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EFFECT OF DILATION OF COAL BLEND ON PUSH FORCE AND COKE QUALITY IN STAMP CHARGED COKE MAKING PROCESS

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ABSTRACT

An abstract of no more than 200 words The blending of coals as practiced for stamp charged coke making is determined primarily by technical factors and secondary by economic factors. The most common problem in stamp charged coal blending is whether to adjust an operational blend, a common need is to predict the effect on oven health. In stamp charged coke making, push force is a bottleneck for smooth operation of coke oven battery to produce superior quality of coke.

In the present study, the relation between dilation characteristics of the coal blends has been investigated by the Audibert-Arnu Dilatometry test. The behavior of different coal blends has been studied to determine the effects of dilation of coal blend on coke CSR and push force. Coke plant data have been used for assessing the impact of dilation of coal blend on coke CSR and oven health. Results showed that dilation of coals blend is important parameters for controlling the coke quality and push force. The influence of some other important parameter on coke quality was also made in this study.

KEYWORDS: coal blend, dilation, stamp charged coke making, push force, coke CSR.

INTRODUCTION

The coke quality, in terms of coke strength after reaction, coke reactivity, ash content and chemistry, plays an important role in smooth operation of a blast furnace. The quality of coke depends basically on the quality of coal charged as well as on the use of coke making technologies. The final selection of coal charge used for coke making depends not only on requirements of coke quality and coal processing conditions, but also on restrictions imposed safe coke oven operations.

Stamp charged coke making technology facilitates reduction in volume of voids between the coal particles from almost 40% in usual top charging operations to less than 20%. These proximities of individual particles lead to a strong coke structure, though there are many positive attribution of stamp charging. It has to be highlighted that dilation behaviour of coal cake during carbonization plays a very important role in the success of this process. For controlled dilation, the plastic range of individual coal used should overlap and where this cannot be achieved, a suitable bridging additive may need to be incorporated to reap the full advantages of this technology. In general, coal blends with low volatile matter, causes excessive swelling of the coke / semi-coke mass. At high charge densities (as in the case of stamp charging), the swelling increases to such an extent that it cannot only give rise to coke pushing problems but in some cases, may damage the fabric of the ovens on account of excesses pressure excreted on the oven walls during carbonization[1].

The physical properties of coke are determined largely by the behavior of parent coal in the plastic zone. It is well known that when coking coals are heated in the absence of air, they become soft and plastic over a temperature range of 330 °C to 540 °C. The coal particles coalesce into a coherent mass which swells and then resolidifies to form coke with a porous structure. The prime quality coal transform in to plastic state during which active decomposition starts. The viscosity of coal and rate of volatilization are such that intergranular swelling is relatively small and coal

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particles adhere strongly. The resultant coke has pores of small diameter surrounded by thick walls. This structure is associated with high resistance to abrasion, provided inerts and minerals matters are within the allowable limits.

The plastic layer of coal is a highly heterogeneous phase which intricate the physical and chemical equilibria between solid, liquid and gaseous components and make the study complex[2]. The formation of a coal plastic layer during coking is a pledge to obtain a coking residue, and the gas pressure arises over layers which predetermines the magnitude of coking pressure. The zones, which vary in viscosity[3], in a magnitude of the force to perforate the layer[4], can be separated from the plastic layer. A relatively small amount of the work is connected with the investigation of the “active” role of a coal plastic layer in coking process[5-11]. A significant research efforts were focused on selection of coal blend based on a mixed linear programming and binary decision tree analysis[12, 13]. These models are employed in steel plants according to its operational characteristics and availability of coal in the market. The most relevant methods applied in coke quality prediction were reviewed and it was concluded that there is no universally applicable prediction model available for predicting coke quality due to the great excessive diversity of the coals used for coke making[14, 15]. Preceding research work on selection of coals based on composite coking potential (CCP) has been reported for assessing the suitability of coal and coal blend for making coke of desired quality[16].

The objective of this work is to maintain consistent level of production. It is essential to keep battery health in good condition. One of the major causes of oven deterioration is high push force leading cross leakages, thereby, resulting in damage to oven wall and reducing pushing (coke production). In order to achieve this, it was felt necessary to develop a methodology to prevent high push force to for prolonging the coke oven battery life.

