Application of Binder in Stamp Charge Coke Making

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(Received on November 26, 2003; accepted in final form on March 16, 2004)

Successful and sustainable implementation of Stamp Charging Technology in Tata Steel has given it an edge over conventional Top Charging Technology in terms of production of superior quality of Blast Furnace grade coke from a wide range of coal base, even permitting use of inferior coals. But, the stability of stamped coal cake and the additional thermal energy necessary to drive the extra quantity of water (3–4 %), added intentionally to the coal blend to impart requisite coal cake strength, have always been the two haunting issues associated with this technology. This paper describes the role of coal tar pitch, used as a binder to the coal blend that not only imparts required strength and stability to the coal cake even at lower moisture level and thereby, reducing energy consumption, but also improves the rheological properties of coal blend that contributes to the quality of coke produced from inferior coals. This paper also describes the laboratory scale experimentation and its results followed by commercial plant-scale trials that confirmed the R & D findings on the use of coal tar pitch.

KEY WORDS: binder; stamp charging; cake stability; blend moisture; fluidity; thermal energy; coke strength.

1. Introduction

Stamp charging has been established as a versatile technology which not only improves the coke properties that can be obtained from a given coal blend, but also broadens the coal base for coke making, permitting the use of inferior coals without impairing the coke quality. But, when compared to the conventional top charging, stamp charging is a more energy intensive process as the extra quantity of water (3–4 %), added intentionally to the coal blend to impart requisite coal cake strength, have always been the two haunting issues associated with this technology. This paper describes the role of coal tar pitch, used as a binder to the coal blend that not only imparts required strength and stability to the coal cake even at lower moisture level and thereby, reducing energy consumption, but also improves the rheological properties of coal blend that contributes to the quality of coke produced from inferior coals. This paper also describes the laboratory scale experimentation and its results followed by commercial plant-scale trials that confirmed the R & D findings on the use of coal tar pitch.

In experiments carried out by Saarberg Interplan, Germany, using coal-tar pitch as an active binding agent for coal blend, it was found that especially in stamp-charged coke ovens, coal tar pitch in quantities of 2–6 % improved the propensity of low-rank coking coals.

Coal tar pitch is a resinous material containing α and β types of resins. α resins, indicated by the difference between Quinoline Insoluble (Q.I.) and Benzene/Toluene Insoluble (B.I./T.I.) contribute significantly to the binding of coal particles. Moreover, the imported semi-soft coals, presently being used in the stamp charging coal blend in Tata Steel, although have low ash and low V.M., lack in rheological properties. Additives such as coal tar and pitch, commonly referred to as fluidity enhancers, can play a more direct role in improving the strength characteristics of the resultant coke made from coals having poor rheological properties.

In the mid-twenties H. Brosche, extracted so called coal bitumen from high grade coking coal and showed that, when the extracted bitumen coal added to a low-rank coal type, it proved possible to produce usable blast furnace coke. These experiments were the basis for later technical purposes to produce coke from low rank coal by the addition of binders. Since then, different types of additives have been tried to alter the basic coking propensity.

Coal tar pitch, the main fraction of the primary distillation of coal tar from coking coal has been tried by many researchers and has been found to be the best additive. Coal tar pitch contains approximately 93 % carbon, 97 % of which is in the form of condensed aromatic compounds. Because of this chemical structure as well as its good wetting & coking properties coal-tar pitch is pre-designed for use as an active binder for coal blends.

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Coal tar pitch is a resinous material containing α and β types of resins. β resins, indicated by the difference between Quinoline Insoluble (Q.I.) and Benzene/Toluene Insoluble (B.I./T.I.) contribute significantly to the binding of coal particles. Moreover, the imported semi-soft coals, presently being used in the stamp charging coal blend in Tata Steel, although have low ash and low V.M., lack in rheological properties. Additives such as coal tar and pitch, commonly referred to as fluidity enhancers, can play a more direct role in improving the strength characteristics of the resultant coke. It is reported that addition of coal tar pitch to coal blends improves the fluidity of the blends, favours wetting of non-softening grains, effects the homogenisation of coal mass and facilitates moving and binding of the structure elements. The pitch penetrating the porous structure of coal retards the thermal decomposition of the group components of the blend at plastic temperatures and promotes the rearrangements of the structure. Coal tar pitch has an advantageous influence on the formation of homogeneous optically anisotropic coke structures with high mechanical strength.

