STATENS VÄG- OCH TRAFIKINSTITUT
National Swedish Road and Traffic Research Institute

COMPACTION OF BITUMINOUS PAVEMENTS

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The compaction of bituminous pavements is a most important factor governing their performance and investigations are being carried out worldwide into the subject. This article describes the work in progress at the National Swedish Road and Traffic Institute and deals particularly with the influence of the cooling process in pavements during compaction, roller characteristics, and the measurement of density in situ using the nuclear method.

The performance and service life of bituminous pavements are determined by several factors, one of the most important being compaction. Owing to the rapid increase in traffic, the increasing damage from vehicles with studded tyres and the growing use of chemical snow-remover on our roads, the importance of compaction has become more pronounced in recent years. Increased requirements for the quality of compaction have therefore been introduced; at the same time the volume and the capacity of paving work have grown considerably. This development has necessitated further knowledge of the compaction process for satisfactory technical and economical results. Compaction is normally expressed in terms of void content and degree of compaction.

The service life of a pavement increases when the void content is reduced, provided that void content does not fall below a certain critical value. Below this value the stability of the pavement decreases, and thus the risk of permanent deformation and bleeding of binder is greater. The pavement surface in this condition is unsuitable from a traffic safety point of view.

At increasing void content the cohesion and internal friction of the bituminous mixture decrease, as will its strength and resistance to wear. At the same time there is a greater risk of intrusion of air and water into the pavement, and of embrittlement of the binder under the influence of the atmosphere. These processes also reduce the service life of the pavement.

From a technical point of view the compaction should be such that the degree of compaction and void content of the pavement are fulfilled according to specifications. The void content should be within certain limiting values and the degree of compaction above a permissible lower limit. In order to realize these requirements an extended knowledge of the rolling process for each type of pavement is needed, in the light of the type of roller to be used and the time available for rolling.

From an economic point of view, the compaction should be carried out in such a way that the above-mentioned requirements can be fulfilled at the lowest possible cost. The cost of the laying capacity required then has to be compared with the cost of the compaction needed.

To meet the requirement of satisfactory compaction at lowest cost there is a need for further knowledge of the compactability of bituminous mixtures at different cooling rates and rolling processes, as well as better methods to measure quickly the degree of compaction on the road. At our institute investigations of the type outlined above have been performed, and a few of the results obtained are summarized below.

The nuclear method

The increased requirements in the quality of compaction, together with the increased volume and capacity of pavement work, have strongly emphasized the need for a reliable and quick field method for measurement of compaction. Normally these checks are made in the laboratory by measuring the void content and degree of compaction of cores taken from the pavement. This method is, however, time-consuming and reduces the possibilities of efficient compaction control during pavement work.

During the past years nuclear methods for determination of density of bituminous pavements have been used increasingly in the field. In this method the pavement is subjected to gamma radiation. The part of the radiation which is absorbed or back-scattered to the measuring instrument is determined and is a measure of the density of the pavement. The method is fast and non-destructive, and the measurement is made *in situ*.

At our institute this method has been investigated during the years 1968–70 in field trials, in which the relationship between the nuclear method and the standard paraffin wax method was studied in pavements of varying degree of compaction, composition, surface texture and thickness. The instrument used was from Decca Navigator and Radar AB, type HDM 4 S. The probe has a double encapsulated ceramic radiation source of the isotope Cs 137, with a half-life 30 years. The back-scattered radiation is detected by means of GM-tubes.

With this instrument the absorber should theoretically be placed on a flat smooth surface. Normally a pavement surface does not fulfil these requirements. To compensate for the roughness of the surface, the pavement surface was smoothed by means of filler before the measurements were made. Comparative measurements were made without any compensation for surface roughness – the probe being placed directly on the unprepared surface. The influence of variations in the chemical composition of the pavement was eliminated by so-called air-gap measurements.

The following observations were made within the measuring range used. The correlation between the nuclear method and the paraffin method was good and approximately linear. A systematic discrepancy of about 0·05–0·15 g/cm^3 was observed between the two methods. The standard deviation referring to the regression line was about 0·02–0·03 g/cm^3, as shown in Figure 1.

