

Chapter Seven

HIGH SILICA SANDS

Rajmahal Sand

The sand, supplied by *Messrs Tata Locomotive & Engineering Co. Ltd.*, Tatanagar, was tested with respect to its suitability for use in moulds and cores in their steel foundries.

Rajmahal sand is obtained by crushing the intertrappean sedimentary rocky beds of the Rajmahal hills in Santhal Parganas, Bihar. These deposits belong to the Rajmahal series of the Upper Gondwana system and are believed to be of the Lower Jurassic age. The rocky beds have undergone considerable weathering and occur as loosely consolidated sandy lumps bonded with clay, mostly kaolin. The overburden is 6-7 ft in thickness and is composed of morram and other earthy matter. The deposits are quite extensive and the average height of the stratum ranges from 100 to 150 ft. Being loosely consolidated, the sandy lumps require no elaborate crushing and grinding treatment ; simple wet crushing in locally fabricated units gives sand grade intermingled with about 15 per cent clay. The sand and clay slurry is then treated in a series of settling tanks to remove as much of the clay as possible. By this treatment, about 10 per cent of the clay matter is removed. This is sold in the market as china clay. The treated sand contains 4-5 per cent of clayey matter. No special grading is usually done on the washed sands at the pit site excepting removal of the 12 mesh fraction by hand screening. Dry compressive and dry shear strength increased with increase in moisture content. Shatter index value was fairly satisfactory (Table 80).

As received, the sand was pale in colour and contained about 13 per cent of silt and clay grade matter. It was, therefore, deslimed in the Ore Dressing Division of the National Metallurgical Laboratory, prior to investigation of its moulding characteristics.

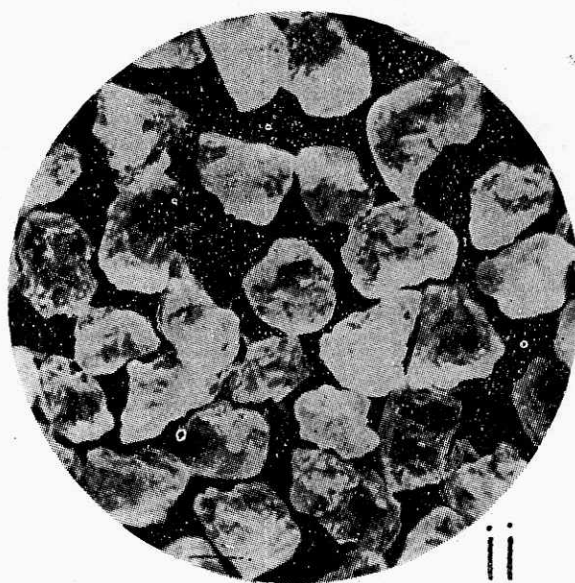
The deslimed product contained 4-5 per cent moisture. It was, therefore, dried in the first instance before sampling.

The deslimed sample showed the presence of 1.02 per cent clay grade matter. The sand grains were mostly of medium grade. Size grading and fineness characteristics of the sand are shown in Tables 78(a) & 78(b). Cumulative grading curves are presented in Fig. 18.

Microscopic examination of the washed sample showed it to be composed of



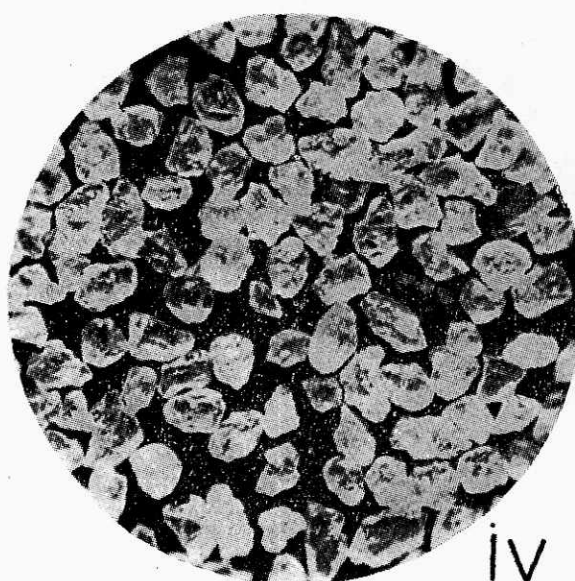
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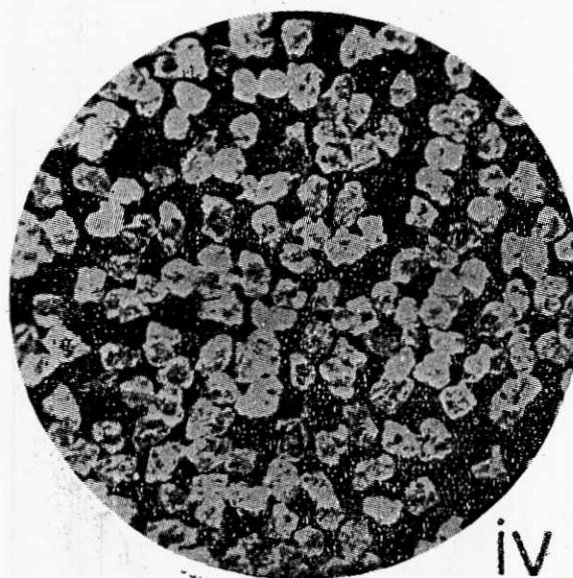
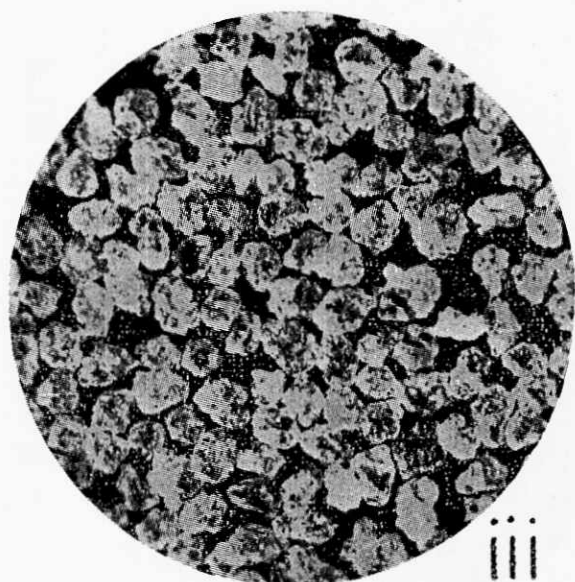
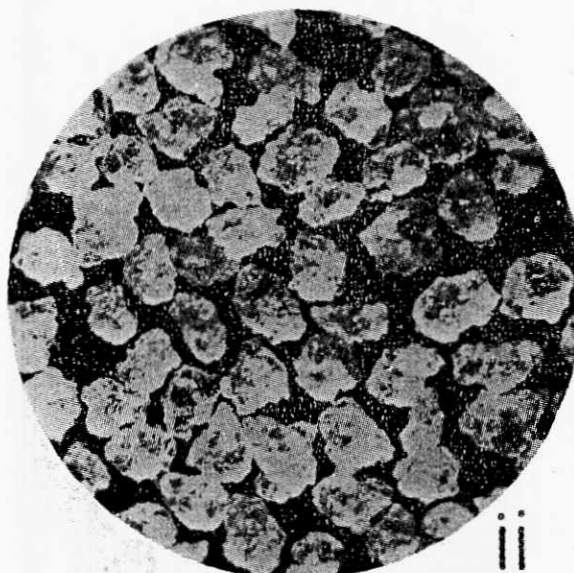
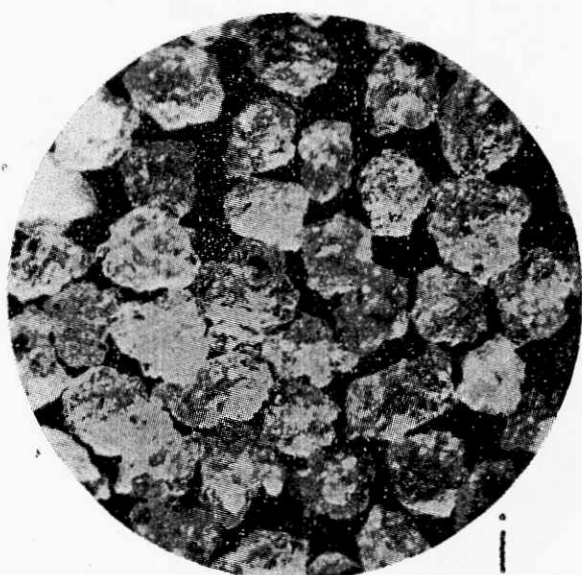
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WASHED SAND GRAINS OF RAJMAHAL SILICA SAND RETAINED ON (i) 40 MESH ; (ii) 50 MESH ;
(iii) 70 MESH ; AND (iv) 100 MESH ($\times 30$)

PLATE VIII



WASHED SAND GRAINS OF BENEFICIATED QUARTZITE SAND RETAINED ON (i) 40 MESH ;
(ii) 50 MESH ; (iii) 70 MESH ; AND (iv) 100 MESH ($\times 100$)

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TABLE 78(a)—RAJMAHAL SAND: SIZE GRADING

U.S. SIEVE EQUIVALENT No.	% RETAINED	
	As-received	After washing
6	Nil	Nil
12	Nil	Nil
20	0.05	0.04
30	3.23	1.54
40	28.79	16.18
50	31.54	29.64
70	19.45	25.58
100	11.52	18.64
140	3.59	5.80
200	1.03	1.20
270	0.21	0.20
Pan	0.17	0.28

TABLE 78(b)—RAJMAHAL SAND: FINENESS CHARACTERISTICS

	AS-RECEIVED	AFTER WASHING
Clay, %	—	1.02
Clay class	—	B
Grain fineness No.	46	52
Max. retention on 3 sieves, %	79.78	73.86

mostly quartz grains of subangular to rounded shape. The subangular grains predominated in the different mesh fractions. The grains were found to be completely free of coating or staining by clay and limonitic matter (Plate VII).

The deslimed sample assayed nearly 98 per cent silica, with low percentages of alumina, iron oxide and alkalis. Lime and magnesia were present in traces (Table 79).

The refractoriness of the deslimed sand was fairly high, the fusion point being above 1720°C., corresponding to Orton Cone 31-33.

TABLE 79—RAJMAHAL SAND: CHEMICAL ANALYSIS

CHEMICAL CONSTITUENT

SiO ₂ , %	97.9
Al ₂ O ₃ , %	0.76
Fe ₂ O ₃ , %	0.56
TiO ₂ , %	0.60
CaO, %	Trace
MgO, %	Trace
Na ₂ O + K ₂ O, %	0.28
Loss on ignition, %	0.27

Before studying its moulding characteristics, the sand was bonded with different binders. Mixture 1 prepared by the addition of bentonite (5 per cent), plastic fireclay (2 per cent), Kordek (0.5 per cent), and silica flour (8 per cent) exhibited a permeability of 200 and compressive strength of 8.8 lb./sq. in. in the green state at 3.4 per cent moisture content. Test pieces baked at 200°C. for 2 hr showed a dry compressive strength of 135 lb./sq. in. and shear strength of 39.5 lb./sq. in. (Table 80).

Green sand test pieces showed slight friability which persisted even in dried test pieces. Green sand test pieces when tested under compression underwent a little bulging prior to rupture. This indicated that moulds rammed with this sand composition may strip well from the pattern.

Mixture 2 was prepared using the following binders : 'K' bentonite, 5 ; plastic fireclay, 1 ; and Kordek, 0.5 per cent. This mixture showed a permeability of 220 and green compressive strength of 7.2 lb./sq. in. at a moisture content of 3.6 per cent. The dry compressive and shear strengths at the same moisture content were 107.5 lb./sq. in. and 33 lb./sq. in. respectively. The flowability and shatter index values were fairly satisfactory and the surface characteristics of the rammed test pieces were similar to those of Mixture 1.

Mixture 3 was prepared for baked oil sand cores using the following binders: 'K' bentonite, 2.5 ; linseed oil, 2.5 ; and silica flour, 16 per cent. It exhibited a green permeability of 84 and green compressive strength of

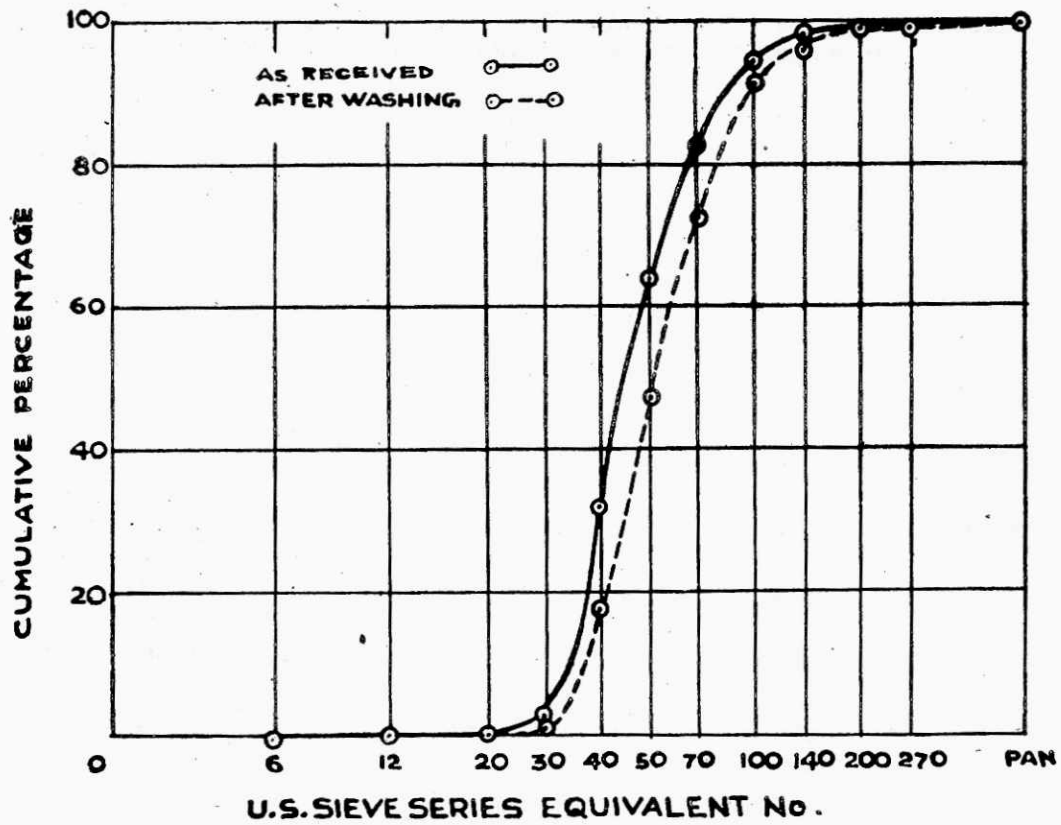


FIG. 18—RAJMAHAL SAND: CUMULATIVE GRADING CURVES

6.9 lb./sq. in. at a moisture content of 3.2 per cent. Baked test pieces possessed a compressive strength of 95 lb./sq. in. and shear strength of 19 lb./sq. in. The surfaces of the green and dried test pieces showed comparatively lesser friability on rubbing than those of Mixtures 1 and 2.

