in the value of this report and is also an indication of the intense interest in this aspect of the construction process.

The data from the questionnaires were summarized, and the analysis of the results indicates the following:

1. Most state agencies (91 percent) will accept one or more properties in the construction and materials of asphalt concrete pavement that are outside of specification tolerances.
2. The specific properties that are accepted outside of specification tolerances by a large majority of agencies, generally with a pay adjustment, are compaction asphalt content, asphalt properties, and mix gradation. Pavement thickness and smoothness are additional properties accepted outside of specification tolerances by approximately half of the agencies.
3. Most of the agencies that accept construction and materials outside of specification tolerances apply a pay adjustment in reducing the compensation to the contractor. It is significant that the current philosophy is to penalize the contractor for properties that are below specification. A few agencies are considering the provision of a bonus for properties that are found to be above specification and provide increased pavement serviceability or life. Illinois appears to be the only state agency that currently provides a bonus for high quality and uniform work.
4. The background most relied on for establishing pay factors is experience.
5. Only 26 percent of the agencies consider their pay factors to be proportional to reduced pavement serviceability. Other widely used rationales for pay factors are to discourage noncompliance by application of the penalty and to comply with the recommendations of FHWA.
6. Approximately half of the agencies consider the use of pay-factor plans to be effective in encouraging compliance with specifications. The remaining agencies either will not use specified pay factors or do not believe the plans currently available are sufficient.
7. There is a wide disparity in the pay-adjustment factors currently used by the different state agencies. Several approaches are used to determine pay factors for each material property evaluated. In addition, agencies that use the same approach have widely varying values for the pay factor applied to a common level of material quality.

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# Texturing of Cement Concrete Pavements by Chip Sprinkling the Fresh Concrete

F. FUCHS

**One of the research projects on slipperiness being conducted by the Centre de Recherches Routières in Belgium concerns the chip sprinkling of cement concrete pavements. Of all the surface treatments for fresh concrete, this technique is the only one that permits the use of polishable aggregates in the bulk of the concrete without prejudicing skid resistance. This is an obvious economic advantage in regions that do not have sufficient reserves of materials with a high resistance to polishing. The large-scale application of the procedure has required the construction of a chip-sprinkling machine, which is now operational for works carried out with both fixed and slip forms. Between 1974 and 1980, a number of large works have been completed in Belgium and France. Guidelines for optimal execution have been published that deal with the laying of the concrete and the chip sprinkling. Existing experimental roads have demonstrated the effectiveness and durability of the technique. The degree of skid resistance is related to the quality of the chipping stones used. The surface rolling noise is less annoying than the noise produced by transverse grooved concrete and is comparable to the rolling noise of other types of skid-resisting pavements that have a random surface texture.**

For several years, a major effort has been under way in various countries to improve the skid-resisting properties of pavements. Up to now, research has shown that high skid resistance on wet road surfaces is linked to the following factors (1): (a) a coarse macrotexture, obtained by applying a suitable surface treatment, and (b) a harsh microtexture, obtained by excluding polishable aggregate from the surface of the pavement.

The most widespread surface treatment used today for cement concrete pavements is the deep transverse grooving of the fresh concrete. This treatment has evolved tremendously during the past 15 years or so, both in Europe (2,3) and, more recently, in the United States (4). The application of this technique gives excellent results with regard to skid resistance and ensures effective transverse draining of the road. Nevertheless, the simple and inexpensive technique is sometimes criticized for the in-

Figure 1. Appearance of concrete after chip sprinkling at rate of 7 kg/m$^2$ with 14- to 20-mm-gauge stones.

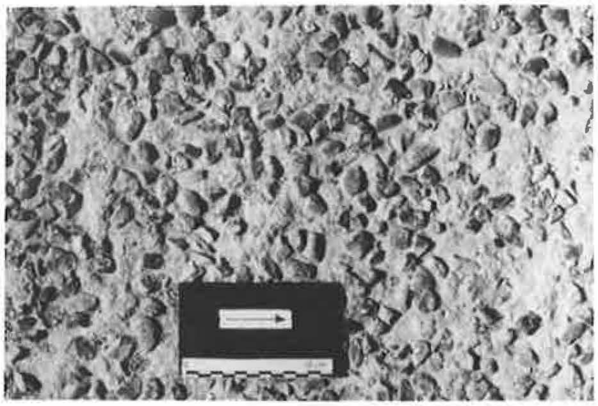


Figure 2. Rear view of chipping machine on rails.

crease in rolling noise it produces. Variable spacing of the grooves lessens, but cannot eliminate, this disadvantage.

