OPTIMISATION OF NON-SKID CHARACTERISTICS IN CONSTRUCTION OF CONCRETE PAVEMENTS

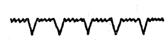
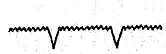
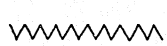
Yves CHARONNAT LABORATOIRE CENTRAL DES PONTS ET CHAUSSEES - FRANCE -

Jean-Pierre LEFEBVRE ENTREPRISE GTM-BTP - FRANCE -

Alain SAINTON ENTREPRISE BEUGNET - FRANCE -

1. INTRODUCTION

A burlap drawn over the fresh concrete was the first method used to create a friction surface. Its role was to expose the ridges of the sand grains of the surface mortar. The roughness thus obtained is afforded by upward projecting bumps measurable in millimetres. The sand-patch test result obtained is approximately 0.6 mm and the longitudinal friction index at 120 km/h averages 0.15 after six months traffic [1]. As water drainage was not ensured by this aspect of the surface (risk of aquaplaning), the size of these bumps was increased by scoring the fresh concrete with a broom (1966). The new bumps thus obtained can be measured in centimetres. Generally, these two processes are combined as a rule, whence the simultaneous existence of micro-roughness and macro-roughness. There is a considerable improvement in the grip to the ground of the surface concrete. It was Wehner [2] who first introduced a roughness scale (table 1).

SURFACE TYPE	DIAGRAM OF PROFILE	DESCRIPTION
1		Without micro-roughness or macro-roughness
2		Micro-roughness only (H.S.~ 0.5mm)
3		Macro-roughness (by hollows and dales) and micro-roughness
4		Micro-roughness and macro-roughness as in 3, but with less dense macro-roughness (greater distance between dales)
5		Macro-roughness (by intervals between aggregates) and micro-roughness (by aggregate ridges)
6		Macro-roughness (by intervals between aggregates) without micro-roughnsess (H.S.~ 2 to 3 mn)
7		Macro-roughness (by hollows and dales) without micro-roughness

2. THE DEVELOPMENT OF SURFACE CONCRETE

If the above-mentioned values were considered satisfactory, they were nonetheless irregular and a fast decrease could be stated in course of time.

There are at least three possible causes for the irregularity of the macro-roughness, i.e. the grooving resulting from scoring :

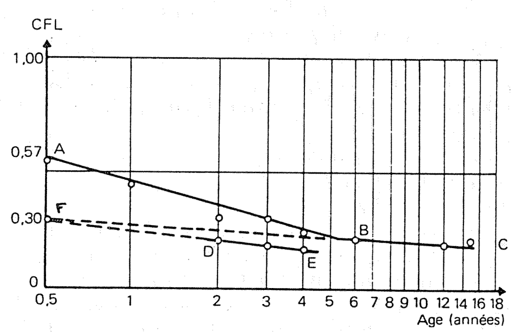
. The material in situ can produce various aspects. The quality and the quantity of the mortar in surface can be irregular.

. The moment of brooming is not always carried out at exactly the same stage. The hardening of the mortar plays then an important part.

. The pressure exerted on the broom is not constant. The state of the ground on which the tractor is driven is not always satisfactory, the connecting point of the broom varies in height.

Fig 1. Decrease of CFL (40 km:h) in time (heavy truck lane A6 motorway built before 1970)

ABC : scoring
FCB : burlap
FDE : Burlap with very early reopening



CFL = Longitudinal non skid index

In, 1973, J.BARON and JL NISSOUX [3] published a very complete analysis about the development of roughness under the effect of traffic (table 2) and the life of the grains located on the surface of the pavement (fig. 2).

Table 2 Evolution of roughness under the effects of traffic

<table>
<tr><th colspan="4">Probable evolution of profile according to the nature of materials</th><th>Number and diagram of balance profile (1)</th></tr>
<tr><td>(2)</td><td colspan="3">(3)</td><td>2b
2bs</td></tr>
<tr><td rowspan="3">(4)</td><td>(5)</td><td colspan="2">(6)</td><td>72b
72 hl</td></tr>
<tr><td rowspan="2">(7)</td><td>(8)</td><td>(9)</td><td>62b</td></tr>
<tr><td>(10)</td><td>(11)</td><td>52b</td></tr>
</table>

(1) This number refers to table 1 which shows CFL variation according to vehicle's speed for different profiles.

