On the SUPERPAVE Asphalt Mixture Gradations for the Mix Design of Traditional and Special Asphalts

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Synopsis

The Author proposes a methodology for the verification of the fulfilment rate of the particle size distribution specifications of the prescriptions on limit grading curves, which are commonly used for the definition of bituminous asphalt admixtures, with the SUPERPAVE conditions related to the control points and to the restricted zone boundary.
The operative phases of such methodology provide for the determination of the maximum nominal size of the aggregate, referred to the average curve of the limit grading curves in the semi-logarithmic plane of the sieves opening d-% passing and in the $d^{0,45}$-% passing.
Afterwards, once the referring SUPEPAVE chart where to put the prescriptions on limit grading curves is found, the critical points can be characterised in this way: type "α" when the violation of control points occurs , and type "β" when violations of the restricted zone boundary are experienced.
Actions modifying the limit grading curves are proposed for each of these typologies, in order to get to curves consistent with the SUPERPAVE specifications.
The methodology used for the limit grading curves of the main Italian prescriptions shows that, referring to traditional asphalts, small changes can make the limit grading curves consistent with the SUPERPAVE specifications.
On the contrary, the Author found a strong incompatibility with special conglomerates (porous asphalts, stone mastic asphalts, etc).

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Mix Design is a process articulated in a series of procedural phases and/or experimental trials aimed to select the mineral aggregates and their gradation, the type and the content of binder, the nature and the quantity of possible additives and/or modifiers, defining a mix of aggregates and bituminous binder that satisfy pre-fixed characteristics.
A modern approach to the asphalt Mix Design consist in setting the proportions of each component, starting from the available materials, in such a manner that each of them reaches optimal performances, according to the traffic conditions, environmental and stress conditions to which the pavement is subjected. The mix performances are reached if all the design functions assigned are verified.
Recently, some asphalt Mix Design methods have been developed on performance criteria, between which the SUPERPAVE system (SUperior PERforming asphalt PAVEments), that was made in the SHRP Research Program at the end of '90 years. Through such methods, the laboratory tests (fundamental and simulation tests) allow, with optimal correlation between the experimental measures and the real asphalt behavior (in place), knowing the answer of materials to different stress states.
The present job intends to analyze, in a critical way, the degree of compatibility of the gradation definitions of the principal Italian Specifications, normally employed for the design of the hot mix asphalt, with the SUPERPAVE prescriptions. This to define the limits of employment of such gradations according to the prescriptions introduced from SUPERPAVE Mix Design methodology. At the end, the article proposes the adjusting of same Italians gradations according to the SHRP directives.

SUPERPAVE GRADATION

To specify gradation, SUPERPAVE modifies an approach already used by the same American Agencies. The 0.45 power gradation chart is used to define a permissible gradation. The point 45 power chart uses a unique graphing technique to show the cumulative particle size distribution of an aggregate blend. The ordinate of the chart is the percentage passing. The abscissa is an arithmetic scale of sieve size in millimetres, raised to the 0.45 power.
An important feature of the 0.45 power chart is the maximum density gradation. This gradation (Talbot line) plots as a straight line from the maximum aggregate size to the origin.
Defined the sieve series (ASTM), with the sieve size in millimetres equal to: 0,075 - 0,15 - 0,30 - 0,60 - 1,18 - 2,36 - 4,75 - 9,5 - 12,5 - 19 - 25 - 37,5 - 50, the SUPERPAVE system introduce these aggregate size definitions:

- Maximum Nominal Size: one sieve size lager than the first sieve to retain more than 10 percent;
- Maximum Size: one sieve size lager than the maximum nominal size.

The maximum density gradation, that is the Talbot line, represents a gradation where the aggregate particles fit together in their densest possible arrangement. SUPERPAVE specifies aggregate gradation by adding two features to the 0.45 power chart: Control Points and a Restricted Zone. Control Points function as master ranges between which gradations must pass. They are placed on the maximum size and the nominal maximum sieve, an intermediate sieve and the smallest sieve (0,075mm).
The Restricted Zone resides along the Talbot line between an intermediate sieve (2,36 or 4,75mm) and the 0.3mm sieve. The Restricted Zone forms a band through which the gradation cannot pass.
Gradations that pass through the Restricted Zone from below the zone are called humped gradations because of their characteristic hump shape.
In most cases, a humped gradation indicates an over-sanded mixture and/or a mixture that possesses too much fine sand in relation to total sand.
This gradation often results in a mixture that poses compaction problem during construction and offers reduced resistance to permanent deformation during its performance life.
Likewise, the Restricted Zone prevents a gradation from following the maximum density line in the fine aggregate sieves.
Gradations that follow this maximum density gradation often have inadequate voids in the mineral aggregate VMA to allow enough asphalt for adequate durability.
These gradations are very sensitive to asphalt content and can easily become plastic with even less variations in asphalt content.
Figure 1 shows the Control Points and the Restricted Zone for a 12.5mm maximum nominal size mixture.

