(ULTRA)FAST-TRACK CONCRETE PAVING: BELGIAN EXPERIENCE

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ABSTRACT

For three years the Roads and Traffic Administration (AWV) of Flemish Brabant in Belgium has been using the technique of ultrafast-track (UFT) concrete paving for the rehabilitation of several road sections. The aim is to achieve a compressive strength of 40 MPa on cores after 30 to 36 h of curing. The materials used are commonly available in concrete mixing plants, without the addition of fly ash or silica fume. Cement type and content and the water-cement (w/c) ratio are set in a preliminary laboratory study. On most of the work sites the results have been excellent and the goals have been achieved. However, a number of lessons have been learnt from field practice.

In the preparation stage of the project workability plays a key role in the final design of the concrete mixture, particularly in the dosage of the superplasticizer. The base layer must resist heavy traffic loading within a day, since the paving concrete is to be delivered on that layer. Because of the limited tolerance in timing, all necessary precautions – such as checking the existing road for the presence of obstacles in the construction zone – have to be taken in advance, and measures must be taken if the bearing capacity of the subgrade is inadequate.

In the execution stage a steady supply of concrete mixture has to be ensured, as the time window between mixing at the plant and laying on site is very narrow. Depending on temperature conditions, the composition of the concrete mixture may have to be altered to guarantee sufficient workability. Adjacent pavements have to be demolished carefully, to avoid damaging the newly laid section. And because of the high cement contents used, sawing and curing are even more crucial than for normal concrete pavements.

The technique is suitable for application mainly on road sections with a length between 50 and 200 m (max. 1200 m²). Further laboratory research is carried out with a view to extending experience to different mixtures and ambient temperatures and to different superplasticisers. Besides the aspects of concrete technology, good organization of the work and quality management are the key factors for the success of a UFT project.

1. INTRODUCTION

After thorough research by the Roads and Traffic Administration (AWV), the Katholieke Universiteit Leuven (KUL), the Belgian Road Research Centre (BRRC) and the Federation of the Belgian Cement Industry (FEBELCEM), a mix composition was developed that enables a cement concrete pavement to be opened to traffic within 36 h after concreting.

For three years, the Flemish Brabant division of AWV has been using this technique of "ultrafast-track (UFT) concrete paving" for the rehabilitation of several road sections. This method is the outcome of a research programme on the further development of the operational technique of fast-track (FT) paving, which reduces job completion times to five days.

2. CHRONOLOGICAL STAGES IN A PROJECT

2.1. Preparation and design stage

2.1.1. Environmental characteristics of the construction zone

In the design stage, the designer should inspect the site to make sure that there are no obstacles in the zone between the edges of the existing cement concrete pavement, with an extra width of 1.10 m. This extra width is required for the passage of the slip-form paver and must, therefore, be free of obstacles (trees, circulation fixtures, roadside furniture, etc.).

On the other hand, the designer should take the necessary precautions to minimize damage to vulnerable (e.g. bituminous) pavements adjacent to the existing concrete pavement, which will have to be partly repaired after the slip-form paver has passed.

2.1.2. Subgrade

The bearing capacity of the local subgrade should be a consideration in the design of the project. To allow continuous execution, the design should make provisions for subgrade soil improvement where necessary, while preferring measures that cause no delay (e.g. the application of a geotextile combined with an extra layer of crushed stone, rather than stabilizing the soil with lime and/or cement). In many cases, the old concrete road was placed directly on the soil, without any base.

2.1.3. Base layer

The design should include a base layer that can be laid rapidly and develops high compressive strength in very little time. Preference should be given to roller-compacted concrete (RCC) with a cement content high enough to enable the layer to resist heavy transport for the delivery of paving concrete the day after construction – without being subject to rutting.

