Chapter 3

Manufacturing Controls and Procedure

3.1 Introduction

Approximately 10000 concrete pavers were required for the construction of a bus lane and pedestrian sidewalk. (The wear in these pavers was later measured after six years of traffic). A further 2304 concrete pavers were required for various laboratory tests, including three abrasion tests.

In most research projects the samples required for experimentation are made in a laboratory. However in this investigation the ‘laboratory’ was a concrete block-paving factory situated in Roodepoort. Owing to the number of test samples required, it was more practical to manufacture the blocks in a mass production environment. This also had the advantage of simulating the kind of quality that is produced in cbp factories. To this end the Schlosser plant (see Figure 3.1) was committed to producing 100 mm thick paving blocks on the 12th, 13th, and 14th August 1987.

Special care was taken to ensure that the correct manufacturing controls and procedures were adhered to.

3.2 Good Practice in Cbp Manufacture

In manufacturing cbp there are five areas that call for special attention:

3.2.1 Type of Material

The type of *cement* and cement extender (e.g. OPC, MGBS, Fly Ash, Silica Fume) that is selected and the process used to blend them together affects the strength of the concrete. The other major mix constituent, i.e. the *aggregate*, is also important. Alexander(1991) has shown that even with traditionally accepted aggregates from crushed rock there is a considerable difference in performance, with a variation of 15 MPa in compressive strength being possible between aggregate types. Finally the *water* must be free of any deleterious substances.

3.2.2 Mix Proportions

The ratio of binder:aggregate:water will largely influence the strength and cost of the concrete. In particular the important role of the water in lubricating the mix is not well understood by all manufacturers and this materially reduces the potential strength, or alternatively increases the cost of their pavers, if additional binder must be added to compensate for a mix that is too dry.

3.2.3 Dosing and mixing

Both the sequence in which the respective mix constituents are added to the mixer and the duration of mixing is important if quality-paving blocks are to be made. The aggregates should always go in first, followed by the binder. Only once a uniform colour has been achieved indicating that the cement is evenly blended with the aggregates should the water be added. Further mixing is required after the last of the water has been added to achieve a uniform water content in the mix.

In some factories, the capacity of the mixer (a high cost item) is often inadequate and the mixer operator adds the water too soon in an attempt to keep up with the output of the paving machine. This can result in cement conglomerations and even balling.

3.2.4 Machine settings

The way the machine is adjusted plays a very major role in the production of quality concrete pavers. The author has often seen poor quality machine output completely transformed by making one or two simple adjustments. Such adjustments include the duration of the vibration, especially the ‘pre-vibration’, the pressure exerted by the tamper, the method of filling the mould, the setting of the stabilizer bars etc. These settings will naturally vary depending on the type and make of machine.

3.2.5 Curing and packaging

This is an often-neglected process in the production of cbp. Certain manufactures take care to cover the freshly made blocks with nylon covers etc., and some will even seal them in plastic packs during storage. The importance that curing has on the strength of a concrete surface has been well documented by Sadegzadeh(1984) and others.

In the production of the 100 mm thick interlocking paving blocks (trade name BC100) for this investigation, variables were selected from points 3.2.1 (with the exception of the aggregate) and 3.2.2, while all points in 3.2.3, 3.2.4, and 3.2.5 were kept constant, and consistent with good practice.

3.3 Procedure Followed in the Production of the ‘BC100’ cbp specimens

The production process may be summarised in nine steps as follows:

storage of raw materials
weighing of raw materials
loading of raw materials into mixer
mixing
filling and moulding
initial curing and storage
marking and packaging
storage and final curing
despatch

These steps are illustrated in figure 3.1, a schematic layout of the plant and equipment used in the manufacture of the 100BC cbp.

The production processes will vary from factory to factory depending on the manufacturing systems and type of equipment used at the particular locality, and this has a bearing on the ‘local’ limits selected for the abrasion test (see chapter 15). It is however important that production systems, once optimised, be kept as constant as possible at a given factory in order to minimize variability in quality.

