Chapter 2

Background

2.1 Preview of Chapter

In order to place the abrasion resistance of concrete block paving in perspective, it will be useful to briefly review the origins and evolution of the product. Following this the main functions and technological aspects will be addressed.

Thereafter a survey is made of the development of abrasion testing of cbp. This reflects the importance attached to abrasion resistance by the various countries. Special attention is given to the events that led to this investigation and other related research into abrasion resistance in South Africa. The ideal criteria of a cbp abrasion test are outlined, and reasons are given for the selection of the three chosen abrasion tests.

Although a survey of the factors that affect the abrasion resistance of cbp (and concrete surfaces in general) properly belongs here, this aspect is comprehensively investigated in chapter 2 of Volume 2, and is therefore not covered here.

2.2 The Evolution of Cbp – from Ancient Stones to Precisely Shaped Concrete

Segmented blocks have been used for surfacing roads from earliest times. Examples still exist from ancient Rome, Greece and India. The segments used then were hand *chiselled stone;* stones were selected at random and chiselled to fit into neighbouring stones. The spaces between the stones were filled with sand.

In more recent times (i.e. the 19th century) *stone setts* were prepared. These conformed to more exact dimensional tolerances so that the pavements could be laid in regular patterns. The stones were generally of uniform size and could be easily handled. This alleviated many of the problems experienced with the irregular shapes and larger stone blocks used previously. However old-fashioned steel-tired wheels caused spalling of the arises and uneven wear on the stone setts. In time individual stones became dome shaped producing a very uneven surface, such as in the cobblestone streets, which still survive in parts of Europe [Clifford(1984)].

Lilley(1991) reports that the very high abrasive/impact effects from the steel-tired wheels and also steel-shod horses meant that a premium was placed on the wear-resistance properties of the stone that was used. Quarry men used to market their materials on the basis of their superior abrasion resistance, for stone setts were being worn away by as much as 50 to 75 mm within a few years.

During the 19th century new ideas for urban street paving design were introduced. These included the use of triangular *cast iron* roadblocks, described by Clifford(1984) from the book ‘Iron Roads’(1938). It is interesting from a historical point of view to note that they were hollow and about 50 mm thick, designed to be laid on bitumen over concrete with a bitumen filler between each block.

Wood block roads enjoyed a long and varied history [Clifford(1984) quoting Fowler(1935)]. They were first used experimentally in the USA in the cities of New York and Philadelphia in 1835. However the first roads paved with wood blocks were in London, in Whitehall and the Old Bailey, in 1839.

The problem with wood-block paving was to obtain suitable wood for trafficking requirements, and to preserve the block immovably in position and in a watertight condition under traffic. Wood-blocks varied in size but generally were about 200 x 75 x 100 mm thick. Joints were bitumen grouted and adequate waterproofing was achieved. The life of a well-constructed wood block pavement was estimated to be about 20 to 30 years even under heavy urban trafficking [Clifford(1984) quoting Greenhill(1901)]. .

Bricks have been used for block paving for several hundred years. After the 1930 International Road Congress in Washington (USA) at which experience of brick roads laid in America, Britain and Holland was discussed, brick roads became popular, but because of the demand for fired clay brick products for housing, this trend was short lived. The Netherlands was the only country regularly constructing brick roads during the 1940's and later.

In the 1950's precast *concrete blocks* immerged as an alternative material to brick. Concrete blocks gradually became more popular and by 1978, according to Lilley(1981), nearly 16 million square meters of paving had been produced in the UK alone. By the end of the 1970's, in some countries, up to 1,0 square meter of concrete blocks per person were manufactured annually, notably Germany and Holland.

Cbp was introduced into South Africa in the late 1960's and gradually became an acceptable means of surfacing roads, sidewalks, and even such heavy-duty applications as servicing yards for container terminals and bus depots.

This largely came about as a result of very significant groundbreaking research relating to the structural performance of cbp in 1979 and the early 1980s at the CSIR’s testing station in Silverton [Shackel(1981)], providing a basis for design models, and leading to a much greater acceptance and application of the pavers particularly in heavy duty applications.

The survival of the ancient Roman stone roads and the 19th century stone setts in European cities as described by Clifford(1984) earlier, testifies to the excellent abrasion resistance qualities of most quarried rock types. This quality is used to good effect in cbp today, where the relatively hard aggregate component (such as granite, quartzite, andesite or dolerite) serves to protect the softer mortar component. The hardwearing aggregate thus becomes the major contributor to a concrete paving block’s abrasion resistance.

Other surfaces have not survived:

a. Iron roads: Iron, although very hard, is heavy, expensive and rusts.

b. Wood block roads: Wood is relatively soft, expensive and rots. The blocks can also float away, if the road becomes flooded owing to inadequate storm-water drainage.

c. Clay brick roads: Only the carefully blended clays that are fired at very high temperatures are comparable to the hardness of typical aggregates used in cbp. However the cost of such clay products is normally so high as to limit their use to prestigious projects. A further disadvantage is that the firing process distorts the shape of the brick to a greater or lesser extent, so that a substantially greater gap is required between the bricks relative to concrete pavers that are manufactured in precision moulds.

Asphalt

The massive exploitation of the earth's oil reserves in the 20th century has brought about the most economical means of surfacing roads to date. These asphalt surfaces also make use of the proven abrasion resistant qualities of quarried aggregates. As in the binder component of cbp the asphalt serves to glue together the individual aggregate particles.

Although most economical, asphalt surfaces have some limitations:

a. In very hot climates the asphalt can soften/liquefy and segregate from the aggregate component.
b. A minimum traffic loading is necessary to slow down deterioration from the sun's ultra violet rays.
c. It dissolves in the presence of diesel, petrol, oil etc.
d. Asphalt roads have minimal aesthetic appeal.

Cbp does not suffer from these conditions. The binder component of cbp (the hardened cement paste) is stable under all road temperatures, traffic loadings, petrol and oil spills etc., thus holding the aggregate component permanently in place to resist abrasion-wear.

In conclusion it is evident that the paving surfaces of rocks and stone setts, that were installed in ancient times and in the early 1900s, have resulted in a very hard and durable surface with excellent abrasion resistance. However, the introduction of pneumatic rubber tyres greatly reduced the need for such hard surfaces. Notwithstanding, cbp made with hard aggregates that are well bonded by a high strength binder, may be regarded as nearly equal to the stone setts, in terms of abrasion resistance. Furthermore, modern technology has made it possible to mass produce concrete units economically, which are superior to their ancient counterparts in that they fit together so precisely that the ideal joint width of between 2mm an 4mm can consistently be achieved. This allows for excellent load-shedding to the adjacent blocks, thus reducing the pressure on the sub-base/sub-grade.

2.3 Survey of Cbp’s Most Important Attributes

In this section the five most important attributes of cbp are considered. In order of review they are, economic advantages, waterproofing ability, load-shedding capability, aesthetic appeal, and abrasion resistance. They explain why the cbp industry has grown so dramatically over the past fifty years.

2.3.1 Economic Advantages

Prior to the Second World War, Germany was the most mechanised country per capita in the world. This undoubtedly contributed to their early successes in the war. After the war, and with the assistance of American capital, the West German economy soon recovered and great strides were again made in mechanisation. Stringent restrictions on the development of military hardware meant that their exceptional mechanical abilities could be focused primarily on industrial advancement.

One of the products of this post war industrial revival in Germany was the development of machines well suited to the mass production of concrete paving blocks. Manufacturers of machines like Zenneth, Schlosser, Hess, Knauer etc, enabled the cost of producing cbp in Germany to be greatly reduced, in much the same way as mass production of automobiles reduced the price of cars in America. Cbp soon emerged as a very economical method of providing hard and durable surfaces.

A most useful characteristic of concrete is that it can be moulded into virtually any shape. However under normal circumstances only one product can be moulded per day, unless special processes and sophisticated curing methods are used, since demoulding can only be done the day after when the concrete has set and gained a certain degree of strength.

To overcome this, the mass production paving machines were made with powerful high frequency vibrators which enabled a relatively dry mix (zero slump) to be substantially compacted in a matter of seconds. These blocks could be demoulded immediately and ejected from the machine. A typical cycle time was about 20 seconds and in this time 0,75m^2 of paving could be produced - a good days production with no major stoppages would be in the order of 1000m^2 per machine.

Meyer(1980) states that ‘by large scale automations in production, wage costs have been considerably reduced in the course of time. In 1936 the production of 100m^2 of concrete paving stones required about 15 wage hours. Today (meaning 1980) this figure is approximately 1,5 wage hours.

