Studies to overcome the manufacturing problems in blast furnace tap hole clay of Integrated Steel Plants: Experimental approach

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Abstract. Integrated Steel Plants commonly uses Blast Furnace route for iron production which accounts for over 60% of the world iron output. Blast Furnace runs for ten to twenty years without repairing hearth walls and Tap Hole (TH). Tap hole is an outlet for hot metal produced in a Blast Furnace and run from the shell of the furnace into the interior allowing access to the molten material. Tapping is the term used for drilling a hole through the tap hole which allows the molten iron and slag to flow out. In Iron making process, removal of liquid iron from furnace and sending it for steel making is known as cast house practice. For tapping liquid iron and operating the tap hole requires a special type of clay. Tap hole clay (THC) used to stop the flow of liquid iron and slag from the blast furnace. Present work deals with the study on manufacturing of THC at Visakhapatnam Steel Plant and problems related to manufacturing. Experiments were conducted to solve the identified problems and results are furnished in detail. The findings can improve the manufacturing process and improve the productivity of tap hole clay.

1. Introduction

Tap hole clay (THC) is a plastic refractory and the desired properties are decided based on blast furnace capacity. Various parameters taken into account while designing tap hole clay are furnace capacity, tap to tap time, type of mechanism used for opening and closing, curing time required, production, temperature of metal and slag, life of blast furnace and hearth conditions. THC ingredients are mixed in proportion and the clay forms a lump with these ingredients. These lumps are cut and stored at required temperature and ready for use when required for closing the tap hole. Tap Hole Clay (THC) is exposed to a wide variety of temperatures in the blast furnace around 50°C at the shell and 1500°C in the interior. During casting, THC is also exposed to molten material as it flows through the drilled tap hole and it is important for THC to withstand these harsh conditions. Inadequate understanding of the behaviour of the Tap Hole Clay (THC) has lead to problems in the blast furnace operation and can result in significant financial loss. Understanding the factors that affect the Tap Hole Clay (THC) can widen the knowledge of how different clays behave in the furnace. Major improvements have taken place with the objective to open and plug the tap hole carefully to avoid damage to carbon bricks. It must be ensured to have a smooth surface channel to ensure smooth flow of liquid iron and get a correct tap hole diameter to allow the correct flow rate of liquid iron. Tap Hole Clay (THC) compositions are generally divided into three major groups; binder, aggregate, and matrix. Many past studies have been made to know the properties of THC. More focus was not given on design of clay. The Tap Hole Clay (THC) production is the responsibility of refractory supplier and the problem with present system is focus for production leaving the furnace life and hearth condition.
Fig. 1 Tap Hole Clay (THC) constituents and roles

| Furnace type                              | THC type       | Equipment used in cast house |
|-------------------------------------------|----------------|------------------------------|
| Pressure less furnace                     | Water based    | Manual closing               |
| Bell type furnace with blower             | Tar based      | Electrical                   |
| Bell less furnace small capacity          | Tar based      | Electrical                   |
| Bell less high capacity                   | Resin based    | Hydraulic                    |
| Bell less high top pressure high capacity | Resin based improved ingredients | Hydraulic |

Table 2 some of the raw material constituents of the Tap Hole clay mixes and its main functions

| Raw materials                              | Main functions                                      |
|--------------------------------------------|-----------------------------------------------------|
| Fused Alumina, Calcined Bauxite, Grog (Alumina brick powder) | Main Aggregates, Filling materials Improves strength |
| Plastic clay, Fly ash                      | Workability; Injection                               |
| Pyrofillite, Andalusite                    | Workability; Expansion (500/1300°C)                  |
| Silica, Fine sand                          | Expansion (600/1000°C)                               |
| Fine Calcined Alumina / Fume silica        | Sintering/Mullite formation/Expansion                |
| Zirconium                                  | Special additives/Spalling/Corrosion                 |
| Silicon Carbide, Carbon                    | Corrosion resistance                                |
| Metallic powders                           | Erosion resistance/Sintering                         |
| Coke, ultra fine carbon                    | Drying, Drilling                                    |
| Tar/Resin/Special Oils                     | Binders                                             |

Composition variation is inevitable due to the limited supply of Tap Hole Clay (THC) and the cost of ingredients used. Present studies have been made to develop and design tap hole clay with consistent quality. Present studies have been made to solve the manufacturing problems at Visakhapatnam Steel
Plant. THC constituents and roles are given in Fig. 1. Tap Hole Clay development with development of Blast Furnace is listed in Table 1. Some of the raw materials constituents of the THC mixes and its main functions are given in Table 2.