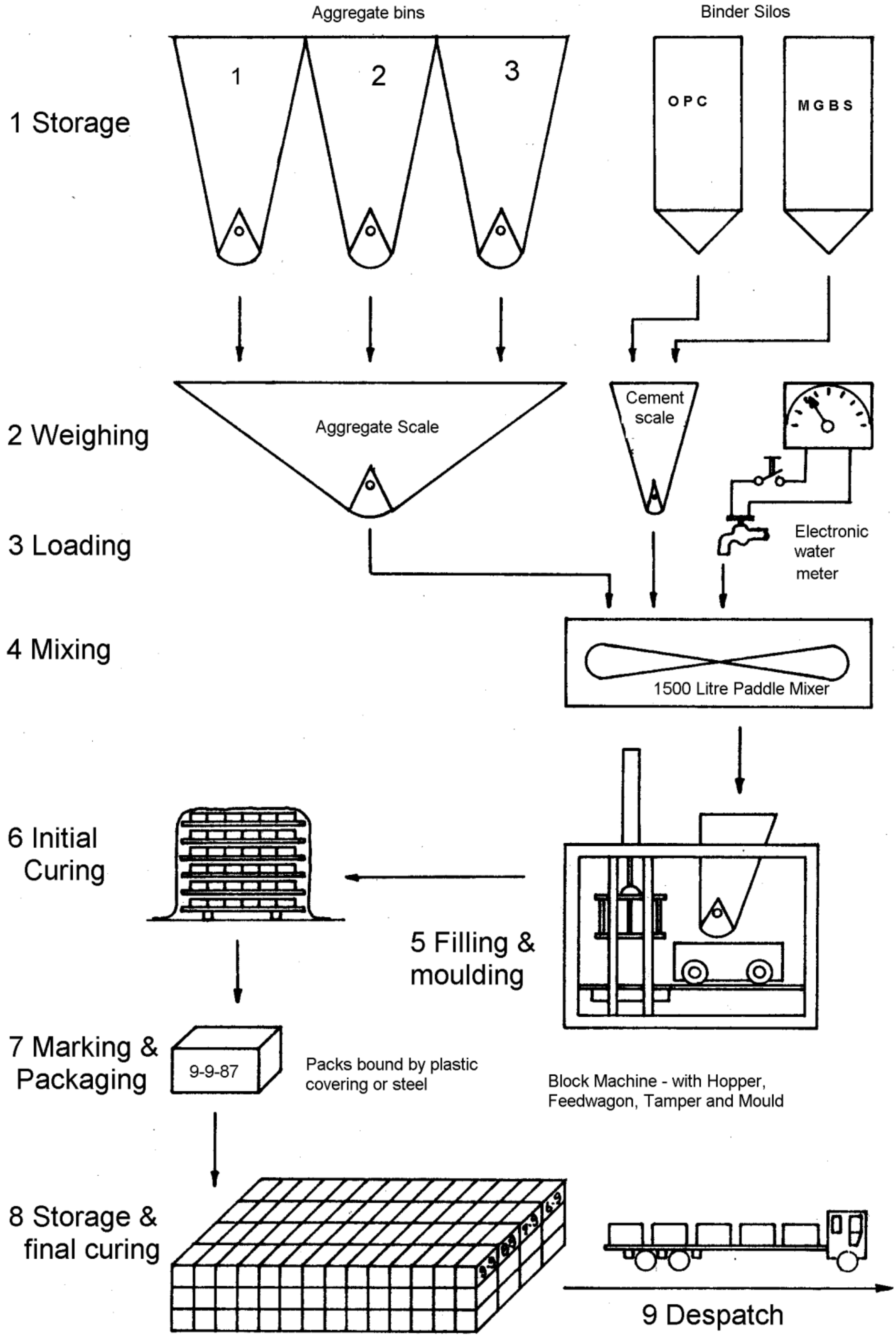

Figure 3.1 Schematic layout of Schlosser paving plant.

3.3.1 Storage of raw materials

Aggregate

A well-graded reef quartzite crusher sand was used as the sole component for the aggregates. Several truckloads from a single batch were blended together by means of a front-end loader to further achieve additional uniformity (see figure 3.2). Two samples were taken and the grading and fineness modulus determined. The results confirmed the uniformity of the sand (see appendix A.1). The sand was stored in aggregate bin number two (see figure 3.3), with no possibility of contamination with other aggregates.

