Convergence of Advances in Design, Test Methods and Stabilization Product Technologies
Laboratory Testing

The EMC SQUARED System (EMC2) — Advanced Stabilization Product Technology. Clean. Green. Concentrated power to improve the stability of earth materials at low cost. Applied as compaction water additives to aggregates, soils and recycled pavement materials with pre-established compaction controls and construction procedures, preconditioning aggregate materials to behave more like conglomerate rock, clays like claystone, sands like sandstone, and silts like siltstone, paralleling the natural processes of consolidation and lithification. These stabilizer products have been in use for over three decades for construction of city streets and expressways, county roads, interstate freeways, industrial and renewable energy sites, military supply routes and runways, remote unpaved highways, border roads, haul roads, forest roads, oilfield access roads, temporary and permanent closures of construction sites and landfills, and for other applications.

Laboratory Technology

Advances are being made in the materials laboratory in regards to the testing of aggregate and soil materials used in construction of transportation structures and earthworks. The very simplistic tests developed more than fifty years ago, and still conducted on apparatus designed in that era, such as the California Bearing Ratio (CBR) and Resistance Value (R-Value), provide reviewers with an index number for the strength of the material at the point of failure. These test methods are slowly but surely being replaced by methods that more closely approximate actual field service conditions and that actually attempt to predict field performance. These older laboratory tests most often modeled “worst case” conditions that could only be answered with extraordinarily expensive road designs that relied on thick layers of asphalt and concrete pavement and even thicker layers of aggregate base rock and cement or lime treated subgrades. In spite of the tremendous expense in building roads according to designs based upon these index tests, the road structures have often deteriorated rapidly due to dynamic loading and environmental factors not well addressed by the older tests. These old test methods have been written into public agency design manuals, accounting for their amazing longevity despite the availability of more sensitive modern test methods that provide improved correlation with field performance.

Resilient Modulus Testing

The data developed by the Resilient Modulus test method is the primary input required by the Mechanistic – Empirical Pavement Design Method (M-E Design), the state of the art design system developed as a National Cooperative Highway Research Program (NCHRP) project and adopted and first published by the American Association of Highway and Transportation Officials (AASHTO) in 2003 with funding support provided by the State DOT members and the Federal Highway Administration (FHWA). The 3rd Edition of the Mechanistic-Empirical Pavement Design Guide: A Manual of Practice, was published in 2020. Resilient Modulus is a performance-based test method that allows determination of how the pavement system will respond to traffic loading. The modulus of resilience is the maximum energy that a material can absorb and still return to its original position, without creating a permanent deformation. This is a test of the stiffness of the material, in contrast to the traditional strength tests (CBR, R-Value, and Unconfined Compressive Strength) that simply measure the point of failure when a material breaks or fractures. While the Dynamic Modulus test method is used to evaluate asphalt pavement surface course materials, whose modulus values will vary according to both temperature and loading conditions, Resilient Modulus is the test method for project-specific evaluation of base, subbase and soils materials and determination of the level of stiffness they will be capable of providing in their position within the pavement structural section. Using the resilient modulus test data and varying the layer thickness and stiffness of each layer while running the M-E Design program, the pavement engineer can design a pavement system capable of carrying the anticipated design axle load applications during its planned service life.

In addition to developing the primary input for the M-E Design, which allows the pavement engineer to produce a pavement design that will guide the construction of roads and highways that will cost less to build and outperform conventional designs in service life, the Resilient Modulus test method also provides the engineer with the ability to determine the equivalency of different materials in their modulus values and their capability to contribute stiffness to the overall pavement structural section. This allows the design engineer to take advantage of major cost savings by specifying flexible stabilized base course layers with a modulus similar to that of Hot Mix Asphalt (HMA) mixtures and reducing the layer thickness of the costly asphalt pavement surface courses while still providing the same degree of stiffness for the pavement system. As the test data in the chart below shows, an application of EMC SQUARED System stabilizer product to a high quality crushed aggregate material increased its modulus by a factor of over five times. The modulus value determined by Resilient Modulus testing translated into a Structural Coefficient, or Layer Equivalency Factor similar to that of the HMA mixture. As an alternative to reducing the layer thickness of the HMA surface course pavement, the pavement engineer could reduce the layer thickness of the base course that otherwise would be constructed with untreated crushed aggregate with a modulus over five times lower than the stabilized aggregate.