2.1.4. Cement concrete pavement

The primary concern of the project designer is, of course, the composition of the mixture for the paving concrete. The designer should not only aim to achieve the minimum required compressive strength (40 MPa after 36 h), but also pay specific attention to the workability aspect under the prevailing conditions of ambient temperature. The final section of this paper will focus on concrete mix composition in relation to temperature. A few recommendations are given here.

a) Compressive strength:

- only CEM I 42.5 LA or CEM I 52.5 LA cement appears to be capable of developing the required compressive strength while preserving workability;
- a cement content of ± 450 kg/m³ is necessary to achieve the required compressive strength;
- the use of an air-entraining agent should be avoided, as, on the one hand, owing to the high cement content of the concrete good resistance to de-icing salts is already achieved and, on the other, the agent would have a detrimental effect on compressive strength at younger age;
- a maximum water-cement (w/c) ratio of 0.38 should be specified.

b) Workability:

- a superplasticizer must be used to produce a workable mix;
- cement content should be limited to a maximum of 460 kg/m³. With higher contents, hydration is too fast for the mixture to remain workable;
- with a blend of CEM I 52.5 N LA and CEM I 42.5 N LA, the mixture seems to be more workable than with CEM I 52.5 LA alone;
- high-early-strength cement (type R instead of N) should be avoided, as the cement content is already high.

2.2. Execution stage

2.2.1. Staging principle

The goal of the technique is to limit the duration of road closure to three days, so that rehabilitation can take place over the weekend:

- Friday: demolition of the road, laying of RCC as a base layer;
- Saturday: laying of UFT concrete till 6 p.m., sawing and sealing of contraction joints;
- Sunday: jointing and finishing: application of road markings;
- Monday morning, 6 a.m.: reopening to traffic.

2.2.2. Demolition of the existing pavement

When the road section is to be repaired in both directions, the first half of the carriageway should be demolished with an extra width of ± 0.50 m (demarcated by a saw cut) beyond the road centre line.

The new section should be laid along the initial centre line, leaving a gap between the newly laid section and the section still to be demolished in the other direction (see figure 1).

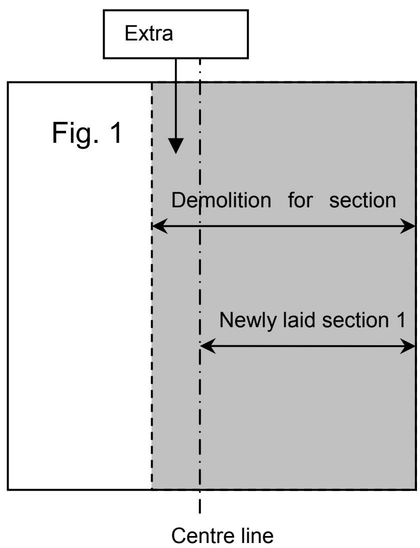

Figure 1 - Demolision schedule

This extra demolition width is desirable for the following reasons:

a) great risk of lateral damage to the newly laid section during the demolition of the second section when any contact between the two remains possible;

b) the extra width creates a free strip where tie bars can be inserted into the fresh concrete immediately after the slip-form paver has passed. This is a better way to ensure the bond between the two sections than subsequent drilling and chemical anchoring of the bars after the concrete has hardened.

2.2.3. Improvement of the subgrade

After the existing road foundation (including the base layer) has been removed, the bearing capacity of the subgrade may prove to be inadequate. If such is the case, soil-improving measures should be taken that can be carried out rapidly, in order to minimize delay in the subsequent stages of the work. The best option – as already suggested under the design stage – is further excavation followed by the application of a geotextile and an additional layer of crushed stone, rather than stabilizing the subgrade soil with lime and/or cement.

2.2.4. Base layer

When the base layer in RCC has been laid, transverse joints – in the same places as the future contraction joints in the paving concrete – should be made by making incisions to a depth of at least one third of the total thickness of the layer. The distance between joints should not exceed 5 m.

If necessary, dowels are placed on top of the base layer at the possition of the futur joints in the top layer. They should be sufficiently anchored in the layer (by nailing, blocking with steel plates, etc.), to prevent their displacement during the passage of the slip-form paver.

