

INVESTIGATION OF THE OPTIMUM TIME FOR CUTTING JOINTS IN CONCRETE ROADS

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ABSTRACT

This paper describes an investigation of the optimum time for cutting joints in concrete pavements with a normal surface and a surface with exposed aggregate. The results from the laboratory test show differences in the earliest cutting times for a normal surface and for a surface with exposed aggregate. For a normal surface the concrete is sufficiently strong to begin cutting without causing external damage at a compressive strength around 6.5 MPa, while an exposed surface has to reach about 9 MPa. In this trial this means that the earliest cutting time is 9.25 hours for the normal surface and 10.25 hours for the exposed surface.

INTRODUCTION

In Sweden, concrete roads are normally constructed with joints and without reinforcement. Concrete pavements that are built without reinforcement must have joints in order to reduce tensile stresses and limit cracking. The transverse joints are usually made every 5 metres and are cut in two stages. The first cut is made as soon after pouring as possible, Petersson /8/ and VÄG 94 /16/. This involves cutting a notch around 3 mm wide, one-third of the depth through the concrete. The second cut is made a couple of weeks later when the joint is widened using a saw blade around 8 mm thick to make space for the joint strip or tape. This time the depth of the cut is around 40 mm and the top edges of the joint can be smoothed at the same time. The critical factor in cutting joints in concrete roads is the timing of the first cut. There are two main factors to consider: I) cutting must not be carried out at so early a stage that the concrete has not had time to harden properly, otherwise there is a risk that the aggregate will be torn out instead of being cut, II) on the other hand one must not wait so long that shrinkage reaches the stage where unrestricted cracks appear in the pavement. Another factor that can have an influence on cutting results is whether the aggregate on the surface of the road has been exposed or not.

On a concrete road that was built in 1993 outside Falkenberg, Sweden, the surface aggregate was exposed. After cutting it was noticed that there was minor damage to a number of joints, Figure 1.

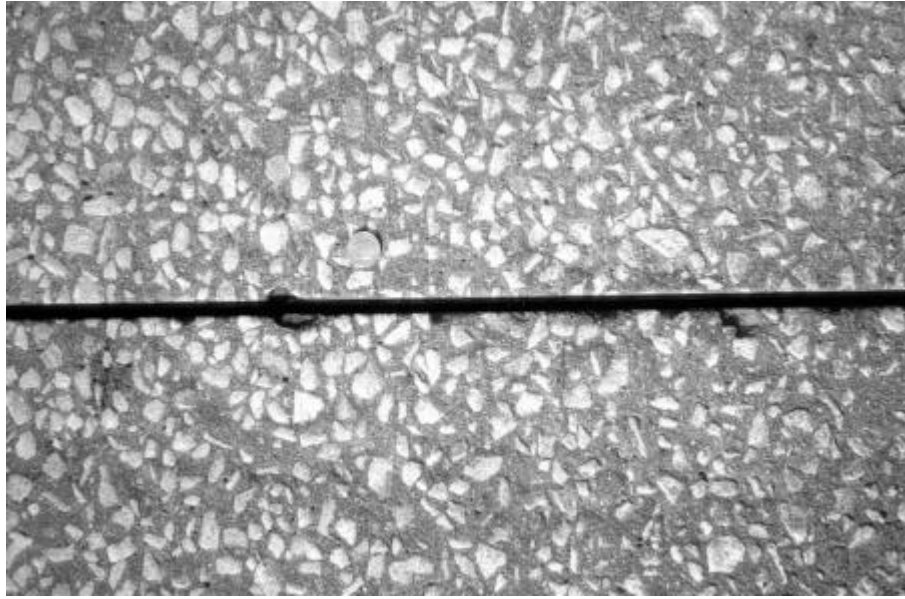


Figure 1 – Example of joint damage on the Falkenberg road.

Small half-moons (diameter 15–25 mm) had broken away from the edges of the joint in a number of places. A survey of the damage is presented by Nissan /6/. The damage occurred before traffic was released onto the road and has not worsened since then. There are several, more or less likely, theories as to why the damage arose. But the reason that seems most likely is that the joints were cut at the wrong time, i.e. the first cut was made too early. Similar damage has not been observed on the concrete road outside Arlanda, Sweden. One difference between the two roads is that the Falkenberg road has a surface of exposed aggregate, while the Arlanda road has a transverse texture (due to diamond grinding after pouring). Hultqvist & Carlsson /3/, /4/ report that the first cut was made on the concrete roads outside Arlanda and Falkenberg 6–15 hours after pouring.