Binders

In order to ensure that the cementitious materials (OPC, MGBS, fly ash, silica fume) were sourced from a single batch, it was necessary for these materials to be supplied in bags. Samples were taken, from which laboratory test reports were later obtained, defining the various physical and chemical characteristics of these materials. (See Appendices A.2, A.3, A.4). On delivery from the suppliers the bags were stored in a weatherproof shed for the short period prior to the tests. Care was taken to prevent any breakage of the bags and no contamination was therefore possible.

3.3.2 Weighing

The aggregate and cement scales are suspended by loadcells. The loadcells were manufactured to a specification allowing a maximum error of 0,05%. The loadcells are connected to a sophisticated computerised device complete with monitor and output signals which control the pneumatically operated aggregate bin doors, motorized cement screws, as well as the pneumatically operated aggregate and cement scale discharge doors. A printout of every mix was also obtained from the device, which confirmed the accuracy of the weighing operation relative to the desired proportioning. Furthermore, as part of the quality control system in the factory, the scales are tested daily by means of adding calibrated mass pieces to the bottom, top, and middle of their respective working ranges.

Since the cementitious materials (OPC, MGBS, fly ash, silica fume) were bagged (to ensure uniformity), no use was made of the cement silo or cement screw. Instead the materials were carefully scooped by hand into the cement scale (see figure 3.4). In order to do this, radio contact was maintained between the control room (where the scale monitor is) and the operators at the scale (see figure 3.5). The aggregate was fed by means of a pneumatically controlled bin door, while the pigments used for colour coding were weighed out by means of a triple beam balance.

3.3.3 Loading

Once the binders, aggregates and pigments had been weighed in their respective scales, the mixer was loaded in the following order:

a. **Sand.** The aggregate scale doors opened allowing the sand to fall onto an inclined conveyor belt feeding the mixer.

b. **Pigment.** The pigment, used purely for purposes of identification was poured onto the aggregate on its way to the mixer. The quantity of pigmentation (various iron oxides) used was of such a small proportion, generally 4 % by mass of cement, or about half of one percent of the mass of the total mix, that it was not expected to impact on the strength characteristics of the blocks. On the contrary, providing excessive amounts are not added, the fine filler effect of the pigment more than makes up for the higher surface area of the combined pigment/cement/aggregate. Research done by Bayer and reported by Buchner(1987) has shown that red, black and brown pigments are only detrimental to strength at dosages above 10% by mass of cement, while the break even point for yellow oxides is 6%. Furthermore, they are chemically inert and do not play any part in the formation of the products of hydration. The iron oxide in the mix may be considered as a small additional quantity of fine aggregate.

c. **Binders.** Once all the aggregate was in the mixer the cement scale door opened and the cementitious materials were gravity fed into the mixer.

3.3.4 Mixing

The 1500 litre paddle mixer operates on the principle of a rotating vertical central shaft to which the arms and paddles are connected. The outside drum is fixed.

Once all the materials were loaded into the mixer, a time of 90 seconds was allowed for dry mixing, to ensure thorough blending. Following this the water programme commenced. Water was dosed by means of sequencing three solenoid-operated valves of size 1 inch, 3/4 inch and 1/2 inch (see figure 3.6). The solenoid valves are controlled by an electronic water meter that continuously monitors the conductivity within the mix and switches the valves accordingly. The repeat accuracy of the unit is ± 1/2 litre. Once the water programme was completed, a further 4½ minutes was allowed for wet mixing, after which the mix was discharged into the hopper of the machine.

Generally this mixing regime would be too slow in a production environment, but it was considered important in this exercise that all the mixes be completely homogenous, to eliminate ‘mixing’ as a variable. For example Buchner(1987) found that 1½ to 2 minutes in a forced circulation mixer was sufficient to allow for a fully homogenous mix without compromising potential compressive strength.

3.3.5 Filling and moulding

The feed-wagon is stationed beneath the hopper and receives a certain proportion of the mix, depending on the duration that the hopper door opens. (The hopper door is actuated by a time controlled hydraulic cylinder). It is important that the feed-wagon has sufficient material to completely fill the mould once it moves to and fro over the mould. On the other hand a feed-wagon that is too full has a slow action, is prone to develop lumps, and the free flow of the material into the mould is generally inhibited.