(2) There is only mortar on the surface.

(3) The micro-roughness is regenerated but macro-roughness tends to disappear. If the mortar is scored, the grooving can only disappear.

4) The pebbles and fine gravel appear on the surface.

5) The pebbles and fine gravel disappear quicker than the mortar.

(6) The micro-roughness is regenerated between te aggregates. The aggregates show either flat (the case of "Los Angeles" limestones) or hollow (the case of light-weights) surfaces.

(7) The pebbles and fine gravel disappear less quickly than the mortar.

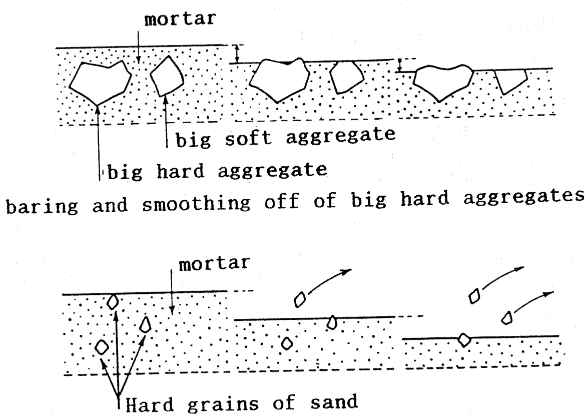
(8) The pebbles and fine gravel are pea-sized.

(9) A macro-roughness is regenerated but the micro-roughness is limited to the mortar surfaces included between the aggregates.

(10) The pebbles and fine gravel are crushed.

(11) Macro-roughness and micro-roughness are partially regenerated.

Fig 2. Life of surface grains



In particular, this analysis points out :

. That the micro-roughness is most efficient at low speeds.

. That the micro-roughness is jointly achieved by the effects of the mortar and the micro-roughness of the fine gravel.

. That at 120 km/h the macro-roughness is mostly felt by the drainage effect.

. That the angularity of the grains have a positive effect on the roughness.

. That the general wear on a green concrete pavement is usually between 0.3 and 0.7 mm per year.

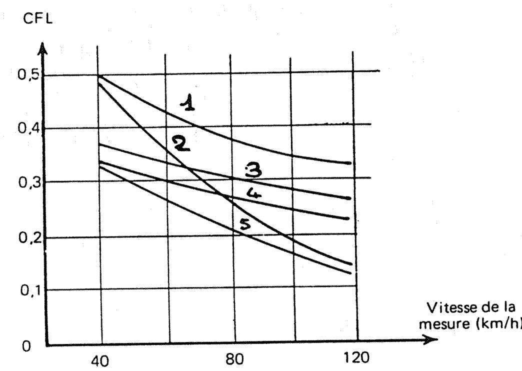
With such results the relative roles of both the fine surface gravel and the matrix made of the mortar can be appreciated. This analysis enabled to propose different methods for cement concrete pavements. Two were selected :

. Moulding of deep grooving.
. Increase of the resistance to wear of the surface.

Fig 3. CFL values for different surface treatments.