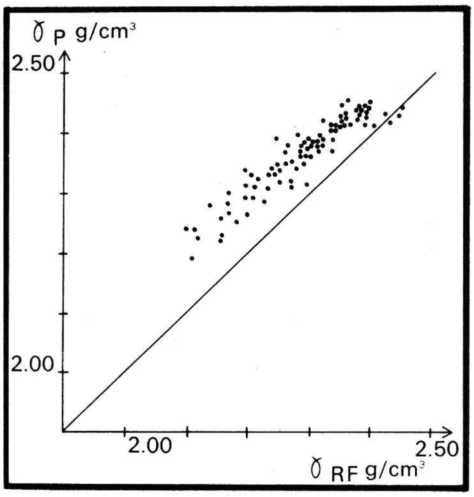


Figure 1: *Correlation between bulk density measured by the paraffin method (P) and the radiation method with smoothing filler (RF). Densely graded asphaltic concrete, maximum particle size 16 mm.*

The conclusion drawn from these experiments is that the nuclear method is useful as an orientation during routine control of the compaction of bituminous pavements. A continued check of the calibration against the paraffin method has, however, to be made. For measurements of pavements of varying surface roughness the filler smoothing method was preferred.

The cooling process

When compacting a bituminous pavement of a given composition, on a base of acceptable bearing capacity, the combined effect of the rolling and the cooling process of the pavement are the two factors which have the dominant influence upon the compaction result.

As the temperature decreases, the viscosity of the binder increases and so does the stability of the mixture. The higher the viscosity the more difficult it is to rearrange the stones, in that further compaction is prevented. To utilize the compaction equipment in a suitable way it is important to know the time available for efficient compaction. This time is the interval from the point when the stability of the asphalt is high enough to start compaction to the point when the asphalt has reached such a stiffness that no more compaction is possible.

This lower temperature limit is not constant but is determined by the compactability of the mix, the rolling process and the temperature range within which compaction of the mix can be effected. The time before

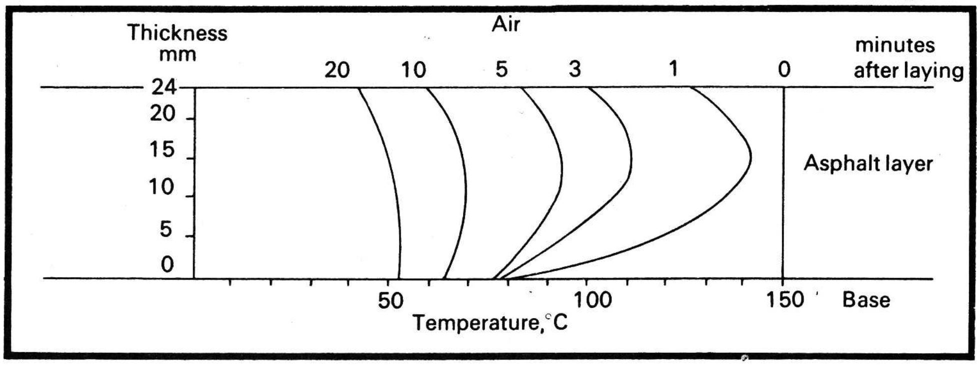


Figure 2: *The temperature distribution in a 24mm thick asphaltic layer on a cool, windy, summer morning at different times after laying.*

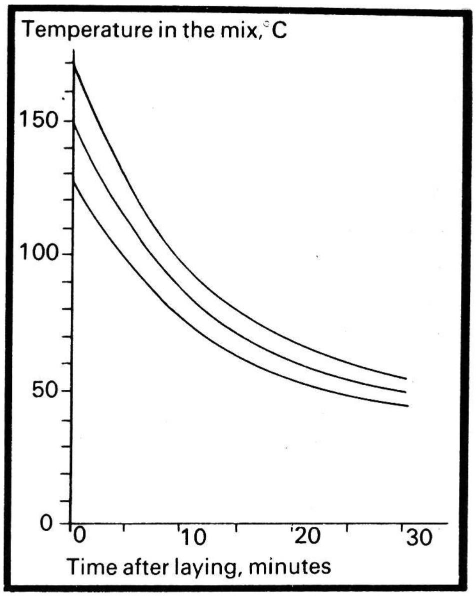


Figure 3: *The cooling process in a 32 mm thick asphaltic layer on a cool, rather windy autumn morning, at different temperatures in the mix before laying. The temperature is measured half way between the top and the bottom of the layer.*

the asphalt has reached this temperature is not constant either. The cooling process is influenced by factors such as weather (wind velocity, solar radiation, air temperature, etc), the temperature of the base, the thickness of the layer and the temperature of the mix immediately before laying. At our institute the cooling process in bituminous pavements has been studied during the years 1965–7 in field trials and by theoretical analysis.

