Coal in Greensand Systems

“A new look at a very old practice”

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Abstract

The history of the use of Coal in greensand for the production iron castings is reviewed. Factors influencing the correct choice of Coal for different applications are listed and a coherent theory to explain the action of Coal is suggested. Individual case studies in European and Asian foundries are highlighted.

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Typical mass produced castings at knockout from a Greensand System

Introduction

The basic advantage of the greensand system is that the moulding material is a plastic mass, which can be squeezed almost instantaneously into the required shape. Additionally greensand moulding is competitive because it uses cheap raw materials, namely silica sand, clay, water and a carbonaceous additive. It is primarily for these reasons that greensand moulding reigns supreme in high production foundries.
The occurrence of burn-on of sand or bonding material to the surface of iron castings is a common problem found in chemically bonded sands and greensands alike. Burn-on seriously impairs the surface finish of castings and necessitates extra fettling. It is a phenomenon whereby the sand grains, or a fused mass of binder and sand, are chemically bonded onto the surface of a casting. It is generally agreed that liquid iron does not react directly with silica and that any reaction depends upon the formation of an intermediate iron oxide. This iron oxide then reacts with the silica to form an iron oxide-iron silicate phase on the casting surface. It may be concluded therefore, that burn-on will only occur if oxidising conditions exist in the mould at some stage during casting solidification.

Burn-on should not be confused with metal penetration, which is the result of sand being attached to the surface of a casting by liquid iron, which has penetrated into the voids between the sand grains.

In chemically bonded sands, refractory coatings are widely used to prevent burn-on and metal penetration. However, with greensand these problems have traditionally been overcome by the addition of a carbonaceous additive such as Coal. Indeed, the addition of pulverised Coal to greensand in order to improve surface finish is as old as the foundry industry itself. The aim of this paper is to examine in detail the various types and origins of Coals available and to put forward a coherent theory to explain its action and to illustrate with practical foundry experiences, the benefits to be obtained through the use of high quality graded Coals.

**Occurrence of Coal**

Coal is a fossilised product of decomposed plant and forest growths under marshy conditions. Within it is a proportion of material that will not burn, largely the residue of silt deposited between the rotting vegetable matter, and it is this incombustible part that yields ash within the coal. Coal is therefore composed primarily of organic matter together with smaller quantities of inorganic (mineral) matter. Coal is not a single material of one chemical composition but is a range of natural solids, which are rich in carbon. These carbons are part of a metamorphic series extending from Peat to Diamond.

The geological factors of temperature, pressure and time altered the original precursors of the coal and were largely responsible for the changing properties within this metamorphic series. The name given to these changes is ‘coalification’, and how far this process has gone is signified by the rank of the coal. This whole process is generally more advanced in older seams of coal, which tend to produce the higher ranks of coal such as anthracite. The most notable change that occurs as the coal rank increases is in the total carbon content, which can increase from about 50% to over 90% (Table 1).
**Composition of Coal**

Two standard tests which are widely used for coal are the proximate and ultimate analysis.

The proximate analysis is actually a rather simple assay of the chemical nature of a coal. Nevertheless, its value as an assessment of quality is well established. It involves determination of the moisture, ash and volatile matter and calculation of the fixed carbon value. Briefly the moisture content (M) is the loss in weight of a sample heated to 105°C, the ash content (A) is the residue after combustion, and the volatile matter (V) is the loss in weight of a sample heated in the absence of air for a fixed time under prescribed conditions. In effect the volatile content is a measure of the amount of gas, mainly carbon dioxide and hydrocarbon gases, in the coal sample. The **Fixed Carbon** (FC) is NOT a chemical entity and it is reported as the difference between 100% and the summation of the moisture, ash and volatile matter values. Thus:

\[
\% \text{ FC} = 100 - \% (M + A + V)
\]

The determination of the principal elements in coal, which consist of carbon, hydrogen, oxygen, nitrogen and sulphur, is called the ultimate analysis.

**The influence of heat on Coal**

When Coal is heated it decomposes and volatile materials are evolved. Decomposition occurs in three quite well defined temperatures intervals as follows:

**Stage A** At temperatures below 200°C, water and small quantities of carbon dioxide are evolved and the rates of reaction tend to be low.

