TECHNIQUES FOR ACHIEVING NONSKID PAVEMENT SURFACES ESPECIALLY BY DEEP TRANSVERSE GROOVING OF FRESH CEMENT CONCRETE

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One of the research projects conducted by the Belgian Centre de Recherches Routières on slipperiness was on deep transverse grooving of fresh cement concrete. Several test sections were constructed, and their behavior was followed for over 10 years. Deep transverse grooving consists of imprinting into the pavement surface 5- to 7-mm-deep grooves, 15 to 30 mm apart. The measurements that have been carried out have brought to light the substantial increase of the sideway force coefficient (SFC) of a grooved pavement as compared to that of a smooth one. These measurements have permitted the definition of quality factors of a grooved concrete pavement. For example, the SFC drop between 20 and 80 km/h is correlated linearly to the inverse of the surface mean leveling depth, and the SFC value for a low speed depends, for practical purposes, on only the polish condition of the surface aggregate. Practical criteria have been based on this: (a) No polish-susceptible stony or sandy element may appear at the pavement surface; and (b) the average leveling depth of the grooved surface must reach at least 2 mm. Grooving may be achieved by combs or fork-like tools. A prototype machine for both grooving and spreading the curing compound has been developed and is now in use. Practical recommendations for users and machine manufacturers are offered. In addition to antiskid properties, grooved surfaces have several secondary advantages and drawbacks: (a) noticeable improvement of surface drainage, (b) reduction of dazzling glare due to the reflection of grazing light, (c) possible increased tire wear, and (d) an unpleasant whizzing noise, which could, however, be checked by a random spacing of grooves.

•ACHIEVING high and lasting pavement skid resistance, even at high speed, is becoming a primary aim of road construction. The roughness criteria to be adopted depend on the site, allowed speed, and traffic volume. Those proposed in 1957 by Giles of the British Transport and Road Research Laboratory (TRRL) are still pertinent (1, 2, 3). It is important that proved construction techniques be made available to the road engineer.

As early as 1956, the Belgian Centre de Recherches Routières initiated several research projects on roughness and the development of both cement concrete and bituminous concrete skid-resistant pavements (4, 5). The results of those investigations have been published and are reflected in official specifications. The following 5 solutions are allowed by these specifications:

1. Bitumacadams and tarmacadams (6, 7),
2. Unchipped bituminous concrete (8, 9),
3. Chipped bituminous concrete (10),
4. Chipped cement concrete (11, 12), and
5. Transversely grooved cement concrete.

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As a consequence of inadequate construction or the polishing action of traffic on polishable aggregates, the road engineer is faced with the problem of restoring the skid resistance of both bituminous pavements and cement concrete pavements. For cement concrete, mechanical procedures, such as the use of a diamond saw, may enable some roughness to be imparted to slabs that have grown slippery. Such procedures, however, are costly. They are technically efficient when the surface aggregate is hard and has a very low polish susceptibility, but they yield poor results when the aggregate has polished under traffic or when it is made of too polishable a stone.

For both cement concrete pavements and bituminous pavements, very promising techniques are being developed to restore antiskid properties by synthetic resin surfaces. Such surfaces must be waterproof, thin, rough, harsh, and lasting. Their use implies that their support and foundation are in good condition (13, 14). In addition to synthetic resins, they include a hard, little polishable aggregate. The high cost of such surfaces has been criticized. However, they appear to offer the best cost-performance ratio when use of traditional materials is difficult and when particularly exacting safety, time, or thickness requirements are imposed.

CHOICE OF A SURFACE TREATMENT TECHNIQUE FOR CEMENT CONCRETE

From 1950 to 1961, numerous manual, on-site experiments on various surface textures were carried out in Belgium. Observation of the performance of those test sections under traffic indicated that achievement of high skid resistance on wet pavement is related to 2 general features (34):

1. The presence of a rough surface texture and
2. The absence of polishable aggregate or polishable sandy elements at the concrete surface (harsh surface).