Typically a modern paving factory requires no more than 3 operators per machine to do the various tasks of dispensing the raw materials, mixing, forming the blocks, storing the fresh pavers in curing tunnels, stacking the production from the previous day, and loading vehicles from stock. These factories are fully mechanised and highly automated. This means that 3 men can produce 1000 m^2 [Page(1998)], the equivalent of R33 000 per day turnover of completed paving, (at 2001 prices). If each operator is paid R540 per day (R60 per hour for a highly trained skilled operator), then the total cost of labour amounts to 3 operators x R540 per day = R1620 per day. This is obviously a small proportion of the total turnover and serves to illustrate how mass production can allow for price cutting and consequently increase market penetration.

However, the cost of producing the paving blocks is not the only cost advantage. The blocks are installed quickly and easily. This is because the moulds are exactly made and hence the blocks are dimensionally identical (for all practical purposes) and consequently easily fit together. Therefore minimal skills are required on the part of the laying team.

Furthermore it is not necessary to screed individually beneath each block, (as was done with the stone setts owing to considerable variations in height between individual blocks). Rather, a straight edge running over screed rails is used to screed many meters of bedding sand quickly and evenly prior to placing the blocks. In this way a paving team of 15 relatively unskilled labourers is capable of installing 500 m^2 of paving per day. In Europe, far fewer paviours are capable of a similar installation target using mechanised laying bogeys.

Smith(1987) was involved in a project involving the replacement of 60-year-old brick paving in the city of Dayton, Ohio. It was found that mechanized installation could be achieved in half the time of manual installation, The bid for the manual work as \$46,81/m^2 (including materials and labour) compared with \$27,65/m^2 for mechanized installation. Thus the economics of installation adds to the economics of manufacturing.

New systems for the rapid installation of pavers using mechanical equipment are described by Hodson(1996). Advantages include advanced interlock, reduced manpower, a lower supervision requirement, and of course faster laying rates.

The lag in mechanised installation of cbp in South Africa relative to Europe/USA is purely a matter of economics. Simply put this means that the cost of purchasing and repairing complex machines is substantially more than the cost of labour, i.e. the interest payments on the borrowed capital, the associated cost of depreciation, and maintenance costs, are significantly higher.

Smith(1996) reviews the design, construction, and maintenance aspects of four airport and three port projects involving cbp that he was involved in. All but one of the projects was based in the U.S.A. The projects demonstrate the structural, maintenance, and life-cycle cost advantages of interlocking concrete pavements.

Economics aside, there are other important features of a more technical and aesthetic nature that have also contributed to the success of cbp. These can be summarised as follows.

2.3.2 The waterproofing aspect of cbp

While the initial impetus for cbp was undoubtedly linked to the economies achieved through (1) the advent of machines capable of mass producing a semi-dry concrete into units of precise dimensions that (2) could therefore be fitted together very easily without the use of mortar that (3) therefore allowed for high installation rates, it soon became apparent that the installed blocks were also capable of acting as a remarkably good water proofing layer.

This is of cardinal importance. If water is allowed to enter through the joints between the blocks, this will normally result in a softening of the underlying foundation, adversely affecting the bearing capacity and useful life of the pavement.

Many investigators testify to the important role played by the jointing sand in rendering a cbp surface ‘waterproof’: Tests conducted by Clifford(1984) have shown that providing the correct jointing sand is used, and assuming the density of the blocks renders the blocks virtually impermeable, the ingress of water into the supporting layers is so minimal that the block pavement can for all practical purposes be regarded as water tight. Shackel(1990) confirmed that in a cbp pavement the blocks themselves can be regarded as being impermeable, and that water can only penetrate the pavement via the joints, and then only in the early life of the pavement prior to the joints becoming clogged with detritus, rubber and oil. Thus in the long term the block paving ‘can be regarded as being largely impermeable’. Pesch(1980) explains that ‘the joints of concrete block paving seal themselves through the natural process of detritus forming in the joints and sealing the area from the passage of moisture’. Takeshi(2000) reported on experiments with an ultra-high-pressure water jet, which is used for grinding and cleaning concrete surfaces. Laboratory and field trials showed that the integrity of the jointing sand was not adversely affected, and that damage to the bedding sand layer and base coarse ‘were almost non-existent’.

It is clear that the impermeability of the joints will largely depend on certain characteristics of the jointing sand, such as the degree that it fills the joints (the sand should be very dry at the time of sweeping it into the joints), the degree that it is compacted (under the action a plate vibrator), the grading and other characteristics of the jointing sand (special envelopes exist indicating that a degree of very fine material, even some clay, is advantageous), its consolidation characteristic, and the level of detritus that builds up in time.

Qvist(1996) concurred that infiltration is linked to the characteristics of the jointing sand. He measured an average infiltration rate of 4mm/hour (or 10litres/s/hectare) through cbp with joints filled with joint gavel, whereas if trass-lime was mixed with the joint gravel the joints became virtually impermeable.

That concrete block paving is not always ‘waterproof’ is evident from the following:

Leenders (1988) stated that field tests have shown that infiltration of rainwater through the joints can amount to up to 45% of the annual rainfall.

Smith(1988) concluded that cbp placed on a sand and gravel base, trafficked by automobiles, does not always have the joints fill over time with detritus (and so does not generate a high run-off coefficient). The sealing action of sediment and detritus in the joints may be negated by the sucking and pumping action of automobile tyres. He recommended a runoff coefficient of 0,8, relative to asphalt of 0,95/1,0.

Shackel(1994) studied the effects of pavement cross fall, joint width and area, paver shape, paver thickness and jointing sealers in *newly laid, untrafficked* cbp pavements. While some of these factors contributed to water ingress more than others, he concluded that their cumulative effect could result in significant water penetration. Up to 65% of the rainfall penetrated through the joints for unsealed blocks and 50% in the case of sealed blocks.

Given that *newly laid* cbp pavements may be susceptible to significant levels of percolation through the joints, it is always advisable to construct the earthworks to a fall of at least 1%, preferably 2% or more to facilitate surface run off. In order to avoid a problem with ponding SABS 1200 MJ[1] specifies a maximum allowable gap of 10 mm beneath a 3 m straight edge placed on the compacted earthworks, to be verified prior to placing the blocks.

Permeable Eco-Paving

More recently there has been a shift away from 'waterproof' surfaces in certain applications. Karasawa(1996) explains that 'harmonization with nature' has become a key phrase in Japanese urban planning, and that government and municipal offices have adopted this as their basic policy. To this end regulations have already been enacted in the Tokyo, Osaka, Ngano prefectures that permeable paving must be used for newly constructed *footpaths*. (Clearly, this only applies where the bearing load is in no danger of exceeding the bearing capacity).

Shackel(1996) found that the best compromise between water penetration and structural load capacity for 'eco-paving' was achieved using relatively uniform bedding, jointing and drainage materials, having a maximum size of between 4mm and 5mm. Water penetration rates ranged up to about 600 l/sec/ha.

Pearson(1996) explains that permeable 'eco-paving' provides important new options, both for municipal consolidation schemes and for industrial areas. Such pavements can:

(a) reduce the amount of rainfall runoff from pavement surfaces and, thereby, eliminate or reduce the extent of the storm water runoff system
(b) reduce the size or need for rainwater retention facilities in road works
(c) reduce or avoid downstream flooding
(d) help recharge and maintain aquifers and the natural groundwater
(e) help trap pollutants that would otherwise contaminate groundwater or drainage systems
(f) assist in the biological decomposition of hydrocarbon contaminants

To conclude it may be said that permeable paving is only an option in applications where the bearing capacity of the supporting layers will not be overstressed by the applied load. Knapton(2000) cautions that if permeable paving is used in heavily loaded conditions, a great deal of care is needed in the design and specification of pavement construction materials. No material whose strength will reduce should be specified and care must be undertaken to ensure that the underlying sub grade can absorb the water percolating through the pavement.

The writer has noted from the literature that there are two systems for permeable paving. The first consists of dense blocks that fit together in such a way that there are gaps or holes in the resultant pattern, for drainage purposes. The other system relies on the blocks themselves being permeable, e.g. the blocks may be made form no fines concrete. The blocks corresponding to the former system may be made dense, have a high compressive strength, and be hard wearing. On the other hand published results [Hata(1998)] show that the compressive strength of the latter system blocks is relatively low, in the region of 30/40MPa, compared to 60MPa typical for dense blocks. In time this is likely to result in relatively high abrasion wear, since abrasion resistance is generally related to compressive strength. There is the danger that this will tarnish the image of cbp.

Apart from the special considerations of 'Eco-paving', the majority of the evidence presented shows that providing care is taken with sealing the joints using the correct jointing sand etc, cbp pavements have the capability of rendering a surface virtually impermeable, thus safeguarding the structural integrity of the underlying base and sub grade.

