EVALUATION OF FIRE CLAYS FOR IRON AND STEEL REFRACTORIES

Part II. Physical Properties

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Physical properties of six representative Mianwali fire clay samples have been studied. It can be ascertained from these investigations that four fire clays, representing the Dak Post and Dakwala (Moza Bazar) areas, can be used as safe materials under the severe conditions and other two clays representing the Turta area can also be considered in moderate conditions for iron and steel plant refractories.

Key words: Fire clays; Refractories; Metallurgical industries.

INTRODUCTION

Fire clays refractories are extensively used in the metallurgical and associated engineering industries; i.e. in the blast furnaces reverberatory furnaces, drill sharpening and tempering furnaces; boiler lining and chemneys; liners, runners and crucibles in foundry practices etc. The testing of refractory materials in accordance with standard specifications not only results in the formulation of bricks from the properties of the materials but also helps in the production of articles of improved quality. Detailed information regarding deposits, chemical analysis, mineralogical composition and refractories of Mianwali fire clays, has been already presented in the first part of our paper[1] The present study is confined essentially to the physical properties of the six representative fire clay samples. These studies have been made in accordance with the standard methods; requirements of the Pakistan Steel and the suggestions of its Russian Consultants; and for the production of various refractory products.

EXPERIMENTAL

The following physical properties have been studied according to their standard procedures:

1. *Percent moisture content.* The moisture content of clay samples has been determined by the usual standard method. The results are shown in Table 2.

2. *Apparent density and specific gravity.* Apparent density and specific gravity have been determined in accordance with the British Standards by means of the specific gravity bottle. The results ae included in Table 2.

3. *Percent water of plasticity.* Percent water of plasticity of the samples has been determined in accordance with

the Atterberg tests [2].

4. *Particle size analysis.* Dried clay samples were used for the determination of particle size distribution by means of the Bouyocos Hydrometer in accordance with H-152 ASTM method [3]. The data for size distribution have been presented graphically in Fig. 1 and given in Table 1.

5. *Modulus of rupture.* The determination of the modulus of rupture has been made according to the ASTM method [4]. The results are included in Table 2.

6. *Dry and fire shrinkage.* The test specimens of each sample were subjected to firing at 1000, 1520 and 1670° in different crops and the percent shrinkage was calculated according to the ASTM methods [5]. The results have been recorded in Table 3.

7. *Percent apparent porosity, water absorption and bulk density.* After measuring the fire shrinkages, the same
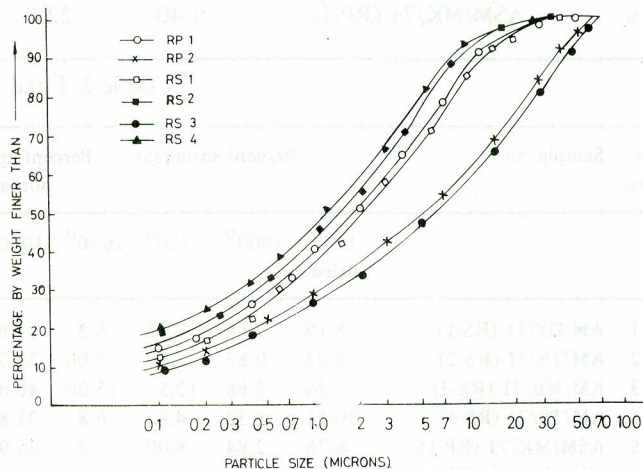

Fig. 1. Sizing analysis (cumulative plot) logarithmic scale

specimens were used for determining these properties in accordance with ASTM methods [6]. The results have been included in Table 3.

8.   *Cold crushing strength.* The test specimens were prepared in the form of briquettes and fired at temperatures of 110, 1000, 1400 and 1600°. Their shrinkage,

apparent porosity, water absorption and bulk density were also determined by ASTM methods [6]. The specimens were compressed in a standard compressing machine and the crushing strength was calculated with the help of the ASTM methods [7]. The results have been registered in the Table 4.

