

Experimental Study on Environment Friendly Tap Hole Clay for Blast Furnace

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Abstract. Blast furnace (BF) is the best possible route of iron production available. Blast furnace is a high pressure vessel where iron ore is melted and liquid iron is produced. The liquid iron is tapped through the hole in Blast Furnace called tap hole. The tapped liquid metal flowing through the tap hole is plugged using a clay called tap hole clay. Tap hole clay (THC) is a unshaped refractory used to plug the tap hole. The tap hole clay extruded through the tap hole using a gun. The tap hole clay is designed to expand and plug the tap hole. The tap hole filled with clay is drilled using drill bit and the hole made through the tap hole to tap the liquid metal accumulated inside the furnace. The number of plugging and drilling varies depending on the volume of the furnace. The tap hole clay need to have certain properties to avoid problems during plugging and drilling. In the present paper tap hole clay properties in industrial use was tested and studied. The problems were identified related to tap hole clay manufacturing. Experiments were conducted in lab scale to solve the identified problems. The present composition was modified with experimental results. The properties of the modified tap hole clay were found suitable and useful for blast furnace operation with lab scale experimental results.

1. Introduction

Blast Furnace is used for iron production in steel plants. Blast Furnace is a pressure reaction vessel where iron ore is melted. Blast furnace route of iron making is the best possible method for high productivity. The liquid melt is tapped through a hole from the furnace called tap hole. The tap hole is filled with special type of clay named tap hole clay (THC) and to drain out liquid iron, the clay has to be drilled through tap hole and plugged. The high quality tap hole clay must have the property to expand while heating which makes the tap hole to plug the tapping. To maintain the high top pressure of 2.0 to 3.0 kg/Cm² in blast furnace, high quality tap hole clay is used. Better quality of clay can increase the productivity of blast furnace. Tap hole clay is produced at the steel plant with a proper selection of ingredients mixed in proportion. The typical tap hole clay composition consists of matrix material (clay), filler(coke), binder(pitch), lubricant(oil), material to impart high temperature strength(alumina), material to decrease curing time(resin) and abrasive material (silicon nitride, silicon carbide). The quantity and the material used may vary according to the availability, cost and furnace capacity. It is better to have less number of ingredients to have a better control on chemical composition, particle size, cost and consistency in tap hole clay quality. In Visakhapatnam Steel Plant, two blast furnaces are operated with a volumes of 3200M³ and 3800M³ capacity respectively. The tap hole clay is prepared in house and its properties are plant specific. In our present work, an attempt has been made to study and develop new tap hole clay for blast furnace operation to improve the iron production in Visakhapatnam Steel Plant. The main aim of the research work is to make a plant based study on tap hole clay manufacturing and problems related to tap hole clay and to improve the



performance of the blast furnace operation. Design for the optimum mix of special clay for blast furnace operation is attempted in the present research work. The tap hole clay mix used in the steel plant was replaced with other materials for reducing the cost, improving the quality and performance of the blast furnace operation. Existing tap hole clay uses clay, alumina, pitch, resin, coke and lubricant as ingredients. Clay is one of the major ingredient used in the manufacture of tap hole clay but it is having limited availability. There is a need to find a replacement for clay in tap hole clay manufacturing.

1.1. Tap Hole Clay (THC) Composition

THC can be divided into three groups of materials.

1. Aggregate
2. Matrix
3. Binder

The coarser material in the THC is the aggregate while the finer material is the matrix. Both of these groups consist of refractory ceramic materials. The aggregate material is used as filler whilst being chemically inert to the molten iron and slag. The materials used in the matrix fulfil several functions; they optimize reactivity and density and provide non wetting characteristics. The binder holds the aggregate and matrix material together in the unfired form and allows them to be moulded. Variations in the individual components of the THC significantly influence its behaviour.

1.2. Aggregate

Aggregate is the coarse material within the THC microstructure. It usually consists of large particles of alumina and in some cases carbon. The composition of the aggregate material affects the high temperature strength and stability of the THC. Alumina (Al_2O_3) is a hard strong refractory material, as is not readily attacked by acids or alkalis at high temperatures [1]. It is used in many products because of its resistance to high temperatures. Silica (SiO_2) is also a common refractory material.

