Skid Resistance of Concrete Pavement Surfaces – Practical Experience in Germany

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Abstract

Skid resistance of a pavement surface is important for safety. Therefore the surface of a concrete pavement must have a roughness suitable for a high skid resistance but also for a low noise emission. These surface properties must be as durable as possible. In Germany there are various possible ways for producing surface textures in fresh and hardened concrete surfaces with high skid resistance. For noise-sensitive areas good results can be achieved by dragging a burlap or an artificial turf over the fresh concrete in the longitudinal direction. Also, good and durable skid resistance and low noise emission can be achieved on an exposed concrete surface. Surface grinding a hardened concrete can provide high skid resistance. The practical experiences in Germany for producing a concrete pavement surface with high skid resistance are described in the paper.

Current State, Regulations

Skid resistance is one of the most important properties for safe traffic areas. This is principally not a new finding. Even some centuries ago, quite often natural stone roads or squares, subjected to heavy traffic of horsemen and horse-drawn vehicles, were laboriously textured with hammer and chisel in order to avoid grave skidding of the animals. For the same reason, squares of about 100mm x 100mm were impressed in the plasticized concrete of the first modern concrete road that was constructed in Ohio (USA), in order to improve the traction for the horse hooves (ACI Committee 325 1988).

Nevertheless, in Germany construction contracts didn't contain concrete requirements for the skid resistance of traffic areas until some years ago (i.e. compliance with specific measurement values was not required). Due to rapid increasing traffic volume associated with German reunification and the no speed limit on German expressways (which is justified because of the low number of accidents) skid resistance has come into focus. This is justified because the road safety standards applied to other fields as well for the same reasons, such as routing principles or passive safety devices (for example protective concrete walls), are becoming ever stricter. Therefore, today the currently valid technical regulations for concrete roads in Germany (German Road and Transportation Research

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Association 2001-1) - and analogously for asphalt roads (German Road and Transportation Research Association 2001-2) - include requirements for skid resistance that can be verified by measurements.

The high-speed measuring system known as SCRIM (Sideway-force Coefficient Routine Investigation Machine, Figure 1) with a slanting measuring wheel on a wetted pavement surface (German Road and Transportation Research Association 2001-3) is used as a rule no earlier than four weeks after opening for traffic. This system is used as well for subsequent measurements (for example within the scope of recording and evaluation of road conditions). For expressways acceptance (i.e. opening to traffic), the SCRIM results are obtained at a measuring speed of 80kmph, and the results cannot be less than 0.43. After 4 or 5 years (end of the warranty period) the skid resistance value cannot be below 0.40. However, there are still some uncertainties regarding the reproducibility of the skid resistance results for acceptance and forecasting methods (Gumprecht and Sparmann 2003), as well as the influence of temperature on the measurements (Franke 2003). Research projects are currently being executed to develop suitable forecasting methods, for example to enable the contractor to optimize material selection and construction method to meet the skid resistance requirements (Sulten 2004).

Figure 1. Sideway-force Coefficient Routine Investigation Machine (SCRIM), a high-speed measuring system used in Germany for measurement of the skid resistance of road surfaces.

Definition of Technical Terms

Skid resistance. Skid resistance denotes the effect the texture and material properties of the pavement surface have on the friction drag of the vehicle tire under defined conditions (German Road and Transportation Research Association 2000, 2001-1). The friction drag value (road adhesion ability) between a vehicle tire and the wet road depends mainly on the texture or roughness of the road surface, the thickness of the water film on the road, possible dirt, the properties and condition of the tire, as well as on the rolling velocity.

Surface texture and roughness. Each road surface shows deviations from a plane surface. These deviations can be considered to be waves of different wavelengths (horizontal size) and amplitudes (vertical deviations), which are superimposed as a spectrum. The wavelength spectra range from a few micrometers to some decimeters (German Road and Transportation Research Association 2000). In this description of the geometric shape, the two identical terms, roughness and texture are used in everyday usage.

The texture of the road surface is differentiated into micro, macro and mega texture, or analogously into micro, macro and mega roughness (German Road and Transportation Research Association 2000, 2001-3).