Conclusion. The refractoriness of deslimed sand is sufficiently high and it can withstand molten steel temperatures without fusion. In view of its composition, the sand is very suitable as a base for synthetic moulding sands. The moulding characteristics of synthetic sand mixtures prepared with the addition of different combinations of the binders 'K' bentonite, plastic fire-clay, Kordek, silica flour and linseed oil meet the requirements of green sand moulds for steel castings. In the case of baked cores, some change of composition from the one prepared (Mixture 3) may be necessary to enhance its dry strength properties. Treatment of the surface of the cores with a spray or core wash of suitable composition may give improved surface toughness and resistance to the washing or cutting action of the metal. This treatment besides enabling the cores to be more easily shaken out and broken up than untreated cores possessing high strength is expected to improve their performance as well.

After washing, Rajmahal sand is suitable as a high silica sand for use in moulds and cores for steel castings.

TABLE 80—EFFECT OF BONDING RAJMAHAL SAND WITH DIFFERENT BONDING COMPOSITIONS ON ITS MOULDING CHARACTERISTICS

	MIXTURE 1*	MIXTURE 2†	MIXTURE 3‡
Green permeability No.	200	220	84
Green compressive strength, lb./sq. in.	8.8	7.2	6.9
Green shear, lb./sq. in.	2.8	1.85	1.2
Mould hardness No.	84	82	82
Flowability, %	68	74	74
Shatter index	83	61	31
Dry compressive strength, lb./sq. in.	135	107.5	95
Dry shear, lb./sq. in.	39.5	33	19
Bulk density after compression, g./cc.	1.544	1.544	1.738

* Moisture, 3.4% † Moisture, 3.6% ‡ Moisture, 3.2%

Quartzite Rock Sand

This investigation was also undertaken on behalf of *Messrs Tata Locomotive & Engineering Co. Ltd.*, Tatanagar for studying the suitability of beneficiated local quartzite sand for use in moulds and cores. As received, the sample was in the form of lumps, 5–6 in. in size, which were crushed and beneficiated in the Ore Dressing Division of the National Metallurgical Laboratory prior to investigation of the moulding characteristics.

The sand was obtained by crushing weathered quartzitic sandstones occurring on the banks of the river Swarnarekha and adjacent areas near Jamshedpur. The rock was fairly fine-grained and due to extensive weathering it had become extremely friable and had an open texture. Simple crushing and washing at pit-site yielded a sand grade assaying 88 per cent silica. The sand so produced was low in silica content and was contaminated to a considerable extent with muscovite, mica and other impurities. In the raw state, the sand sample was unsuitable for use in steel foundry and required beneficiation. Crushing and hydroclassification carried out in the Ore Dressing Division yielded a fairly clean product free from micaceous impurities and assaying nearly 96 per cent silica. The sand thus beneficiated was taken up for investigation.

Size grading and fineness characteristics of the sand as received and after beneficiation are given in Table 81.

The beneficiated sand was pale white in colour. The chemical compositions of the raw and beneficiated sands are given in Table 82.

The grains were of medium fine grade and had a good grain distribution (Fig. 19). Microscopic examination of the sand sample revealed it to contain mostly quartz of fairly angular shape, mainly in composite form even up to 70 mesh (Plate VIII).

In view of the presence of composite grains, representative samples of the beneficiated sand were repeatedly cooled from 600° and 1100°C. to find if these resulted in breaking up of the composite grains owing to phase transformations in quartz. Mechanical grading of the beneficiated sand as received and after 6 heating and cooling cycles is shown in Table 81. The results in Table 81 indicate that on cooling from 600°C. very little change occurred while on cooling from 1100°C. an appreciable change took place in

TABLE 81—QUARTZITE SAND: SIZE GRADING IN THE AS-RECEIVED STATE AND AFTER BENEFICIATION

U.S. SIEVE EQUIVALENT NO.	% RETAINED		
	As-received*	After 6 heating and cooling cycles at 600°C.	After 6 heating and cooling cycles at 1100°C.
6	Nil	Nil	Nil
12	Nil	Nil	Nil
20	Nil	Nil	Nil
30	0.19	Nil	Nil
40	5.40	5.60	3.18
50	27.09	29.00	21.69
70	33.55	33.69	33.55
100	29.29	27.37	33.88
140	3.86	3.78	6.49
200	0.12	0.16	0.45
270	0.03	0.06	0.20
Pan	0.02	0.03	0.31

* Grain fineness No. 55; grain class No. 5; maximum retention on 50, 70 and 100 mesh sieves, 89.93%; fines, 0.17%

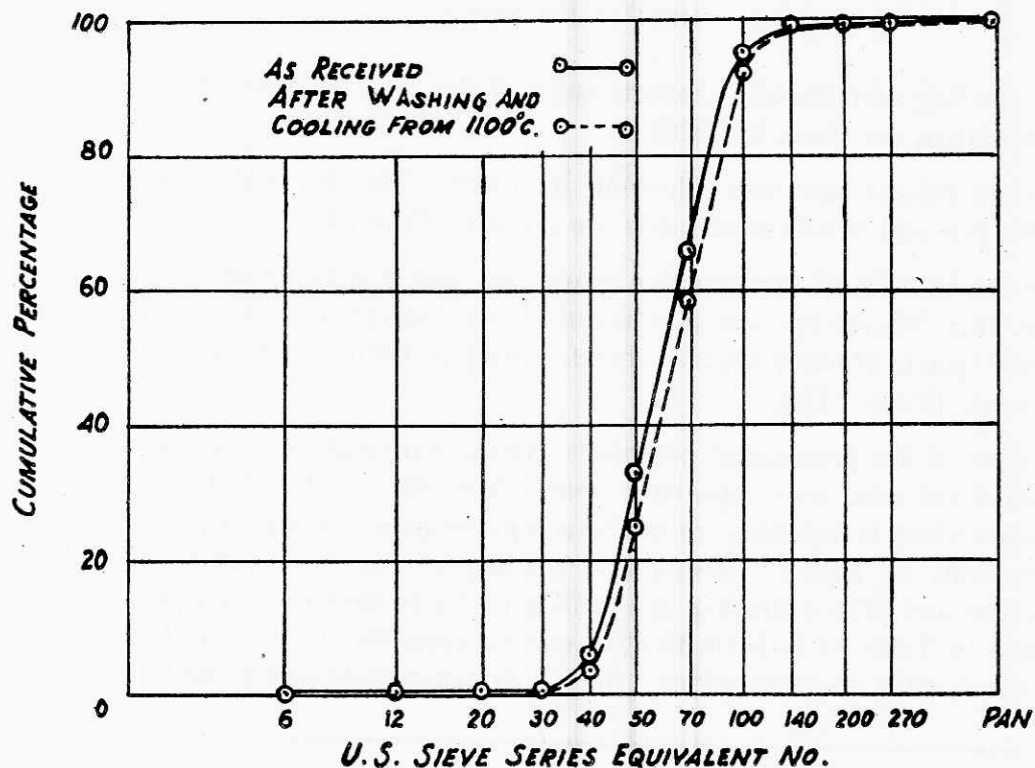


FIG. 19—QUARTZITE SAND: CUMULATIVE GRADING CURVES

TABLE 82—QUARTZITE SAND: CHEMICAL ANALYSIS

CHEMICAL CONSTITUENT	BEFORE BENEFICIATION	AFTER BENEFICIATION
SiO ₂ , %	88.76	95.57
Al ₂ O ₃ , %	4.34	2.14
Fe ₂ O ₃ , %	1.46	—
TiO ₂ , %	0.14	—
CaO, %	0.43	—
MgO, %	0.39	—
Na ₂ O + K ₂ O, %	2.45	1.11
Loss on ignition, %	0.64	—

the grading, increasing the percentage of fines at the expense of 40 and 50 mesh grades.

The beneficiated sand had fairly high refractoriness, the softening point being 1720°C. corresponding to Orton Cones 32-33.

TABLE 83—QUARTZITE SAND BONDED WITH 5% BIHAR BENTONITE: FIRING CHARACTERISTICS

FIRING TEMP. °C.	VOL. AFTER FIRING <i>cu. in.</i>	CHARACTERISTICS AFTER FIRING	ULTIMATE CRUSHING STRENGTH <i>lb./sq. in.</i>
1250	6.633	Pale yellow colour; surfaces friable with very little strength	22.0
1350	6.569	Mottled appearance; brown spots in a pale yellowish brown matrix; cracks at a few places, and signs of fritting; dull sound when struck	218.6
1450	6.352	Brown spots in a pale white matrix; friability when surfaces were rubbed; cracks at a few places, marked signs of sintering, compact mottled texture; dull sound when struck	313.6
1550	6.884*	Mottled appearance at a few places; compact texture; incipient cracks at a few places, dull sound when struck	924.5

* Soaking period, 2 hr

Standard test pieces (2 in. × 2 in.) fired at different temperatures in the range 1250–1550°C. showed cracks (Table 83, Plate IX).

For studying the moulding characteristics of the beneficiated sand it was bonded with different bonding agents. Mixture 1 containing 'K' bentonite (5 per cent), dextrine (1 per cent) and 'Mogul' corn flour (0.5 per cent) showed a permeability of 225 and green compressive strength of 4.1 lb./sq. in. at 3.5 per cent moisture content (Table 84). The mixture exhibited good flowability and possessed adequate dry strength to meet the requirements of light and medium green sand moulds. However, green sand test pieces showed a fair degree of friability which persisted even after drying.

Mixture 2 containing bentonite-cereal in the approximate ratio of 3:1 according to American practice showed an overall improvement in the physical properties over Mixture 1. However, the surface friability of the rammed test pieces showed no improvement (Table 83).

Mixture 3 was prepared for heavy castings and contained 'K' bentonite (5 per cent), plastic fireclay (2 per cent), dextrine (1 per cent), 'Mogul' corn flour (0.5 per cent) and silica flour (8 per cent). It showed a green permeability of 180 and a green compressive strength of 7.1 lb./sq. in. when tempered to 3.5 per cent moisture. Dried test pieces showed compressive strength of 198.9 lb./sq. in. and shear strength of 45.5 lb./sq. in. Flowability and shatter index values of this mixture were fairly satisfactory (Table 84). On tempering to 5–6 per cent moisture the mixture is likely

TABLE 84—EFFECT OF BONDING QUARTZITE SAND WITH DIFFERENT BINDERS ON ITS MOULDING CHARACTERISTICS

	MIXTURE 1*	MIXTURE 2*	MIXTURE 3*	MIXTURE 4†	MIXTURE 5‡
Green permeability No.	225	225	180	145	170
Green compressive strength, lb./sq. in.	4.1	4.3	7.1	1.5	3.3
Green shear, lb./sq. in.	1.1	1.1	1.65	—	0.95
Mould hardness No.	72	75	80	—	6.5
Flowability, %	77	76	74	—	75
Shatter index	52	65.9	54	—	67.6
Dry compressive strength, lb./sq. in.	97.13	124.15	198.9	202	350
Dry shear, lb./sq. in.	33	35	45.5	—	—
Bulk density after compression, g./cc.	1.40	1.408	1.456	—	1.505

* Moisture, 3.5% † Moisture 2.0% ‡ Moisture 2.8%

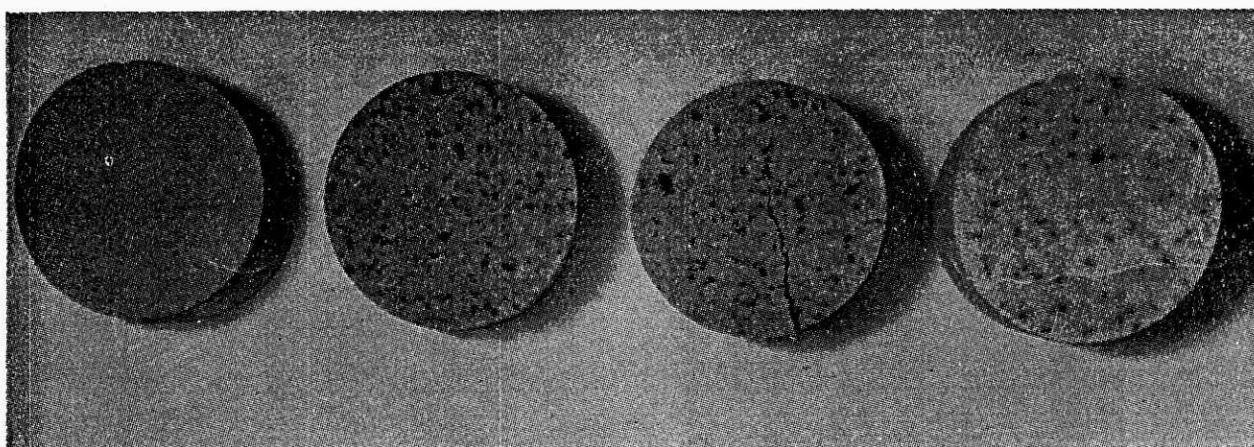
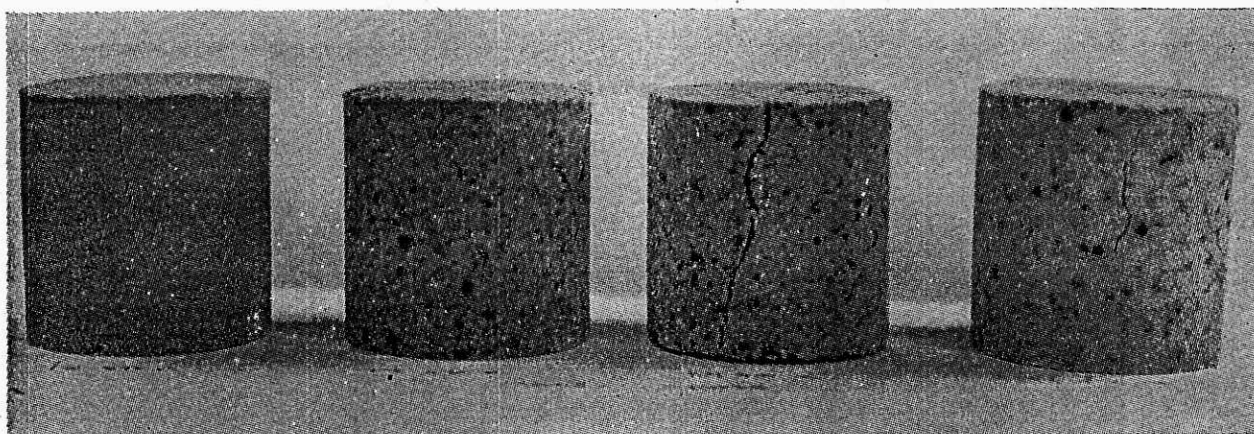
to prove equally satisfactory for use in the preparation of dry sand moulds, pouring cups, etc. However, in this case also surface friability was apparent in the rammed test pieces.

Mixtures 4 and 5 were prepared for use in cores. Mixture 4 contained 'Mogul' corn flour (0.5 per cent), double-boiled linseed oil (0.5 per cent) and paraffin base parting fluid (0.5 per cent). With 10 rams this mixture showed a green compressive strength of 1.5 lb./sq. in., permeability of 140 and a dry compressive strength of 202 lb./sq. in. at a moisture content of 2 per cent. The surface hardness of the baked test pieces was fairly satisfactory, though friability was apparent. This type of composition can be adopted for the production of cores by core blowing.