In the field trials the temperature was measured by means of thermistors, which were placed inside the pavement immediately after laying. The disadvantage of measurements of this type is that the influence of different factors cannot usually be distinguished, and that empirical formulae of very limited validity have to be used. The measurements can, on the other hand, be valuable as checks of the assumptions made during the theoretical analysis.

In the theoretical analysis of the cooling process the temperature change in the mixture has been described by the physical laws and quantities that describe the heat conduction between a gas and a solid, within a solid, and between two solids. In order to reach practically useful expressions and formulae, certain empirical approximations had, however, to be used.

The heat transfer between air and pavement was assumed to take place normally through convection and radiation. The temperature distribution in the pavement surface was calculated considering the influence of wind velocity, radiation from the pavement and re-radiation (long-wave) from the atmosphere. When determining the influence of solar radiation upon the heat exchange it appeared suitable to use an equivalent outdoor temperature, the so-called solar-air temperature. In this fictitious temperature the combined effect of air temperature, as well as the short-wave solar and sky radiation, was implied.

The heat transfer inside the pavement was assumed to be by conduction. The heat flow was assumed to be one-dimensional and to occur, through a homogenous isotropic material, perpendicularly to the pavement surface. The change of the temperature with time was calculated according to the general heat equation of conduction and the solution of this equation was performed by calculation of differences.

The heat transfer between the pavement and the base was assumed to occur by conduction. The base surface temperature was assumed to have the usual daily variation. In the calculation of the temperature distribution in the base the general solution of the propagation of a periodic heat wave into a half space was applied. The temperature distribution in the layers on both sides of the boundary between the pavement and the base was calculated according to the general heat equation of conduction; immediately after laying according to an exact mathematical solution and then by calculation by differences.

Good agreement was usually obtained between the result obtained in the field trials and those calculated according to the methods described above. The factors which mainly affected the cooling process in a pavement in these calculations were the wind velocity, the solar-air temperature, the temperature in the base and the temperature in the mixture immediately before laying. An example of the temperature distribution occurring in a 24 mm thick pavement on a cool, windy summer morning is shown in Figure 2. As it appears from the figure, it is not possible to give a cooling process of a pavement without at the same time stating which part of the pavement the temperature describes. In Figure 3 the curves describe the cooling process in a 32 mm thick asphaltic layer with different mix temperatures before laying.

Field trials

In the field trials, carried out in order to study the compaction of bituminous pavements, one of the aims was to work out the rolling programme for compaction using a static three-wheel roller. This rolling programme should then give a satisfactorily uniform and good compaction across the entire pavement surface, even under unfavourable weather conditions. By a satisfactory compaction result we mean an average void content not higher than 5% by volume and a standard deviation not greater than 1·5% by volume and an average degree of compaction (according to Marshall density) above 90%. The laying capacity should be kept at a level of 80 to 100 tons/h.

During the autumn of 1965 compaction experiments were performed on asphaltic pavements to study the influence of the cooling process during rolling. The layer was compacted by means of a 10-ton static three-wheel roller, and the rolling was started when the temperature of the asphalt was 100, 80 and 60 C – the temperature being measured halfway between the top and the bottom of the layer. During each cooling process the layer was compacted by 8, 16 and 24 roller passes according to a certain rolling programme. The asphalt was of ordinary composition for Swedish highways and was made 32 mm thick. The binder penetration was 240. The air temperature varied between 5 and 10°C. The compaction was established by measurements of void content of cores cut from the pavement.

Figure 4 shows the difference between compaction at different initial temperatures and at different numbers of passes of the rear wheel.

It is well-known that pavements laid during the autumn usually receive little after-compaction by traffic during the first winter. Furthermore, if the compaction is performed at a relatively low mix temperature the compaction of the surface layer is normally lower than in the intermediate layer of the pavement. Under such conditions the risk of damage to the surface, for instance by studded tyres, is great, even if the pavement, except the surface layer, has satisfactory compaction. It was found that on pavements, compacted to the same void content with different combinations of initial temperatures and number of passes, the frequency of damage decreased as a rule when the initial temperature increased. Another observation was that the frequency of damage appeared minute on pavements where the compaction started at 100 C and where the number of passes of rear wheel was eight or more.