While SUPERPAVE recommends that gradations pass below the Restricted Zone, this is not a compulsory requirement.
SUPERPAVE defines five mixture gradations by their nominal maximum aggregate size (Cfr. Tab.1) and for each one fixes Control Points and Restricted Zone.

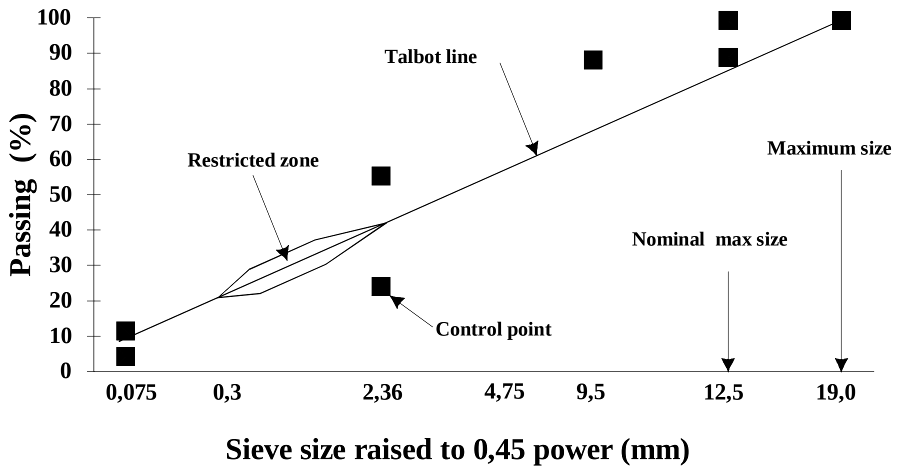


Figure 1: Point 45 power chart

Table 1: SUPERPAVE mixture gradations

SUPERPAVE Designation	$D_{nom\ max}$ (mm)	D_{max} (mm)
37,5mm	37,5	50,0
25,0mm	25,0	37,5
19,0mm	19,0	25,0
12,5mm	12,5	19,0
9,5mm	9,5	12,5

Considered the SUPERPAVE exclusive employment of the point 45 power chart, it is opportune to represent in such a plane the classical configuration of the main aggregates gradations curve concerning the function of Talbot. All the graphics showed in Figure 2 are related to aggregates with a maximum dimension of to 19mm. Particularly it is possible to distinguish, in Figure 2a, the trend of a uniform gradation, in Figure 2b the trend of a discontinuous particle size distribution, in the Figure 2c the representation of a open gradation and finally in Figure 2d the trend of a closed gradation.

ANALYSIS OF THE ITALIAN SPECIFICATIONS

To perform a comparison of compatibility between the norms of Italian Specification and the SUPERPAVE aggregate gradations specifics, the 4 principal Italian Specifications have been analyzed, that are:

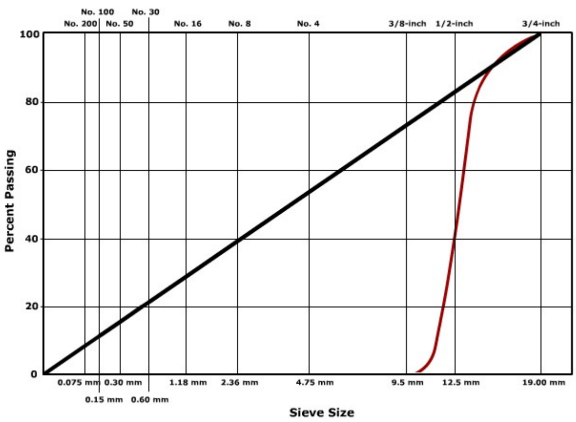
- “Capitolato d’Appalto per Pavimentazioni Stradali con Bitume Modificato” - Associazione Italiana Bitume Asfalto Strade (SITEB), 2000;
- “Norme Tecniche prestazionali per Capitolati Speciali d’Appalto” - Centro Sperimentale Interuniversitario di Ricerca Stradale (CIRS), 2001;
- “Norme Tecniche d’Appalto di tipo prestazionale per la costruzione e la manutenzione delle pavimentazioni stradali” - Autostrade Spa, 2001;
- “Norme Tecniche d’Appalto ANAS” - ANAS Spa, 2004.