New pavement
1. Scoring and burlap
2. Burlap

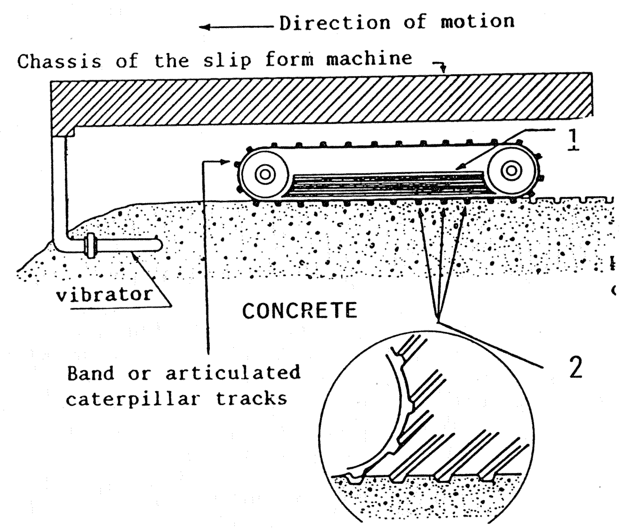
Apparition of aggregates
3. Crushed aggregates
4. Hard natural rounded aggregates
5. Soft natural rounded aggregates



CFL = Longitudinal non skid index

Moulding tests were carried out at the Laboratoire Central des Ponts et Chaussées [4], and then in situ. (Fig 4).

Fig 4. Project of a machine enabling transversal grooving to be moulded



(1) Apparatus ensuring the surface evenness of the band or carterpillar tracks

(2) Elements attached to the band or articulated caterpillar tracks

This grooving is made beneath the moulding table when the concrete is subjected to vibration. If there is no difficulty in making the longitudinal grooving, on the other hand transversal grooving requires major modifications on equipement.

The abandon of longitudinal grooving in 1976 brought this analysis to an end. Thus remained the second solution which had begun as early as 1974 but which had only progressed very slowly because of the small number of concrete pavement sites in France.

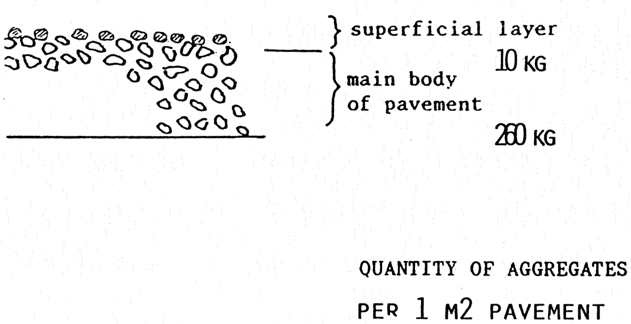
This analysis enabled major progress to obtain a good roughness. Indeed, it was at this stage that the dissociation of the two functions starded :

. Mechanical resistance, which concerns the aggregates in the main body of the slab.

. Capacity of resistance to wear, which concerns the surface aggregates.

Fig 5. Dissociation of functions

- Mechanical strength
- Wear



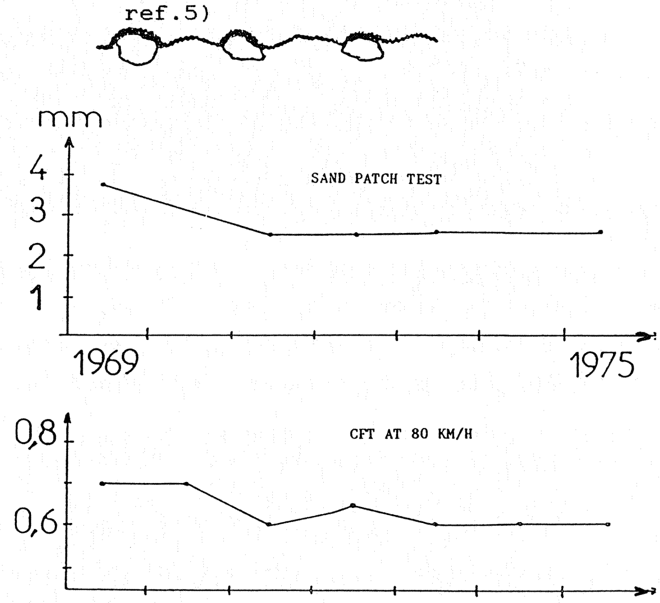
Moreover, according to these theories, it appears that the only means to ensure surface longevity is to incorporate the fine surface gravel, and consequently to select a non-polishable type.

3. STUDDING

The solution adopted in 1976 to satisfy these criterias was to incorporate very hard fine gravel (studs) into the surface mortar.