Mixture 5, prepared for trial in the making of cores for heavy castings, contained double-boiled linseed oil (2 per cent), 'Mogul' corn flour (3 per cent), 'K' bentonite (0.5 per cent) and silica flour (10 per cent). When tempered to 2.8 per cent moisture, it exhibited a permeability of 170 and a compressive strength of 3.3 lb./sq. in. prior to rupture. The mixture had fairly satisfactory green flowability and good baked surface hardness.

Conclusion. The beneficiated sand containing the bonding materials is satisfactory for steel foundry practice. But the surface of the product exhibits friability. This should be borne in mind while making plant trials.

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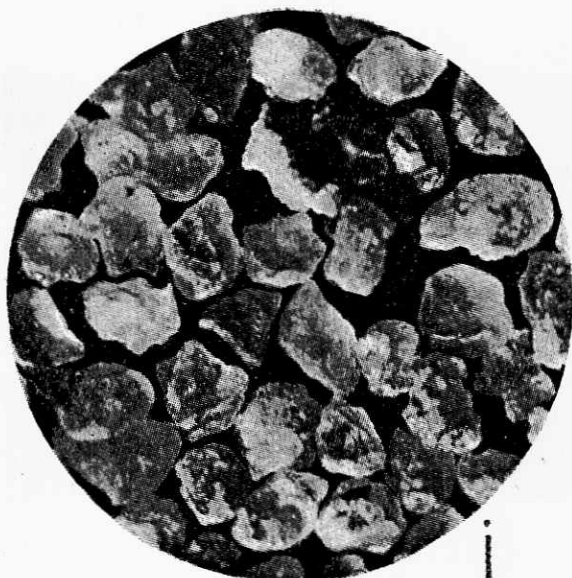
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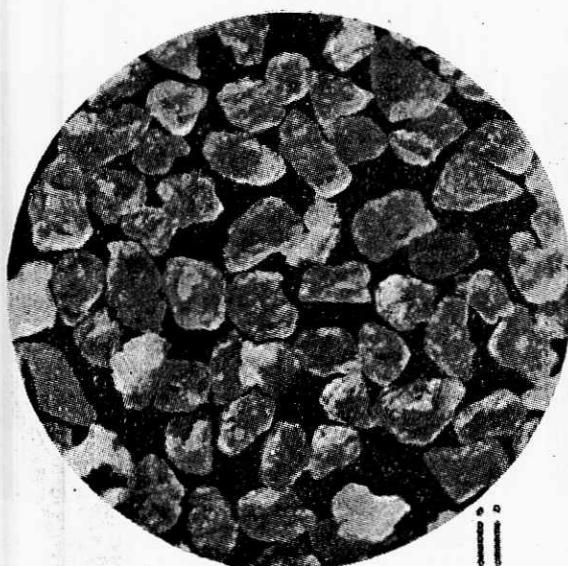
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TEST PIECES OF BENEFICIATED QUARTZITE SAND FIRED AT DIFFERENT TEMPERATURES (°C.)

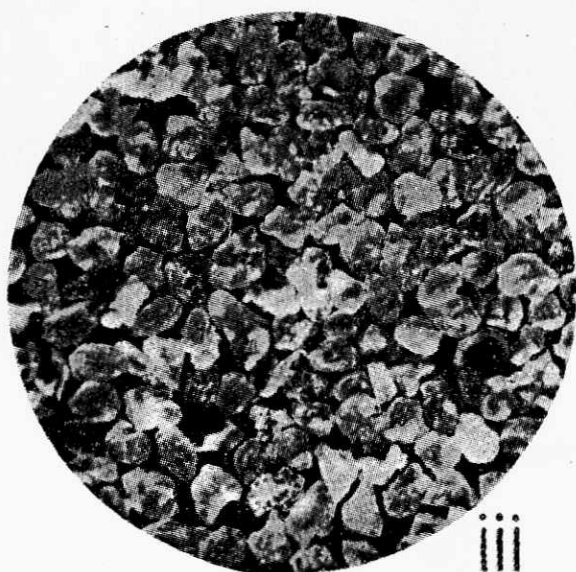
PLATE X



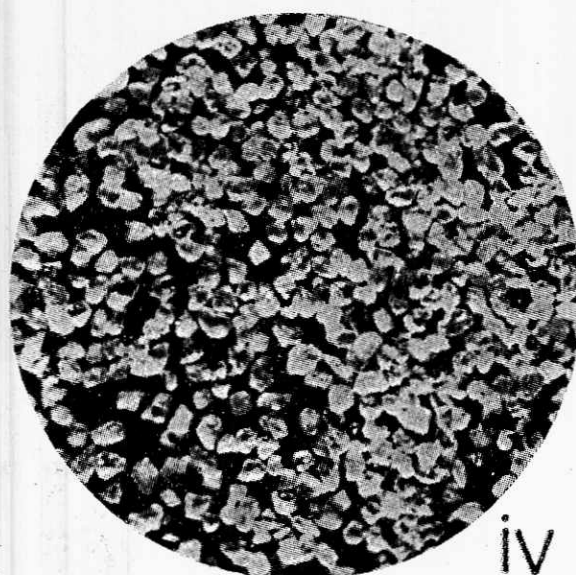
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WASHED SAND GRAINS OF JUBBULPORE RETAINED ON (i) 30 MESH ; (ii) 40 MESH ;
(iii) 50 MESH ; AND (iv) 70 MESH ($\times 25$)

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Durgapur Sand

The sand sample was received from *Messrs. Hindustan Steel (Private) Ltd.*, Durgapur, for the determination of its suitability for steel foundry jobs.

The sample, as received, was pale and was in the form of lumps of thickly consolidated quartzitic sandstone. The lumps were crushed, first in a jaw crusher and then in a roll crusher. The crushed product was sifted through a 12 mesh sieve and the portion passing through the sieve was taken up for investigation.

TABLE 85(a)—DURGAPUR SAND: SIZE GRADING

U.S. SIEVE EQUIVALENT NO.	% RETAINED	
	As-received	After washing
6	Nil	Nil
12	Nil	Nil
20	42.10	44.04
30	18.50	17.96
40	11.20	10.66
50	7.30	7.00
70	—	—
100	3.00	3.30
140	3.45	2.30
200	2.40	2.36
270	1.30	1.20
Pan	2.70	2.04

TABLE 85(b)—DURGAPUR SAND: FINENESS CHARACTERISTICS

	AS-RECEIVED	AFTER WASHING
Clay, %	—	0.55
Clay class	—	B
Grain fineness No.	38.08	34.69
Grain class No.	7	7
Max. retention on 20, 30 and 40 mesh sieves, %	71.80	72.66
Fines, %	6.4	5.6

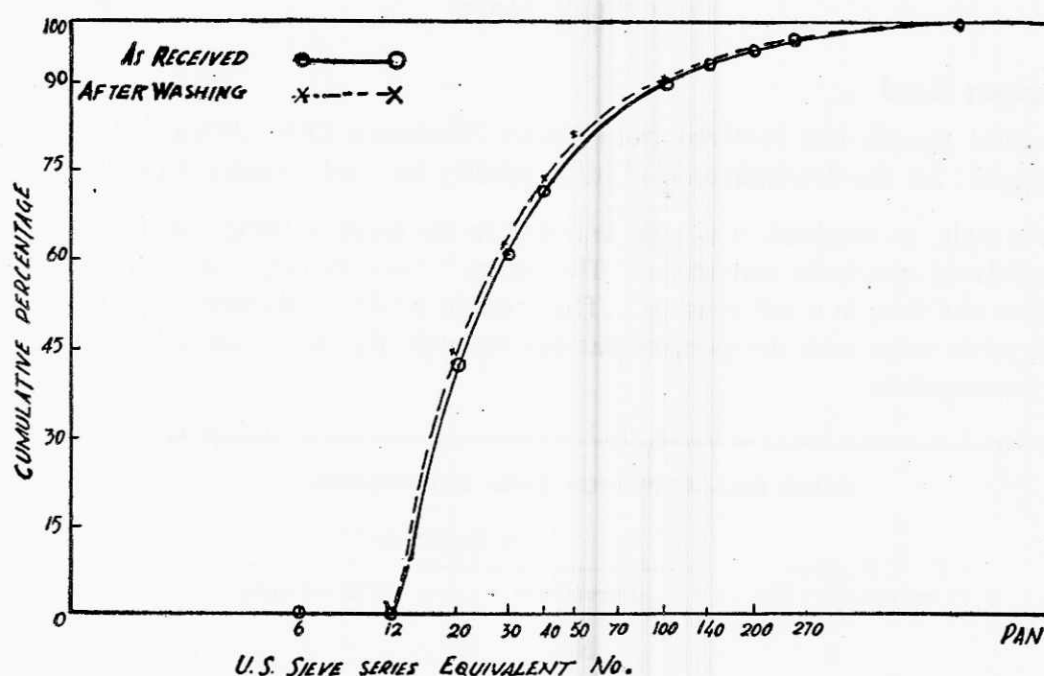


FIG. 20—DURGAPUR SILICA SAND: CUMULATIVE GRADING CURVES

TABLE 86—DURGAPUR SAND: CHEMICAL ANALYSIS

CHEMICAL CONSTITUENT	AS-RECEIVED	AFTER WASHING
SiO ₂ , %	97.96	98.20
Al ₂ O ₃ , %	0.41	0.66
Fe ₂ O ₃ , %	0.10	0.15
TiO ₂ , %	Trace	Trace
CaO, %	0.36	0.42
MgO, %	Trace	Trace
Na ₂ O + K ₂ O, %	0.2	Trace
Loss on ignition, %	0.56	0.20

The sample was of coarse grade, the sand grains being subangular to rounded in shape. Size grading and fineness characteristics of the sand are shown in Tables 85(a) & 85(b) and Fig. 20.

Petrological examination of the sample showed it to consist mostly of quartz. No other minerals could be identified. Chemical analysis of the raw and washed sand showed it to contain nearly 98 per cent silica (Table 86).

The sintering range of the sand grains was appreciably high ($>1400^{\circ}\text{C}.$).

TABLE 87—EFFECT OF BONDING DURGAPUR SAND WITH DIFFERENT BINDERS ON ITS
MOULDING CHARACTERISTICS

	Mixture 1								Mixture 2*	Mixture 3†
	1.2	2.3	2.9	4.0	4.6	5.0	5.4	5.9		
Green permeability No.	165	230	250	345	370	500	440	370	210	135
Green compressive strength, lb./sq. in.	7.5	5.2	4.2	3.25	3.05	2.77	2.25	2.95	1.45	9.5
Green shear, lb./sq. in.	1.9	1.2	0.95	0.80	0.65	0.60	0.50	0.40	0.30	2.4
Mould hardness No.	82	80	77	74	70	64	63	61	54	81
Flowability, %	75	75	74	73	73	71.5	70	69.5	71.5	73
Shatter index	31.4	28.7	25.8	24.5	23	21.7	14.6	11.2	8.2	58
Dry compressive strength, lb./sq. in.	10.7	28.0	49.2	61.7	73	82.2	87.5	106	148	262
Dry shear, lb./sq. in.	3	7.2	11	15	22	26	29.5	31.5	30	39.2
Bulk density after compression, g./cc.	1.530	1.549	1.558	1.577	1.598	1.617	1.628	1.637	1.656	1.615

* Moisture content, 1.7% † Moisture content, 2.4%

On bonding with 5 per cent Bihar bentonite, the sand showed maximum green compressive strength (7.5 lb./sq. in.) at 1.2 per cent moisture content (Table 87). The specimens rammed hard in the moulds and a maximum hardness of 82 was recorded at 1.2 per cent moisture content. Flowability was maximum (75) at 1.2 and 2.3 per cent moisture contents. The sand mixture possessed maximum dry strength value (125 lb./sq. in.) at 6.4 per cent moisture content. However, the surfaces of the green and dry sand test pieces were very friable.

For overcoming the surface friability of the moulds and for obtaining smooth surface, the addition of silica flour and dextrine in addition to bentonite was attempted (Mixtures 2 and 3).

As compared to Mixture 1, Mixtures 2 and 3 exhibited slightly higher strength. The dry strength was particularly high in the case of Mixture 3. Permeability was satisfactory in the case of Mixture 2, but low for Mixture 3. Shatter index was higher in both (Table 87). Specimens prepared from the three sand mixtures showed no friability both in the green and dry states.

Standard test blocks (3 in. $\times$ 3 in. $\times$ 3 in.) of steel were cast in green and dry sand moulds employing the three sand mixtures. In the case of Mixture 1, metal penetration into the sand mould took place. To overcome this defect, plumbago dressing was tried on the mould ; it yielded castings with slightly better surface finish. In the case of Mixtures 2 and 3, metal penetration was considerably less.

Conclusion. The sand, on crushing to a suitable grade, can be successfully employed for light steel castings after bonding with silica flour (10 per cent), Bihar bentonite (5 per cent) and dextrine (2 per cent). The optimum moisture range for green sand practice is about 3 per cent and for dry sand practice 5-6 per cent. Control of size grading, while crushing, is of utmost importance. In a big foundry, it would be rather difficult to maintain the same grade as more and more fines will be produced in handling and recycling operations. It is felt that actual trials in the steel foundry should establish its value as a moulding sand. Application of suitable mould dressings to the moulds is considered necessary to get good surface finish to the castings.

Jubbulpore Silica Sand

The sand sample, obtained through *Messrs Mukand Iron & Steel Works Ltd*, Bombay was pale grey in colour. It was collected from deposits situated near the north civil station, Jubbulpore, located as overburden in adjacent fireclay quarries. The deposits belong to the Upper Gondwana system and are of fluviatile or lacustrine origin. The sand is washed and screened to the requisite mesh size prior to supply.

The mechanical grading of the sand was more or less similar to that of the

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usual natural moulding sands, bulk of the sand grains being spread over a fairly wide mesh range. The results of the fineness tests are presented in Tables 88(a) & 88(b) and Fig. 21.

Petrological examination of the raw sand showed it to consist mainly of quartz and calcareous matter. Heavy minerals were present only in traces. Microscopic examination of the washed sand grains showed them to be mostly subangular to rounded in shape, the rounded grains being more conspicuous on the finer meshes. Some grains were stained with limonite (Plate X).

