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Mould characteristics of Azare foundry sand

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Abstract

This paper investigates the mould characteristics of Azare foundry sand such as moisture content, bulk density, flowability, permeability, shatter index, green strengths, dry strengths, hot strengths, thermal linear expansion and refractoriness. A thorough review of literature was made and comparison made between the existing values and values obtained experimentally. Based on the experimental results, Azare foundry sand is essentially very good for non-ferrous foundries. Also, based on the closeness of the characteristics of the Azare foundry sand to the existing characteristics of foundry sand used in cast iron foundries, practical trials carried out on a small cast iron casting (crusher bearing-housing) showed an excellent surface finish.

Introduction

Azare foundry sand is scattered all over Azare in Bauchi State of Nigeria. Foundry sand is rounded fine-grained, red-colour, naturally bonded containing 10.68% of clay. It is a foundry sand with medium size GFN of 58%, low fines (1.21%), low coarse grains of 7.87% and a size distribution of 4-sieves (160 microns) as investigated in [1].

Azare foundry sand has been in use for about 30 years in local foundry industry in Bauchi State and later in Jos and its environs for casting aluminum cooking utensils, radiator fans and other simple shape aluminum products. This had been done without the knowledge of mould determination such as bulk density, flowability, permeability and shatter index tests under green state of the mould. The mechanical strength tests under varying thermal conditions such as green, dry and hot strength (compression and shear and tests for thermal linear expansion and refractoriness of the sand mould at varying elevated temperatures had not been conducted on these foundry sand. The purpose of this paper is to discuss the physical characteristics of Azare foundry sand mould and emphasize its acceptance specification and application in the foundry industries. Also, it seeks to equip the researchers of foundry materials with information for future development and adaptation of Azare foundry sand for use in Nigeria foundries.

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Materials and Methods

Azare foundry sand was collected from Azare in Bauchi State of Nigeria. The sample was dug from its deposit and lumps were broken down by the use of hand rammer into particles.

The equipment used were hand rammer, small hand foundry shovel, sand rammer, flowability meter, speedy moisture tester, anvil, strength testing machine and heat treatment furnace.

Table 1: Experimental Trial table

Experiment	**1**	**2**	**3**	**4**	**5**	**6**
Sand %	**97**	**96**	**95**	**94**	**93**	**92**
Water %	3	4	5	6	7	**8**
Bulk Density, g/cm^3	1.75	1.69	1.70	1.68	1.72	**1.75**

Sand Mould Sample Preparation

Sand mould sample preparation for moisture, bulk density, flowability, permeability, shatter index, green, dry and hot strength test refractoriness and thermal linear expansion tests were made. Experimental trials of the following sand mixture ratio were carried out as shown in Table 1 [2].

The sand water mixture for each of these experiments 1 to 6 were thoroughly mixed with using mixer. These were hand squeezed and the mixture poured into a tube and rammed by impact with three blows of a 6.35kg weight to fall a distance of 5cm one after another. A stripping post was used to remove the specimen for measurement. At the end, experiment 4 met the standard requirement to make cylindrical standard mould specimen of 5cm by 5cm size.

Moisture Content Test

A representative sand mixture sample weighed on the balance of the speedy moisture tester was placed in a special container to which a calibrated scale is attached. 2 spoon measure of powdered calcium carbide was added, covered up and shaken firstly for 2 minutes with the calibrated side of the container turning down, shaken again for 1 minute with the calibrated side of the container turning upward this time.

The moisture content was read directly from a calibrated scale on the instrument.

Flowability Test

The standard specimen in the tube was placed in position in rammer machine for the fourth blow. A weight of 6.35kg of the rammer was used to give the fourth blow of the rammer head on the specimen, which was followed by the fifth blow. The movement that occurred between the fourth and fifth blow was taken from scales of values assigned to this movement with zero travel corresponding to maximum flowability.

Permeability Test

The test specimen of 5cm by 5cm (diameter) size still in specimen tube was fixed on the instrument water provides a mercury soil, and air under constant pressure was caused to flow through a large orifice (1.5mm) into the specimen tube and through the sand mould specimen. The permeability number was read directly on the calibrated scale of the machine.

The Shatter Test

The test specimen of 5cm by 5cm (diameter) size was ejected from its tubular mould by means of a tripping post and allowed to fall through a height of 18m to the steel anvil. The fragments were collected in a 12.5mm mesh sieve. The shatter index being that percentage of the total weight retained on the sieve was determined.