Yamamoto and Toritani studied the effects of aggregate compositional variation on the corrosion of refractory raw materials. The slag corrosion index of a variety of Al_2O_3 - SiO_2 materials was studied. They found that the greatest corrosion of the raw materials occurred when the composition contained approximately 50% each of Al_2O_3 and SiO_2 , Yamamoto and Toritani confirmed that an increase in the ratio of alumina in THCs leads to a reduction in the slag corrosion index. Other authors [2, 3] have also found that the THCs performance increased by increasing the quality of the alumina used.

The addition of SiC to the aggregate was also found to reduce the slag corrosion index. When up to 10 % SiC was added to the THC the slag corrosion index reduced rapidly, with any further increases in SiC having little influence on the corrosion resistance. Most technical developments of THC originate from the iron making BF industry, where the high productivity, combined metal and slag duty, high pressure approximate 10 bars at Tap Hole [4] and long Tap Hole length (2.5 – 4.0m) impose high demands on THC quality. These include progression from coke, to alumina, to silica and back again to pitch impregnated alumina and high alumina fine matrix (<45microns and >50% by clay[5] and or coarser aggregates (approximately 20 % by clay 1-3mm[6], variously with zirconia. Kyanite[7] Silicon carbide and silicon, aluminium and ferrosilicon metal and or nitride matrix additions as fine powder to lower porosity, shrinkage, decrease, volatiles, increase antioxidant action, lower wet ability by slag and improve extrudability, corrosion, sintering and erosion performance. The improved corrosion resistance and higher positive residual expansion coefficient performance of pure silica and pure alumina sources compared with alumino-silicates is also reported. A swelling characteristic[8] is important to help seal a Tap Hole subject to temperature fluctuation from the extreme of superheated tapping temperatures to cold closure conditions in water cooled Tap Hole's. Some more empirical approach has similarly led to convergence on use of THCs of high alumina content for high intensity operations.

1.3. Matrix material

The matrix of a THC consists of four major groups of powders [9].

1. Alumina and alumina silicates inert refractory fillers

2. Carbon increases both the erosion resistance and the drilling rate. It also increases the permeability that enables the release of volatiles from the clay[10]
3. Silicon carbide- reduces the oxidation as well as increasing the corrosion resistance.
4. Special additives – vary depending on producer and are generally added to increase the corrosion and/or erosion resistance

The majority of the work examining the matrix of THCs has really focused on the special additions. Alumina, carbon, and silicon carbide are common refractory materials and are found in most standard THC's so the literature has focused on the addition of small amount of other materials. Delabre [11] summarized the work performed which studied the affect of special additives. The additives that were studied were ferro-silicon nitride, silicon, aluminum, silicon carbide and alumina - silica mixtures. They studied the variation in hot modulus of rupture, extrusion resistance, corrosion resistance and permanent linear change. Aluminum and silicon had the greatest affect on the THC followed by ferro-silicon nitride. The affects of small additions of silicon carbide were found to be insubstantial compared to the other materials. The addition of silicon and aluminum were found to influence the hot modulus of rupture "favorably". Permanent dimensional change after firing was found to increase when the material contained silicon and decrease when it contained aluminum. Extrusion resistance of the material was found to increase with nitrides but decrease with aluminum. This report also stated that the corrosion resistance of the material is reduced by the addition of aluminum and nitrides. This statement contradicts other references[12] that have found the corrosion resistance of the material is increased with the addition of alumina and nitrides. However, Yamamoto and Toritani also found that the slag corrosion index decreased with the addition of nitrides.

1.4.Binder

Binders are the materials, usually liquids that hold the particles of the mixture together in a green or unfired structure. In THCs the binder coats the refractory particles and provides strength prior to injection. Thus, the binder has a significant effect on the extrusion of clay into the furnace and its initial strength. The binder is not entirely consumed when fired and the remaining carbon from the binder will affect the high temperature performance of the THC. Originally, the binders for THCs were clays but later mixtures of clay, grog, coke and coal were used. These clays had the common feature of using water as the plasticizer. When hearth linings began to be made of carbon water could not be used in the clays as it could potentially oxidize the carbon refractory. Anhydrous tar bonded THCs came into use. These materials were found to be more resistant to corrosion than the water based clays. More recently phenolic resin bonded clays have started to replace tar bonded THC although many Blast Furnaces still utilize tar based products [13]. Phenolic resin based clays are safer to use than tar based clays, which contain many carcinogens and produce fumes when in use [14]. The emissions from tar can be 1000 times greater than that of resins, although given the nature of the cross linking agents used in the resin odour and fumes in the work place are still a concern. The change in resin bonded clay was also an attempt to increase and control the curing speed of the clay. The time taken for the THC to harden in the TH could be six times longer using a tar based mix [15].