A short duration of approximately 0,5 seconds of ‘pre-vibration’ assists in the filling operation, and allows a certain degree of compaction to take place in the mould while the feedwagon is stroking to and fro directly above. This pre-vibration is critically important as it will determine the degree of compaction of the material in the compartments of the mould, which in turn has a direct bearing on the eventual height of the blocks.

The final reverse stroke of the feed-wagon serves to evenly strike off the material, leaving the upper surface of the mould just visible. Here again if the feed-wagon was overfilled, it will tend to float on top of the material, leaving progressively more mix on top of the mould as it reverses. This is a common source of height variation in the blocks.

Once the mould has been evenly filled and the feed-wagon is out of the way, the tamper (or press) comes to bear on the face of the blocks, exerting a relatively small pressure on the blocks, of the order of 0,1 MPa.

Compaction is primarily achieved by means of high-energy vibration and the chief function of the tamper shoes is to prevent the mix from jumping out, and also to create a smooth surface. A wooden pallet is pressed down by the mould onto the vibrator table. This table oscillates up and down at a frequency of 2900 rpm. The final vibration duration was kept constant at 10 seconds, (allowing 1 second per cm for the 10 cm high blocks). Note that Komonen(1998) also used a 10 second vibration cycle on his trial pavers, although typically 2 to 4 seconds suffices in Finland, allowing four pallets to be processed per minute.

The exact heights of the blocks were monitored by means of a depth gauge immediately after their ejection from the machine. If necessary a correction was made to the pre-vibration duration (generally up or down by less than 0,2 seconds) to keep the height of the next blocks as close to 10 cm as possible.

3.3.6 Initial curing and storage

Following moulding the wooden pallet carrying the blocks was ejected from the machine onto a rope conveyor (see figure 3.7). At this point each wooden pallet was sprayed with a paint identification marking (see figure 3.9), as it was not practical to paint the wet blocks. The pallets moved along the rope conveyor to an overhead gantry, and were stacked in curing rows. These rows were covered with impervious nylon tarpaulins (as may be seen in figure 3.8) for a period of approximately 72 hours. The tarpaulins served to prevent drying out of the blocks and to a certain extent promoted accelerated curing due to elevated temperatures occurring underneath the covers from the action of the sun combined with heat of hydration.

3.3.7 Marking and packaging

At age 24 hours, the blocks destined for laboratory and site testing were individually sprayed with paint identification markings (see figure 3.10) according to Table 3.1.

With eight different pigment colours and six different paint colours it was possible to achieve 48 different identifiable combinations.

Thereafter the blocks were hand packed into prismatic packs, and enclosed with a double layer of shrink-wrap plastic (see figure 3.11 and 3.13).

Blocks destined for the laboratory were further identified with numbers, from one to eight, indicating a particular position on the production pallet (see figure 3.10 and 3.12). The numbers on the blocks corresponded to the particular laboratory test they would be subjected to. These tests are discussed in chapter 4.

Prior to the sealing operation, the blocks were well drenched with water to facilitate curing.

3.3.8 Storage and final curing

The sealed packs were stored in a separate area to allow for further curing. The plastic packs were marked stating mix design, mix number, date made and destination (see figure 3.13)

3.3.9 Despatch

Eight packs containing the eight mix designs and corresponding six variations in water content were despatched to PCI at approximately 24 days to be tested at age 28-days. The balance were despatched at approximate age 35 days and installed into the access road and side-walk at Westgate bus terminus.

3.4 Summary and Conclusion

In order to construct a road and sidewalk with concrete pavers, it was necessary to embark on a manufacturing programme at a typical paving factory. A considerable number of blocks were also required for various laboratory tests, including three selected abrasion tests.

Great care was taken to manufacture the paving blocks corresponding to each of the 48 mix designs as uniformly as possible, to keep the coefficients of variation of the subsequent laboratory tests as low as possible. Consequently careful consideration was given to each stage of the production process.