Table 3 THC composition used by different steel plants in India

| Mix   | Mix-1 | Mix-2 | Mix-3 | Mix-4 | Mix-5 | Mix-6 | Mix-7 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| Quartz| 13.09 | 15.63 | 29.11 | 18.92 | X     | x     | X     |
| Silicon Carbide| 3.19  | 6.24  | 5.92  | 5.77  | 16    | 16    | 13    |
| Corundum| 9.22  | 10.56 | 8.81  | 8.57  | X     | x     | X     |
| Graphite| 15.13 | 21.60 | 23.55 | 27.88 | 6     | 6     | 6     |
| Pyrophyllite| 8.39  | 15.25 | X     | X     | X     | x     | X     |
| Silicon Nitride| 5.29  | 4.5   | x     | x     | 5     | 5     | 5     |
| Sillimanite| X     | 26.13 | 17.25 | 27.63 | X     | x     | X     |
| Kyanite| 45.7  | x     | x     | X     | 17    | 17    | 13    |
| Kaolinite| 13.09 | x     | 15.35 | 11.22 | X     | x     | X     |
| Alumina| X     | x     | x     | x     | 37    | 37    | 37    |
| Resin | X     | x     | x     | x     | 9     | 9     | 6     |
| Coke  | X     | x     | x     | x     | 10    | 10    | 10    |
| Binder(solid) | x     | x     | x     | x     | X     | x     | 10    |
| Binder (Liquid) | x     | x     | x     | x     | 18.8  | 17    | 17    |

3. Manufacturing
3.1 Study on THC and problems related to Tap Hole Clay (THC) at Visakapatnam steel plant
3.1.1 Production of Tap Hole Clay (THC) at Visakapatnam Steel Plant. The THC is produced in pan mixers of 1 ton capacity. The ingredients are charged from top. Dry and wet ingredients are added separately. The ingredients are weighed before adding in mixer. Production of THC is a batch process. One batch weighs from 800 to 900 kgs. The dry mixing is for 15 mints. Lubricant is added after 15 mints and mixing continued for 10 more mints. The mixer body shell temperature is maintained at 65-70 degree centigrade using steam jackets. The dry mixing is done to avoid load on mixer. Mixer parameters are given in Table 4. The mixing never stopped after addition of lubricant to avoid jamming of mixer. The mixing continued during discharge of clay lump. Lubricant is added gradually to ensure uniform addition.

Table 4 Pan Mixer parameters

| S. No | Parameter               | Capacity |
|-------|-------------------------|----------|
| 1     | Capacity                | 1 ton    |
| 2     | Batch weight taken for mixing | 800 – 900 kgs |
| 3     | Shell temperature °C    | 65-70    |
| 4     | Maximum motor current   | 150 Amps |
| 5     | Type of mixer           | Double roll |
| 6     | System of temperature maintenance | Steam jacket |
| 7     | Process                 | Batch process |
3.2 Problem identification