As a result of those tests, the following 2 types of surface treatment were retained:

1. Imbedding of chips at the surface of the fresh concrete (Fig. 1) and
2. Deep transverse grooving of the fresh concrete (Fig. 2).

After over 10 years of traffic wear, the test sections thus treated yielded excellent roughness values at high speed (80 km/h), as given in Table 1 (4, 15). Results noted on untreated reference sections are included in this table for comparison. The Centre de Recherches Routières started a technological research project as early as 1966 for the development and mechanization of deep transverse grooving.

Mechanical imbedding of chips in fresh concrete has recently met with renewed interest in Belgium (11, 12) because it permits use of polishable aggregates in the bulk of the concrete when chips of very low polish susceptibility are used on the surface.

PRINCIPLE OF TRANSVERSE GROOVING

Deep transverse grooving consists of creating a rough surface texture made of transverse grooves 5 to 7 mm deep and 15 to 30 mm apart (Fig. 3). In rain, these grooves provide for surface drainage and decrease the thickness of the water film between the tire and the pavement. This procedure is an efficient means of checking hydroplaning. We consider that lengthwise grooving of fresh concrete should be banned because such grooving does not provide for drainage as does transverse grooving. Furthermore, it brings on a yaw effect that is detrimental to vehicle driving and passenger safety.

PERFORMANCES ATTAINED BY TRANSVERSELY GROOVED CONCRETE

Belgium is one of the few countries in the world where transversely grooved cement concrete sections that have carried traffic for over 10 years can be found. Figure 4 shows the performance of 1 pavement. The constant gain in sideway force coefficient (SFC) displayed at 50 km/h on a transversely grooved concrete is compared to that of

Figure 1. Imbedding 10/18-size porphyry chips by tamping.

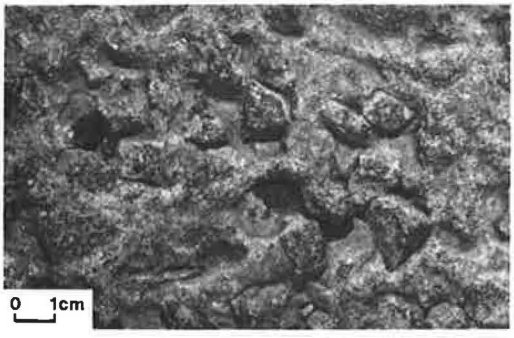


Figure 2. Tranverse grooving with a metal stand comb.

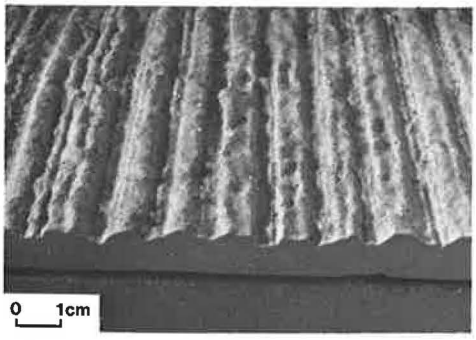


Table 1. Performance of different types of fresh concrete surface treatments.

Type	Surface Treatment	Traffic in 1970, 6 to 22 h (vpd)	Number of Years of Traffic	SFC at 80 km/h and 20 C	SFC Drop Between 20 and 80 km/h
1	Embedded chip	2,800	13 to 16	0.53 to 0.64	0.24 to 0.30
2	Smooth reference section	2,800	16	0.40	0.41 to 0.45
3	Transverse grooving	10,700	11	0.55 to 0.75	0.04 to 0.27
4	Smooth reference section	10,700	11	0.42 to 0.50	0.29 to 0.42
5	Reference section with polish-susceptible aggregate	12,100	13	0.25 to 0.44	0.22 to 0.34

Figure 3. Deep transverse grooving with 6-mm-diameter metal forks, 20 mm apart.