Aggregate is exposed by applying a retarder to the concrete surface immediately after pouring. The effect of the retarder on the optimum cutting time supports the theory of premature cutting. The retarder has the effect of delaying the hardening of the surface concrete. One hypothesis is that when cutting is carried out according to the guidelines given earlier, which were developed for surfaces without exposed aggregate, the surface of a road with exposed aggregate is still too weak, so it may be necessary to adjust the guidelines for the optimum cutting time in the case where surface aggregate is exposed. The reason for having exposed aggregate in the surface is because it reduces the noise levels considerable. In comparison to asphalt pavements, pavements of concrete have traditionally had higher noise levels. But by exposing the aggregate of the concrete surface the noise level can be reduced at the same time as a high friction value can be obtained. The result is a concrete pavement with noise levels as low as asphalt pavements. The recommendations that are currently used for the first cut, around 6–15 hours after pouring, are also imprecise. (Normally, however, good results are still achieved, which is undoubtedly due to the fact that cutting contractors have acquired considerable practical experience.) The factor that governs the optimum time for cutting is the development of compressive strength in the concrete. The rate at which strength develops depends on the ambient air temperature and on

the cement type, cement content, w/c ratio, thickness, wind and insulation, if used. The optimum cutting time can therefore vary from project to project and even within a project.

Zollinger et al /15/ and Soares & Zollinger /13/ have studied the cutting of joints in terms of fracture mechanics. They believe that strength is not a material constant, but that it varies with geometry and size. Working from this standpoint they have developed guidelines for determining the cutting depth, which ought to be between $H/3-H/4$, where H is the pavement thickness. The discussion covers both early-age cutting and conventional cutting. Early-age cutting is carried out with a lightweight portable cutting machine that allows the pavement to be cut earlier than with conventional cutting methods. Soares & Zollinger /13/ have also studied the timing of cutting and how it is affected by the type of aggregate and the slab thickness. (For more detailed information refer to Okamoto et al /7/ and Tang et al /14/, for example). Their focus is more towards obtaining a cutting time that prevents joints from being cut too late. Their results cannot be compared directly with the results of this paper, since the cutting depth was also varied when determining the optimum cutting time. However it is worth noting that the cutting time varies from 6–12 hours after pouring, depending on type of aggregate, slab thickness, cutting depth and cutting method. With early-age cutting, the joints can be cut earlier than with the conventional method. Early-age cutting has been widely discussed because of the fear of cracking. The analyses that have been carried out have also been validated on test pavements.

The requirements governing concrete roads in Sweden are regulated by Swedish highways standard VÄG 94 /16/, which describes the method of cutting, the cutting depth and the width of the cutting blade. Because this is a standard it does not give any recommendations for the precise timing of cutting. The method of producing joints is also described by Petersson /8/ and Andersson /1/.

Silfwerbrand /12/ describes a case (on the old E4 motorway north of Märsta and Stockholm in Sweden) where joint damage occurred in a similar way to that seen on the Falkenberg road. The likely cause of the damage is reported to be premature cutting, coupled with poor cutting procedure. Cutting commenced 48 hours after pouring and the air temperature at the time was +5°C. The writer comments that although the damage has led to an unsightly appearance it does not impair the function of the pavement.

For further information on the cutting of the concrete roads outside Arlanda and Falkenberg refer to Hultqvist & Carlsson /3/, /4/. An analysis of the concrete aspects and the joints in both concrete roads is reported by Petersson et al /9/ and Petersson & Sundbom /10/.

A laboratory test has been performed at the Swedish Cement and Concrete Research Institute (CBI) in Stockholm regarding optimum cutting time for plain jointed concrete pavements.

The objective of the trial is to recreate joint damage similar to that, which occurred on the Falkenberg road, and to try to determine the cause/mechanism of the damage. The trial also includes taking a look at the differences in frequency of damage and the optimum time for cutting between surfaces with and without exposed aggregate. Further information about the results are presented in Löfsjögård /5/.