This has been one of the main reasons, apart from economic considerations (discussed below), behind the search for new types of nonskid pavement, a search that has led to two techniques: (a) chip sprinkling the fresh concrete or (b) stripping the aggregate in its surface (5). These techniques have now been perfected to the point that they are completely operational for use with both fixed forms and slip forms and are permitted by Belgian official specifications as alternatives for deep transverse grooving (6).

Stripping of the aggregate consists of removing the superficial mortar of the concrete so that the aggregate is exposed. The treatment can be carried out by simultaneously sprinkling water and brushing the surface of the fresh concrete with a rotating brush. The sprinkled water is subsequently removed with the laitance from the surface of the concrete. Another technique, used in Denmark since 1976 (7) and more recently in Belgium, consists of spraying a retarder onto the surface of the fresh concrete. The following day, after the concrete has hardened, the surface is brushed vigorously with a metal-bristled brush so that the surface mortar is removed.

The chief advantage of the chip-sprinkling technique, according to the studies carried out by the Centre de Recherches Routières (8), is that, in contrast to grooving and stripping of the aggregate, it permits the use of polishable aggregate in the bulk of the concrete without affecting skid resistance. Indeed, in this case the contact area between the pavement and vehicles tires is essentially made up of chippings that have a high resistance to polishing. The intention of this paper is to expound the latest developments in this technique, particularly its large-scale application, made possible by the mechanization of the slip-form technique.

## BASIC PRINCIPLE AND ADVANTAGES OF CHIP SPRINKLING

The chip sprinkling of cement concrete pavements consists in evenly strewing polish-resistant stones of a determined size--e.g., 14-20 mm--onto the surface of the already compacted and profiled fresh concrete and setting them in such a way that they slightly protrude from the surface, creating a coarse macrotexture (see Figure 1).

The main economic advantage of the procedure is that it permits the use of local aggregates in the bulk of the concrete, even those aggregates that do not stand up well to polishing, such as limestone. This is of particular interest to those countries or regions whose local geology does not allow the cheap supply of hard materials that have a high resistance to polishing.

In countries such as Belgium, where the available aggregates are polish-resistant or polishable, according to the location of the building site, contractors and directing officials are free to choose the cheapest materials without changing techniques or construction equipment: Chip sprinkling is always possible. Moreover, the chipping materials can be chosen to suit the site, the volume of traffic, and the maximum permitted speed. It is thus possible to obtain a high level of skid resistance at dangerous spots, or on heavily trafficked roads, by selecting chipping stones that have a very high resistance to polishing. Even in that case, the extra cost of chip sprinkling remains low because of the limited quantities of chippings required (6-8 kg/m$^2$) and is amply compensated for by the savings on the concrete aggregate.

## MAIN PHASES IN DEVELOPMENT OF THE PROCEDURE

The application of the procedure has taken place in two main phases. The first phase, from 1949 to 1969, consisted in setting up rather limited experiments that used manual techniques on heavily trafficked roads (9). The results obtained from these roads showed that (a) the chipped areas showed a significant improvement in the sideway force coefficient (SFC) in comparison with untreated areas and (b) these chipped areas stood up well to long-term use (20-25 years).

As early as 1973, the Centre de Recherches Routières, in collaboration with a machine constructor, began studies on the mechanization of the procedure. These studies led to the construction of a chip-sprinkling machine that is capable of simultaneously ensuring that the exact amount of chipping stones is spread evenly over the surface and that the stones are driven the correct depth into the fresh concrete by means of a vibrating tamping beam (10). The machine has been operational since 1974 for fixed-form operation (8,11), and since 1979 for slip-form work (12). Thus far, this machine has been used to lay more than 400 000 m$^2$ of pavement, in both Belgium and France.