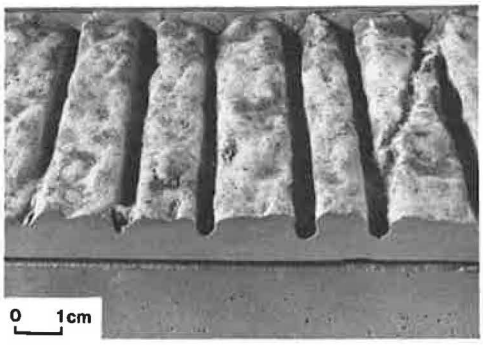
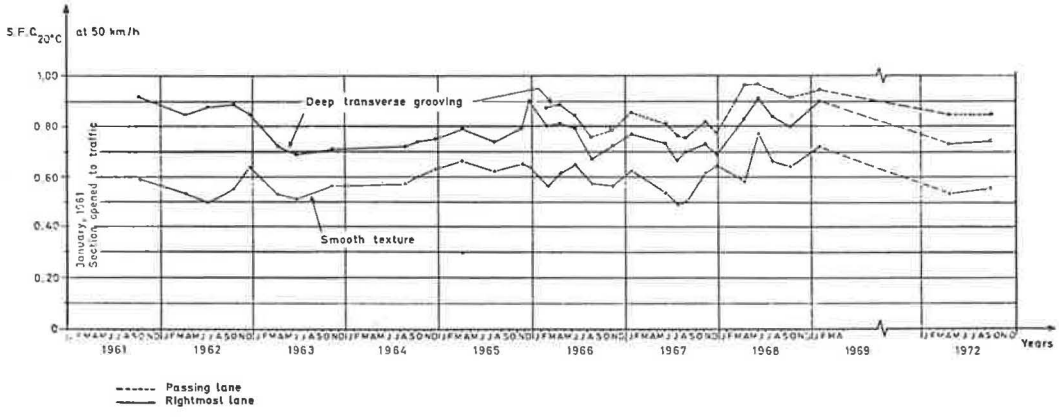


Figure 4. Evolution of sideway force coefficient at 50 km/h of 2 identical pavements, one deeply grooved, the other smooth.



a concrete with a smooth surface. SFC on wet pavement was measured with a TRRL odoliograph outfitted with a smooth tire. A correction was applied for conventional reduction of the measured value to a water temperature on the pavement of 20 C (3). Investigations also brought out the influence exercised on SFC by the difference in weight of the traffic (15, 16). The SFC values measured in the far right lane and passing lane of an expressway are shown in Figure 4 (86 percent heavy vehicles were in the far right lane and 14 percent were in the passing lane).

QUALITY FACTORS OF TRANSVERSE GROOVING

Systematic analyses of SFC values at different speeds (20, 50, and 80 km/h) have brought to light 3 facts (17).

1. The larger the mean leveling depth, H, of the grooved texture [sand patch test, (18)], the smaller the SFC drop between 20 and 80 km/h at any time during the life of the pavement. The linear regression equation between these 2 variables reads, in the interval 0.40 mm < H < 3.0 mm,

$$\Delta SFC_{20-80\ km/h} = \frac{23}{H} + 2$$

H is expressed in millimetres and ΔSFC is expressed in hundredths of unity (19).

The correlation coefficient obtained by putting together 43 measured pairs of values from 3 different grooved sections was found to exceed 99.9. This relationship is independent of the state of polishing of the pavement.

2. The SFC value at 20 C at a speed of 25 to 30 km/h is for practical purposes independent of H; it depends mainly on the polishing condition of the elements present at the pavement surface at the time of measurement. This is shown by Figure 5 which compares the SFC values of a grooved concrete and a smooth concrete at different speeds after 3 years and 10 years of traffic wear. The poor results obtained at 80 km/h as a consequence of a smooth surfacing should be stressed.

3. For pavements with identical large-scale surface texture, the rate of decrease of the SFC, at any speed, under the action of traffic, is larger or smaller according to whether the pavement surface contains or does not contain polish-susceptible elements (Fig. 6).