Green Compression Strength Test

The green standard mould specimen 5cm by 5cm (diameter) size was fixed on strength testing machine using compression-holding device. A uniformly increasing load was applied on the specimen until the specimen crushed or squeezed. The point on the scale at which the specimen crushed or squeezed was read as the green compression strength.

Green Shear Strength Test

The procedures in green compression strength was used except that compression strength holding device was changed to shear strength holding device. The point on the scale at which fracture occurred on the specimen was read as the green shear strength.

Dry Compression Strength Test

The test specimen (green) of diameter 5cm (diameter) and length 5cm size was dried in an oven at 110°C for 10 minutes. The specimen was allowed to cool to a temperature of 30°C. The specimen was then mounted on the strength-testing machine with compression holding device. A uniformly increasing load was applied on the specimen until the specimen crushed or squeezed. The point on the scale at which the specimen crushed or squeezed was read as the dry compression strength.

Dry Shear Strength Test

The procedures in dry compression strength were used except that compression strength holding device was changed to shear strength holding device. The point on the scale at which fracture occurred on the specimen was read as dry shear strength.

Hot Compression Strength

The cylindrical test specimens of 5cm by 5cm (diameter) size 10 in number were heated in heat treatment furnace to the following temperatures: 700°C, 800°C, 900°C, 1000°C, 1100°C, 1200°C, 1300°C, 1400°C, 1500°C, and 1550°C respectively and allowed for 2 minutes soaking time per specimen. Each hot specimen was positioned and held on the strength-testing machine with the aid of compression strength holding device one after another. A uniform increasing load was applied on each specimen until the specimen crushed or squeezed. The points on the scale at which each specimen crushed or squeezed were read as hot compression strength respectively.

Hot Shear Strength

The same equipment, materials and procedures were used but with a change of compression strength holding device to shear strength holding device. The points on the scale at which each specimen fractured were read as hot shear strength respectively.

Thermal Expansion Test

Nine cylindrical test specimens of 5cm by 5cm (diameter) size were heated in a heat treatment furnace to the following temperatures: 100°C, 200°C, 300°C, 400°C, 500°C, 600°C, 700°C, 800°C and 900°C respectively. Each of these nine heated specimens was measured with height gauge immediately each was removed from the furnace at the respective temperatures. The thermal linear expansion of each specimen was calculated.

Refractoriness Determination

15 cylindrical test specimens were heated in heat treatment furnace one after another to the following respective temperatures 200°C, 300°C, 400°C, 500°C, 600°C, 700°C, 800°C, 900°C, 1000°C, 1100°C, 200°C, 1300°C, 1400°C, 1500°C and 1550°C for a soaking time of 2 hours. The specimens were observed one after the other for the following signs: cracks, changes in colour, fissures and distortion.

Results and Discussion

Mould Characteristics of Azare Foundry Sand

On the basis of the foundry laboratory and workshop floor tests carried out, the following observations and application results of Azare foundry sand were obtained.

i. **Moisture Content of the Sand Moulding Mixture**

The moisture content of Azare foundry sand is 6.8% as shown in Table 2. This amount of moisture content of naturally clay-bonded sand is acceptable since it is not over 8% as maximum moisture content accepted in naturally clay bonded sand [3]. This implies that the amount of clay (10.76%) mentioned in the introduction with 6.8% of moisture content, will impart to mass of sand a high green strength and high permeability.

ii. **Bulk Density of the Green Sand Mould**

The bulk density of the sand is 1.73g/cm^3 as shown in Table 2. This bulk density is adequate for casting, especially non-ferrous metals [4]. This adequate bulk density is as a result of good compaction with reasons ranging from fine-grain, well spread grain distribution, rounded grains, 10.67% of clay as stated in the introduction to 6.8% of moisture content of Azare foundry sand mixture [5]. This implies that metal penetration into the wall of mould cavity during liquid metal pouring will be minimized.

iii. **Flowability of the Sand**

Azare foundry sand moulding mixture has a flowability of 68% as shown in Table 2. This high flowability should be as a result of rounded grains sand [3]. This value of flowability enhances the sand ability to be compacted to a uniform density easily with less effort.