Figure 2 - Incision in the RCC for the transverse shrinkage joint

2.2.5. Cement concrete pavement

a) Ambient temperature

All road sections constructed with the UFT technique should be laid at a temperature between 0 and +20°C. Higher temperatures accelerate the hardening process and reduce the workability of the mixture, which becomes too stiff for laying. Ambient temperature should ideally range between +5 and +10°C.

b) Transport timing

The most important mix-related aspect in the execution stage has to do with timing. In view of the composition and the consequent fast hydration of the mixture, the time elapsed between mixing at the plant and laying on site must be shorter than 50 min. Longer transport times will make good spreading and compaction of the concrete virtually impossible. It is, therefore, of primary importance to choose a mixing plant in the vicinity of the construction site.

c) Timing in laying

The concrete supplier should take the necessary measures to ensure constant delivery to the site. Any interruption longer than 30 min. in laying due to late delivery will lead to differences in hardening over the full thickness of the concrete, making reconstruction necessary.
After the slip-form paver has passed, operations (such as brushing) to achieve the necessary skid resistance should start as soon as possible, as the surface rapidly becomes too hard for further treatment.

d) Additional points requiring special attention

At the transverse borderline between old and new material, the contractor should compact the first two metres of the new section adequately with hand-held equipment (poker vibrator) to improve spreading and compaction in the corners. This is necessary as the built-in vibrators of the slip-form paver have insufficient radius of action to reach those corners, which would result in locally poor compaction (and a weaker concrete pavement!).

2.3. Finishing stage

2.3.1. Curing compound

Because of the high cement content and hydration speed of the mix, the paving concrete must be treated with a curing compound as soon as possible after finishinf and texturing activities, to prevent fast drying of the surface and consequent severe shrinkage cracking.

Figure 3 - Finishing stage, prior to the application of a curing compound or covering with plastic sheet

2.3.2. Contraction and warping joints

All required contraction, expansion and/or warping joints should be sawn and sealed within 24 h, as shrinkage stresses in fast-track concrete are much higher than in conventional applications. Depending on weather conditions, sawing may start after a few hours.

2.3.3. Road markings

Before applying any road markings, the surface should be cleaned by high-pressure water jetting. This is necessary to remove the curing compound from the surface and to achieve good bond between the marking and the concrete.

If markings are applied without removing the curing compound, the bond will be much weaker and the markings will have to be replaced much sooner.

3. FIELD OF APPLICATION OF UFT

3.1. Typical lengths per section

The minimum length of a road section eligible for renovation with the UFT technique is 50 m. With shorter sections, the cost-effectiveness ratio is too high to warrant the application of the technique (except for example in motorway repairs, where the economic cost of longer unavailability is much higher).

The maximum section length is about 200 m, i.e. 1200 m². The speed at which fast-track concrete can be spread, compacted and finished does not allow constructing longer sections in one day. Longer stretches can, of course, be constructed in several stages.

3.2. General field of application

Repairing road sections with the UFT technique should be considered mainly for high-volume roads, where the economic cost of long-lasting unavailability – even partial – of a given section is very high.

As the total road foundation is replaced, the renovated road section has a guaranteed design life of thirty years.

With its flexibility in thicknesses to which both the base layer and the pavement can be laid, the technique can be used on various types of road (motorways, primary and secondary roads, etc.).

4. LABORATORY RESEARCH

With a view to being able to open the road to traffic after 36 h of curing, a strict testing programme is imposed on the contractor. A laboratory study with the composition proposed for the concrete mixture is compulsory before work can start.

To simulate the field curing conditions of the concrete, slabs with dimensions of 400 x 300-250 mm³ were cast on site. At the age of one day, cores were drilled from these slabs. To simulate the actual behaviour of the concrete in the pavement under low ambient temperature conditions as truly as possible, the sides and bottom of the cores were insulated if further curing was necessary. Similar tests were performed on cubes manufactured with the concrete used on site, as well as on cores taken from the pavement itself.

4.1. Recording of temperatures

One of the most important factors in the development of strength is the temperature of the concrete. At higher ambient temperatures, temperature in the concrete will rise more rapidly and hydration will start sooner, resulting in faster gain in strength. On the other hand, workability will decrease rapidly at higher temperatures. The composition of the concrete mixture will, therefore, have to be adjusted to the expected ambient temperature.