2.3.3 The Structural Aspect of Cbp

It has been shown by Clifford(1984) that the blocks in a block pavement serve to distribute forces from applied loads to adjacent blocks, and in this way serve as a definite structural element in the pavement design. This distribution of applied loads is enhanced when the blocks are fully interlocking and installed in a herringbone pattern. The reduced bearing pressure allows for fewer foundation layers, or a reduction in the thickness of the base and sub grade.

Design Catalogues [Clifford(1984)] and user-friendly computer design programmes [Shackel(1990)] exist where the blocks act as a definite structural element, the basecourse. The effect of thickness, shape and laying pattern can be seen to have a clear bearing on the underlying structural layers.

Numerous investigators have researched the structural performance of cbp, and their findings have variously been published, inter-alia in the six international conferences beginning in 1980. For example, in the conferences held in Israel in 1996, and in Japan in 2000, there were 12 publications on this topic at both events. This makes cbp a very versatile surfacing material useable not only in aesthetic applications but also as a structural element subject to heavy loads.

Pearson(1996) states that as well as traditional residential applications, and aesthetic applications such as landscaping, municipal malls, access ways and streets, cbp has been established as a viable alternative for heavy duty pavements, in areas such as hardstands, material handling facilities, and container depots. More recently it has been used in high performance aircraft pavements such as runways, aprons and taxiways.

Knoesen(2000) reported the rehabilitation of damaged asphalt paving using concrete block paving. The trial sections were laid in the crawler lanes of the N3, in KwaZulu-Natal, where 30% of the traffic consists of heavy long haulage vehicles, 25% of which are generally overloaded. After 18 months of service 'the cbp had performed very well with no signs of rutting'.

Visser(2000) reported on an experiment at the Kaserne container terminal, including two test panels surfaced with cbp designed and constructed to obtain design input under ultra heavy loading conditions. Accordingly the section was trafficked by trucks and Reachstackers during normal container distribution operations, with axle loads of up to 100 tonnes. Following an evaluation period of 15 months Visser concluded that there was no indication of stress sensitivity of the unbound materials, and typical stiffness values used in road pavement design could be used. Limiting vertical compressive strains in the trial sections were as suggested by the South African Mechanistic Design Method for road pavements.

Knapton(1998) reports that in the 1980s paver usage included such heavy-duty applications as bus roads and bus stations. Luton Airport pioneered the use of pavers on aircraft pavements in 1983 and today pavers are specified commonly on aircraft stands [to support Boeing 747s] at major international airports, both in the UK and elsewhere.

It may be concluded that cbp has gained wide acceptance as a useful system for heavy loads.

2.3.4 **Aesthetics**

As well as waterproofing the surface and acting as a structural layer, concrete pavers with interesting shapes and imaginative colours are commonly used in shopping malls, car parks, secondary roads, domestic driveways, park footpaths, etc. to brighten up the environment. There are various iron oxides on the market that are colour fast regardless of the intensity of exposure to ultra violet light. Colour stability does however depend on several design criteria being duly considered such as minimum pigmentation concentration, c/w ratio and cement content. Pavers made from mixes that have relatively high cement *and* oxide contents are much brighter, being substantially coloured in the direction of the pigmentation. The amount of water is also critical. Mixes that are too wet will be too light in colour, and mixes that are too dry will be rather darker and dull. The colour of the aggregate also influences the overall colour of the pavers. As progressively more aggregate is exposed through abrasion processes, there will increasingly be a shift in the direction of the aggregate's colour [von Szadkowski (1987)].

Blocks of different colours are often arranged to create various attractive features. Figure 2.1 illustrates how a variety of different patterns can be created from blocks of the same shape.

Figure 2.2 shows blocks of different shape. The figure shows how blocks with the correct symmetry can be installed in patterns such as herringbone, stretcher bond or fan weave.

Thus shape, colour and laying pattern contribute significantly to the aesthetics of cbp.

Pearson(1996) has observed that cbp offers the benefits of not only the a choice in colours, but also a wide range of surface finishes including rumbled, washed, sandblasted, bush hammered or polymer flame surface finished.

Thus the designer has a considerable measure of control over colour, texture, and pattern. In addition, designers recognise that, in contrast to asphalt or cast-in-place concrete, cbp provides a human sense of scale because of the size of the pavers and their associated joints.