TABLE 3.1 GENERAL MAUFACTURE PLAN
IDENTIFICATION OF 48 MIXES

DATE MADE	MIX NUMBER	CEMENTITIOUS MATERIAL		WATER CONTENT	
		TYPE OF MATERIAL	PIGMENT CODE	CONDUCTIVITY SETTING	PAINT CODE
12/08/87	1.1	9% OPC	BAYER 110	650 (SLUMP POINT)	PURPLE DOT
	1.2	9% MGBS	RED 4%	600	GREEN DOT
	1.3	82 % FINE	(By mass of	550	BLUE DOT
	1.4	AGGREGATE	cement)	500	ORANGE DOT
	1.5			450	RED DOT
	1.6			400 (VERY DRY)	YELLOW DOT
12/08/87	2.1	7% OPC	BAYER 960	650 (SLUMP POINT)	PURPLE DOT
	2.2	7% MGBS	YELLOW 4%	600	GREEN DOT
	2.3	86 % FINE		550	BLUE DOT
	2.4	AGGREGATE		500	ORANGE DOT
	2.5			450	RED DOT
	2.6			400 (VERY DRY)	YELLOW DOT
13/08/87	3.1	5% OPC	BAYER 318	575 (SLUMP POINT)	PURPLE DOT
	3.2	5% MGBS	BLACK 4%	525	GREEN DOT
	3.3	90 % FINE		475	BLUE DOT
	3.4	AGGREGATE		425	ORANGE DOT
	3.5			375	RED DOT
	3.6			325 (VERY DRY)	YELLOW DOT
13/08/87	4.1	10% OPC	BAYER 610	650 (SLUMP POINT)	PURPLE DOT
	4.2	4% FA	BROWN 4%	625	GREEN DOT
	4.3	86 % FINE		575	BLUE DOT
	4.4	AGGREGATE		525	ORANGE DOT
	4.5			475	RED DOT
	4.6			425 (VERY DRY)	YELLOW DOT
13/08/87	5.1	11% OPC	BAYER 160	650 (SLUMP POINT)	PURPLE DOT
	5.2	3% FA	RED 4%	625	GREEN DOT
	5.3	86 % FINE		600	BLUE DOT
	5.4	AGGREGATE		550	ORANGE DOT
	5.5			500	RED DOT
	5.6			450 (VERY DRY)	YELLOW DOT
13/08/87	6.1	12% OPC	BAYER 663	650 (SLUMP POINT)	PURPLE DOT
	6.2	2% FA	BROWN 4%	625	GREEN DOT
	6.3	86 % FINE		600	BLUE DOT
	6.4	AGGREGATE		550	ORANGE DOT
	6.5			500	RED DOT
	6.6			450 (VERY DRY)	YELLOW DOT
14/08/87	7.1	6.65% OPC	BAYER	625 (SLUMP POINT)	PURPLE DOT
	7.2	6.65% MGBS	CARBOFIN	600	GREEN DOT
	7.3	O.7% SF	BLACK 4%	550	BLUE DOT
	7.4	86 % FINE		500	ORANGE DOT
	7.5	AGGREGATE		450	RED DOT
	7.6			400 (VERY DRY)	YELLOW DOT
14/08/87	8.1	6.3% OPC	BAYER 960	625 (SLUMP POINT)	PURPLE DOT
	8.2	6.3% MGBS	YELLOW 1.5%	600	GREEN DOT
	8.3	1.4% SF		550	BLUE DOT
	8.4	86 % FINE		500	ORANGE DOT
	8.5	AGGREGATE		450	RED DOT
	8.6			400 (VERY DRY)	YELLOW DOT

NOTE: The binder is identified by the pigmentation colour and the water content by the colour of the paint markings on the blocks.