MECHANISM OF SWELLING DURING CARBONIZATION

A coal is charged in to the oven for coke making, physico-chemical changes begins with the coal portion adjacent to the hot surface of the chamber wall becomes plastic and as the heat front advances to the next layer, the layer closest to the hot surface solidifies first. This sequence continues, layer by layer, until the plastic layer reaches the center of the oven as layer near the hot surface get transformed from semi-coke to coke. Gases and vapours from the inner layers escapes through the hot coke and fissures develop in the layer of semi-coke. In normal operation, around 75% of the gases escape through the hot end and the rest through the cold side during the period when the coal is in transient plastic state as the resistance to flow of gases is lower at the hot end. The physical expansion of the coal charge is mainly due to the expansion of plastic mass caused by the evolution of gases and it is maximum in the direction of through which the major portion of gases escapes. However, gases trapped in the plastic layer generate pressure which gets transmitted to the oven wall if the charge is in contact with the wall. This pressure again depends on the permeability of the plastic layer and the rate of gas evolution at the time of softening. In addition to the nature of coal and carbonization conditions, the gas pressure in the plastic zone and the dilation behaviour of the coal mass depends on various other factors [17].

PARAMETERS EFFECTING THE DILATION OF COAL CHARGE

In stamp charged coke making, the stamped coal charge expands first as one body and later shrinks-the width of the final coke mass is generally more than the initial width of the coal cake. The major factors responsible for the dilation behaviour of any coal charge during carbonization are: a) rank of the coal charge; b) the bulk density; c) the total inert content; d) size granulometry; d) carbonization conditions. Coal rank: in general, both expansion and contraction are related to coking pressure and reflectance of the charged coal/coal blend.

Bulk density: the bulk density of charged coal/coal blend has a significant effect on its dilation characteristics. Compacting of coal charge no doubt improves the throughput of the oven and the coke strength, but because of tight packing, the plastic mass formed during carbonization offer greater resistance to gas flow, resulting in higher gas pressure and swelling of the coke mass. Stamp charging which results in marked increase in bulk density upto 1150 kg/m3, thus calls for a proper selection of the coal blend inert content of the coal charged: Higher the total inert content, the lower is the expansion of the coal charge. With a coal of a given rank, the pressure exerted is less with higher inerts at the same bulk density. This may be explained by the fact that the inert do not become plastic and increase in inerts simply reduces the amount of material in the coal which becomes plastic during coking. Hence, stamp charging is ideal for Indian coals having high total inerts.

Size granulometery: Another factor influencing dilation is the coal particle size. For production of high quality of coke, it is a common practice to crush coal as much as possible to below 3 mm size to minimize the adverse effects of coarse mineral matter. Increasing the degree of crushing of moist coal reduces its packing density leading to a reduction of the pressure in the plastic layer and consequently, resulting in a higher shrinkage of coal.

Carbonization condition: besides the characteristics of coal and its bulk density, changes in carbonization condition also affect the expansion/contraction behaviour of the coal charge. Expansion of the coal charge is enhanced by faster rate of heating due to formation of a larger quantity of plastic mass.

MATERIALS AND METHODS

Materials

In this study, fifteen imported coals and three Indian medium coking coals were used. These coals were characterized for chemical, rheological and petrographic analysis. The important properties of all the coal samples are shown in Table 1. Based on availability and properties of individual coals, binary, ternary and quaternary blends were prepared for coke plant.

Table 1: Typical properties of individual coals

Coal ID	Ash, %	VM, %	CSN	Fluidity, ddpm	Expan-sion, %	Contr-action, %	Dilati-on, %	Ro, %
A	3.0	35.9	5	3	NIL	26	26	0.97
B	7.6	22.7	7.5	8	NIL	25	25	1.17
C	8.2	18.2	5	2	NIL	17	17	1.24
D	8.9	21.9	7.5	1129	61	26	87	1.19
E	10	23.6	9	1705	128	20	148	1.14
F	9.4	24	8	1738	87	22	109	1.11
G	7.3	22.8	6	400	20	20	40	1.12
H	8.0	20.4	6	4	NIL	17	17	1.16
I	8.5	21.2	6.5	5	-21	21	0	1.21
J	7.8	22.0	7	37	NIL	19	19	1.2
K	9.0	20.2	7.5	9	NIL	17	17	1.32
L	8.9	23.9	8.5	1055	57	26	83	1.11
M	9.4	29.2	7.5	14712	231	21	252	0.97
N	9.7	19.4	2.5	NA	NA	NA	NA	1.31
O	12.0	21.6	4	25	5	23	28	1.15
P	15.0	25.0	5.5	3750	78	21	99	0.99
Q	16.0	24.0	5	3250	51	21	72	1.02
R	17.0	24.0	4.5	3000	45	22	0	1.05

Carbonization at Plant Scale

The entire work was carried out in recovery stamp charged coke oven batteries of Tata Steel. In this study, different coals were collected from the coal yard and were fed with the help of a conveyor belt into the identified blending bunkers. After collection of selected coals in the required proportions, the blended coal was passed through coal crusher and crushed to the extent so that 90 (±2) % coals were below 3.2 mm. The moisture content of the blend was maintained in the range of 10 (±1) %. The stamped coal cake density was ~1.15 t/m3 (on wet basis). The coal cake was then charged into the identified oven with the help of pushing-cum-charging machine. The pushing was done at the normal operation schedule and quenched with water.

