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THE PERFORMANCE OF AGGREGATES IN A SINGLE SURFACE DRESSING, SUBJECTED TO WEAR BY STUDDED TYRES

IMPORTANCEMENT DE GRANULATS EN ENDUITS SUPERFICIELS SOUMIS A L'ACTION DE PNEUS CRAMPONS

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Abstract

Sweden, studded tyres cause considerable wear on road surfacings. The properties of aggregates are known to be of importance, but lack of experience with road conditions has prevented relevant specifications.

The performance of nine aggregates – in a single surface dressing – has been studied by means of small test surfacings in road E4. The flakiness of two of the aggregates was varied, too. The change of the texture depth was determined with the aid of a laser profilometer and sand-patch measurements. The former is considered to give more reliable results. After two years in service, the test surfaces have been rated by an expert panel and aggregate samples have been removed from the road after heating the binder. The changes in grading and flakiness have been analyzed.

The macro surface depths after two years and the changes of that property, not considering the first summer's change, because of particle orientation and embedment going on, correlates well with the Swedish aggregate abrasion value. Also, the flakiness of the worn aggregates and reduction of that property in the road, due to traffic wear, correlate. The aggregate impact value does not correlate. However, a fair relationship exists with the aggregate crushing in the road. Obviously, most of these particles, that have been crushed by traffic stresses, can go on functioning in the surface dressing. The condition is, however, that proper aggregate-binder adhesion exists. The aggregate flakiness is also of importance mainly as it determines the "particle size" of the road surfacing. A lack in the abrasion property of an aggregate can partly be compensated by improving its flakiness.

Résumé

En Suède, les pneus à crampons usent fortement la surface des chaussées.

On a étudié l'évolution de 9 granulats utilisés en enduits superficiels sur de petites planches expérimentales. Des mesures ont été faites : profilomètre à laser et hauteur au sable. Après 2 ans de trafic on a extrait les gravillons pour mesurer l'évolution de leur forme et de la granularité.

Un essai suédois d'abrasion se corrèle bien avec les résultats de ces constatations, ce qui n'est pas le cas de la fragmentation mécanique.

La forme des gravillons joue un rôle important et une faible résistance à l'abrasion peut être en partie compensée par des gravillons plus cubiques.

1. Introduction

During wintertime in Sweden, studded tyres cause wear on road surfaces with heavy traffic. On correctly laid road surfaces, the quality of the aggregate is one of the most important wear-determining factors. The classification of the aggregates for road surfacing purposes has been done through testing particle shape and strength, Swedish flakiness and impact value respectively. The first mentioned method represents the approximate average ratio between the width and thickness of the particles, obtained by sieving the aggregate on quadratic and slotted formed screens.

In cases with similar aggregate sizes, the impact value gives a good correlation with results from foreign testing methods for aggregate strength. The impact value is strongly influenced by the flakiness value. The polishing of road surfacing aggregates is not considered to be a problem in Sweden and no test exists. This is considered partly due to the petrological characteristics of the aggregates, partly to the wear of studded tyres.

The wear caused by studded tyres on road surfaces has demanded a new method for testing aggregate abrasion resistance. Some aggregates with rather low impact values can rapidly be worn out in the road. Tests commissioned by the Swedish Road Administration, mainly in the VTI's circular road simulator, have shown that a method, similar to the British Abrasion Test (BS 812), is classifying the aggregate according to observed wear resistance [1, 2]. The test has, however, been modified and emery flour has been used as abrasive powder instead of natural sand. The

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powder consumption has been considerably reduced and the result is calculated in a different way. This test method is now tentatively prescribed in the Swedish Road Administration directives [3]. A similar method has been developed in Norway and favourable correlation has been noticed with wear by studded tyres both in road simulator and test roads [4]. A good correlation exists between the two abrasion test methods. These are, however, unsuitable for very heterogeneous aggregates.

Test roads, where different aggregates are studied, have been constructed rather late in Sweden and have not yet been totally evaluated. Results are to be found from a test surface experiment, where different aggregates have been studied in a single surface dressing.

