ACTUAL EXPERIENCE REGARDING THE CHIPPING OF CEMENT CONCRETE

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The chipping of fresh cement concrete pavements, developed by the Belgian Road Research Center, is one of the techniques for creating, during the laying, a coarse macrotexture indispensable for obtaining a high degree of skid resistance, even at high speed, on wet pavements.
After a period of study and experimentation dealing, on the one hand, with the characteristics of the technique (composition of the concrete, the stones to be used in the chipping) and the performances achieved with regard to skid resistance and durability and, on the other hand, with the conception and development of an operational chipping machine, the process made its appearance in the specifications in Belgium with a view to its application on a large scale.
The technique comprises two phases :
a) uniform distribution of the chipping stones, sized 14-20 mm (1/2 in. - 3/4 in.) and highly resistant to polishing, over the concrete surface, previously compacted and profiled, in the proportion 6 to 8 kg/m² (11-15 lbs/sq.yd),
b) insertion of the chippings into the fresh concrete by tamping with vibration.
In addition to the safety it provides, chipping offers economic advantages of its own :
- the process permits the use of polishable aggregates in the concrete mass without reducing skid resistance, the contact surface between the pavement and the tread of the tires being constituted by the slightly polishable chipping stones,
- it is possible to obtain economically a high degree of skid resistance in certain dangerous places or on roads with heavy traffic, given the small quantity of chippings of high Polished Stone Value used,
- from the durability of the micro- and the macrotexture results a long-term maintenance of the pavement's non-skid qualities.

The surface of road pavements is characterized by the following two factors : the macrotexture and the microtexture. In order to achieve pavements with good and durable skid resistance, even at high speed, the following criteria must be met :
- a coarse macrotexture, assuring the evacuation of surface water between the pavement and the tires of the vehicles,
- a rough microtexture, assuring the adherence of the vehicles' tires to the pavement.

In the case of cement concrete pavements,a coarse macrotexture can be made at the time of execution in three different ways :
- by deep transversal grooving (1, 2),
- by removal of the surface mortar in order that the stony skeleton be bare from the beginning,
- by chipping (3, 4, 5).

In order to obtain a rough microtexture on the surface, the first two techniques imply the use of slightly polishable materials in the concrete's composition. The chipping technique, on the other hand, permits the use of local stones in the total mass even if they are less resistant to polishing, since the surface is chipped with aggregates highly resistant to polishing.

This is one of the reasons that brought the Belgian Road Research Center to undertake the systematic study of this latter process, which is the subject of this present report.

1. Principle and Principal Advantages of Chipped Cement Concrete

The chipping of fresh cement concrete pavements consists in distributing slightly polishable stones in a uniform manner on the concrete's surface which has first been compacted and profiled and in then incrusting them in the concrete in such a way as to create a sufficiently coarse macrotexture, about 2 to 3 mm (0.08 to 0.12 in.) by the sand patch test (6).

The chief interest in the process resides in the fact that it is possible to use polishable aggregates

in the concrete mass while the chippings of high polish resistance, constituting the separation between the pavement and the tread of the tires, are used on the surface and give it its high and durable qualities of skid resistance.

On the other hand, it is possible to adapt the desired level of skid resistance in relation to the site, the volume of traffic and the maximum authorized speed, by a judicious choice of the chipping stones.

Finally, the traffic noise produced by the surface, which is characterized by a random distribution of the chippings, is less annoying than in the case of transversal grooving, and comparable to the noise obtained with pavements in chipped bituminous concrete or those covered with a surface dressing.

Figure 1. Aspect of chipped concrete after 21 years of traffic.

2. Principal Phases of the Application in Belgium

The chipping of fresh cement concrete first took place in Belgium in the 1950's on several experimental sections. The spreading was done by hand and the stones were inserted into the concrete by a vibrating finisher. These sections still exist and have proven their resistance to weather and traffic as well as the durability of the process (Figure 1).

In 1969 the Belgian Road Research Center undertook the systematic study of chipping at the time of execution of an experimental section of a road with heavy and intense traffic (6,500 vehicles per day in 1970 for the two directions together).