iv. **Permeability of the Sand**

Azare foundry sand moulding mixture at green state has a high permeability of 88% as shown in Table 2. This high permeability is due to a clay content of 10.67% a low moisture content (6.8%), less dust of 1.21%, well spread grain distribution and rounded-grains of the sand as stated in the introduction. The permeability value is excellent for casting cast iron which requires a permeability between 40% to 120% [5]. Azare foundry sand will allow the escape of vapours and gas from the mould during liquid metal pouring process.

v. **Shatter Index of the Sand**

The shatter index value of Azare foundry sand is 80% as shown in Table 2. This high shatter index value indicates that the sand is tough enough to aid satisfactory lift during pattern withdrawal. The low amount of clay (10.67%) with corresponding low amount of moisture content (6.8%) and low dust (1.21%) was attributed to high value of shatter index.

The shatter index is acceptable in foundry practice since values between 50% to 85% is quoted as representing the mouldable range [6].

vi. **Green Compression Strength**

The green compression strength of Azare foundry sand mould is 4.6N/cm^2 as show in Table 3 and appendix I plate i & ii show the samples. The sand being rounded-grain fine sand with less dust (1.21%), low clay (10.67%) and moisture content (6.8%) contributed immensely to the relatively high green compression strength. This green compression strength falls within the range 3.1N/cm^2 - 4.5N/cm^2 which is acceptable compression strength for non-ferrous castings and it can also be used for small ferrous castings since 4.8N/cm^2 to 12N/cm^2 green compression strength is acceptable for ferrous castings [5]. This implies that the sand will withstand the withdrawal pattern from the sand mould without breakage, resist the turbulent reaction of the liquid metal in the mould, prevents erosion of the mould cavity walls and reduces metal penetration into the mould walls [7].

vii. **Green Shear Strength**

The green shear strength of Azare foundry sand is 1.4N/cm^2 as shown in table 3. Appendix I plate iii shows the samples. This strength may prevent shearing of the mould as molten metal is being poured from the gating system and vapour along with gas escaping from the riser. However, shear strength of 2N/cm^2 is quoted as standard for sand casting [4].

viii. **Dry Compression Strength**

The dry compression strength of Azare foundry sand mould is 8.5N/cm^2 as shown in the Table 3. Appendix I, plates iv and v show the samples. This strength is as a result of good compaction of the sand. This dry strength is adequate in a situation where one day is used in making the moulds and pouring them the next day. This strength is close to an acceptable value of 10 N/cm^2 [5,6].

ix. **Dry Shear Strength**

The dry shear strength of Azare foundry sand mould is 3.7 N/cm^2 as shown in Table 3 and the sample in appendix I, plate vi. The same condition applicable to dry compression strength also exist in dry shear strength only that the acceptable strength should be higher than 2 N/cm^2 [4].

x. **Hot Compression Strength**

The hot compression strength of Azare foundry sand is as shown in Table 4. Figure 1, and appendix I, plates vii – ix show the samples. The strength increases as the temperature increases (though it is non-linear) until at a temperature of 1400°C when the strength started decreasing. This implies that the sand is suitable for metals of pouring temperature up to 1400° C. The sand can only be used ordinarily as core for thin casting of 5mm as the sand hot strength does not reach up to 40N/cm^2 required for standard core [3,4].

xi. **Hot Shear Strength**

The hot shear strength of Azare foundry sand is as shown in table 4 and samples shows in figure 1 and appendix I, plates x – xii. The hot shear strength increases gradually as from 900 $^\circ$ C to 1100 $^\circ$ C and then increases rapidly from 1100 $^\circ$ C to 1300 $^\circ$C and then falls gradually from 1300 $^\circ$C to 1550 $^\circ$ C in a similar way for hot compression strength. The sand can be used naturally as core if the core length is short (low slenderness ratio) [4,9].

xii. **Thermal Linear Expansion**

Azare foundry sand showed a relatively low-uniform thermal linear expansion up to 500 °C. This is shown in Table 5 and figure 2. At 600 °C, there is a sudden increase in thermal linear expansion as the colour of the sand mould becomes reddish as shown in table 5 and figure 2 and Appendix I, plate xiii to xvi. This is because of the presence of red oxide. Between 600°C to 900° C the thermal linear expansion increases gradually as shown in table 5 figure 2 because of uniform distribution of clay and rounded sand grain for strength bond.