RESILIENT MODULUS RESULTS AND LAYER EQUIVALENCY FACTORS

Sample ID	Average Resilient Modulus (psi)*	Layer Equivalency Factor**
Aggregate Base with EMC SQUARED	272,500	0.35***
Untreated Aggregate Base	51,000	0.10

*Resilient Modulus results reported by the University of Nevada, Reno
**Professional Service Industries, Inc.
***Standard practice in Southern Nevada is to assign a layer coefficient of 0.35 for dense graded hot mix asphalt

What is most important to note here is that the EMC SQUARED Stabilized Aggregate retains flexible, or elastic behavior, which is far more compatible with the flexible and viscoelastic behavior of the HMA pavement. This is in contrast to the rigid and slab-like behavior of a cement treated base (CTB) material with its unavoidable shrinkage cracking that generates reflective cracking in the asphalt pavement surface course. This incompatibility with asphalt pavement is the reason that CTB is so seldom used as a base course immediately under the asphalt pavement, and why pavement designers have historically given so little consideration to the benefits of base stabilization. Fortunately, pavement engineers now have availability of the M-E Design Method than can fully give credit to the resilient modulus of the stabilized base layer, and they have access to a modern base stabilization product technology that eliminates the risk of pavement reflective cracking generated by a rigid base course. This is a timely convergence of new technologies for the construction industry.

As previously discussed, EMC SQUARED Stabilized Aggregate materials can be produced with modulus values equivalent to Hot Mix Asphalt (HMA) mixtures, permitting pavement design engineers to consider meeting their design requirements with stabilized base layers and thinner, less costly asphalt surface course pavements. As will be understood in the discussion about the Dynamic Modulus test method further on in this White Paper, there are good reasons, other than economics, to design pavements with EMC SQUARED Stabilized Aggregate base course layers and reduce reliance on thick asphalt surface course pavements. Known as Bottom-Up Design, the pavement engineer first focuses on the lower portions of the pavement structural section, the subgrade, subbase and base course layers. This is where the majority of the stiffness of the overall pavement section can most economically be achieved. With results from resilient modulus testing of stabilized subgrade soils and stabilized base layers available as input for the M-E Design, the surface course pavement can be designed as an economical wearing surface with less contribution required to the overall stiffness of the pavement system. Bottom-Up Design is in contrast with the conventional Top-Down Design methods still in wide spread use. Top-Down Design methods assign relatively limited value to stabilized base and subgrade layers and instead concentrate on the surface course pavement layer as the primary source of stiffness for the pavement system. These are the most costly pavement designs to construct and their questionable history of performance has provided the motivation for the development of the advanced laboratory test methods and the AASHTO Mechanistic-Empirical Pavement Design Guide.