The studding was carried out under the supervision of the Highway Research Center in Brussels [5], firstly on pavements laid between set forming (Bury Graffe 1969) and then on pavements laid with slip form machines (Bernissart 1979). The longevity results of the surface aspect are excellent (fig 6) after over six years of use.

Fig 6. Evolution of grip to the road for a studded pavement (see bibliography ref.5)



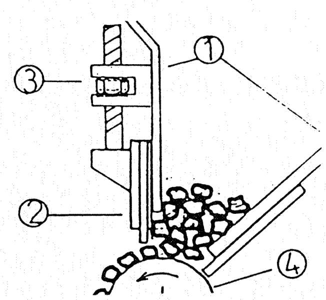
The studding involves of three successive operations [6] :

. The gauging
. The distribution
. The embedding.

The gauging of studs is performed by extraction. A notched drum, situated beneath the bin in which the studs are stored, extracts the studs by rotation (fig. 7). For a consistent gauging; the rotation speed of the drum must be proportional to the progressing speed of the machine. The studs must also be extracted in one layer. The notching of the drum must be very prominent (ribmesh lacing) with meshing of dimensions adapted to the size of the studs.

Fig 7. Studding gaugin of studs

1. Walls of the bin
2. Trapdoor
3. Opening control
4. Drum



The ramdom distribution of the studs is obtained by the presence of "impediments" in their path. These impediments consist of wires stretched in a parallel direction to the drum. These wires are layed out on two secant planes to avoid the "chimney flow" phenomenon between the drum and the upper series of wires.

Fig 8. Studding - spreading of studs

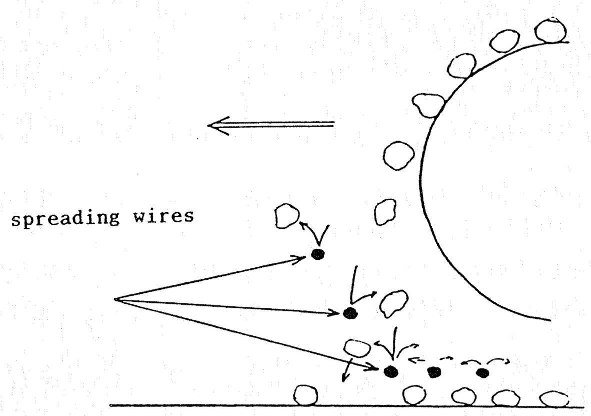
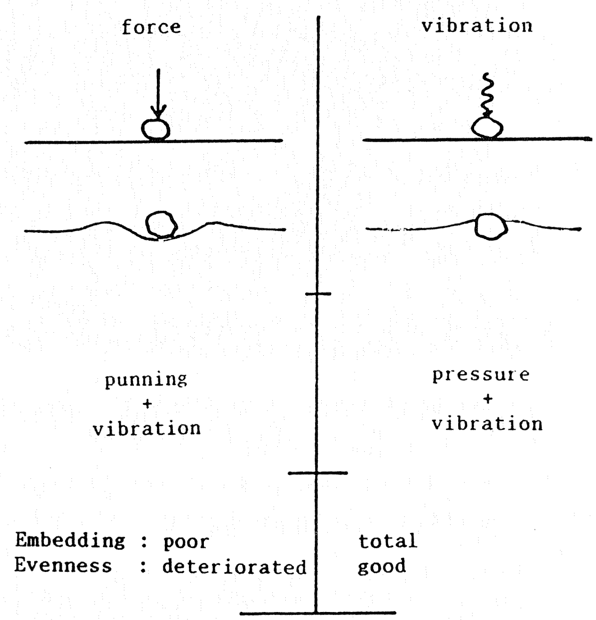