Although there are numerous binders like coal tar, pitch, bentonite, sodium ligno sulphate, latex, phenolic resins, molasses, sodium silicate etc.; coal tar pitch, being a coal...
derivative and easy to handle, as it exists in solid form, was selected for the trials. Most of the other binders do not help in improving the strength of the resultant coke, on the other hand add harmful constituents to the coal blend.

2. Experimental

Experiments were conducted first in the laboratory prior to plant trials. For carrying out the experiments in the laboratory and for plant trials, coal blends having five different types of coals were used. Two of them are captive coals of prime and medium coking types and the rest three are imported coals. The details of the properties of these coals are summarised in Table 1. The effect of coal tar pitch addition to the stamp charging coal blend was studied in the following steps:

a. On the stability of coal cake (indicated by the compressive and shear strengths)

b. On the fluidity of coal blend

c. On the quality of resultant coke produced.

Table 1. Properties of coals used.

| PARAMETERS                      | Ind. Medium Coking | Ind. Prime Coking | Imp. Blended Semi-soft | LELVLA | Imp. Hard Coking |
|--------------------------------|--------------------|-------------------|------------------------|--------|-----------------|
| Proximate Analysis (db), %     |                    |                   |                        |        |                 |
| Ash                            | 17.20              | 17.12             | 8.67                   | 9.32   | 9.50            |
| VM                             | 26.25              | 22.80             | 23.01                  | 16.16  | 18.65           |
| Gieseler Fluidity Test         |                    |                   |                        |        |                 |
| Maximum Gieseler Fluidity, dpem| 3230               | 1328              | 5                      | 0      | 67              |
| Initial Softening Temperature(IST), °C | 435             | 440              | 450                    | -      | 467             |
| Resolidification Temperature, °C | 505               | 510              | 485                    | -      | 511             |
| Audibert - Arnou Dilatometry   |                    |                   |                        |        |                 |
| Max. Contraction, %            | 26                 | 26                | 19                     | 7      | 24              |
| Max. Expansion, %              | 28                 | 90                | Nil                    | Nil    | 44              |
| Crucible Swelling Number (CSN)/FSI | 3.5            | 6.5               | 5.0                    | 1.0    | 8.5             |
| Petrographic Analysis, %       |                    |                   |                        |        |                 |
| Reactives                      | 54.1               | 50.4              | 49.7                   | 51.1   | 54.6            |
| Inerts                         | 45.9               | 49.6              | 50.3                   | 48.9   | 43.4            |
| Mean Max. Reflectance (MMR)    | 1.06               | 1.22              | 1.14                   | 1.46   | 1.40            |

Fig. 1. Equipment for making coal cake.

Fig. 2. Equipment for determination of compressive and shear strength.
principle in accordance with the operating parameters followed in large scale stamping units. The coal cakes produced were cylindrical in shape of size 0.05 x 0.05 m. The test cakes were made after determination of the number of drops required to produce cake with specified stamping energy of about 500 Nm/kg. The coal cakes thus made, were subjected to testing in the other equipment for the determination of compressive and shear strengths.

The first series of tests were conducted to find out the optimum level for the moisture content of the coal blend to achieve maximum possible strength and stability under the conditions being followed presently in the plant (without any pitch addition).

Keeping these strength values as the base, a second series of tests were carried out to determine the compressive and shear strengths of the coal cakes made under different dosages of pitch addition (0–1%) to the coal blend at two different levels of moisture contents (7% and 9%). These two moisture levels were chosen mainly because of the fact that the moisture contents of the as received coals in the coke plant remain at an average level of 7% and 9% during non-monsoon and monsoon respectively. The properties of the pitch (hard pitch obtained as a derivative of tar distillation, which is being carried out by outside party using the coal tar generated at coke plant, Tata Steel) used in all these tests are given in Table 2. The tests were continued with higher dosages of pitch addition (beyond 1%) at 7% moisture level to find out the maximum achievable cake strength through binder addition.

b. On the Fluidity of Coal Blend

The effect of pitch addition to the base coal blend, on its maximum fluidity was also studied using P-31 Automatic Gieseler Plastometer designed close to match ASTM Standard D2639-74 (reapproved 1985). The maximum fluidities of the base blend (as such) as well as with addition of 0.25% and 0.50% pitch were determined.

c. On the Quality of Resultant Coke Produced

A number of carbonisation tests were conducted in the 7-kg test oven, under stamp charging conditions using a standard procedure established at R & D, Tata Steel. The coals and pitch samples to be used for making the coal blends were crushed to a fineness of 90% below 0.0032 m. Water was added to the coal blend to obtain the desired value of moisture content. For preparing the coal cake, a card board box with open top meant for stamp charging, having internal dimensions, length 0.34 m, width 0.09 m and height 0.27 m was taken. From the internal volume data, the weight of the coal charge to be taken for the test was calculated so as to maintain a bulk density of 1 150 kg/m³. The card board box was positioned inside a steel mould and coal mass was transferred in parts into the card board box gradually and stamped manually with a rammer. The final coal cake thus made was charged into the Carbolite test oven. The construction and operation of the 7-kg electrically heated test oven are based on the recommendations of the British Carbonisation Research Association (BCRA).