3.2.1 Problems during production of Tap Hole Clay (THC). The THC is produced using mixer which mixes the ingredients. The ingredients are added in required proportion. The mixing is done without adding lubricant for 15 minutes called dry mixing. The mixing is continued for 10 minutes after adding lubricant called wet mixing. The produced Tap Hole Clay (THC) comes out as a lump. The lump is cut into pieces manually. It is allowed to dry for 1 hour before it is packed using the polythene covers to avoid sticking together. The cutting of clay into pieces is a difficult process as the THC is pitch bonded. During the production process, Pitch dissolves in lubricant and the liquid becomes viscous. The clay becomes hard (pitch dissolves in lubricant and becomes a viscous liquid) at room temperature and it needs to be heated before use. Current during the mixing was noted and it was observed the current increases after addition of lubricant in the mix. Lab scale experiments showed the pitch dissolves in lubricant and becomes more viscous. The viscosity of lubricant decreases with decrease in temperature. Tap Hole Clay (THC) cannot be used at room temperature without heating due to viscosity problem. Suitable lubricant is to be identified. The lump formed after mixing is very hard. At room temperature manual cutting is difficult. Manual cutting made the clay into irregular shape, size and weight. Automatic cutting and packing has failed due to high viscosity of the binder at room temperature of the THC. During the mixing the load on mixer is high. The current was as high as 150 Amps, which sometimes tripped the mixer motor. The alternate way of mixing is to be found out to avoid tripping. The tripping of mixer has resulted in production loss amounts to 60 tons.

3.2.2 Environmental related problems in Tap Hole Clay (THC) production. The production of THC is using pitch, resin, lubricant, coke, alumina and clay. Resin and pitch are used as ingredients to increase bond strength. The pitch dissolves in lubricant as both are by-products generated inside the plant and both are generated from coke oven gas. The generated by-product lubricant was analyzed and found to contain naphthalene 3 to 5 %. Naphthalene is highly inflammable and naphthalene becomes vapor at room temperature. The vapor naphthalene deposits on the workers and surrounding environment. The vapors, smoke and flames produced during the use made the working environment difficult. At room temperature the viscosity of dissolved pitch in lubricant was less. The extrusion of clay becomes difficult because of less workability. The clay needs heating to improve workability as pitch dissolved in lubricant becomes less viscous at room temperature. The few ingredients used are from by product plant, which is from coke making mainly the byproducts like pitch and oil. Both the ingredients are by products from tar distillation plant. Pitch and oil are mixed in THC to increase the bonding strength. The pitch dissolves in wash oil to produce a viscous liquid and act as a binder. The lubricant used contains naphthalene up to 5 %. Variation in naphthalene content in the lubricant is given in Table 5. During the usage problems were observed with oil from byproduct. The flash point of the oil was 94°C. THCs are used in temperature of 1450 to 1600°C. Flames were observed during the tap hole opening. The cleaning of the equipments became difficult because of flame. The filled mud gun with clay has to be heated for use as the clay is tough. The workability varies with temperature as pitch softens with rise in temperature. THC with mud gun is heated before use to make the THC workable. The heating of mud gun generated smoke and fumes. Fumes containing naphthalene are generated in the shop floor. Mud gun heating also can be avoided by identification of proper lubricant, which is less viscous at room temperature. Suitable identification of lubricant can solve the environmental problem during production and operation. To replace coal based lubricant with lubricating oil for better working environment and production.

Table 5 Naphthalene content of existing lubricant

| Specific gravity | Naphthalene |
|-----------------|-------------|
| At 30°C         |             |
| Min             | Max         |
| 1.085           | 3.34        | 4.99        |
4. Experimental Details
Main aim of introducing new lubricant is to eliminate naphthalene content and avoid pitch dissolving in coal based lubricant. The lubricant is a reclaimed product and is given in Table 7. The lubricant was replaced with viscous lubricant 320 mm²/sec at 40°C temperature. The lubricant has a high viscosity and flash point. THC aggregates and functions at Visakhapatnam Steel Plant are given in Table 6. The THC mix prepared with designed composition with new lubricant was tested.