TABLE 88(a)—JUBBULPORE SILICA SAND: SIZE GRADING

U.S. SIEVE EQUIVALENT NO.	% RETAINED	
	As-received	After washing
6	—	—
12	2.34	1.660
20	13.05	11.450
30	11.57	9.88
40	17.36	15.10
50	21.45	20.13
70	15.27	16.64
100	6.57	7.46
140	4.36	4.82
200	3.19	3.38
270	1.22	1.56
Pan	2.78	2.78

TABLE 88(b)—JUBBULPORE SILICA SAND: FINENESS CHARACTERISTICS

	AS-RECEIVED	AFTER WASHING
Max. retention on three adjacent sieves, %	54.085	51.87
Grain fineness No.	—	53.07
Clay, %	—	5.14
Clay class	—	D

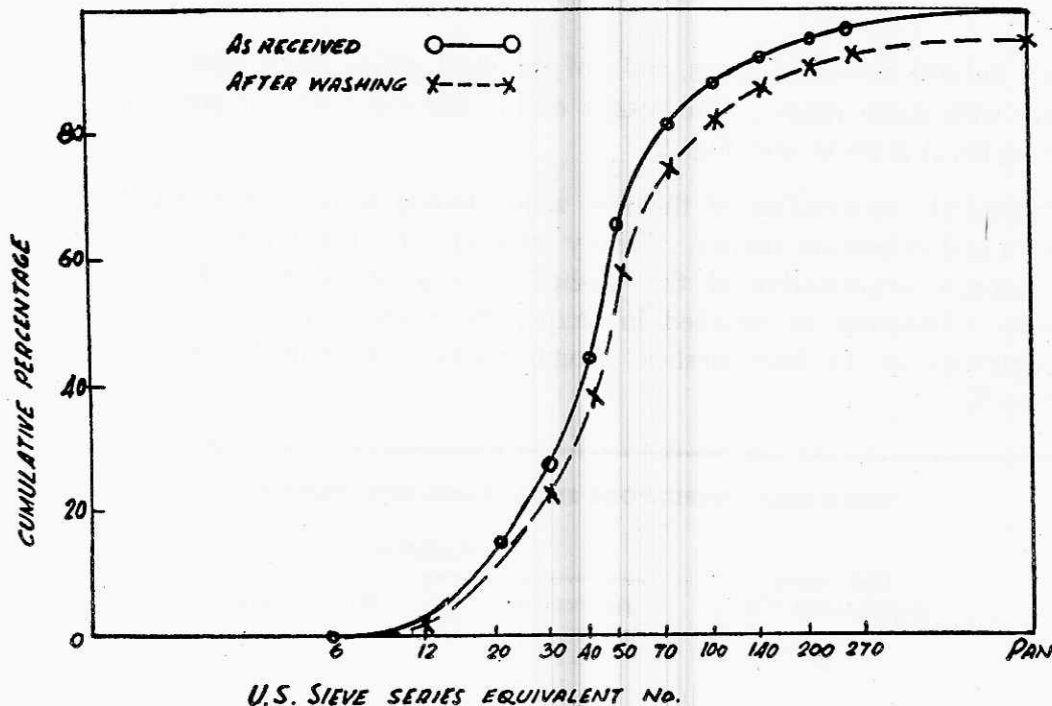


FIG. 21.—JUBBULPORE SILICA SAND: CUMULATIVE GRADING CURVES

The results of chemical analysis of the sand in the as-received condition and after washing free of clay grade matter are given in Table 89.

The raw sand showed fairly satisfactory refractoriness, the fusion point being $1650^{\circ}\text{C}.$, corresponding to Orton Cone 30. Sintering of sand grains was found to take place between 1350° and $1450^{\circ}\text{C}.$ Standard test pieces (2 in. $\times$ 2 in.) fired at $1150^{\circ}\text{C}.$ crumbled to powder on cooling to room temperature. Those fired at higher temperatures were compact and rigid. No signs of cracking were observed in any of the test pieces (Plate XI). The test pieces fired at $1550^{\circ}\text{C}.$ revealed slight bulging (Table 90).

The raw sand showed maximum green permeability (130) at 3.2 per cent moisture, which came down to 90 at 6.7 per cent moisture. The green compressive strength varied from the maximum value of 17.6 lb./sq. in. at 2.4 per cent moisture to 10.5 lb./sq. in. at 6.7 per cent moisture. The flowability over the entire moisture range (2.4–5.7 per cent) was fairly satisfactory. The mixtures rammed fairly hard in the specimen tube, the hardness values being as high as 91. The sand revealed high dry strengths, the maximum value being 160 lb./sq. in. at 6.7 per cent moisture. The dried test pieces showed increasing tendency toward bulging prior to rupture with high percentage of moisture (Table 91).

Steel test blocks (3 in. $\times$ 3 in. $\times$ 3 in.) cast in green and dry moulds of the sand showed good surface characteristics with no signs of 'burning on'.

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Conclusion. The sand is suitable for dry sand moulding for steel castings, particularly for medium and heavy jobs.

TABLE 89—JUBBULPORE SILICA SAND: CHEMICAL ANALYSIS

CHEMICAL CONSTITUENT	AS-RECEIVED	AFTER WASHING
SiO ₂ , %	37.2	89.5
Al ₂ O ₃ , %	2.9	2.6
Fe ₂ O ₃ , %	1.3	1.1
TiO ₂ , %	0.2	0.2
CaO, %	2.6	1.9
MgO, %	0.69	0.65
Na ₂ O + K ₂ O, %	1.11	0.55
Loss on ignition, %	3.90	3.10

TABLE 90—JUBBULPORE SILICA SAND: HIGH TEMPERATURE CHARACTERISTICS

(Initial vol. of test pieces, 6.284 cu. in.; soaking period, 1.5 hr)

FIRING TEMP. °C.	VOLUME AFTER FIRING cu. in.	CHARACTERISTICS OF TEST PIECES AFTER FIRING	ULTIMATE CRUSHING STRENGTH lb./sq. in.
1150	—	Brick red colour; crumbled to powder on cooling to room temperature; no cracks	—
1250	—	Dark brown colour; surface rough and very friable; dull sound when struck; no cracks	—
1350	6.354	Mottled texture with light brown spots in a pale white matrix; surfaces slightly friable, compact; low metallic sound when struck; tendency towards sintering; no cracks	561.8
1450	6.566	Mottled texture with brown spots in a pale white matrix; no friability on surface, compact; positive signs of vitrification; a clear sound when struck; no cracks	716.4
1550	6.874*	Mottled texture with light brown spots and a pale white matrix; rigid, but slight bulging on sides; complete fritting; a dull brick sound when struck; no cracks	1411.0

* Soaking period, 2 hr

TABLE 91—JUBBULPORE SILICA SAND: MOULDING CHARACTERISTICS AT DIFFERENT MOISTURE CONTENTS

	MOISTURE, %					
	2.4	3.2	4.1	5.0	5.9	5.7
Green permeability No.	93	130	125	120	110	90
Green compressive strength, lb./sq. in.	17.6	17.4	15.6	14.0	12.8	10.5
Green shear, lb./sq. in.	8.7	3.5	3.8	3.3	2.9	2.5
Mould hardness No.	91	90	88	86	84	82
Flowability, %	76	—	71	70	72	71
Shatter index	51.4	67.5	81.62	85.4	90.4	98.4
Dry compressive strength, lb./sq. in.	80	93.2	100	135	145	160
Dry shear, lb./sq. in.	16	18	19.5	27.0	26.0	34

Allahabad Sand

The sand sample was supplied by *Messrs Mukand Iron & Steel Works Ltd*, Bombay. It is obtained from deposits lying on the outskirts of the Vindhyan mountain range south-west of Allahabad. The quarries are situated at a distance of about 3–6 miles from Shankergarh station on the Central Railway. The deposits belong to the Upper Vindhyan system and are of fluviatile or estuarine origin. They occur in regular thick layers with little overburden. The quarried sand is in the form of lumps, which are sorted, powdered and screened to the requisite mesh size.

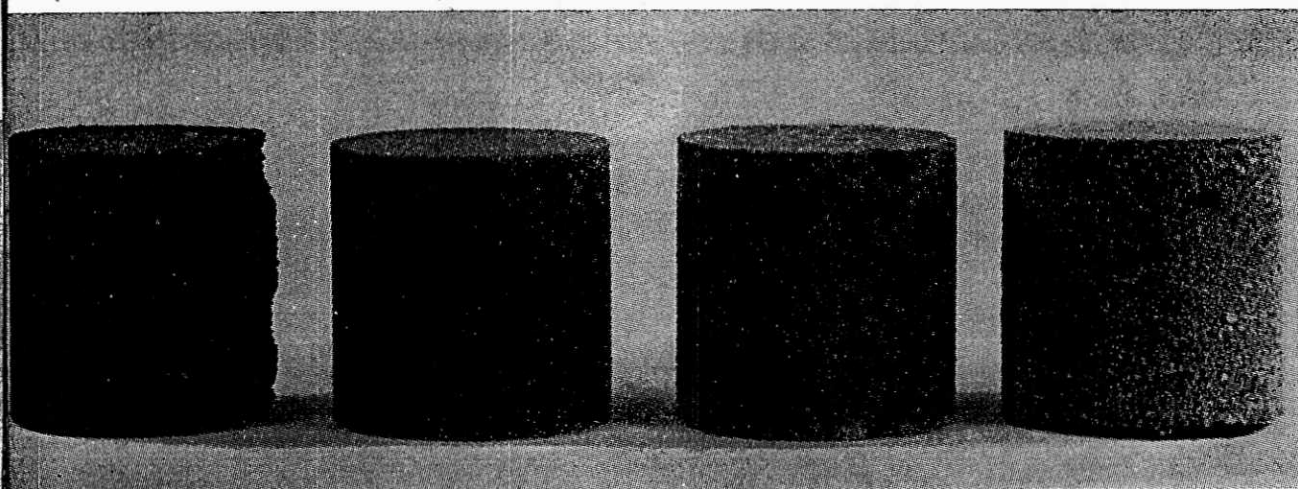
The sand sample, in the as-received condition, was pale brown in colour. It belonged to 'fine' grade and showed poor grading. The size grading and fineness characteristics of the sand are shown in Tables 92(a) & 92(b). Cumulative grading curves are shown in Fig. 22.

Petrographic examination of the sand in the unwashed and washed conditions showed it to consist mostly of quartz of subangular to rounded shape (Plates XII & XIII). Feldspar, tourmaline and magnetite were present only in small amounts. The results of chemical analysis of the sand are shown in Table 93.

Sintering of the sand grains was found to take place in the range 1350–1450°C. Test pieces fired to different temperatures in the range 1250–1550°C. developed cracks during cooling to room temperature (Table 94, Plate XIV). The sand showed fairly high refractoriness, the softening point being 1720°C., corresponding to Orton Cones 32–33.

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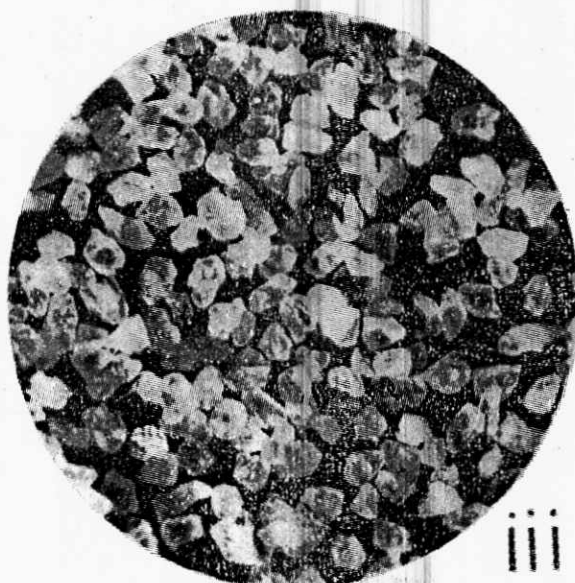
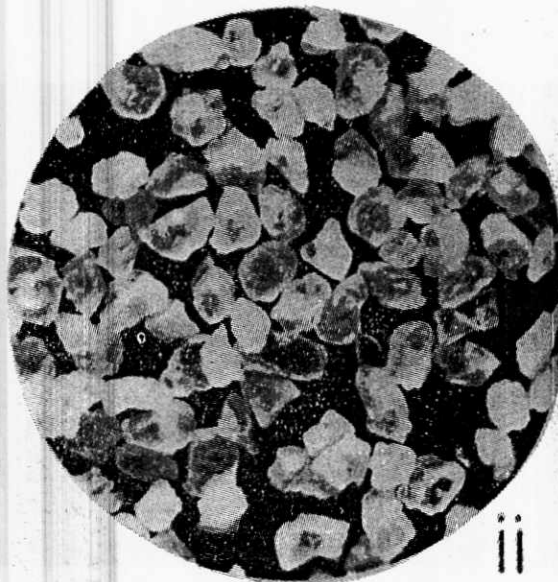
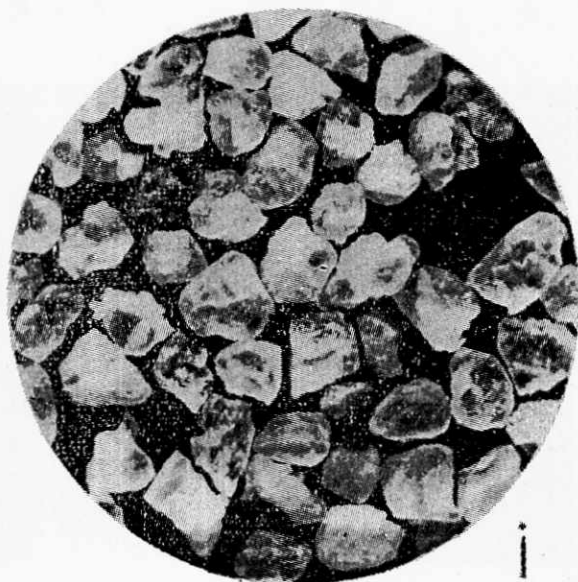
TEST PIECES OF JUBBULPORE SILICA SAND FIRED AT DIFFERENT TEMPERATURES (°C.)