The internal chamber dimensions are, length – 0.37 m, width – 0.115 m and height – 0.305 m. The oven is heated by twelve equally spaced vertical silicon carbide heating elements (rod type), which are 0.98 m long, 0.019 m diameter with a heating zone length of 0.355 m. Before charging the coal cake into the oven, it was ensured that the empty oven temperature is 900±5°C. After 5 h of carbonisation time, the hot coke was pushed out and quenched with water. The first series of carbonisation tests were carried out following the above mentioned procedure to study the influence of different levels of pitch addition to the base blend under stamp charging conditions. All the above test results were analysed to derive the optimum level of pitch addition to the coal blend at 7% moisture level that could ensure coal cake stability and resultant coke strength. The next series of experiments were carried out to find out whether pitch addition would enable use of less expensive, low V.M., low ash (LEL VLA) poorly coking coals in the stamp charging coal blend.

In all the Carbolite oven tests, the maximum lateral expansions of the coal mass during carbonisation were measured using calipers. The resultant gross coke yields and the ash content of the coke samples were determined. The coke samples were also tested for CSR and CRI.

Based on the above background work, supported by the laboratory findings, trials were carried out in Battery No #8 of Tata Steel's coke plant using 0.5% pitch in the stamp charging coal blend. Necessary arrangements were made for mixing the pitch homogeneously with the coal blend and charging them separately to the stamp charging box without any extra water addition. The coal cakes, thus prepared were charged in five different ovens. All operating parameters were kept constant during this trial run. Plant data during normal operation were also collected for comparative evaluation to assess the benefits of using pitch in the stamp charging coal blend.

3. Results and Discussion

3.1. Effect of Pitch Addition on the Stability of Coal Cake

The laboratory experimental results for determining the optimum level of moisture content in the coal blend to achieve maximum possible strength and stability under the conditions being followed presently in the plant (without any pitch addition) are depicted in Fig. 3.

At constant specific stamping energy, the stamping density increases as moisture content increases, resulting in closer packing of coal particles, creating a stronger inter-particle surface interaction force. This leads to improvement in compressive and shear strength of the stamped coal

| Table 2. Analysis of coal tar pitch used in the tests. |
|-----------------------------------------------|------|
| Inherent Moisture, %                        | Nil  |
| Ash (db), %                                 | 0.2  |
| V.M. (db), %                                | 42.2 |
| Total Alkalis (Na₂O + K₂O), %              | 0.015|
| Sulphur, %                                  | 0.61 |
| Phosphorus, %                               | 0.035|
| Coking Value (by Conradson method), %        | 48   |
| Softening Point, °C                         | 80   |
| Q.I. Content, %                             | 4.96 |
| F.I. Content, %                             | 23.6 |
cake up to a threshold limit as observed in Fig. 3. But then, with increasing the moisture level over this limit, the presence of excess moisture inside the pores and in between particles prevents the formation of surface forces of interaction between particles leading to deterioration in strength of the coal cakes. Therefore, there exists an optimum moisture level where the positive effect of increasing moisture is maximum and from the plotted experimental data in Fig. 3, it becomes obvious that Maximum coal cake strength (both Compressive and Shear Strength) could be achieved at around 9% moisture level, without any binder addition.

The laboratory test results of coal cake strength at different levels of pitch addition, in lower (0–1%) dosage of pitch at 7% and 9% moisture levels as well as higher (>1%) dosage of pitch for 7% moisture level are represented in Figs. 4 and 5. In all these tests, the coal blends used were of identical crushing fineness. The bulk density was maintained within a close range of 1150±10 kg/m³.