2. Description of the test surfaces

The test surfaces have been applied on road E4, at Ålberga, appr. 130 km south of Stockholm. They have a size of only 1 x 2 m with the longer side in the outer wheel track. The average daily traffic is 9400 vehicles and the speed limit 90 km/h. In winter 1980 the frequency of vehicles with studded tyres was 50.4%. The test surfaces were applied in June 1979 in connection with a double surface dressing, a regular maintenance operation. Plastic fabric was placed on the road surface which consisted of asphaltic concrete, before spreading binder and aggregate. The fabric was then rolled away and test surfaces applied in a realistic way by spreading 1.9 kg/m² cationic bituminous emulsion and aggregate from a binder tank and aggregate spreader respectively.

3. Aggregates

The aggregates studied and the results from laboratory tests appear in table 1. The flakiness and impact values have been determined for size 11.2-16.0 mm, abrasion values for size 8.0-11.2 mm. Aggregates, originating both from quarried rock and crushed gravel, have been tested. The characteristics of the aggregates have been varied, quartzite and porphyry-rich gravel, have for example low abrasion values (good wear resistance) amphibolite, diorite and two mica-rich gneisses have, on the contrary, high abrasion values. Diabase has a low impact value (good aggregate strength), but rather high abrasion value, due to the absence of the

hard mineral quartz. There is no relationship between abrasion and impact values for the test materials (correlation coefficient $r = 0.57$).

To be able to study the influence of the aggregate characteristics, determined by the petrographic composition, all the material necessary for a test surface was sieved to a size 11.2-16.0 mm. The flakiness values were not the same for the aggregates, but the variations are not excessive (Tab. 1). Furthermore, the particle shape was varied for two aggregates through sieving on slotted sieves so that both "cubic" and flaky aggregates (flakiness indexes 1.1 and 1.5 respectively) could be studied (see Tab. 2).

4. Investigations of the test surfaces

It is difficult to measure directly the wear on a surface dressing. In France, a photogrammetric method has been tested [5]. The macrotexture depth is easier to measure than the direct wear and must be considered to adequately characterize the condition of a road surface, for example the speed dependence of the skid resistance on a wet road is related to the macrotexture [6].

Tab. 1 : Aggregates in test surfaces and results from laboratory tests

Aggregate	Sw Flakiness value	Sw Impact value	Sw Abrasion value	Density kg/dm ³	Average particle weight* g
Quartzite	1.35	48	55	2.65	4.81
Gravel, mainly porphyry	1.34	34	62	2.64	3.92
Gravel, mainly granite	1.33	41	102	2.68	3.67
Diabase	1.38	25	119	2.97	3.90
Gravel, mainly gneiss	1.41	60	149	2.67	3.64
Gneiss, micaceous	1.36	36	143	2.76	3.82
Amphibolite	1.42	58	196	3.06	3.57
Diorite, coarse grained	1.36	60	171	2.76	3.57
Granite, fine grained	1.39	37	79	2.65	3.77

*Corrected to an "average" density of 2.66 kg/dm³.

Tab. 2 : Results of measurements of texture depth with sand patch-method and laser profilometer. Results from judgement by expert panel.

Aggregate in test surface	Texture depth sand patch (mm)				Texture depth, laser profilometer (mm)			Rating (expert panel)
	7906	8004	8105	8109	7909	8105	8109	
1 Quartzite	4.12	2.21	1.84	1.37	1.33	1.17	0.81	5
2 Gravel, rich in porphyry	3.64	1.97	1.56	1.21	1.43	1.20	0.89	4-5
3 Gravel, granitic	3.97	1.52	0.83	0.73	1.32	0.97	0.55	4
4 Diabase	3.57	1.57	0.92	0.82	1.41	1.11	0.74	4
5 Gravel, rich in gneiss	3.50	1.24	0.69	0.60	1.24	0.86	0.42	3
6 Gneiss, micaceous	3.47	1.21	0.55	0.50	1.42	0.83	0.38	3
7 Amphibolite	3.25	0.71	0.40	0.34	1.30	0.56	0.29	1
8 Diorite, "cubic"	3.97	1.24	0.53	0.46	1.53	0.89	0.43	2-3
9 Diorite, "normal"	3.55	1.02	0.47	0.41	1.30	0.69	0.31	2
10 Diorite, "flaky"	2.95	0.97	0.42	0.37	1.05	0.61	0.30	1
11 Granite, "flaky"	4.36	1.49	0.67	0.62	1.36	1.02	0.57	3
12 Granite, "normal"	3.85	1.59	0.99	0.78	1.42	1.18	0.68	4
13 Granite, "cubic"	3.53	1.62	1.02	0.82	1.55	1.33	0.82	4