- Micro roughness – also called fine roughness – covers roughness elements with a horizontal size of less than 0.5mm. Roughness values up to 1/100mm strongly influence the wet rub between rubber and road surface. Micro roughness is determined both by the surface roughness (sharpness) of the structured surface of mortar and the surface roughness of the aggregate grain used. As a result of the polishing action of the tires, the texture depth decreases with increasing traffic load. Therefore, a high polishing resistance of the aggregate grain, especially of the fine grain sizes, is required.
- Macro roughness – also called coarse roughness – consists of roughness elements with a horizontal size from 0.5mm to 50mm. However, here only the roughness elements up to a size of 10mm have an influence on the skid resistance due to their drainage effect. The macro roughness is impressed in the surface when the concrete is still plastic. Additional measures are used when placing the concrete pavement. In addition to the surface finish, macro roughness also depends on the type and composition of the aggregate grain and the composition (consistency) of the mortar. Over the long term, the traffic load, together with the weather conditions (acid rain, frost, de-icing agents), cause a change in the concrete pavement surface and thus the macro roughness.
- Mega roughness consists of roughness elements with a horizontal size from 50mm to 500mm, i.e. already unevenness. This may influence the formation of water accumulating on the road surface (e.g. in undulations or wheel tracks). The mega roughness is mainly influenced by the construction method. As the undulations in the mega roughness range have a negative effect on virtually all surface properties, it must be ensured during paving that the concrete pavement has a surface with little mega texture.

Besides skid resistance, the surface roughness also influences noise developing on a road surface. Here, it has to be taken into account, that the influences may frequently be opposed. This means that a high roughness may result in a good skid resistance, but at the same time in a strong noise development and vice versa. This implies that noise control requirements have also to be taken into account and complied with in the requirements for an optimum and long-term skid resistance of a road surface (Sulten 2004).

The surface of a concrete road pavement is essentially divided up into three zones (Figure 2) (German Road and Transportation Research Association 2000, Fleischer 1995):

- A fine-grained mortar layer is produced at the concrete pavement surface as a result of the compacting and vibrating action of the paver (Sulten 2004, Huschek and Böhnisch 2003). This surface mortar consists of the first two zones:

- The topmost first zone consists of superfine materials (filler and cement) and water.
- The second surface zone of the mortar underneath also contains fine sand in addition to the above superfine materials. The water/cement ratio of the surface mortar is higher than that of the concrete itself (Huschek and Böhnisch 2003).

• Underneath the surface mortar, there is the third zone with the actual concrete composition, consisting mainly of coarser aggregate grain and cement mortar.

To simplify things, the development of the surface during the course of the concrete pavement's service life can be divided into three phases (Figure 2) (German Road and Transportation Research Association 2000):

• The first phase is characterized by the texture of the surface mortar that is impressed during concrete placement. Therefore, initially the texture of the green concrete is decisive for the skid resistance.
• In the second phase, the sand is predominant.
• In the third phase, the coarse grain sizes are (at least partially) exposed determine the skid resistance besides the sand.

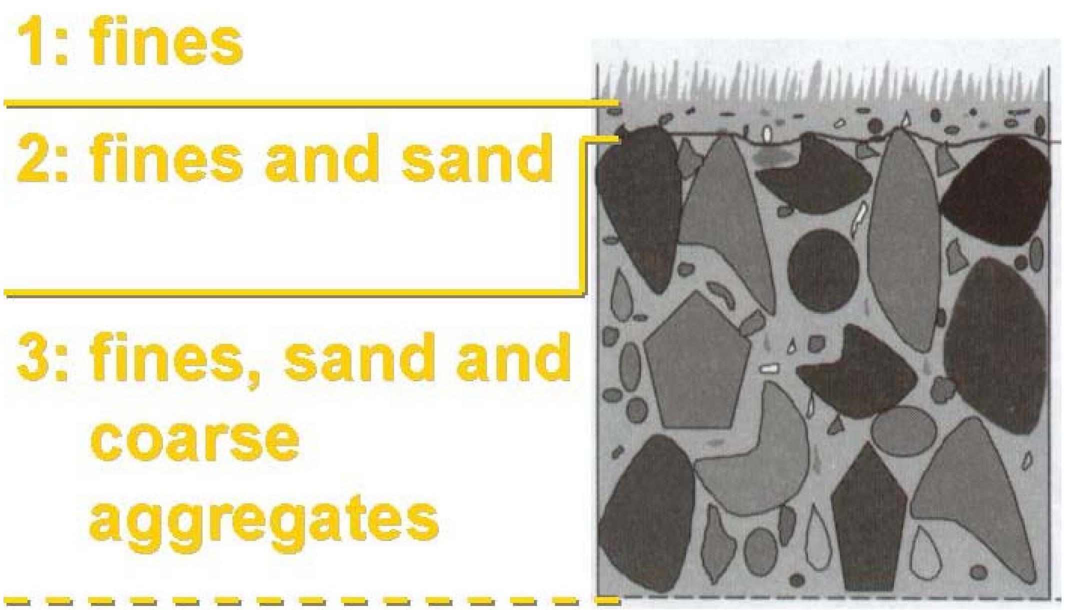

Figure 2. A road pavement of concrete has three different zones in its upper area, which also correspond to three different phases of development of the surface during its service life.

