent lead content; both castings had similar base compositions.

The groupings of spiky/Widmanstätten graphite acted in a similar manner to coarse kish graphite, which may be plucked out of the surface during the machining operation, and lead to an open grain appearance.

**Effect on casting soundness**

Two Italian workers, Barbero & Fortino of Fiat Foundries, related a shrink defect in certain automotive castings with abnormal graphite structures, due to lead contamination. They carried out a programme of work on test castings and confirmed their observations in production castings, that there was a direct relation between lead content and shrink defects.

BCIRA has so far been unable to confirm this effect on test castings, but the author has considerable field experience in production castings to support the findings of the Italian workers. Frequent sporadic outbreaks of internal shrinkage porosity in such castings as cylinder heads and blocks and heat exchangers have been related to high lead contents. Surface-tear/pipe defects have also been observed when high lead contents have been experienced. Fig. 16 illustrates a severe tear in a large cover casting, and Fig. 17 shows similar defects in a heat-exchanger casting. It is the author's experience that such internal and external unsoundness defects are located at heat centres, and there is always evidence of abnormal graphite form associated with the defect; Fig. 18 illustrates this observation. It is also believed that the influence of lead on such defects is dependent upon casting design and geometry, and thermal conditions during cooling and solidification. Castings having heat centres connected by thinner and more rapidly cooling sections seem to be more prone to such defects than castings having uniform solidification and cooling patterns.

**Losses of lead during melting and holding**

There is considerable experience to show that although the charge materials melted may be similar, greater loss of lead occurs in cupolas than in electric furnaces. Simmons showed that in the melting of dirty engine scrap in a cupola, the resultant iron contained less than $0.0002$ per cent lead, but when the same type of scrap was melted in a coreless induction furnace the lead content of the iron was $0.04$ per cent. Whilst the cupola is effective in removing a substantial proportion of lead, particularly when it is in the form of lead compounds, contamination of the iron may occur if high levels of lead are charged. Instances are known where high proportions of pig iron containing lead, or leaded steel, have
been charged into a cupola and resulted in significant and dangerous lead levels in the iron obtained.

There are many instances of foundries which have converted to electric from cupola melting and have subsequently experienced problems of lead contamination. An example occurred in a foundry which, when cupola-melting, had a lead content in the iron of consistently 0.0004 per cent; yet with electric melting, and using the same charge materials, had a lead content at the dangerous level of 0.002 per cent. Whilst there is a greater loss of lead during cupola-melting, many instances are known of high levels of contamination of cupola-melted iron. For example, severe contamination has been experienced in iron produced from certain pigs containing high levels of lead, and the use of vitreous-enamelled scrap has been known to have the same effect.

Greenhill and Dawson investigated the loss of lead in electric furnaces, and showed that it was dependent on furnace type and operation. In small coreless furnaces where there is a high surface-area-volume ratio, lead content can be reduced by high power input and turbulent conditions within the melting cycle, but the results may be inconsistent and cannot be justified economically. For example, when contaminated baled cans were melted in a 350 kg coreless furnace, a melt-out level of lead was 0.006 per cent, which was reduced to 0.003 per cent after one hour of holding with occasional power input to increase temperature and give turbulent conditions.

When metal is held under static conditions in large coreless or vertical channel furnaces for long periods, very little or no lead loss may occur. For example, holding contaminated iron in two 30 tonne vertical channel furnaces for periods up to 12 hours had little effect on lead content, as can be seen from Table 3. In one furnace a reduction from 0.002 to 0.001 per cent occurred, and in the other no other significant change took place.

### Table 3 Changes in lead and hydrogen contents during holding of grey iron in 30 t vertical channel furnaces at different plants.

<table>
<thead>
<tr>
<th>Time after first tap</th>
<th>Plant A</th>
<th>Plant B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pb %</td>
<td>H, ppm</td>
</tr>
<tr>
<td>First tap</td>
<td>0.002</td>
<td>1.9</td>
</tr>
<tr>
<td>1 hour</td>
<td>0.001</td>
<td>1.3</td>
</tr>
<tr>
<td>2</td>
<td>0.003</td>
<td>1.1</td>
</tr>
<tr>
<td>3</td>
<td>0.002</td>
<td>1.2</td>
</tr>
<tr>
<td>4</td>
<td>0.003</td>
<td>1.2</td>
</tr>
<tr>
<td>0.08% carbon added</td>
<td>0.002</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>0.002</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>0.002</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>0.002</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>0.001</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>0.002</td>
<td>1.4</td>
</tr>
</tbody>
</table>

* Returned scrap added during this period.