Coke Quality

The coke samples from the plant were collected through auto sampler. The CRI and CSR of the collected coke samples were assessed by the testing procedure developed by the Nippon Steel Corporation (NSC) method.

RESULTS AND DISCUSSION

In recovery stamp charge coke making, it was being observed that coal blend changes were leading to deterioration in coke quality at many a times and also coke makers were facing problem of higher push force (kW) while pushing the ready oven coke cake leading to frequent coal blend changes. Coal blend properties and operating parameters are usually controlled parameters at the coke plants. It is generally agreed that the chemical, rheological and petrographic blend characteristic are the most significant determinant of coking pressure and that low volatile coal participation in the blend is the primary cause of high pressure. Dilation is an important parameter for deciding the proportion of coal blends but, unfortunately for lower rank of coals, dilation is more easily controlled. It is a fact that Indian coals are generally inferior in quality as compared to imported coals which are used in other steel plants. The ash content of these coals varies in the range of 15−18% (clean coal); the average reflectance of vitrinite of these coal varies in the range of 0.7% to 1.8% and richer in inerts[18]. It makes stamp charging a ‘tailor made’ resource for India. Therefore, it should be obvious that blend proportion control is one of the most important key for the coke makers. The blend proportioning system must be operated in such a manner that variability of the equipment is comprehended so that an excessive-pressure blend is never charged. In addition to proportioning accuracy, the other self-evident caveat is to keep close control of coals so that high pressure coals never become mislabeled and used in place of low pressure coals.

Effect of moisture on push force

Figure 1 shows the influence of coal blend moisture on push force during pushing the coke from the coke ovens. Results depict that increasing moisture content in coal blend increases push force, reduction in oven temperature and opening up of any small joints due to thermal shock. On another hand, coal blend moisture has also impact on bulk density of coal cake having same stamping energy. Higher coal blend moisture content and bulk density lead to reduction in heat penetration rate, increase in coking time and high thermal shock of oven wall. Some evidence has been found which implies a dependence of coking pressure on coal moisture which is independent of bulk density consideration. In one case, it seems that the optimum (low coking pressure) occurs in the range of 4-6% moisture range. Above and below this range coking pressure has been increased[19]. Although moisture is a function of coal mine preparation plant operation (in Tata Steel, approximately 50% of captive coal used in the coal blend), weather and other factors and hence it is not directly under control of the operators. Therefore, some adjustments required at the coke plant are feasible and might be effective in adjusting coke plant operation.

Effect of granulometery on push force

Figures 2 and 3 show the effects of crushing fineness on push force. It was observed that increasing the fraction of minus 3.2 mm and minus 0.5 mm results in increase in push force. The higher level of fines are detrimental for the batteries as it leads roof carbon formation and lower level leads to the higher proportion of +0.5 mm coal fraction. When coal is heated, a smaller particle due to its greater surface to volume ratio is able to fuse well with the neighboring particle and gives an almost homogeneous mixed phase. When the particle size is large, this mixed phase is limited since the particles retain their individually. So, any coal bed composed of smaller particles shrinks to a greater extent than those made up of larger ones. Therefore, the high pushing energies related to excessive carbon deposit at the top of the ovens and increasing degree of crushing automatically results in a higher shrinkage of the coke mass.

