Resistance to polishing and mechanical properties of aggregates for asphalt concrete wearing courses

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Lancieri F.
Full Professor - Department of Civil Engineering - University of Pisa

Losa M.
Associate Professor - Department of Civil Engineering - University of Pisa

Marradi A.
Senior Researcher - Department of Civil Engineering - University of Pisa

Synopsis

The durability of skid resistance properties of pavements is considerably dependent on the polish–wear characteristics of aggregates. As a road surface comes into contact with the vehicle tyre under repeated traffic movements, the exposed aggregates will experience a wearing or abrasive effect. This effect is accelerated by the presence of sand or grit on the road surface. If aggregates are of a particular nature, the gradual wearing will result in a loss of aggregate angularity and polishing may occur. If this happens, the overall skid resistance of the road surface decreases. Aggregates selected for use in road surface mixes must be able to withstand repeated heavy loads without undue polish/wear; certain aggregates in road surfaces are more susceptible to wear and polish effects than others, becoming extremely slippery when wet.

In this paper, the Authors present the results of laboratory tests on physical, mineralogical and mechanical properties of aggregates currently used in Tuscany for hot mix asphalt wearing courses. The aim is to evaluate relationships between empirical characterization of aggregates (Los Angeles Abrasion Test LA, Fragmentation Coefficient FC, Aggregate Abrasion Value AAV) and friction performance of pavements, as related to changes in microtexture, simulated by using the Accelerated Polishing Device; the analysis takes into account the aggregate shape and flakiness index as well as mineralogical properties determined by a petrographic analysis. Results of aggregate performance tests, with regard to the decrease of pavement skid resistance, combined with empirical tests and mineralogical properties, can suggest new specifications for aggregate parameters; by using the results of aggregate wear-polish characteristics, it seems reasonable to accept lower limits for the aggregate parameters determined by using empirical tests.

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INTRODUCTION

The preservation of acceptable levels of surface friction represents one of the main factors warranting safety of vehicle movement. Among the requirements of stone aggregates used to produce asphalt mixes for wearing courses there is the evaluation of their polishing characteristics, introduced more than twenty years ago. It is well-known that this test measures the residual value of the friction given by a surface composed of aggregates undergoing an accelerated polishing action that simulates, in a standardized manner, the effects of road traffic. In such way Standards try to integrate the specifications of the materials with a test that is related more to their actual performance on site. It is well-known that there are numerous factors capable of influencing skid resistance and of considerable importance are the minerological nature of the original rock, the size and shape of the grains. However, the determination of the relationship between the values of the various qualifying parameters of aggregates is a rather complex operation because of the wide variation in the single parameters, the uncertainties of the experimental methods used in their determination and, above all, the diversity of the phenomena they describe, which in some cases can lead to conflicting conclusions.

In order to verify the existence of relationships between the parameters used for the qualification of such aggregates, this research has tried to identify an experimental link between the evolution of microtexture, evaluated by means of the Polished Stone Value PSV, and the parameters that characterize their mechanical behaviour and shape, in relation to their petrographic nature.

POLISH-WEAR CHARACTERISTICS OF AGGREGATES

Aggregates used in the production of asphalt mixes for wearing courses are notoriously subject to continual polishing action due to the interaction of the tyre with the road surface. As a result, in all the phases of movement of the vehicle, the transmission of tangential action by the wheel to the road surface is determined. Such an interaction occurs in the presence of particles and substances that, if the surface is wet, intensifies the polishing action of the aggregates.

Some aggregates exhibit the ability to resist this polish/wear action more than others. Figure 1 provides a grouping of different materials according to their wear and polish characteristics. The groupings of materials listed in Figure 1, according to Naval Facilities Engineering Command (NavFac), will provide satisfactory skid resistant qualities.

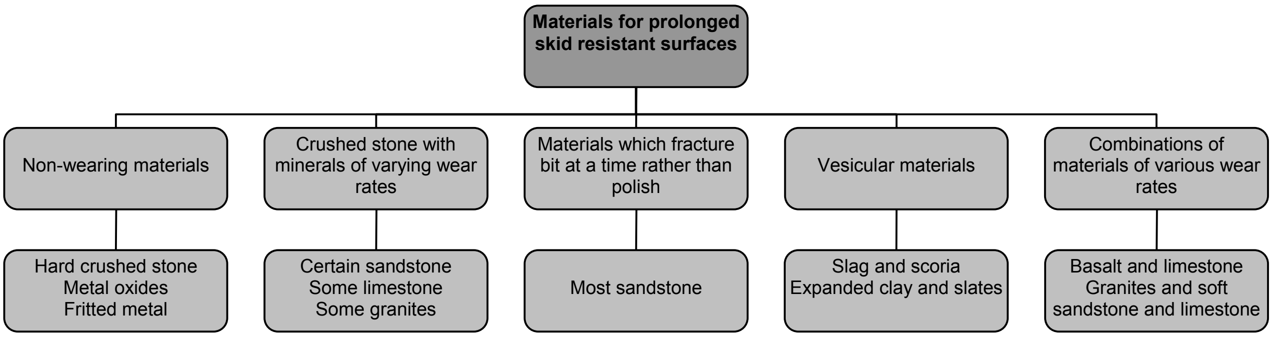

Figure 1 – Materials with high skid resistant qualities (NavFac)

Aggregates with course grain sizes and large differences in grain hardness lead to differential wear and breaking off of grains resulting in a constantly renewed abrasive surface. Generally, rocks high in silica content perform more satisfactorily than those high in carbonate content; fine-grained aggregates such as oolitic limestone consisting essentially of pure calcium carbonate are poor performers and rocks with high silica content such as sandstones, granite, and diabase are satisfactory performers. Other acceptable aggregates include unweathered crushed quartzite, quartz, diorite, and granodiorite.

The resistance of grit to the polishing action of vehicle tyres in similar conditions to those on road surfaces, is normally evaluated in the laboratory through the measurement of the Polished Stone Value (PSV).

The test is currently carried out according to the experimental methods established by the UNI EN 1097-8/2001 standard and defines a numerical value obtained as the result of a friction test carried out on a sample previously undergoing the action of simulated traffic, corrected in relation to the result of the same test carried out on a control material (control stone).

Hosking refers to a work that quotes a PSV ranging from 27 to 75 for 292 natural roadstones and shows significant differences in the mean values for many of the roadstone groups: gritstones give the highest average value and limestone the lowest, but the range of each group is so great that even the extreme groups (gritstone and limestone) show overlaps.

Furthermore the same sources can vary considerably in the uniformity of their material. A thick sediment of rock such as a corboniferous limestone is relatively uniform, but more often the quarry face shows considerable variation. In one particular quarry, the petrological nature of the rock can vary quite considerably, and even the same type of rock can be weathered to different degrees in different parts of the quarry. Gravels can also vary considerably within a deposit.