Concrete Engineering Measures

Concrete strength and its resistance to frost attacks with de-icing agents is of particular importance in order to ensure the required performance characteristics and durability. In addition, the concrete must be able to be placed with the available pavers, that is normally with slipform pavers (Springenschmid and Fleischer 2001, Fleischer and Wagner 2003), in such a manner that the required evenness is achieved. This means that a surface is produced which has a low mega texture and is as even as possible, and which is finally textured to achieve a high skid resistance and low noise development. Concrete materials technology is decisive for these properties. Therefore, German regulations include, among other things, requirements for the cement content, the water-cement ratio, the aggregate grains and their composition, the concrete strength and air content.

The following concrete engineering aspects play a role for skid resistance (German Road and Transportation Research Association 2000, Springenschmid and Fleischer 2001):

- The surface mortar must be as durable as possible. To achieve this, especially the following issues have to be taken into account:
    - Sufficient cement content (currently, a minimum cement content of 350kg/m³ is required for heavy-traffic roads);
    - Cement type: Normally, Portland cement CEM I 32.5 R with additional properties (for example maximum Na_2O equivalent 0.80%) is used; the suitability of other cement types (e.g. CEM II) has to be further investigated, particularly regarding the surface durability;
    - The lowest possible cement temperatures at time of delivery should be agreed with the cement supplier, especially during the summer season, in order to obtain a sufficiently long concrete processing time (according to experience the cement temperature at delivery should be less than 80°C, a demand which the cement producer cannot fulfill easily, especially during summer time);
    - Low water-cement ratio (maximum 0.45 during the qualification test, the ratio of the concrete intended for placement should be even lower);
    - The air content must be at least 3.5%, on average at least 4.0%; on the other hand, care has to be taken that there is no uncontrolled air development in the concrete (e.g. due to overdosing of the air-entraining agent and subsequent energy supply by the paver's spreader screw), which may result in a surface mortar, concrete or even foamed concrete with little strength, little abrasion resistance and little resistance to frost and de-icing agents; and finally
    - Careful curing is an absolute must.
- When the macro roughness has worn off, the sand is decisive for the skid resistance. Sands of grain size 0/2mm or 0/4mm with the highest polishing resistance possible are needed. Sands of uniform composition containing low-polishing mineral constituents (e.g. quartzitic natural sands) are especially well suited. The polishing resistance of the fine aggregate grain should be as high as possible (tested in Germany using the polishing test according to Wehner-Schulze (PWS value) (German Road and Transportation Research Association 1999). The PWS value should be at least 0.55 (German Road and Transportation Research Association 2000). The sand composition can also be determined by a petrographic analysis alone or in combination with the PWS test.
- Coarse grains contribute to the skid resistance in the third phase of the surface development during the service life of a concrete pavement. Thus they must also satisfy minimum requirements: The concrete or top concrete layer for routes with high traffic loads must contain at least 50wt.% of crushed aggregates with a grain size above 8mm and a total of at least 35wt.% of crushed aggregates (German Road and Transportation Research Association 2001-1,

German Federal Ministry of Transport, Building and Housing 2003). In addition, these twice crushed and screened chips must have a high resistance to polishing. The importance a high polishing resistance of the aggregates has can be seen in many old stairs and roads with natural stone surfacing, which were heavily polished over the centuries by just light traffic – in many cases only by pedestrians (Figure 3). Therefore, crushed aggregates for pavements of construction classes SV, I to III with standard loading must conform to category PSV_{50}. For long-term extra heavy polishing loads (for example narrow curves, gradients and braking zones for heavy traffic) they must have a minimum PSV value of 53, where polishing-sensitive construction methods (for instance exposed aggregate concrete surfaces) are used.

It can also be cost-effective to pour the concrete pavement in two layers in order to achieve skid resistance. The top concrete layer can then be optimized accordingly without having to use more expensive crushed aggregate for the entire concrete pavement.

Figure 3. Old stairs of stones with little resistance to polishing, were heavily polished over centuries by pedestrian traffic only, show the importance of a high PSV value of the aggregates for skid resistance of our roads with heavy traffic loads.

Because the principal correlation applies that the skid resistance is the higher and the noise development the lower, the smaller the top size of the aggregate exposed at the surface is, in Germany the minimum thickness of the top concrete layer is reduced from 70mm to 40mm (Fleischer and Wagner 2004). This allows crushed aggregate of up to just 8mm to be used, which is then exposed at the surface in the third phase with a positive effect on skid resistance and noise development. It has to be noted that this thin top concrete layer with aggregate size of up to 8mm requires a cement content of about 430kg/m³. Furthermore, the size fraction of 4/8mm, for example, must be made up of fully crushed material throughout and must meet the requirements for a nearly cubic grain shape (German Federal Ministry of Transport, Building and Housing 2003). Whether the method using a thin top concrete layer involves higher costs than a traditional 70mm thick top concrete, depends on the respective case. If, for example, the cement price is low and the chippings are expensive, this method may be competitive due to the reduced thickness of the top concrete layer. On the other hand, it may also be directly specified in the bidding documents because of the advantages it offers in terms of its long-term properties.