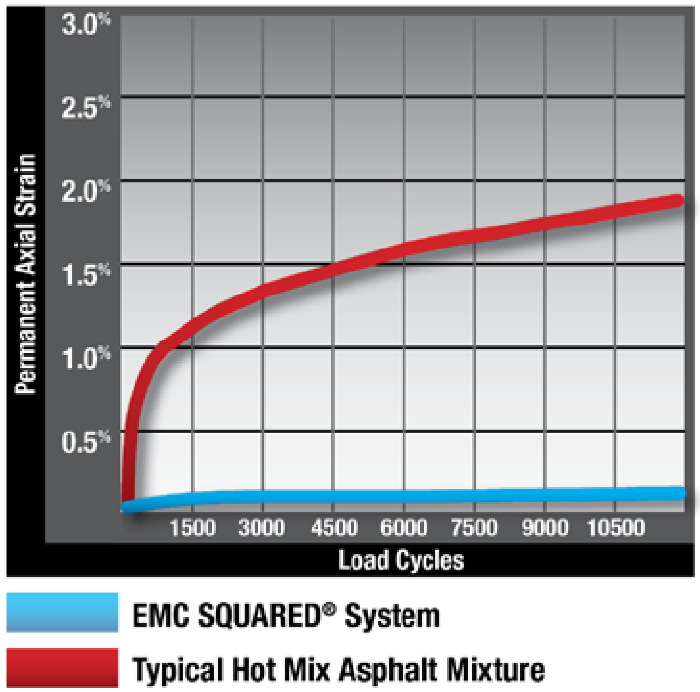
Equally exciting is the opportunity with resilient modulus testing to replace the use of costly crushed aggregate materials with EMC SQUARED Stabilized Soils that provide equal or better modulus values than the locally available crushed aggregate materials. Design engineers no longer have to guess at the contribution that a soil, a stabilized soil, a crushed aggregate or an EMC SQUARED Stabilized Aggregate will provide to the stiffness of the overall pavement design. The modulus of each can be determined in the materials testing laboratory and confirmed during and after construction with Falling Weight Deflectometer (FWD) testing. Knowledge is power. Many road projects have been constructed at far lower cost by eliminating the need to import crushed aggregate materials, by utilizing EMC SQUARED Stabilized Soils of similar or higher modulus in place of base or subbase aggregate materials for projects of scale where the cost-savings can be tremendous.

For engineers not conversant with Resilient Modulus testing results, AASHTO has available a chart for Base Course applications that shows the equivalency of a Resilient Modulus test result with other test methods that may be more familiar. See http://stabilizationproducts.net/docs/18632.pdf. As indicated by the chart, a Resilient Modulus value of 30,000 psi is equivalent to CBR 100, R-Value 85, Texas Triaxial 2.0, and a Structural Coefficient of 0.14.

Repeated Load Triaxial (RLT) Testing

The Typical Deformation Curve for HMA Mixtures and the Permanent Deformation Characteristics of the EMC SQUARED Stabilized Aggregate, are developed from the results of Repeated Load Triaxial (RLT) testing. RLT testing measures the resistance of a material to rutting and permanent deformation. In testing conducted at the Western Regional Superpave Center (WRSC) located at the University of Nevada Reno Campus, RLT tests were conducted to compare the resistance of an EMC SQUARED Stabilized Aggregate material with typical Hot Mix Asphalt (HMA) mixtures. In comparison to the HMA Mixture, which experiences almost 2.0% permanent axial strain, the EMC SQUARED® Stabilized Aggregate Mixture showed only 0.1% permanent axial strain. The report on the testing indicated that the deformation characteristics of the EMC SQUARED Stabilized Aggregate are expected to remain constant at all temperatures used in the related Dynamic Modulus testing and that the stabilized aggregate was not anticipated to generate any permanent deformation under a wide range of loading conditions.

Permanent Deformation Characteristics of the EMC SQUARED Stabilized Aggregate Cured for 72 hrs at 104°F in Comparison to Typical Hot Mix Asphalt Materials



The performance of the EMC SQUARED Stabilized Aggregate material as evaluated in RLT testing resulted in a finding that under a wide range of loading conditions no permanent deformation would be anticipated. Furthermore, even in the worst case conditions for a flexible pavement layer, which are slow moving loads in hot environments, the report concludes that the behavior of the stabilized aggregate "...makes it a good candidate for pavements loaded under such severe conditions."

