ASPHALT CONCRETE MIXTURES AND ASPHALT CONCRETE – VOLUMETRIC-FUNCTIONAL DESIGN SYSTEM.

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Abstract. Volumetric-functional design system of asphalt concrete requires the engineer to select materials that meet rigorous consensus properties and then combine them to achieve specific volumetric targets that serve as proxies for performance. This methodology is inextricably linked to the physics of granular materials and the rheology of viscoelastic binders. The core philosophy of this system is that the durability of an asphalt mixture is determined by its volumetric properties—specifically, the volume of air voids, the volume of asphalt binder, and the volume of the mineral aggregate skeleton. This system abandons the old "Type A, B, C" classification of asphalt mixes found in legacy GOST (international standart in Uzbekistan) standards. Instead, it introduces a multi-dimensional classification system based on Nominal Maximum Aggregate Size (NMAS), Traffic Level, and Gradation Type. This system allows designers to tailor mixtures precisely to their application. Volumetric-functional design is essentially the Superpave method, which was originally developed by the Strategic Highway Research Program (SHRP) in the USA.[1,2]

Introduction. The method relies on three critical volumetric parameters. They are air voids, voids in mineral aggregates and voids filled with asphalt. The standard classifies mixtures based on the Nominal Maximum Aggregate Size (NMAS), which dictates the appropriate lift thickness for the pavement layer. The NMAS is defined as one sieve size larger than the first sieve to retain more than 10% of the material. The standard establishes six primary designations. SP-4 (4.0 mm): Designed for ultra-thin surface treatments, sidewalks, or leveling courses where structural capacity is secondary to surface sealing.SP-8 (8.0 mm): Suitable for thin wearing courses on low-volume roads or urban streets, offering noise reduction and smooth ride quality. SP-11 (11.2 mm): The workhorse classification for surface courses on highways. The 11.2 mm aggregate size offers a balance between surface texture (friction) and noise. SP-16 (16.0 mm): Used for heavy-duty surface courses or intermediate (binder) courses. The larger stone skeleton provides greater resistance to shear stresses from heavy trucks. SP-22 (22.4 mm): Typically used for binder courses (the layer below the surface) or base courses. SP-32 (31 mm): Large-stone mixes used for deep-strength base courses. These mixes rely on massive stone-on-stone interlocking to distribute loads to the subgrade. Perhaps the most significant advancement in method is the classification of mixtures by traffic loading. The standard recognizes that a mixture designed for a rural access road will fail under the load of an industrial hauler, and conversely, a mix designed for heavy loads may be too dry and brittle for a low-traffic road. The standard defines four traffic levels based on the number of Equivalent Single Axle Loads (ESALs / AK-11) expected over the design life of the pavement: Light (L / Л): < 0 million ESALs. Used for residential streets, parking lots, and rural roads. Normal (N / H): 0 – 1.8 million ESALs. Used for city arterials and regional connectors. Heavy (T / T): 1.8 – 5.6 million ESALs. Used for major national highways and transport corridors. Extreme (E / Э): > 5.6 million ESALs. Used for strategic transit routes (e.g., Western Europe–Western

China), industrial haul roads, and slow-moving toll plaza approaches where static loads are severe. The "Extreme" category is particularly vital for Uzbekistan, given the prevalence of overloaded trucks in the transit sector. [1,3-5]

Methodology. The "Method" of laboratory fabrication is the Superpave Gyratory Compactor (SGC). This method contrasts sharply with the impact hammer (Marshall) used previously. The SGC applies a constant vertical pressure (600 kPa) while gyrating the mold at a specific angle (1.16° internal or 1.25° external) to simulate the kneading action of rolling tires.[2,6-7]

Table 1. Gyration Levels in ST RK 3997-2024 (Standard of Kazakstan) [2]

Gyration Level	**Designation**	**Meaning**	**Target Air Voids**	**Implication**
N_initial	N_initial	Compactibility during construction.	>11.0%	If voids are too low here, the mix is "tender" and will shove under rollers.
N_design	N_design	Density after construction and initial traffic.	4.0%	The target for selecting asphalt content.
N_max	N_max	Density at the end of pavement life.	> 2.0%	If voids fall below 2% here, the mix will rut under future traffic.