The condition of the test surfaces has been monitored by regular inspections, photographic recordings, surface casts and measuring of road surface macro-textures, the latter both according to the well-known sand-patch method and the VTI's contactless laser profilometer. The latter gives the road surface profile from which the average texture depth is automatically recorded. The laser moves on a one meter long horizontal bar. With the aid of a lens system, the optical axis of which forms a 30° angle to the laser beam, the light spot is reproduced on a light-sensitive sensor. The position of the light spot on the sensor is related to the distance of the road surface and influences electrical signals monitored from the sensor.

The condition of the test surfaces was assessed in autumn 1981 by an expert panel. After that samples of the aggregates were removed for laboratory testings by careful peeling of the bituminous binder.

1. Measurements of macrotexture depth

The macrotexture of surface dressings is influenced by aggregate factors as embedding of the particles in the underlying road surface, orientation of the particles by traffic load, especially during the first period after laying. In the UK, where no studded tyres are used, the macrotextures of surface dressings with nominal sizes 12 and 19 mm, have been studied during a 12-year long period [6]. The macrotextures (sand patch measurements) decrease mostly during the first year but to a lesser degree also during the following ones.

The macrotexture depth decrease depends on the hardness of the underlying pavement surface. The influence of the embedment and orientation of the aggregates should have been reasonably constant for the different test surfaces. Loosening of single particles has not occurred to any significant extent.

Only sand-patch measurements were made on the newly laid surfacings in May 1979. The first measurement with laser profilometer was performed in October the same year (Tab. 2). According to the sand-patch method, the newly laid single surface dressings had in 1979 macrotexture depths of 3-4 mm, but the values decrease and have even for the most wear resistant aggregates approximately been halved the next year. In spring 1981 a further, but smaller decrease can be observed. Also a further decrease occurred during the summer, according to the autumn measurement.

The macrotexture depth measurements with the laser profilometer show that the level of the values is lower than for sand patch measurements, a fact that has also been observed by the TRRL [7]. Their vehicle-mounted laser profilometer was, however, of a different construction. The most-wear-resistant aggregates show the greatest difference in the macrotexture depth values according to measurements with both methods. With increasing wear, the differences become smaller. According to subjective observations, the differences in macrotexture depth between the aggregates are exaggerated by the sand patch measurements, especially on the lightly worn surfaces.

The macrotexture depths from both measurements are set in relationship in figure 1. Because the first measurements in 1979 were made on different occasions, these values do not fall to the same curve as the values from the later measurements. In the diagram, the scattering of the values from the same measurement increases with time because of the influence of the different wear of the aggregates. The laser profilometer seems to give the most relevant values and only these are considered in the following text.

Fig. 1 : Relationship between measurements of texture depth, sand-patch and laser profilometer methods.

The changes in macrotexture depth are rather small at the beginning, when the main influencing factor is the particle shape. "Cubical" aggregates have the highest and the flaky ones tend to have the lowest values. The differences between the aggregates increase with wear. If only aggregates with "normal" particle shapes are examined, the highest values for macrotexture depth are obtained for aggregates with low abrasion values, the most wear-resistant are quartzite and porphyry-rich gravel, both rich in the hard quartz mineral. Diabase, with a rather high abrasion value, has also given good results and obviously the exceptionally good aggregate strength compensates for the lack of hardness. The same three aggregates, when tested in asphaltic concrete in the VTI's road simulator, have also given the best resistance to studded tyre wear [2]. The lowest texture depths have been obtained for aggregates with high abrasion values, namely amphibolite, two mica-rich gneisses and diorite. The three first mentioned aggregates have also been tested in the road simulator with poor results [2].