Table 6 THC aggregates and functions at Visakhapatnam Steel Plant

| S.No | Material | Function Of Ingredients | State of material | Functions                      |
|------|----------|-------------------------|-------------------|--------------------------------|
| 1    | Binder   | Binder                  | Solid             | Binder, Thermo setting         |
| 2    | Resin    | Thermo setting          | Solid             | Thermo setting                 |
| 3    | Filler 1 | To give cold crushing strength | Solid         | Cold crushing Strength          |
| 4    | Filler 2 | To give volume and heat  | Solid             | Carbon                         |
| 5    | Binder 2 | To give workability, Expansion | Solid         | Expansion                      |
| 6    | Lubricant| To make extruding smooth | Liquid            | Extrusion                      |

Table 7 Properties of new lubricant

| Sample  | Specific gravity at 30 °C | Moisture % | Sediments % | Viscosity at 40 °C |
|---------|---------------------------|------------|-------------|--------------------|
| Lubricant | 0.895                     | nil        | 0.1%        | 320mm²/sec         |

4.1 Preparation of the Tap Hole Clay (THC) sample
THC batches prepared with required composition in laboratory scale for testing. The test results were compared with the properties of the existing Tap Hole Clay (THC) composition. Experiment includes laboratory preparation of Tap Hole Clay (THC). Weighing, preparation of samples, testing of dried samples and testing of fired samples. The fired samples were removed after 8 hours of cooling and samples were cleaned before subjecting to any test. THC ingredients were measured on weight percentage (%) basis. The weight was accurate to single digit. THC is prepared in 5 Kg muller mixer. The dry ingredients were mixed for 10 mints. The lubricant was added after 10 mints and mixing continued for 15 mints. The total mixing time was 25 mints. Lubricants were added while mixing in a uniform manner to avoid accumulation of lubricant at one portion. Samples were prepared from batch of 2 kg batch of THC mix. Each sample weighted was 150 grams. The sample shape is cylindrical. The samples were made immediately after preparation to avoid ageing. The samples were made with split mould wherever required as it is easy to remove the sample and again apply load for further testing. The crushed ingredients were collected from the unit to minimize the error. Prepared tap hole clay samples are shown in Fig.2. Sample removal after firing is shown in Fig.3. Refractory tube for single sample firing is shown in Fig.4.
4.2 Testing Methods

4.2.1 Apparent Porosity (AP). Weight of the sample taken was 150 grams. The samples were pressed in metal cylindrical mould. The sample is made by applying 2.5 tons load. The sample is dried in drier at 100 °C for 1 hour and cooled to room temperature in the same drier. The samples were packed with carbon coal powder in a refractory or metal container. The containers for sample firing are covered with castable to avoid air contact. The packed samples were fired at 1000 °C in 4 hours. The rate of heating is 250 °C per hour. The furnace temperature of 1000 °C the samples were kept for 1 hour. Total firing time is 5 hours.

Percentage of AP = \((W-D)/(W-S) \times 100\)

W= saturated weight (Thinner +sample weight)
D= Dry weight
S = Suspended weight (Immersed in Thinner)

The dry weight of the sample is taken and then the sample is soaked in thinner for 6 hours. Specific gravity of thinner taken is 0.77.

4.2.2 Bulk Density (BD). Weight of the sample taken was 150 grams. The samples were pressed in metal cylindrical mould. The sample is made by applying 2.5 tons load. The sample is dried in drier at 100 degree centigrade for 1 hour and cooled to room temperature in the same drier. The samples were packed with carbon coal powder in a refractory or metal container. The containers for sample firing are covered with castable to avoid air contact. The packed samples were fired at 1000 degree centigrade in 4 hours. The rate of heating is 250 degrees per hour. The furnace temperature of 1000 degrees the samples were kept for 1 hour. Total firing time is 5 hours.

BD = \(D/(W-S) \times \text{specific gravity of thinner 0.77}\)

W= saturated weight (Thinner +sample weight)
D= Dry weight
S = Suspended weight (Immersed in Thinner)

4.2.3 Linear expansion. Weight of the sample taken was 150 grams. The samples were pressed in metal cylindrical mould. The sample is made by applying 2.5 tons load. The height is measured for the pressed sample. The sample is dried in drier at 100 0 C for 1 hour and cooled to room temperature in the same drier. The samples were packed with carbon coal powder in a refractory or metal container. The containers for sample firing are covered with castable to avoid air contact. The packed samples were fired at 1000 0 C in 4 hours. The rate of heating is 250 0 C per hour. The furnace temperature of 1000 0 C the samples were kept for 1 hour. Total firing time is 5 hours. The fired sample was measured to measure the expansion. The sample height difference before firing and after firing is taken as the expansion.