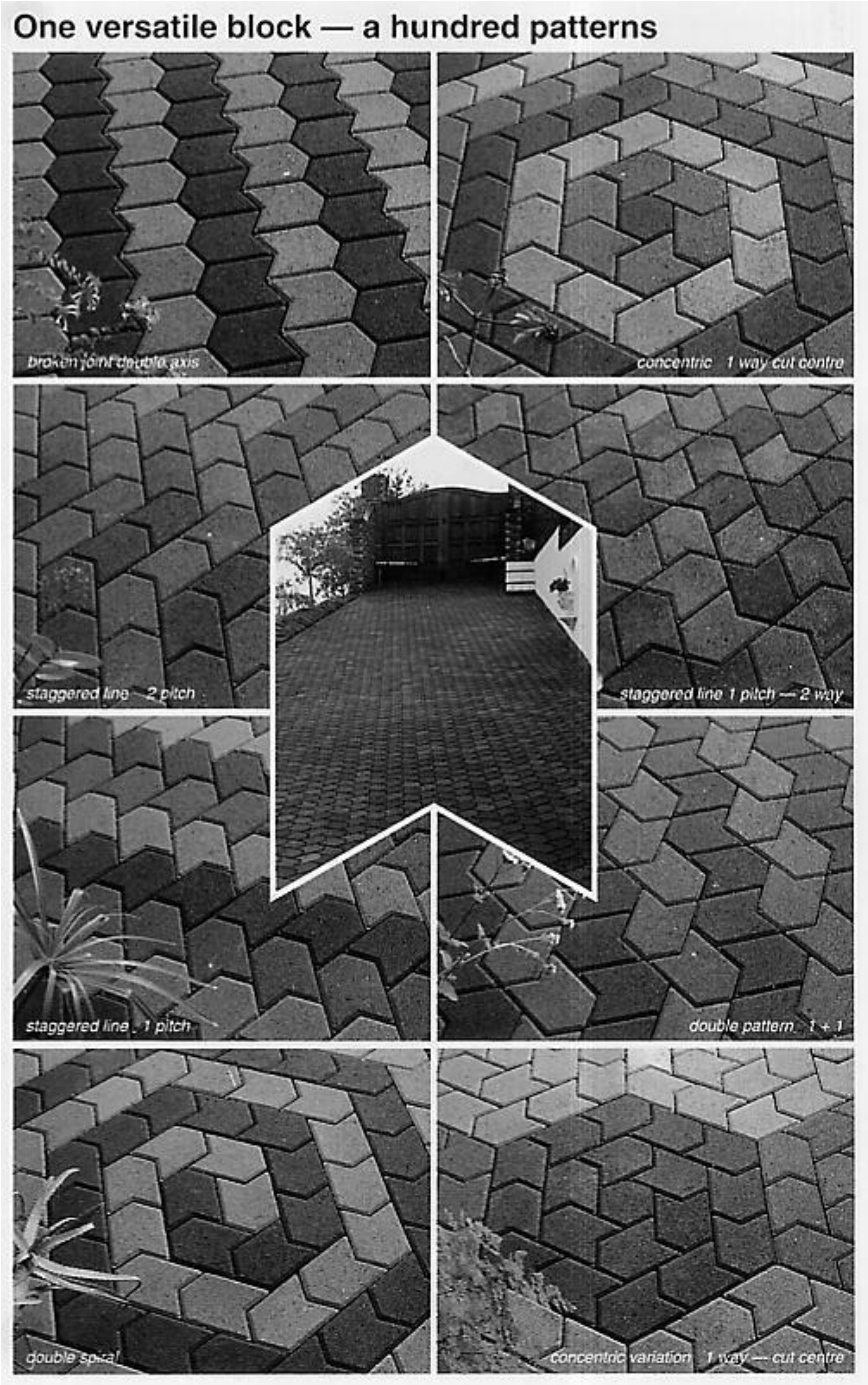

Figure 2.1 Various laying patterns from one block

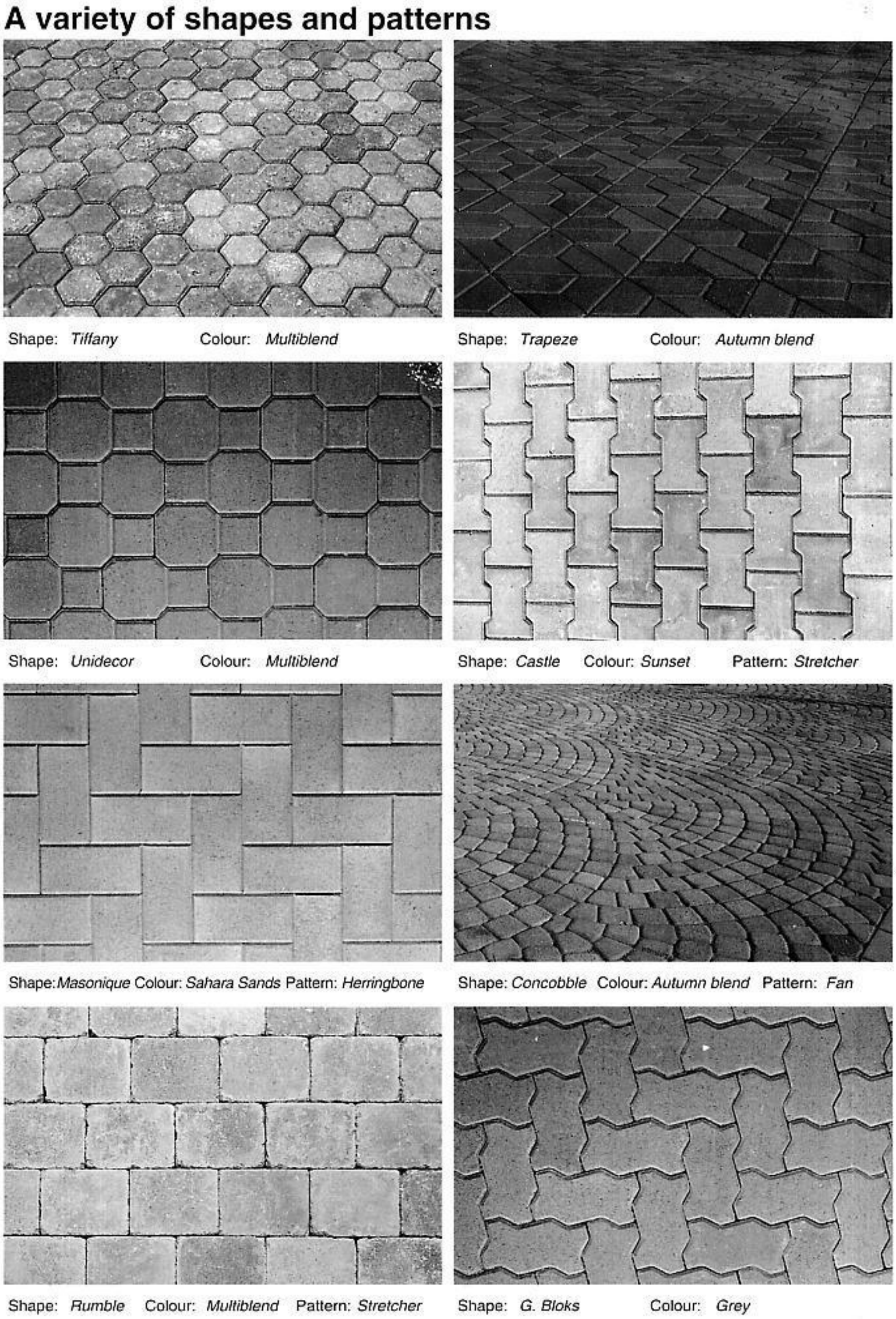

Figure 2.2 Blocks of different shape and laying pattern

2.3.5 **Abrasion Resistance**

In the foregoing sections cbp has been shown to be economical, an effective barrier against water ingress, an effective structural element, and aesthetically enhancing. These attributes will however be undermined if the surface does not have adequate abrasion resistance. Then even mild abrasion will diminish aesthetic appeal, and increase the roughness, although it is unlikely to affect the waterproof/structural capability. On the other hand severe abrasion in cbp of inferior quality may lead to the total demise of the cbp system including the supporting layers.

As with compressive strength, tensile strength etc, concrete has the potential for both high or low abrasion resistance, depending on the materials and processes used in making and finishing the surface. There are many factors that influence the abrasion resistance of concrete, and these are discussed in great detail in chapter 2 of volume 2 (see figure 2.2 of volume 2 for the outline).

Definitions

ACI-201(1977) defines abrasion resistance of concrete as the ability of the surface to resist being worn away by rubbing and friction.

Alexander(1984) defines abrasion resistance as ‘the ability of concrete to withstand abrasive forces, whether these be due to friction, attrition, grinding, rolling, impact, high local stresses, or the action of fluids containing abrasive media’.

Sukandar(1993) defines abrasion resistance of concrete pavers as the ability of the surface to resist its materials from being removed by sliding, cutting, rubbing, scraping and impact forces, both in a dry state and in the presence of water.

Abrasion resistance of cbp relative to asphalt

An example of concrete’s potential for excellent abrasion resistance is reported by Marais(1985). He shows that correctly made concrete surface are significantly longer lasting than asphalt:

‘The type of surface texture currently specified for national concrete roads in this country (South Africa) is expected to last as long as the life of the road. The French experience with concrete roads suggested an average service of 25,5 years for concrete’.

In spite of concrete’s superior abrasion resistance, asphalt is still the most common means of providing a waterproof wear resistant surface in many applications. This is chiefly because it has the lowest initial cost. However the asphalt surface will normally require resurfacing every 5 to 10 years, whereas a well-designed concrete surface should be able to outlast asphalt by a factor of roughly two.

This is confirmed by Marais(1985): ‘An alternative Bureau of Public Roads Study of 553670 km of construction and 310120 km of retirements (obsolete roads) showed the weighed probable average service of bituminous concrete as 66% that of concrete; that of mixed bituminous roads as 51%, and that of bituminous surface-treated roads as 49% of that of concrete’.

Tveter(1994) used the Norcem studded tyre-testing machine (see appendix U.3.03) and found that high strength concrete gave 2-3 times the wear resistance of asphalt.

Murakami(1998) did abrasion tests using a studded tyre (see appendix U.3.05) and found that the depth of wear in asphalt was three times that of concrete pavers.

Silverbrand(2000) reported on a research project carried out in Sweden and it was found that concrete block pavements are competitive with asphalt pavements providing they were not designed according to ‘old and unfashionable guidelines that lead to unnecessary thick pavement system (*sic*)’.

These findings potentially make cbp more economical than asphalt in the long term.

Asphalt also has other disadvantages that need to be taken into account:

a. Asphalt needs to be trafficked regularly in order to remain sound. Untrafficked asphalt breaks up under the action of the sun's ultra-violet rays. This means that for areas in shopping complexes where parking bays are infrequently used an asphalt surface can be problematic.

b. Asphalt deteriorates from oil leaks, which is a common scenario in car parks. Unlike concrete, it is particularly vulnerable to the spills of petrol/diesel/oil at filling stations.

c. An asphalt surface is commonly 20 mm thick, and when this layer comes away from the basecourse below, potholes will soon develop. Cbp is mostly 60 or 80 mm thick and it is extremely difficult to remove a paving block that as been in service for some months. Where pavers *have to* be uplifted (to install underground services etc.), this invariably involves breaking a few blocks in small pieces with a 2kg hammer and chisel, only then can the area be opened up.

Cbp is therefore an ideal material for urban roads, car parks, garage forecourts, etc., providing that it can be shown to have adequate wear resistance. It is therefore somewhat surprising to note that relatively little research has been undertaken specifically into the wear resistance of cbp.

2.4 Survey of Current Research Undertaken into Abrasion Resistance of Cbp

The extent that cbp has developed (since the early 1950s when it was first made in The Netherlands) may be perceived by two informative handbooks, one by Shackel(1990) and the other by Lilley(1991). They adequately cover most of the many facets of cbp, although abrasion resistance is only briefly considered.

Since 1980 there have been six international conferences and three international workshops specifically devoted to concrete pavers:

- 1980 England (1st international conference)
- 1984 The Netherlands (2nd international conference)
- 1996 Australia (1st international workshop)
- 1988 Italy (3rd international conference)
- 1992 New Zealand (4th international conference)
- 1994 Norway (2nd international workshop)
- 1996 Israel (5th international conference)
- 1998 Columbia (3rd international workshop)
- 2000 Japan (6th international conference)

Proceedings have been published for each of these events. A huge diversity of topics reveals a surprising large and well-developed sub culture in the world of concrete, i.e that of cbp. To accommodate this, the proceedings sometimes run to 600 pages with as many as 63 contributions.

The writer has made a thorough study of those papers that have a bearing on abrasion resistance and other related characteristics. Thus historical developments as they have unfolded since 1980 have been extracted from the various proceedings, and are discussed hereafter. Furthermore, it has generally been possible to reconstruct developments prior to 1980, since a number of the authors have reviewed the origins of abrasion testing in their respective countries.