Comparison methodology

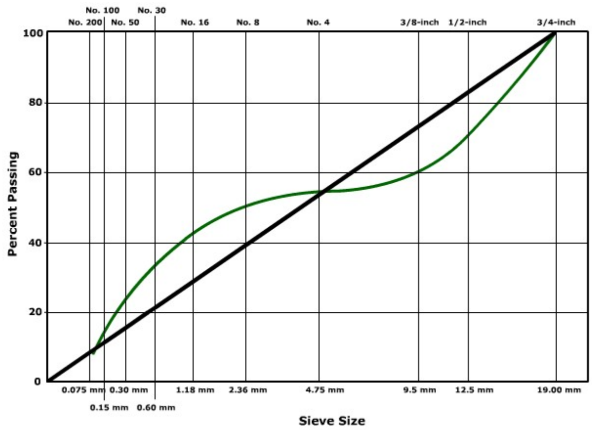
The main purpose of the present is to verify analysis the degree of satisfaction of the aggregate gradation specific contained in the Italian Specifications listed into respect the SUPERPAVE conditions concerning Control Points and Restricted Zones.
The phases carried out for the study are the followings:

- determination of the maximum nominal dimension of the limit curves aggregate Specification gradation, in the semi-logarithm chart of the sizes of the sieves and in that of the 0.45 power;

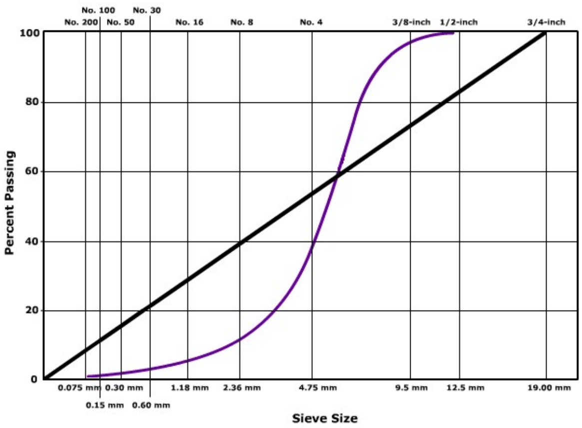
- comparison of Specification gradation's limits curves with SUPERPAVE's gradation chart selected in the previous step;
- determination of the point 45 power chart criticalities.



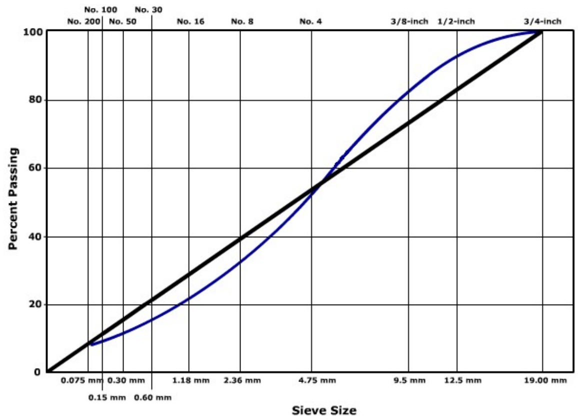
(a) **Uniform gradation**



(b) **Discontinuous gradation**



(c) **Open gradation**



(d) **Close or dense gradation**

Figure 2: Classic particle size distributions on the point 45 power chart

Concerning the last phase, an innovative method has been applied with the definitions of the α and β criticality indicators, that are formulated in the following way:

- type α criticality: violation of the SUPERPAVE Control Points condition by the superior and/or inferior limits curves of the Specification. Each α type criticality must be measured through the distance, valued in vertical, between the violated Control Point and the limit curve that does not respect it;
- type β criticality: violation to the SUPERPAVE Restricted Zone condition by the Specification aggregate gradations. Each β type criticality is measured through a value equal to the percentage ratio between the area of the intersection between the Restricted Zone and the Specification gradation limits curves and the total area of the same.