During the autumn of 1968 experiments with the use of cut-back bituminous mixes were performed, the purpose being to study the influence of roller types and roller parameters on compaction under unfavourable conditions. The rollers studied were a 9-ton vibrating roller, a 10-ton static three-wheel roller and a 11-ton rubber-tyred roller. The roller parameters varied were roller speed, oscillation amplitude (vibrating roller), weight and tyre pressure (rubber-tyre roller). The density was determined by the

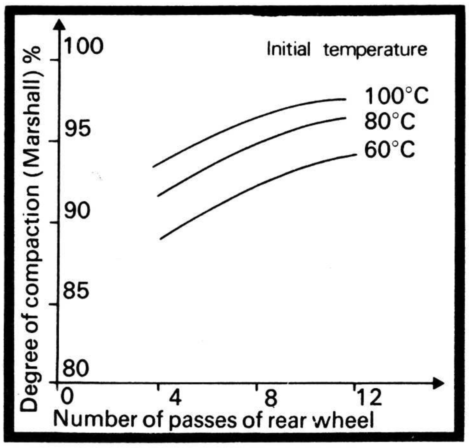


Figure 4: *The compaction process of a 10-ton static three-wheel roller at different initial temperatures, measured half way between the top and the bottom of the asphaltic layer. The compaction was performed under unfavourable weather conditions.*

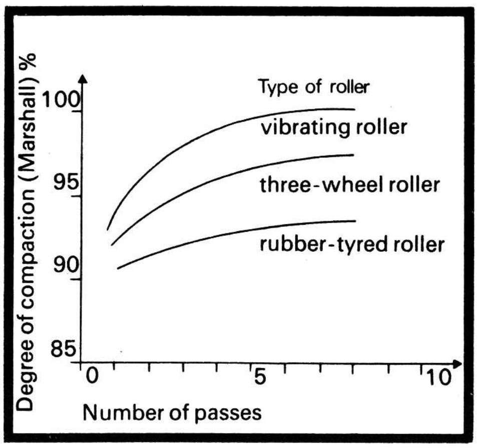


Figure 5: *The compaction processes of three different types of roller. The compaction was performed on a cut-back bituminous mixture under unfavourable weather conditions.*

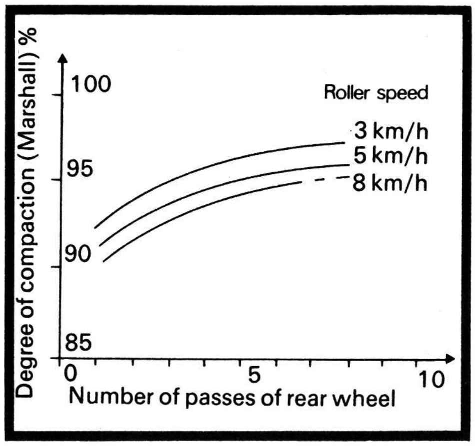


Figure 6: *The compaction process of a 10-ton static three-wheel roller at different speeds of the roller. The compaction was performed on a cut-back bituminous mixture under unfavourable weather conditions.*

nuclear method, calibrated against the paraffin wax method, and the measurements were performed at each pass.

In all cases the compaction of the mixture by the vibrating roller gave higher density than the compaction by the static roller. Furthermore, the density of the pavement was higher after compaction by the steel-wheel roller than the rubber-tyred roller throughout. Figure 5 shows the compaction processes that gave the best compaction results with the different rollers. Figure 6 shows the compaction process of the static three-wheel roller.

Based upon these results, a rolling programme was worked out for compaction by the 10-ton static three-wheel roller according to the following lines (compaction by the paver was assumed to be normal):

1. Rolling wheels start as soon as the pavement has reached a satisfactory stability and continue for the shortest possible time, thereby most effectively utilizing the influence of high temperature for the compaction. These principles can be realized by letting two rollers work simultaneously in a tandem operation according to Figure 7. The rollers should operate about 5 m after each other and, in order to avoid rutting, have a lateral displacement of about 10–15 cm.
2. Each part of the pavement surface should be compacted by at least eight rear-wheel passes. According to the rolling programme shown in Figure 7, each roller should perform 12 passes at a laying width of 3·5–4 m.
3. The roller speed should be about 5 km/h.