4.2. Relationship between texture depths, changes in macrotexture depth and results from tests on aggregates

The change of macrotexture depth has been calculated in such way that the influence of particle embedment and orientation, mainly occurring the first summer, has not been considered. The macro-texture change is therefore calculated for the period October 1979-October 1981.

The results from the aggregate tests (Tab. 1) have been set in relationship to the macrotexture depth only for aggregates with "normal" particle shapes. A good relationship (correlation coefficient $r = 0.92$) results between the abrasion value and the macrotexture depth according to the last measurement (October 1981), figure 2. This also applies to the relationship between the change in macrotexture depth and the abrasion value ($r = 0.89$). However, no relationship is obtained between the macrotexture depth change and the impact value ($r = 0.44$). The conclusion must be that the change in the surface macrotexture mostly depends on a slow abrasive process and not so much on crushing of the aggregates.

In UK a test road has been performed with different aggregates in single surface dressings [8]. A good linear relation-

Fig. 2 : Change of texture depth (obtained with laser profilometer) for test surfaces. Aggregate type and particle shape in table 1 and 2.

Fig. 3 : The macrotexture of test surfaces related to the Sw. abrasion value for the aggregates.

Fig. 4 : Relationship between the Sw. Abrasion Value and change in macro-texture depth, measured with laser profilometer in October 1979 and October 1981.

Fig. 5 : Relationship between Sw. abrasion value and Sw flakiness value for aggregates worn in test surfaces.

up was obtained between the British aggregate abrasion test and the macrotexture depth after 9 years. No such relationship exists with the British aggregate crushing test.

French test road experiment [9] with surface dressings, so established a correlation between surface wear (photo-astimetric measurements) and the abrasion resistance of the aggregate determined by the Microdeval test (an wet abrasion test) but not the Los Angeles test (mainly an impact test). It has been shown also in Hungary [10] that there is a linear relation between the change of macrotexture depth of hot-rolled asphalt surfacings and the British abrasion value. It can be said that the abrasion resistance of aggregates is a matter of importance not only in countries where studded tyres are used.

Former studies made in Norway [4] and Sweden [2] have shown that the product value between aggregate abrasion and impact strength values has given the best correlation with the studded tyre wear of asphaltic concrete. That result cannot be confirmed for the test surfaces, the abrasion value has given a slightly better result than the product value ($r = 0.89$ and 0.84 respectively).

certain crushing of the aggregates has occurred in the test surfacings according to examination of photographs and the aggregate samples taken from the road (chapter 3). Some crushing occurs already at compaction, but most of it is caused by traffic stresses.

3. Investigation of aggregate samples removed from the road

It has been observed that the wear of studded tyre wear uses the aggregates in the road surface to become more and more flaky. The flakiness values of aggregates in the test surfaces have also increased (Tab. 3). For aggregates with "normal" initial particle shapes, there is a good correlation between the abrasion values and the flakiness values

resulting after road wear ($r = 0.93$), figure 5. Also the impact test has been determined on the worn aggregates from the road. The values have increased to a varying extent in comparison with the original ones because of the worn, flakier and therefore weaker particles (see Tab. 1 and 3).

The aggregate samples have also been sieved to determine the degree of crushing that has occurred in the road. If material passing 11.2 mm sieve is considered and related to the impact values, a certain relationship is found ($r = 0.81$), figure 6. If material < 8.0 mm is considered, the relationship is better, $r = 0.84$. The conclusion must be that the crushed aggregates are still effective in the surface dressings due to good adhesion with the binder. This fact can also clearly be seen in photographs taken at different times. Such behaviour of aggregates in the road has been named "post-failure" condition [11]. It can also be observed that the binder has been pressed up in cracks formed in the aggregates. Such action is more difficult e.g. in an asphaltic concrete when the binder even in warm weather is stiffened by filler and fine aggregate. Normally no adhesion promoting agent is used in asphaltic concrete. It has also been observed in another test road on the E4 near Gävle that the same quartzite does not perform as well as expected in an asphaltic concrete, obviously because particle fragments formed by crushing are lost from the road surface.