2. Industrial Study

2.1.Matrix

Matrix is mainly ingredient give strength at high temperature called cold crushing strength. These have high melting point. This ingredient quantity is varied according to the cold crushing strength required. Alumina is used in THC to increase cold crushing strength. Alumina content is must for high temperature strength. Alumina content varied depending on furnace parameters. With increase in alumina content drill ability decreases and more number of drill bits are to be used for drilling.

2.2.Binder

Visakhapatnam steel plant use two binders for Tap Hole Clay (THC) production. Clay contains alumina and silica in required quantity. Expansion of the clay ensures proper closing with high pressure maintained inside the furnace. Clay sticks to the TH wall. Clay gives the workability for the clay. Typical chemical analysis of clay used in steel plant is given in Table-2.8. Workability is the

important property of THC, gives the clay to be extruded in required shape. Usually THC's extruded in circular shape. The other binder used is pitch. Pitch is a by product from coke oven in steel plant. Toughness of the clay gives the opposing force to flow of metal and avoids the leakage of clay. There are liquid as well as solid binders. Binders like pitch increases toughness of the Tap Hole Clay (THC) at room temperature. Chemical analysis of pitch is given in

2.3. Resin and Filler

Resin used is phenol formaldehyde based resin with setting temperature of 150 °C. Coke is used as a filler material. Coke is more homogenous material and less reactive at high temperature. Coke gives volume stability and act as a carbon source. The coke particles increase the porosity of clay and allow the gases to escape. The escape of gases through the clay makes it to dry fast and decreases the curing time as gases burn as soon as coming out of Tap Hole (futlayer).

2.4. Lubricant

Coal based oil is used as lubricant. Viscosity of coal based lubricant varies with temperature. The correct temperature should be maintained to control the viscosity of lubricant. Main function is to make the extrusion process smooth and reduce the load on the piston motor. The lubricant should have high flash point to avoid fire near Tap Hole. Lubricant should have less pollutants and easy to handle. Lubricant from coke oven by product is used as a lubricant, Main disadvantage is the solid content and naphthalene percentage in the lubricant.

3. Problem Identification

3.1. Economic impact on Tap Hole Clay (THC) production

The major constituent in Tap hole clay production is clay. The availability of clay and required quality of clay is limited in Visakhapatnam steel plant. The one day consumption is 3 tons in furnace of 3200 – 3800 M³ volume. The cost of THC varies depending on the ingredients used. The quality of the clay depends on physical and chemical properties of the ingredients. Number of ingredients can be decreased through the quality and reduce the specific consumption of the THC. The consistency in tap hole clay quality depends on the ingredients used in manufacturing. The major focus of all steel industry is to bring down the consumption of raw materials without compromising on production. The ingredients which are purchased from external sources can be replaced with by products from steel plant or reduce the number of ingredients to bring down the cost of THC.

3.2. Operation problem

TH related problems affect the iron production. For better production the Tap Holes are operated diagonally. The two TH operations at the alternate interval is called twin TH operation. The number of tapping are more in twin TH operation as alternate Tap Holes opened immediately after closing. The duration of tapping also less in twin TH operation as more time is not given for reduction of iron bearing material (formation of molten metal). This method of operation is common in 3200 to 3800 M³ furnaces to keep the hearth dry and for safe operation

4. Experiment Approach

4.1. Fly ash

Aim of using fly ash in tap hole clay (THC) is to replace clay. Dry fly ash is an industrial waste abundantly available in Visakhapatnam Steel plant. Fly ash when mixed with liquid component forms a lump with good workability. Fly ash contains mainly Al₂O₃ and SiO₂. The fly ash is a suitable material available for use in the powder form. The fly ash was dried in the furnace at 250 °C for an hour to evaporate moisture. The dried fly ash was used in tap hole clay (THC) mix preparation. The mix was prepared after mixing the dry powder for 10 mints. The lubricant was added after dry mixing the mixing continued for 15 mints.