CRITERIA FOR A LASTING TRANSVERSE GROOVING

The practical application of the aforementioned rules has led to the formulation of execution criteria aimed at ensuring the following performances after many years of traffic wear: (a) SFC value at 20 C and 80 km/h larger than 0.50 and (b) SFC drop between 20 and 80 km/h of about 0.15 to 0.25. The criteria are fine- and large-scale texture. For fine-scale texture, no polish-susceptible stony or sandy element may appear at the pavement surface. Therefore, the surface aggregate must have a high enough polished stone value (PSV) (20). The required value depends on the site, allowed speed, and traffic volume (21, 22). Sands made from a polish-susceptible material must be banned. For large-scale texture, the grooves must be 15 to 30 mm apart, and their depth must be such that, after early trimming of the grooves under traffic, H is at least 2 mm. This should meet the requirement for a residual H of at least 1 mm after 2 or 3 years of traffic wear. These performances have been achieved with the conventional Belgian concrete mix design, which is relatively dry, rich in cement, and rich in mortar compared to concrete mixes used in other countries. That is to say

$$W/C \approx 0.42$$

$$C = 375 \text{ to } 400 \text{ kg/m}^3$$

$$C + S = 805 \text{ to } 825 \text{ kg/m}^3$$

Figure 5. Sideway force coefficient values.

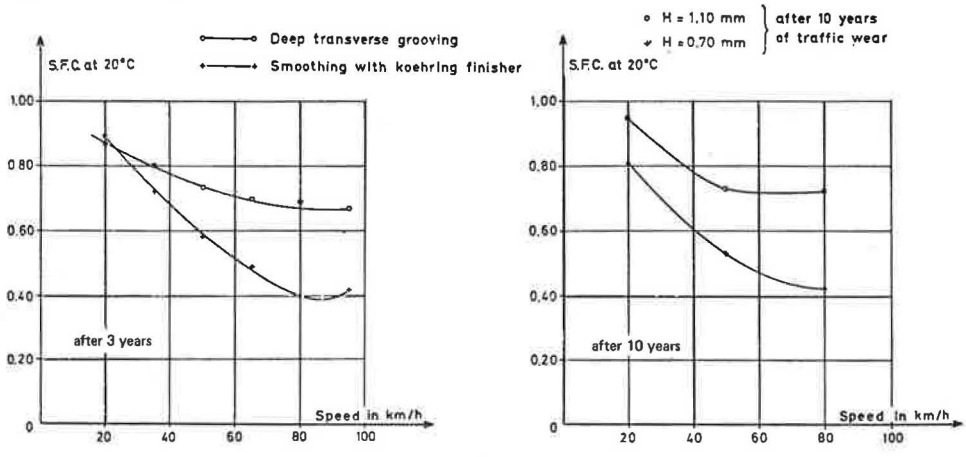
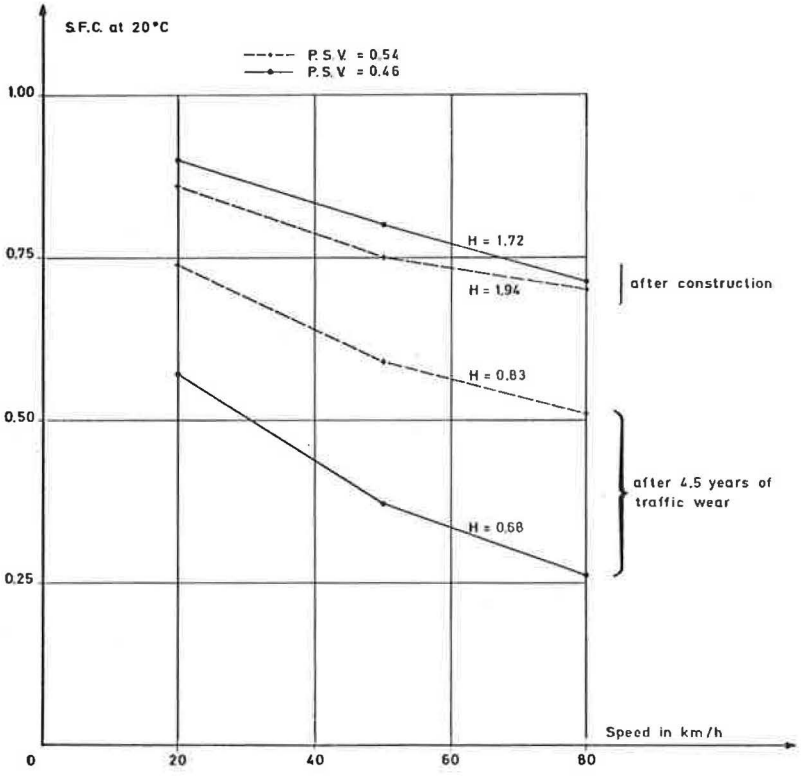


