

REFERENCES

AASHTO, 1989, **Standard specifications for transportation materials and methods of sampling and testing**, Part II, Methods of Sampling and Testing, American Association of State Highway Officials.

Abdelrahman, G.E., Kawabe, S., Tsukamoto, Y. and Tatsuoka, F., 2008, "Small-strain properties of expanded polystyrene geofom", **Soils and Foundations**, Vol. 48, No. 1, pp. 61-71.

A.I. Al-Hadidy , Yi-qiu Tan., 2009, "Mechanistic analysis of ST and SBS-modified flexible pavements", **Construction and Building Materials**, Vol. 23, pp. 2941–2950

Airey, G.D., 2004, "Styrene butadiene styrene polymer medication of road bitumens", **Journal of Materials Science**, Vol. 99, pp. 951–999.

Asphalt Research Program, Institute of Transportation Studies, University of California 1994, **Permanent Deformation Response of Asphalt Aggregate Mixes**, The Strategic Highway Research Program, SHRP-A-415.

ASTM D6927, 2004, **Marshall Stability and Flow of Bituminous Mixtures**, ASTM International.

Atkins, H. N., 1997, **Highway materials, Soils and Concretes**, Fourth Edition, Pearson Education Inc., Upper Saddle River, New Jersey.

Becker, Y., Mendez, M.P. and Rodriguez, Y., 1999, **Polymer Modified Asphalt**, Wisconsin Technol. 9, pp. 39–50.

Bouldin, M.G., and Collins, J.H., 1992, "Influence of Binder Rheology on Rutting Resistance of Polymer Modified and Unmodified Hot Mix Asphalt", **American Society for Testing and Materials (ASTM)**, STP 1108, pp. 50-60.

Casagrande, A. and Carillo, N., 1944, "Shear Failure of Anisotropic Materials", **Proc. Boston Soc. of Civil Eng.**, Vol. 31, pp. 74 – 87

Department of Highways, 1989, "Asphalt Concrete or Hot Mix Asphalt", **DH-S 408/2532**, Bureau of Materails, Analysis and Inspection.

Department of Highways, 1993, "Specification for Polymer Modified Asphalt Cement for Asphalt Concrete (Asphalt Concrete or Hot-mix Asphalt)", **DH-SP. 408/2536**, Bureau of Materails, Analysis and Inspection.

Department of Highways, 2006, "Modified Asphalt Concrete", **DH-S 409/2549**, Bureau of Materails, Analysis and Inspection.

Di Benedetto, H., Delaporte, B. and Sauzéat, C., 2007, "Three-dimensional linear behavior of bituminous materials: experiments and modeling", **International Journal Geomechanics**, Vol. 7, No.2, pp. 149-157.

Feizi-Khankandi, S., Mirghasemi, A. A., Ghalandarzadeh, A. and Hoeg, K., 2008, "Cyclic triaxial test on asphalt concrete as a water barrier for embankment dams", **Soils and Foundations**, Vol. 48, No. 3, pp. 319-332.

Goto, S., Tatsuoka, F., Shibuya, S., Kim, Y.-S. and Sato, T., 1991, "A simple gauge for local strain measurements in the laboratory", **Soils and Foundations**, Vol. 31, No. 1, pp. 169-180.

Graba, R., 2002, "**Permanent deformation properties of asphalt concrete mixtures**", D. Eng. Thesis, Department of Road and Railway Engineering, Norwegian University of Science and Technology, Trondheim, Norway.

Hardin, B. O., 1978, "The nature of stress-strain behavior for soils", **Proc. Geotech. Div. Specialty Conf. on Earthquake Eng. And Soil Dynamics**, ASCE, 98-SM7, Pasadena, I, 3-90.

Hayano, K., Sato, T. and Tatsuoka, F., 1997, "Deformation characteristics of a sedimentary softrock from triaxial compression test rectangular prism specimens", **G'eotechnique**, Vol. 47, No. 3, pp. 439-449.

Hayano, K., Matsumoto, M., Tatsuoka, F. and Koseki, J., 2001, "Evaluation of time-dependent deformation property of sedimentary soft rock and its constitutive modeling", **Soils and Foundations**, Vol. 41, No. 2, pp. 21-38.