MECHANICAL PROPERTIES OF AGGREGATES

Resistance to fragmentation

The characterization of the mechanical properties of aggregates was carried out in various ways in the past. When the road surfaces were constituted by macadam protected with water-proofing surface treatments carried out with a layer of tarred grit, the grits were qualified by means of the Fragmentation Coefficient (FC), given that they had to resist fragmentation effectively in order to allow the layer to maintain its stability and continuity.

Even after the introduction of asphalt mixes in the practice of road surface construction, the fragmentation coefficient was still considered a reliable index of qualification of aggregates used for road surfaces.

The best values for such a parameter (between 60 and 120) are characteristic of tough rocks (serpentine, diabase, porphyry, basalt), while the poorest were generally found in the gravels and calcareous crushed stone. Although the Fragmentation Coefficient (FC) is no longer in use, there are still in existence certain Specifications of an old kind that require its measurement, and it is for this reason that it was considered appropriate to use also this parameter in the evaluation of the mechanical characteristics of aggregates.

Resistance to abrasion

To evaluate simultaneously wearing due to friction and the tendency to fragmentation of a stone aggregate the “Los Angeles” abrasion test (UNI EN 1097-2/1999), which allows the determination of the relative LA coefficient, was used.

Aggregate Abrasion Value (AAV)

This test has been introduced recently with the UNI EN1097-8/2001 Standard to simulate the abrasion produced by the action of traffic, in similar way to what occurred in the past for the evaluation of stone elements for road surfaces. The experimental method consists in measuring the surface resistance to wear due to abrasion on test specimens undergoing the polish test, with the difference that the moulds for the preparation of the test specimens are flat. According to the indications of the said EN Standard, the determination of the AAV value should be carried out whenever a PSV above 60 is required.

SPECIFICATIONS OF AGGREGATES FOR WEARING COURSES

Polished Stone Value (PSV)

The European Standard UNI EN 1097-8/2001 does not indicate any specification that an aggregate needs to meet in order to be used in wearing courses. According to the CNR B.U. n.139/1992, as far as polishing resistance is concerned, such specifications are commonly represented by the minimum values of the PSV coefficient of the aggregate, which must be between 37 and 45 according to traffic volume (Table 1).

Table 1 – Specifications of aggregates for wearing course asphalt mixes (CNR B.U. n.139/1992)

Specifications	TRAFFIC (*) (c.v./lane/day)			
	VH c.v. > 3000	H 3000 < c.v. < 1000.	M 1000< c.v. < 450	L c.v. < 450
PSV min	45	42	40	37
(*) daily number of commercial vehicles (c.v.) with total mass ≥ 3t on the lane with the heaviest traffic				

Fragmentation Coefficient (FC)

The CNR Standard "Fascicolo 4/1953" defined the specifications of aggregates on the basis of the value of the Fragmentation Coefficient (FC), whose maximum value had to be, for materials suitable for the production of asphalt mixes for wearing courses, between 120 and 140 (Table 2)

Table 2 – Specifications of aggregates for wearing course asphalt mixes (CNR Fascicolo 4/1953)

Specifications	Categories of gravels and grits					
	I	II	III	IV	V	VI
FC max	120	130	140	140	140	160

Abrasion (LA)

Depending on the traffic levels, the CNR Standard B.U. n.139/1992 establishes that the maximum admissible values of the LA coefficient for suitability of aggregates for hot mix asphalt wearing courses must be between 18 and 25 according to the traffic levels (Table 3)

Table 3 – Specifications of aggregates for wearing course asphalt mixes (CNR B.U. n.139/1992)

Specifications	TRAFFIC (*) (c.v./lane/day)			
	VH c.v. > 3000	H 3000 < c.v. < 1000	M 1000< c.v. < 450	L c.v. < 450
L.A. (%) max	18	20	20	25

(*) daily number of commercial vehicles (c.v.) with total mass ≥ 3t in the lane with the heaviest traffic

Aggregate Abrasion Value (AAV)

The English specifications of the Highway Agency establish maximum AAV values which, for traditional bituminous mixtures, range between 14 (traffic < 250 cv/lane/day) and 10 (traffic > 1751 cv/lane/day).

Table 4 - Specifications of aggregates for wearing course asphalt mixes (Highway Agency - UK)

Specifications	TRAFFIC (*) (c.v./lane/day)					
	> 3250	2501-3250	1751-2500	1001-1750	251-1000	< 250
AAV max (for chippings for hot rolled asphalt and surface dressing and for aggregate in slurry and in microsurfacing systems)	10	10	10	12	12	14
AAV max (for aggregate in thin wearing course systems, exposed aggregate concrete surfacing and coated macadam wearing course)	12	12	14	14	16	16

(*) daily number of commercial vehicles (c.v.) over 15KN unladen vehicle weight in the lane with the heaviest traffic

ANALYSED MATERIALS

The aggregates were selected among those most commonly used in the current production of asphalt mixes for upper layers of road surfaces in the Tuscan Region and they were integrated with some samples from other regions (Sicily, Liguria, northern Lazio), limiting the field of inquiry to those whose qualifying parameters fall within, or in any case close, the limits of acceptability indicated above. Further analyses, carried out on clearly unsuitable materials, showed that the relationships identified cannot be used outside the types of materials being studied, without proceeding with more detailed characterizations e.g. the determination of the intrinsic characteristics of the rock carried out on a microscopic scale on thin sections, in order to be able to consider other factors conditioning the on site behaviour of the stone materials, such as: the minerological constituents, the state of aggregation and cementation of the grains, cracking and the state of modification.

Table 5 below shows a petrographic description of the materials analysed based on analyses carried out according to UNI EN 932-3 Standard.

Figure 2
Location of origin of materials in the Tuscan Region

Material	Rock type
A	LIMESTONE+ CALCARENITIC LIMESTONE
B	LIMESTONE
C	LIMESTONE + JASPER
D	LIMESTONE
E	LIMESTONE
F	LIMESTONE
G	LIMESTONE + SANDSTONE ROCK
H	LIMESTONE
I	LIMESTONE
J	WHITE MARBLE+ BARDIGLIO MARBLE
K	MAGMATIC EXSTRUSIVE ROCK (BASALT)
L	OPHICALCITE + OPHIOLITE
M	LAVA PORLY ALTERED
N	LIMESTONE
O	LAVA PORLY ALTERED
P	LIMESTONE+ CALCARENITIC LIMESTONE
Q	MAGMATIC EXSTRUSIVE ROCK (BASALT)
R	OPHIOLITE
S	LIMESTONE
T	LIMESTONE
U	BASALT
V	LIMESTONE
W	OPHIOLITE (FINE GRAIN GABBRO + SERPENTINITE + APHANITICAL BASALT)
X	OPHIOLITE
Y	MAGMATIC EXSTRUSIVE ROCK (BASALT)
Y	PYROXENE ANDESITE (BASALT)
Z	OPHIOLITE
Aa	BASALT
Ba	LIMESTONE + BASALT
Ca	LIMESTONE + BASALT

Table 5
Petrographic nature

RESULTS OF EXPERIMENTAL MEASUREMENTS

Polished Stone Value (PSV)

The mean of the PSVs determined on the analysed materials is shown in Table 6. Tests have been performed on 4 specimens according to UNI EN 1097-8/2001 Standard. To each sample of material is also associated the corresponding average polished value C of the control test-specimens. Moreover, to analyse the effect of the polishing action, the friction that each test-specimen underwent after the period of weathering, before undergoing the polishing process, was measured using the methods established by the UNI EN Standard for polished test-specimens. The result of these measurements is shown in the table with the symbol BPNf.