The thermal linear expansion at 900°C which is 1.49% can give high resistance to metal penetration, as there will be less cracks on the mould. There will be also good dimensional accuracy for non-ferrous casting. The sand does not meet linear expansion of 0.84% to 1.00% at 900 °C that is suitable for ferrous castings [3,4,7,8].

xiii. **Refractoriness of Azare Foundry Sand Mould**

At 300°C to 500°C Azare foundry sand mould showed no change in colour and the moulds did not crumble as shown in table 6 Appendix I plates xiii – xv. At the temperature of 600 °C a change to reddish colour was observed because of the presence of red oxide as shown in table 6 Appendix I, plate xvi. This change in colour indicates change in phase of the sand mould. At this temperature the mould did not crumble and it was not prone to thermal cracking because of high bulk density of the sand. This observation persisted until 1300 °C as shown in table 6 Appendix I, plates xvi – xxiii. From 1000 °C to 1300 °C, the sand mould became bright reddish and still in compact mass with no fritting of grains as shown in Table 6 Appendix I, plates xx – xxiii. At 1400 °C, slight cracks were observed at the bottom of the mould. At 1500 °C, slight deformation with cracks at the bottom of the mould as indicated in table 6. At 1550 °C slight deformation with pronounced cracks at the bottom of the mould and evidence of burn-on were observed. This is due to clay content in the sand as stated in table 6 and shown in Appendix I, plate xii. These imply that casting at temperature above 1300 °C will have problems of surface finish and dimensional accuracy on cast items [4,10].

Conclusion

From the experimental results, it was discovered that Azare foundry sand requires moisture content of 6.8% to make its mould. This sand mould has a bulk density of 1.73g/cm^3, high flowability of 68%, high permeability of 88% and high shattered index of 80%.

Similarly, a green compression strength of 4.6N/cm^2, green shear strength of 1.4N/cm^2, dry compression and shear strength of 8.5N/cm^2 and 3.7N/cm^2 respectively were observed.

The Azare foundry sand mould is highly refractory. It burns at temperature above 1400°C. It showed a low irregular thermal linear expansion. The thermal linear expansion at 900°C is 1.47%, the sand mould is prone to thermal cracking, spalling or scabbing at temperature above 1300°C.

From the experimental results obtained, Azare foundry sand is very suitable for non-ferrous casting, providing benefits in casting-surface finish freedom defects and high dimensional accuracy. The sand is also suitable for casting small size cast iron castings which practical trials have proved satisfactory as shown in Appendix II plates xxiv and xxv.

For this small size of cast iron castings, excellent good surface is obtained especially where making moulds a day before pouring them the next day (dry state). It allows easy removal of fines from the castings. The sand mould can only serve for small in-built cores and cores for thin section of casting up to 5mm.

Table 2: Some Mould Characteristics of Azare Foundry Sand

Characteristics	**Quantification**
Moisture Content	6.8%
Bulky Density	1.73g/cm^3
Flowability	68%
Permeability	88%
Shatter Index	80%

Table 3: Green and Dry Strength of Sand Mould

Characteristics	**Quantification (N/cm^2)**
Green Compression Strength	4.6
Green Shear Strength	1.4
Dry Compression Strength	8.5
Dry Shear Strength	3.7

Table 4: Hot Compression Strength and Shear Strength of Sand Mould

S/No	Temperature °C	Hot Compression Strength N/Cm^2	Hot Shear Strength N/Cm^2
1	700	9.4	4.2
2	800	12.7	4.4
3	900	17.8	4.6
4	1000	19.7	5.0
5	1100	22.4	5.9
6	1200	26.4	7.2
7	1300	30.2	10.5
8	1400	25.0	8.8
9	1500	24.0	8.0
10	1550	23.5	7.4

Table 5: Thermal linear Expansion of Sand Mould

S/No.	Temperature °C	Thermal Linear Expansion %
1	100	0.10
2	200	0.20
3	300	0.40
4	400	0.68
5	500	0.84
6	600	1.34
7	700	1.40
8	800	1.48
9	900	1.49