**Stage B** Between 350 and 550 °C reactions occur more rapidly. The principal products are light hydrocarbon gases and a variety of organic compounds. Bituminous coals also pass through a plastic stage in this temperature range and they often swell and then re-solidify into a porous mass (coke). Such coals are referred to as coking coals.

**Stage C** This begins above 550 °C and involves the evolution of a mixture of various gaseous products including water, carbon dioxide, carbon monoxide, hydrogen, methane, acetylene and ammonia. Condensation of the gases evolved in stages B and C can involve the disposition of a graphite-like film of high carbon content (so-called lustrous carbon).

The change in volume during the plastic stage can be followed by a dilatometer, as shown in Fig. 1. The volume changes are characterised as follows-
- **Initial contraction (C)**
- **Subsequent swelling (S)**
- **Overall dilation (D)**

The coking behaviour of a Coal when heated is measured by the Swelling Index. This test involves heating a known quantity of Coal in a standard crucible under prescribed conditions. The test produces a solid residue, whose profile is then compared with outlines on a standard chart. The sample under test is then assigned a number from 0 to 9 and the coking behaviour is designated as follows:

<table>
<thead>
<tr>
<th>Swell Index</th>
<th>Coking Behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 1</td>
<td>None</td>
</tr>
<tr>
<td>2 – 3</td>
<td>Weak</td>
</tr>
<tr>
<td>4 – 5</td>
<td>Moderate</td>
</tr>
<tr>
<td>6 – 9</td>
<td>Strong</td>
</tr>
</tbody>
</table>

Many factors are thought to influence the coking behaviour of Coal although their individual roles are not fully understood. Two factors which are well known to reduce the coking or swelling of any particular coal are firstly, weathering (oxidation) of the Coal and secondly, fine grinding of the Coal (probably also linked to oxidation).

![Typical casting surface finish](image)

**Improvement in casting surface finish**

The earlier sections have clearly illustrated the nature and properties of various types of Coals as well as indicating the changes they undergo when subjected to heat. Such information allows us to put forward a possible mechanism accounting for the effects of Coal in greensand.
Firstly, when molten iron is poured into a greensand mould containing Coal, the input of heat causes the evolution of reducing gases into the mould cavity and these prevent the formation of iron oxide, which is thought to be an intermediate stage in the production of burn-on.

Secondly, as the oxygen supply in the mould is limited, sooting results and a thin layer of lustrous carbon is condensed onto the mould surface from the hydrocarbon gases.

This film of lustrous carbon acts as a refractory barrier between the molten iron and the sand and thereby improves casting surface finish. In the third and final stage, the coal begins to coke near to the mould surface and in doing so it softens and expands. This softening and coking occurs at the same time as the critical quartz expansion takes place in the surrounding base silica sand and it allows re-adjustment of the sand grains and thus helps to control the formation of expansion-type defects. It has also been established [1] that the development of coke in the sand is an important parameter in preventing metal penetration between the sand grains. Indeed, it was common practice to use 3 – 5% additions of coke powder when dry sand moulds were used to produce castings up to 50 tonnes in weight. Such moulds were coated with water based blackings to improve casting finish. Nevertheless, it was still found necessary to add coke powder to eliminate metal penetration.

Factors influencing the choice of Coal

Many types of Coal are available, although for foundry use only Bituminous Coals are ideal due to the combination of properties, which such Coals exhibit. Nevertheless, in the absence of Bituminous Coals, others have been used with varying degrees of success although it has been found necessary to incorporate other lustrous carbon formers such as Pitch, Asphalt or Gilsonite in order to improve their suitability for use in greensand [2]. Even Bituminous Coals vary greatly in quality and analysis and in order to obtain the most satisfactory all round performance the selection of the correct type and grade of Coal is extremely
important. Such selection should take into account the mechanical grading as well as chemical aspects such as volatile, ash, moisture, sulphur and chlorides, and physical parameters such as swelling characteristics and the lustrous carbon forming tendency. Table 2 shows the analysis of two different coals, both of which are ideally suited for use in greensand systems.