Head, K.H., 1982, **Manual of soil laboratory testing**, Vol. 1, 2, 3, London: Pentech Press.

Hirakawa, D. (2003): "How to make load cell", **Internal Report**, Geotechnical Engineering Laboratory, University of Tokyo.

Hoque, E., Tatsuoka, F., and Sato, T., 1991, "Measuring anisotropic elastic properties of sand using a large triaxial specimen", **Geotech. Testing Journal.**, ASTM, 19-4, pp.277-282.

Hoque, E., Tatsuoka, F., Sato, T., and Kohata, Y. 1995, "Inherent and stress-induced anisotropy in small strain stiffness of granular materials", **Proc. of the 1st Int. Conf.on Earthquake Geotech. Engrg.**, IS-Tokyo '95, Balkema, Vol, pp. 277-282.

Huang, Y.H., 2004, **Pavement analysis and design**, Second Edition, Pearson Prentice Hall, Pearson Education, Inc., Upper Saddle River, NJ 07458, USA.

Isacsson, U. and Lu, X., 1995, "Testing and appraisal of polymer modified road bitumens: state of the art", **Smart Materials and Structures**, Vol. 28, pp. 139-159.

- Isacsson, U. and Zeng, H., 1996, "Low-temperature cracking of polymer-modified asphalt", **Materials and Structures**, Vol. 31, pp 58-63.
- Issaro, P., Kongkitkul, W., and Jongpradist, P., 2009, "Small-Strain Stress-Strain Properties of Asphaltic Concrete", **Proc. of the 14th National Convention on Civil Engineering**, Volume 1, pp. 431-436.
- Iwasaki, T. and Tatsuoka, F., 1977, "Effects of grain size and grading on dynamic shear moduli of sands", **Soils and Foundations**, Vol. 17, No. 3, pp. 19-35.
- Iwasaki, T., Tatsuoka, F. and Takagi, Y., 1978, "Shear moduli of sands under cyclic torsional shear loading", **Soils and Foundations**, Vol. 18, No. 1, pp. 39-56.
- Jardine, R. J., Potts, D. M., Fourie, A. B. and Burland, J. B., 1986, "Studies of the influence of nonlinear stress-strain characteristics in soil-structure interaction", **Geotechnique**, 36-3, **Symposium In Print**, pp. 377 - 397.
- Johnston, J.B. and King, G., 2008, **Using Polymer Modified Asphalt Emulsions in Surface Treatments, Federal Lands Highway**, Washington, DC.
- Khattak, M.J., Baladi, G.Y. and Drzal, L.T., 2007, "Low Temperature Binder Aggregate Adhesion and Mechanistic Characteristics of Polymer Modified Asphalt Mixtures", **Journal of Materials in Civil Engineering**, Vol. 19, No. 5, pp 411-422.
- Kim, K.W., Park, Y.P. and Yeon, K., 1996, "Tensile reinforcement of asphalt concrete using polymer coating", **Construction and Building Materials**, Vol. 10, No. 2, pp. 141-146.
- Kohata, Y., Tatsuoka, F., Dong, J., Teachavorasinskun, S. and Mizumoto, K., 1994, "Stress states affecting elastic deformation moduli of geomaterial", **Proc. Of Int. Symposium Pre-Failure Deformation of Geomaterials**, IS Hokkido '94 (Shibuya et al., eds.), Balkema, 1, 3-9.
- Kohata, Y., Tatsuoka, F., Wang, L., Jiang, G. L., Hoque, E. and Kodata, T. 1997, "Modelling the non-linear deformation properties of stiffness geomaterials", **Geotechnique**, 47-3, **Symposium In Print**, pp. 563-580.
- Kokusho, T., 1980, "Cyclic triaxial test of dynamic soil properties for wide strain range", **Soils and Foundations**, Vol. 20, No. 2, pp. 45-60.
- Kongkitkul, W., Issaro, P., Jongpradist, P. and Youwai, S. (2010): "Deformation characteristics of asphaltic concrete in uniaxial compression", **ASCE Geotechnical Special Publication**, GeoShanghai 2010, Shanghai, 3 – 5 June
- Kongsukprasert, L., and Tatsuoka, F., 2005, "Effect of compaction –induced anisotropy in the stress-strain time behavior of cement –mixed gravel soil", **Proc. 40th Annual conference, JGS**.