The effect of temperature on compressive strength can be seen in figure 4, with data from the N272 job at Galmaarden. A concrete mixture with 450 kg/m³ of CEM I 52.5 N HSR LA, a w/c ratio of 0.38 and 1.5 % of superplasticizer was used.

To determine the properties of the hardened concrete, different specimens were prepared on site: cubes 150 x 150 x 150 mm³ and laboratory slabs 400 x 300 x 150 mm³, both insulated and non-insulated. The concrete was vibrated on a vibrating table. The specimens were covered with a plastic sheet to prevent the evaporation of water. Some of the laboratory slabs were insulated at the top and bottom with expanded polystyrene board 50 mm thick. After 24 h of curing on the construction site, the specimens were transported to the laboratory and stored outside for six more days.

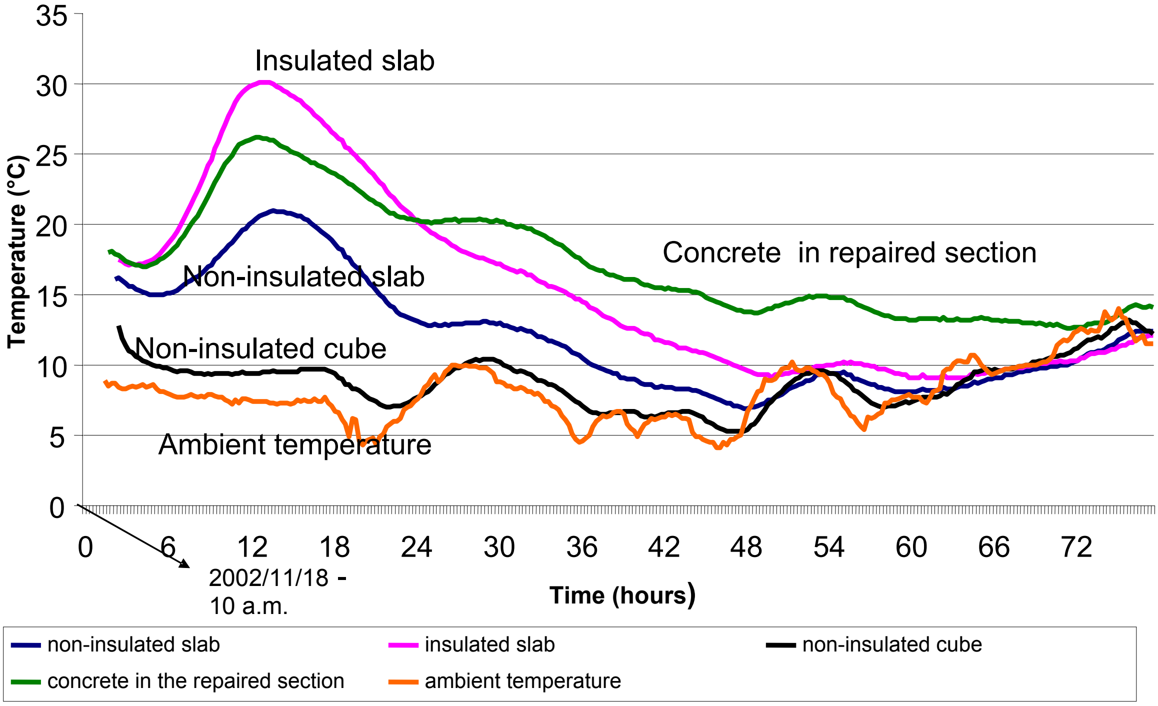

Figure 4 - Trend with time of temperatures measured in different samples

As can be seen in figure 4, the temperature in the non-insulated cube is comparable to the ambient temperature. A slightly higher temperature is observed during the first 24 h, owing to the higher temperature of the concrete at the time of casting and the hydration process of the concrete.

The temperature in the pavement and in the slabs is clearly higher than the ambient temperature. During the first few hours, it increases as a result of the hydration reaction. A peak is reached at the age of 12 h, after which the temperature decreases to follow the trend of ambient temperature at approximately 50 h of age in the case of both the insulated and non-insulated slabs. The temperature in the paving concrete is lower during the first 24 h than in the insulated slab, but drops to ambient temperature only after 72 h. This is beneficial to the ultimate strength of the pavement.