**Grading**

As a general rule it can be stated that the Coal used in a greensand moulding system should have a grading slightly finer than that of the base sand. Where a particularly good surface finish is required on small iron castings, a fine sand would normally be used together with a superfine grade of Coal. As the casting size increases it is more appropriate to use a coarser grade of Coal. Typical gradings of Coal ranging from 75 to 250 GFN are listed in Table 3.

The coarse 75 grade Coal has considerable advantage in terms of handling characteristics as it has extremely low fines content (10% <75μm). An additional benefit of coarse grade Coal is that lower additions are required each casting cycle due to the lower oxidation rate of such Coal. It is important, however, that the upper size limit of the coarse coal dust is accurately controlled and as particles above 1000 μm can give rise to blow defects.

![Excellent surface finish and definition using a Medium Grade Coal](image)

**Volatile matter**

The volatile content of Coal for foundry use should be a minimum of 30%, although a high volatile content itself does not necessarily mean that a Coal is ideally suited for use in moulding sand and other factors must also be taken into consideration.
**Ash**

During the recycling of foundry sand the ash content of the sand is increased. As this ash is of a very fine nature it requires additional clay and moisture to bond it and also has the effect of reducing the permeability of the sand. These effects are obviously detrimental and therefore it is preferable to use only low ash Coal.

**Moisture**

This is present in Coal in two forms: first as surface moisture and secondly as inherent moisture. In a good quality Coal the inherent moisture will be in the range 2-4% whereas in cheaper, lower quality coals it may be as high as 8%. The difference in moisture levels should be taken into account when comparing the relative costs of Coals.

Inherent moisture should not be removed from the Coal during the drying process as reabsorption can occur with the liberation of heat and the risk of spontaneous combustion during storage. The supplier should, therefore, provide Coal with the inherent moisture intact and the surface moisture removed in order to promote good flow and handling properties.

**Sulphur**

Foundries producing ductile iron castings require a coal having low sulphur content in order to reduce the possibility of sulphur pick-up, the effect of which can be to produce flake rather than spheroidal graphite at the casting surface (so called flake reversion). The sulphur content of the coal should therefore be at a minimum and preferably below 1%. An equally important factor to consider is that there will be a gradual build-up of sulphur in the sand and this can only be reduced by ensuring sufficient new sand is added during each moulding cycle. It is recommended that the sulphur content of the sand be maintained below 0.12%.

**Chlorides**

The effect of electrolytes on the swelling behaviour of clays is well established. The presence of chlorides in a Coal can significantly influence the swelling behaviour of the bonding clay in a greensand system, the overall effect being a marked reduction in the wet tensile strength of the sand. In one UK foundry changing from a high (0.6%) to a low (0.05%) chloride content coal increased the wet tensile strength from 0.15 to 0.24 N/mm² with a corresponding reduction in defects such at rat tails.

It is certainly preferable, therefore, to specify Coal having a low chloride content.

**Swelling/Coking**

The swelling and coking of Coal is important in controlling mould wall movement and in providing a coke residue in the moulding sand. A Coal with a crucible swelling index of 2 to 6 is ideal for foundry use.
**Lustrous Carbon**

The formation of lustrous carbon from the volatile phase is accepted as being an important parameter in promoting a good casting surface finish. It has been suggested [3] that the lustrous carbon forming power should be about 0.3 to 0.4%, depending upon the section size of the castings produced. As a good quality Bituminous Coal has a lustrous carbon content of 10-12% it is necessary to maintain the active Coal above 3% in order to obtain the desired lustrous carbon forming capability in the sand.

![Lustrous Carbon formation from a quality Coal](image)

**Control of Coal in Greensand**

Although Coal is very tolerant of misuse within foundries it is essential that close control be maintained if optimum performance is to be obtained from this additive. In particular it is necessary to measure and control three sand parameters, namely:

- **Volatile**
- **Loss on Ignition**
- **Clay grade**

The clay grade consists of a mixture of live active clay, ‘dead’ clay and spent coal (coke), and it is accepted that the clay grade absorbs approximately 10% by weight of moisture. This combined moisture in the clay grade is evolved from the sand when both the volatile (V_{sand}) and loss on ignition (L on I_{sand}) determinations are made.