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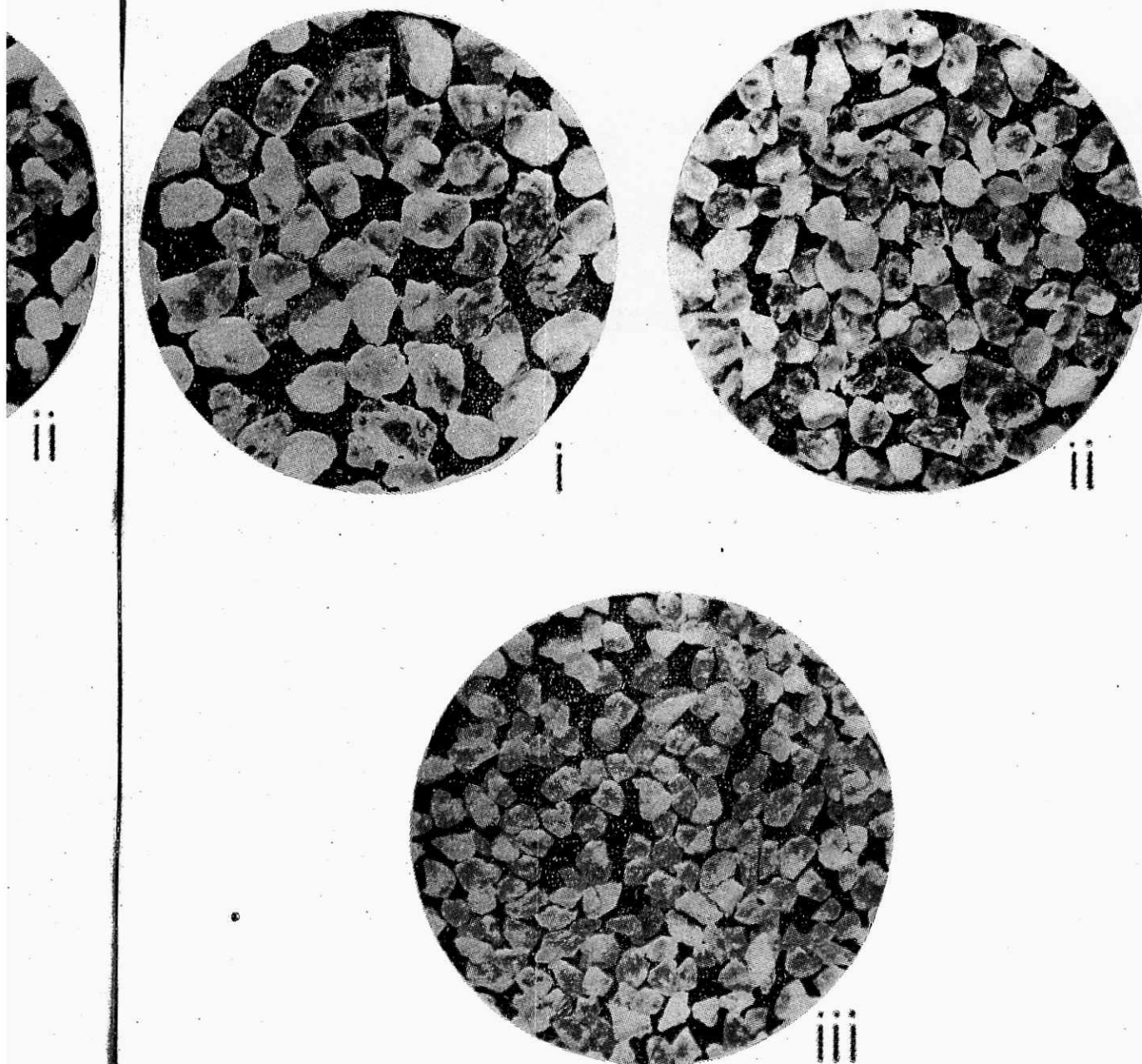
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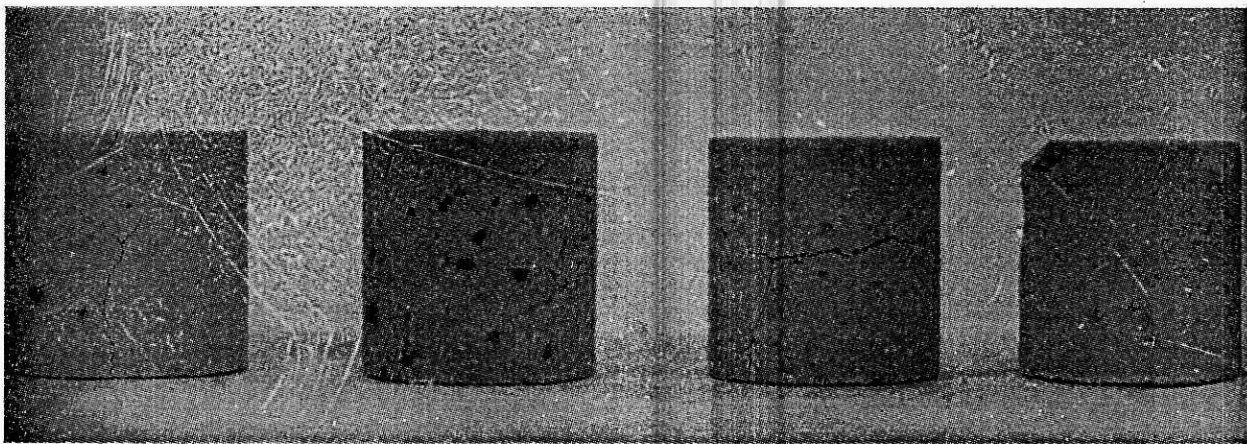
UNWASHED SAND GRAINS OF ALLAHABAD SAND RETAINED ON (i) 50 MESH ; (ii) 70 MESH ;
AND (iii) 100 MESH

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WASHED SAND GRAINS OF ALLAHABAD SAND RETAINED ON (i) 50 MESH ; (ii) 70 MESH ;
AND (iii) MESH

PLATE XIV



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TEST PIECES OF ALLAHABAD SAND FIRED AT DIFFERENT TEMPERATURES ($^{\circ}\text{C}.$)

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TABLE 92(a)—ALLAHABAD SAND: SIZE GRADING

U.S. SIEVE EQUIVALENT No.	% RETAINED			
	As-received	After washing	After one washing in hydroclassifier	After two washings in hydroclassifier
6	—	—	Nil	Nil
12	—	—	Nil	Nil
20	0.42	0.31	0.21	0.32
30	1.55	1.29	1.58	1.93
40	9.27	8.42	10.768	15.69
50	15.575	15.23	19.688	25.965
70	17.24	17.65	22.88	25.405
100	17.295	17.02	21.40	18.165
140	15.13	15.11	16.02	9.845
200	9.23	9.26	5.38	2.21
270	5.53	5.24	0.96	0.13
Pan	8.30	7.49	0.54	0.04

TABLE 92(b)—ALLAHABAD SAND: FINENESS CHARACTERISTICS

	AS-RECEIVED	AFTER WASHING	AFTER ONE WASHING IN HYDRO- CLASSIFIER	AFTER TWO WASHINGS IN HYDRO- CLASSIFIER
Max. retention on 3 adjacent sieves, %	50.11	49.9	63.968	69.535
Grain fineness No.	—	91.1	65.5	54.4
Clay, %	—	1.89	—	—
Clay class	—	B	—	—

On admixture with Bihar bentonite to the extent of 5 per cent, the sand showed a permeability of 80 and compressive strength of 4.9 lb./sq. in. in the green condition, at a moisture content of 3.2 per cent. Test pieces baked at 200°C. for 2 hr showed a dry compressive strength of 63 lb./sq. in. and a dry shear strength of 20 lb./sq. in. (Table 95).

Upgrading. In view of the low green permeability and poor grading of the sand in the as-received condition, it was considered worth while to study the

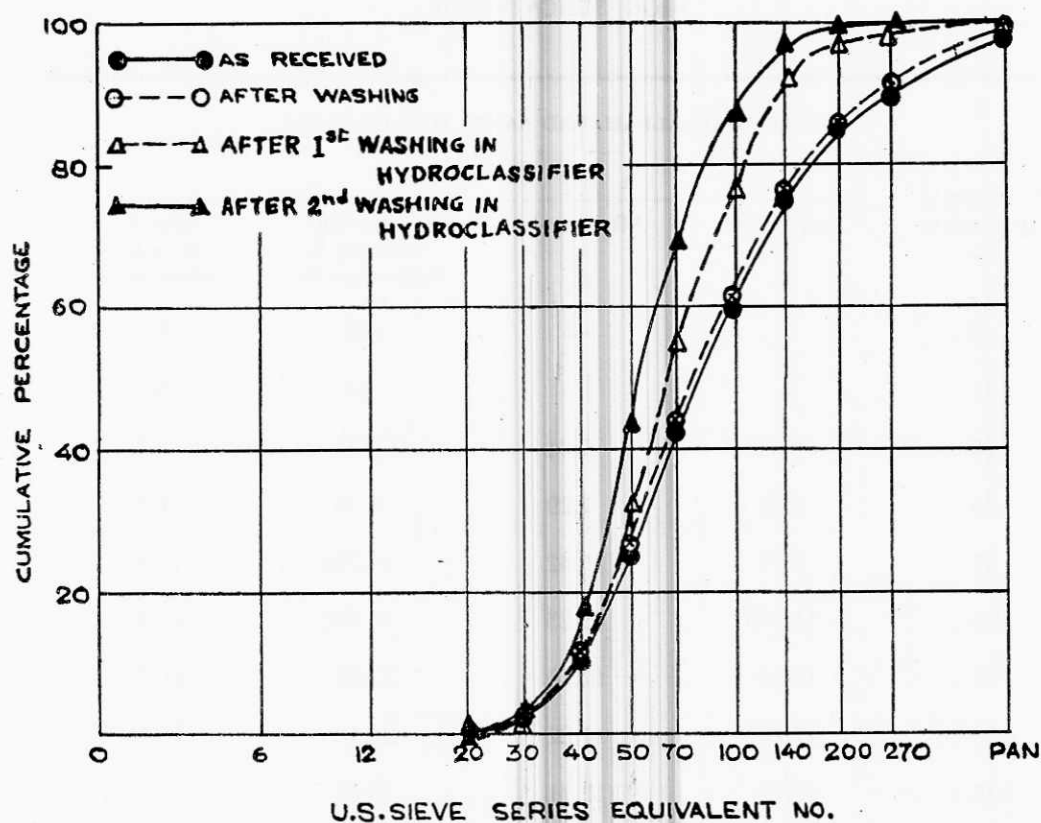


FIG. 22—ALLAHABAD SILICA SAND: CUMULATIVE GRADING CURVES

TABLE 93—ALLAHABAD SAND: CHEMICAL ANALYSIS

CHEMICAL CONSTITUENT	AS-RECEIVED	AFTER WASHING
SiO ₂ , %	98.1	98.56
Al ₂ O ₃ , %	0.78	0.45
Fe ₂ O ₃ , %	0.34	0.20
TiO ₂ , %	0.14	0.13
CaO, %	0.74	0.70
MgO, %	Trace	Trace
Na ₂ O + K ₂ O, %	Trace	Trace
Loss on ignition, %	0.25	0.22

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TABLE 94—ALLAHABAD SAND BONDED WITH 5% BIHAR BENTONITE: FIRING CHARACTERISTICS*(Initial vol. of test pieces, 6.282 cu. in.; soaking period, 1.5 hr)*

FIRING TEMP. °C.	VOL. AFTER FIRING cu. in.	CHARACTERISTICS OF TEST PIECES AFTER FIRING	ULTIMATE CRUSHING STRENGTH lb./sq. in.
1250	6.430	Pale yellowish colour, highly friable, very little strength	—
1350	6.633	Slightly mottled structure; yellowish brown colour with dark brown spots in the matrix, fairly compact cracks visible in the body of the test piece, slightly friable on rubbing, dull sound when struck	218.9
1450	6.792	Colour light yellowish brown with white and dark brown spots, compact texture, incipient cracks, sand grains showed signs of fritting, dull sound when struck	573.05
1550	6.918	Colour pale grey, open cracks observed at a few places, compact and rigid texture, dull sound when struck, grains completely fritted	1579

TABLE 95—ALLAHABAD SAND BONDED WITH 5% BIHAR BENTONITE: MOULDING CHARACTERISTICS*(At 3.2% moisture)*

Green permeability No.	80
Green compressive strength, lb./sq. in.	4.9
Green shear, lb./sq. in.	1.0
Mould hardness No.	80
Flowability, %	76
Shatter index	25.3
Dry compressive strength, lb./sq. in.	63
Dry shear, lb./sq. in.	21
Bulk density after compression, g./cc.	1.623

effect of desliming it by hydro-classification. Two treatments in the hydro-classifier gave an improved grading with 69.5 per cent distribution on three adjacent sieves (50, 70, 100 mesh) as compared to 49.9 per cent in the case of raw sand [Table 92(a)]. The percentage of fines was reduced to 2.33.

For improving the moulding characteristics of the sand, it was bonded with different binders. Mixture 1 prepared with Bihar bentonite (5 per cent) and dextrine (1 per cent) showed satisfactory green permeability (140) but low

TABLE 96—EFFECT OF BONDING WASHED ALLAHABAD SAND WITH DIFFERENT BINDERS
ON ITS MOULDING CHARACTERISTICS

(Moisture content, 3.4 %)						
	MIXTURE 1	MIXTURE 2	MIXTURE 3	MIXTURE 4*	MIXTURE 5†	MIXTURE 6‡
Green permeability No.	140	155	170	135	150	90
Green compressive strength, lb./sq. in.	3.2	4.5	5.4	1.5	1.7	4.5
Green shear, lb./sq. in.	0.8	0.9	1.2	0.4	0.5	0.8
Mould hardness No.	72	78	78	55	60	80
Flowability, %	77	74	76	81	79	79
Shatter index	28.3	30.6	44.3	—	—	—
Dry compressive strength, lb./sq. in.	83.5	57	86.5	39.0	40	120
Dry shear, lb./sq. in.	26	11	28	16	13	56.5
Bulk density after compression, g./cc.	1.545	1.526	1.526	1.576	1.575	1.672

* Moisture content, 1.8 % † Moisture content, 1.3 % ‡ Moisture content, 1.7 %

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green compressive strength (3.3 lb./sq. in.) at a moisture content of 3.4 per cent. The flowability was fairly satisfactory, but the shatter index value was poor. Test pieces dried at 200°C. for 2 hr showed dry strength of 83.5 lb./sq. in. and dry shear of 26 lb./sq. in. (Table 96).

The washed sand when bonded with 5 per cent Rajasthan bentonite (Mixture 2) showed a better combination of green permeability (155) and green compressive strength (4.5 lb./sq. in.) as compared to Mixture 1. It also possessed fairly good flowability. Dried test pieces showed a compressive strength of 57 lb./sq. in. and shear strength of 11 lb./sq. in. The shatter index was poor. Mixture 3 was prepared by the addition of 1 per cent dextrine to Mixture 2. It showed considerably higher green permeability (170) and compressive strength (5.4 lb./sq. in.) as compared to Mixture 2 at an identical moisture content (3.4 per cent). Its shatter index and flowability values were comparatively better. Dried test pieces baked at 200°C. for 2 hr showed compressive strength of 86.5 lb./sq. in. and shear strength of 28 lb./sq. in.

Mixtures 4 and 5 were prepared for cores using the following bonding composition: Rajasthan bentonite, 2; Kordek, 1-1.5; and linseed oil, 1.5-2 per cent. These mixtures showed green permeabilities in the range 135-150, and green compressive strength in the range 1.5-1.7 lb./sq. in. Dry test pieces exhibited rather low dry compressive strengths (39-40 lb./sq. in.); dry shear values ranged from 13 to 16 lb./sq. in. The test pieces required careful handling in the green state. In dried condition also they were highly friable.

Keeping in view the low strengths of Mixtures 4 and 5 for cores, in both green and dried states, addition of silica flour was also attempted. Mixture 6 was prepared employing the following compositions: silica flour, 10; Rajasthan bentonite, 2; Kordek, 1; and linseed oil, 2 per cent. This mixture showed better green compressive strength (4.5 lb./sq. in.) and diminished green permeability (90). Its dry compressive strength was as high as 120 lb./sq. in. and dry shear 56.5 lb./sq. in.

Conclusion. The sand can be used as a high-silica base sand for moulds and cores for light and medium steel castings in green sand practice, but thorough washing to reduce the fines and to improve the size grading is essential in the first instance.

Madras Silica Sand

The sand, supplied by the Southern Circle of the Geological Survey of India, Madras, was collected (as coarse sand grade) from alluvial deposits near Ennore, Chingleput district. Geologically, the deposits are of Recent and post-Pliocene origin, occurring on the Coromandel coast.