Table 6 – Mean of PSVs

Material	A	B	C	D	E	F	G	H	I	J
BPNi	62.4	66.9	64.2	66.5	66.7	64.5	65.8	64.0	68.0	59.7
S (BPNf)	55.0	52.9	54.0	59.2	60.5	52.5	58.0	48.7	53.0	40.3
ΔBPN	7.4	14.0	10.2	7.3	6.2	12.0	7.8	15.3	15.0	19.4
C	50.2	50.2	50.2	50.2	50.2	50.2	50.7	50.7	50.7	50.7
PSV	**57.3**	**55.2**	**56.3**	**61.5**	**62.8**	**54.8**	**59.8**	**50.5**	**54.8**	**42.1**

Material	K	L	M	N	O	P	Q	R	S	T
BPNi	63.2	64.2	68.2	67.0	63.0	63.2	56.9	66.7	64.7	62.2
BPNf	56.9	46.4	56.5	54.3	49.8	46.0	52.1	58.5	49.8	46.6
ΔBPN	6.3	17.8	11.7	12.7	13.2	17.2	3.8	8.2	14.9	15.6
C	50.7	50.7	50.7	50.3	50.3	50.3	50.1	50.3	50.3	50.3
PSV	**58.7**	**48.2**	**58.3**	**56.5**	**52**	**48.2**	**54.5**	**60.7**	**52**	**48.8**

Material	U	V	W	Y	Z	X	Y	Aa	Ba	Ca
BPNi	58.6	68.6	62.3	64.1	66.5	62.1	58.8	61.4	61.0	64.0
BPNf	53.2	52.9	55.8	54.3	58.7	52.8	53.6	51.8	53.0	55.9
ΔBPN	5.4	13.7	6.5	9.8	7.8	9.3	4.2	6.6	8.0	8.1
C	50.1	50.1	50.1	50.1	50.1	50.1	50.1	50.1	50.1	50.1
PSV	**55.6**	**55.3**	**58.2**	**56.7**	**61.1**	**55.2**	**56**	**54.2**	**55.4**	**58.3**

It can be seen that the PSVs are almost all in conformity with the limits established by specifications in current use, even for the highest levels of traffic. In particular, the sample "J" is the only sample whose use should be limited to pavements subject to heavy traffic.

The consideration seems to be rather different when the comparison is made with the United Kingdom standards which are much more restrictive: minimum values vary, according to the traffic level and type of infrastructure, from 50 to 70. (I.e. Even using the correlation between PSV and SFC (Sideway Friction Coefficient) developed by Salt and Szatkowski for one specific mix, in order to warrant friction value over 0.60, as suggested by the specifications for traditional asphalt mixes, it would be necessary to use an aggregate with a PSV greater than 60, even for lower traffic volumes).

Fragmentation (FC)

Table 7 shows the mean values of the Fragmentation Coefficient for the materials tested in the laboratory; tests have been performed on 4 specimens according to the procedure described in the CNR Standard "Fascicolo 4/1953".

Table 7 – Mean values of the Fragmentation Coefficient for the examined materials

Material	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	Y	Z	X	Y	Aa	Ba	Ca
FC	129	151	139	121	125	138	135	159	144	202	112	182	130	146	152	170	76	112	139	168	83	146	118	135	119	118	82	91	101	97

It can be observed that only 5 types of material fall into category I (FC < 120), 4 into category II (120 < FC < 130), 5 into category III (130 < FC < 140), while the remaining 10 are unsuitable for use in the production of wearing courses, according to CNR Standard Fascicolo 4/1953.

Abrasion (LA)

The results of the measurements, carried out on samples of material of grain size 6.3 – 10.0 mm, equal to that used for the other tests, are shown in Table 8. Tests have been performed on 3 specimens according to the procedure described in the UNI EN 1097-2/1999.

Table 8 – Mean Values of the Los Angeles abrasion coefficient

Material	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	Y	Z	X	Y	Aa	Ba	Ca
LA (%)	18.4	24.0	23.4	16.3	17.2	22.8	19.7	26.4	23.8	33.6	14.5	31.5	21.0	23.5	27.5	28.5	9.5	14.0	24.0	27.0	15.6	23.0	16.0	19.2	17.2	15.5	11.0	19.5	21.5	14.8

According to CNR Standard B.U. n.139/1992, of the 30 types of material analysed, 11 are suitable for use in very heavy traffic conditions (LA < 18), 4 for heavy or average traffic (18 < LA < 20), 9 are suitable only for conditions of light traffic, while the remaining 6 do not provide a sufficiently low abrasion coefficient value to allow their use.

Aggregate Abrasion Value (AAV)

The results of measurements are shown in the following Table 9. Tests have been performed on 3 specimens according to procedure described in the UNI EN 1097-8/2001.

Table 9 – Mean of Aggregate Abrasion Values AAV

Material	K	L	M	N	O	P	Q	R	S	T	V	W	Y	Z	X	Y
AAV	5.08	13.49	9.72	11.01	11.61	12.39	3.32	5.66	11.60	11.76	11.95	7.04	9.48	8.13	6.86	3.60

The Italian Standard does not include the qualification of aggregates for wearing courses by the measurement of the AAV. According to the United Kingdom specifications for the 14 types of material analysed, 7 are characterized by AAV values below 10, 5 have values below 12, while the remaining 2 have in any case values below 14.

ANALYSIS OF THE EXPERIMENTAL DATA

The collected data were analysed with the aim of identifying the existence of links between the polish-wear characteristics of aggregates and related mechanical properties of resistance to fragmentation and abrasion.
In addition to the parameters defining the results of laboratory tests, a further index was considered that would provide further data about the properties of the materials as related to resistance to the polish-wear effect:

- the ratio between the variation in the BPN value before and after the accelerated polish-wear test and the value of BPN before the accelerated polish-wear test ((ΔBPN/BPNi)

On the basis of these comparisons it was possible to observe the following.