In a straight coal+clay+greensand system the following relationships hold

**equation (1)**

\[
\% \text{ active coal} = \left( \frac{V_{sand} - 0.1\% \text{ clay grade}}{V_{coal}} \right) \times 100
\]
**equation (2)**

\[ \text{% spent coal} = \text{% L on I}_{\text{sand}} - (\text{% active coal} + 0.1\% \text{ clay grade}) \]

**Control of Active Coal**

The active Coal content in greensand can be determined from **equation (1)** above. The amount of active Coal required in a greensand system depends to a large extent upon the section size of the castings being produced. Typical values are as follows:

- Light sections: 3%
- Medium sections: 4%
- Heavy sections: 5%

The Coal addition required during each milling cycle depends on the amount of new sand (including core sand) added as well as the amount of active Coal which has been destroyed during the previous casting cycle. The loss of active Coal is accompanied by a decrease in the volatile content of the moulding sand and this is normally between 0.05 and 0.10% per casting cycle.

**Control of Spent Coal (Coke)**

A certain amount of spent Coal has a beneficial effect in greensand by improving the non-wetting properties of the sand and by filling the larger voids between the sand grains, so reducing metal penetration. However, the presence of too much spent Coal is detrimental to the sand system as it will increase the moisture demand and decrease the permeability. Both effects can cause scrap due to gas defects and cause a general deterioration in casting surface finish.

In practice it has been found that the amount of spent Coal should be maintained around 2% by the introduction of new sand into the system. The spent Coal in the system can be calculated from **equation (2)**.

Inadequate control of active and spent Coal accounts for many problems in greensand systems. Foundries often assume that all of the core sand (considered as new sand) enters the greensand system, whereas in practice much of this core sand is often removed at the knockout stage. Consequently, a major reason for the production of defective castings in greensand is the use of insufficient new sand. It is usually found that about 15% of the weight of metal cast should be added as new sand. It is therefore a simple matter to calculate the new sand addition required if the average sand / metal ratio is known.
Coal in High Pressure Moulding Systems

In the past 20 years, high-pressure moulding systems have become increasingly popular. Such moulding systems can give very hard compacted moulds having low permeability. Use of a superfine grade coal in such systems can give rise to a further reduction in permeability and may give rise to gas defects on the surface of castings. Coals having grain fineness numbers (GFN) in the range of 75-100 are now widely specified in high-pressure moulding foundries.

There are considerable benefits to be obtained from the use of a coarse graded Coal in high-pressure moulding systems. This is true in all cases except one. If large quantities of core sand are being returned into a greensand system the average grain size of the sand can be larger than ideal and in such instances benefit can be obtained from the use of a finer grade of coal (145 or 190 GFN) in order to reduce excessively high permeabilities. Additionally, if cold box cores are used these can contribute lustrous carbon from their binder system and accordingly lower additions of Coal may be required.

Additional benefits of Coal

Coal has a considerable influence on many sand properties and on the technical quality of castings produced in greensand. Additional benefits of Coal are as follows:

- Reduced hydrogen pin-holing defects
- Reduces expansion defects such as scabs and rat-tails
- Improves dimensional stability of moulds
Individual case studies

1 Production of Automotive Castings – UK Foundry

Previously this company had used a “Coal Dust Replacement (CDR)” product containing a lustrous carbon enhancer in combination with Coal and Bentonite. Surface finish problems and sand related defects (figures 2 & 3) such as inclusions and penetration were common place leading to scrap rates approaching 10% plus with considerable re-work and increased shot blasting. 100 GFN Coal (Type A) was introduced in combination with a specified Bentonite with the following benefits:-

- Reduced overall scrap level (now <3% total scrap)
- Improved surface finish and casting definition
- Sand inclusions and erosion type defects eliminated
- Reduction in total additive due to greater flexibility
- Reduced shot blasting with faster casting processing

2 General engineering Asian Foundry Grey Iron & Ductile Iron Hubs

Previously this company had used a “Coal Dust Replacement (CDR)” product containing a lustrous carbon enhancer in combination with Coal and Bentonite. The main problem here was single isolated sand inclusion defects (figure 4), which scraped castings due to high inspection standard and safety critical application. This was traced to particles of carbonaceous additive above 1 mm giving rise to random surface defects. Graded coal (Type A) was introduced in combination with a known Bentonite with the following benefits:-