Figure 4 shows the improvement in compressive and shear strengths of the coal cakes made under different dosages of pitch addition (0–1%) to the coal blend at two different levels of moisture contents (7% and 9%). Coal tar pitch being a resinous material, plays an instrumental role in manifesting superior inter-particle binding characteristics through strong adhesive force developed within coal-pitch-coal matrix of particles as compared to moisture, which improves the packing density of particles. Due to such excellent binding characteristics of pitch over that of water the requisite coal cake strength (as that of coal cake made of 9% moisture, without binder) could be achieved at lower moisture level (7%) with only 0.5% pitch addition. 0.5% addition of pitch to the coal blend increased the coal cake strength by around 10% (both compressive and shear) at 7% moisture, but at 9% moisture level, the cake strength improved only by 3.5%. Moreover, at 9% moisture level coal cake strength achieved was already optimum (without binder addition) as found earlier, so this also might have caused less realisation in strength improvement even with pitch addition.
But this improvement in coal cake strength by pitch addition is limited up to certain percentage of pitch addition, beyond which the excess amount of pitch in between particles cause the particle interfaces to slip across each other, which can be seen from Fig. 5. Pitch addition up to a level of 2% helps improving the coal cake strength at 7% moisture level, but further addition of pitch deteriorates its strength.

3.2. Effect of Pitch Addition on the Fluidity of Coal Blend

Rheological characteristics of coal in general and fluidity in particular play an important role in the strength characteristics of resultant coke. The fluidity of the stamp charging coal blend being used at Tata Steel is on the lower side of the optimum range prescribed and hence any attempt to enhance its fluidity would result in improving the quality of the coke made. With pitch addition the maximum fluidity of the blend was found to increase substantially. This may be seen from Fig. 6. Just 0.5% addition of coal tar pitch improved the maximum fluidity of stamp charging blend from 120 to 220 dpm.

3.3. Effect of Pitch Addition on the Resultant Coke Quality

The results of the tests carried out in 7-kg. Carbolite furnace are depicted in Table 3 and Fig. 7. As expected, addition of coal tar pitch to the base blend increased the CSR of the resultant coke. Such improvement in coke quality is attributed basically due to effective homogenisation of coal mass accompanied with formation of more optically anisotropic coke, as a result of pitch addition. With only 0.5% pitch addition the CSR of coke improved by 1.35 points.

Also 0.5% addition of pitch permitted use of Less Expensive, Low V.M., Low ash poorly coking coals (LEL VLA), as a partial (one fourth) replacement for the imported blended semi-soft coal in the stamp charging blend without deterioration in coke CSR. This establishes the credibility of pitch addition in accommodating highly carbonaceous inert materials that straight away enhances the coke yield.

Moreover, with 10% LELVLA + 30% Blended semi-soft coal, as imported coal component in the stamp charging blend, the yield of coke improved by 0.54% point and the coke ash reduced by 0.4% point (due to low VM and ash of resultant coal blend) when compared with the base blend. In all the test results, the maximum lateral expansion was

![Fig. 6. Effect of pitch addition on the fluidity of base coal blend.](image)

![Fig. 7. Effect of pitch addition on the CSR of coke in 7 kg test oven.](image)

### Table 3. Results of carbonisation tests carried out in 7-kg. test oven.

| Sl. No. | Composition of coal blend, % | Pitch, % | Moisture, % | Proximate analysis of coal blend (db), % | Maximum Lateral Expansion (+)/ Contraction (-) during carbonisation, % | Proximate analysis of coke (db), % | CSR | CRI | Yield, % |
|--------|-------------------------------|---------|-------------|--------------------------------------|-------------------------------------------------|-----------------------------------|-----|-----|---------|
| 1      | Ind. medium coking - 30       | 0       | 10.0        | 14.26 24.34                          | +5.92                                            | 18.75 0.38                        | 56.49 | 35.99 | 73.66   |
| 2      | Blended Semi-soft - 40       | 0.25    | 7.0         | 13.99 24.38                          | +6.11                                            | 18.42 0.33                        | 57.03 | 33.61 | 73.62   |
| 3      | Ind. medium coking - 30       | 0.5     | 7.0         | 13.96 24.43                          | +6.11                                            | 18.38 0.33                        | 57.84 | 34.02 | 73.57   |
| 4      | Blended Semi-soft - 40       | 0.75    | 7.0         | 13.92 24.47                          | +7.04                                            | 18.35 0.34                        | 58.63 | 32.59 | 73.53   |
| 5      | Ind. medium coking - 30       | 0.5     | 7.0         | 14.02 23.80                          | +6.11                                            | 18.31 0.35                        | 56.40 | 34.23 | 74.20   |
|        | Blended Semi-soft - 30       |         |             |                                      |                                                 |                                   |      |      |         |
|        | Ind. Prime coking - 10       |         |             |                                      |                                                 |                                   |      |      |         |
|        | LELVLA - 10                  |         |             |                                      |                                                 |                                   |      |      |         |

Note: Safe max. lateral expansion, % - +8.2 max.
Acceptable coke CSR - 54 min. (Equivalent to CSR of 64 - 65 in commercial oven)
found to be well below the maximum specified limit of +8.2%, indicating safe carbonisation with respect to wall pressure.