4.2. Development of compressive strength

Compressive strength was determined on the cubes as well as on cores ∅113 mm² drilled from the laboratory slabs and from the road pavement. The concrete in the cores from the pavement was the same as that used to prepare the specimens.

The results are presented in figure 5. As can be seen, the target value was reached after 36 hours of curing: a compressive strength of 40 MPa ± 10 % was measured on the cores from the pavement as well as on the cores from the insulated laboratory slab.

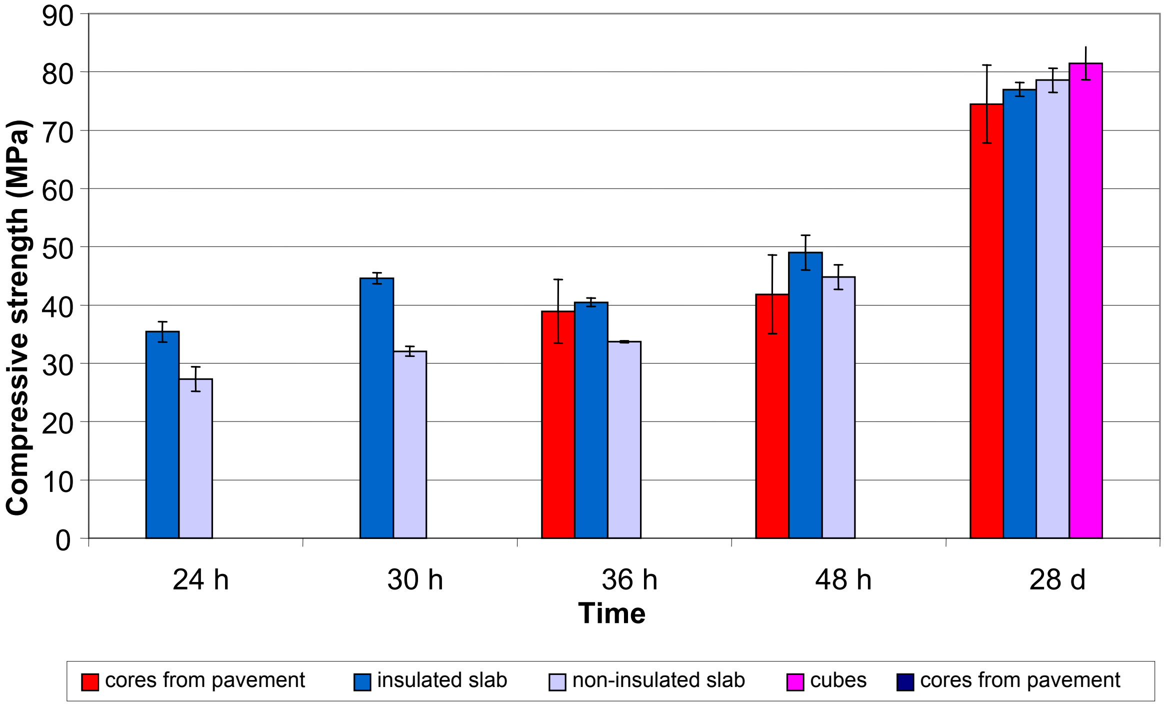

Figure 5 - Development of compressive strength in the different specimens

The results indicate a wider deviation for the samples drilled from the pavement. A standard deviation of 10 to 15 % was found on site, whereas the deviation for the laboratory samples was only 1.5 to 7 %. The widest deviation occurred at young age. At this stage, the effect of temperature is very great.

5. FURTHER RESEARCH

One way to achieve fast development of strength at low temperatures – without drastically increasing cement content – is to insulate the concrete after laying.

A few tests were performed in this respect at the research centre of the Belgian cement industry (OCCN-CRIC). Concrete was prepared with 450 kg/m³ of cement CEM I 52.5 R LA and a w/c ratio of 0.38. Cubes were manufactured in moulds of expanded polystyrene (with a cover board). Slabs 40 x 30 x 15 cm³ were manufactured and insulated at the top and bottom with Styrofoam board. The specimens were then stored outside at an ambient temperature averaging just below 15°C.