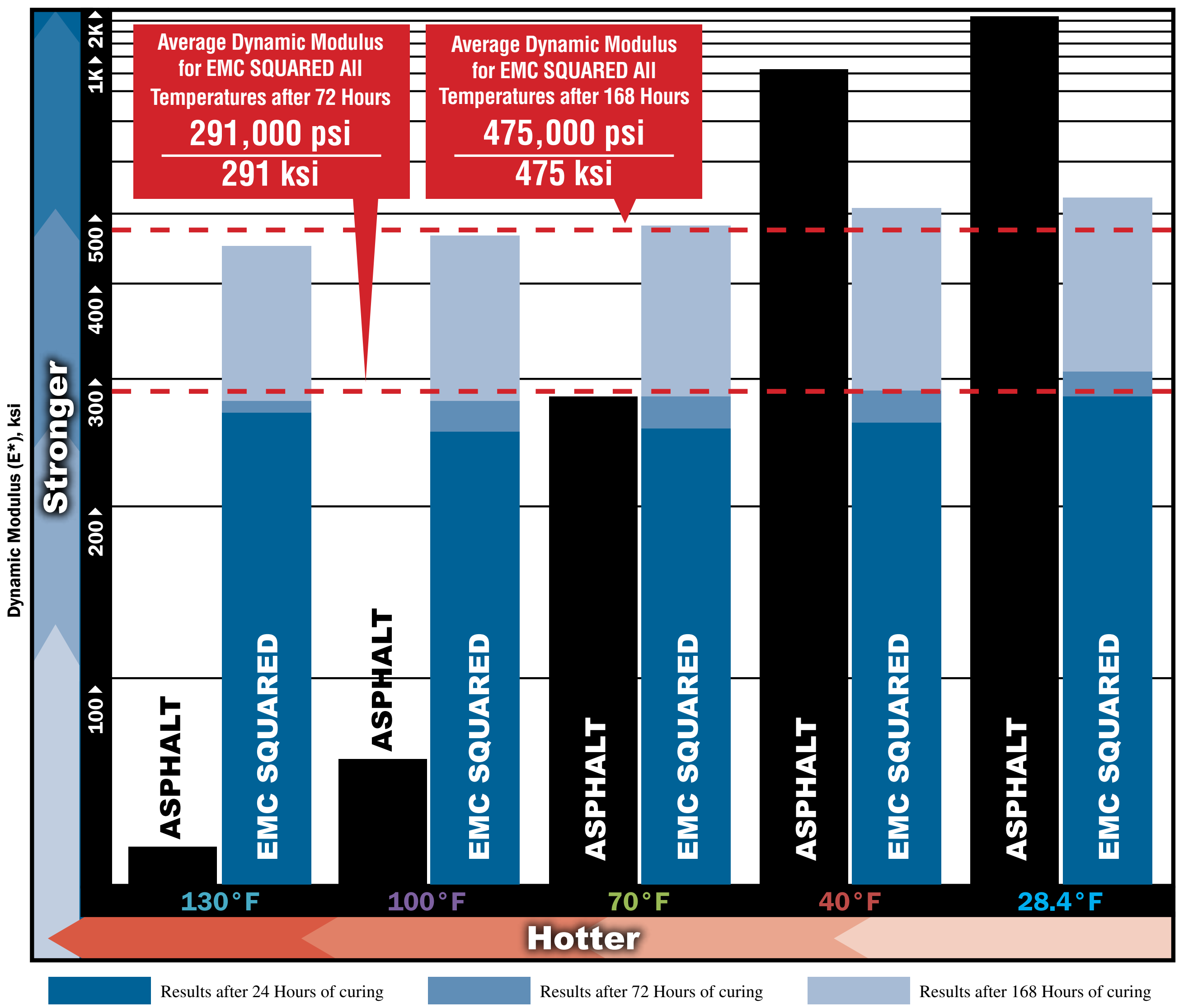
For more information on Repeated Load Triaxial Testing, go to http://stabilizationproducts.net/docs/18678.pdf

Dynamic Modulus Testing

Dynamic modulus is the main input required for design of Hot Mix Asphalt (HMA) pavements using the nationally recognized AASHTO Mechanistic-Emperical Pavement Design Guide (MEPDG). HMA pavement materials are viscoelastic in nature and their dynamic modulus values vary dramatically in response to changes in loading rate and temperature. For example, HMA mixtures exhibit much lower modulus values (significant strength loss) as pavement temperatures increase. As evidenced in the test results developed from research studies at the Western Regional Superpave Center at University of Nevada Reno graphed below, HMA mixtures dramatically lose stiffness as temperatures increase. In contrast, dynamic modulus testing shows that EMC SQUARED Stabilized Aggregate materials retain a relatively consistent dynamic modulus (consistent stiffness) through the full range of loading rates and temperature changes, indicating elastic rather than viscoelastic behavior. Cold-mixed EMC SQUARED Stabilized Aggregate materials have the further advantage of gaining strength with additional curing time beyond the 7 curing day test results illustrated on the graph.