Figure 6. Influence of polishing of surface aggregate on evolution of slipperiness with time.



where

C = kilograms of cement per cubic metre of fresh concrete on the site,
S = kilograms of sand per cubic metre of fresh concrete on the site, and
W = litres of water per cubic metre of fresh concrete on the site.

The practical execution of the grooved concrete must comply with current expertise for choice of materials, mix preparation, application on the site, and grooving and curing of fresh concrete.

CHOICE OF A GROOVING TOOL

Choosing an adequate grooving tool is essential to achieve an effective transverse grooving. The tool must groove the fresh concrete without appreciably disturbing the surface or pulling stones away. Two types of grooving tools were selected, namely,

1. Fork-like grooving tools (Fig. 7) made of pivoted curved metal teeth, 4 to 6 mm in diameter, 15 to 30 mm apart, individually loaded with 300 to 500 g each, that imprint transverse grooves 5 to 7 mm deep into the mortar (Fig. 3); and
2. Combs made of a single row of bundles of metal or PVC strands, 15 mm apart (Fig. 8). Each bundle, ballasted with 30 to 50 g, consists of 10 strands 65 to 75 mm long. The grooves obtained with such combs are somewhat less regular and shallower than those made by the fork-like tools, but the texture of the mortar is harsher than in the case of fork-made grooves (Fig. 2).

Whatever the type of grooving tool used, some authorities feel that it is advisable to randomly space the grooves (23).

MECHANIZATION OF TRANSVERSE GROOVING

Various machines for grooving and spreading the curing compound have been at work for several years in Belgium. The first ones were the outcome of the development of a prototype conceived in 1967 by the Centre de Recherches Routières in collaboration with a group of contractors (24) (Fig. 9). The wide experience gained on numerous works from 1967 to the present enabled us to specify several criteria to benefit practitioners and machine manufacturers (19). We recommend study of the possibility of conveniently exchanging various rational tools, adjusting grooving pressure, carrying out a repeated grooving at the same place, devices for avoiding nozzle clogging and sedimentation of the curing compound pigments, existence of safety devices, possibility of controlling the spray flow, automatization of the full cycle (grooving and curing compound spraying), ease of displacement on the works, quick extension of the machines to different concreting widths, and progression speed of the grooving process being appreciably larger than the average concreting speed.

PRACTICAL POPULARIZATION OF TRANSVERSE GROOVING IN BELGIUM AND EUROPE

The early mechanical executions of transverse grooving data back to 1967. From 1968 to 1970, grooved pavements increased in number in Belgium; since January 1, 1970, a standard specification for state highways (25) has prescribed the method of generalized application of the mechanical transverse grooving of fresh concrete. This requirement has resulted in the execution of 4 800 000 m^2 of grooved expressway pavement, 1 350 000 m^2 of state highways, and 45 000 m^2 of airfield runways. The present cost of fresh concrete transverse grooving varies between 1.70 and 7.00 Belgian francs per m^2 (0.04 to 0.16 U.S. dollars).