- Reduced overall scrap level (now running at 4% total scrap)
- Total elimination of “fish-eye defect” within 1 month
- General surface finish improvement
- Reduction in total additive due to greater flexibility
- Reduced shot blasting with faster casting processing

Quality surface finish after shot blast
3 Asian Municipal Foundry – Man Hole Covers/Frames/Street Furniture

Previously this company had used a straight Coal product with high ash (8%) and low volatile (29%) in combination with Bentonite. This product was supplied as a 250 GFN Superfine blend. The main problem was general poor surface in combination with surface penetration (figure 5). This caused considerable problems due to excessive dressing.

The system lacked flexibility and the Coal quality and grading was simply not capable of producing enough controlled volatile to meet the needs of the casting quality. A graded Coal 100 GFN (Type B) was introduced with the following immediate benefits

- Controlled release of volatile
- Much improved surface finish with reduced dressing time
- Faster throughput of castings
- Reduction in overall scrap
- Better/Cleaner working environment due to larger Coal particle size

Future Trends

In the 1960s there was a significant trend away from the use of Coal owing to environmental considerations. This trend reversed in the 1980s following the more widespread use of high-pressure moulding systems. Whilst other carbonaceous additives have found niche markets, there has also been a trend towards blending Coal with such additives due to the many benefits that Coal can offer.

The use and control of graded Coal in greensand moulding systems is easily achieved and can be instrumental in producing high quality castings with excellent surface finish and free from burn-on and metal penetration, at a relatively low cost.

References:


3) I.Bindernagel, A Kolorz and K.Orths, Controlled additions of hydrocarbon components to moulding sand mixtures to improve casting surface finish. *Transactions of the American Foundrymen’s Society*, 1975, 85, 557-568
Fig. 1  Volume change in bituminous coal on heating

Fig. 2  Sand inclusion defect

Fig. 3  Surface defects

Fig. 4  “Fish-eye” defect

Fig. 5  Surface penetration
Table 1

<table>
<thead>
<tr>
<th>Substance</th>
<th>% Total Carbon</th>
<th>Rank</th>
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<tbody>
<tr>
<td>Peat</td>
<td>50</td>
<td>ND</td>
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<tr>
<td>Lignite</td>
<td>60</td>
<td>Low</td>
</tr>
<tr>
<td>Brown coal</td>
<td>70</td>
<td>Medium</td>
</tr>
<tr>
<td>Bituminous coal</td>
<td>80</td>
<td>Medium</td>
</tr>
<tr>
<td>Anthracite</td>
<td>90</td>
<td>High</td>
</tr>
<tr>
<td>Graphite</td>
<td>&gt;90</td>
<td>ND</td>
</tr>
<tr>
<td>Diamond</td>
<td>&gt;98</td>
<td>ND</td>
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</table>

ND – not designated

Table 2

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<tr>
<th>Coal</th>
<th>%FC</th>
<th>% Ash</th>
<th>%Vol</th>
<th>%Mois</th>
<th>%S</th>
<th>%Cl</th>
<th>Swell Index</th>
<th>% L Carbon</th>
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<tr>
<td>A</td>
<td>54.5</td>
<td>3.0</td>
<td>38.0</td>
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<td>0.02</td>
<td>2/3</td>
<td>8-10</td>
</tr>
<tr>
<td>B</td>
<td>62.0</td>
<td>3.0</td>
<td>33.0</td>
<td>2.0</td>
<td>0.9</td>
<td>0.10</td>
<td>4/5</td>
<td>10-12</td>
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Table 3

<table>
<thead>
<tr>
<th>Size, μm</th>
<th>% retained</th>
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<tbody>
<tr>
<td></td>
<td>Coarse 75</td>
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<tr>
<td>-1000</td>
<td>-</td>
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<td>+500</td>
<td>10</td>
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<td>+210</td>
<td>40</td>
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<td>+150</td>
<td>15</td>
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<td>+75</td>
<td>25</td>
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<td>-75</td>
<td>10</td>
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