Polish-wear characteristics and resistance to fragmentation

The PSVs obtained by the accelerated polish-wear tests were related to the mechanical resistance characteristics observed by means of the test for resistance to fragmentation. The results are shown in Figure 3. It can be observed that, in the field of values FC < 140 (triangular points), it is not possible to identify a relationship between the PSV and FC values; otherwise, for values FC < 140 (circular points), for materials with a compact structure (low porosity), it is possible to associate a lower resistance to polish-wear with a decrease in the resistance to fragmentation.
As shown in previous experiments (Lo Bianco-Marino, Cafiso-Taormina) cases can occur in which PSV above the minimum values prescribed by the Italian Standard, can be reached or exceeded even by materials that are not able to satisfy the required mechanical resistance specifications. It is well-known that certain materials that are particularly porous and have a considerably open crystalline structure (typical, for example, of effusive rocks with a low degree of maturation) can regenerate the conditions of surface microtexture of the grains as the polishing action proceeds.

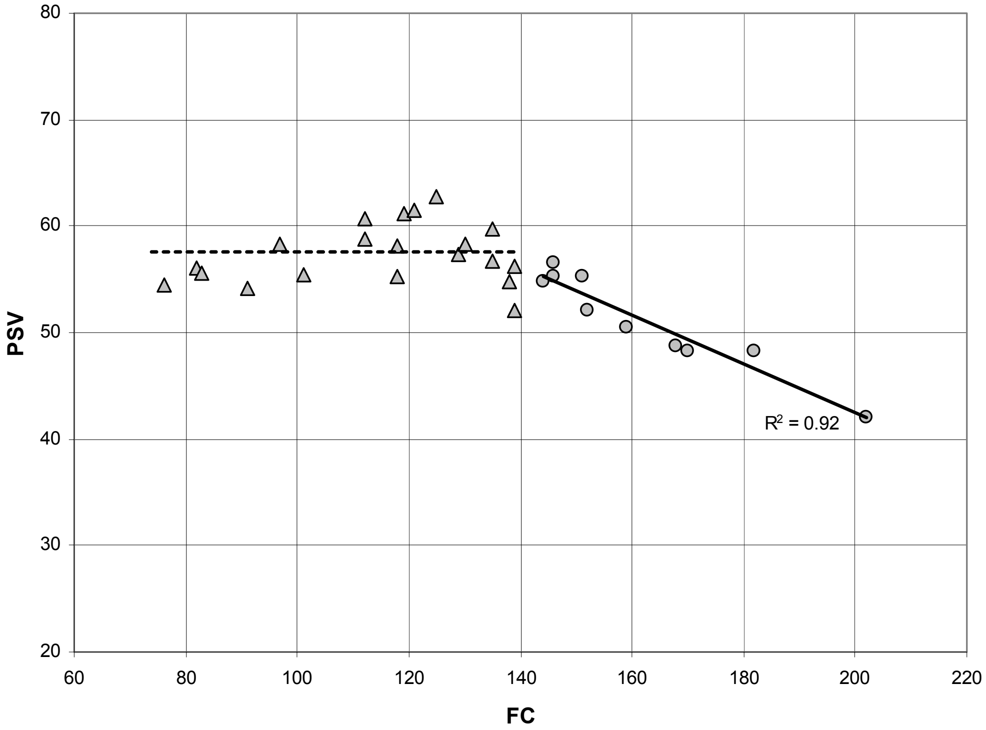

Figure 3 – Relationship between PSV and FC values

The results confirm the conclusions already reached by Hosking on the effect of an inadequate mechanical resistance on polish-wear resistance.
It can be observed that materials considered suitable for the production of asphalt mixes for surface layers, on the basis of the FC, have PSV always above the limits established.

Polish-wear and abrasion resistance

The PSV found were correlated with the relative values of loss in weight due to abrasion with the Los Angeles device (Figure 4). Again, in this case it is not possible to identify a relationship between LA and PSV for values of LA < 20 (rhomboidal points), while for values of LA > 20 (circular points), there is a linear dependency between the two parameters with a good degree of correlation (R^2=0.89).

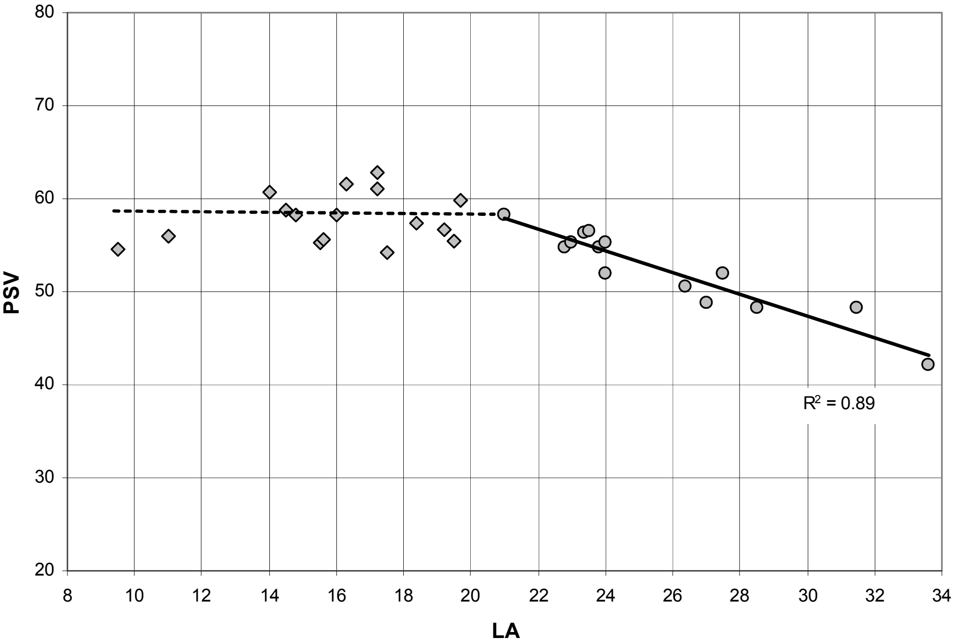

Figure 4 – Relationship between PSV and LA values

In order to verify whether the results of the LA test were not affected by the shape of the aggregates, the shape characteristics of several samples were also analysed. It is indeed well-known that the polished stone value test does not take into account the particles whose shape is not suitable, both because they are eliminated during the selection of the material for the production of the test specimens and because of the method of production of the specimens themselves, which involve positioning the flattest surface of each grain in contact with the bottom of the mould. The measurement of the Los Angeles coefficient, on the other hand, can be considerably affected by the presence of grains with an unsuitable shape because of their greater sensitivity to impacts produced during the test.

Some of the materials undergoing the Los Angeles test were therefore also characterized by means of tests for the determination of shape characteristics according to the experimental methods of the UNI EN 933-3/2004 (Flakiness Index FI) and 933-4/2001 (Shape Index SI) Standards. The results of these measurements are shown in the following Table 10.