Considering the substantial volume of material covered in the above-mentioned proceedings, it soon becomes evident that the topic of abrasion resistance has received relatively scant attention. (A notable exception is Japan, where a considerable number of investigations *have* been made, using an abrasion machine with steel studded tyres).

The cold winters prevailing in Japan, USA and Europe require pavers that are largely resistant to freeze/thaw effects, and are therefore made with substantially more cement than is the case in countries in the Southern hemisphere. Typically compressive strengths of between 50 and 60 MPa are specified. Consequently the pavers usually have adequate abrasion resistance, and so countries like the UK and Germany consider abrasion resistance testing superfluous.

In the Southern hemisphere, where climates are more moderate and freeze/thaw effects are not generally a factor, blocks are made with lower cement contents. This has over the years led to a number of surfaces with unacceptable abrasion resistance. In response a number of investigations have been undertaken in Australia, New Zealand and South Africa. To date only the Australians and New Zealanders have published their findings at the above stated conferences and workshops. South Africa's findings into abrasion resistance in cbp have been reported by various authors (Papenfus, Doulgeris, Holland, Rocha, Robertson), but only at local conferences, or otherwise they are 'hidden' in unpublished theses.

Given the different climatic conditions, it seems logical to consider the remainder of section 2.4 under the two headings 'Northern Hemisphere' and 'Southern Hemisphere'.

2.4.1 Northern Hemisphere

The research into abrasion resistance (or absence of it) reported at the conferences has been summarised on a country by county basis.

Germany

Germany has been a leader in cbp production for many years. The average national production equates to 1,9 m^2/capita/annum [Watz(1994)], the highest in the world, although the Netherlands, Belgium and Denmark are not far behind. In spite of this no research into abrasion resistance appears to have taken place for many years, indeed abrasion testing has been dispensed with. Initially the specification for testing concrete pavers, DIN 18501, did require that abrasion testing be done, using an Amsler apparatus (see appendix U.5.02 for details of this test). However, in time, it became apparent that the high compressive strength requirement of 60MPa adequately curtailed both freeze/thaw damage and abrasion-wear, and it appears that by 1980 abrasion testing was no longer mandatory. Meyer(1980) reports that the 'earlier requirement regarding wear is also dispensed with because it has been shown that all concrete paving stones with a compressive strength of 60 MPa are sufficiently wear resistant'.

United Kingdom

Cbp has seen remarkable growth in the UK, beginning in 1969 [Knapton(1998)], increasing to 50,000 m^2 p.a. by 1978 and accelerating to 16 million m^2 p.a. by 1996 [Dowson(1998a)].

Lilley(1980) reported that experience in the UK indicates that providing a compressive strength of 50 MPa is achieved, the blocks are expected to perform satisfactorily, based on general observations over a five year period.

While BS6717(1986), the specification for concrete paving blocks does not have a requirement for abrasion testing, Lilley(1991) has suggested that the test included in BS 6431:Part 14 could be adopted, i.e. Method of determination of resistance to surface abrasion :Unglazed tiles. However, it is now more likely that the European Harmonised Standard, essentially the French Standard NFP 98.303, would be used if deemed necessary.

Although abrasion resistance of insitu concrete floors has been thoroughly researched by investigators such as Sadegzadeh(1984) and Chaplin(1990), it appears that no studies have been made in the UK specifically on the abrasion resistance of cbp.

The Netherlands

After the Second World War, fired-clay bricks were used almost exclusively to repair and rebuild houses, and were therefore in short supply for paving. This led to the use of *concrete* pavers, from 1951. By 1978 15,8 million m^2 p.a. of paving were being produced, equivalent to 1m^2 per person [v.d.Vlist(1980)].

In 1955 the State Road Laboratory took the initiative in publishing 'Specifications for concrete paving blocks', a world first. Municipal and provincial authorities used this as well, till 1966, when the first Netherlands Standard relating to concrete paving blocks, NEN 7000, was published.

In 1959 a working group ‘D2’, investigated ways of manufacturing and testing cbp. They investigated many strength characteristics including compressive strength, flexural strength, impact resistance, tensile splitting strength, water absorption, density, and abrasion resistance. Three abrasion resistance tests were used in the studies; a ‘rattler test’ to ASTM C-7, edition 1942 (the details of this test are unknown), a test involving fastening wire brushes to an Amsler apparatus (see appendix U.6.3 in volume 2), and a sandblast test (see appendix U5.19 in volume 2).

In 1963 the working group published their report concluding that the flexural strength test best represented the paver’s quality.

Notwithstanding, NEN 7000 (1966) incorporated the sandblast test, but essentially as a freeze/thaw resistance indicator rather than an abrasion resistance test. This test specified that a mass of 3 500g of sand be applied.

In 1971 a test programme was launched (by an association of producers of concrete pavers) that involved various laboratory tests, as well as the installation of pavers in a road. The pavers were inspected annually for signs of wear, from 1972 through 1976. It was concluded in 1978 that: ‘If concrete paving blocks meet the requirements for loss of weight due to the blasting of 1000 grams sand and for the flexural strength, it can be assumed with great certainty that these blocks are resistant to frost and de-icing salts’ [Dreijer(1980)] The work reported by this author includes the experimental results, both for the laboratory ‘abrasion’ tests, as well as the field assessments of wear. This is most useful as it allows a comparison to be made with the wirebrush test and sandblast test of this thesis, reported further on in chapters 10 and 11, while his field wear results may be compared with those reported in chapter 14.

In 1982 a critical review of NEN 7000 was undertaken, and a number of changes were made and innovations introduced [Wagenmaker(1984)]. As far as the sandblast ‘abrasion’ test is concerned, it was decided that less sand should be blasted (1000g), thus making the test more of a measure of the surface quality; the 3500 g of sand formerly specified tended to make a substantial crater, and was thus more a measure of the quality of the ‘core’ concrete.

Given that paving is frequently made with a second ‘topping’ or ‘surface’ layer, the Dutch sandblast test has the advantage of exposing any deficiencies in this layer, e.g. insufficient density or cement content etc., whereas the compression test used in the UK and Germany, the sole measure of strength in these countries, would not detect this if the base concrete was of acceptable quality.

Belgium

In Belgium cbp has become a major means of surfacing. According to Hendrikx(1994) production rose from 1 million m^2 in 1980 to 8 million m^2 in 1993. In 1992, a new standard, NBN B21-311 ‘Concrete Paving Blocks’ was issued. It replaces compression testing with a splitting test. The specification also has an abrasion test, NBN B15-225/1990, based on the Bohme principle (see appendix U.5.07), with limits varying from 2,0mm through to 3,5mm, depending on block thickness and individual-versus-average-result. This specification recognises that pavers are often made with a layer of face concrete, and hence the abrasion test over and above the splitting tensile test is most appropriate.

Norway

Grayston(1994).reports that in 1970 two Schlosser paving machines started producing concrete pavers. The market grew steadily, and by 1994 there were 18 manufacturers producing some 800 000 m^2 per annum, or 0,25 m^2 / capita p.a., the lowest production rate in Europe.

Norway have tended to follow other countries, e.g. Germany, rather than ‘re-invent the wheel’. Accordingly the bulk of their paving products are made under licence, and virtually no research work has been done. However they have made special pavers for use on floors in smelters. These pavers are capable of withstanding 800 degrees C and have a very high wear resistance. They have also developed products with special aggregate with compressive strengths of 75 MPa, to take the special wear from studded tyres. These products will last 3 to 4 times longer than good quality asphalts.

According to Houben(1984) no abrasion testing is done, and this is still likely to be the current situation, given Norway’s tendency to follow Germany.

Sweden

Sweden has a somewhat unique position with respect to cbp. It has the second lowest per capita consumption in Europe (0,4m^2 as of 1994) after Norway. There are two reasons for this.

Firstly Asphalt producing plants are generally owned by the contractors, who price very competitively. Therefore virtually all roads are surfaced in this way. Secondly, the concrete flag industry in the country is highly developed, and Sweden has the highest per capita usage of concrete flags in Europe. Watz(1994) reports that the ‘flag-standard introduced in Sweden in the early 1980’s seems to have raised the quality of flags in Sweden significantly and thus saved flags from being used under false conditions and as a consequence loose credibility among clients and designers’.

The high quality flags stand up exceptionally well to structural loads (governed by flexural testing), freeze thaw, and abrasion resistance. These products are subjected to artificial wear in accordance with Swedish Standard 22 72 10, whereby a cast iron disc rotates against the flat surface of the product. The tests are carried out in four stages and the amount of material worn away is measured after each stage. Products must not show more than 1000cm^3/m^2 (η 1mm depth) for any of the tests in stages 3 or 4 [Watz(1994)].

