Heat Altered Coal and Its Use in Metallurgical Coke Making

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1. Introduction

The effects of igneous intrusion on coal are observed in various parts of the world. Thermally altered coals are known by various names, such as, geological coke, natural coke, cinder etc. The nature and intensity of coal alteration depend on the temperature of the intrusion, the duration of magmatic heating and the distance from direct contact with the igneous rock. In general, igneous intrusions cause dramatic changes in vitrinite reflectance, mineralogy and geochemistry of the coal seams. In most cases, these changes are gradual with distinct physical, chemical and microscopic properties.1,2) Three zones in the intrusion affected coal seams can be demarcated as (i) normal coal (%Romax 0.8–1.2%) (ii) slightly thermally altered coal (%Romax 1.2–1.8%) and (iii) highly thermally altered coal (%Romax 1.8–5.0%).3) In India, a large amount of thermally metamorphosed coal has been found in the Damodar Valley coalfields in Jharia, which is locally known as “jhama”. Jharia coalfield of Damodar Valley has a reserve of approximately 5313 million tonne which is about 2% of total coal deposits of India. Major part of the reserve of coking coal is altered due to igneous intrusion (Fig. 1). Due to metamorphism, the pseudo carbonization takes place and coking coal is converted into natural coke or jhama. The total reserve of jhama at Jharia division of Tata Steel is 154.10 million tonne wherein the extractable reserve is only 8.64 million tonne till date.4)

The nature and amount of influence of the igneous intrusions seems to be quite complex and it has substantially altered the physico-chemical properties of the surrounding coal mass. Due to various difficulties very few systematic characterizations were done earlier. Hence, proper industrial utilization of heat affected coal could not be made till now.

With this background a laboratory scale study has been designed to find the possibility of using moderately affected jhama coal in coke making using some specific pre-carbonization techniques, adding some additives and by combination of both. Result shows that pre-carbonization techniques like “groupwise crushing” and some binders are useful for utilization of maximum quantity of jhama coal as a component of coal blend in coke making.

2. Experimental

2.1. Characterization of Jhama Coal

In order to use jhama as one of the components in coal blend for coke making, some preliminary tests like proximate analysis, ultimate analysis, fluidity, crucible swelling number and petrographic studies have been conducted. Tables 1(a) and 1(b) presents the proximate and ultimate analysis data of moderately affected jhama coal. It has been noticed that jhama has very poor fluidity property and its crucible swelling number (CSN) is also very low (Table 1(b)). Tables 2(a) and 2(b) represents the petrographical properties of jhama coal with vitrinite distribution. Results indicate that jhama has significant amount of reactive material (reflectance of desired level) and it can also fulfill the requirement of reactives in coal blend.4)

2.2. Pre-carbonization Technique (Groupwise Crushing)

Pre-carbonization technique like groupwise crushing is adopted in this study. In group wise crushing the constituents of coal blend categorized in different groups. Each group is then crushed separately. The component of coal
blend divided in two groups: (i) Conventional component and (ii) Jhama coal. Conventional component comprises indigenous medium coking coal, prime coking coal and imported coal. The conventional blend component to be used for making the coal blends were crushed to a fineness of 90% below 3.2 mm. Whereas, jhama coal has crushed separately to a fineness of 0.2–0.4 mm and then mixed with other component.

2.3. Additives

In this study we have used different types of additives, namely, pitch, phenolic resin and molasses. Pitch commonly referred to as fluidity enhancers, can play a more direct role in improving the strength characteristics of the resultant coke.5) Phenolic resin binder is produced by condensation of phenol and aldehyde and thermosetting by nature.6) Molasses is an organic by-product of cane or beet sugar refining. It is residual heavy syrup left after the crystallization process.7) Some properties of the different binders are shown in Tables 3(a), 3(b) and 3(c).

2.4. Carbonization Test

Coal blends comprising of medium coking, prime coking and semi soft and anthracites were used for carbonization tests along with jhama coal. The details of the properties of different coals are presented in Table 4. A number of carbonization tests were conducted in the 7-kg carbolite test oven, under stamp charging conditions using a standard procedure established at R&D, Tata Steel. The coal samples to be used for making the coal blends were crushed to a fineness of 90% below 3.2 mm. Water was added to the coal blend to obtain the desired value of moisture content. The coal cake was made inside a cardboard box keeping the bulk density 1 150 kg/m³. The final coal cake thus made was charged into the carbolite test oven. Before charging the coal cake into the oven, it was ensured that the empty oven temperature is 900°±5°C. The construction and operation of the 7 kg electrically heated test oven are based on the recommendations of the British Carbonisation Research Association (BCRA).5) After 5 h of carbonisation time, the hot coke was pushed out and quenched with water. The series of carbonisation tests were carried out following the above mentioned procedure to study the possibility of using jhama coal in blend. The coke samples were tested for ash, coke reactivity index (CRI) and coke strength after reaction (CSR).