Table 10 - Flakiness Index FI and Shape Index SI of some materials undergoing LA test

Material	K	L	M	N	O	P	R
SI (%)	4	7	2	9	7	10	9
FI (%)	7	9	9	9	8	8	9

Material	S	T	V	W	Y	Z	X
SI (%)	14	16	3	3	5	9	4
FI (%)	15	20	14	7	6	10	9

The values that characterize the shape of the samples of aggregates are all in conformity with the existing specifications for use in the production of asphalt mixtures for wearing courses (FI ≤ 20 for PP and P traffic, FI ≤ 30 for M and L traffic). The differences between the various samples are limited and such as to not involve any kind of clear effect on the relationship between the PSV and LA values.

Again in this case, as mentioned above regarding the fragmentation coefficient FC, the validity of the relationship is limited to LA abrasion values obtained on materials falling into the area of suitability established by the Specifications or immediately outside it. Measurements of PSV carried out on a sample of Carrara marble, characterized by LA values above 45, gave PSV above 45, so that the material, considering only this parameter, would seem to be suitable also for very heavy traffic. Moreover, as shown for the case of the fragmentation coefficient, all the materials characterized by LA within the limit provided for by the

Specifications for wearing courses (LA ≤ 25), show PSV above 50, i.e. well over the limit provided for by the Specifications themselves (PSV ≥ 45).

Polish-wear and Aggregate Abrasion Value

The polish-wear values were also compared with the AAV determined according to experimental methods provided for by the Appendix of the said Specifications relative to the polished stone value test (UNI EN 1097-8/2001). Although the Standard provides for the measurement of AAV when a PSV > 60 is required, not having available a sufficient number of samples for which such a limit of resistance to polishing could be reached, the test was carried out on a limited number of samples, selecting those with the highest PSV.

Here again we note the tendency to have limited or null PSV variations below a certain AAV (Figure 5).

For AAV below the minimum established by the United Kingdom specifications (AAV < 9), the PSV remains unchanged with the variation in the AAV (triangular points), while for increasing values of AAV above 9, a gradually decreasing of PSV was recorded (circular points).

In this case also the relationship must be assumed to be valid for the range of values suitable for the production of asphalt mixes for wearing courses.

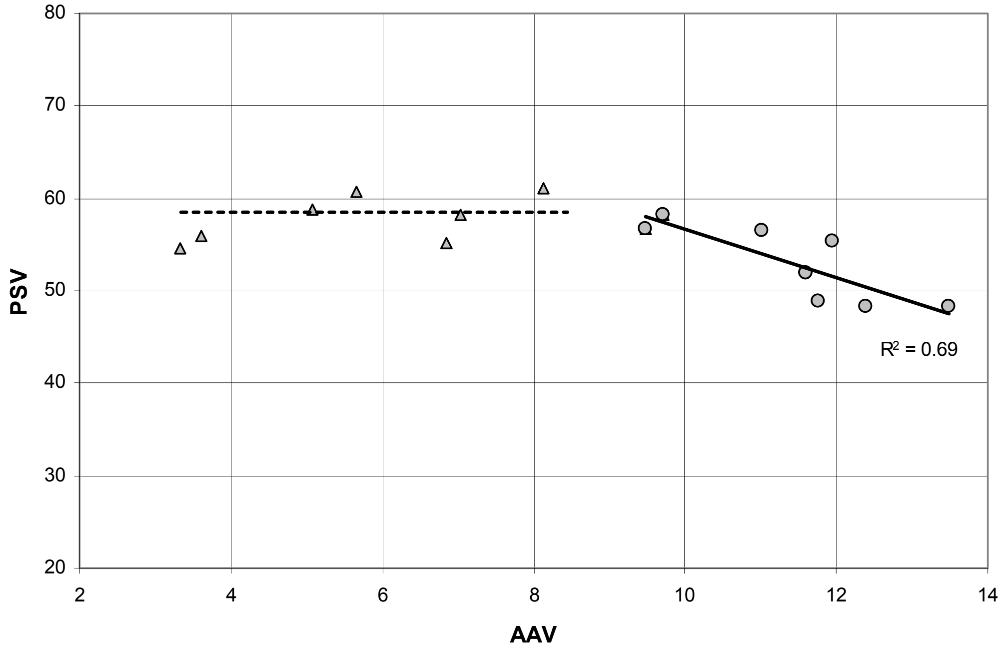

Figure 5 – Relationship between PSV and AAV

LOSS OF SKID RESISTANCE AFTER ACCELERATED POLISHING

The experimental procedure for determining the PSV involves determining skid resistance only after the polishing action and measuring PSV on the basis of the same result obtained on the control stone.

If we consider the polishing action of the aggregates, applied during the accelerated polishing test, as a reliable simulation of the effect of traffic, it might be interesting both to evaluate the loss of friction resistance obtained by the test and to compare it with the mechanical resistance parameters characteristic of the samples of aggregate being examined.

For this reason, before proceeding with the polished stone value test, specimens were conditioned for the evaluation of friction resistance (BPNi), using the methods established by the Standard for the same measurement to be carried out after the polishing action (BPNf): immersion in water for between 30 and 120 minutes.

The results of these measurements were used to calculate the loss of resistance of each sample (as the mean of the measurements on four specimens being tested for PSV) by means of the parameter ΔBPN/BPNi, which relates the global loss of skid resistance ΔBPN=BPNi-BPNf to the initial skid resistance of the samples BPNi.

Comparison of the PSV and the relative loss of skid resistance is shown in figure 6. It can be seen that the PSV, closely correlated to the value of BPNf, can also be related to the relative loss of skid resistance. In particular, the aggregates characterized by the highest PSV have a ΔBPN/BPNi ratio that oscillates between 0.06 and 0.20. The materials with the best PSV show smaller skid resistance losses, to which are associated smaller friction reduction of the road surfaces built with them. An examination of the graph shows the independence of the PSV from the ΔBPN/BPNi for those materials with a high resistance to polish (square points) and, at the same time, the linear dependency between the two for those with a smaller resistance to polish (circular points). However, the materials that underwent decreases of over 25% are characterized by PSV values below 50, so that such a limitation on the value of ΔBPN/BPNi in any case warrants that adequate PSV are reached.