Table 1. Particle size analysis

Equivalent diameter in microns		Over 50μ	50-10μ	10-5μ	5-1μ	1-0.5μ	0.5-0.2μ	Below 0.5μ	Less than 2μ
Sr. No.	Sample No.	Percentage particle size distribution							
1.	AM/DP/71 (RS-1)	1	15	14	34	10	9	26	55
2.	AM/TS/71 (RS-2)	1	10	13	34	12	11	32	54
3.	AM/MB/71 (RS-3)	6	38	10	20	6	6	18	35
4.	AM/TS/71 (RS-4)	1	9	12	32	10	12	36	58
5.	ASM/MK/71 (RS-1)	2	12	14	32	11	8	27	54
6.	ASM/MK/71.(RP-2)	6	34	12	21	8	6	20	36

Table 2. Physical characteristics

Sr. No.	Sample No.	Percent moisture	Percent water of plasticity	Apparent density g/cm^3	Specific gravity	Modulus of rupture of dried material (110°)	
						lb/sq. inch.	kg/sq. cms
1.	AM/DP/71 (RS-1)	2.0	35.00	2.32	2.650	282.7	20.19
2.	AM/TS/71 (RS-2)	3.0	34.00	2.31	2.640	246.3	17.59
3.	AM/MB/71 (RS-3)	1.50	23.00	2.37	2.670	71.2	5.08
4.	AM/TS/71 (RS-4)	2.50	34.9	2.30	2.635	267.2	19.08
5.	ASM/MK/71 (RP-1)	2.1	34.21	2.33	2.652	260.0	18.57
6.	ASM/MK/71 (RP-1)	1.40	22.6	2.38	2.675	66.00	4.71

Table 3. Fired physical properties

Sr. No.	Sample No.	Percent shrinkage				Percent apparent porosity			Percent water absorption			Bulk desnity g/cm^3			
		110° dried	1000°	1520°	1670°	1000°	1520°	1670°	1000°	1520°	1670°	1000°	1520°	1670°	
1.	AM/DP/71 (RS-1)	8.19	2.66	7.13	6.8	35.87	17.00	4.83	20.97	8.2	2.08	1.705	2.01	1.89
2.	AM/TS/71 (RS-2)	9.03	0.83	5.0	7.00	31.39	14.5	0.38	17.93	7.87	0.23	1.74	1.79	1.64
3.	AM/MB/71 (RS-3)	5.26	2.66	12.5	15.00	40.80	19.20	16.37	24.41	8.5	6.45	1.67	2.34	2.58
4.	AM/TS/71 (RS-4)	10.41	1.33	4.8	6.8	31.89	13.90	0.30	17.9	7.44	0.18	1.74	1.77	1.67
5.	ASM/MK/71 (RP-1)	6.76	2.84	8.00	7.3	35.9	17.4	4.99	21.0	8.25	2.12	1.70	2.10	1.98
6.	ASM/MK/71 (RP-2)	3.80	3.06	10.09	13.76	41.0	20.7	16.76	25.0	8.7	7.0	1.66	2.38	2.59

Table 4. Physical properties in the form of bricks

Sr.	Sample No.	Percent linear shrinkage			Percent apparent porosity			Percent water-absorption			Bulk density gm/cm³			Crushing strength lb/sq. inch		
		1000°	1400°	1600°	1000°	1400°	1600°	1000°	1400°	1600°	1000°	1400°	1600°	1000°	1400°	1600°
1.	AM/DP/71 (RS-1)	7.57	10.82	—	22.89	1.87	—	11.66	0.71	—	2.02	2.45	—	13879	24011	—
2.	AM/TS/71 (RS-2)	8.22	12.04	—	15.05	1.36	—	6.77	0.51	—	2.22	2.30	—	14250	25855	—
3.	AM/MB/71 (RS-3)	6.71	10.38	13.07	29.6	22.10	13.50	14.88	12.64	5.48	1.99	2.23	2.46	9878	19810	23208
4.	AM/TS/71 (RS-4)	8.00	11.47	—	17.32	1.18	—	7.90	0.49	—	2.19	2.36	—	14600	26263	—
5.	ASM/MK/71 (RP-1)	7.35	10.84	—	20.44	1.87	—	10.06	0.75	—	2.10	2.41	—	13997	24206	—
6.	ASM/MK/71 (RP-2)	6.49	10.17	12.99	31.01	24.31	16.10	15.90	11.22	7.12	1.94	2.17	2.37	9901	18889	23843

RESULTS AND DISCUSSION

Particle size distribution of fire clays profoundly influences their physical properties like plasticity, shrinkage, strength, porosity and vitrification. Generally, good quality chinaclays contain particles over 90% finer than 10 micron and over 50% finer than 2 micron size. The size distribution of RS-1, RS-2, RS-4 and RP-1 fireclays as indicated in Table 1 and Fig. 1 conform to this general distribution. RS-3 and RP-2 clays contain particles 56 and 60% finer than 10 microns and 35%, 36% finer than 2 microns respectively. Thus, they are coarser than the rest of the four clays. According to Freundlich's definition, [7] the particles of the colloidal range, present in RS-1, RS-2, RS-4, RP-1, RS-3 and RP-2 are 9, 11, 12, 8, 6 and 6 percent respectively. This further shows that RS-3 and RP-2 are coarse grained clays.