Concrete Mixing and Placement

The principle applies that all influences leading to a deterioration of the concrete quality in the area near the surface are also detrimental to the skid resistance. Besides the usual items that have to be taken into account for concrete mixing (for example those concerning the dosing of the concrete base materials and the mixing time), it is expressly pointed out that the mixing site area must be sufficiently prepared (e.g. with frost resisting layer or cement stabilized) so as to prevent dirt from reaching the concrete through the aggregate feeder. In addition, intermingling and confusion of aggregates for the top and bottom layers of concrete must be reliably prevented.

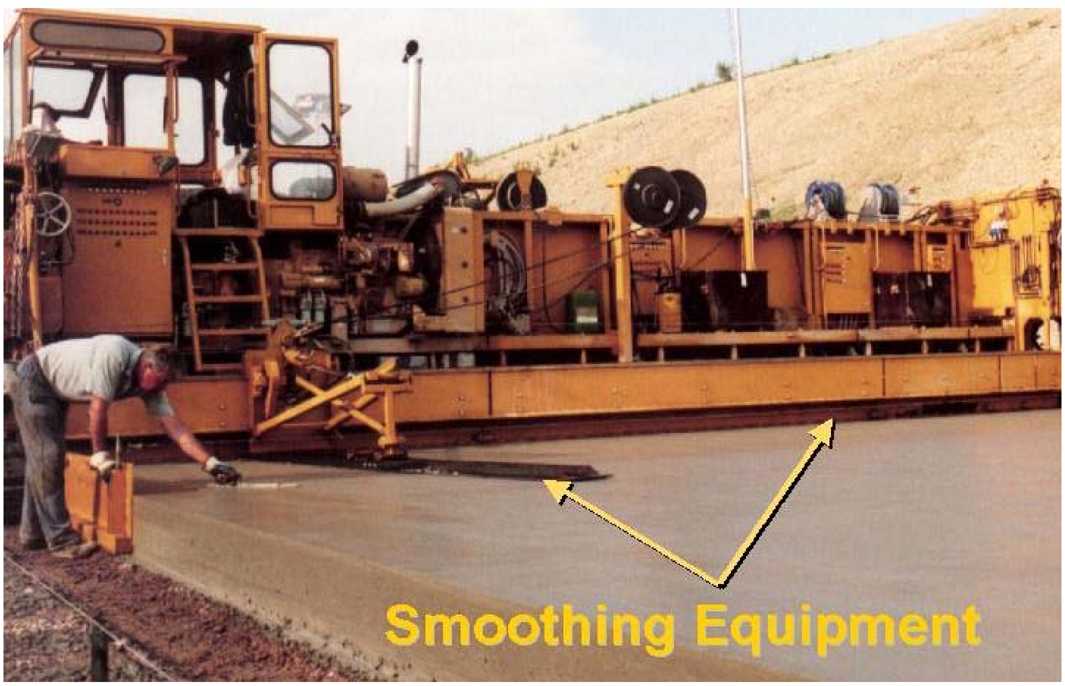

Figure 4. The concrete, after compacting and strike off to the planned level, is smoothed crosswise with a screed and lengthwise by a ”Supersmoother”.

The concrete has to be compacted completely and evenly across the entire cross-section, without de-mixing taking place. To achieve this, the type and power of the vibrating equipment must be matched to the concrete consistency and be suitable for the placing thickness and rate.

The smoothing equipment (transverse and longitudinal smoother, Figure 4) must be adjusted so as to produce an even and closed surface of the concrete pavement. Streaks in the surface, and variations in the thickness and quality of the fine-grained mortar, etc. result in different surface properties of the concrete pavement.

Surface Texturing

General. The surface of concrete road pavements can be provided with different textures, both in the green concrete after smoothing and after hardening (German Road and Transportation Research Association 2000). Usually, texturing of the green concrete is the more cost-effective option. Currently, the following texturing methods on green concrete are commonly used:

- Longitudinal texturing with burlap or artificial turf (combinations such as broom and then burlap were also tried out),
- Cross texturing with a steel broom, and
- Texturing by removing the top mortar ("exposed concrete").

Additionally, numerous other combinations have been investigated (German Road and Transportation Research Association 2000, Sulten 2004), which are, however, not yet sufficiently tested or have turned out to be a wrong approach.

Texturing of already hardened or older concrete road pavements can be carried out by mechanical treatment or coating of the surface (German Road and Transportation Research Association 2002).