The above compaction programme has been tested on about 15 test sections having pavements of different standard composition for roads. In each section the length was 250–300 m. The pavers used were of standard construction. The compaction was determined from cores and gave the following results:

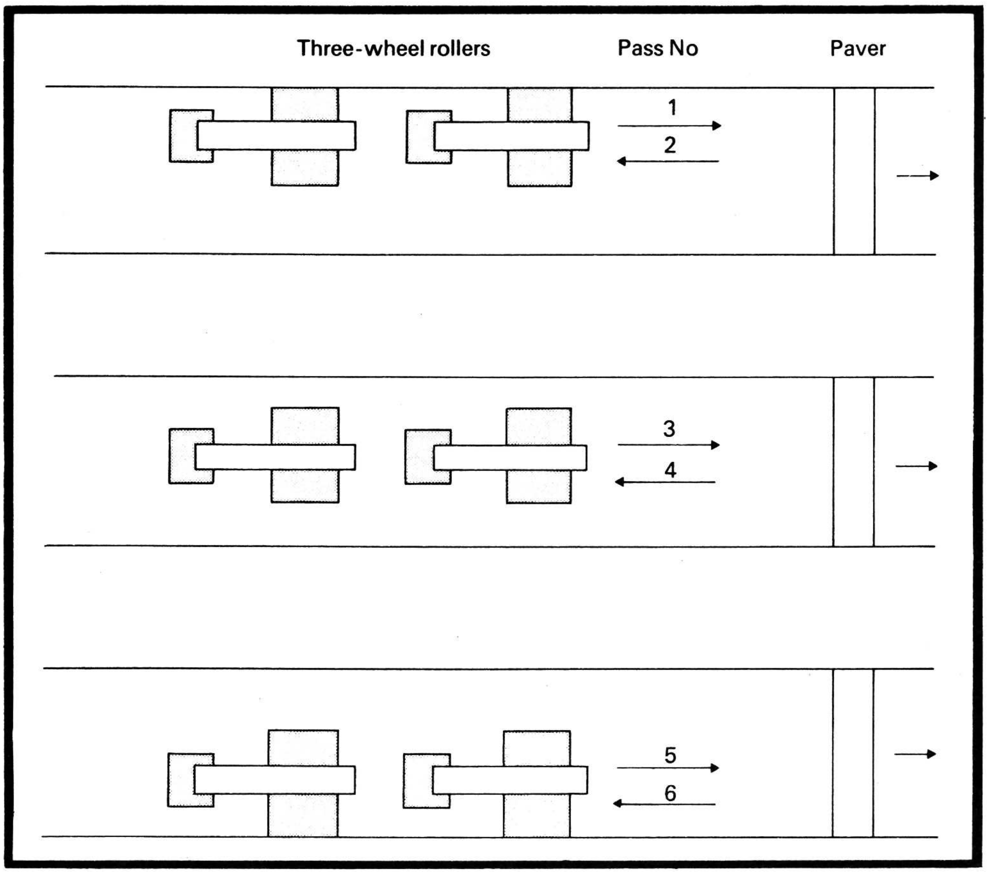
1. The averages varied between 2 and 5% by volume.
2. The average standard deviation was 1% by volume.
3. The average degree of compaction (Marshall) varied between 97 and 100%.

The paving capacity was normally about 90 tons/h and the compaction was generally concluded after about 15–20 minutes. The evenness of the pavement was satisfactory. The wear of the pavement resulting from studded tyres, as determined from seven of the sections, was about 30% lower than on pavements laid and compacted according to routine methods.

The above technical design of the compaction programme for a three-wheel roller should be considered only as one of several possible alternatives. It is not possible from technical and economical points of view to give a general solution of, for instance, the required number of passes or suitable roller speed; the compaction of bituminous pavements is too complicated a process to allow such general conclusions.

The results from field and laboratory examinations show how different factors affect the compaction of bituminous pavements. However, to apply these results direct to construction work in general is difficult. The difficulties primarily consist in determining, in each case, the total effect of the existing factors on the compaction. Methods of measurement have lately, however, been found that at the site can rapidly measure the compaction of the pavement. From this, possibilities arise to carry out compaction in a more reliable way than previously to reach more satisfactory final results from a technical and economic point of view.

Figure 7: *Rolling programme for compaction by two static three-wheel rollers. Laying width 3·5–4 m.*



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