In the as-received state, the sand was pale white in colour and belonged to medium coarse variety, with almost no clay grade matter. The size

TABLE 97(a)—MADRAS SILICA SAND: SIZE GRADING OF SAND AFTER WASHING

U.S. SIEVE EQUIVALENT NO.	% RETAINED	U. S. SIEVE EQUIVALENT NO.	% RETAINED
6	Nil	70	3.62
12	0.75	100	0.75
20	18.44	140	0.20
30	28.91	200	0.06
40	29.82	270	0.03
50	16.91	Pan	0.11

TABLE 97(b)—MADRAS SILICA SAND: FINENESS CHARACTERISTICS OF WASHED SAND

Clay, %	Nil
Clay class	—
Grain fineness No.	26.4
Grain class No.	8
Max. retention on 20, 30 and 40 mesh sieves, %	77.17
Fines, %	0.20

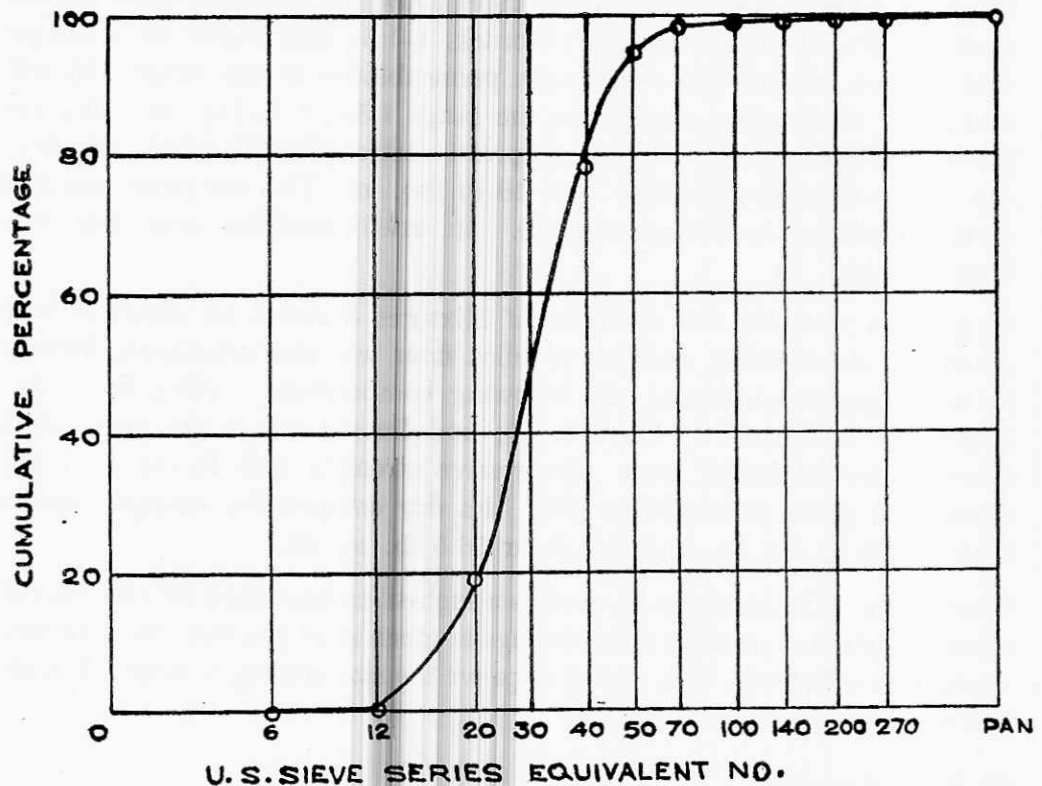
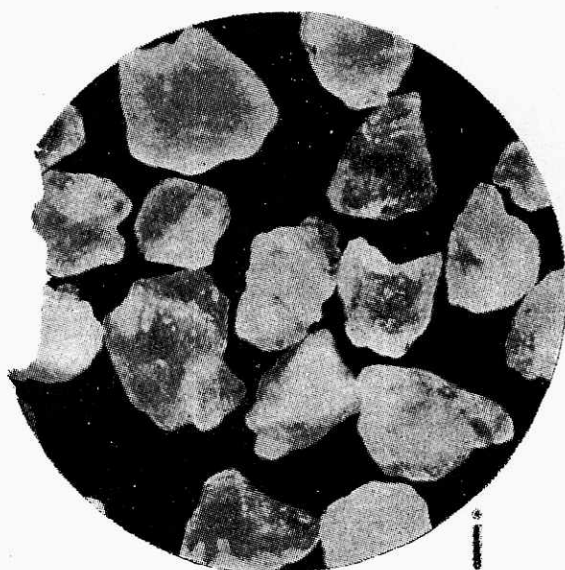


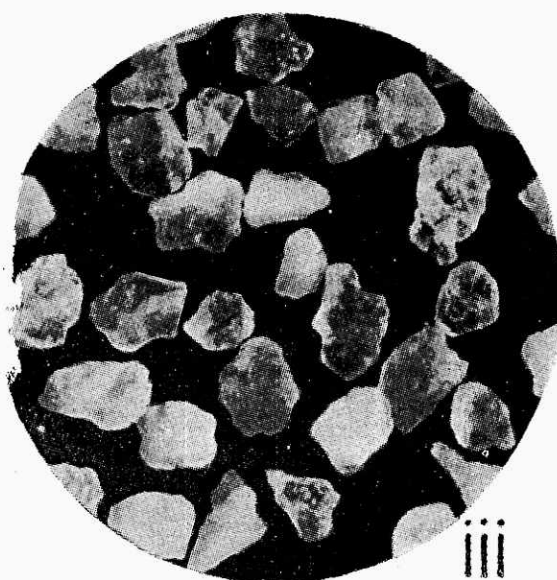
FIG. 23—MADRAS SILICA SAND: CUMULATIVE GRADING CURVES



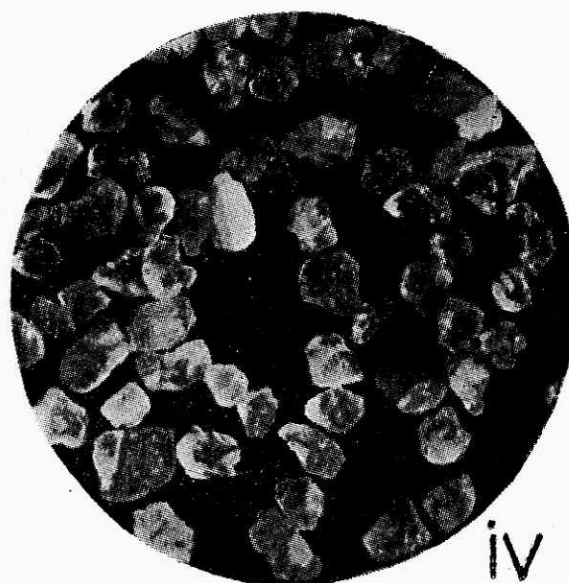
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WASHED SAND GRAINS OF MADRAS SILICA SAND RETAINED ON (i) 20 MESH ; (ii) 30 MESH ; (iii) 40 MESH ; AND (iv) 50 MESH ($\times 25$)

PLATE XVI



TEST PIECES OF MADRAS SILICA SAND (BONDED WITH 5 PER CENT BENTONITE) FIRED
AT DIFFERENT TEMPERATURES (°C.)

grading and fineness characteristics of the sand are shown in Tables 97(a) & 97(b) and Fig. 23.

Petrological examination of the sand revealed abundance of quartz with little feldspar; heavy minerals, viz. ilmenite, magnetite, garnet and rutile, together constituted only 2.7 per cent of the total. No calcareous mineral was present.

Microscopic examination of the washed sand grains showed them to be mostly subangular to rounded (Plate XV). Some of the grains were transparent. The results of chemical analysis of the sand are presented in Table 98.

The raw sand showed fairly high refractoriness, the fusion point being $1710^{\circ}\text{C}.$, corresponding to Orton Cone 32-32.5. From high temperature studies on standard test pieces (2 in. $\times$ 2 in.) vitrification was observed to commence at $1450^{\circ}\text{C}.$ and to be complete before $1550^{\circ}\text{C}.$ as indicated by the sudden increase in ultimate crushing strength of the test pieces after firing at that temperature. Slight cracks appeared on the test pieces fired at $1350^{\circ}\text{C}.$ (Table 99, Plate XVI).

Since the sand in the as-received state did not exhibit satisfactory moulding characteristics, different bentonite compositions were tried for upgrading it. Mixture 1 containing Bihar bentonite (5 per cent) as the bonding material showed maximum permeability (740) and green compressive strength (6.6 lb./sq. in.) at 2.4 per cent moisture. Dry strength was maximum 49 lb./sq. in.) at 4 per cent moisture content. The flowability was fairly satisfactory in the moisture range employed, while the shatter index values were low. The mixture rammed hard in the specimen tube. The surfaces of the test pieces were friable (Table 99).

In Mixture 2, in addition to 5 per cent Bihar bentonite, 2 per cent dextrine

TABLE 98—MADRAS SILICA SAND: CHEMICAL ANALYSIS

CHEMICAL CONSTITUENT

SiO_2 , %	97.10
Al_2O_3 , %	1.15
Fe_2O_3 , %	0.42
TiO_2 , %	0.21
CaO , %	0.18
MgO , %	0.15
$\text{Na}_2\text{O} + \text{K}_2\text{O}$, %	0.82
Loss on ignition, %	0.12

TABLE 99—MADRAS SILICA SAND BONDED WITH 5% BIHAR BENTONITE: HIGH TEMPERATURE CHARACTERISTICS

(Initial vol. of test pieces, 6.284 cu. in. ; soaking period, 1.5 hr)

FIRING TEMP. °C.	VOL. AFTER FIRING cu. in.	CHARACTERISTICS OF TEST PIECES AFTER FIRING	ULTIMATE CRUSHING STRENGTH lb./sq. in.
1350	6.735	White spots in a pale yellowish brown matrix; sand grains loosely adhered at places and fell off when rubbed; slight cracks at surfaces, mottled texture, dull brick sound when struck	79.0
1450	6.787	More dense-white spots in a pale brown matrix; grains more adherent; signs of frittling, mottled texture on surfaces; low metallic sound when struck	254.7
1550	7.683*	Dull white; considerable bulging; positive signs of frittling; metallic sound when struck	624.0

* Soaking period, 2 hr

TABLE 100—EFFECT OF BONDING MADRAS SILICA SAND WITH DIFFERENT BINDERS ON ITS MOULDING CHARACTERISTICS

	MIXTURE 1		MIXTURE 2		MIXTURE 3	
	Moisture, %		Moisture, %		Moisture, %	
	2.4	3.4	4.0	2.6	3.4	4.3
Green permeability No.	740	590	570	800	650	220
Green compressive strength, lb./sq. in.	6.6	3.9	2.9	7.1	4.8	4.4
Green shear, lb./sq. in.	1.5	0.9	0.7	2.05	1.35	1.0
Mould hardness No.	83	80	77	80	82	75
Flowability, %	78.5	80	84	68	79.5	77
Shatter index	32.95	24.42	17.14	68.55	50.88	28.65
Dry compressive strength, lb./sq. in.	36	42	49	65	75	246
Dry shear, lb./sq. in.	—	9	12.5	16	18	—
Bulk density after compression, g./cc.	1.553	1.603	1.621	1.553	1.573	1.767

TABLE 101—MADRAS SILICA SAND: AIR SETTING PROPERTIES

[Mixture composition: Bihar bentonite, 5; and dextrine, 2 per cent; standard test pieces (2 in. × 2 in.) rammed by 3 blows were exposed to laboratory atmosphere]

EXPOSURE PERIOD hr	CRUSHING STRENGTH lb./sq. in.
0	5.1
$\frac{1}{2}$	7.9
1	9.7
2	11.6
3	13.7
4	16.5
24	56.0

was added so as to improve dry strength and shatter index values. The result was satisfactory. Dry strength up to 75 lb./sq. in. could be attained at 3.4 per cent moisture; the maximum value for shatter index obtained was 68.55 at 2.5 per cent moisture. However, the flowability of the mixture was slightly lower than in the case of Mixture 1.

The setting properties of Mixture 2 were studied by exposing rammed test pieces to the laboratory atmosphere and then determining the compressive strength at regular intervals of exposure. The results are presented in Table 101. It is evident that the green strength of the test pieces increased twofold after 2 hr exposure and ten-fold after 24 hr exposure.

Mixture 3 was prepared specifically with the requirements for cores in view. The binder composition employed was: silica flour, 13.4; wheat flour, 1; and linseed oil, 1 per cent. The moulding characteristics of the sand mixture are shown in Table 100. It is characterized by exceptionally high dry strength (246 lb./sq. in.). However, the rammed test pieces were found to have friable surfaces.

Standard steel blocks cast in moulds of the three mixtures had rough surfaces, presumably due to the coarse grain size of the base sand.

Conclusion. While the sand is suitable for medium and heavy steel castings, both in the green and dry states, a more finer grade might be required for light castings. For reducing the surface friability of the sand mixtures a suitable surface coating or washing is necessary.

Hyderabad Sand

The sample of silica sand obtained through Messrs Hargovindas Shivalal & Co., Bombay, on behalf of Messrs Mukand Iron & Steel Works Ltd,

Bombay was collected from Umdanagar, near Hyderabad. The deposits are in the form of quartz veins (granite or gneiss) outcropping in a length of 300 ft and a width of 100 ft. The rock is crushed, calcined, if necessary, powdered and screened before use. Microscopic examination of the washed sand grains showed them to be mostly subangular in shape.

The size grading and fineness characteristics of the sand are shown in Tables 102(a) & 102(b) and Fig. 24.