The market for cbp therefore appears to be severely restricted by alternative traditional surfacings that have an established track record and standards that uphold quality. Under these circumstances, the cbp industry has been unable to attain a critical mass that would enable it to launch into research programmes, including investigations into abrasion resistance.

As of 1984 no abrasion testing was being done [Houben(1984)], and this is likely to still be the case. Like Germany, Sweden’s cbp specification calls for a high compressive strength, 60Mpa, and again this safeguards against numerous freeze/thaw cycles each year and contributes to a high abrasion resistance.

France

In 1980 the first edition of the officially authorised standard NF P 98.303 ‘concrete paving blocks’ was disseminated. A second edition followed in 1983 [Sanchez(1984)]. These specifications call for abrasion testing. (For more information on this test and its historic development, see appendix U.5.11).

European Union

A survey of various European paving standards [Houben(1984)] revealed that Denmark, Finland, Germany, Norway and the UK do not test for abrasion resistance. On the other hand Austria, Belgium, Italy and France do test. Austria and Belgium use the Amsler apparatus and test according to the Bohme Principle, (see appendices U.5.09 and U.5.07 respectively). The details of the Italian abrasion test are unknown to the writer, but may be the same as the Austrian/Belgium test. In agreeing on a European standard, one of the criteria was that it should already be a test currently operative in Europe. This meant that the choice was between the Amsler apparatus and the French test. [Hendrikx(1994)].

In 1996 the French Standard NFP 98.303 (see appendix U.5.11) was selected by a working committee of the European Union as the preferred test method to be adopted in the European Harmonised Standard.

United States of America

Cbp in the USA is not as established as in some of the leading European countries, in terms m^2/capita/annum.

However this country is in a unique position in that they have three official ASTM abrasion tests that all lend themselves to testing pavers, in that they each have a sufficiently small 'footprint'.

The paving specification ASTM C936-82 requires abrasion resistance testing to be carried out in accordance with a sandblast test, ASTM C418 (see appendix U.5.21). However this test does not seem to have gained universal approval. One reason for this may be that too much sand is applied over too concentrated an area, resulting in relatively deep penetrations – 3mm is deemed acceptable. However at these depths the test is more a measure of core abrasion rather than surface abrasion. A reduction in the mass of the applied sand, as was done in the sandblast test in the Netherlands would rectify this, making the test a true measure of surface abrasion.

Rohn(1985) has suggested that the use of a dressing wheel abrasion machine as described in ASTM C944 (see appendix U.3.06) can provide a simpler and cheaper alternative for testing pavers. Sukandar(1993), also did not consider that ASTM C418 was the best test for simulating wear in cbp, and he chose to use ASTM C779 Proc C (see appendix U.2.12), a test involving orbiting steel balls under load.

Although there is a very solid track record of abrasion testing in conventional insitu concrete, starting with Abrams(1916), and although the sandblast abrasion test was incorporated into ASTM C936 as early as 1982, it seems as if the first published investigation into the abrasion resistance of *concrete pavers* was in 1993.

Sukandar(1993) stated that 'to date, no laboratory or field data regarding the surface characteristic of concrete paving blocks produced in North America has ever been reported'. Consequently he investigated the effect of aggregate/cement ratio on various bulk characteristics (density, water absorption, compressive strength, tensile splitting strength), as well as surface properties such as abrasion resistance and initial surface absorption.

It does not appear that other investigations have followed, and again, this may be attributed to the requirement in ASTM C936 that the average compressive strength of a paving block be at least 55MPa, for freeze/thaw considerations.

Japan

Japan's Northern Island has a very cold winter climate with a great deal of snow. To prevent sliding, vehicles were in the past fitted with studded tyres and this resulted in severe abrasion in the asphalt surfaces (more recently studs are forbidden). Consequently numerous investigators over the years have considered the possibility of substituting asphalt with concrete, either insitu, or cbp. The investigators generally used an apparatus consisting of a rubber tyre with steel studs (it is still used). The axle of the tyre is orientated horizontally and is fixed in position, such that the tyre revolves around it while running on concrete specimens that are set in a horizontally orientated circular track moving beneath the tyre (see appendix U.3.5).

Another common practice in Japan is to install pavers/test-specimens in trial areas subject to heavy traffic volumes. For example Sato(1988) installed cbp in a road subject to 5000 'ordinary vehicles' per day, where spiked tyres were used in the snow/ice months. Average abrasion wear was measured as 2,9mm after one year, while the equivalent for asphalt was 6mm. After three years of traffic, the wear in the blocks was only 7,2mm; the wear performance of the concrete blocks was therefore adjudged 'sufficiently successful'.

Horiguchi(1994) reported on an experimental program where pavers were tested using four different abrasion tests; ASTM C779-B, a test with dressing wheels (see appendix U.3.06); ASTM C779-C, a test with ball bearings (see appendix U.2.12); ASTM C944, a test with steel cutters (see appendix U.3.09); and a test developed by the author involving steel balls bouncing in water (see appendix 2.06). Horiguchi noted that the depth of penetration of the different tests varied from 0,2mm through 3,6mm, and stated that it was *'very important to select a wear test method by considering expected wear depth'* for the application. He also found that some tests were more sensitive to variations than others. (His variables were fine-aggregate/coarse-aggregate ratio, w/c ratio, surface treatments). Interestingly his results show that the penetrating ball bearing test is clearly the most severe (capable of penetrations of 1mm in even the hardest surfaces), and that it is also sensitive (i.e. penetration depth varies significantly according to surface hardness).

Horiguchi(1995) did abrasion testing (ASTM C944) on pavers bonded to a steel plate. The upper surface of the steel plate was rubber lined.

Even as late as 2000 Suda(2000) used the studded tyre apparatus for testing experimental pavers. In addition, a 'chipping' test, referred to as a Cantabro test, was also used, whereby pavers are tumbled inside a Los Angeles abrasion machine (see appendix U.1.02).

It is clear that Japan does not have one fixed abrasion test, and selects the test that will best simulate the expected wear. More often than not the studded tyre test is chosen.

Recently various authors [Takeyama(2000), Karasawa(2000), Iwai(2000)] have reported on research done into 'whisper concrete' that reduces noise made by traffic, particularly at higher speeds. This is achieved by making the pavers permeable, but it appears that none of these researchers investigated the abrasion resistance of the pavers. This may be a matter of concern given that when Hata(1998) investigated the abrasion resistance of 'low-noise drainage-concrete' block pavement using the studded tyre apparatus, depth of wear measurements were only marginally less than that achieved in asphalt, whereas generally concrete pavers wear substantially less than asphalt. For example, Marakami(1998)'s considered the abrasion wear in low porosity, low w/b pavers; it was only about 30% of that in asphalt.

Summary of Abrasion testing in the Northern Hemisphere

If the countries considered above are considered representative of the Northern hemisphere, then it may be said that:

- not all countries test for abrasion resistance. (The high cement contents that are required to resist freeze/thaw effects and to meet the high compressive/flexural/splitting strength criteria, generally means that they also have adequate abrasion resistance).
- there is no uniform abrasion test, although conformity has now been achieved in Europe

2.4.2 Southern Hemisphere

Apart from the southern tip of Argentina and Chile, the countries in the Southern hemisphere are substantially free of freeze/thaw effects. This initially led to compressive strength requirements that were much lower than those specified in Europe, North America and Japan, and in the absence of an abrasion test, a number of surfaces manifested unacceptably high abrasion-wear. It was also not appreciated that abrasion wear is not related to compressive strength if poor attention is paid to curing, or the topping layer is poorly compacted etc.

Bullen(1994) acknowledged that the lack of knowledge (of abrasion processes) was instrumental in the 'premature failure' of many cbp pavements in Australia.

Shackel(1994) reports: 'In the early application of concrete segmental paving in countries with temperate climates such as Australia, New Zealand and South Africa, it was assumed that, because frost was not a problem in pavement engineering, the specifications need not include durability tests (freeze/thaw, abrasion resistance). However significant wear occurred in the surface of many segmental pavements laid in the 1970s and early 1980s in the southern hemisphere'.

Latin-America

Of eleven Latin-American countries that have national standards for concrete pavers, (Argentina, Brazil, Chile, Columbia, Ecuador, Guatemala, Haiti, Mexico, Peru, Uruguay and Venezuela) only three have abrasion tests [Madrid(1992)]. Argentina and Uruguay both use the 'Dorry' testing apparatus (see appendix U 5.1) and it appears that Guatemala uses a test that is similar in principle, the Amsler apparatus (see appendix U.5.2). Abrasion specifications in some of these countries are urgently required, particularly in Mexico and Ecuador, which have very low compressive strength requirements (respectively 24 MPa and 20 MPa). Alternatively the compressive strength should be revised upwards, although there is no ideal substitute for abrasion testing. The paving industry in these countries clearly lag that of the leading European states such as Germany and the Netherlands, both in terms of production capacity and technological sophistication. On the other hand some of these countries, e.g. Ecuador, have a very old tradition of stone paving blocks of 'superior quality' [Madrid(1994)].