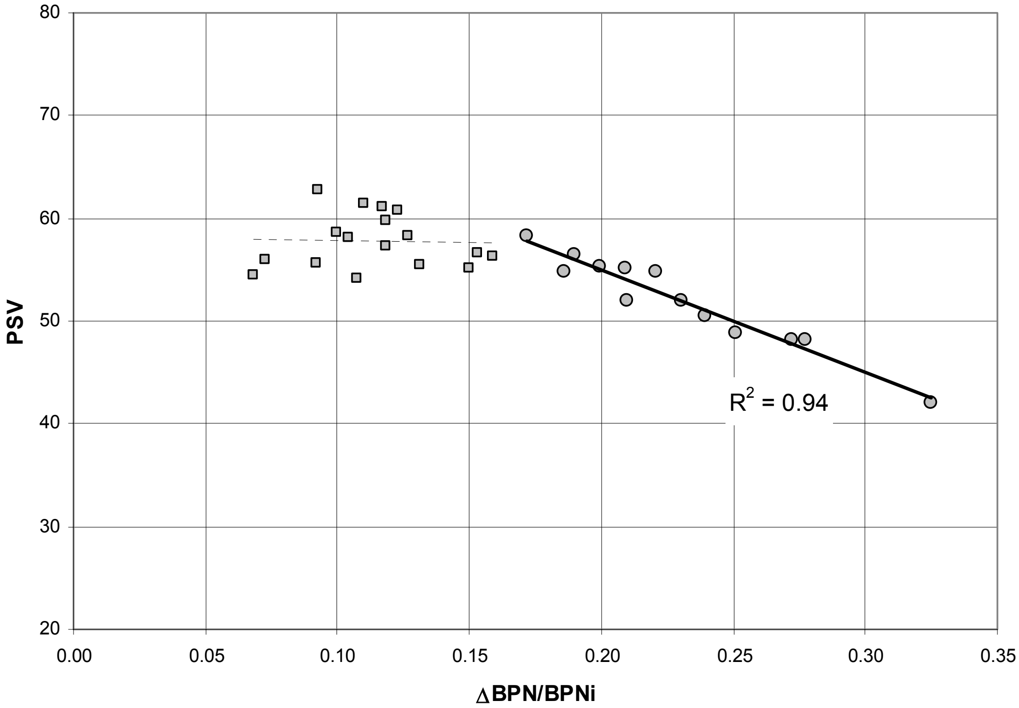

Figure 6 – Relationship between PSV and ΔBPN/BPNi values

It follows that, considering only the PSV, as an index characterizing the materials analysed, it does not seem possible to establish the degree of decrease in friction with the ongoing action of the traffic.

This can be attributed to the fact that the measurement of the PSV is relative to the BPN evaluated at the end of the accelerated polishing test; it can occur that a sample of aggregate characterized by high initial BPN, even if it undergoes a considerable decrease in skid resistance ΔBPN, will still be able to provide a high PSV and that two materials with the same PSV will be characterized by significantly different behavior with regard to skid resistance during the life of the road pavement surfaces.

For this reason knowledge of the ΔBPN/BPNi value can contribute to a more complete evaluation of the performance of the material on site.

The parameter that indicates loss of skid resistance was also related to the mechanical characteristics of the aggregates. The comparison between the Fragmentation Coefficient FC and the values of ΔBPN/BPNi highlights a linear type relationship that associates the greatest reductions in skid resistance to the worst FC values (figure 7).

It can be said that percentage losses of skid resistance above 20% are characteristic of aggregates that are not suitable for the production of asphalt mixes according to the CNR Fascicolo 4/1953, being characterized by FC > 150. In actual fact, if reference is made to the limitation on PSV > 50, to which corresponds, in the previous graph in figure 6, a relative skid resistance loss ΔBPN/BPNi < 0.25, we might consider accepting fragmentation resistance values of FC < 170.

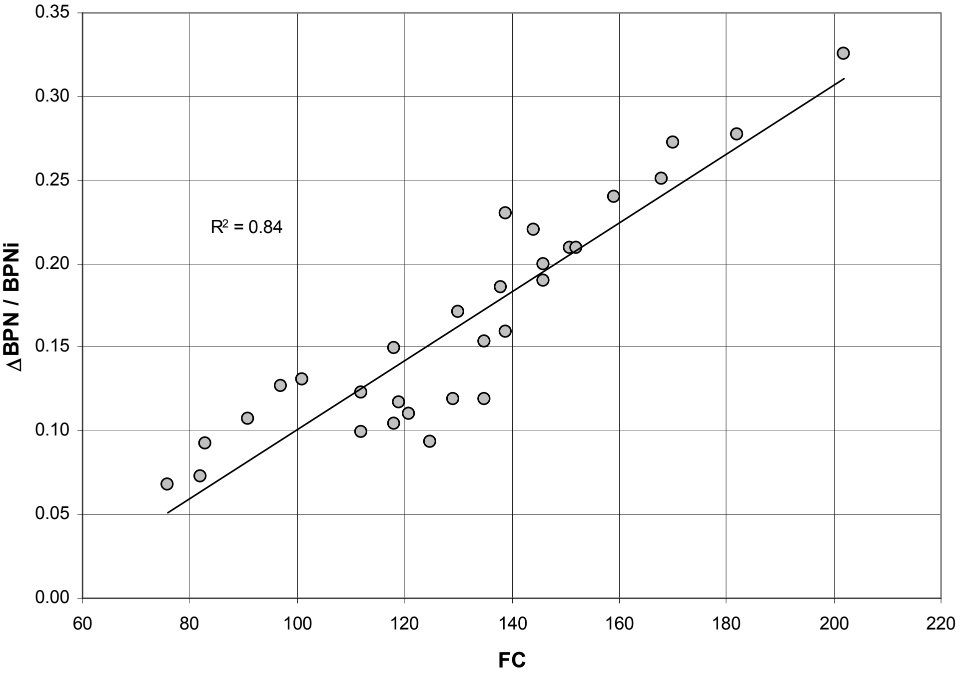

Figure 7 – Relationship between FC and ΔBPN/BPNi values

The comparison between reduction in skid resistance due to polishing and the Los Angeles abrasion coefficient presents a linear pattern and is on line with expectations. With a good approximation (R^2=0.9) the analyses carried out on the various samples of aggregate show a clear tendency to have greater reductions of skid resistance for samples characterized by increasing LA values (figure 8).
The relationship in figure 8 shows that the ΔBPN/BPNi reductions above 0.25 are associated with LA values above the maximum allowed for suitability; it should also be noted that for LA values < 20 the relative loss in skid resistance is less than 0.15, and is therefore considerably restrictive.