Apart from Belgium, which, at present, is the most important concrete road builder in Europe, transverse grooving has also spread out in France, in Great Britain, and in Denmark. Spain also is turning to this technique for its new cement concrete highways program. In Great Britain, several experiments of manual transverse grooving have been undertaken since 1964 (16). Since 1969, contractual rules of execution and acceptance of fresh concrete transverse grooving are enforced (26). In France, the first

Figure 7. Fork-like grooving tool made of metal teeth 6 mm in diameter, 20 mm apart.

Figure 8. Metal strand comb with bundles 15 mm apart.

Figure 9. Grooving and curing-compound-spraying machine.

Figure 10. Reflection of vehicle headlights at night on a lightly brushed surface (background) and a deeply grooved surface (foreground).

deep transverse grooving executions on the Montpellier-Nîmes expressway date back to 1968 (27). They were followed by others on both airfield runways and expressways; in 1969, the Ministry of Equipment and Housing issued specifications about the texture depths for grooved pavements (28). In Denmark, executions done after 1969 were inspired by the British experience in grooving (29).

SECONDARY ADVANTAGES AND DRAWBACKS OF DEEP GROOVING

Deep grooving displays some secondary advantages and drawbacks of which the road engineer must be fully aware.

Behavior In Rain

As compared with a smooth texture, a definite reduction of the fine water spray behind trucks is noticed. On the other hand, after rain the pavement remains wet for a longer time between the grooves although it retains nonskid characteristics that are well above those of a wet, smooth concrete (27).

Dazzlement

Troublesome mirroring, which is particularly felt on a wet pavement, at night, or at sunset and sunrise, is strongly reduced by the presence of deep transverse grooves (Fig. 10). Road lighting experts consider, though, that the dulling aspect of grooved pavements requires an increase of the electric power required to obtain the same lighting.

Tire Wear

It has been contended that tire wear would be increased on grooved pavements, but, to our knowledge, no systematic measurements have been carried out in this respect. If the contention is true, the expenses incurred for a slightly more frequent replacement of tires should be compared to the resulting improvement of driver safety.

Studded Tires

In Belgium, the use of studded tires dates back to 1967-1968. Although no systematic observations have been made, no detrimental action of studded tires on cement-rich grooved concretes has been reported.

Noise

The problem of noise has been much debated. It must be acknowledged that, especially on newly built pavement and some regularly patterned or sine-wave-shaped groovings, an inconvenient whizz can be heard, particularly with radial ply tires. To avoid this, randomly spaced grooving, as advocated by Weaver (23), seems to be commendable. On the total set of numerous grooved sections constructed since 1961, the average noise has been found to be similar to that produced by other deep, rough texture pavements such as chipped cement, asphalt concrete, or precoated chips (30). The noise level produced on dry, grooved pavements exceeds that on smooth and polished pavements. In rainy weather, the situation is reversed because, on smooth pavements, finely sprayed water is stirred up by passing vehicles.

Riding Quality

This is an important area in which the experts are only now trying to define basic criteria (31). The only method at our disposal is the comparison of two 1 100-m sections differing only by type of surface treatment—either with deep transverse grooving or with no grooving at all. The comparison of the evenness of these 2 sections by means of the viagraph discloses no significant difference (32). On some recent expressway sections, however, obvious signs of inadequate comfort and safety have been reported by users. Their natural reaction was to look at the pavement and infer that

the grooved surface was the cause. Actually, scrutiny by the Belgian roads authority disclosed a systematically wave-like surface duplicating the pattern of the reinforcing mesh (33).

GENERAL CONCLUSIONS

After over 12 years of experience with cement concrete roads treated by deep transverse grooving of the fresh concrete, we developed a technically and economically satisfactory solution that makes it possible to retain, after many years of heavy traffic, a high and lasting skid resistance on wet pavements, even at high speed. A trend is now developing in several countries toward burdening road engineers with civil and penal responsibility for some traffic accidents. They must be aware of the necessity of improving compromises and of the field still open to research for better future control of nuisance factors such as noise and lack of riding quality.

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