The EMC SQUARED Stabilized Aggregate materials were subjected to laboratory evaluation at the Western Regional Superpave Center, one of five centers established by the Federal Highway Administration (FHWA) to support the implementation of the Superpave Technology for hot mix asphalt materials, included both Dynamic Modulus (E*) and Repeated Load Triaxial (RLT) testing. These are two state of the art test methods for evaluating Hot Mix Asphalt mixtures and providing input for M-E Designs. EMC SQUARED Stabilized Aggregate materials exhibit flexible, or elastic behavior, and modulus values most similar to HMA mixtures. Consequently, those test methods are equally appropriate for evaluation of EMC SQUARED

Dynamic Modulus Data for Typical HMA Mixture and EMC SQUARED® Stabilized Aggregate Mixture



The above chart references data from a report by Peter Sebaaly, Ph.D., P.E. University of Nevada, Reno, Director of the Western Regional Superpave Center. The original charts, including the Repeated Load Triaxial results, may be seen at http://stabilizationproducts.net/docs/18678.pdf

Stabilized Aggregate materials and for pavement design purposes. The study found that the Dynamic Modulus property of the EMC SQUARED Stabilized Aggregate after one week of curing was in the range of 450,000 to 500,000 psi and that it was a very stable material that could be expected to resist permanent deformation very effectively and without excessive stiffening and risk of shrinkage cracking. The final report states “The combination of the elastic behavior of the EMC SQUARED stabilized aggregate material with its good level of long-term modulus makes it an appropriate choice for pavements serving heavy loads at slower speeds (worst case conditions) as well as for pavements subjected to standard loading conditions.” Unlike HMA mixtures, which are weakened by increasing temperatures and slower loading conditions due to their highly viscoelastic nature, the study found that changes in loading frequency and temperature, from below freezing to 130^{O}F temperature, had minimal impact on the modulus of the EMC SQUARED Stabilized Aggregate, and that the EMC SQUARED Stabilized Aggregate can therefore be represented by an average constant Dynamic Modulus property of 300,000 psi when tested after 3 days of curing and of 475,000 psi after 7 days of curing, versus the Master Curve required for HMA, which dramatically fluctuates in modulus value with changes in temperature or loading conditions.

Dynamic Modulus Setup

As an example of a severe service application, it should be noted that the EMC SQUARED Stabilized Aggregate materials for this laboratory evaluation were sampled during the construction of military heavy haul road projects designed by the U.S. Army Corps of Engineers (USACE). This EMC SQUARED Stabilized Aggregate material was plant-mixed and placed by asphalt paving machines as a surface course, or running surface, to be used by convoys of Abrams M1A2 military battle tanks weighing approximately 136,000 pounds and other tracked military equipment as well as heavy haul trucks weighing over 240,000 pounds when fully loaded. The EMC SQUARED System Stabilizer product was specified by USACE for stabilization of subgrade soils as well as stabilization of aggregate surface course materials for heavy haul road construction projects totaling over 116 miles in length. Of additional interest, the stabilization of subgrade soils eliminated the need to manufacture and transport over 1 million tons of crushed aggregate subbase material that otherwise would have been required for these projects. The stabilized subgrades were rated at 40,000 psi by FWD testing, more than equivalent to CBR 100 or R-Value 85

For more information on Dynamic Modulus Testing, go to http://stabilizationproducts.net/docs/18678.pdf

Tube Suction Testing (TST)

An effective performance-based test method to evaluate the moisture and frost susceptibility of earth materials was lacking until the last two decades. Fortunately, research conducted by the Texas Transportation Institute (TTI) and the Finnish National Road Administration (FNRA) has demonstrated that electrical properties, dielectric value and electrical conductivity, can be used to classify aggregate materials in regards to both strength and deformation properties as well as moisture and frost susceptibility. This test method, known as Tube Suction Testing (or Suction and Dielectric), has been incorporated in the National Cooperative Highway Research Program (NCHRP) for classification of aggregate materials. Many papers have been published by the Transportation Research Board (TRB) in the *Transportation Research Record* on this laboratory testing methodology, including a paper which reports on the effectiveness of the EMC SQUARED System stabilizer products in treating crushed aggregate materials that had previously tested as being highly moisture and frost susceptible.