For each criticality, the Author propose the modification of the Specific gradation limits curves, to make it compatible (where it is possible) with the SUPERPAVE gradations specifics. Particularly:

- to resolve the α type criticality, when it is possible, it is proposed to move the limit curves (inferior and/or superior) to respect the violated control points;
- to resolve the β type criticality it is proposed to the area of the Restricted Zone from the Specification limits curves aggregate area.

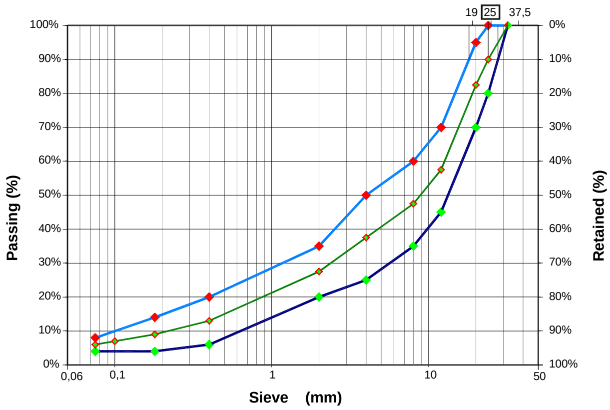
Methodology application

The proposed methodology has been applied to the analysis of 32 aggregate gradations included in different Specification prescriptions. For example, it is presented the compatibility verification with the aggregate mixture gradation of a base asphalt mix proposed from the CIRS Specification (Tab.2) to demonstrate the effectiveness of the proposed methodology.

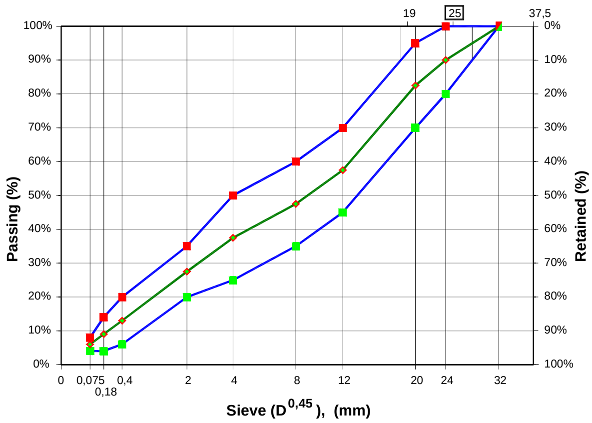
Departing from the Specification prescriptions (Tab.2 - columns 1 and 4), one can define both the size series of equivalent sieves on the point 45 power chart (Tab.2- column 3), and the passing of the middle curve of Specification gradation (Tab.2 - column 6). Subsequently, the three characteristic curves (limits curves and middle curve) in both the reference chart, that are, chart "% of Passing, Retained - sieves size logarithm " (Fig.3a) and "% of Passing, Retained - sieves size raised to the 0.45 power" (Fig.3b) and is calculated the maximum nominal size is calculated, that results equal to 25mm.

Table 2: CIRS Specifications base aggregate mixture gradation

UNI ID	Equivalent Sieve Diameter (mm)	$D^{0,45}$ (mm)	Gradation Limits Curves Passing (%)	Middle Curve Passing (%)
40	32	4,757	100 - 100	100
30	24	4,179	80 - 100	90
25	20	3,850	70 - 95	82,5
15	12	3,059	45 - 70	57,5
10	8	2,549	35 - 60	47,5
5	4	1,866	25 - 50	37,5
2	2	1,366	20 - 35	27,5
0,4	0,4	0,662	6 - 20	13
0,180	0,180	0,462	4 - 14	9
0,075	0,075	0,312	4 - 8	6



(a)



(b)

Figure 3: Gradation limits curves in the different plane

With the determined maximum nominal size the SUPERPAVE designation is identified, that allows to trace on the point 45 power its Control Points and Restricted Zone (Fig.4). This representation allows establishing the Specification gradation limit curve criticalities from the corresponding SUPERPAVE prescriptions.

In this case β criticality is observed equal to 100%, while 4 α criticalities are recorded the first three of which interest the superior limit curve and one the inferior one. Particularly the first is recorded on 0,075 sieve size and it is equal to 0.8, the second for the 19mm sieve size is equal to 2.2, the third for the 25mm sieve size it is equal to zero (the curve pass for the Control Point) and finally the last one in correspondence of the 25mm sieve size has a value as 7.4.