When 30 tonnes of iron were held in a mains-frequency coreless induction furnace for five hours at 1480 °C under static conditions, the lead content remained constant at 0.003 per cent. Fig. 19 illustrates the reduction in lead content during holding of grey iron in a 2 tonne coreless furnace with frequent applications of power to create turbulence.

In practice therefore, lead loss in electric melting-furnaces depends on the degree of turbulence and temperature of operation; increasing both, promotes favourable conditions for its removal. On the other hand, static bath conditions as in vertical channel furnaces tend to make lead persist in the melt, and continued melting of contaminated material may have an adverse effect on the inductor. There is evidence that once lead has penetrated the refractories, iron subsequently produced from lead-free scrap will continue to be contaminated with lead. There is no evidence that duplexing or holding, or duplexing iron through closed channel furnaces, results in any significant reduction in lead.

The Control of Lead at Work regulations which came into force in 1981 in the UK stipulate that special measures must be taken to provide adequate protection for the operators if significant quantities of lead are present in the working atmosphere. Significant levels are those above a shift average of 0.075 mg/m³, or one half of the control limit.

BCIRA findings are that if lead-bearing scrap is melted in electric furnaces, lead fume around the furnaces can be at concentrations above the Control Limit for lead. In such circumstances, blood lead levels higher than the normal range for foundry personnel have occasionally been measured. Well-designed ventilation and fume extraction systems are effective in reducing such airborne fume to acceptable levels.

BCIRA work has shown that health hazards can exist in the vicinity of unventilated electric induction furnaces used for cold melting when traces of lead, even at very low levels, are present in the metal.

It must therefore be remembered that there are overwhelming metallurgical and environmental reasons why lead-contaminated scrap should not be used in electric melting-plant.

The effects of cerium in flake graphite irons

Cerium is known to neutralize the harmful influence of lead on nodular graphite formation in magnesium-treated irons, and recent French work has suggested that the addition of cerium to contaminated grey iron prevents the formation of Widmanstätten graphite, although unsatisfactory forms of graphite still persist. The cerium additions in this French work failed to restore the strength of contaminated iron to that of the original base iron; this suggests they were unable to neutralize the effect of lead completely.

Recent work at BCIRA has demonstrated that additions of cerium to flake graphite irons are incapable of neutralizing the harmful effect of lead, particularly in heavy sections, and cerium additions to flake graphite irons cannot therefore be regarded as a cure for the presence of lead.

### Concluding summary

The presence of trace amounts of lead in flake graphite irons can have serious adverse effects on their structure and mechanical properties, and therefore poses a threat to the
satisfactory performance of castings produced in contaminated irons.

In addition to the known effects on the mechanical properties and problems of casting failures, BCIRA has considerable field experience with other problems such as poor machinability and surface finish, unsoundness defects and abnormal carbide formation, which have been associated with high levels of lead contamination.

In nodular irons lead contamination rarely creates structural or mechanical problems, since these irons invariably contain sufficient cerium to neutralize the effect of lead. There may in fact be instances in heavy-section castings, where the presence of trace amounts of lead may be beneficial in improving nodule form. Unfortunately, cerium does not have the same effect of neutralizing lead in flake graphite irons.

The contamination of flake iron with lead is an increasing problem, since so many types of steel and cast iron scrap may be contaminated with lead unless very careful selection is made of these materials. Furthermore, the complete elimination of lead in electric melting and holding plant is more difficult than in cupola furnaces, and the increasing use of electric melting is therefore compounding the problem.

The contamination of flake iron castings with lead increases the risk of failure by cracking during processing, and poses a threat of catastrophic failures of large-section castings and premature failure of those castings subject to cyclic stresses, particularly at elevated temperatures.

The use of contaminated scrap, particularly if used in unventilated electric furnace plant, creates environmental hazards which may result in lead levels higher than normal in the blood of the operators.

There are, therefore, overwhelming metallurgical and environmental reasons why every endeavour should be made by foundrymen to eliminate lead from charge materials and the resulting iron. Lead is certainly the most dangerous element which can commonly occur in grey iron castings.

REFERENCES


7 Simmons, W. Unpublished work at BCIRA.


11 Dawson, J. V. Unpublished work at BCIRA.


Reprints of this article can be ordered on the reader service card at the inside back cover of this Journal.