Madrid(1994) is of the opinion that abrasion testing should be the definitive test in South American countries. It should take precedence over compression, tensile splitting, and flexural testing. He concedes however, that in places of high altitude or the regions of Argentina and Chile that are far to the South, a freeze thaw test may be required in addition.

Australia

In 1977 the CMAA asked the University of New South Wales to undertake a series of accelerated trafficking trials of full-scale prototype block pavements with the objective of establishing a sound technology for the use of the new paving system in Australia. The results of this work were presented at an Australian Road Research Board (ARRB) Workshop on Interlocking Concrete Block pavements in 1978 [Shackel(1986)].

In 1982 CMAA published a specification document 'Guide to Blocks' (MA15), for assisting with quality control of cbp production and supply. Although this document provided guidelines for sampling and testing there were no clauses relating to abrasion resistance.

In 1986 'Specification for Concrete Segmental Paving Units' (MA20) was published. This document contained an interim guide for abrasion resistance. The abrasion resistance is represented by an abrasion index, that is inversely proportional to the depth of penetration of steel ball bearings moving in a circular orbit on the surface of the block, (see appendix U.2.12). The test was developed by the Perth City Council and is derivative of ASTM C779-82 Proc C.

In developing this test, the Australians took samples of blocks from sites all over Australia with varying degrees of wear. They tested these specimens on their apparatus to see what abrasion resistance values the manufacturers had been obtaining. Newly made blocks from producers in the various states were also tested at age 28-days. After various discussions an abrasion index was selected which was acceptable to the manufacturers, and within their capabilities [Shackel(1985), Sharp(1986)].

However, it soon became apparent that the MA20 abrasion test had a relatively high standard deviation (see chapter 9). This led to investigations comparing MA20 with a 'Tumbler' abrasion test that was used by the South Sydney Council.

In 1993 the 'Draft Guide to the Specification of Concrete Segmental Units' (MA34) was produced. Here the 'Tumbler' abrasion test is specified (see appendix U.2.3). The test involves tumbling steel balls against the paver's surface.

However, according to Humpula(1996b) MA20 was still widely used for acceptance as of 1996. Nevertheless it seems that the 'Tumbler' test had gained the ascendancy by 1997, since it was incorporated as the official abrasion test in the new Australian/New Zealand Specification: 'AS/NZS 4456(1996), Masonry Units and Segmental Pavers - Methods of Test'.

The move from the MA20 to the 'tumbler' test reported in Shackel(1994) appears to be based on comparative testing reported by Shackel(1993a). The respective coefficients of variation were 13,4% and 8,5%, based on testing the sides of 12 concrete cubes, each cube being subjected to both tests.

MA20's high variability seems to be confirmed by results obtained by Bullen(1994), who subjected 10 randomly selected *pavers* to the MA20 abrasion test, and obtained a coefficient of variation of 28% at age 28-days. However, the fact that the equivalent compressive strength variability was 23% explains the increased variability of the abrasion results relative to those obtained by Shackel (who tested laboratory made *cubes*).

MA20 is partly exonerated by Humpula(1996b)'s result. He obtained a poor correlation between dry density and '*tumbler*' test wear, indicated by a R^2 value of 0,561, in spite of the fact that the 80 paver specimens were from 'four identical mix designs' and were all subjected to '28-days of laboratory curing'. Given these constants, the large variation in density (from 2040kg/m^3 to 2350kg/m^3) suggests very poor control during the filling/moulding/compaction process. However, even where the densities were the same, the abrasion index varied from between 4 cm^3 to 12 cm^3. (In these paves the density in the 'bulk' zone may have been substantially the same, while substantial variations may have existed in the 'surface' concrete).

It is therefore evident that poor correlation with accepted quality indicators such as density and compressive strength is possible with both tests, but under carefully controlled laboratory conditions the ‘tumbler’ test has the lower variability, thus justifying the move in that direction.

(Variability, while an important consideration, should not be taken as the sole selection criteria. In chapter 4 of volume 2, the writer discusses the different mechanisms of abrasion wear. The ‘tumbler’ test in question may be described primarily as a mild impact test, whereas MA20 results in localised crushing with minimal impact. The writer is of the opinion that vehicular and pedestrian traffic abrade by a gradual crushing process, which is better simulated by the MA20 test).

If the Australians are guilty of adopting abrasion tests that fall short of the ideal, they cannot be accused of paralysis. Any abrasion test is better than no test at all. Furthermore, their tests came out complete with recommended limits, and this gives both manufacturers and specifies alike a measuring tool to uphold standards.

In contrast, the industry in South Africa, faced with a similar or worse situation, have not seen abrasion testing through to the implementation stage, even after some 15 years of being made aware of the problem.

Summary of Northern and Southern Hemisphere

Before considering developments in abrasion resistance in South Africa it is interesting to reflect on a worldwide survey by Lilley (1991), tabulated in figure 2.1. Although Lilley does not give details of the type of abrasion tests, the table does indicate that relatively few countries demand abrasion testing for cbp. Even though the table is ten years out of date, it appears that little has changed regarding which countries test for abrasion resistance.

TABLE 2-1 WORLD-WIDE SURVEY OF ABRASION TESTS

COUNTRY	ABRASION TEST	
Australia	Yes	
Austria		No
Belgium		No
Brazil		No
Bulgaria		No
Canada		No
Columbia		No
Czechoslovakia		No
Denmark		No
Finland		No
France	Yes	
German Democratic Republic		No
German Federal Republic		No
Hungary		No
India		No
Ireland		No
Israel	Yes	
Italy	Yes	
Japan		No
Morocco		No
Netherlands		No
New Zealand		No
Norway		No
Poland		No
Romania		No
Saudi Arabia		No
Singapore		No
South Africa	Yes	
Spain	Yes	
Sweden	Yes	
Switzerland		No
Taiwan		No
Turkey		No
USA	Yes	
USSR		No
Yugoslavia		No

2.5 South Africa

2.5.1 Problematic Compressive Strength Criteria

Although an abrasion resistance test for SABS 1058 - 1985 (the official paving specification) was considered at the time of drafting, no test was included. (The interim CMA(1982) specification for pavers at the time did have an optional abrasion test. It consisted of pavers fastened to 4 plates which in turn made up the sides of a rotating box with steel balls inside as the abrading medium [see appendix U.2.04]. This test duration was 24 hours, making it very slow, and was therefore not well suited as a means of quality control in a production environment).

The only strength requirement finally included in SABS 1058 was and still is compressive strength. Accordingly a sample of 12 blocks must attain an average compressive strength of 25 MPa, with 20 MPa as an absolute minimum for individual blocks. (The value of 25 MPa (wet) is based on tests reported by Shackel(1979). He found that pavers with a compressive strength of 25MPa were in no way inferior to 55 MPa pavers in terms of load bearing capability; Lane(1988)).

The calculation used to derive the compressive strength in SABS 1058 uses the net chamfered area (the gross area is used in most other countries). The affect of this is that concrete with an intrinsic strength of less than 20 MPa may still comply.

Furthermore, most pavers are relatively squat, i.e. their height is substantially less then their width, compared to a cube. Therefore relative to a cube lateral dilation is more constrained owing to the increased contact of the upper and lower faces with the testing platens, relative to the height of the block.

The net effect of 'squat' pavers and of using a smaller area in the strength calculation is that the strength of the paver appears much higher than that of a cube made with equivalent material, by as much as 100% - see chapter 7 for fuller explanation.

In defence of SABS - 1058 it may be argued that the stresses under pneumatic tyres range between 0,15 to 0,8 MPa, and therefore providing the bedding sand supports the block in a uniform fashion (to minimise any bending effects) then 10 MPa should suffice.

However although borderline blocks with an intrinsic strength of the order of 10 MPa may be adequate from a structural point of view, they wear excessively under even moderate traffic conditions. The saving grace in many instances is that several manufacturers make their blocks well above the '25/20 MPa level.

In any event, when the SA strength requirement is compared with the 55 MPa requirement in the USA or 60 MPa requirement in Europe, there is clearly a huge difference. The questions that immediately come to mind are, 'Are the Europeans and Americans not perhaps over-designing for freeze / thaw conditions? And is the South African requirement and method of calculation realistic?' Lilley(1991) has commented, 'The strengths accepted in South Africa are much lower than strengths adopted elsewhere'.