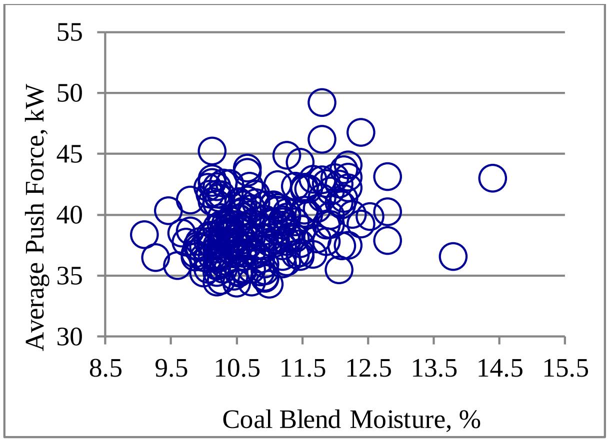

Figure 1: Effect of coal blend moisture on push force

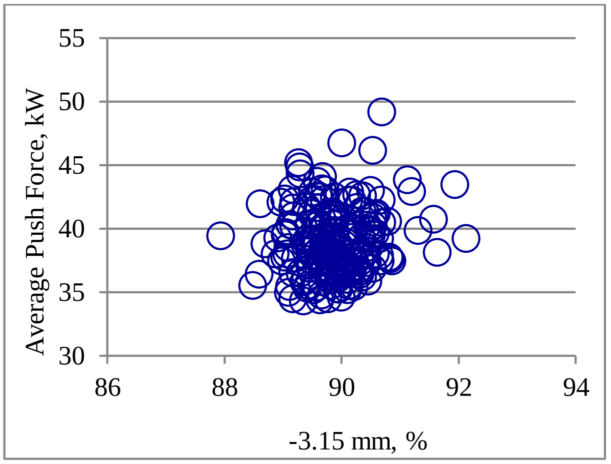

Figure 2: Effect of -3.15 mm fraction on push force

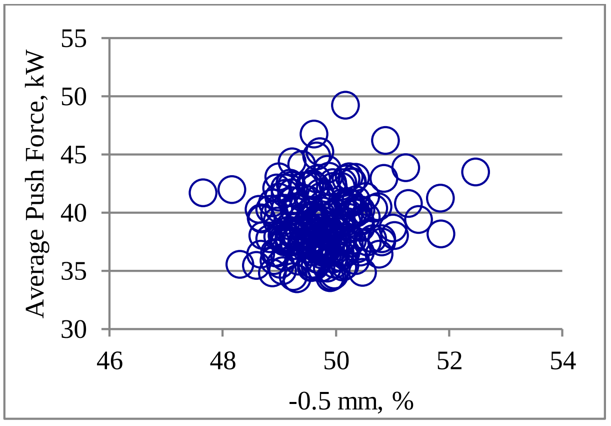

Figure 3: Effect of -0.5 mm fraction on push force

Effect of dilation on push force

Figure 4 shows the influence of dilation on the measured push force of the oven during coke pushing. Result shows that dilation is one of the significant determinants of push force and was found that the relationship between dilation and push force in nonlinear and, in fact, the lower and higher dilation have normal operating push force range as compare to middle band. The push force is significantly higher at the dilation range of 30-60% as compare to lower and higher ends. A higher expanding coal is expected to leave fewer gaps between the cake and walls resulting in higher push force and likely damages to oven walls with poor oven health conditions. Whereas, a lower or moderate expanding coal leaves sufficient gap between the cake and oven walls resulting in normal push force.

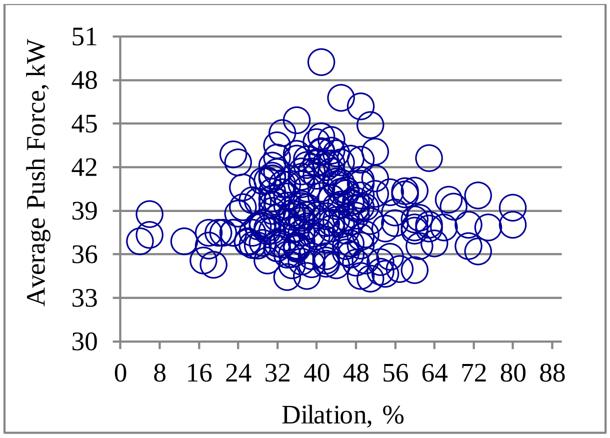

Figure 4: Effect of dilation on push force

Effect of dilation on coke quality

Figure 5 depicts the relation between dilation of coal blend and coke CSR. Result depicts that increase in dilation of coal blend tends to increase in coke CSR. A higher dilation value indicates more and more coal particles getting wetted with fluid state portion of the coal mass. In the process thin layers are formed over the solid state particles the fluids come across. The thin layer creates bonding between particles with formation of lump coke mass. Thicker the bonding layers, more the strength of hard mass. Higher dilation also assimilates more and more no of particles which remains in solid state throughout the process resulting in higher CSR. The phenomenon is more prominent when higher rank coals are part of the blend. In the course of investigation, coal blend contraction, which may have been adequate during a battery's early life, may become unacceptable as battery ages, subsequently requiring a higher specification to be established for coal blends contraction. Another key reason observed for high push force was higher lateral expansion of coal blend and with lower vertical shrinkage of the coal during carbonization. The coal/coal blends yielding 7 kg oven coke of acceptable quality (coke strength after reaction (CSR) = 54 minimum) without excessive lateral expansion (8.2% maximum) were recommended for producing commercial oven coke with a CSR of 64 minimum[20]. Analysis for possible causes for stickers indicated that, while many factors affect the ability to push coke, (in particular, damage and irregularity of oven wall surfaces, loss of coke mass integrity due to highly fissured or weak coke, machinery failure, and operational errors, such as overcharging, heavy roof carbon buildup, etc.[21-24]. Coal charge contraction in the oven was considered to be one of the main factors determining pushing performance of aged ovens. In addition, it was realized that coal charge contraction is one of the factors affecting oven pushing performance, which could be controlled by carbonization parameters. This means that, by adjusting the magnitude of the contraction, a charge could be successfully pushed from the ovens with deteriorated and uneven walls which would have otherwise been pushed.