LABORATORY TESTS

Materials Data and Equipment

The mixture for the concrete was chosen on the basis of two criteria: firstly it should be a traditional road concrete, and secondly the mixture for the concrete should be as close as

possible to that used for the Falkenberg road. This is to allow comparisons to be drawn with the damage that occurred on that road. It was not possible to obtain the exact same concrete mixture as was used in laying the Falkenberg road since the contractor was not obliged to report the concrete mixture in detail. However, Petersson & Johansson /11/ reports an investigation of a hard-wearing road concrete with exposed aggregate that includes data from the concrete road outside Falkenberg. The mixture for concrete K60 was selected from this reference. The formula was modified to suit the aggregate used in these tests, see Table 1.

Table 1 – Concrete mixture.

	K60 Kg/m ³
Cement, Std Degerhamn	375
Aggregate 0–8 mm	737
Aggregate 8-11 mm, X-100*	615
Aggregate 11-16 mm, X-100*	403
Silika, 7 % (slurry)	26,3
Air entraining agent	0,15
Plasticiser, 92 M, 2 %	7,5
Water (totally)	155
W/C-ratio	0.41

* fine grained metavolcanite

The cement used in this trial, Std Degerhamn, is a low alcalisulfate resistant cement suitable for civil engineering structures.

The surface was sprayed with a retarder in order to expose the aggregate.

New concrete roads are constructed using slip form paving that pours, compacts and smooths the concrete. In order to simulate the real-life conditions a plate vibrator was used to distribute the concrete in the formwork and a vibrating beam was used in the laboratory test to smooth the concrete surface.

The cutting equipment consisted of a petrol-driven cutting machine with a 3.2 mm wide diamond blade. The blade was brand new in order to eliminate any effects of poor equipment on the results.

A yard broom was used to expose the aggregate on the surface of the concrete.

Removing the cement mortar from the surface exposes aggregate. This can be done mechanically or chemically. The mechanical method is carried out by simultaneously watering and brushing the surface of the fresh concrete. For the brushing a rotary brush is used. The chemical method is the most common one and this was the method used in this trial. In this method the surface is sprayed with a retarder immediately after pouring. The following day (at the earliest 24 hours after pouring) the surface is mechanically brushed in order to remove the cement mortar that has not set and to expose the surface aggregate of the concrete. The exposure depth should be around 1.5 mm.

Testing

The tests were carried out in March 1999 on a test slab with dimensions $3.40 \times 1.80 \times 0.15$ m. The slab was divided into two halves, one with exposed aggregate and the other without (referred to from here onwards as normal surface), see Figure 2.

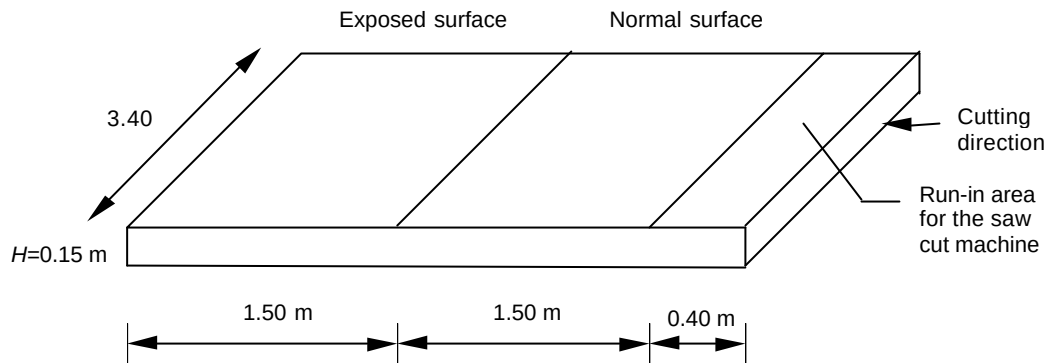


Figure 2 – Test slab (figure not according to scale).