The fixed-form machine is an independent unit that has the following functions (see Figure 2):

1. Supplying chippings from a storage hopper that is filled by means of bins and a loading system built into the machine,

2. Dosing and uniform spreading of the chippings on the surface of the concrete,
3. Driving the chippings into the fresh concrete with a vibratory tamping beam, and
4. After chipping, spraying the fresh concrete with a curing agent.

Thus far, about 150 000 m² of pavement has been laid by using this machine, both for experimental and normal construction, in widths ranging from 3 to 7.5 m. This makes it possible to draw conclusions regarding both the improvement of the technique (13) and its adaptation to slip-form operations.

At the outset, it was possible to imagine two different systems: (a) an independent chipping machine mounted on tracks and (b) a chip-sprinkling machine incorporated in a slip-form paver. Eventually, the second type was selected because (a) it provided easier vertical alignment of the tamping beam (moreover, tamping at the working level of the slip-form paver makes it possible to correct the surface of the concrete, particularly after dowels are inserted by vibration) and (b) it eliminates the necessity of replacing the form work during tamping (this operation is carried out between the sliding forms of the slip-form paver).

Broadly speaking, the machine is made up of the same components as the fixed-form machine (see Figure 3) (8):

1. A storage hopper for the chippings that has a capacity of approximately 800 kg per meter of width;
2. A spreader drum whose speed of rotation can be regulated and that has an adjustable opening for the passage of the chippings so that the chipping rate can be precisely adjusted; and
3. A vibrating tamping beam whose lower face is slightly inclined in relation to the direction of advance so that the chippings will be pushed progressively down into the concrete (the level of the beam can be adjusted while the machine is in operation by means of hydraulic jacks, and the vibrating frequency can be altered in relation to the plasticity of the concrete).

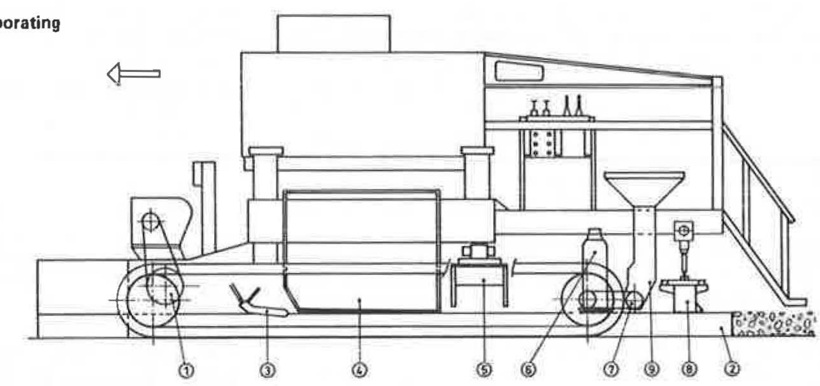
The storage hopper is loaded with chippings by means of a hydraulic grab, mounted either on the lorry that is carrying the chippings or, for large widths, on the slip-form paver itself. Incorporating the chipping equipment into the slip-form paver makes it possible to mount the vibratory dowel-inserting device in front of this equipment. The curing agent is sprayed by a separate machine that follows immediately behind the slip-form paver. This permits finishing touches to be made by hand, if necessary, after the surface has been laid. The chip-sprinkling equipment is operated from an autonomous control station located at the rear of the machine so that the operator has a good view of the work.

Three works had been completed at the time this paper was written. Two experimental works were carried out in Belgium: one at Bernissart toward the end of 1979 and another at Aisemont toward the end of 1980. The first work involved laying a continuous reinforced concrete pavement about 2700 m long and 2x3.5 m wide. The second pavement was 2400 m long and consisted of 6-m slabs separated by doweled contraction joints. The chipping equipment was mounted at the rear of a Guntert and Zimmerman slip-form paver (see Figures 3 and 4).

At Aisemont, the dowels were inserted into the fresh concrete by vibration simultaneously with the chip sprinkling. The concrete was made by using local limestone aggregate, which is usually rejected because of its poor (0.37-0.40) polished stone value (PSV) (14). In one section at Aisemont, the concrete also contained local crushed sand. Chipping was carried out by using 14- and 20-mm and 10- and 14-mm aggregate with a PSV of 0.55, spread at an approximate rate of 6 kg/m².