Longitudinal texturing with burlap. Longitudinal texturing of a wetted concrete pavement surface using a piece of burlap is classified as "low-noise“ in German standards in terms of noise development. Such concrete pavement surfaces are assumed to be 2dB(A) quieter than the reference pavement of un-grooved mastic asphalt. For this reason, this surface texture is used on routes where such a noise reduction is required. For example, road which runs through a residential area. The burlap is drawn along the wet concrete surface from the working platform (Figure 5). It has to be fastened to the platform so that it can be dragged along the concrete without creases.

The requirements for the burlap in the technical rules are, for example, a minimum mass per unit area of 300g/m², or a minimum support length during dragging of 2m. In addition, the burlap must be replaced or washed out in a timely manner, so a satisfactory texture is impressed. After washing out, excess water has to be removed from the burlap before it is placed on the green concrete surface in order to avoid a deterioration of the mortar quality. Before its first use, the burlap has to be slightly wetted. However, whether these measures can be implemented practically depends on the respective concrete engineering, equipment and placement engineering boundary conditions.

Figure 5. A piece of burlap is dragged along the green concrete from a platform; the longitudinal texture produced by this ensures a high skid resistance and little noise development of the concrete road.

In spite of the descriptions of the burlap in the technical rules that are relatively detailed at first sight and its use, experience and engineering common sense, as well as a continuous visual quality inspection by the contractor are needed in order to be able to produce a concrete pavement surface that satisfies the requirements. Therefore, other important issues that have to be observed additionally are:

- The weight, structure and support length of the burlap must be matched to the concrete, its consistency, its mortar content, etc. Each contractor and even each construction site are more or less different in this respect.
- The paving rate and, thus, the travel speed of the platform also have to be taken into account in the selection of the burlap and its support length.
- Another factor is that the concrete properties can slightly change, above all the workability, as a result of unavoidable variations of the base materials and weather changes during placement. This can be responded to within a short time, for example by changing the burlap's support length or by loading the burlap if the texture deteriorates or becomes uneven.

According to the skid resistance measurements that are currently available in Germany, the applicable skid resistance requirements can be met for concrete pavement surfaces textured longitudinally with burlap (Figure 5), if the above-mentioned boundary conditions are complied with and the work is carried out with great care. According to our experience at opening to traffic SCRIM values between 0.46 and 0.58 are reached (measuring speed 80kmph). SRT (skid resistance tester) pendulum values are laying between 68 and 70, the discharge measuring method values between 8 and 12 seconds.

Longitudinal texturing with artificial turf. German technical rules have not yet been classified with regard to noise development from texturing produced by dragging behind an artificial turf (Figure 6) for texturing in the longitudinal direction. But since many routes were already produced in this way, and noise measurements were carried out on them, it is currently being checked whether this surface can also be classed as “low-noise“ in the near future.

When artificial turf is used for texturing, the surfaces produced are frequently coarser than with burlap. The high weight per unit area of approximately 2000g/m² results in a deeper texture than with a burlap. Partly small aggregate sizes are pulled to the surface by the artificial turf. The texture sometimes resembles that of a longitudinal broom finish. Similar to burlap, longitudinal artificial turf texturing offers the advantage over longitudinal broom finishing, that partly unfavorable undulations in the mega texture range are minimized by the support length of at least 2m. This has a positive effect on noise development. It also applies to the artificial turf that it has to be cleaned or washed out as soon as the texturing deteriorates or becomes uneven.

Various types of artificial turf are commercially available. Major differences are, besides the weight per unit area, the pile height (reference value 25mm to 30mm) and the filament type (Figure 6). Here, the same applies as in the selection of the burlap: The type of the artificial turf must be carefully matched to the concrete properties and placement conditions. It is not possible to specify a generally applicable artificial turf type.

Figure 6. The type of artificial turf (especially the pile height and type of filaments) has to be matched to the concrete properties and placement conditions.

The measurement results and experience gained concerning the skid resistance of concrete pavement surfaces that were textured longitudinally with artificial turf are not as many as those with burlap-textured surfaces. Most turf-textured routes initially have a higher skid resistance than burlap-textured routes. At opening to traffic SCRIM values between 0.54 and 0.58 have been measured (measuring speed 80kmph). SRT pendulum values are laying between 64 and 66, the discharge measuring method values between 4 and 6 seconds. It is currently not yet possible to finally assess the development of these surfaces under traffic loads during their service life. It can however be assumed that the skid resistance values are not lower than those of burlap-textured routes.

Cross texturing with steel broom. A concrete pavement surface that was textured crosswise with a steel broom develops more noise than surfaces textured lengthwise. For skid resistance, crosswise texturing is still superior to longitudinally textured surfaces. Even higher initial skid resistance values can be achieved which also remain higher over the long term than longitudinal textures under comparable conditions. At opening to traffic SCRIM values between 0.58 and 0.60 have been measured (measuring speed 80kmph). SRT pendulum values are laying between 70 and 80 (depending on the texture depth), the discharge measuring method values between 2 and 4 seconds. For this reason, crosswise textures should always be used where no noise reduction is required, for example where the route does not run through a residential area.