Before pouring the concrete, two temperature sensors were placed inside the formwork at a height $H/2$, where H is the pavement thickness. Placing the sensors at this height eliminated the risk of cutting the cables, since the cutting depth was $H/3$. One temperature sensor was also placed a short distance from the formwork in order to measure the ambient air temperature. The concrete was mixed at the concrete plant and transported to CBI in a mixer lorry. Road concrete is naturally a stiff concrete mix, which made it difficult to get out of the mixer lorry. A small amount of plasticiser was therefore added, and this may have had a retarding effect on the concrete. This should not however impair the results since we measured the temperature and compressive strength of the concrete throughout testing and can therefore compensate for this delay. The concrete was spread in the formwork and vibrated with a plate vibrator at the time of laying. The concrete surface was then smoothed using a vibrating beam. The “zero time” for the trial was taken as the time when the concrete was fully mixed at the factory. The hypothesis is that the concrete starts hardening as soon as it is fully mixed. If one prefers to work from the time when the concrete was vibrated and smoothed then one should deduct two hours from all the times given in the results. Once the concrete had been smoothed a thin layer of retarder was applied to the surface of one half of the slab. In order to prevent any retarder getting on the wrong half, a thin timber stud was laid on the slab during application to prevent the retarder running away. The concrete was then covered with plastic sheeting. Twenty-two concrete cubes were made at the same time as the concrete was being laid. After compaction on a vibrating table the cubes were stored under plastic sheeting in the same premises as the slab. The cubes were used to determine the compressive strength at each cutting time, and to provide the necessary samples for determining the strength of the concrete (1, 7 and 28 day tests). Cutting was always carried out from the same direction and the same sawcut passed through both the normal and the exposed halves. There were 12 joints in total. At one end of the slab there was

a 40 cm section that was not included in either half, but was simply used as a run-in area so that the cutting machine could begin properly on each sawcut and penetrate the correct depth into the concrete before it reached the two observation areas, see Figure 2. On concrete roads it is common practice to cut straight through the plastic sheeting and then cover the cuts. In order to avoid any problems during cutting we chose to pull the plastic sheeting back from the cutting area when making each joint. The plastic sheeting was then laid back in place immediately after each cut. When making a cut the cutting machine must run over the slab in order to cut the full slab length. To prevent the cutting machine's wheels from damaging the concrete surface a plywood sheet was used to spread the load. Joint no. 1 was cut 7.25 hours after zero time. The first sawcut was not good, since the cutting blade did not penetrate deep enough along the full length. It was therefore decided that a new cut should be made after adjusting the cutting machine. Sawcut 1 was therefore renamed sawcut 1a, and the sawcut made after adjustment was named 1b. Joint 2 was cut around 1 hour after joint 1a and from then on one joint was cut every 20 minutes, up to and including joint 12. These cuts were made without problem. Once cutting was completed the slab was covered with plastic sheeting and then left to water-harden for three days.

One day after pouring, the half of the slab that had been treated with retarder was brushed to expose the aggregate. We used a yard broom and brushed the surface while it was being sprayed with water, in order to expose the aggregate to a depth of around 1.5 mm. The slab was brushed in the same direction all the time. The surface was then washed down carefully to remove excess cement paste.

Once the water-hardening period was completed after three days each sawcut was inspected visually. The surface damage was measured along a measurement distance of one metre for each observation area and each sawcut.

Cores were then drilled from each sawcut. The locations for the cores were chosen so that they covered areas of damage, where these existed. Each test core was then analysed by plane polished sections investigated by stereomicroscopy.

TEST RESULTS

General

During testing there were difficulties in cutting joint 1 (a and b) which means that the results obtained for this sawcut were not fully representative.

On the half of the slab with exposed aggregate the aggregate was exposed to a depth of around 1.5 mm.

Consistency and Temperature

The consistency of the concrete was determined by carrying out a cone slump test when the concrete arrived at the laboratory from the concrete plant. The slump measurement that was obtained was 15 mm. The air content was determined as 2.8 % using the Pressure method (Swedish Standard SS 13 71 24).

The temperature of the concrete in the middle of the slab was measured using two temperature sensors, placed at a height $H/2$, and the air temperature was measured using a single sensor. The temperature of the concrete when it arrived at CBI was 17.8°C.