The use of Tube Suction testing has proven out in evaluating the effectiveness of EMC SQUARED System treatments as it accurately measured the performances of aggregate materials following their field evaluation in both unstabilized and stabilized conditions while serving as running surfaces for gravel roads. The laboratory test results below correlated well with observed field performance. The untreated aggregate materials were highly unstable in the presence of moisture. Following treatment with EMC SQUARED System applications, the stabilized aggregate road surfaces retained strength in the presence of moisture while providing low maintenance running surfaces servicing heavy truck and vehicular traffic.

Aggregate Samples	Untreated	EMC SQUARED Stabilizer
Alaska	17.5	8.0
New Mexico	35.0	7.1
Nevada	17.3	7.7

SUCTION AND DIELECTRIC TESTING

References for Dielectric Constant Values of Highway Materials

MATERIAL	DIELECTRIC VALUE
Dry Aggregates	4 - 6
Asphaltic Concrete	5 - 7
Portland Cement Concrete	7 - 9

A Dielectric Value of greater than 15 indicates that the aggregate is wet or water saturated and extremely moisture and frost susceptible

A Dielectric Value of 10 to 15 indicates that a significant amount of free water has accumulated within the aggregate during the testing period and is a warning signal that the material is moisture sensitive and frost susceptible

Aggregate materials with a Dielectric Value of less than 10 are considered non-moisture sensitive and non-frost susceptible in service for road and highway base applications

For more information on Tube Suction Testing see http://stabilizationproducts.net/docs/18587.pdf. Field performance is very important, but in a world where road design engineers have made a practice to use the materials testing laboratory as the basis for their design decisions, it's equally important to have success in the materials laboratory. The Resilient Modulus, Repeated Load Triaxial, Dynamic Modulus, and Tube Suction Test effectively translate the unique package of stability improvements available from the EMC SQUARED System product technology.

In Conclusion

The historic ground rules of chemical stabilization of soils are based upon the bulk application of two calcium-based chemicals. The use of lime products goes back as far as 3,000 years for stabilization of roads in Chinese villages and construction of the Appian Way during Roman times. The use of cement to dry up saturated soils dates back to the St. Louis World's Fair in 1904, with the first applications for state highway construction projects during the 1930's. The pavement design methods of the time relied upon simplistic laboratory index test methods known as the California Bearing Ratio (CBR) and the Stabilometer, or Resistance Value (R-Value), two tests developed by engineers in the California Highway Department in the 1920's and 1930's. Within the past several decades, there has been a convergence of technologies that have opened up an entirely new world of pavement design and construction. The age of the computer has arrived, and with it the ability to develop and utilize computer-aided design and laboratory test procedures that process massive amounts of data while conducting computationally intensive operations and evaluating a great number of important variables far beyond the capability of dated testing and design methods. The availability of computer-aided testing and design technology has been a game changer. Innovation in stabilizer product technology during the past several decades is also changing the game, in conjunction with the computer-aided testing and design methodologies that are better suited to properly evaluate the greater range of benefits that are now available. With the slow departure of one hundred year old index tests from use by the highway engineering profession, test methods that were relatively insensitive to anything but bulk application of lime and cement products, modern stabilizer product technology can now be realistically evaluated and incorporated in pavement designs with performance validated by nondestructive field test methods. The EMC SQUARED System stabilizer products have now been in service for over three decades. These innovative concentrated liquid formulations are applied with strict engineering quality controls and applied as compaction water additives during the moisture conditioning and compaction procedures that are standard operations for pavement base course construction and subgrade preparation. The resulting constructed materials are resilient and provide stiffer load bearing platforms with greatly reduced moisture susceptibility. We know this thanks to decades of field performance, use of the new computer-aided laboratory tests that are able to model the dynamic and repetitive loading and the environmental conditions that road and highway pavement systems are subjected to on a daily basis, and the nondestructive field tests that can validate effectiveness.