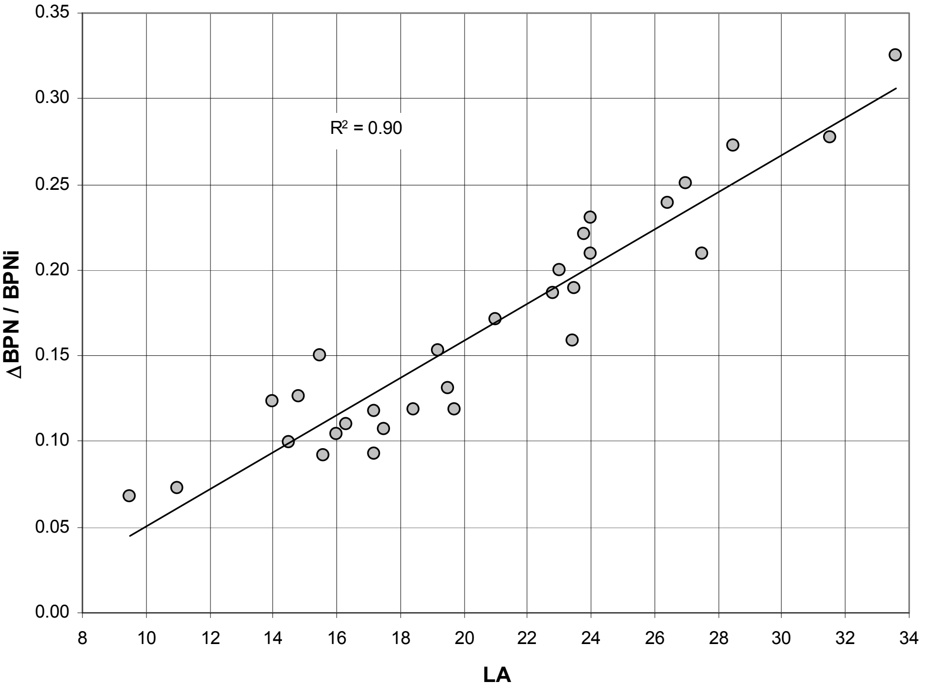

Figure 8 – Relationship between LA and ΔBPN/BPNi values

In the case in which the values of relative skid resistance reduction are compared with the AAV, the relationship is still of a linear type. As shown in figure 9, it is possible to associate the AAV to the loss of skid resistance due to the process of polishing through a linear relationship with a correlation coefficient R^2 approaching 0.9.

ΔBPN/BPNi values below 0.20 correspond to AAV below 10.

On the basis of the results obtained from the analyzed samples, it can be said that the observance of the limit values indicated for the AAV by the English Specifications (AAV=10) warrants lower variations in skid resistance, not more than 20% of the initial value; moreover in each of these cases (figure 5), PSV resulted significantly higher than 50.

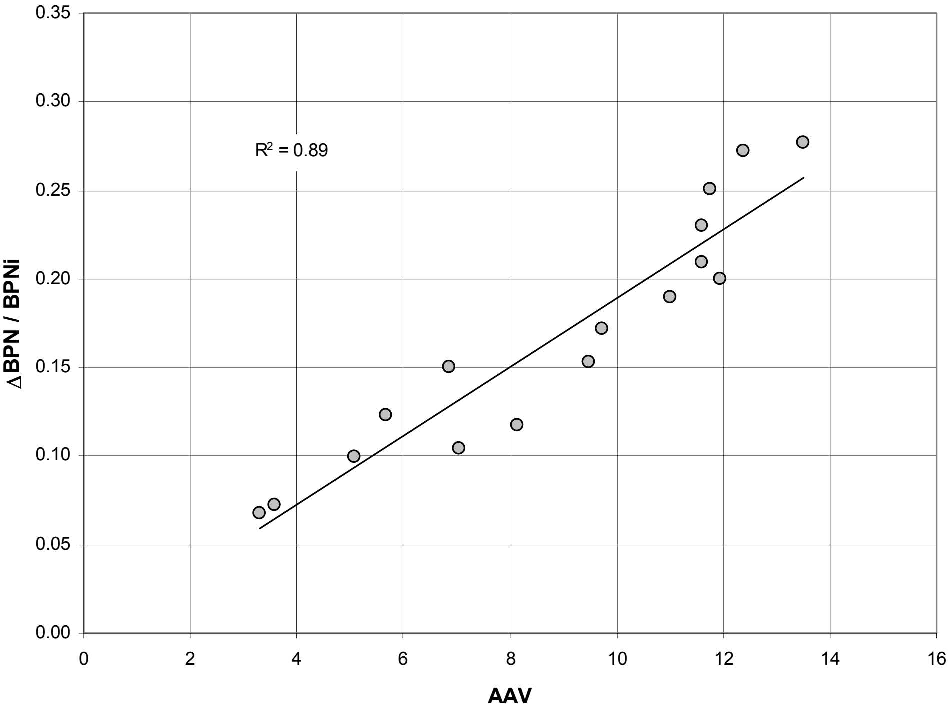

Figure 9 – Relationship between AAV and ΔBPN/BPNi values

CONSIDERATIONS ON THE RESULTS OF DATA ANALYSIS

The materials analysed all present polishing resistance characteristics that make them suitable for the production of asphalt mixes for wearing courses of roads subject to very heavy traffic, the PSV being > 45; the only exception is one type of material for which the PSV is > 42, and is therefore only suitable for roads with heavy traffic.

It seems that while having a good resistance to polishing, the aggregates analysed do not present mechanical resistances of an equal level: indeed, according to the aggregate specifications currently in use, of the 30 materials analysed only 11 are suitable for roads with very heavy traffic, 4 for roads with heavy and average traffic, 9 only for roads with light traffic and 6 cannot be used in the production of wearing courses according to the specifications of the current technical regulations.

At the same time, the analysis of data showed the existence of a dependency between the polishing resistance of aggregates and the abrasion resistance evaluated by the Los Angeles test only for LA values > 20. For LA < 20 a dependency between the two parameters could not be identified; in any case it seems clear that the aggregates with a high resistance to abrasion (LA < 20) are characterized by a polishing resistance PSV > 50, with the peculiarity that a PSV actually exceeding 55 was recorded on the aggregates with a resistance to abrasion 14 ≤ LA ≤ 18.

With respect to this, it can be considered that the dyscrasia just highlighted between PSV and LA specifications might be significantly reduced by establishing :

1) More restrictive requirements than those currently imposed for resistance to polishing, imposing PSV ≥ 50. The effect of an increase of PSV limits can be evaluated according to the model developed by the Transport Research Laboratory expressed by the following relationship:

$$SFC_{50} = 0.0024-0.0000633\cdot CV_{d}+0.01\cdot PSV$$

where

SFC_{50} is the coefficient of terminal sideway friction;

CV_{d} is the average daily traffic of commercial vehicles (weight over 1.5 t)

PSV is the Polished Stone Value of the aggregate used for the wearing course.

This model has been developed for one specific mix and relates the friction at slow slip speed (which can be considered dependent primarily from microtexture), measured by means of the sideway friction coefficient SFC at a speed of 50 km/h (corresponding to a slip speed equal to 50*sin20°=17km/h), with the PSV. By this relationship, it should be observed that to an increase in PSV of 5 units, corresponds an increase in the level of friction at low slip speed equal to 0.05 units and, consequently, a greater road safety

Again, using the same relationship, it can be observed that the use of aggregates characterized by a PSV greater than 5 units warrants the same level of terminal friction at slow slip speed with a daily traffic level of more than about 790 commercial vehicles or, traffic being equal, a considerable increase of the functional life of the layer.
The raising of the lowest prescribed limit on the PSV would bring Italian Specifications closer to what is required in other European countries, such as the United Kingdom and Switzerland, in which the aggregates used for wearing courses cannot, for whatever traffic level, provide PSV values below 50.