4.2.4 Metal and slag reaction test

Weight of the sample taken was 150 grams. The sample is made by ramming. The samples were made within 10 mints of mixing to avoid ageing. The samples were put inside refractory tube. The sample with refractory tube was filled with liquid and kept for 30 mints as shown in Figs.5 and 6.

![Fig.5 Reaction test with slag](image1.png) ![Fig.6 Reaction test with metal](image2.png)

4.2.5 Slag reaction test. Weight of the sample taken was 150 grams. The samples were made within 10 mints of mixing to avoid ageing. The sample is made by ramming. The clay sample was put inside the refractory tube. The refractory tube with the clay sample was filled with liquid slag for 30 mints. The sample was taken out and allowed to cool. The clay samples taken were observed to know the reaction as shown in Fig.7.

![Fig.7 Samples after cooling (Reaction test)](image3.png)

4.2.6 Cold Crushing Strength (CCS). Weight of the sample taken was 150 grams. The samples were pressed in metal cylindrical mould. The sample is made by applying 2.5 tons load for studying CCS. The sample is dried in drier at 100 degree centigrade for 1 hour and cooled to room temperature in the same drier. The samples were packed with carbon coal powder in a refractory or metal container. The packed samples were fired at 1000 0 C in 4 hours. The rate of heating is 250 degrees per hour. The furnace temperature of 1000 degrees the samples were kept for 1 hour. Total firing time is 5 hours. Then the samples were allowed to cool inside the furnace. The fired samples were tested by applying
load. The load at which sample fails is taken as the load applied. CCS value is calculated from load
applied divided by load applied area
\[ CCS = \frac{\text{load applied (at which sample failed)}}{\text{load applied area}} \]

4.2.7 Curing time Cold Crushing Strength (CCS) after 12 minutes. The clay was pressed inside the
refractory tube by applying one ton load. The refractory tube with clay was allowed to float on liquid
metal for 12 mints. Refractory tubes for sample holding for testing setting time are shown in Fig.8. The
setting time was 12 mints after closing, and then the mud gun is removed from the Tap Hole. The
setting time was selected based on designed THC already in use. The pressed samples in refractory
tube were allowed to float on hot metal. The sample with the refractory tube was removed and allowed
to cool. The cooled refractory tube was broken. The sample taken out from the broken refractory tube
is shown in Fig. 9. The taken out sample was tested by applying load. The load at which sample fails
is taken as load applied. The Tap Hole clay (THC) samples for testing setting time is shown in Fig.
10. The load applied divided by load applied area gives the CCS values. CCS value varies with sample
setting time. High CCS values show the sample has acquired enough strength within the given time.
The setting time given for these samples was 12 mints. The CCS test was conducted for these samples
and compared. Sample before and after exposure to molten liquid with refractory tube shown in Fig.
11. The setting time of the samples were also studied at different intervals 5 mints, 8 mints and 12
minutes.

![Fig.8 Refractory tubes for sample pressing](image)

![Fig.9 Sample taken out of refractory tube after floating in metal and slag](image)

![Fig.10 Samples for testing setting time](image)

![Fig.11 Sample before and after exposure to molten liquid with refractory tube](image)

4.2.8 Workability. Weight of the sample taken was 150 grams. The samples were rammed using sand
rammer with 10 blows. After that the samples were removed from the split mould and height was
measured. The sample was again loaded into the split mould and 20 blows were given both sides. The
sample was again removed from split mould and the height of the sample was measured. The
difference in height was taken as workability. The decrease in height in millimeter (mm) is the
measure of workability.

4.2.9 Drill ability. The drilling is to be smooth. TH should open in one bit. If tapping opening delayed
the THC injected becomes hard. The delay in tapping opening will lead to production loss and
variation in furnace parameters. The furnace reduction process has to be slowed down in case of
accumulation of metal and slag in hearth (furnace has to be put down). The lab scale experiments were
conducted by drilling the fired clay. The THC samples pressed inside the refractory tube were allowed
to float in metal. The taken out sample with refractory tube was cooled to room temperature. During
grilling of the sample the current was observed. The increase in correct during drilling shows the difficulty in drilling. Samples of drill ability test with refractory tube are shown in Fig. 12 (a) and (b), drilled samples with refractory tube are shown in Fig. 13.