The type of steel bristles of the broom (rigidity, dimensions, arrangement) has to be matched to the properties of the surface mortar. During execution, it has to be taken into account that the setting angle of the broom, and the contact pressure in connection with the surface mortar have an important effect on the texture depth. These influencing variables are normally controlled by the respective worker. That is, his skill and attention are decisive for the quality of the texture. In addition, the broom must be regularly cleaned from any adhering fine-grained mortar (if necessary after each transition) for example by beating. If these workman principles are not observed, even a crosswise steel broom finish cannot ensure satisfactory skid resistance values.

Texturing by removing the top mortar. Contrary to the surface textures discussed above, exposed concrete surfaces from which the surface mortar has been removed are non-oriented and normally have a greater texture depth. In Austria, for example, the exposed concrete surface has been the standard construction method for expressways for about fifteen years (Sommer 1994, Pertl 2000). Thanks to the small top size of the aggregate at the surface and the higher texture depth, it combines a high long-term skid resistance and low noise development. In Germany, too, some expressway sections have already been produced and measured. The measurement results from German and Austrian routes that are now available, and all of them positive, show that an exposed concrete surface with a coarse aggregate size of up to 8mm produces as little noise as a surface textured longitudinally with burlap. Now that the positive technical evidence is available, exposed-aggregate concrete surface with a top aggregate size of 8mm can be classified as “low-noise” - like a textured surface longitudinally with burlap - with a noise reduction value of 1.0 to 2.0dB(A).

The exposed concrete surface can be regarded analogously to the construction method using a thin top concrete layer. The difference is, that here the surface mortar is already brushed off from the green concrete and the third phase, i.e. the actual concrete with exposed coarse aggregate, exists from the beginning (Fleischer and Wagner 2003). Therefore, the concrete engineering requirements exceeding those of a traditional road concrete are similar: Cement content about 430kg/m^3, fully crushed aggregates above 4mm and up to a maximum of 8mm with a predominantly cubical shape throughout, with a PSV value of at least 53.

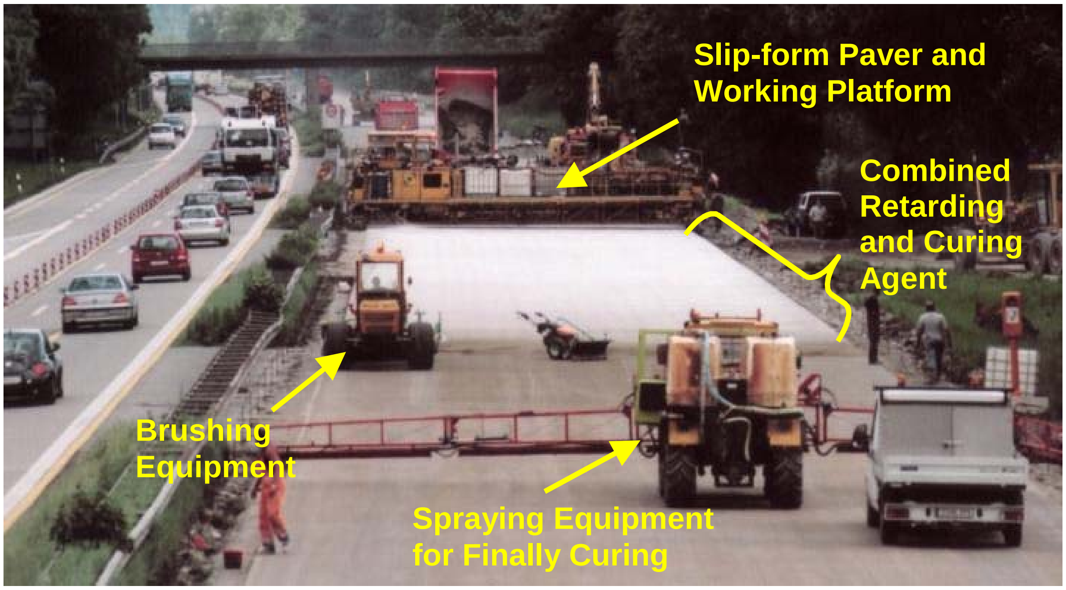

Figure 7. Construction of a concrete road pavement with “Austrian exposed-aggregate concrete surface“: Concrete placement with slip-form paver, spraying with a combined retarding and curing agent from a platform (light shade), brushing off the unhardened surface mortar, and spraying with a customary curing compound from a separate carrier.