The moisture content of a clay depends largely upon the fineness of the grains (i.e. surface area) and its physical nature. The moisture contents of RS-1, RS-2, RS-4 and RP-1 as recorded in Table 2, are greater than those of RS-3 and RP-2 clays. The physical structure of RS-3 and RP-2 is hard and more compact than that of the other clays. The particle size and the physical structure of the fomer clays is finer and softer than the later, therefore the moisture content of RS-3 & RP-2 clays, is low due to their coarse and hard nature.

The apparent density and specfic gravity values of these fire clays, as may be observed from Table 2, increase in the order of RS-4, RS-2, RS-1, RP-1, RS-3 and RP-2. The high values of RS-3 and RP-2 with respect to other clays, may be attributed to the presence of the denser, non-kaolinitic mineral like boehmite. Since the specific gravity of boehmite (3.48) is greater than the kaolinite (2.6) mineral the specific gravity of the clays containing boehmite should be greater than that of quartzitic (2.65) or

kaolinitic clays. This view is further stregthened by the fact that the order of increasing the boehmite mineral in the clays is the same as that of specific gravity.

The highly plastic clays require much more water to develop their plasticity than a clay of low plastic nature. The water required to develop maximum plasticity is 15-38% for fire clays and 15-28% for flint clays. The water of plasticity, of RS-1, RS-2, RS-4 and RP-1 fire clays shown in Table 2, corresponds to the above standard values of the fire clays and those of RS-3 and RP-2 conform with those of the flint clays. It is generally persumed that the water of plasticity varies directly with plasticity. Plasticity depends mostly upon the amount of fine grains and colloidal particles present in the clay. The water of plasticity of RS-1, RS-2, RS-4 and RP-1 is greater than that of the RS-3 and RP-2 clays, as the former clays are fine grained and require more water to develop maximum plasticity. Thus RS-3 and RP-2 clays are coarser and non-plastic in nature.

The modulus of rupture of a material depends mostly upon the chemical, mineralogical composition and physical properties, especially the surface area or the finess of grains. It is evident from the Table 2 that the values of RS-3 and RP-2 are much lower than those of the rest of the clays. Lower values of these clays may be attributed to the presence of large amounts of non-plastic minerals like boehmite [1]. One more reason for their low values is that the percentage of the fine particles of these clays (below 2μ and 0.1 micron) is much less than the other clays, and the strength properties are greatly influenced by the fine particle size.

Of the remaining four fire clays (i.e. RP-1, RS-1, RS-2 and RS-4), the strength values of RP-1 and RS-1 are greater than RS-2 and RS-4, inspite of the fact that RS-2 and RS-4 contain a greater percentage of the fine grains than RP-1 and RS-1 clays. It may be assumed that the lower values of RS-2 and RS-4 are due to the free quartz [1]

present in them and the effect of the fine particles, has been greatly reduced by the presence of non-plastic - quartz particles.

Generally, wet to dry shrinkage is due to the removal of water from the surface of the grains. Thus greater the number of the fine particles in a clay, the higher will be the shirinkage in the drying state. It will be observed from the Table 3 that the order in which the dry shrinkage increases is the same as that of the increase in the percentage of the fine particles in clay samples. Thus, the dry shrinkage decreases as RS-4, RS-2, RS-1, RP-1, RS-3, RP-2. The higher percentage of shrinkage of RS-4 than the rest of the clays may also be related to the high alkali contents of this sample than the other clays, since, alkalis act like electrolytes which may cause flocculation and consequently more dry shrinkage in this sample.

As recorded in Table 3, the fired shrinkage of RS-4 and RS-2 are much less than those of the clays at almost all the temperatures. Although fine grained materials shrink more than those of the coarser grained as the reaction proceeds more rapidly with the smaller particles. The low shrinkage values of RS-4 and RS-2 at various temperatures may be explained by taking into account the transformation of the fine grained free quartz into a low specific gravity form, which has greater volume than the original material and thus the resulting expansion is sufficient to counterbalance the contraction. This type of conversion has started to take place at 1000° in the case of RS-4 and RS-2.