Table 6: Refractoriness of Sand Mould

Firing Temperature °C	Characteristics of Test Piece after Firing
200	Does not crumble, no change of colour
300	Does not crumble, no change of colour
400	Does not crumble, no change of colour
500	Does not crumble, no change of colour
600	Does not crumble, reddish colour
700	Does not crumble, reddish colour
800	Does not crumble, reddish colour
900	Does not crumble, reddish colour
1000	Compact mass, not friable, bright red
1100	Compact mass, not friable, bright red
1200	Compact mass, not friable, bright red
1300	No fritting of grains
1400	Crack slight at the bottom
1500	Slight deformation, cracks at the bottom
1550	Slight deformation, cracks at the bottom and burn on

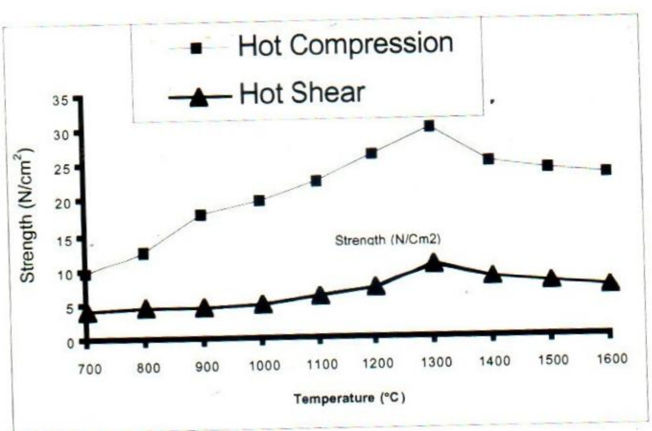