Diagram of spreader

Fig.9. Studding - Embedding



Embedding methods for STUDS

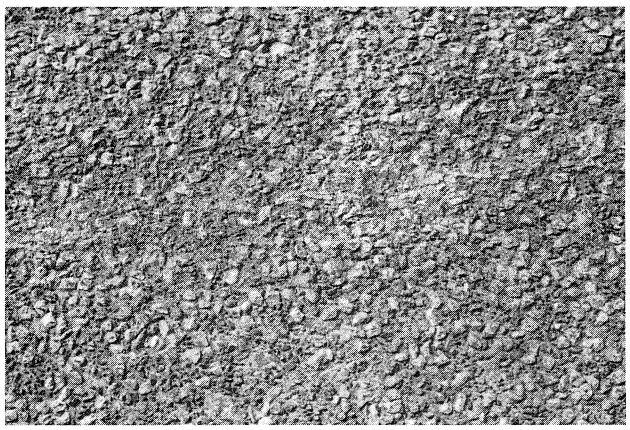
Embedding is created by a beam. In the first tests this beam was knocking on the studs. A vibration was applied to this beam. The period of contact was too short for the vibration to have an effect. Moreover, the impacts tended to deform the surface (evenness). At a later stage, the application of the vibration was improved by maintaining the plate in permanent contact with the stud (fig.9). The vibrating plate has a profile, a structure and a vibrating apparatus that enables progressive and consistent embedding of the studs in the concrete.

4. STRIPPING

The stripping was also analysed at the Higwhay Research Center in Brussels [7]. Originally carried out on test strips of small dimension, it was then carried out full scale on sites in 1980.

It was applied on studded concrete in France in 1984, and on traditional concrete in 1985.

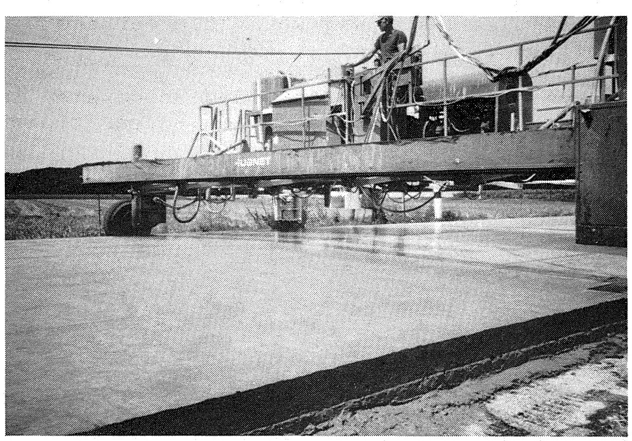
Fig 10. Aspect of studding



The principle of stripping is to throw the fine surface gravel into relief without deterioating its behaviour in the pavement. Because the cohesion of fresh concrete is insufficient to face the mechanical stress of brooming, the concrete in the mass must have reached a certain resistance before the surface mortar has begun to set.

To achieve this goal, a retarding mixture is spread over the surface of the slab (fig.11). This retarding mixture consists of a sugared solution to which is added a pigment that enables the visual monitoring of proper spreading over the slab. The gauging of this product varies according to the proportion of antistripping agent, stripping time and the setting properties of the cement.

Fig 11. Stripping - Spreading of retarding admixture

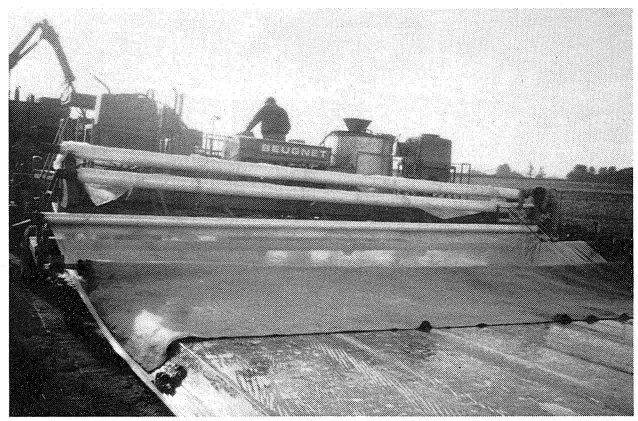


A curing is then carried out to protect the retarding mixture from the weather effects (sun, wind, rain....) and to conserve its effectiveness. Two curing methods are used in France :

. A curing product
. Polyethylene sheets (fig.12)

The curing product is spread as quickly as possible. The two products must be used separately in order to control the desired effects.