![Fig. 12 (a) and (b) drill ability test on THC samples](image1)

![Fig. 13 Samples tested for drill ability](image2)

5. Results and Discussion

5.1 Tap Hole Clay made with new lubricant

The composition of existing THC and THC with new lubricant is given in Table 8. Difference in variation of apparent porosity was observed to be less when compared to existing Tap Hole Clay (THC). The results of the tested properties are given in Table 9. The change in lubricant had not affected the surface of fired samples. The lubricant used was highly viscous at room temperature. The high viscous lubricant has given good bond strength and not much change in shape during firing. The porosity change in case of high viscous lubricant usage was high compared with existing tap hole clay. The increase in porosity was due to the undissolved pitch with new lubricant. The change in bulk density was in proportion with apparent porosity change. The expansion characteristics were studied and the sample had positive expansion. The samples showed smoke coming out while bath test. The samples were intact after the test and no deformation was observed with rise in temperature. High viscosity of the lubricant with the temperature rise had no effect on the sample. Cold crushing strength (CCS) was comparable with existing THC. With replacement of lubricant CCS has increased and bond strength has improved. The CCS improvement has showed good bonding in samples. There was change in workability with new lubricant at room temperature. Unlike the existing lubricant there was no tar formation. The pitch does not dissolve in the new lubricant. Bath test has showed no sticking of metal or slag on the surface and no distortion on shape was observed. Curing time after 12 mints of floating has shown the CCS was better compared to existing THC. The setting time indicated the better bonding in the sample. The higher CCS with setting time is due the high porosity of the sample and allowed hot gases to pass through the pores.

![Fig. 14 Variation in Apparent porosity with new lubricant THC](image3)
Comparison Variation in the tap hole clay properties is shown in Figs. 14 to 19. The CCS of tap hole clay with new lubricant was high compared to existing tap hole clay due to the better bonding strength. The curing time results with new lubricant is higher when compared to the existing Tap Hole Clay (THC) also proved that bond strength is high. Tap hole clay with new lubricant had positive expansion on heating. Hence the new lubricant has not affected the expansion characteristics of the tap hole clay. The workability was better compared to existing tap hole clay. The better workability will make the operation of mud gun easy and heating of the mud gun can be avoided. The THC is soft and workable at room temperature.
Table 9 THC properties of existing and THC with new lubricant

| S.No | Property                             | Existing THC | THC with new lubricant |
|------|--------------------------------------|--------------|------------------------|
| 1    | Apparent porosity (%)                | 27           | 37.3                   |
| 2    | Bulk Density (g/cc)                  | 1.806        | 1.63                   |
| 3    | Expansion:                           | 0.3 mm       | 0.2 mm                 |
| 4    | Metal and slag reaction test         | Metal and slag were not sticking | less Smoke was observed , No Metal and slag sticking to sample |
| 5    | Cold Crushing Strength (CCS)         | 167 Kg/Cm²   | 170.0 Kg/Cm²           |
| 6    | Curing time CCS after 12 mints       | 44 kg/cm²    | 48 kg/cm²              |
| 7    | Workability test                     | 0.7 mm       | 1 mm                   |
| 8    | Drill ability                        | 2 Amps       | 3 Amps                 |

Fig. 17 Variation in Cold crushing strength (CCS) with new lubricant THC

Fig. 18 Variation in Curing time CCS after 12 mints
6. Conclusions
1. The coal based lubricant containing naphthalene was replaced with suitable new lubricant.
2. The use of new lubricant can save the labour cost Rs5000/day on labour apart from better manufacturing and working conditions.
3. The advantage with new lubricant is higher production and better working environment apart from other operating advantages.
4. Overall study established that new lubricant can be a replacement for coal based lubricant with significant advantages in term of improving the production of tap hole clay and operation of Blast Furnace in integrated steel plants.

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