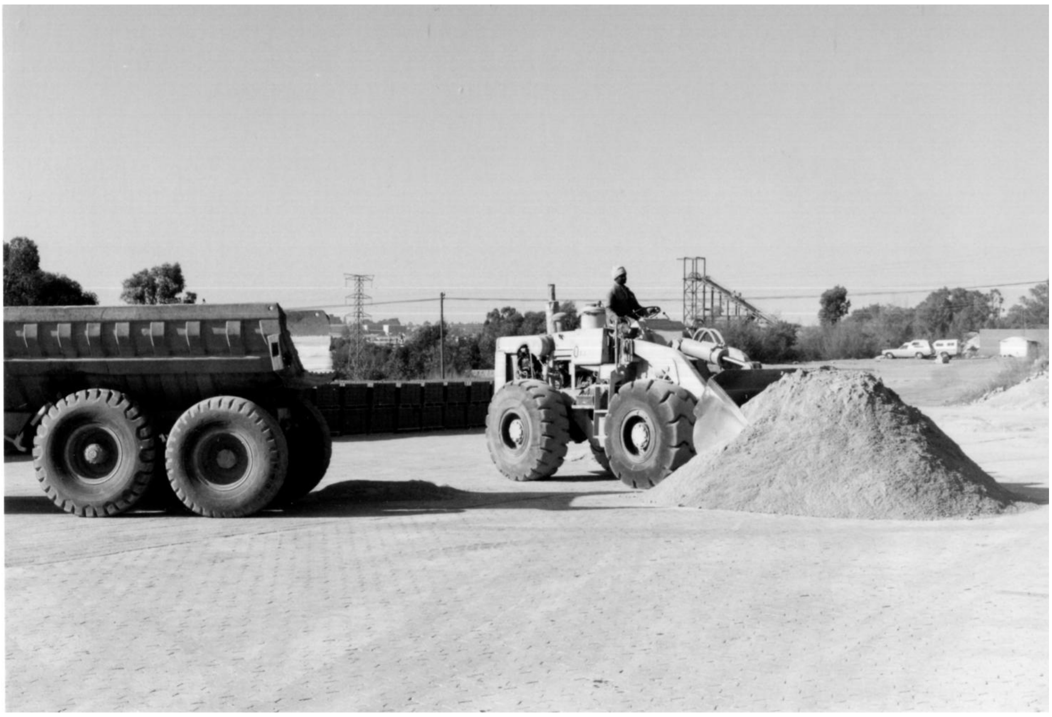

Figure 3.2 Blending of the sand to ensure uniformity

Figure 3.3 Sand being loaded into aggregate bin No. 2

Figure 3.4 Binders of known quality were poured into the top of the cement scale from bags

Figure 3.5 An inside view of the control room housing the cement scale monitor - radio communication was maintained with operators at the cement scale

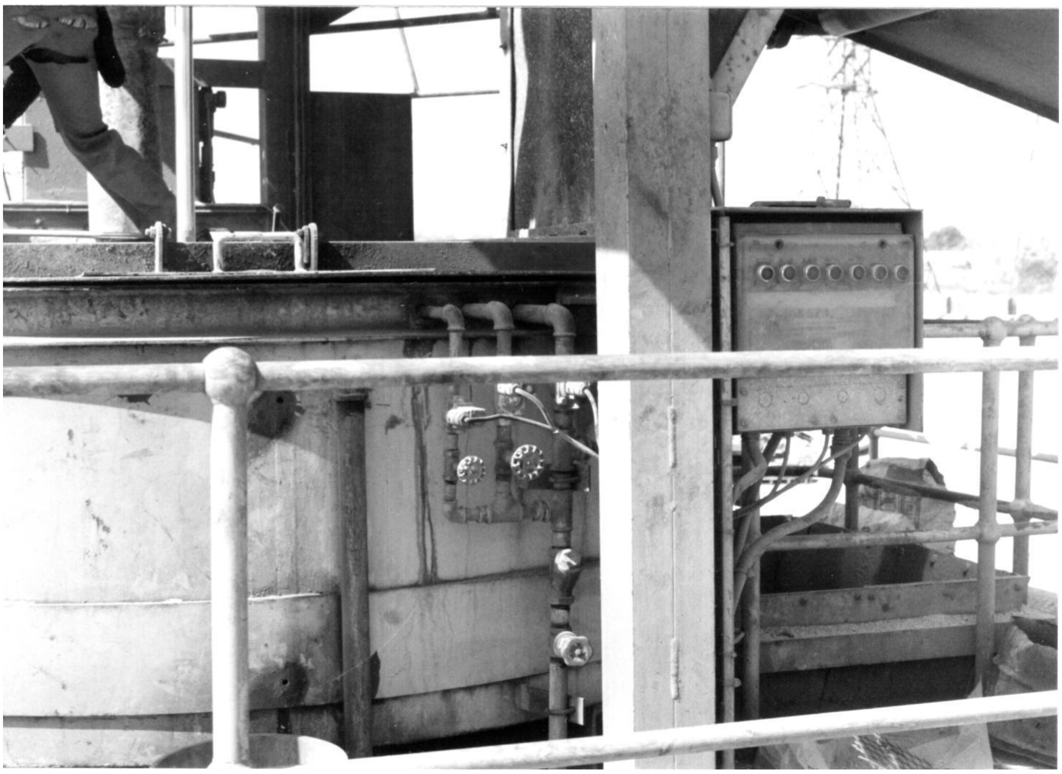

Figure 3.6 Solenoid valves situated at the mixer are operated by a sophisticated instrument inside the control room