Fig. 1: Hot Compression and Shear Strength of Azare sand mould

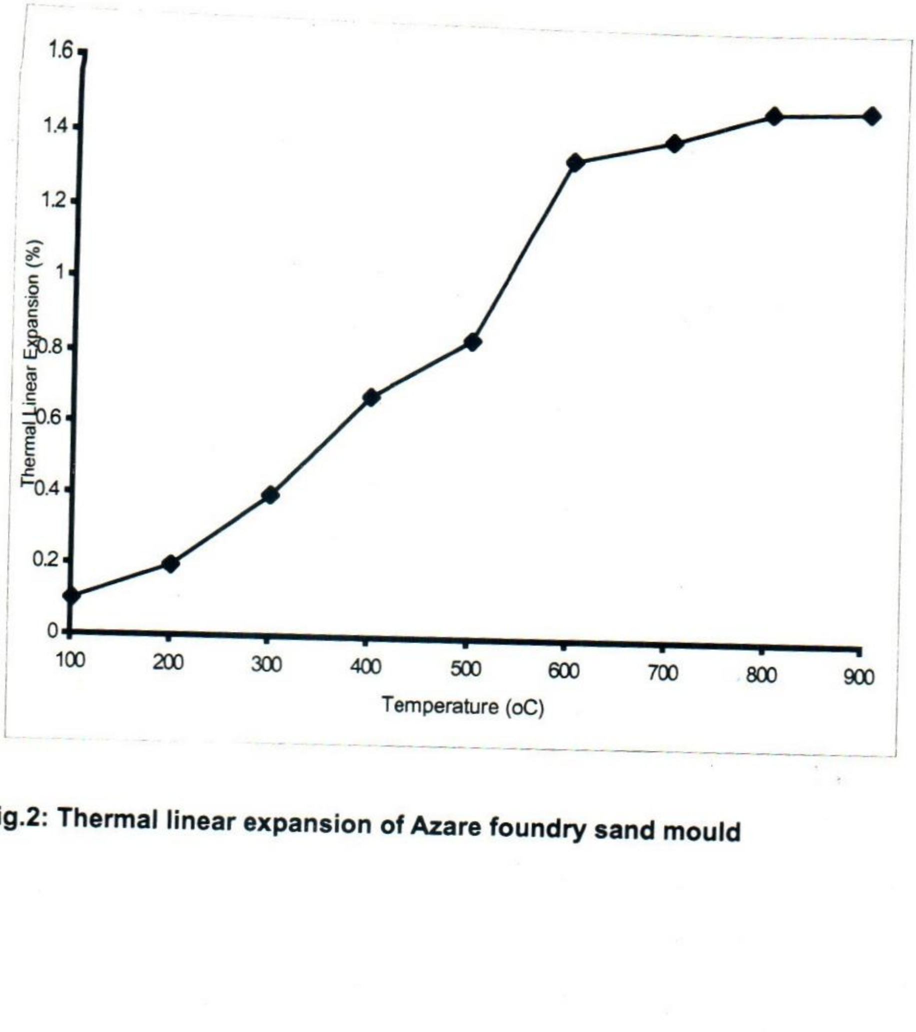


Fig.2: Thermal linear expansion of Azare foundry sand mould

APPENDIX 1: TESTED SPECIMENS OF AZARE FOUNDRY SAND

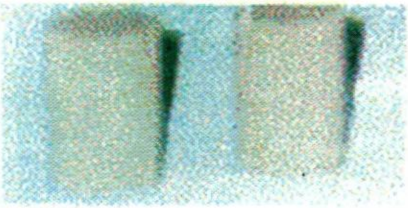


Plate i: Standard gree moulds

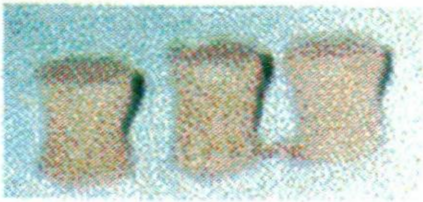


Plate ii: Green compression strength specimens (after compression)

Plate iii: Green shear strength specimens (After shearing)

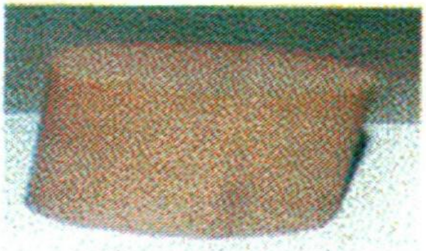


Plate iv: Standard dry mould specimen

Plate v: Dry compression strength specimens (after compression)

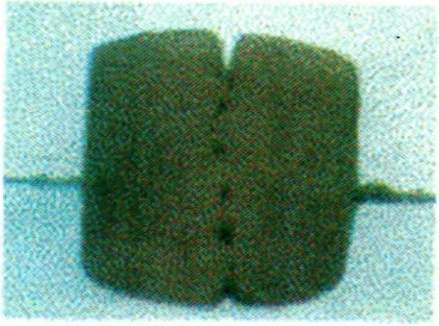


Plate vi: Dry shear strength specimen (after shearing)

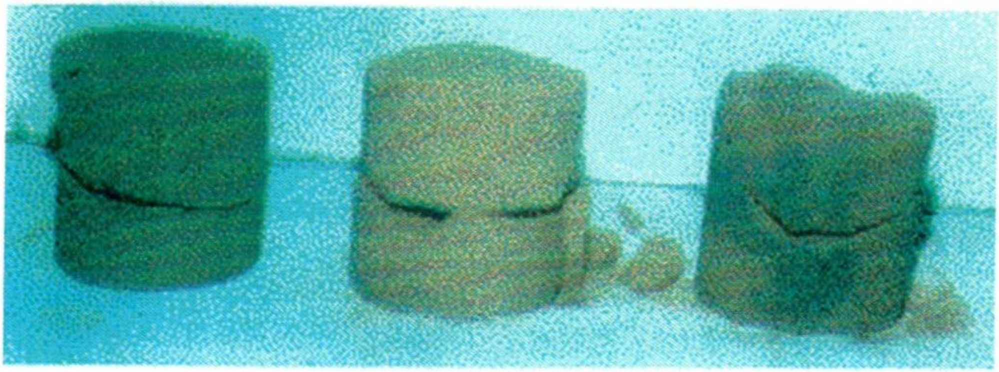
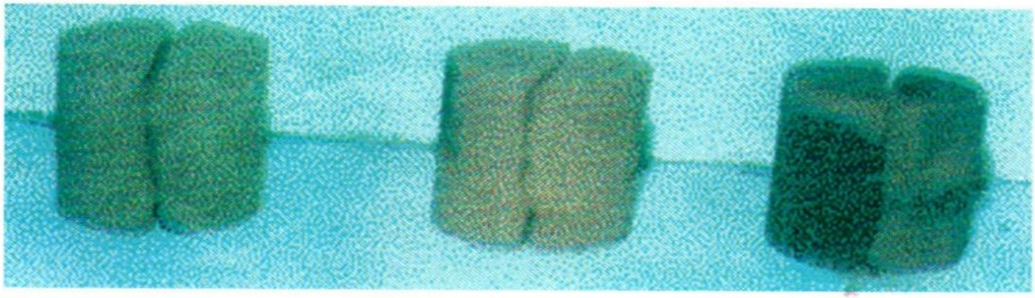