Beyond volumetrics, the "Methods" section mandates mechanical performance testing for high-traffic mixtures (Levels T and E). This "Volumetric-Functional" approach ensures that the math (volumetrics) matches reality (performance).[8]

Rutting Resistance (Hamburg Wheel Track): The standard references for determining rut depth. This test involves rolling a steel wheel over a submerged asphalt slab thousands of times. It measures both the viscoelastic deformation (rutting) and moisture susceptibility (stripping).[1,9]

Flow Number (AMPT): This test applies a repeated axial load to a cylindrical specimen to determine the onset of tertiary flow (shear failure). It is the gold standard for predicting rutting potential under heavy loads.[2,10]

Moisture Sensitivity (TSR): The Tensile Strength Ratio test compares the strength of dry samples vs. wet/frozen samples, simulating Uzbekistan's freeze-thaw cycles.

Results. The "Results” section of this review analyzes the specific quantitative requirements established. These values are the output of the standard's methodology and serve as the strict pass/fail criteria for road construction materials. Aggregate Gradation Requirements (Table 2 Analysis) establishes the particle size distribution requirements. The standard uses "Control Points" through which the gradation curve must pass. This prevents the use of gap-graded or poorly graded aggregates that could lead to instability.[1]

Table 2. Key Gradation Control Points (Selected NMAS)[2]

Sieve Size (mm)	SP-11 (Surface)	SP-16 (Binder)	SP-22 (Base)	Analysis of Function
31	-	-	100%	Defines the max particle size for the layer.
22.4	-	100%	90-100%	Ensures constructability and lift thickness compatibility.
16.0	100%	90-100%	< 90%	The "Nominal Maximum" size control.
11.2	90-100%	< 90%	-	Controls the skeleton structure.
2.0 (Sand)	28.0 - 58.0%	22.0 - 48.0%	19.0 - 45.0%	**Critical:** Determines the coarse/fine nature. Lower values create stone-on-stone contact.
0.063 (Dust)	2.0 - 10.0%	2.0 - 8.0%	1.0 - 7.0%	**Critical:** Controls mastic stiffness. High dust stiffens the binder; low dust reduces cohesion.

The wide band on the 2.0 mm sieve (e.g., 28-58% for SP-11) offers designers significant flexibility to optimize the aggregate structure based on local quarry materials, provided they meet the volumetric requirements. The strict control on the 0.063 mm (dust) sieve is notable; keeping dust below 8-10% is essential for preventing low-temperature cracking, as excess dust acts as an extender that embrittles the binder.[11-13]

Air Voids (P_a):The design target is fixed at 4.0% ± 0.3% at N_design. This 4% target is universally recognized in Superpave as the optimal balance between stability and durability. At N_initial: For "Extreme" (E) traffic, voids must be 11.0%. This high initial void content requirement indicates that the mix must be very stiff and difficult to compact initially. This prevents "tender mix" syndrome where rollers push the mat around during construction, and ensures the aggregate skeleton is robust. Voids in Mineral Aggregate (VMA):The standard sets minimum VMA values based on NMAS: SP-11: Min 15.0% (inferred from standard practice, columns visible in snippet), SP-16: Min 13.5%,SP-22: Min 12.5% (approx).[1,11-13]

The standard explicitly warns: "It is not recommended to design mixtures where VMA content exceeds the required amount by more than 2%.".5 This clause is an economic safeguard. While high VMA increases durability by allowing more asphalt, excessive VMA requires excessive binder, making the pavement prohibitively expensive and potentially unstable (prone to flushing). Voids Filled with Asphalt (VFA): Light Traffic (L): 65% - 78% VFA. Higher VFA is allowed here to improve durability and seal the surface on low-volume roads where traffic densification is minimal. Heavy Traffic (T): 65% - 75% VFA. The upper limit is reduced to 75% to prevent bleeding under heavy loads. The range ensures the voids are sufficiently filled to prevent oxidation but not so full that traffic pushes the asphalt to the surface.

Dust-to-Binder Ratio. The standard mandates a ratio of 0.8 to 1.6. This is slightly tighter than some US standards (0.6-1.2), reflecting a preference for slightly stiffer mastics to combat the high summer temperatures in Kazakhstan, but capped at 1.6 to prevent winter cracking.