Compressive Strength

The compressive strength was determined by compressing a total of 22 cubic samples in a compression press (Swedish Standard SS 13 72 10). One cube was tested when each cut was made, and after 1, 7 and 28 days respectively, in order to fully document the development of compressive strength in the concrete. The development of compressive strength during the test day is shown in Figure 3.

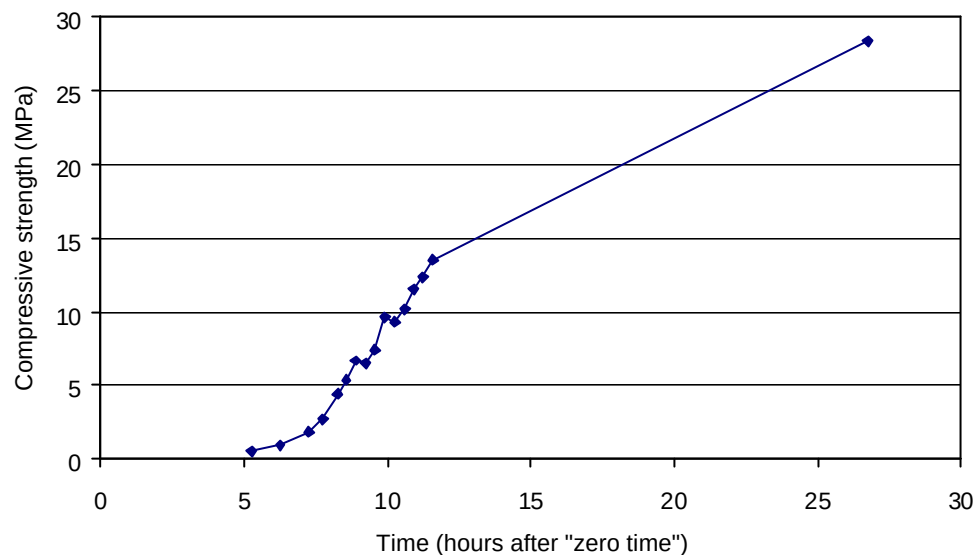


Figure 3 – Compressive strength during the first 24 hours.

The compressive strength of the concrete after 28 days was around 90 MPa, which means that the concrete was excessively strong, since the mixture was for a K60 concrete (Swedish standard class K60 indicating a cube strength of 60 MPa).

External Damage

The surface damage on each sawcut was determined by visual inspection and the area of each damage was measured according to Figure 4.

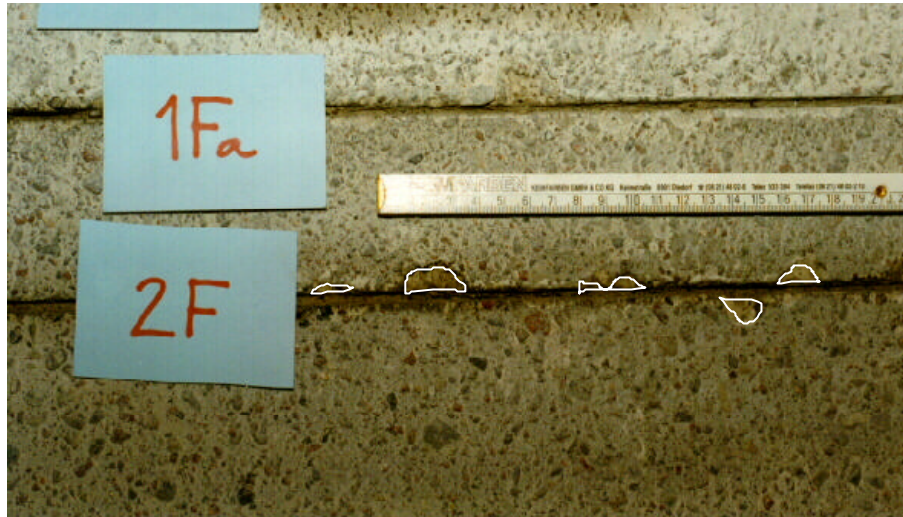


Figure 4 – The surface damage was defined as the sum of the areas of the minor damage that are surrounded by white lines in the photo.

The measurement length in each half of the slab (normal and exposed) was one metre for each sawcut. The total area of material removed from each joint is presented in Figure 5.