4.2 Zirconia containing refractory

The aim of using zirconia containing refractory is to increase the tapping duration. Zirconia refractory is available in steel plant in sufficient quantity. Zirconia containing refractory is used at the temperature of 1650 to 1700°C. The ash fusion test conducted with zirconia containing refractory

show a melting point more than 1500°C. Zirconia containing refractory gives good abrasion resistance in contact with metal and slag. With the aim to increase tapping duration without cost escalation used zirconia containing refractory material was introduced in Tap Hole Clay (THC). The tapping duration is an important tapping parameter as this is related to metal and slag draining. Blast Furnace operator prefers a longer tapping duration. Longer tapping duration can ensure smooth reduction inside the furnace and continuous draining of metal and slag from the furnace. Accumulation of liquid metal and slag inside the furnace can be avoided by draining of metal and slag at regular intervals. By ensuring hearth without liquid metal and slag tuyeres can be protected from jamming in case of power failure and slipping. Presently manufacturers of tap hole clay (THC) improve abrasion resistance by introducing SiC, Si₃N₄. The function of these materials is to give better abrasion resistance. The Existing composition was altered to accommodate new material of refractory waste. The zirconia containing used refractory was collected and crushed to the required size. Tap hole clay (THC) was prepared using < (-) 1mm size the zirconia refractory waste.

4.3. 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 mins. The lubricant was added after 10 mins and mixing continued for 15 mins. The total mixing time was 25 mins. 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 prepared in sand rammer and universal testing machine. 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.1.



Fig. 1 Prepared tap hole clay samples

Tap Hole Clay (THC) samples arrangement in container for firing is shown in Fig. 2. Samples packed in container for firing is shown in Fig. 3.



Fig.2 THC samples arrangement in container



Fig.3 Samples packed in container for firing

5. Testing Methods

5.1. 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.

$$\text{Percentage of AP} = (W-D)/(W-S) * 100$$

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.

5.2. 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.

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

W= saturated weight (Thinner +sample weight)

D= Dry weight

S = Suspended weight (Immersed in Thinner)

5.3. 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 °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. The fired sample was measured to measure the expansion. The sample height difference before firing and after firing is taken as the expansion.

5.4. 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. The samples were removed allowed to cool to room temperature.

5.5. 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.

5.6. 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 °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. Testing Cold crushing strength testing is shown in Fig.4. CCS value is calculated from load applied divided by load applied area. $CCS = \text{load applied (at which sample failed)} / \text{load applied area}$



Fig.4 Cold Crushing Strength (CCS) testing

5.7 Curing time Cold Crushing Strength (CCS) after 12 minutes

The clay was pressed inside the refractory tube by applying one ton load as shown in Fig. 5. The refractory tube with clay was allowed to float on liquid metal for 12 mints. 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. 6. The taken out sample was tested by applying load. The load at which sample fails is taken as load applied. 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.



Fig.5 Sample pressing inside refractory tube



Fig.6 Refractory tubes for sample pressing

The setting time of the samples were also studied at different intervals 5 mints, 8 mints and 12 mints shown in Fig.7.

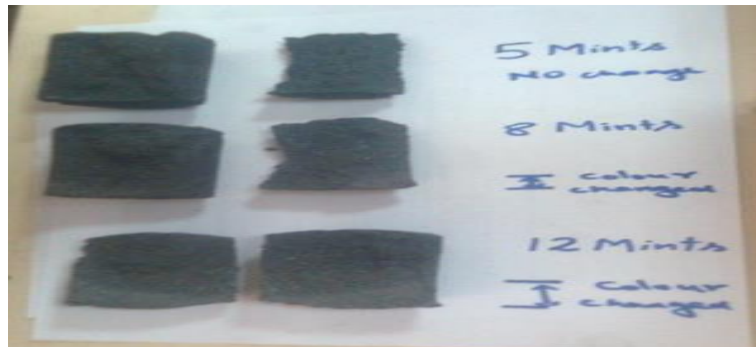


Fig.7 Samples studied during different time interval (Curing time)

5.8. 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 millimetre (mm) is the measure of workability.

5.9. 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 current during drilling shows the difficulty in drilling.

6. Results and Discussion

6.1. Existing Tap Hole Clay (THC)

The existing tap hole clay composition, tap hole clay composition with fly ash and tap hole clay composition with zirconia containing refractory are given in Table 1. The existing THC had a good workability of 0.7mm and the CCS of 167kg/cm². The test results of the existing THC are given in Table 2.