TABLE 102(a)—HYDERABAD SILICA SAND: SIZE GRADING

U.S. SIEVE EQUIVALENT No.	% RETAINED	
	As-received	After washing
6	Nil	Nil
12	Nil	0.10
20	2.4	2.02
30	4.4	4.42
40	12.7	13.20
50	27.8	26.64
70	27.7	25.98
100	13.5	13.56
140	5.8	6.24
200	3.9	2.20
270	0.6	0.96
Pan	1.0	1.50

TABLE 102(b)—HYDERABAD SILICA SAND: FINENESS CHARACTERISTICS

	AS-RECEIVED	AFTER WASHING
Clay, %	—	3.0
Clay class	—	C
Grain fineness No.	54.9	49.1
Grain class	5	6
Max. retention on 40, 50, 100 and 140 mesh sieves, %	81.7	79.38
Fines, %	5.5	4.66

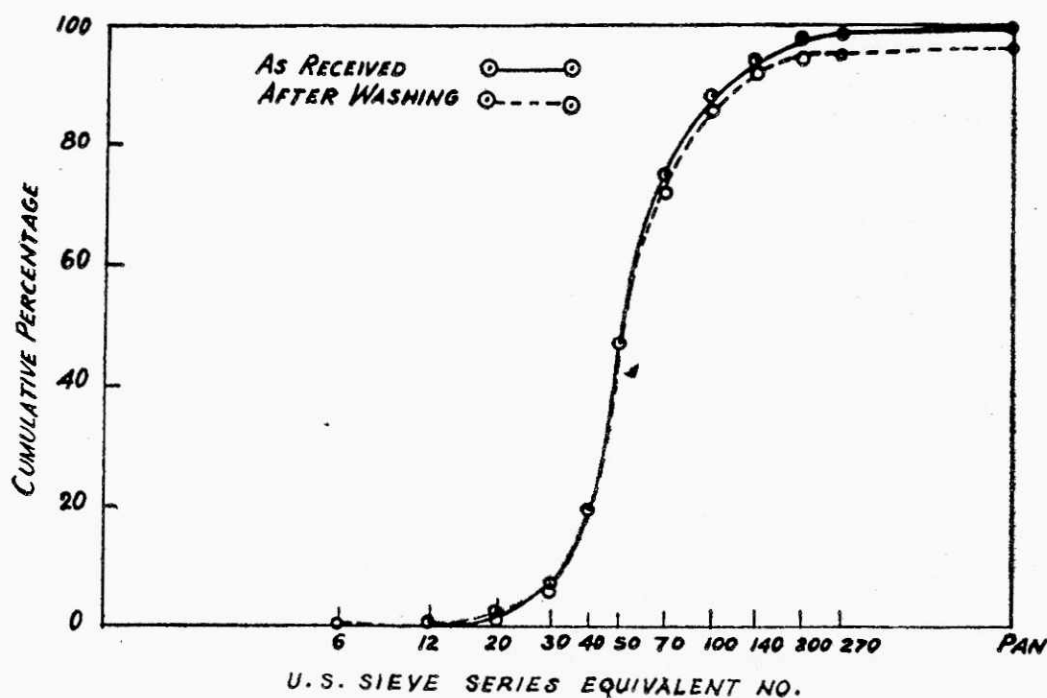


FIG. 24—HYDERABAD SILICA SAND: CUMULATIVE GRADING CURVES

TABLE 103—HYDERABAD SILICA SAND: CHEMICAL ANALYSIS

CHEMICAL CONSTITUENT	AS-RECEIVED	AFTER WASHING
SiO ₂ , %	97.48	98.6
Al ₂ O ₃ , %	1.08	0.60
Fe ₂ O ₃ , %	0.40	0.08
TiO ₂ , %	0.04	Trace
CaO, %	0.30	0.24
MgO, %	0.30	Trace
Na ₂ O, %	0.01	0.01
K ₂ O, %	0.04	0.05
Loss on ignition, %	0.42	0.18

Petrological examination of the sand showed it to consist mostly of quartz, coated with limonite; feldspar and ilmenite were present in small quantities. The results of chemical analysis are shown in Table 103.

The raw sand showed fairly high refractoriness, the fusion point being above 1680°C., corresponding to Orton Cone 31–32. The sintering range of the sample was found to be appreciably high (1400–1450°C.).

TABLE 104—HYDERABAD SILICA SAND BONDED WITH 5% BIHAR BENTONITE: MOULDING CHARACTERISTICS AT DIFFERENT MOISTURE CONTENTS

	MOISTURE, %				
	1.2	2.0	2.8	3.8	4.6
Green permeability No.	165	170	170	160	155
Green compressive strength, lb./sq. in.	9.8	6.8	5.5	4.3	3.0
Green shear, lb./sq. in.	2.7	1.5	1.0	1.8	0.7
Mould hardness No.	86	79	77	73	69
Flowability, %	80	79	78	76	75
Shatter index	34	21	14	11	6
Dry compressive strength, lb./sq. in.	19	30	47	57	65
Dry shear, lb./sq. in.	5.5	8.5	10.0	13.5	16.0
Bulk density after compression, g./cc.	1.476	1.495	1.524	1.553	1.592

On bonding with Bihar bentonite to the extent of 5 per cent, the sand showed fairly steady permeability values in the moisture range 1.2–4.6 per cent, the maximum value (170) being obtained at 2 and 2.8 per cent moisture. Green compressive strength was maximum (9.8 lb./sq. in.) at 1.2 per cent moisture. Dry compressive strength increased steadily from 19 lb./sq. in. at 1.2 per cent moisture to 65 lb./sq. in. at 4.6 per cent moisture. The sand rammed hard in the specimen tube, the maximum hardness being 86 at 1.2 per cent moisture. The flowability (75.80) was satisfactory (Table 104).

The mixture obtained by bonding the sand with Bihar bentonite (5 per cent) possessed the requisite moulding properties for use in steel and iron casting. Test blocks of both iron and steel prepared in both green and dry sand moulds possessed adequate surface smoothness with no signs of 'burning on'. The moulds stripped clear off the specimens easily.

Conclusion. Green and dry moulds prepared from the bonded sand are quite suitable for casting of iron and steel.

Vengurla Silica Sand

This sand sample supplied by *Messrs Mukand Iron & Steel Works Ltd*, Bombay was obtained from Vengurla in Malvan, and Kudal taluks of Ratnagiri district (Bombay). The thickly consolidated massive rocks belonging to coastal Tertiary deposits are quarried by open cast method and are ground by manual labour to the requisite grain size.

The sand grade was found to be mostly medium coarse, the sand grains being distributed over a wide range of sieves. Microscopic examination of the washed sand grains showed them to be compound grains, those belonging to the finer mesh fractions being mostly angular to subangular in shape [Tables 105(a) & 105(b) and Fig. 25].

TABLE 105(a)—VENGURLA SILICA SAND: SIZE GRADING

U.S. SIEVE EQUIVALENT No.	% RETAINED		
	As-received	After washing	After six heating and cooling cycles at 900°C.
6	Nil	Nil	Nil
12	3.0	2.72	1.30
20	16.5	14.56	10.64
30	13.8	16.10	13.10
40	17.3	18.20	17.10
50	19.2	19.34	21.70
70	15.7	14.60	18.62
100	7.7	7.48	10.60
140	3.7	3.48	4.90
200	1.2	1.20	1.40
270	0.5	0.66	0.30
Pan	1.0	0.64	0.28

TABLE 105(b)—VENGURLA SILICA SAND: FINENESS CHARACTERISTICS

	AS-RECEIVED	AFTER WASHING	AFTER SIX HEATING AND COOLING CYCLES AT 900°C.
Clay, %	—	1.0	—
Clay class	—	B	—
Grain fineness No.	41.2	39.1	85.2
Grain class	6	7	4
Max. retention on 30, 40, 50 and 70 mesh sieves, %	82.5	82.8	81.16
Fines, %	2.7	2.5	1.98

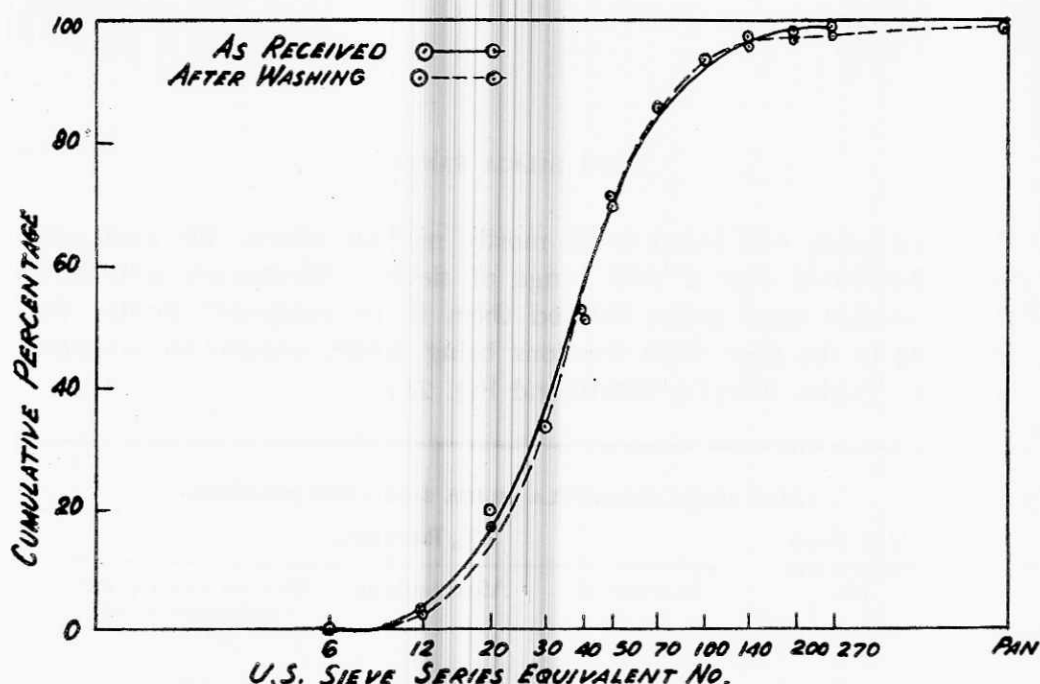


FIG. 25—VENGURLA SAND: CUMULATIVE GRADING CURVES

In view of the presence of composite grains in the sample, it was repeatedly heated to 900°C . and cooled to room temperature to see if breaking up of composite grains could be effected as a result of phase transformation in quartz. Size grading of the sand subjected to six heating and cooling cycles is shown in Table 105(a). Definite break-up of the coarser grains is indicated by the results.

Surface finish of test blocks of steel cast in moulds of sand mixture containing 5 per cent Bihar bentonite was fairly satisfactory and no signs of 'burning on' of the sand were observed, both in the case of green and dry moulds.

Petrological examination of the sand showed the sand grains to be coated with limonite. Eighty-eight per cent of the grains were identified as quartz and 10 per cent as feldspar; muscovite and kyanite were present in traces. The results of chemical analysis are shown in Table 106. On washing, the silica content rose from 97.04 to 98.04 per cent.

Refractoriness of the sand was found to be fairly satisfactory, the fusion temperature being above 1650°C ., corresponding to Orton Cone 30.

The approximate sintering range of the sand as determined by Methods A and B was found to be $1350\text{--}1450^{\circ}\text{C}$. and $1400\text{--}1450^{\circ}\text{C}$. respectively.

On bonding with Bihar bentonite (5 per cent), the sand showed maximum green permeability (255) at 2.9 per cent moisture content. The green compressive strength was maximum (5.9 lb./sq. in.) at 1.4 per cent moisture

level. The flowability was fairly satisfactory in the entire moisture range (1.4–4.6 per cent), while the mould hardness gradually fell from 84 to 65 with increase in moisture content (Table 107).

Conclusion. At the moisture range, 1.5–3.0 per cent, the sand can be used for green sand moulding. However, addition of auxiliary binders like dextrine along with bentonite is necessary to increase the strength to the desired level

TABLE 106—VENGURLA SAND: CHEMICAL ANALYSIS

CHEMICAL CONSTITUENT	AS-RECEIVED	AFTER WASHING
SiO ₂ , %	97.04	96.04
Al ₂ O ₃ , %	1.72	1.00
Fe ₂ O ₃ , %	0.40	0.40
TiO ₂ , %	0.04	0.04
CaO, %	0.42	0.42
MgO, %	0.25	0.16
Na ₂ O, %	0.01	0.01
K ₂ O, %	0.04	0.04
Loss on ignition, %	0.40	0.32

TABLE 107—VENGURLA SAND BONDED WITH 5% BIHAR BENTONITE: MOULDING CHARACTERISTICS AT DIFFERENT MOISTURE CONTENTS

	MOISTURE, %				
	1.4	2.0	2.9	3.6	4.6
Green permeability No.	175	210	255	200	210
Green compressive strength, lb./sq. in.	5.9	4.9	3.6	2.5	2.0
Green shear, lb./sq. in.	1.5	1.2	1.0	0.7	0.4
Mould hardness No.	84	79	75	68	65
Flowability, %	81	80	79	79	78
Dry compressive strength, lb./sq. in.	8.5	22	38	49	59
Dry shear, lb./sq. in.	5.5	6.0	10.5	16.0	21.0
Bulk density after compression, g./cc.	1.476	1.505	1.524	1.544	1.573

so as to make it suitable for green and dry sand moulding for light and medium steel castings. Since disintegration of the composite grains after a few runs increases the percentage of fines in the sand it is necessary to investigate the performance of the sand under actual plant conditions.

Ratnagiri Silica Sand

The sand sample was obtained through *Messrs Premier Automobiles Ltd*, Bombay for investigation of its moulding characteristics and suitability for casting automobile components. Deposits of this sand occur in Malvan and Kudal taluks in the Ratnagiri district of Bombay State. As received, the sample was pale brown in colour. The sand grains were mostly of medium grade. The size grading and fineness characteristics of the sand are shown in Tables 108(a) & 108(b) and Fig. 26.

Petrological examination showed that the sample contains mostly quartz; heavy minerals constituting about 5 per cent of the sand, were limonite, hematite and rutile. Feldspar was present to the extent of 3 per cent.

Microscopic examination of the washed sand grains showed them to be mostly subangular to rounded in shape. Some of the grains were coated with limonite. Results of chemical analysis of the raw and washed sand are shown in Table 109.

The sand as-received showed satisfactory refractoriness, the fusion point being 1700°C., corresponding to Orton Cone 32.

TABLE 108(a)—RATNAGIRI SAND: SIZE GRADING

U.S. SIEVE EQUIVALENT No.	% RETAINED	
	As-received	After washing
6	Nil	Nil
12	0.10	Nil
20	3.25	2.8
30	13.67	14.0
40	30.34	28.5
50	27.25	26.2
70	15.53	15.0
100	7.74	6.2
140	2.15	2.8
200	0.66	1.2
270	0.25	0.50
Pan	0.18	0.60

TABLE 108(b)—RATNAGIRI SAND: FINENESS CHARACTERISTICS

	AS-RECEIVED	AFTER WASHING
Clay, %	—	0.7
Clay class	—	B
Grain fineness No.	40.37	42.19
Grain class No.	6	6
Max. retention on 30, 40, 50 and 70 mesh sieves, %	86.79	83.7
Fines, %	1.09	2.30

TABLE 109—RATNAGIRI SAND: CHEMICAL ANALYSIS

CHEMICAL CONSTITUENT	AS-RECEIVED	AFTER WASHING
	%	%
SiO ₂ , %	96.77	96.4
Fe ₂ O ₃ , %	0.75	0.72
Al ₂ O ₃ , %	2.3	0.74
TiO ₂ , %	Trace	Trace
CaO, %	0.65	1.72
MgO, %	Trace	Trace
Na ₂ O, %	0.05	0.05
K ₂ O, %	0.03	0.04
Loss on ignition, %	0.47	0.18

Standard (2 in. × 2 in.) test pieces fired at different temperatures ranging from 1150 to 1550°C. showed a slight overall increase in volume (Table 110). Sintering of the sand grains took place in the temperature range 1450–1500°C.

Moulding characteristics of mixtures of the sand with different binders are shown in Table 111.