On the whole, the results obtained can be regarded as excellent with respect to the actual execution--the even spreading of the chippings and the uniform penetration of the stones into the fresh concrete. The works aroused much interest, particularly in France, where the chipping technique used in conjunction with slip forms is a key point in the construction of motorway pavements in cement concrete because there is not a sufficient supply of aggregate with a high PSV. Although the application of surface dressings to new concrete roads gives good results with respect to skid resistance, it has not entirely solved the problem because of generally

**Figure 3. Cross section of slip-form paver incorporating chipping equipment.**




Slip-form paver:
1. Screw distributor
2. Slip-form
3. Internal vibrator
4. Extrusion box
5. Device for dowel insertion
6. Smoothing beam

Chipping equipment:
7. Spreader drum
8. Tamping beam
9. Storage hopper

Figure 4. Slip-form paver at work at Bernissart site over 3.5-m width.

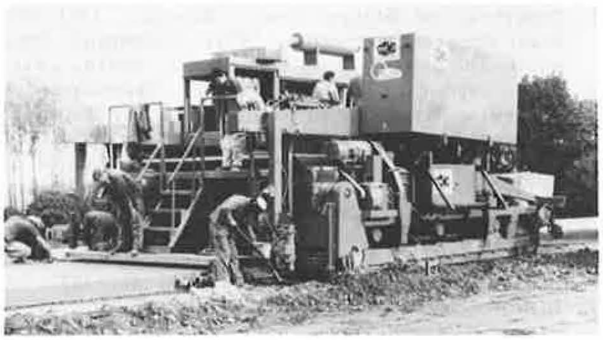


Figure 5. Sélestat bypass under construction in 8-m-wide sections.


poorer durability (5-7 years) and the relatively high cost of the technique (15).

The first large-width application was carried out near Strasbourg in France during the summer of 1980, on a motorway section 17 km long and 2x8 m wide (autoroute A35, the Sélestat bypass) (see Figure 5). This time the equipment was incorporated into a "CMI autograde" slip-form paver. The concrete, laid on a lean concrete base, uses rounded aggregate from the Rhine that is gathered from a ballast pit near Sélestat. The surface was chip sprinkled with hard crushed stone of 16- and 20-mm gauge. The spreading rate was approximately 6 kg/m². The Californian method of concrete laying was used: short slabs of 4.5-6 m separated by undoweled contraction joints sawed in the hardened concrete. The average rate of advance of the machine was about 2 m/min.

As a sequel to these works, another chip-sprinkled concrete project is planned for the spring of 1981 on the Calais-Arras motorway. A concrete pavement 2x8 m wide and consisting of 32- to 38-cm-thick slabs will be laid over a length of 30 km.

## RECOMMENDATIONS FOR ACHIEVING SATISFACTORY RESULTS

Based on the experience gained on existing experimental roads, the following recommendations can be drawn up for the construction of chipped cement concrete pavements.

### Composition of Concrete

When a surface is to be chip sprinkled, the concrete used does not have to have any special composition as long as it has a uniform consistency and retains sufficient plasticity after compaction to allow insertion of the chippings. In Belgium, continuously graded 0/32 concrete is normally used. It has a high cement content (400 kg/m³) and contains no air-entraining agents. Slump measurements that use Abram's cone vary from 1 to 2 cm for works carried out with fixed forms and from 2 to 4 cm for slip forms. The concretes used in France are probably closer to those encountered in the United States and have a cement content of 330 kg/m³ and an air content of 3-6 percent (16). Slump values vary from 1 to 5 cm according to the type of machine used. In this respect, it should be pointed out that the quality of the mortar, and particularly its cement content, can have a long-term effect on the durability of the chip-sprinkled surface, since the surface mortar anchors the chippings into the pavement.

### Execution of Chip Sprinkling

The chipping stones should be 14- to 20-mm or 10- to 14-mm gauge. They should be angular, cube shaped, hard, and clean. Official requirements (6) set a minimum PSV of 0.50 for general use and 0.60 for dangerous spots or for use on heavily trafficked roads.

The stones are sprayed just before they are used so that they are wet, which helps them to stick well to the concrete. The rate of chipping is adjusted so that the surface is covered as much as possible without pockets of chippings being formed. For the gauges mentioned above, this usually lies between 6 and 8 kg/m².