Here too the spreading was done by hand with stones sized 10/14 mm (3/8 in. - 1/2 in.) and 14/20 mm (1/2 in. - 3/4 in.) (square sieves), but the insertion was also done manually with a wooden tamping beam.

At the end of 1976, the S.F.C. (sideway force coefficient on wet pavement measured with the aid of the TRRL-type odoliograph equipped with a smooth tire ; a correction is applied to bring the measured values back to a water temperature of 20°C (68°F) on the pavement) measured on these sections at the speed of 80 km/h (50 mph) varies from 0.52 to 0.57 and this in spite of a relatively low PSV (polished stone value, determined according to reference 7) of the chippings used (0.54). The decrease in S.F.C. between 20 and 80 km/h (12.5 and 50 mph), linked to the pavement's macrotexture, varies from 0.10 to 0.16, thereby showing that the vehicles' adherence on the wet pavement is only slightly sensitive to an increase in speed.

Insertion with the tamping beam having revealed itself particularly promising, the acquired experience was to lead to the mechanization of the chipping technique on the basis of this last method.

In collaboration with a firm for construction of contractors' material, the Belgian Road Research Center conceived and developed a machine for chipping (4, 5). This machine is presently operational for work done on fixed forms and thus permits chipping to be rapidly applied on a large scale.

3. Characteristics of the Chipping Process

One of the objectives pursued at the time of the experimental phase of the process was the determination of the optimal composition of the concrete as well as of criteria concerning the choice and application of the chipping stones.

During the course of experiments at the work site, it became apparent that concrete made of continuously graded aggregate of 0-32 mm (0-1 1/4 in.), whose composition is given in table 1 to serve as an example, having a slump of about 1 cm (0.4 in.) at the time of fabrication and chipped within 90 minutes (time limit can vary depending on the atmospheric conditions) gives excellent results.

In addition, it is of primary importance that the profile followed by the chipping machine be exactly the same as that of the paving machines ; thus the chipping machine was immediately preceded by a self-propelling surfacer, following the same profile references lengthwise and perfecting the surface's evenness after the passage of the vibrating finisher (Figure 2).

As for the stones to be used in the chipping, it became apparent that cubic crushed ones of the size 14-20 mm (1/2 in. - 3/4 in.) are ideal for chipping concrete made of continuously graded aggregate of 0-32 mm (0-1 1/4 in.). With larger stones the resistance to insertion is too great. If they are too small, this resistance is too little, and there is a risk of pushing them completely into the concrete. These stones must also meet severe criteria in regard to resistance to polishing (minimum PSV of 0.50 to 0.60 according to the road's category), to crushing and to wear.

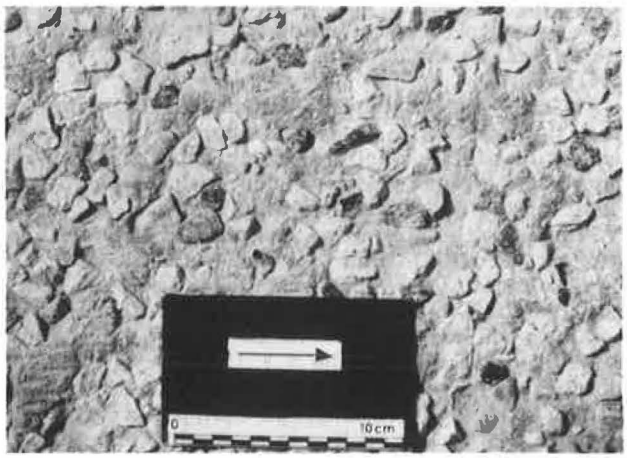
The chippings should be wet prior to their application in order to increase their adherence to the concrete. The spreading rate ranges from 6 to 8 kg per m² (11 to 15 lbs./sq.yd) for stones with a density of 2.6 to 2.8). The anchoring of the stones in the concrete must be assured without their sinking, in order to confer on the surface an average levelling depth of about 2 to 3 mm (0.08-0.12 in.) by the sand patch test (Figure 3). A fine layer of mortar on top of the stones, which will wear off from the traffic, is, however, tolerated.

Table 1. Composition of the cement concrete.