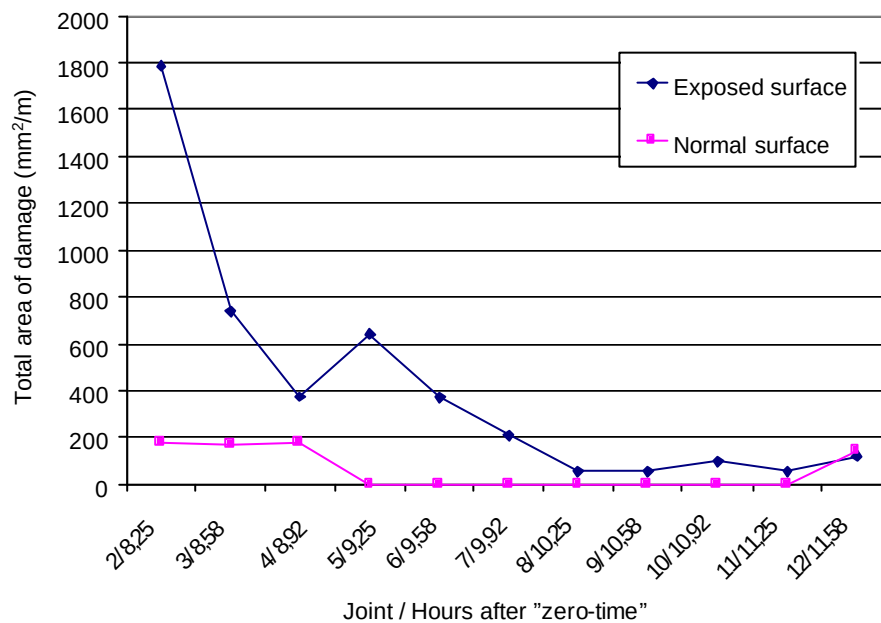


Figure 5 – Total area of surface damage for each joint.

The figure shows a clear difference in the area of damage between the normal and exposed surfaces. If one looks at surface damage alone one can draw the conclusion that for the normal surface it would be acceptable to make the cut from joint 5 onwards (after 9.25 hours), while for the exposed surface it would be necessary to wait until joint 8 (after 10.25 hours). This support

the initial theory that a surface with exposed aggregate should be cut later than a normal surface, because of the effect of the retarder on the surface layer. On the basis of these results it can be said that surface damage below 150 mm² per metre is acceptable. The reason for choosing the value 150 mm²/m is because it correspond to two or three aggregates spalling from a joint edge. This can therefore be used as a criterion for determining the optimum cutting time. No unrestricted cracks were observed in the slab during visual examination.

Internal Damage

A 100 mm diameter cylinder was drilled out of each sawcut and then analysed by plane polished sections investigated by stereomicroscope to determine the number of cracks and the number of crushed aggregate. The location of each cylinder was chosen so that it covered one or more areas of surface damage, where these existed. All the joints examined had internal cracks, regardless of when they were cut. The number of cracks varied between 3 and 10. Only joints 1Fa-b and 1Na-b had cracks that ran all the way through the investigated plane polished section. The number of crushed aggregates varied from several to just one or two or none at all. This range of results was seen in both the exposed surface and in the normal surface.

Relation Between External and Internal Damage

No direct relationship can be seen between external and internal damage. It is interesting to note that joints 5N–11N all have internal cracks despite having no measurable external damage. It is uncertain whether the cracks that were seen have any practical significance. The same applies to the crushed aggregate; there is no relationship with surface damage. This means that despite cutting at a time when external damage is minimal there will still be internal damage, mainly in the form of cracks. The reason for the internal damage is that the internal structure of the concrete is disturbed during cutting, although the damage is probably also related to the formulation of the concrete and its internal structure. It will therefore be difficult to determine the optimum cutting time by looking at internal damage. One must instead concentrate on the external damage and hence obtain the optimum cutting time. It is probable that, despite everything, the observed internal damage has no effect on long-term properties.

Relation Between Compressive Strength and External Damage

If one compares Figure 3 with Figure 5 it can be seen that there is a link between them, Figure 6. The stronger the concrete, the smaller the area of damage at the joints. One can also see a clear difference between the normal surface and the exposed surface.