Table 1 composition of existing THC and THC with fly ash, refractory waste

| No | Existing | With Fly Ash | With Refractory waste |
|----|-----------|--------------|--------------------------------------|
| 1 | Clay | Fly Ash | Clay |
| 2 | Alumina | Alumina | Alumina |
| 3 | Coke | Coke | Coke |
| 4 | Pitch | Pitch | Pitch |
| 5 | Resin | Resin | Resin |
| 6 | Lubricant | Lubricant | Lubricant |
| 7 | -- | -- | Zirconia containing refractory waste |

6.2. Tap hole clay (THC) preparation with fly ash

Initial workability tests have shown fly ash clay was more plastic compared to existing THC clay, due to the uniform particle size of fly ash. Tap Hole Clay (THC) made with fly ash shown in Fig.8.

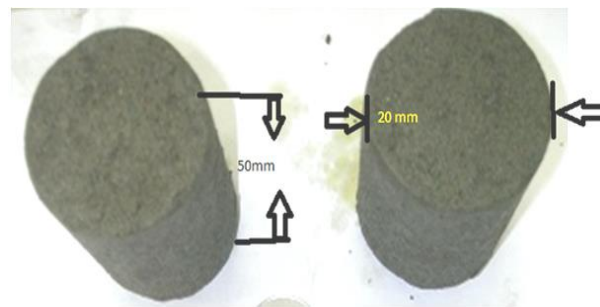


Fig.8 THC samples with Fly ash

Due to high workability of tap hole clay (THC), it may not withstand the flow of metal and slag while closing of the tap hole. Expansion studies have shown there was no positive linear expansion with fly ash tap hole clay (THC). It was observed there was contraction in the sample after firing. The expansion is the basic property of the tap hole clay (THC). The negative expansion also observed during the setting time test, after soaking of samples in metal and slag the samples were observed to have a gap between the refractory tube and tap hole clay indicating there was some negative expansion during heating is shown in Fig.9. The clay sample was bulged during firing indicating the workability increased with increase in temperature. The surface was not smooth on sides shown in Fig.10. The surface of the fired samples showed uneven surface finish indicating the better adhesion nature of the fly ash clay.

Apparent porosity was on lower compared to existing clay. The finesse of the fly ash made the samples dense. The weight of the samples after firing was lower compared to existing clay sample. The less porosity can increase the setting time due to less pores for the gases to escape. Bulk density was high compared to existing clay. The CCS was observed to be in the lower compared to the existing tap hole clay (THC) sample. The reaction test carried out showed more smoke coming out of sample, indicating the entrapped moisture was high in the fly ash clay. The smoke was observed for 10 mins. The reaction test did not show any change in shape as the temperature was raised immediately.



Fig.9 Fired fly ash Tap Hole Clay (THC) samples

The curing time was found to give lower cold crushing strength compared to existing clay. Tap Hole Clay properties with fly ash are given in Table 2.

6.3. Tap hole clay (THC) preparation with Zirconia containing refractory waste

Difference in workability is less when compared with existing tap hole clay. Due to the reason the refractory powder was not having any volume change. The expansion characteristics were studied and the sample had positive expansion. The expansion was as that of existing clay. The reduction in apparent porosity was due to particle shape and reduction of coke quantity. Bulk density increased with use of refractory powder. This is due to high density of refractory powder compared to coke. CCS has increased with use of refractory powder as the bond strength has improved. Bath test has showed no sticking of metal or slag on the surface. There was no distortion in shape of sample after firing. Curing time after 12 mins has shown the CCS was improved compared to existing clay. The setting time indicated the better bonding in the sample. The test results on use of zirconia containing refractory in tap hole clay (THC) are given in Table 2. Comparison of the experimental results showed that the properties of the THC clay with fly ash have deviated from other compositions. Comparison Variation in the tap hole clay properties are shown in Figs.10 -16. The results showed workability of

fly ash is high and the THC with liquid resin had very less workability compared to all other compositions. With low CCS, high workability and negative linear expansion fly ash cannot be a replacement for clay. The workability of the THC with liquid resin will further decrease on storage. To increase the workability the mud gun has to be heated. In case of overheating the mud gun may result in further decrease in workability of the Tap Hole Clay (THC). The decrease in workability will increase the load on mud gun piston and lead to closing problem.