2) A less strict abrasion resistance requirement of the aggregates used in wearing courses; it is possible to envisage a raising of the LA limit of a 15 to 20% with respect to that prescribed by the B.U. n.139/1992 of the CNR. Indeed, also in the latest Specifications there seems to be the tendency to require values that are less restrictive than such a parameter for roads with very heavy traffic.
With such a provision the required specifications would tend towards those adopted in other Countries, such as the United Kingdom and the United States, where the maximum limit of the LA coefficient, for the type of use examined here, is never below 30.
A further, by no means secondary, aspect, linked to the predicted raising of the LA abrasion resistance limits, regards the important advantages, both economic and environmental, linked to the use of materials with inferior mechanical characteristics, but more easily obtainable locally, with the consequent reduction in the use of high-quality materials, still necessary for the production of special surfacings such as draining courses, microsurfacings and SMA.

Even if a technical specification should be related to in situ performance and not only to laboratory measured properties on a part of aggregate source, the aforementioned results suggest some useful considerations; it's obvious they need to be confirmed by the results of in situ performance of aggregates.

In particular, having found that for values of relative loss of skid resistance of $\Delta BPN/BPNi < 0.20$, the PSV values are well above 50, the FC values are below 140 and the LA values are below 22, this last LA value could be taken as the limit of acceptability for roads with very heavy (VH) and heavy (H) traffic; the limitation of $\Delta BPN/BPNi$ to the value of 0.2 would in any case satisfy the English specifications which require, for heavier traffic conditions, AAV values of < 10. On roads with medium (M) and low (L) traffic, on the other hand, reference could be made to a relative loss of skid resistance of 0.25, to which FC values of < 160 and LA values of < 26 correspond.
Referring to the performance classes for aggregates provided in the UNI EN 13043 with regard to LA values, aggregates for VH and H traffic must still belong to the LA_{20} class while those for M and L traffic could belong to the LA_{25} class.

CORRELATIONS BETWEEN THE MECHANICAL CHARACTERISTICS OF AGGREGATES

The results of the three tests of mechanical characterization carried out on samples of aggregates for wearing course asphalt mixes were compared in order to analyze possible correspondences between them.
Although they were measurements which involve very different experimental methods and for which the aggregates of the mixture being studied are analyzed by means of selection of different grain sizes as well as with different shape requirements, the comparison between the results gave significant relationships, again of a linear type, as shown in the following figures 10, 11 and 12.
One characteristic common to all three tests is certainly the actions with respect to the aggregate grains which, although induced in different ways, are all very significant.

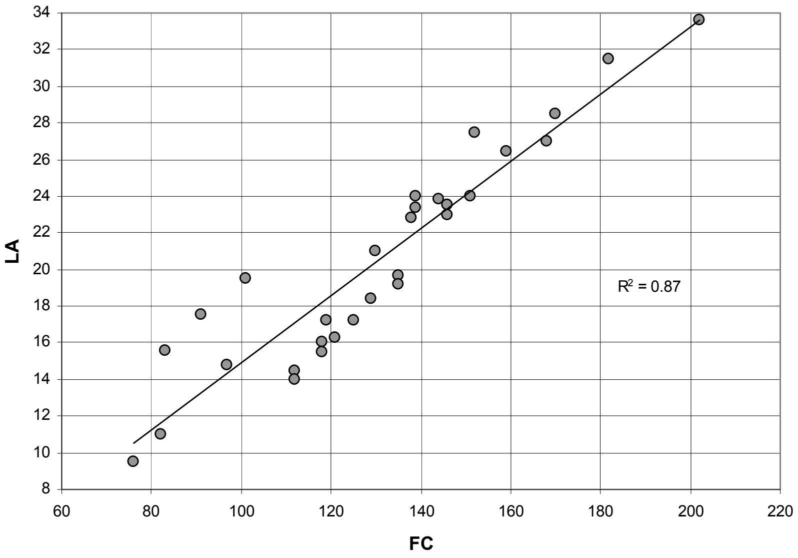

Figure 10 – Relationship between FC and LA values

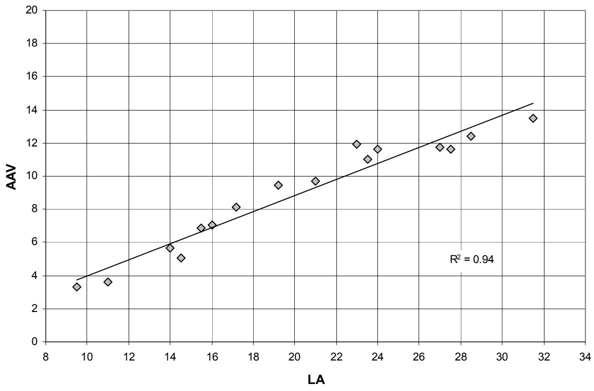

Figure 11
Relationship between AAV and LA values

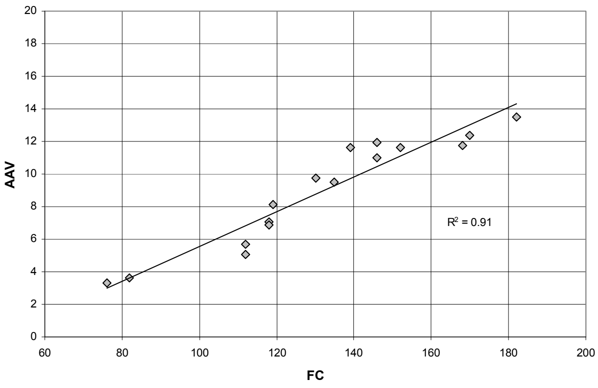

Figura 12
Relationship between AAV and FC values

CONCLUSIONS

In this paper, in order to identify specifications for empirical tests performed on aggregates for wearing courses, that are better related to friction performance, the results of the first kind of tests have been related to polishing resistance properties of aggregates that are currently used in Tuscany.
For the examined aggregates, it seems that above some limit values of mechanical properties, expressed by the FC, the LA and the AAV, there isn't a well defined relationship between these parameters and polishing resistance properties of aggregates; on the other side, for mechanical properties decreasing below this limit the effect of poor mechanical properties on the polish-wear resistance can be identified.
Moreover, in this paper, in order to assess the dependence between mechanical properties and polishing resistance of aggregates, a new parameter has been identified to evaluate the loss of microtexture, which is related to the loss of the friction performance at slow slip speed; by this parameter, good relationships of linear type have been determined between the investigated mechanical properties and the relative loss of friction resistance.

The results of this study suggest that lower limits for the abrasion resistance of aggregates can be introduced in specifications; this reduction is of moderate importance for roads with VH and H traffic but is considerable for those with M and L traffic. It is obvious that this reduction needs to be confirmed by the results of in situ performance of aggregates.

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