Figure 6 shows the trends of temperatures in the specimens. The temperature of the concrete and the concurrent hydration of the concrete and strength development in the cubes and slabs appear to agree very well. The initial build-up of heat indicating incipient hydration takes place at about the same time and the maximum temperatures reached are similar.

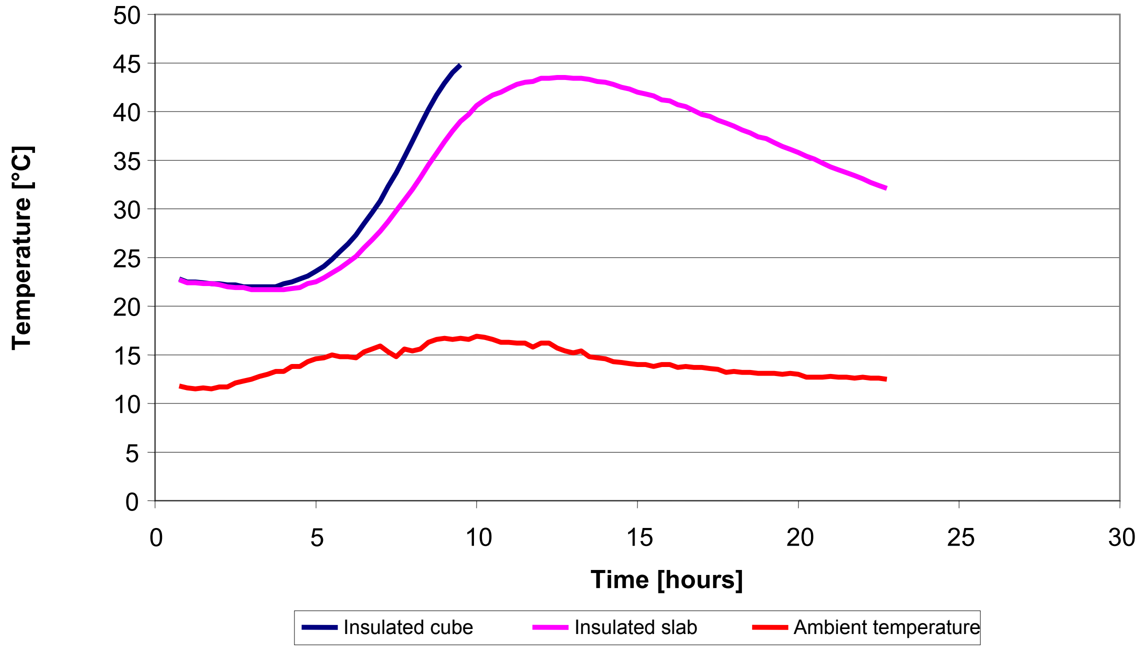

Figure 6 -Trends of temperature in the insulated specimens

When the results in figure 6 are compared with those represented in figure 4, the effect of ambient temperature becomes clear. The initial temperature was about the same under laboratory conditions as on site, i.e., 22°C. On the other hand, the ambient temperature was nearly 15°C in the laboratory tests and averaged only 7°C in the tests on site. As a result, the rise in temperature in the insulated specimens on site was much smaller than in the laboratory-made specimens. This affects the development of strength, as shown by the results represented in figure 5 and in figure 7.

Figure 7 shows the development of strength in the insulated concrete prepared in the laboratory. Strength was determined on cubes up to the age of 10 h. For ages exceeding 10 h after the mixing of cement and water, strength was determined on three cores drilled from the slabs. No corrective conversion was made to account for the shape of the specimens.