To obtain the compatibility of the Specification grading curves to the SUPERPAVE prescriptions it is sufficient to exclude the Restricted Zone from the area of the gradation limit curves and to modify the limit curves according to the raised criticalities. In this way a modified gradation is obtained that respects both the Specification norms and the SUPERPAVE prescriptions. In Tab.3 the α type criticality corrections are quoted between brackets and the boundary characteristics points of the Restricted Zone.

Analysis of Results

The analysis has allowed of the main Italian gradation Specifications to identify the criticalities and provide the modification proposals to obtain new more restrictive prescriptions, in the possible cases, that at the same time also to satisfy the SUPERPAVE specifications.

Particularly any gradation has resulted 100% compatible as regards the relative SUPERPAVE Control

Points, that has not α type criticality, and therefore their modification it consists only in the definition of the Restricted Zone (β type criticality). CIRS and Autostrade Specifications, both for binder layers, are an example of this typology (Fig.5 and Tab.4).

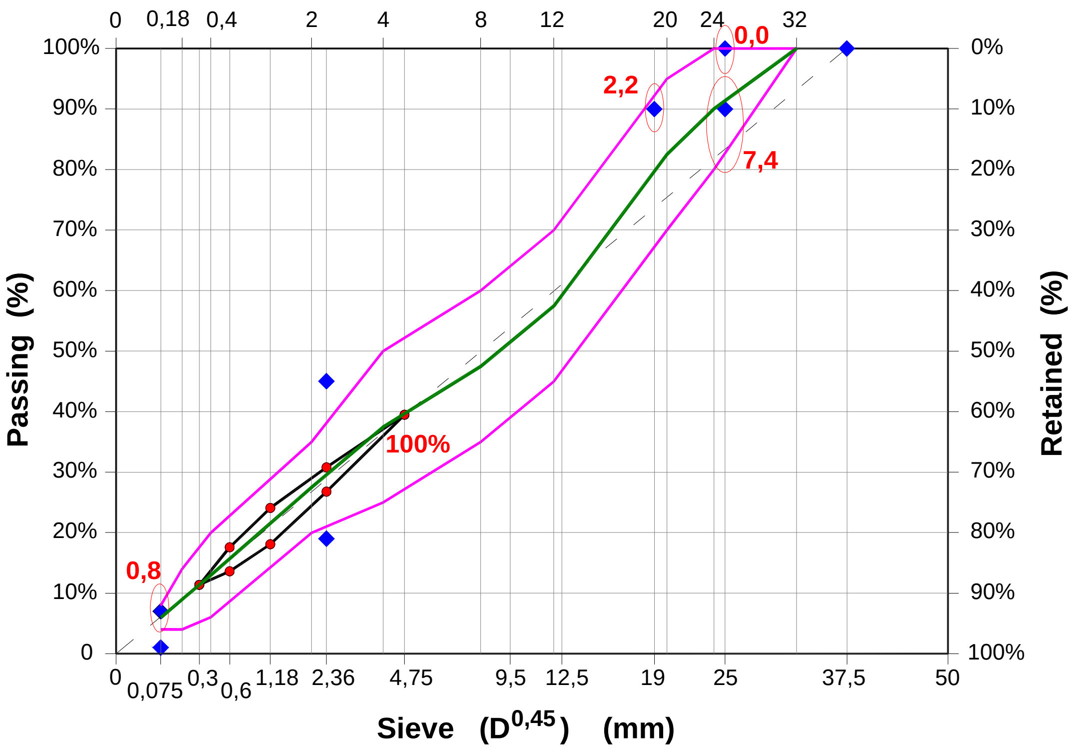


Figure 4: Criticalitys analysis

Table 3: CIRS modified base asphalt gradation

Sieve (mm)	Gradation Passing (%)	Sieve (mm)	Restricted Zone Boundary (min-max)
32	100-100		
24	80 (**90**) - 100		
20	70 - 95 (**90**)		
12	45 - 70		
8	35 - 60		
4	25 - 50	4.75	39.5 - 39.5
2	20 - 35	2.36	26.8 - 30.8
0,4	6 - 20	1.18	18.1 - 24.1
0,180	4 - 14	0.60	13.6 - 17.6
0,075	4 - 8 (**7**)	0.30	11.4 - 11.4