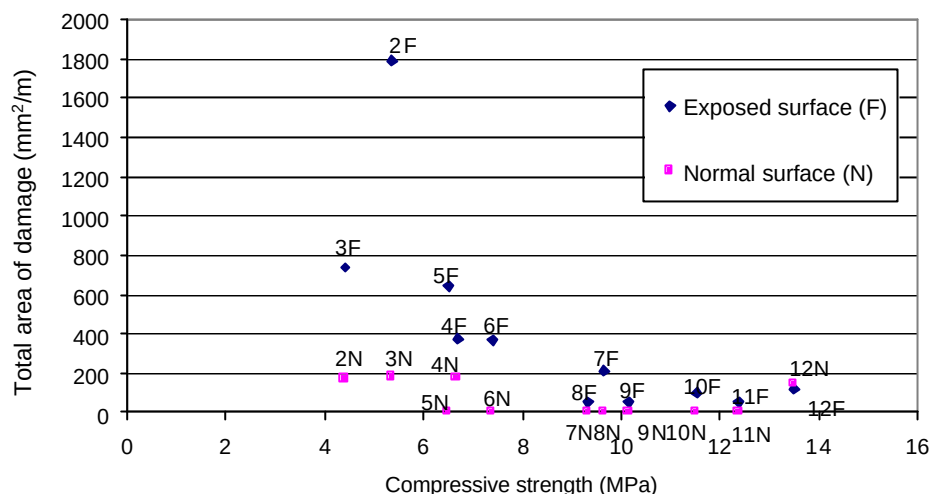


Figure 6 – Relation between compressive strength and total area of surface damage.

In the case of the normal surface it was suitable to make a cut after 9.25 hours (joint 5), and by that time the compressive strength of the concrete was around 6.5 MPa. The corresponding figures for the exposed surface were 10.25 hours (joint 8) and around 9 MPa. It is however important to remember that there are certain differences in strength between the slab and the test cubes. This is because the rate at which strength develops depends to some extent on geometric form. However, the differences should not be so great that one cannot draw any conclusions in this context. The relationship between the compressive strength of the concrete and the area of external damage makes it possible to identify the optimum cutting time for the two surfaces.

MODELING WITH COMPUTER PROGRAM HETT97

The Hett97 computer program /2/ can be used to model the development of strength in a concrete structure. The program can therefore be used as an aid in determining the optimum time for cutting joints in a concrete road. By measuring the air and concrete temperature continuously and then inputting this data in Hett97 /2/ it is possible to obtain the optimum cutting time for each individual job. This is of considerable use, particularly when laying concrete in conditions where the air temperature varies greatly. The program also allows us to see how the optimum cutting time is affected by variations in the concrete mixture. To illustrate how Hett97 /2/ can be used, and show the differences in the optimum cutting time for different types of project, the following runs were carried out:

1. Simulation of laboratory investigation using measured air temperature data (referred to as Test).
2. Generally low temperature, 12°C (referred to as Cold).
3. Generally high temperature, 22°C (referred to as Warm).

Figure 7 shows the results from run 1 (test) and Figure 8 shows the results from the two other runs (cold and warm).