The stones are driven into the fresh concrete so that they are properly anchored to the pavement, remain visible on the surface, and provide a coarse surface texture. Nevertheless, the covering of a certain proportion of the chippings with a thin film of mortar can be tolerated, since this film wears off later under traffic. Before the section is opened to traffic, the surface should be swept mechanically in order to remove any loose chippings.

Recommendations have been published for operations carried out with fixed forms (13). These recommendations will be supplemented in due course by the new experience gained and adaptations made for the slip-form method.

## PERFORMANCE OF CHIP-SPRINKLED CONCRETE

In addition to the technological aspects, several variants were tried out on experimental works in chipped cement concrete that were constructed between 1969 and 1975. These variants had mainly to do with the composition of the concrete and the characteristics of the chipping stones.

Systematic measurements of the surface characteristics of these pavements show the following:

1. The average texture depth (H), determined by the sand-patch test (17), usually lies between 2 and 2.5 mm at the completion of the works. This depth rapidly stabilizes after a few months of traffic wear and will not be subsequently affected except by the wear of the chipping stones and the mortar due to traffic; this wear turns out to be insignificant if hard chippings are used.
2. Skid resistance--as typified, for example, by the SFC--is very satisfactory and depends mainly on the qualities of the chipping stones used. By way of an example, Table 1 summarizes the results of measurements made on the Hasselt bypass (constructed in 1975) five years after it was opened (the traffic density is 5000 vehicles of all categories per day). From these measurements, it can be concluded that (a) the SFC changes in direct relation to the PSV of the chipping stones and (b) the use of bulk aggregate that has poor resistance to polishing does not affect the SFC.
3. No loss of chippings caused by traffic was ob-

**Table 1. Results of measurements made on experimental road at Hasselt in November 1980.**

| PSV | | | SFC[a] | | |
|---|---|---|---|---|---|
| Stones in Concrete Aggregate | Chipping Stones | H (mm) | At 20 km/h | At 80 km/h | Δ SFC[a] at 20-80 km/h |
| 0.55 | 0.71 | 1.71 | 0.81 | 0.59 | 0.22 |
| 0.55 | 0.58 | 1.83 | 0.72 | 0.55 | 0.17 |
| 0.55 | 0.50 | 2.20 | 0.72 | 0.55 | 0.17 |
| 0.39 | 0.58 | 1.75 | 0.75 | 0.55 | 0.20 |

[a]Measured with a TRRL-type odoliograph fitted with a Permanent International Association of Road Congresses smooth tire; water temperature on the pavement reduced to 20°C.

served, nor did frost or the action of deicing salts have any adverse effects.

4. Possible effects of the chipping technique on surface evenness have not been substantiated. On the whole, chip-sprinkled pavements offer satisfactory comfort to the road user. Moreover, the tamping beam acts as a profile corrector, particularly when dowels are inserted by vibration.

5. As far as the noise problem is concerned, a research project currently in progress has succeeded in providing evidence that there is a relation between the geometric characteristics of a surface and the rolling noise due to it, both inside and outside the vehicle (18). The results show that for chip-sprinkled cement concrete--which, like chip-sprinkled bituminous concrete, cement concrete with exposed aggregate, and surface dressings, has a random texture--the noise spectrum does not behave in the same way as it does for transverse grooved cement concrete, where a single wavelength related to groove spacing dominates and occasionally causes an annoying whistle. Furthermore, it appears that noise levels are adversely affected by surface irregularities whose wavelengths exceed 10 mm, which indicates that less noisy chip-sprinkled surfaces could be obtained, in built-up areas, for example, by making use of appropriate gauges of chippings. Further research is planned in this area.

## CONCLUSIONS

Chip sprinkling of fresh concrete is, to the best of my knowledge, the only surface treatment that makes it possible to construct cheap and durable skid-resistant cement concrete pavements in areas where there are large formations of polishable materials. Savings are possible both on the aggregate used in the bulk of the concrete and on transportation costs. The projects completed to date have demonstrated that chip-sprinkled surfaces perform well, particularly with respect to skid resistance and durability. The existence on the market of an operational machine for works carried out with both fixed and slip forms has contributed to the large-scale development of this procedure since 1980.

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