2.5.2 Selection of abrasion tests

Without arguing the point any further, excessive wear was found on certain sites where blocks conforming to SABS 1058 had been installed, and this came to the attention of the CMA. It was realised that the industry's viability and image depended on the satisfactory long-term performance of the blocks. In the interests of upholding cbp as a sound construction material with good durability a decision was taken to explore ways of addressing this problem [Alexander(1989)].

In 1986 John Lane, on behalf of the Concrete Masonry Association, invited M G Alexander of the University of the Witwatersrand to research the problem of abrasion wear in cbp, and in particular to recommend an abrasion test for the paving industry. (Alexander(1984) published a paper on the different abrasion resistance tests currently in use in Germany, Belgium, France, Spain, USA and Israel. The paper included a critical examination of the tests including such aspects as the ability of the test to simulate practical conditions).

Alexander(1987) pointed out that the task of selecting the right test is complicated by the host of abrasion test types available:- Sandblast tests, rattler-type tests, mechanical abrasion type tests with discs, wheels or steel balls and so on. This proliferation is confirmed by the 32 abrasion tests examined by the Concrete Masonry Association of Australia (CMAA) in search of a suitable abrasion test [Sharp(1986)]. Appendix U of this thesis examines 66 abrasion/surface tests, and even this cannot be regarded as an exhaustive list.

After some deliberation between Alexander and the CMA, and an investigation into the latest work done on abrasion resistance, it was decided to make a study of a limited number of carefully selected tests that met at least some of the following criteria:

a. The test should be in current use locally or abroad since there would be no point in adding to the bewildering array of tests already in use.

b. There should be some existing data for purposes of comparison with clearly defined acceptance criteria.

c. The test should simulate the kind of abrasive actions that paving blocks are subjected to. Fortunately most cbp applications are limited to either leather soled pedestrian traffic or rubber tired vehicular traffic. It is therefore not necessary for the test to simulate hydraulic abrasion, abrasion due to high velocity impact from steel rims etc.

d. The test should be relatively simple and well suited to factory laboratory conditions. The test equipment required should be locally obtainable.

From this it was decided that four test types would be suitable:

a. The ASTM C418-81 sandblast test (see appendix U.5.21). The abrasive action is that of impinging and impacting forces on the surface of the block. The cutting action of the sand in this test can be expected to simulate the action of abrasive grit under vehicular and pedestrian traffic. Additional reasons for using this test were: (1) This is the specified abrasion test in ‘ASTM C936 – 82 Standard Specification For Solid Concrete Interlocking Paving Units’. (2) The test was already in use at the SABS. Thus comparisons with other tests results would be possible. (3) SABS were prepared to loan out the equipment if requested, although, making up the apparatus eventually proved to be more convenient.

b. The Australian MA20 - 1986 rotating ball bearing test (see appendix U.2.13). This test is a derivative of ASTM C779 Proc C-82. The abrasive action is that of ‘impact and sliding friction’ [Alexander(1987)] produced by the rolling steel balls. This can be expected to simulate the infinitesimal crushing effects of vehicular and pedestrian traffic. Considering the review of 32 abrasion tests done by the Australians, their research into the abrasion problem, and the eventual inclusion of this test into their national specification, it seemed logical to benefit from their results by including MA20 in this research programme. The apparatus (see appendix U.2.15) was also relatively simple to make up

c. The rotating wirebrush test adopted by PCI.TM7.11, see appendix U.6.02. Although this is a purely local test the PCI engineers believe that of all the abrasion tests in use it produces wear patterns that most closely resemble observed abrasion in cbp. The abrasive action is that of scratching, scraping and gouging out, and simulates the gouging action of abrasive grit beneath vehicular or pedestrian traffic, particularly during acceleration, deceleration and turning.

d. The ASTM C944-80 rotating cutter test (see appendix U.3.09). The abrasive action is predominantly that of impact and high local stresses due to the steel rotating cutters. This can be expected to simulate the impact and high local stresses caused by abrasive grit pressed down onto the paved surface by vehicular or pedestrian traffic.

It was a relatively simple matter to obtain and construct the test equipment for the MA20 and ASTM-C418 tests, while the equipment for the Wirebrush test was readily loaned from the PCI. It was therefore decided to proceed with these three tests. The only test for which equipment was not locally available was the ASTM C944 test. If the three selected tests all proved unsatisfactory the equipment for the ASTM C944 test could be imported and the test evaluated. However this test was later examined in a separate research initiative sponsored by the CMA, but has not shown any special merit [Robertson(1991)].

2.5.3 Other Abrasion Tests

Some other tests studied by Alexander(1984) are briefly reviewed below:

a. The DIN 52108-1968 grinding test. This test is described and discussed in appendix U.5.02. The apparatus is bulky and relatively expensive, and was therefore not considered as a test that would readily be adopted as a means of quality control in simple factory laboratories. Furthermore the wear mechanism of the test is such that aggregate particles that become unbonded cannot be released, which is unrealistic. This aspect is discussed more fully in appendix U.5.2. It is also necessary to prepare the specimen by sawing a piece of plan area of 70 mm x 70 mm

b. Other tests that were studied have their country of origin in Spain, Israel and Belgium. They are similar to that described in the DIN 52108 specification above and were left out for the same reasons.

c. In England the Cement and Concrete Association (C & CA) have a test apparatus for testing the abrasion resistance of concrete floors insitu [Chaplin(1987)]. This equipment has three rolling wheels which abrade a circular path approximately 225 mm in diameter and 25 mm wide (see appendix U.4.06) and is therefore not suited for laboratory testing of relatively small specimens such as paving blocks.

d. The Japanese have a rotary wear test in which a horizontal ring of pavers travels under a tired wheel, with or without chains (described in appendix U.3.05). The size and configurations of the apparatus requires that as many as 20 specimens would need to be tested at a time, and moreover the test specimens would first need to be sawn into wedge shaped blocks in order to neatly butt together in the circular track. A final consideration is that the test apparatus is cumbersome and too expensive, more than the average manufacturer would be prepared to pay for a piece of equipment in a factory laboratory.

(It should be stressed that the considerations given above that led to the exclusions of these tests date back to 1986/7. However the recent considerations of the ‘mechanisms of wear’, discussed in chapter 4 of volume 2, shows some reversal of thought, whereby the C&CA test is recommended as one of three tests that deserve fresh consideration as an abrasion test for pavers).

2.5.4 The Test Programme

With the selection of the sandblast, ball bearing and wirebrush test, phase 1 of the testing programme was initiated. Alexander(1989) named the objectives of this phase as:

a. To become acquainted with the test equipment, and to become proficient in its use.

b. To determine the basic functional relationships of each type of test (i.e. the form of the wear-duration curve).
c. To determine suitable limiting abrasion values and indices, as well as the most suitable way of calculating indices. (e.g. Should lower bound, average or 80th percentile values be used?).
d. To assess the tests critically in terms of abrasive action, sensitivity, reproducibility, repeatability, and the relative ranking of the different tests.
e. To correlate test results with insitu performance of pavers.

Two students were involved in the phase 1 work, Papenfus (the writer) and Holland.

1. Papenfus – this work is fully described in the remainder of this thesis.

2. Holland(1991) - Tests using the same three abrasion tests selected by the writer, plus a compression test, were carried out on groups of blocks from six sites in Johannesburg and a control set of blocks supplied by the CMA. The ages of the city blocks varied from three to six years, with insitu appearance varying from ‘very good’ to ‘very poor’. The abrasion tests were analysed in terms of wear-duration curves, variability, suitability, limiting values and indices.

   Holland found that the relationship between compressive strength and abrasion resistance at the respective sites was very varied. He concluded that compression testing alone is inadequate, and that an abrasion test is required.

2.6 Summary and Concluding Remarks

This chapter has reviewed the origins and development of paving systems, from ancient times where paving was done with flat stone slabs, to recent applications of cbp.

This was followed by a consideration of its five most useful attributes, i.e. economic viability, waterproofing ability, load-shedding capability, aesthetic appeal and finally abrasion resistance. The abrasion resistance of cbp is therefore seen in a wider context.

A section is devoted to the emphasis placed on abrasion testing by the various countries. Where abrasion tests are in force, the historical developments leading to the adoption of those tests is traced. Special attention is given to the events that led to this investigation and other related research into abrasion resistance in South Africa. The ideal criteria of a cbp abrasion test are outlined, and reasons are given for the selection of the three chosen abrasion tests.

Although a survey of the factors that affect the abrasion resistance of cbp (and concrete surfaces in general) properly belongs here, this aspect is comprehensively investigated in chapter 2 of Volume 2.

This concludes the Introductory Section consisting of:

Chapter 1 – Introduction
Chapter 2 – Background

The next three chapters will focus on the experimental phase relating to this investigation.