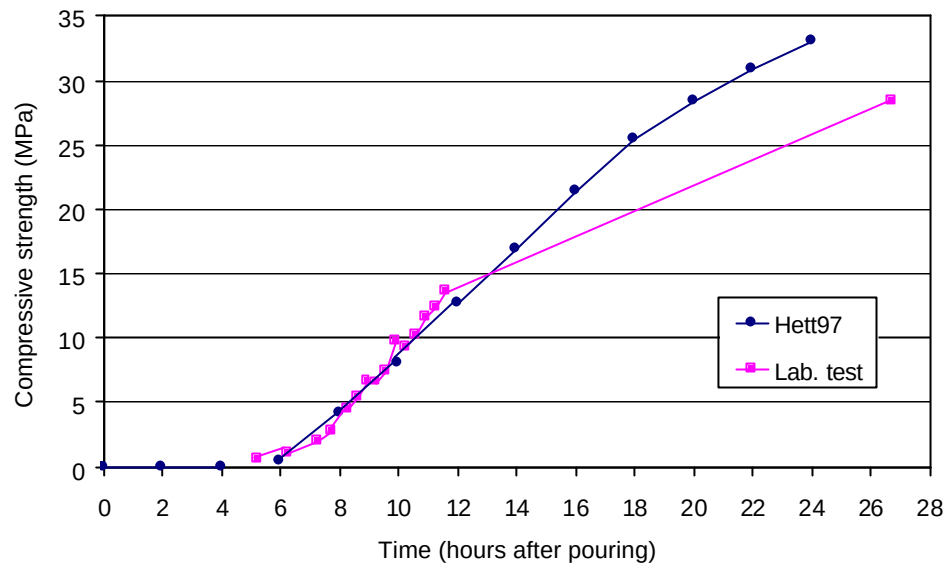


Figure 7 – Result from Test with Hett97, also included in the figure is the development of the compressive strength for the laboratory test.

The results of the Test run show that it is possible to use Hett97 /2/ to simulate the optimum cutting time for a project. By inputting the ambient air temperatures we get roughly the same strength development curve as in the laboratory investigation.

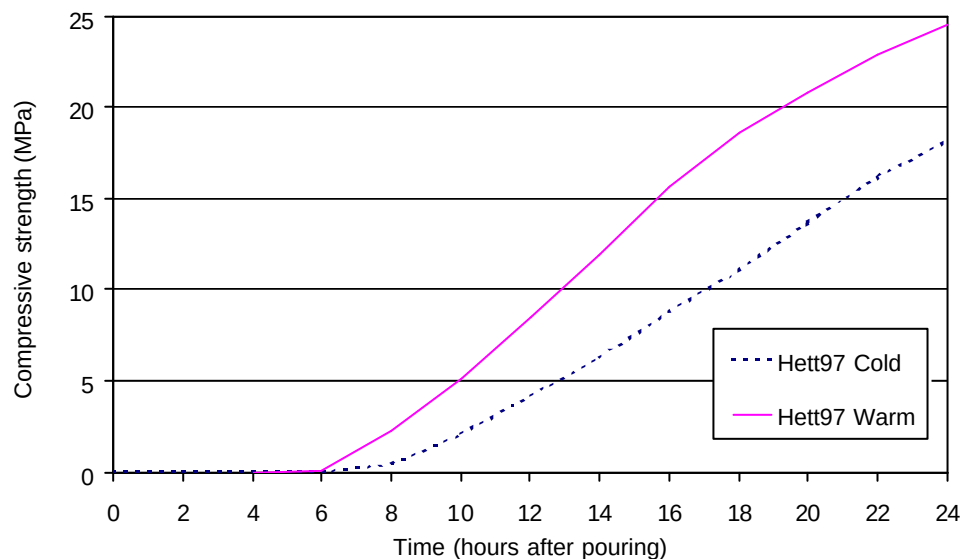


Figure 8 – Results from the runs Cold (temperature 12°C) and Warm (temperature 22°C) with Hett97.

The difference in optimum cutting time between projects where the temperature is generally warm and those where it is generally cold can be several hours. In the figure above we see that for a normal surface the optimum cutting time would be around 10.5 hours after pouring under warm conditions, while the corresponding figure in cold weather would be around 14 hours after pouring (guideline strength over 6.5 MPa from laboratory investigation). For an exposed surface the corresponding optimum cutting times would be 12.5 hours and 16.5 hours respectively (guideline around 9 MPa from laboratory investigation).

CONCLUSIONS

The conclusions of the trial are that it is possible to determine how soon cutting can begin and that there are differences between a normal surface and a surface having exposed aggregate. For a normal surface the concrete is sufficiently strong to begin cutting without causing external damage at a compressive strength around 6.5 MPa, while an exposed surface has to reach about 9 MPa. In this trial this means that the earliest cutting time is 9.25 hours for the normal surface and 10.25 hours for the exposed surface. As a criterion for determining the optimum cutting time one can accept surface damage of less than 150 mm² per metre of joint. To determine the right cutting time when laying road concrete one must monitor the temperature of both the concrete and the ambient air and consider the concrete mixture in order to find out the strength of the pavement in question. The computer modeling program Hett97 /2/ could be a useful aid in determining the strength of the concrete.

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