Plate vii: specimen at 300°C (after compression)

Plate viii: Specimen at 600°C (after compression)

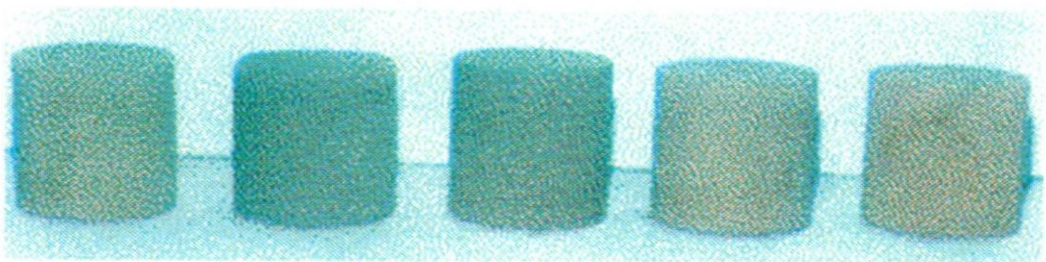
Plate ix: Specimen at 1400°C (after compression)



Platex x: Specimen at 300°C (after shearing)

Platex xi: Specimen at 600°C (after shearing)

Platex xii: Specimen at 1550°C (after shearing)



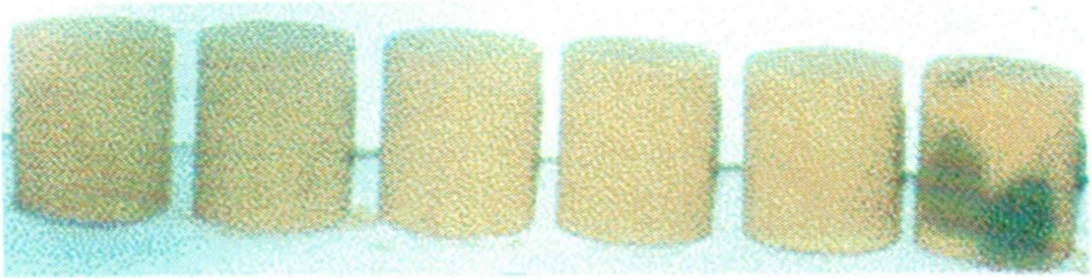
Platex xiii: at 300°C

Platex xiv: at 400°C

Platex xv: at 500°C

Platex xvi: at 600°C

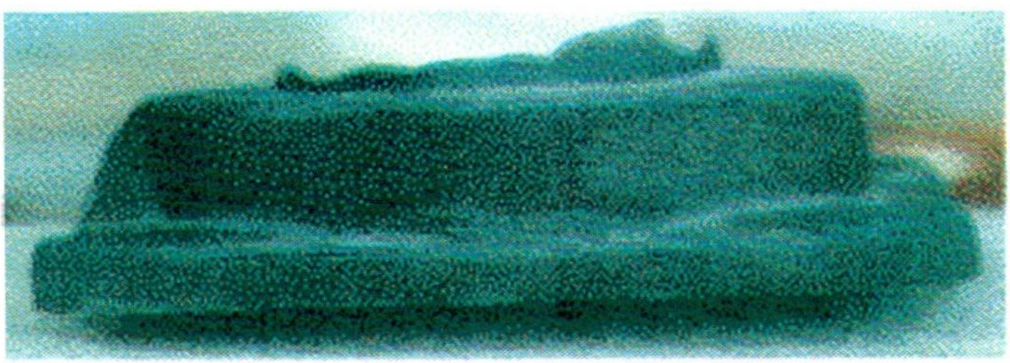
Platex xvii: at 700°C



Platex xviii: at 800°C	Platex xix: at 900°C	Platex xx: at 1000°C	Platex xxi: at 1100°C	Platex xxiii: at 1200°C	Platex xxiii: at 1300°C

APPENDIX 11: CASTING FROM AZARE FOUNDRY SAND

Platex xiv: Crusher bearing - housing casting as recovered from mould



Platex xxv: Crusher bearing – housing casting after cleaning

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