The shrinkage values of RP-2 and RS-3 are greater than the rest of the clays at high temperatures and this difference becomes more significant at 1670° where it is very high. These greater values are probably due to the decomposition of boehmite with evolution of the combined water, together with a later change due to the recrystallisation of the resulting alumina and liquid formation at elevated temperatures. On the other hand, RS-4 and RS-2 were bloated at high temperature, thus causing less overall shrinkage.

It is evident from Table 3 that the apparent percent porosity of RP-2 and RS-3 is greater than RS-1 and RP-1 which have greater values than RS-2 and RS-4 as determined at various temperatures. These fireclays are very porous at 1000°, having porosity values as 31-41%; these are reduced to about half their original values when fired at 1520°. This reduction is due to the fusion and formation of the molten mass which flows into the pores of the material at high temperatures. The temperature was raised to 1670°, and the porosity values of RS-2 and RS-4 were further decreased to 0.38% and 0.03%. The low porosity values of RS-2 and RS-4 at all tempeatures may be assumed

to be due to the presence of the large amount of the fine grains and comparatively greater alkali contents which cause fusion more readily. This molten mass thus formed fills the interstices and voids of the material and consequently reduce the porosity [6]. On the contrary the high porosity of RS-3 and RP-2 and RP-2 may be due to the presence of the coarser particles and high Al_2O_3 contents [1] which retard early vitrification and fusion to the in order to fill in the pores of the material even at 1670°

The percent apparent porosity values of all these clays in the form of bricks have also been presented in Table 4. By increasing the pressure, used in shaping the bricks, a considerable reduction in porosity can be secured. The porosity values of these bricks are less by about one-third than those of the extruded test pieces. The apparent porosity can also be expressed in the form of water absorption, where it is the amount of the water require to fill the pores of the material. The percent water absorption values are also included in Table 3 and 4.

The bulk density of all the clay samples increases as the temperature increases from 1000° to 1520°, but when the temperature rises to 1670° the bulk density of RS-1, RS-2, RS-4, RP-1, decreases while that of RS-3 and RP-2 still increases. The increases in the bulk density of RS-3 and RP-2 at 1670° may be due to their high refractoriness [1]. The bulk density values of all the samples fired at 1000° varies inversely to the Al_2O_3 contents [1]. i.e., it is greater where the Al_2O_3 content is lower and vice versa. This can be explained by taking into consideration the high porosity and the greater external volume of the material containing the high Al_2O_3 content. However, the results of the samples when fired at 1520° vary, as the B.D. values are lower in the case of high silica containing samples i.e. RS-2 and RS-4 and are greater of aluminous samples, i.e, RS-1, RS-3, RP-1, RP-2. This variation in the results may be due to partial fusion of the material and recrystallization or recombination of the mineral components.

B.D. values of all the samples in the form of the bricks are slightly different from those of the extruded pieces fired at the different temperatures. The values of the bricks are greater at the lower temperatures and lesser at high temperature than those of the respective extruded samples. This difference in values is possibly due to the difference in the methods of preparation of the specimens.

It is apparent from Table 4 that cold crushing strength increases with the rise of the firing temperatures. The strength values of the high silica clays (i.e. RS-2 and RS-4) are greater than the samples containing high alumina contents (i.e RS-3 RP-2) at 1000° and 1400° firing temperature. This might be due to an early occurence of the

glassy phase by disintegration of silica and the presence of a larger quantity of fine grains in these samples. The lower values of the RP-2 and RS-3 when contain high alumina contents and coarser particles may be due to underfiring because, as the firing is increased from 1400 to 1600° their cold crushing strength values also increase and nearly approach the values of RS-1 and RP-1 when fired to 1400°. Hence, these clays especially RP-1, RS-1, RS-3 and RP-2, can be facibly used for the required steel refractory products by a carefulselection of the amount and quality of the grog, so that there is no loss of strength at high temperatures.

CONCLUSION

The above discussion leads to the final conclusion that RS-2 and RS-4 clays can be used as refractory products where slag attack is negligible. RS-1 and RP-1 fire clays can be considered for superduty fire bricks or for 50% alumina bricks in combination with RS-3 and RP-2 flint clays. RS-3 and RP-2 clays are safe materials to be tried for 60% alumina refractory bricks.

Thus, it can be ascertained from detailed chemical and physical investigations of the Mianwali fire clays that by a judicious blending of the RS-1, RS-3, RP-1 and RP-2 clays, the superior quality of refractories can be produced, which can be successfully used in the constructing work of the iron and steel furnaces.

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