With the exposed concrete method, the bottom and top concrete layers are placed, compacted and smoothed as usual, with the vibrator for compaction of the top concrete layer having to be adapted to its smaller thickness (for instance by reducing the vibrating power). Following this, currently a combined retarding and curing agent is sprayed on from a working platform as standard (Figure 7), which delays hydration of the cement in the topmost layer (millimeter range) and at the same time prevents the green concrete from drying out. When the concrete as a whole has hardened sufficiently and can be driven on, the unhardened surface mortar is brushed with a motor-powered steel broom (Figure 7, 8) and removed, producing an even exposed-aggregate concrete surface where now the aggregate of size fraction 4/8mm, for example, is exposed. Finally, a customary curing agent is sprayed on from a mobile carrier for further curing (Figure 7). The groove for the joints can be cut before or after brushing off the surface mortar, depending on weather conditions and the concrete properties.

Figure 8. Construction of a concrete road pavement with "Austrian exposed-aggregate concrete surface": Brushing off the unhardened surface mortar.

Due to the more expensive concrete composition and the more time-consuming production, the construction costs for an exposed concrete surface are slightly higher than those for a textured concrete pavement. But because the skid resistance values and their long-term behavior are obviously even better, exposed concrete surfaces should be specified directly in bid documents. At opening to traffic SCRIM values between 0.56 and 0.60 can be reached (depending mostly on the PSV values of the aggregates between 4 and 8mm size; measuring speed 80kmph). SRT pendulum values are laying around 66, the discharge measuring method values are lower than 2 seconds, i.e. nearly unmeasurable. This will give the public construction agency the certainty that it will have to initiate almost no skid resistance-improving measures. On examination of the lifetime costs, this construction method is therefore ultimately a cost-effective alternative.

Texturing of hardened concrete. There are several improvement options for old concrete pavements (e.g. those that were heavily polished by very high traffic loads and therefore have an insufficient skid resistance according to the current technical rules) and for route sections with insufficient drainage and therefore insufficient skid resistance of the road surface during rain due to unfavorable longitudinal and/or transverse gradients, or in the case of damage (Fleischer 1995, German Road and Transportation Research Association 2002, Sulten 2004):

- Grinding of the concrete surface
- Milling of the concrete surface
- Cutting grooves length- or crosswise
- Coating of the concrete surface

The best experience and the best results regarding an improvement in skid resistance, without developing more noise, have been obtained by fine surface grinding (Figure 9).

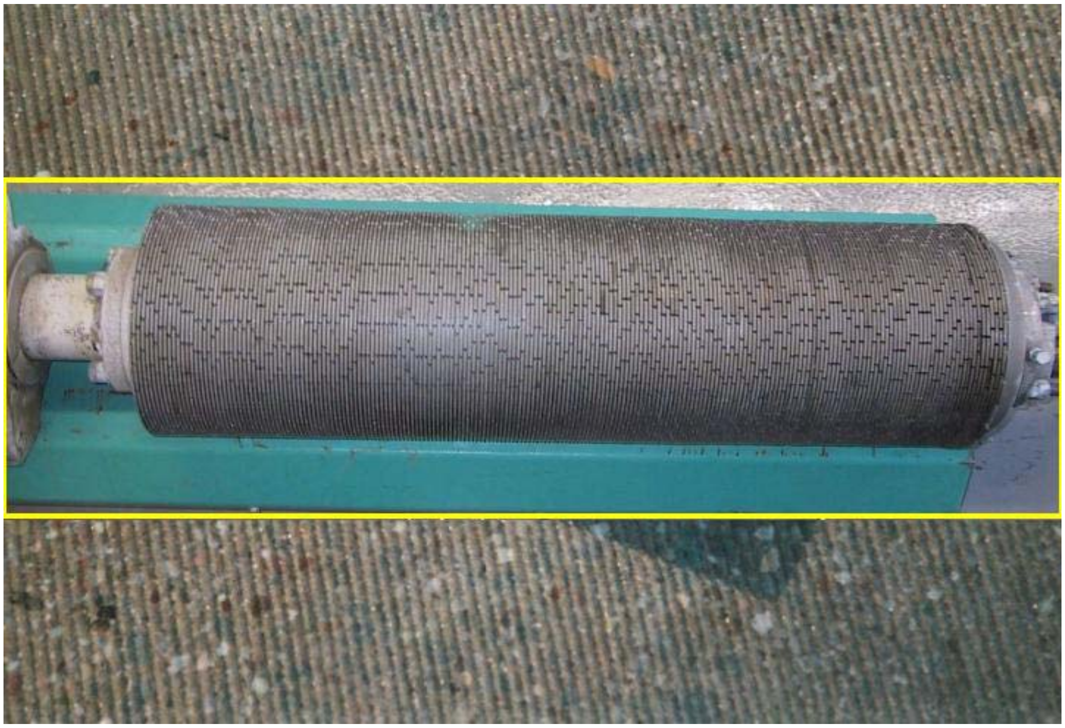

Figure 9. Heavily polished old concrete road pavements can again get a permanently skid-resistant and low-noise surface by grinding in longitudinal direction (shown in the figure: ground surface and roller which is used for grinding).