Figure 3.7 After moulding, the blocks are ejected from the block machine onto a rope conveyor

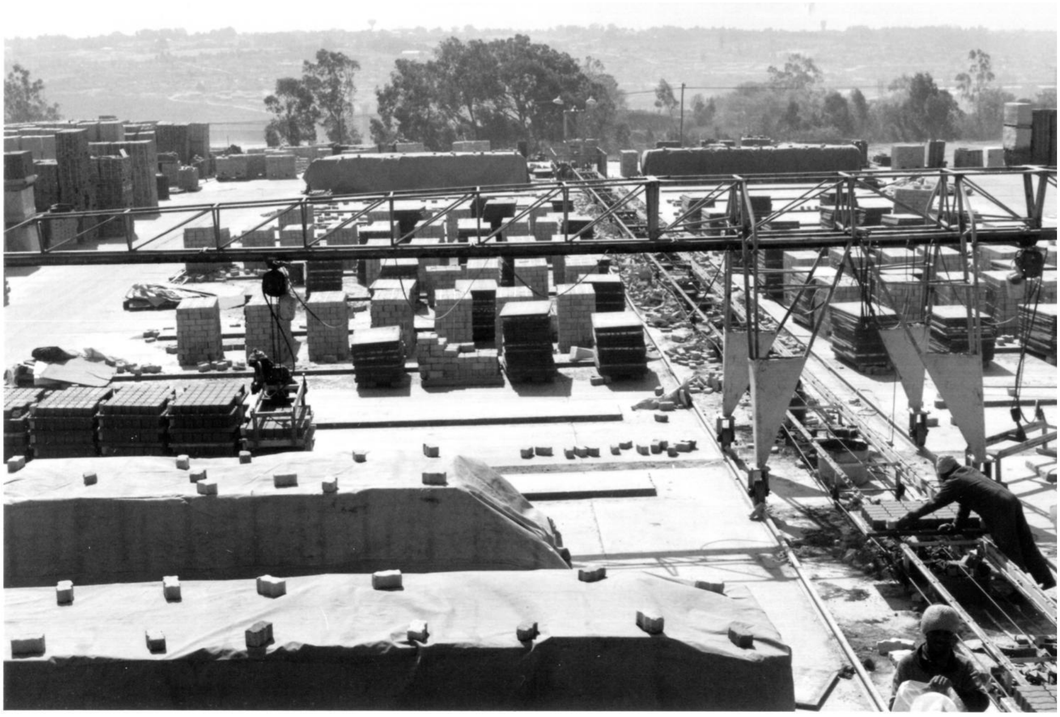

Figure 3.8 The gantry removes the pallets from the rope conveyor and stacks them in the initial curing area in rows

Figure 3.9 The pallets were marked with different paint colours to identify the various mix designs (the blocks could not be marked at this stage since they were still wet)