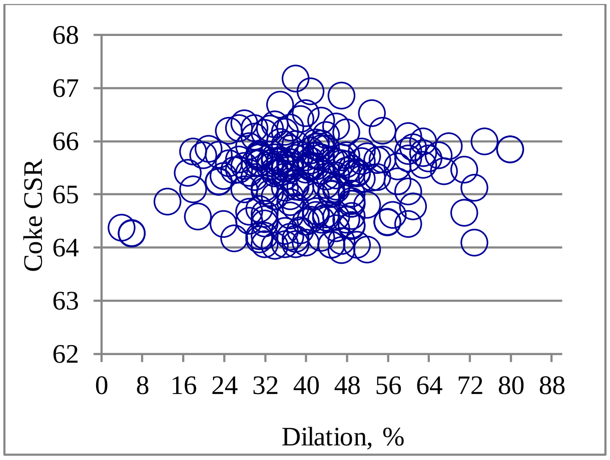

Figure 5: Effect of dilation on Coke CSR

Figure 6 depicts the relation between dilation of coal blend and coke M40. Results show that increase in dilation tends to increase in coke M40 value. It was observed that expansion in the stamp charged during carbonization was found maximum in the lateral direction since the major portion of gases escape in this direction and there is partially no change in cake dimensions in longitudinal direction and only some expansion in the vertical direction. The maximum expansion occurs at around 60% of the total carbonization time predominantly in the lateral direction and found that the dilation of coal/coal blend has a significant impact on push force and coke quality. Coke M40 depends on the thermal destruction of the coals in the plastic state. The properties of the plastic coal mass (viscosity, gas permeability, plastic-layer thickness, and temperature range of the plastic state) play a significant role in producing coke of specified quality. This is because the porous structure of semi-coke that will be converted to coke on subsequent heating is formed in the plastic state. In the process thin layers are formed over the solid state particles the fluids come across. The thin layer creates bonding between particles with formation of lump coke mass. Thicker the bonding layers more the strength of hard mass and eventually higher mechanical strength [M40]. Therefore, with increase in dilation, the porous body strength of the coke increases and hence, dilation of coal blend is an important key in recovery stamp charged coke making to produce desired quality of coke and battery life.

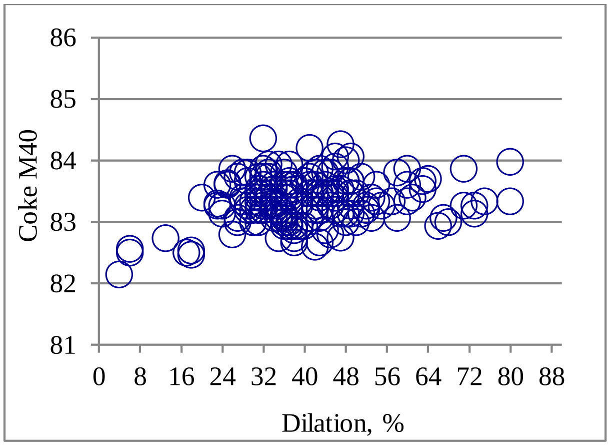

Figure 6: Effect of dilation on Coke M40 value

CONCLUSION

The success of stamp charge coke making depends on proper selection of coal blends and close controls of the carbonization conditions so that the lateral contraction at the end of carbonization allows coke to be easily pushed out. The study confirmed that coal dilation has significant impact on push force and coke quality. The influence of coal blend dilation was found to be non-linear throughout the dilation range practiced, with changes within the high and medium rank coal having a greater effect than changes with in low rank coals. In commercial ovens, it is not possible to measure the lateral expansion or contraction so accurately, hence judiciously interpreted vertical dilation measurements have to be used for control purposes. Therefore, it may be concluded that push force is highly dependent on dilation of coal/coal blends in a specified range.

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