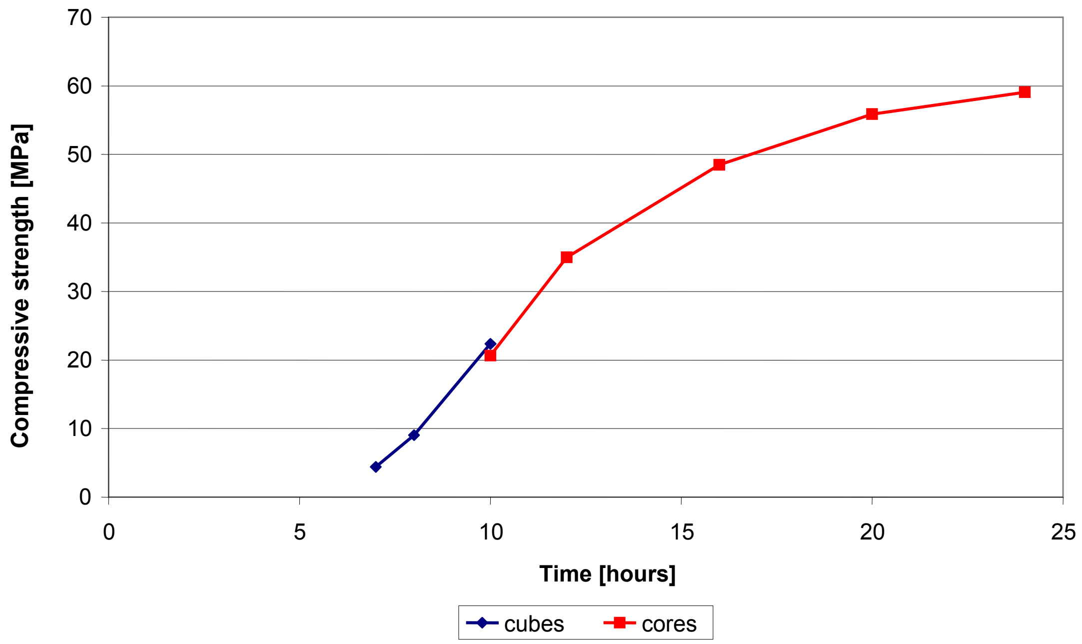

Figure 7 - Development of strength in the insulated concrete cured at 15°C[1]

[1] Test reports Nos. -04-407 en 417 (OCCN-CRIC).

The results in figure 5 indicate that, under the given conditions and with insulation, 40 MPa can be reached at the early age of about 13 h. Tests carried out during the repair job at Galmaarden have shown that, even with insulation, the required strength is achieved only after 30 h when ambient temperature averages 7°C – as can be seen in figure 3. This lower ambient temperature reduces the build-up of heat in the concrete and consequently affects hydration speed.

More extensive laboratory research will follow to develop a reliable mix composition that combines good workability with rapidly developing strength and high durability. The effects of ambient temperature and composition will be investigated to arrive at real-practice compositions that can be suited to strength requirements and ambient conditions.

6. CONCLUSION

Over the past few years, it has become possible to shorten the hardening times of concrete mixtures from five days to 36 h by optimizing their composition and adapting the dosage of superplasticizer. Several applications in Flemish Brabant (Galmaarden, Meise, and Zaventem) have shown that the required strength of 40 MPa can be achieved on site after 36 h of curing at ambient temperatures as low as 7°C, with mixtures using standard materials available in a concrete mixing plant. By using superplasticizers the w/c ratio is reduced to 0.33 (CEM I 42.5 R LA) or 0.38 (CEM I 52.5), with a cement content of 450 kg/m³. It is important to obtain this development of strength while preserving the workability of the mixture.

The shorter hardening time reduces the time to complete a UFT repair job on a 1200-m² section of road to three days. This completion time includes demolition, the laying of the base layer and the pavement, the hardening stage, finishing, and opening to traffic.

Laboratory research and site experiments with insulating materials have resulted in even shorter hardening times. At present, it is possible – in the laboratory and with insulation – to achieve the required strength after 13 to 14 h of curing at an ambient temperature of 15°C.

By way of conclusion, it can be stated that the prospects for further shortening of concrete hardening times in road repairs are good. Deeper insight into the interactions between superplasticizer and cement and into the rheological characteristics of the fresh concrete mixture will further reduce the time to develop the required strength, without losing workability and workability time.