Materials	Quantity/volume of concrete in place	
	kg/m³	lbs./yd³
Crushed stones 19-32 mm (3/4 in. - $1^{1/4}$ in.)	750	1265
Crushed stones 6-19 mm (1/4 in. - 3/4 in.)	375	632
Crushed stones 1.6-6 mm (ASTM n° 12 - 1/4 in.)	350	590
Natural sand	450	760
Cement	375	632
Water	150 to 160	253 to 270

Figure 2. Paving train for the application of a pavement in chipped cement concrete. Width of work : 7.50 m (25 ft.).

Figure 3. Aspect of mechanically chipped cement concrete with chippings 14-20 mm (1/2 - 3/4 in.). Spreading rate 6 kg/m² (11 lbs./sq.yd).



4. Chipping Machine

The chipping machine for concrete roads (4, 5), specially conceived and developed by the Belgian Road Research Center, possesses the following functions :

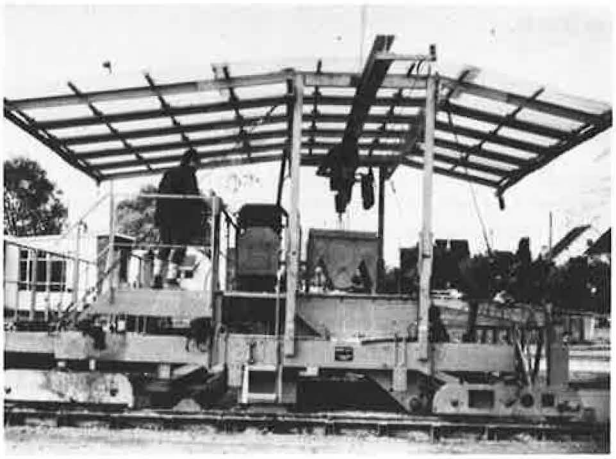
1) control of the transversal evenness of the surface before spreading the chippings,
2) loading of the chippings in a storage compartment,
3) dosage and uniform distribution of the chippings on the concrete's finished surface by means of a spreader drum,
4) insertion of the chippings into the fresh concrete by tamping with vibration,
5) spraying of a curing compound after the chipping.

In a first stage the machine was developed for works on fixed forms and for concrete widths of 3 to 13.25 m (10 to 44 ft.), with the understanding that adaption to slip forms was foreseen for the near future. The work is carried out in the following way : after verification of the concrete's profile, the chippings are spread on the surface, the machine progressing at the speed of 2.7 m/min. (9 ft./min.). They are immediately incrusted into the fresh concrete during the same passage of the machine, thus with a continuous advancement of the machine. At any moment the operator can adjust, during the course of work and in a precise and continuous manner, the depth of incrustment of the chippings by regulating the level of action of the tamper and its frequency of vibration. The beam is inclined by 3 % in relation to the direction of advancement, so that the chippings may be incrusted in a progressive way, each place being tamped about ten times. If need be and depending on the obtained result, it is possible to back the machine and proceed with a second phase of tamping.

The spraying of the curing compound is done during a supplementary passing of the machine at the speed of 10.8 m/min. (36 ft./min.). Thus one can easily follow a classical paving train on fixed forms, making an average daily advancement of about 300 m (330 yd).

A view of the machine in operation is illustrated in Figure 4.

Figure 4. Side view of the chipping machine for concrete roads.



The machine has been patented in Belgium as well as abroad (8).

5. Achievements and Previsions

At present there are about 100,000 m² (120,000 sq.yds) of pavements in chipped cement concrete of which some 70,000 (84,000 yds) were made with the chipping machine described above.

All together there are thus about 22 km (14 ml.) of experimental roads in chipped cement concrete with widths of 3 to 7.50 m (10 to 25 ft.).

In a first stage and after the older sections executed by hand, tests were made towards the technological improvement of the process with the chipping machine. Preliminary tests underlined the excellent regularity of the distribution of the chippings, both in the transversal and in the longitudinal sense (9). On the other hand, different methods were tested in order to optimally realize the insertion of the chippings into the fresh concrete by tamping or rolling, which finally led to the adoption of the process of continuously advancing tamping with variable frequency of vibration (4, 5).