3.4. Commercial Plant Trial

Since the results obtained in the laboratory were found encouraging, arrangements were made to carry out trials using pitch in the stamp charged ovens of coke plant at Tata Steel. Stamp charging involves stamping of coal (coal blend) in a stamping box by a stamping machine to form a monolithic cake with a bulk density of around 1150 kg/m³. The coal cake at Tata Steel weighs about 27,600 kg and its dimensions are close to the oven dimensions. After making the cake using moisture as a binder, the cake is introduced from the ram side into each oven by the same stamping machine. After carbonisation, the coke is pushed out the oven, quenched with water and then coke samples are collected for testing in the laboratory for their room temperature and high temperature properties. Carbonisation time, average flue temperature, coke end temperature (CET), pushing force and vertical shrinkage data are also collected for each of the tests. Carbonisation time is the time for which the coal mass is kept inside the oven i.e. the time between charging of the coal cake into the oven and pushing of the coke mass out of it. Coke end temperature (CET) is the temperature of the coke mass just before being pushed out of the oven using an optical pyrometer. The pushing force is represented in terms of electrical current (amperes) that is required to push the coke mass out of the oven.

Results of subsequent plant trial in five different ovens are shown in Table 4. All the five coal cakes were introduced smoothly into the ovens without any breakage and not even cracks. This shows that it is possible to achieve better coal cake stability, even at reduced moisture level (7.5%) with as little as 0.5% pitch addition to the coal blend.

For the same coal cake weight, plant results show that the coke output is likely to go up by 2–3% due to reduced moisture level in coal cake.

Coke end temperature (CET) was measured for each of the oven in which the trials were carried out. 0.4–0.5 h reduction in cycle time is also envisaged due to an improvement in coke end temperature (CET) by 50–75°C as observed from plant trial results, which may be attributed to lower moisture level in coal blend with 0.5% pitch addition. Also, for every 1% reduction in coal blend moisture, the saving in thermal energy is around 28,000 J/kg. Stamp charging is comparatively less sensitive to the rank of the coal blend but the rheological properties and ash content of the blend of the blend play an important role. Among the coal being used at Tata Steel, only the captive coals have reasonable fluidity, however by blending them with the imported coals deteriorates the overall fluidity and any measure to enhance the fluidity of the blend to the desired value would bring about improvement in coke quality. Even small quantity of addition of pitch seem to have increased the blend fluidity significantly which has facilitated improvement in coke strength. Marginal improvement in both room temperature and high temperature strength of coke was noticed with 0.5% pitch addition. Table 4 shows that M₄₀ dropped by 0.2 to 0.4 points and the CSR went up by around 1 point.

No operational problems like hard pushings, stickers, wall pressure etc. is envisaged due to addition of 0.5% pitch to the coal blend as indicated by the results obtained on the vertical shrinkage and the coke pushing forces (Figs. 8 and 9).

4. Conclusions

Binders such as ‘Pitch’ can play a vital role in improving the strength characteristics of the resultant coke. It is possible to achieve the desired coal cake strength even at 7% moisture level through addition of 0.5% coal tar pitch to the base stamp charging blend and thereby deriving the benefits of saving on thermal energy input. Lower moisture
level and pitch addition also helps in enhancing the carbonising components in the coal charge and thus increases the oven throughput.

Pitch addition improves the rheological properties of the coals/coal blends by favouring wetting of non-softening grains. Addition of coal tar pitch to the base stamp charging blend increases the strength of the resultant coke due to its effects of homogenisation of coal mass and facilitating moving and binding of the structure elements. With 0.5% addition of pitch, the CSR of coke improved by 1.35 points when carbonised in a 7-kg. test oven and by around 1 point in the commercial oven.

Pitch addition permits use of less expensive, low VM., low ash coals like (LEL VLA), as a partial (one fourth) replacement for the imported blended semi-soft coal in the stamp charging blend without deterioration in coke CSR. Pitch addition permits more use of low VM coals in the blend which enhance the coke yield.

Although higher addition of pitch to the stamp charging blend could help to improve quality of coke further or to use more quantity of less expensive, low VM. coals without deterioration in coke strength, its addition is restricted to 0.5% due to economic reasons.

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