Table 1. Properties of moderately affected jhama coal.

| Ash (%) | Volatile Matter (%) | Moisture (%) | Fixed Carbon (%) | Carbon (%) | Hydrogen (%) | Sulphur (%) | Nitrogen (%) | Oxygen (%) |
|---------|---------------------|-------------|------------------|------------|--------------|-------------|--------------|------------|
| 14.55   | 9.40                | 1.93        | 69.54            | 89.90      | 3.28         | 0.44        | 2.25         | 4.13       |

Table 2. (a) Petrographic analysis of jhama coal; (b) vitrinite distribution.

| Vitrinite | Semi Vitrinite | Exinite | Inertinite | Mineral Matter | Average Vitrinite Reflectance (Ro) |
|-----------|---------------|---------|------------|----------------|-----------------------------------|
| 26.5      | 2.5           | 1.0     | 63.2       | 6.8            | 1.07                              |

Table 3. (a) Properties of pitch; (b) Properties of resin; (c) Properties of molasses.

| Ash (db) % | VM (db) % | Total Alkalis (Na₂O+K₂O) % | Sulphur % | Phosphorous % | Coking value (by Conradson method) % | Softening Point 0°C | Q.I. Content % | T.I. Content % | Fixed carbon | pH | Viscosity | Solid Content | Setting time | Nitrogen (%) | Oxygen (%) |
|-----------|-----------|-----------------------------|-----------|--------------|-------------------------------------|---------------------|---------------|---------------|--------------|------|-----------|---------------|---------------|--------------|-----------|
| 0.2       | 0.2       | 0.015                       | 0.61      | 0.035        | 48                                 | 80                  | 4.96          | 23.6          | 36%          | Neutral | 250 cp-s @25°C | 66.2%         | 5 min @150°C | 0.09       | 33.21       |
3. Results and Discussion

The possibility of using jhama coal in coal blend was studied by adding three types of additives and with groupwise crushing. Table 5 contains the percentage of different coals in blend. Jhama coal used in the entire blend was kept at 3%. The coke properties are presented in Fig. 2. Coke ash varies in the range of 16.4 to 17.1% and CRI varies in the range of 25.9 to 28.4. Blend 1 is the base blend; contains 40% medium coking coal, 30% prime coking coal and 30% semi-soft and other weak coking coal like anthracite. In blend 2, 3% of semi-soft and other is replaced by jhama coal which results in a decrease in CSR. As expected, addition of pitch (0.1%) increases the CSR of the resultant coke (blend 3). Among the different additives phenolic resin was found to give the best results (blend 4). At high temperature it produces a cross linked structure which is responsible for the increase in coke strength. Addition of molasses had no effect on coke properties (blend 5). Improvement in coke CSR value observed when jhama coal was crushed separately to a specific size (0.2–0.4 mm) (blend 6). This is due to reduction of heterogeneity among the component of coal blend. Among the different additives, phenolic resin showed better results. Finally the addition of around 0.1% phenolic resin along with crushed jhama gives best results (blend 7). Addition of additives more than 0.15% is not advisable due to swelling problem. Coke CSR in carbolite oven is equivalent to 10–12 unit high CSR in commercial oven.

4. Conclusions

Utilization of heat altered coal will be the biggest issue in the coming decades. Some initiative has taken for industrial use of local heat altered coal (jhama). In order to use jhama coal as one of the components of coke making detail characterization was done. Carbonization test was done in 7 kg carbolite oven with different additives and pre-carbonization technique. It was found from the results that there is a scope of using moderately affected jhama coal as one of the component of coal blend in coke making with different additives and some specific pre-carbonization technique. Among the binders phenolic resin gives better result. Addition of phenolic resin with groupwise crushing gives the best result.

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Table 4. Properties of coals used in blend.

| Parameters                        | Medium coking coal | Prime coking coal | Semi-soft and other |
|-----------------------------------|--------------------|-------------------|---------------------|
| Proximate Analysis, % db          |                    |                   |                     |
| Ash                               | 15.84              | 15.34             | 9.24                |
| VM                                | 23.10              | 18.70             | 23.70               |
| Maximum Gieseler Fluidity, ddpm   | 6110               | 613               | 3                   |
| Crucible Swelling Number          | 5.5                | 6                 | 3.5                 |
| Petrographic analysis, vol %      |                    |                   |                     |
| Reactives                         | 54.1               | 50.4              | 49.7                |
| Inerts                            | 45.9               | 49.6              | 50.3                |
| Mean Max Reflectance (MMR)        | 1.06               | 1.22              | 1.14                |

Table 5. Blend composition.

| Blend | Medium coking coal (%) | Prime coking coal (%) | Semi-soft and other (%) | Jhama coal (%) | Additive |
|-------|------------------------|-----------------------|-------------------------|----------------|----------|
| 1     | 40                     | 30                    | 30                      | 0              | 0        |
| 2     | 40                     | 30                    | 27                      | 3              | Pitch-0.1|
| 3     | 40                     | 30                    | 26.9                    | 3              | Molasses-0.1|
| 4     | 40                     | 30                    | 26.9                    | 3              | Resin-0.1|
| 5     | 40                     | 30                    | 26.9                    | 3              | Molasses-0.1|
| 6     | 40                     | 30                    | 27                      | 3              | Pitch-0.1|
| 7     | 40                     | 30                    | 26.9                    | 3 (crushed)    | Resin-0.1|

Fig. 2. Properties of coke.