Following this development, tests have recently been undertaken on the work sites of roads with heavy and intense traffic, for the purpose of observing, by systematic measurements of the S.F.C., the influence of the following parameters on the evolution of the S.F.C. :

- the PSV of the stones for chipping (from 0.50 to 0.71),
- the PSV of the stones in the concrete mass (from 0.34 to 0.55),
- the type of cement used : Portland cement or blast-furnace slag cement, characterized by a volume of 35 to 60 % of blast-furnace slag.

As for any study of skid resistance and its evolution in time, the analysis of these parameters will require years of observation. However, the measurements made after 6 months of traffic (about 5,000 vehicles per day) show that the S.F.C., measured at 80 km/h (50 mph) on all the experimental sections, varies from 0.53 to 0.66, in function of the PSV of the chipping stones and independently of the PSV of the stones in the concrete mass.

As for riding comfort, the measurements made with the A.P.L. (analyser of the profile in length) do not show any incidence of the presence of chipping stones on the surface.

All of the observations made on the experimental roads have permitted, with a view to application on a large scale, the formulation of provisional recommendations relative to the execution of a chipped cement concrete pavement for the use of those designing and undertaking such work. On this subject, the realization of about 300,000 m² (360,000 sq.yd) of chipped cement concrete pavements has been foreseen within a short period of time.

6. Economic Aspect of Chipping

Besides its advantages with regard to safety, the chipping process offers important economic advantages of its own :

a) In the first place, the process permits the use of local stones in the concrete mass, even if they are less resistant to polishing, which permits new perspectives to be foreseen for regions possessing few or no stones with good resistance to polishing and can largely compensate for the supplementary cost of chipping.
As an example, we have limestone quarries in Belgium whose stones were up to now rejected for the wearing courses of road pavements because of their low PSV (about 0.40) (10). By using these stones in the concrete mass, an economy on materials of about 9 B.F. per m² (₰ 0.18/sq.yd) is made on the cost of a cement concrete pavement, 20 cm (8 in.) thick, without harm to the mechanical properties of the pavement. To this should be added the economy made on the cost of transport in the case where the work is done in the vicinity of the quarries. Now, it is possible to chip the surface by means of a stone of excellent quality whose price in general is about 1,000 B.F. (₰ 25) per metric ton, which, for a ratio of aggregates of 8 kg/m² (15 lbs./sq.yd), would lead to a supplement of 8 B.F. per m² (₰ 0.17/sq.yd).
In addition the use of these softer stones in the bulk permits a decrease in the wear of the equipment for fabrication and laying of the concrete as well as the diamond discs used for the sawing of the joints in the hardened concrete.
b) It is possible to economically obtain a high degree of skid resistance at dangerous places (curves, intersections...) or on roads submitted to an intense traffic. Indeed, given the relatively unimportant amount of aggregates used, the cost still remains limited, even if expensive stones of a high polished stone value are spread.
c) From the durability of the macrotexture and the microtexture results a long-term maintenance of the non-skid qualities of the pavement, which means that special and costly repair treatments for restoring the skid resistance can be ulteriorly avoided.

7. General Conclusions

The technique of inserting chippings in fresh cement concrete, developed and perfected by the Belgian Road Research Center, is one of the techniques for achieving, at the time of construction, a rough microtexture and a coarse macrotexture, which are indispensable for obtaining a high degree of skid resistance, even at high speed, on wet pavements.

The experimental sections (about 100,000 m² (120,000 sq.yds) at the present time) have shown, on the one hand, the efficiency and durability of the process and, on the other hand, have contributed to the development of a chipping machine, presently capable of carrying out work on fixed forms.

With a view to the application of the process on a large scale within a short period of time, the acquired experience has permitted the formulation of provisional recommendations for the use of those designing and undertaking such work. Indeed, in order to be done successfully, chipping, like any surface treatment, requires particular attention in regard to the composition and the laying of the concrete, notably an excellent initial profile, as well as the choice and application of the chipping stones.

Lastly, chipping permits the use of polishable stones in the concrete mass, giving an indication of new perspectives, for those regions having little or nothing in the way of stones with good resistance to polishing, in the field of the conception of non-skid cement concrete pavements.

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