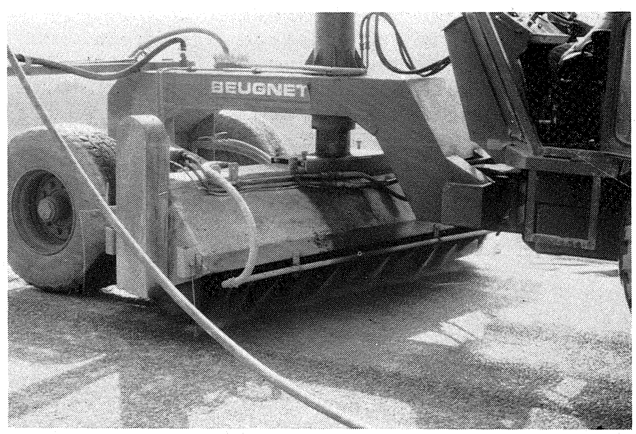
Fig 12. Stripping - Laying of polyethylene



Though the laying down of polyethylene sheets is more incovenient (wind), on the other hand it affords greater protection against rain low temperatures etc.

The stripping is carried out by using a broom with metallic or plastic bristles, with or without water (fig.13).

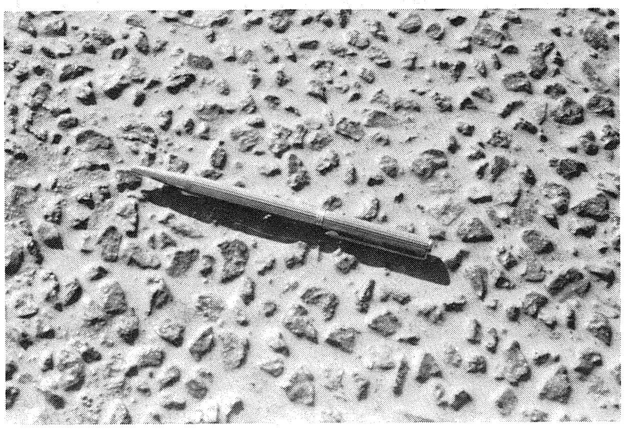
Fig 13. Stripping - Brooming of pavement



The brooming takes place between 6 and 24 hours, depending on ambient temperature. Several passes are sometimes necessary. This operation depends on a number of paremeters evaluated on the site (fig.14).

When the brooming takes place very early, another concrete curing must then be carried out.

Fig 14. Aspect of stripping



5. CHARACTERISTICS OF SURFACE GRAINS AND CHOICE OF TECHNIQUES.

For stripping to be carried out on a cement concrete pavement it is necessary that the fine gravel be suited to the slab surface.
The grains in question are of 12 mm dimension (particle size class 10/14). This dimension seems as far as we can tell at present, to be the least noisy with good drainage efficiency. Moreover, this is quite a common size grading, used in surface dressing. These grains are extracted from massive rock (presence of sharp ridges), and must be "cube-shaped". Their mechanical properties (MDE, Los Angeles, CPA...) must be the same as those of aggregates for high performance surface dressings [8] (fig.15).

Fig 15. Quality of surface grains

Granularity	Regularity of upward projecting bumps
Cleanliness	Adhesion to mortar
Flattening	Regularity of embedding
Hardness	Evolution of macro - roughness and resistance to frost
Grinding off	Survival of macro - roughness

Four situations can be defined depending on the quality of all the aggregates used.
The aggregates are up to specifications against wear. The stripping is performed directly on the concrete. For the density of 10/14 surface grains to be sufficient, the concrete mix design is carried out by loading this class (at least 400 kg per cubic metre of concrete).

When the agreggates and eventually the sand do not meet the specifications, three solutions can be considered.