Mixture 1 prepared with the addition of 5 per cent Bihar bentonite showed a very narrow working moisture range. Maximum green permeability (375) was obtained at 1.9 per cent moisture content. Green compressive strength was poor, the maximum value being 5.4 lb./sq. in. at 1.2 per cent moisture. The dry strength and shatter index were also poor, maximum values

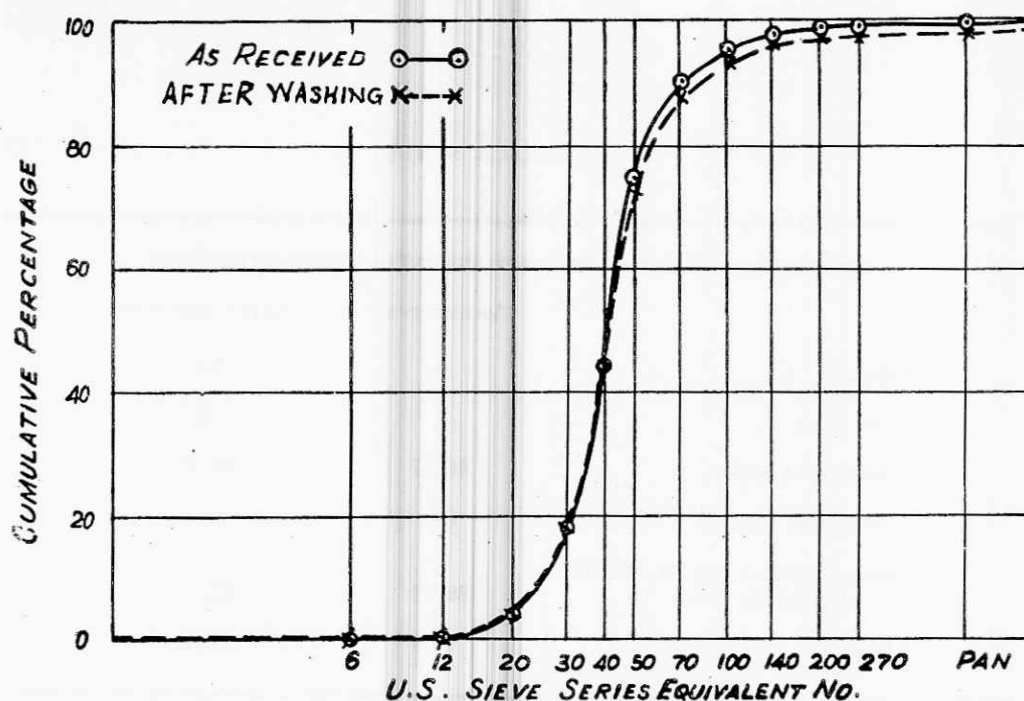


FIG. 26—RATNAGIRI MEDIUM SILICA SAND: CUMULATIVE GRADING CURVES

TABLE 110—RATNAGIRI SAND BONDED WITH 5% BIHAR BENTONITE: HIGH TEMPERATURE CHARACTERISTICS

(Soaking period, 1.5 hr)

FIRING TEMP. °C.	CHARACTERISTICS OF TEST PIECES AFTER FIRING
1150	Light orange colour; surface highly friable; test pieces collapsed on cooling to room temperature
1250	do.
1350	do.
1450	Yellowish brown colour, open texture; dull sound when struck
1550	Hard and compact mass; dull-sound when struck

being 44.6 lb./sq. in. and 24 at 2.6 and 1.9 per cent moisture content respectively. Flowability was fairly satisfactory. For improving the green and dry strengths, 2 per cent dextrine was incorporated in addition to bentonite (Mixture 2). Considerable increase in dry strength was noticed, the maximum value obtained being 224 lb./sq. in. at 4 per cent moisture content. There was also an appreciable increase in shatter index; the maximum value was 56 at 1.3 per cent moisture content. However, there was no appreciable increase in green strength.

TABLE III—EFFECT OF BONDING RATNAGIRI SAND WITH DIFFERENT BINDERS ON ITS MOULDING CHARACTERISTICS

	Mixture 1 Moisture, %			Mixture 2 Moisture, %		
	1.2	1.9	2.6	1.3	2.2	4.6
Green permeability No.	345	375	305	415	355	249
Green compressive strength, lb./sq. in.	5.4	4.6	2.5	6.06	6.5	3.2
Green shear, lb./sq. in.	1.25	1.1	0.7	1.55	1.90	1.00
Mould hardness No.	77	76	69	83	79	69
Flowability, %	80	76	76	76	77	73
Shatter index	22	24	17	56	50	35
Dry compressive strength, lb./sq. in.	26.5	32.5	44.6	41.5	196.7	224.0
Dry shear, lb./sq. in.	6	9	11.4	12.6	29.0	53.9
Bulk density after compression, g./cc.	1.535	1.555	1.575	1.146	1.162	1.261

Test blocks of iron and steel cast in moulds made from Mixtures 1 and 2 were found to possess smooth surfaces.

Conclusion. The high permeability and low green strength values of the bonded sand mixtures may lead to metal penetration. In order to overcome it incorporation of silica flour to the extent of 5–10 per cent in addition to bentonite and dextrine is recommended for preparing light and medium castings of steel.

Ratnagiri Snow White Silica Sand

The sand sample was obtained through *Messrs Premier Automobiles Ltd*, Bombay for determining its suitability for casting grey iron and steel automobile components. The sand deposits occur in the Malvan and Kudal taluks in the Ratnagiri district of Bombay State.

As received, the sand was snow white in colour. The sand grains were mostly of 'medium' grade and subangular to rounded in shape. Size grading and fineness characteristics of the sand are shown in Tables 112(a) & 112(b) and Fig. 27.

Petrological examination of the raw sand showed it to consist mostly of quartz (98 per cent) and feldspar (1.3 per cent); iron oxide and biotite were present in traces. The results of chemical analysis are presented in Table 113.

TABLE 112(a)—SNOW WHITE SILICA SAND: SIZE GRADING

U. S. SIEVE EQUIVALENT No.	% RETAINED	
	As-received	After washing
6	Nil	Nil
12	Nil	Nil
20	0.22	0.20
30	0.70	0.42
40	24.40	15.00
50	55.60	54.00
70	14.20	20.04
100	3.30	6.02
140	0.80	2.20
200	0.18	0.76
270	0.11	0.60
Pan	0.28	0.32

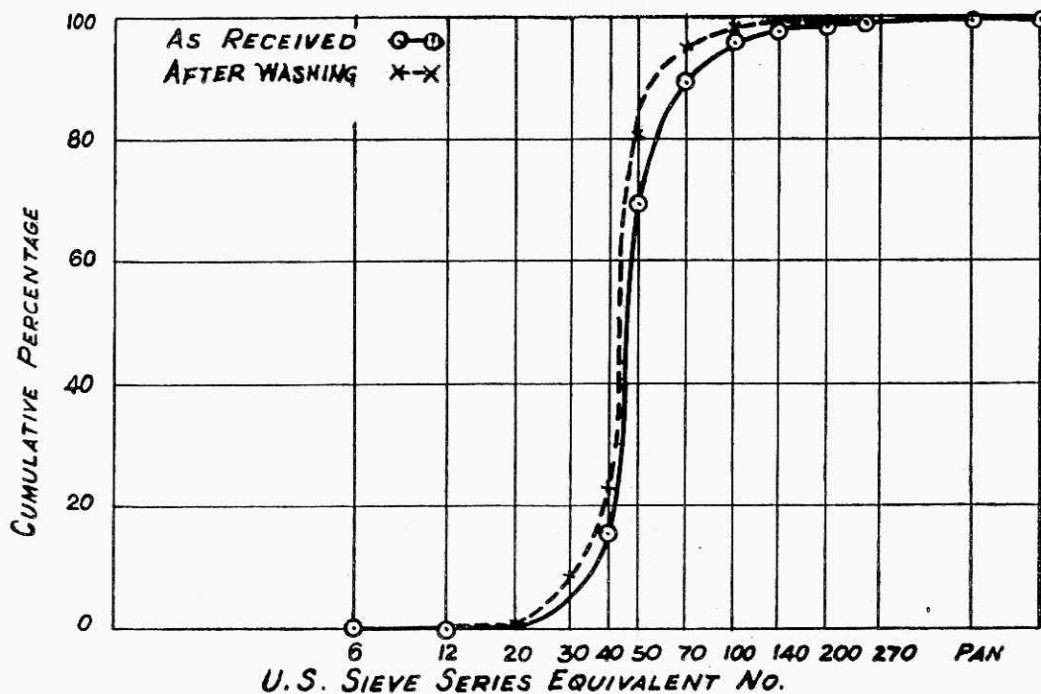


FIG. 27—SNOW WHITE SILICA SAND: CUMULATIVE GRADING CURVES

TABLE 112(b)—SNOW WHITE SILICA SAND FINENESS CHARACTERISTICS

	AS-RECEIVED	AFTER WASHING
Clay, %	—	0.54
Clay class	—	A
Grain fineness No.	41.3	45.9
Max. retention on 40, 50 and 70 mesh sieves, %	94.2	89.4
Fines, %	0.57	1.68

From high temperature tests, the sintering of sand grains was found to take place in the range 1450–1500°C. (Table 114). Refractoriness of the sand was fairly high, the softening point being 1700°C., corresponding to Orton Cone 32.

For investigating the moulding characteristics of the sand, it was bonded with clay and organic binders. Mixture 1, prepared by using Bihar bentonite (5 per cent) alone, showed high and constant values of permeability throughout the moisture range employed, the maximum value being 375 at 2.8 per cent moisture content. Green strength was maximum (7.8 lb./sq. in.) at 1.1 per cent moisture content, but eventually dropped to 1.3 lb./sq. in. at

TABLE 113—SNOW WHITE SILICA SAND: CHEMICAL ANALYSIS

CHEMICAL CONSTITUENT	AS-RECEIVED %	AFTER WASHING %
SiO ₂ , %	96.46	96.4
Al ₂ O ₃ , %	0.93	1.09
Fe ₂ O ₃ , %	0.06	0.06
TiO ₂ , %	Nil	Nil
CaO, %	0.21	0.24
MgO, %	0.71	1.03
Na ₂ O+K ₂ O, %	1.12	0.96
Loss on ignition, %	0.12	0.10

TABLE 114—SNOW WHITE SILICA BONDED WITH 5% BIHAR BENTONITE: HIGH TEMPERATURE CHARACTERISTICS

(Soaking time, 1.5 hr)

FIRING TEMP. °C.	CHARACTERISTICS OF TEST PIECES AFTER FIRING
1250	Yellow colour; surfaces highly friable; collapsed on cooling to room temperature
1350	do.
1450	do.
1550	Yellowish white colour; hard and compact mass; metallic sound when tapped with hand

4.4 per cent moisture. Flowability of the mixture was fairly satisfactory and remained steady in the moisture range 1.1–4.4 per cent. There was a wide variation in the mould hardness, the maximum and minimum values being 83 and 45 at 1.1 and 4.4 per cent moisture contents respectively. Maximum dry strength was 61 lb./sq. in. at 4.4 per cent moisture (Table 115).

In the preparation of Mixture 2, in addition to Bihar bentonite (5 per cent), dextrine (2 per cent) was employed. A remarkable increase in green and dry strengths was observed. Maximum dry strength (153 lb./sq. in.) was obtained at 4.5 per cent moisture. Green strength was more or less the same as in the case of Mixture 1, the maximum value being 7.7 lb./sq. in. at 1.2 per cent moisture content (Table 116).

For further enhancing the green and dry strengths, the addition of coal dust was tried. Mixture 3 containing Bihar bentonite (5 per cent), dextrine (2 per cent) and coal dust (2 per cent) showed maximum dry strength (433 lb./sq. in.) at 4.6 per cent moisture content. Permeability values were still fairly high, the maximum value of 405 being recorded at 3.5 per cent moisture content (Table 117).

TABLE 115—SNOW WHITE SILICA SAND BONDED WITH 5% BIHAR BENTONITE: MOULDING CHARACTERISTICS AT DIFFERENT MOISTURE CONTENTS

	MOISTURE, %				
	1.1	2.2	2.8	3.7	4.4
Green permeability No.	325	345	375	365	355
Green compressive strength, lb./sq. in.	7.8	5.2	3.1	2.03	1.3
Green shear, lb./sq. in.	1.5	1.3	0.7	0.53	0.35
Mould hardness No.	83.0	78.0	63.0	66	45
Flowability, %	80.5	80	80.5	81.5	81.3
Dry compressive strength, lb./sq. in.	20.6	27	33	44.5	61
Dry shear, lb./sq. in.	4.5	6.25	8.5	15.5	20.6
Bull density after compression, g./cc.	1.475	1.495	1.505	1.524	1.554

TABLE 116—BONDED SNOW WHITE SILICA SAND (MIXTURE 2): MOULDING CHARACTERISTICS AT DIFFERENT MOISTURE CONTENTS

	MOISTURE, %				
	1.2	2.3	3.1	3.9	4.5
Green permeability No.	480	455	410	365	355
Green compressive strength, lb./sq. in.	7.7	5.3	4.35	2.3	1.06
Green shear, lb./sq. in.	2.11	1.5	1.2	0.85	0.45
Mould hardness No.	82	78	73	70	48
Flowability, %	75.5	73.5	76.0	77.5	78.3
Dry compressive strength, lb./sq. in.	27	54.5	90.8	135	153
Dry shear, lb./sq. in.	5.8	14	26.6	36.8	46.3
Bulk density after compression, g./cc.	1.408	1.447	1.476	1.524	1.554

It is evident that, in general, Mixture 3 could be worked in a wider moisture range, viz. 2-5 per cent, while possessing optimum combination of strength and permeability.

For evaluating the suitability of this sand for making cores, silica flour was added. Of the two compositions tried, Mixture 4 possessed superior green and dry strength values as compared to Mixture 5 (Table 118). Permeability was not impaired by the addition of silica flour to the extent of 13-15 per cent.

TABLE 117—BONDED SNOW WHITE SILICA (MIXTURE 3): MOULDING CHARACTERISTICS AT DIFFERENT MOISTURE CONTENTS

	MOISTURE, %				
	1.2	2.0	2.7	3.5	4.6
Green permeability No.	315	345	390	405	365
Green compressive strength, lb./sq. in.	8.5	7.5	4.5	4.3	4.1
Green shear, lb./sq.in.	0.45	0.35	0.33	0.26	0.20
Mould hardness, No.	47	46	40	32	32
Flowability, %	83.5	84	83.3	85.5	84.6
Dry compressive strength, lb./sq. in.	105.8	198.3	282	408.3	433
Dry shear, lb./sq. in.	38	102.3	112	176.6	190.6
Bulk density after compression, g./cc.	1.457	1.476	1.505	1.524	1.573

TABLE 118—BONDED SNOW WHITE SILICA (MIXTURES 4 & 5): MOULDING CHARACTERISTICS

	MIXTURE 4*	MIXTURE 5†
Green permeability No.	165	175
Green compressive strength, lb./sq. in.	9.4	3.6
Green shear, lb./sq.in.	2.5	0.9
Mould hardness No.	85	72
Flowability, %	70	80
Dry compressive strength, lb./sq. in.	365	126
Dry shear, lb./sq. in.	65	39
Bulk density after compression, g./cc.	1.613	1.632

* Moisture content, 4% † Moisture content, 3.4%

Test blocks of cast iron and mild steel prepared by employing moulds made from Mixtures 1, 2 and 3 possessed clean surfaces, without any adhering sand layers.

Conclusion. When used in admixture with suitable binders, the sand is quite suitable in cast iron as well as steel foundry practice for the preparation of moulds and cores. Since the sand is a high silica sand, with almost no fines, it might also serve as a base sand for carbon dioxide hardening after addition of a silicate binder.