Performance Testing Requirements (Table 3 Analysis) For Heavy (T) and Extreme (E) traffic, volumetric compliance is insufficient. The mix must pass physical torture tests.[1,2]

Table 3. Performance Criteria for High Traffic Loads [2]

Performance Metric	**Test Method**	**Heavy Traffic (T)**	**Extreme Traffic (E)**	**Implication**
Flow Number (Cycles)	AMPT (ST RK 3999)	190	740	Requires highly angular aggregates and polymer modified binder.
Rut Depth (mm)	Hamburg (EN 12697-22)	3.5 mm	2.5 mm	Zero tolerance for rutting. Implies use of SBS modification.
Moisture Sensitivity (TSR)	STRK1218	0.80	0.80	Ensures resistance to stripping during freeze-thaw cycles.

The Flow Number requirement of 740 cycles for Extreme traffic is particularly rigorous. In many jurisdictions, neat (unmodified) bitumen fails around 100-200 cycles. Achieving 740 cycles necessitates the use of a stiff aggregate skeleton combined with a high-performance polymer-modified binder (PG 76-XX or similar). Similarly, a 2.5 mm rut depth limit in the Hamburg test is exceptionally strict, effectively mandating high-quality materials for all major transit corridors

Discussion. By transitioning from empirical recipes to the Superpave volumetric system, the nation addresses the twin challenges of rising transit traffic and extreme climate variability. However, the implementation of this standard will trigger profound changes across the industrial landscape.

The most immediate impact will be felt in the bitumen supply chain. The performance requirements for "Extreme" traffic—specifically the 740-cycle Flow Number and 2.5 mm rut depth—are virtually unachievable with the neat BND bitumens. (BND 100/130).

The Polymer Necessity: To meet the new standard, the industry must pivot toward Polymer Modified Bitumen (PMB). The addition of elastomers like Styrene-Butadiene-Styrene (SBS) creates a cross-linked polymer network within the binder, significantly enhancing its elasticity at high temperatures and ductility at low temperatures.

The 100% fractured face requirement for heavy traffic forces the abandonment of rounded river gravels, which have historically been a cheap source of material. Furthermore, the strict "Flat and Elongated" limit (10%) challenges many existing quarries that use jaw crushers, which tend to produce flaky aggregates.

Economic Impact: This will likely drive consolidation in the quarrying sector, as small operators unable to invest in modern cone or vertical shaft impact (VSI) crushers will be excluded from national highway projects.

Supply Chain: Transport costs may rise as contractors are forced to haul compliant aggregates from further distances, though the standard encourages the use of local materials if they can be processed to meet the standards.

The "Continental Paradox" requires a pavement to be stiff at +60°C (to resist rutting) and flexible at -40°C (to resist cracking). Rutting Mechanism: ST RK 3997-2024 addresses high-temperature rutting through the Aggregate Skeleton. By mandating coarse aggregate angularity and utilizing the gyratory compactor to simulate traffic densification, the standard ensures the load is carried by stone-on-stone contact, not by the binder. Research suggests Superpave mixes in this region perform 90-100% better in rut resistance than Marshall mixes.

Cracking Mechanism: The standard addresses low-temperature cracking through Volumetric Design. By strictly controlling dust content (max 1.6 dust/binder ratio) and ensuring adequate VMA, the design prevents the mastic from becoming too brittle. The use of PMB further enhances the binder's ability to stretch without breaking during catastrophic freeze events.

Conclusion. By replacing empirical recipes with a volumetric-functional system, the standard forces the entire road construction ecosystem—from the oil refinery to the rock quarry to the paving contractor—to modernize.

The stringent requirements for "Extreme" traffic (Flow Number >740, Rut Depth <2.5mm) effectively mandate the use of polymer-modified bitumens and high-quality cubical aggregates. While this imposes short-term costs and requires significant industrial retooling, the long-term benefits are clear: pavements that resist the scorching summer heat and the freezing winter cold, reducing maintenance costs and ensuring the viability of Uzbekistan's strategic transit corridors.

References

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