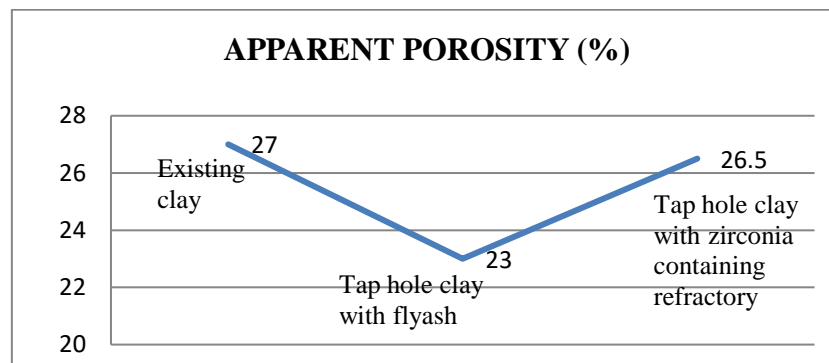


Fig.10 Variation in Apparent porosity with different composition

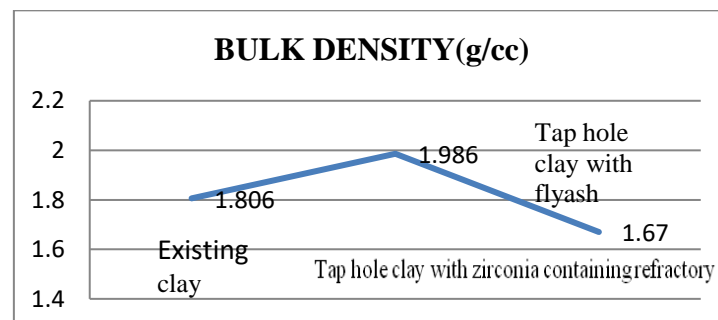


Fig.11 Variation in Bulk density with different composition

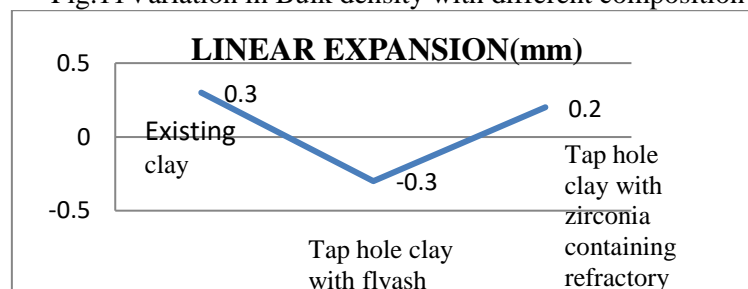


Fig.12 Variation in linear expansion with different composition

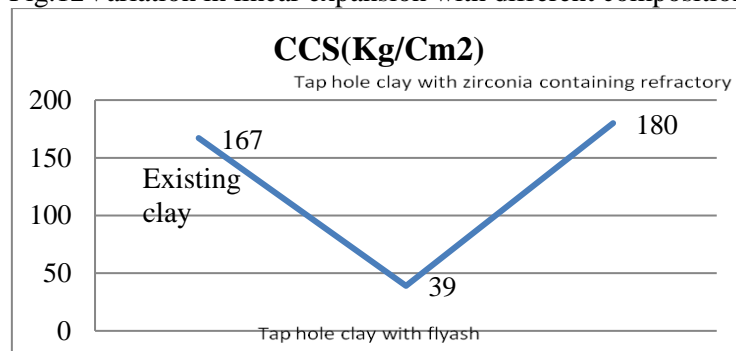


Fig.13 Variation in Cold crushing strength (CCS) with different composition

Table 2 Test results of existing THC, THC with fly ash and refractory waste

| No | Property | Existing | Fly Ash | Refractory waste |
|----|------------------------------|----------------------------------|--|--|
| 1 | Apparent porosity (%): | 27 | 23 | 26.5 |
| 2 | Bulk Density (g/cc) | 1.806 | 1.986 | 1.67 |
| 3 | Linear Expansion: | 0.3 mm | (-)0.3 mm | 0.2 mm |
| 4 | Metal and slag reaction test | Metal and slag were not sticking | Smoke was observed , Metal and slag stuck to sample made little impression while removal | Smoke was observed , No sticking of Metal and slag to sample |
| 5 | Cold Crushing Strength (CCS) | 167Kg/Cm ² | 39 Kg/Cm ² | 180 Kg/Cm ² |
| 6 | Curing time CCS after 12mint | 44kg/cm ² | 20 kg/cm ² | 46 kg/cm ² |
| 7 | Workability test | 0.7mm | 3.5mm | 0.9 mm |
| 8 | Drillability | 2 Amps | 1 Amps | 2 Amps |