The sand is of good quality and there are aggregates up to the specifications near the site. In this case the intermediate fraction is replaced by 10/14 aggregates. As above, gauging will be at least 400 kg/m^3

The sand is not up to the quality required but there are some materials (sand and 10/14) up to the specifications near the site. In this case the wearing surface is carried out with two qualities of concrete, the upper part of the slab being made of a 0/14 concrete. Construction of such a pavement requires suitable equipement. The two qualities of concrete must necessarily be placed simultaneously, as to produce a monolithic layer [9].
Finally, if there are no materials suitable to the surface layer near the site, the studding is carried out. This enables aggregates from distant deposits to be reduced to the lowest possible volume. The surface covering should then be complete, which requires a gauging of at least 5 kg per square metre of pavement. As already mentioned, the equipment must be suitable.

Table 3. Studding and stripping sites

SITE TYPE	DATE	SURFACE TREASTED
Studding only (vibration)	1979 1984	1.600.000 m²
Studding - Stripping	1983 to 1988	2.500.000 m²
Stripping on concrete with class replacement	1985 to 1988	Motorways 6, 71 and 9 1.400.000 m²
Stripping on double quality	1986	Motorway 71 250.000 m²
Stripping on traditional concrete	1985 1986	National Highways 6 and 85 250.000 m²

Fig 16. Noise rating on stripped pavements and on a pavement in coated materials.

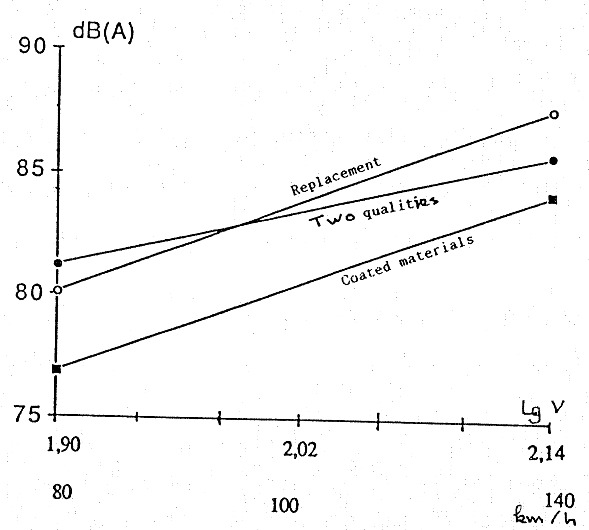


Fig 17 .Coefficient of longitudinal friction (120km/h) on stripped concrete.

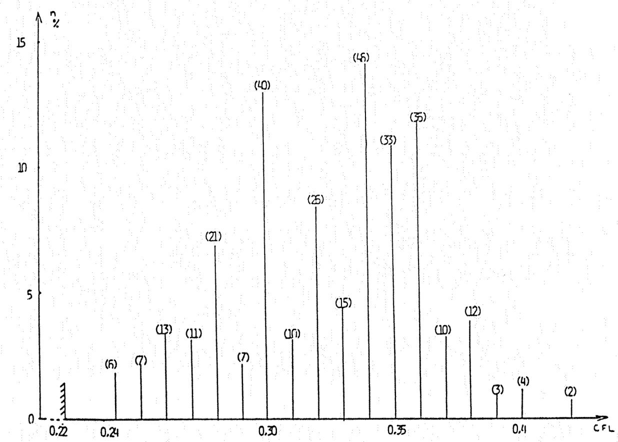


Fig 18. Table of mean CFL values obtained on Motorway 26 between Cambrai and St Quentin, on opening. Thick slab in studded an stripped cement concrete

Speed	40 km/h	90 km/h	120 km/h
CFL	0,61	0,48	0,41

CFL = Longitudinal non skid index

6. APPLICATION AND RESULTS

All these techniques have been applied with perfectly satisfactory results in France. Table 3 summarises the surfaces carried out to date. Different tests have been carried out, and the results of these are presented in figures 16, 17 and 18.

These results show that no matter which technique was applied, the studding-stripping or the stripping comply with the roughness target.

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