Other gradations Specification have not showed a full SUPERPAVE compatibility in term of Control Points, for which some modifications at the limits gradation curves it becomes necessary beyond to introducing the Restricted Zone.
For example, it is the case of the SITEB gradation Specification for wearing courses layers (Cfr. Fig.6), that shows one β type criticality equal to 91.5% and 4 α type criticality. The correction of the α type criticality requires the exclusion of the external limit curves areas, as showed with outline shape in Fig.6.
Finally different gradations, especially for special asphalt mixtures (Splittmastix Asphalt, Porous Asphalt, etc.) are incompatible with the SUPERPAVE gradation prescriptions (Fig.7).
Anyway this was expected it, since the SUPERPAVE prescriptions have as an objective the maximum resistance and the durability of the bituminous concrete, independently from other different performances, like the superficial performance etc.

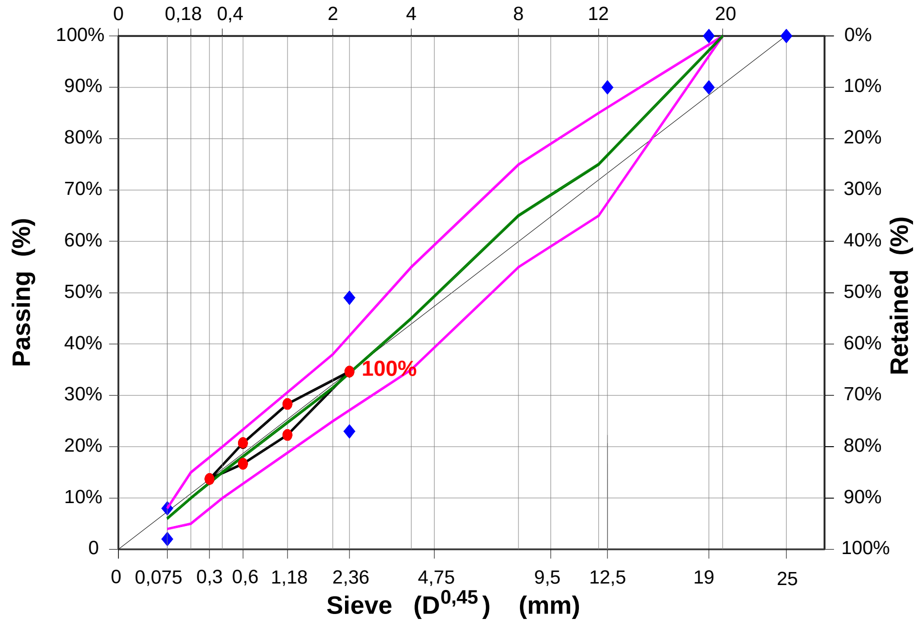


Figure 5: CIRS gradation for binder layer (D $_{\text{max nom}}$ = 19mm)

Table 4: CIRS modified gradation for binder layer

Sieve (mm)	Gradation Passing (%)	Sieve (mm)	Restricted Zone Boundary (min-max)
25	100-100		
15	65 - 85		
10	55 - 75		
5	35 - 55		
2	25 - 38	2.36	34.6 - 34.6
0.4	10 - 20	1.18	22.3 - 28.3
1.180	5 - 15	0.60	16.7 - 20.7
0.075	4 - 8	0.30	13.7 - 13.7