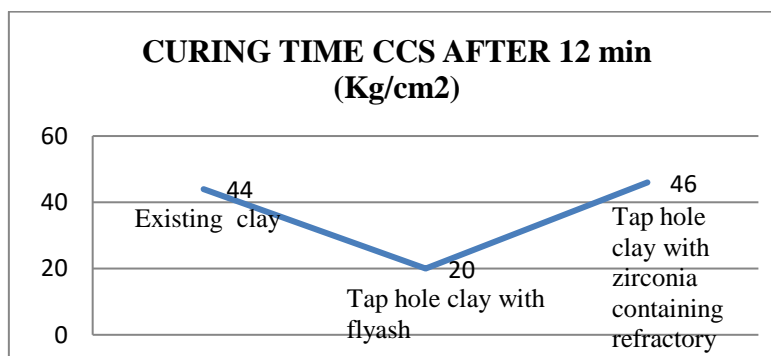


Fig.14 Variation in Curing time CCS after 12 mints

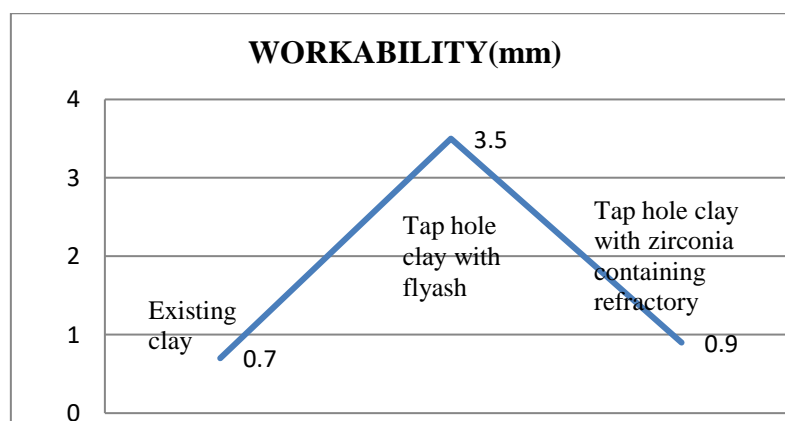


Fig.15 Variation in workability with different composition

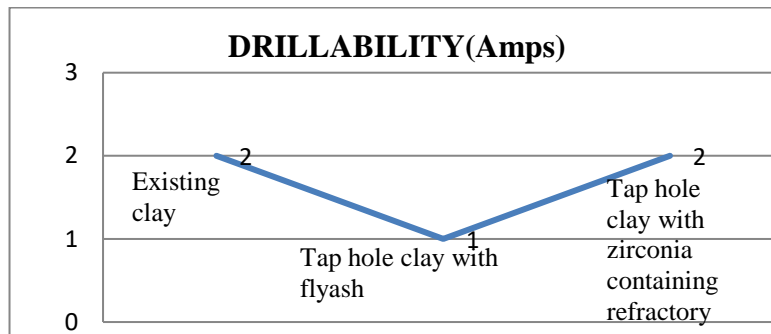


Fig.16 Variation in drill ability with different composition

7. Conclusions

1. Pure fly ash cannot be a replacement for clay. The workability is increased with use of fly ash. The shrinkage of fly ash samples during firing showed complete replacement of clay with fly ash is not possible. Fly ash is an industrial waste available easily.
2. The CCS strength of fly ash clay was lower compared to existing clay samples. The clay setting time results also proved that bond strength is less. The more important property of Tap Hole Clay (THC) expansion on heating is not observed when fly ash is used as a ingredient. Hence clay cannot be replaced with fly Ash.
3. The use of refractory waste containing zirconia is a good abrasive material. It can be used in tap hole clay production. Use of in plant refractory waste can avoid the use of costly material like Silicon carbide; Zirconia containing refractory Tap Hole Clay (THC) had a better cold crushing strength (CCS) when compared to existing Tap Hole Clay (THC).
4. The clay setting time was also better when compared to existing clay. The increase in cold crushing strength (CCS) also proved bond strength is high. Tap hole clay (THC) with zirconia containing refractory had positive expansion on heating.
5. Hence the zirconia containing refractory has not affected the expansion characteristics of the tap hole clay. Zirconia containing refractory can be introduced in tap hole clay as an ingredient.

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