These properties are comparable with coating with gritted reaction resin mortar. However, this method is more expensive, and the experience gained with their durability varies. Such work is normally carried out by specialist contractors, which should have the requisite know-how. If only a more effective drainage of the surface is emphasized, milling of the surface or cutting grooves length- or crosswise can also be considered.

Protective Measures and Curing

The great influence which protection and curing has on the quality of the road concrete, especially in the upper areas of a concrete pavement – and therefore also on the durability of the surface mortar and thus the skid resistance – should be well-known by now. Protective and curing measures are aimed at minimizing unfavorable mechanical effects on the concrete pavement, as well as drying out and heating up of the concrete.

In Germany, usually first a liquid curing agent (German Road and Transportation Research Association 1996, Springenschmid and Fleischer 2001, Fleischer and Wagner 2003) is sprayed onto the green concrete surface for curing, which strongly inhibits evaporation of water from the green concrete. If the concreting work is carried out during the summer season, special curing compounds with a higher lightness value should be used, which, besides protecting against the evaporation of water, reduce heat-up of the concrete as a result of their light shade (reflection) (Hiller et al. 2004). For concrete placement during the summer seasons, German regulations state that for air temperatures above 25°C and / or high wind velocities the full area of the concrete pavement has to be wetted as soon as possible after placement and thereafter directly after cutting of the grooves – that is at a time when lightweight vehicles can already drive on the concrete pavement. The surface should not dry up during this time. This activates the latent heat, and the concrete pavement hardens at it surface at a favorably low temperature, or even at a lower temperature than in the lower area. The latter results in a favorable negative zero stress temperature gradient (Hiller et al. 2004, Springenschmid and Fleischer 1989). Wet curing should be applied for about three days (depending on the weather), in addition to spraying with a curing compound. Other curing methods, such as covering with film and applying water-retaining covers, are only practicable in special cases (for instance single-bay reconstruction at low temperatures). The main disadvantages are blurring of the surface texture and difficulties in joint cutting, as well as a significant rise of the concrete temperature during the summer season (Hiller et al. 2004).

Other Factors Influencing the Skid Resistance

To ensure a high initial skid resistance of concrete pavement surfaces, it has to be ensured that the mud produced during joint cutting is sucked off directly at the saw blade or removed, washed off directly after joint cutting before it hardens on the textured surface, in addition to the above described texturing and curing measures. If the cutting mud is left on the concrete surface, it forms something like a grease layer on the wet surface, which can strongly reduce the skid resistance.

Driving on the new concrete pavement during the first days after placement should be reduced to a minimum, because otherwise there is a danger that the texture in the insufficiently hardened surface mortar is damaged or worn off. Even afterwards, the new concrete pavement should be driven on by site vehicles as late and as little as possible. Especially areas where trucks are tracking, maneuvering or turning, as well as entry and exit points on the new concrete pavement are subject to damage.

Tests Performed by the Contractor

Within the scope of the self-supervision inspections, the contractor has to determine the skid resistance of the concrete pavement surface once a day. In construction practice, it has proven successful to perform these measurements – using the combined SRT (skid resistance tester) pendulum / water discharge measuring method (Figure 10, German Ministry of Transport, Building and Housing 1972) – as soon as possible after concreting on a sufficient, representative number of test areas.

Figure 10. Stationary skid resistance measurements can be carried out using the combined SRT pendulum / discharge measuring method.

This ensures an impression of the skid resistance at an early stage. With some experience, this also allows for a visual and haptic assessment of the skid resistance. When the measurement results are unsatisfactory, appropriate improvement measures can be taken, at least, for the areas yet to be paved.

Conclusion

Concrete pavements can be constructed with skid-resistant properties, so that the applicable requirements are satisfied. However, on route sections in the vicinity of residential areas, for example, the noise development requirements also have to be taken into consideration. In Germany, in areas that are sensitive to noise, green concrete pavement surfaces are textured longitudinally by dragging along a piece of burlap to make them skid-resistant and at the same time reducing the noise. An exposed concrete surface can comply with the applicable requirements for skid-resistance and noise reduction. If the noise development on a surface is not relevant, the green concrete pavement surface should be textured crosswise by means of a steel broom.

For execution of the work, the concrete technology and placement technology have to be carefully matched to one another, taking into account weather conditions, in order to achieve lasting surface properties. Curing is also decisive for a long service life of the surface and has to be adapted to placement conditions. Early measurements of the skid resistance enable the concreting crew to take steps for optimization of the surface texture in time.

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