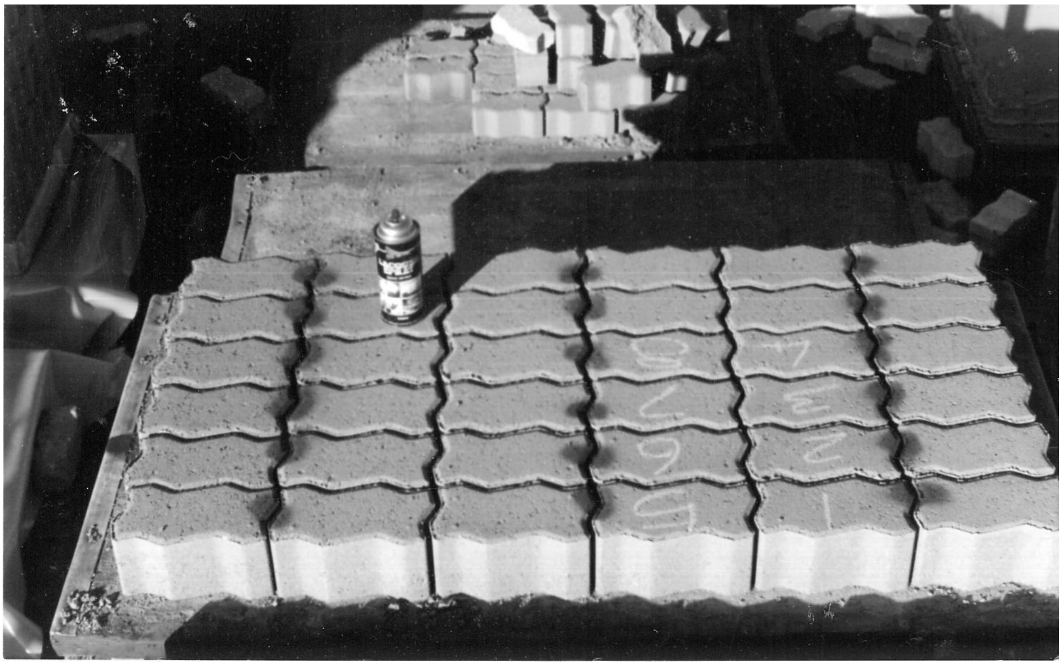

Figure 3.10 Prior to stacking the blocks were marked with different coloured spray paints (at this stage the blocks were 72 hours old and hence dry enough to be painted).

Figure 3.11 The blocks were hand packed and sealed in a double layer of shrink-wrap plastic

Figure 3.12 Blocks destined for the laboratory are numbered on their upper faces from one to eight

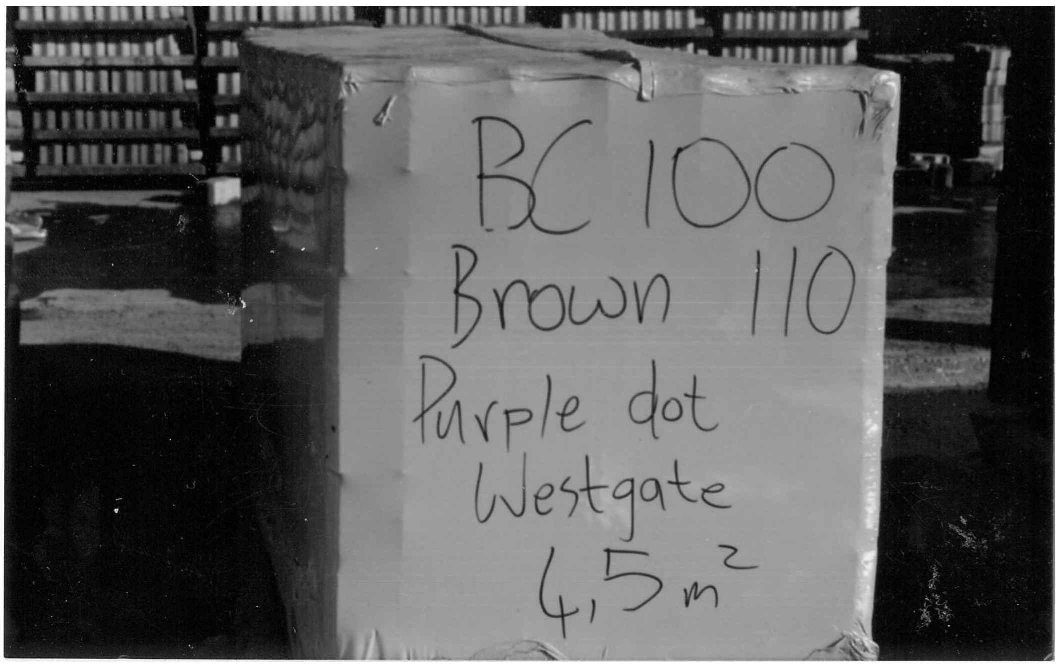

Figure 3.13 The sealed packs are suitably identified