Also the average particle weight has been determined for original and worn aggregates from the road surface. It can be seen (Tab. 3) that the "cubical" aggregates have lost more weight than "normal" or flaky ones. Probably the former have such protruding edges in the road surface that are easily worn away.

If the loss of average particle weight in the road (corrected for differences in density) is correlated with the abrasion value, it is seen that other aggregates than quartzite show some relationship (Fig. 7). Probably this very hard, but rather brittle aggregate has lost weight in a different way to the others, e.g. more splitting of sharp edges has occurred.

Tab. 3 : Tests on aggregate sampled from the test surfaces in October 1981.

Aggregate	Sw. Flakiness index	% passing 11.3 mm sieve	Sw. Impact value	Average particle weight, g
Quartzite	1.44	38.0	55	3.78
Gravel, mainly porphyry	1.41	35.6	42	3.46
Gravel, mainly granite	1.55	54.1	66	3.05
Diabase	1.49	34.4	43	3.34
Gravel, mainly gneiss	1.68	67.5	78	3.00
Gneiss micaceous	1.87	57.9	61	3.15
Amphibolite	2.12	79.6	79	2.93
Diorite "cubic"	1.65	52.1	66	3.65
Diorite "normal"	1.87	70.1	85	2.87
Diorite "flaky"	1.98	81.2	81	3.01
Granite "flaky"	1.55	36.5	52	3.15
Granite "normal"	1.45	28.0	45	3.39
Granite "cubic"	1.35	19.4	44	3.69

Fig. 6 : The relationship between crushing of the aggregates in test surfaces and Sw. impact value.

Fig. 7 : Relationship between Sw. Aggregate Abrasion Value and weight loss (corrected to density 2.66 kg/dm^3) for average aggregate particle with "normal" flakiness in test surface.

4.4. Inspection by an expert panel

The condition of the test surfacings was judged in October 1981. A scale ranging from 1 to 5 was used (Tab. 3). Quartzite and porphyry-rich gravel, that is aggregates with low abrasion values, achieved the highest nominations. The lowest ones were observed in aggregates with high abrasion values. Good agreement is obtained with the results from surface macrotexture depth measurements.

5. Discussion and conclusions

It can be observed that all aggregates with abrasion values exceeding 150 have been ranked lower than 3 by the expert panel and their functional capacity can be considered near the point after two years in the road with the specific traffic.

The macrotexture depth is $> 0.70 \text{ mm}$ for the most wear-resistant aggregates, judged good by the expert panel, and $< 0.50 \text{ mm}$ for the insufficient ones. According to Swiss [12] experience the surface texture (sand-patch measurements) should be $0.6\text{--}1.00 \text{ mm}$ for roads carrying fast traffic. In the UK the sand-patch texture depth for experimental surface dressings have been $0.8\text{--}1.8 \text{ mm}$ after 12 years traffic [6].

The measurement of the surface macrotexture depth and its change with time has made it possible to characterize the condition of the single surface dressings and consequently the aggregate quality. The laser profilometer has given lower values than the sand-patch measurement, the difference being greatest for the less worn surfacings. The first method is considered the more reliable one.

The functional life of the aggregates is mainly determined by their wear resistance as determined by an abrasion test. The particles are worn more and more flaky in the surface. The strength properties are of secondary importance in the case of proper aggregate-binder adhesion as in a piece crushed particles continue to function in the surface. The particle shape is also of importance and cubical particles give the highest initial macrotexture depth. If an aggregate has poor abrasion resistance it can be improved to a certain degree by obtaining as "cubical" particles as possible by adequate processing operations.

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