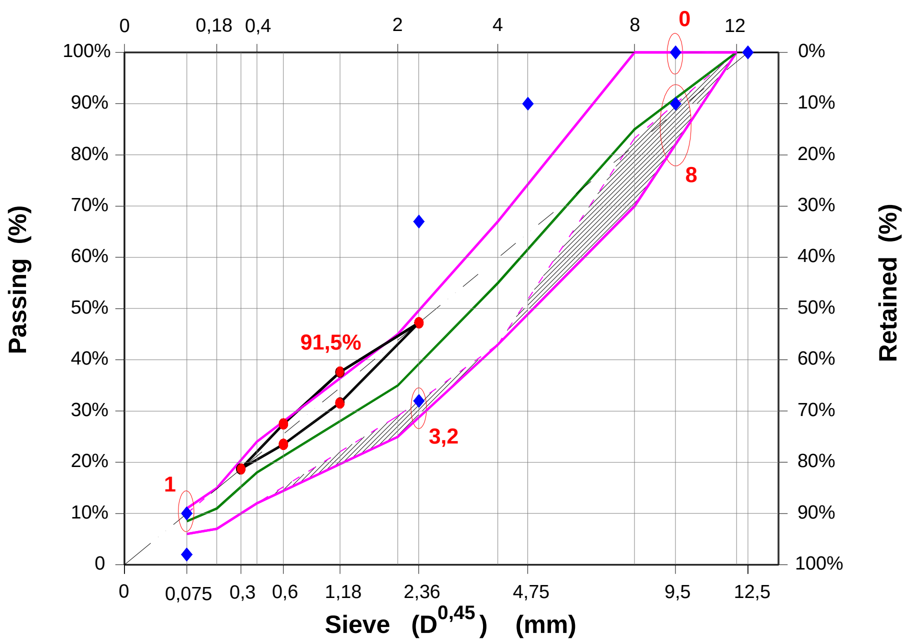


Figure 6: SITEB gradation for wearing course layer (D $_{max\ nom}$ = 9.5mm)

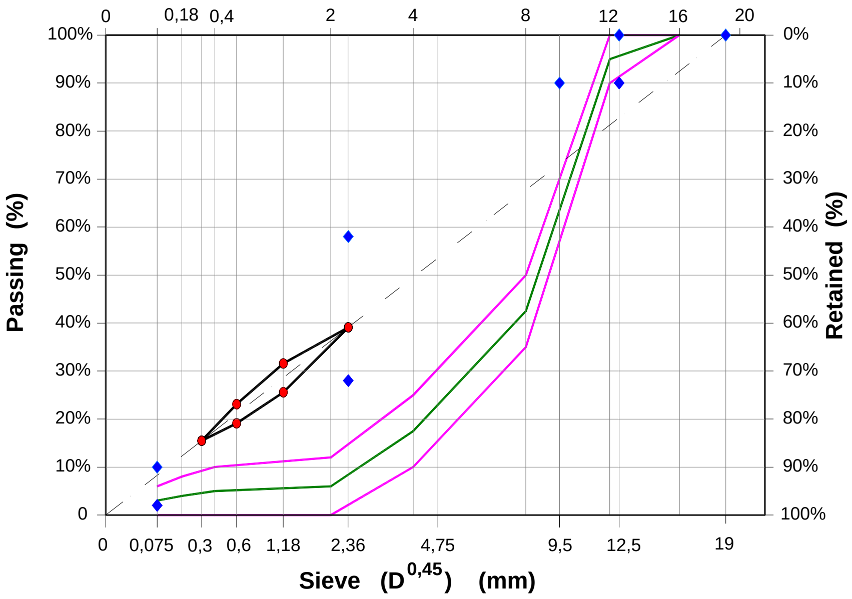


Figure 7: ANAS type B gradation for porous wearing course layer (D $_{max\ nom}$ = 12.5mm)

CONCLUSIONS

As well known, from the SHRP Research Program a Mix Design formulation criterion knows, based on the consideration that the composition of a projected aggregate according to the SUPERPAVE criteriamust be such that it does not go beyond the Control Points, without passing from the Restricted Zone. That comes for avoiding the use of aggregate mixtures with an elevated percentage of thin sand (as regards the total quantity of sand), that is to avoid gradations that draws too near to the curve of maximum density. Generally, this condition doesn't assure the correct percentage of aggregate mineral voids. In many cases, the Restricted Zone discourage the employment of natural sand in an aggregate mixture, to advantage of artificial washed sand. A correct design approach of the structure of the mineral aggregate assures to develops a solid skeleton resistant to permanent deformations, while a sufficient percentage of empty voids increase its durability.

The proposed methodology allows establishing the degree of compatibility of the Italian gradation Specification with the SUPERPAVE prescriptions. At the same time it proposes, in the possible cases, their correction.

The analysis of the mineral aggregate gradation contained in the main Italians Contract Specifications have highlighted that nobody of them is 100% compatible with the SUPERPAVE specifics. But in large part of it the cases it is possible to adequate to the SUPERPAVE prescriptions, as regards the α and β type criticality. Regarding the special wearing course asphalt concrete (Splittmastix Asphalt, Porous Asphalt, etc.), a correction does not result evidently possible, because of the excessive discontinuity of the aggregate gradation.

The Author points out that the gradation subsequent from the application of the proposed methodology for a complete validation will be confirmed with further laboratory tests as already tested for any of the examined cases.

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