Kongsukprasert, L., and Tatsuoka, F., 2007, "Small strain stiffness and non-linear stress-strain behavior of cement-mixed gravelly soil", **Soils and Foundations**, Vol. 47, No. 2, pp. 375-394.

Kongsukprasert, L., Sano, Y., and Tatsuoka, F., 2007, "Compaction-induced anisotropy in the strength and deformation characteristics of cement-mixed gravelly soils" Soil Stress-Strain Behavior: Measurement, Modeling and Analysis, **Proc. of Geotechnical Symposium in Roma**, March 16 & 17, 2006

Liang, R. Y., Abu Alfoul, B. A. and Khasawneh, M., 2006, "Laboratory Investigation of Anisotropic Behaviour of HMA", **2006 International Conference on Perpetual Pavement**, Hilton Columbus at Easton Columbus, Ohio

Lidong Z., Yinghua Z., Yingfang F., and Zhiming L (2008). "Study on road application performance of asphalt concrete reinforced by fiber and modified asphalt", **Journal of materials in civil engineering © ASCE**

Linbing, W., Laureano R. Hoyos, Jay, W., and Chris, A. (2005). "Anisotropic Properties of Asphalt Concrete: Characterization and Implications for Pavement Design and Analysis", **Journal of materials in civil engineering © ASCE**

Lu, X., Isacson, U. and Ekblad, J., 1998, "Low-temperature properties of styrene butadiene styrene polymer modified bitumens", **Construction and Building Materials**, Vol. 12, Issue 8, pp 405-414.

Mamlouk, M. S., Witczak, M. W., Kaloush, K. E. and Ho, Y. S., 2002, "Effect of Anisotropy on Compressive and Tensile Properties of Asphalt Mixtures", **Journal of Testing and Evaluation**, JTEVA, Vol. 30, No. 5, pp. 432-438.

Masad, E., Tashman, L., Somadevan, N. and Little, D., 2002, "Mechanistic-Based Analysis of Stiffness Anisotropy in Asphalt Mixtures". **Journal of Materials in Civil Engineering**, Vol. 14, No. 5, pp. 374-383.

Moryadee, S., Klaycham, K., Kongkitkul, W., Youwai, S. and Punthutaecha, K., "Evaluation of stiffness values of grounds base and asphaltic concrete by Falling Weight Deflectometer (FWD) and Plate Load Test (PLT)", **Proc. of the 14th National Convention on Civil Engineering**, Volume 1, pp. 425-430

Motola, Y. and Uzan, J., 2006, "Anisotropy of field-compacted asphalt concrete material", **Journal of Testing and Evaluation**, Vol. 35, No. 1

Musika N., Kongkitkul W., Jongpradist P., 2010, "Effect of compaction on anisotropic strength and stiffness properties of asphaltic concrete", **Proceedings of the 15th National Convention on Civil Engineering**, GTE-046

Robinson, H.L., **Chapter 5: Polymers Used in Asphalt** [Online], Available : <http://www.globalspec.com/reference/50496/203279/chapter-5-polymers-used-in-asphalt,%202011>. [2011]

Sengoz, B. and Isikyakar, G., 2007, "Evaluation of the properties and microstructure of SBS and EVA polymer modified bitumen", **Construction and Building Materials**, Vol. 22, pp. 1897–1905.

Sousa, J.B. and Weissman, S.L., 1994, "Modeling permanent deformation of Asphalt-Aggregate Mixes", **Journal of the Association of Asphalt Paving Technologists**, Vol. 63, pp. 224-257.

Tatsuoka, F., Modoni, G., Jiang, G. L., Anh Dan, L. Q., Flora, A., Matsushita M. and Koseki, J., 1999b, "Stress-strain behaviour at small strains of unbound granular materials and its laboratory tests", Keynote Lecture, **Proc. of Workshop on Modelling and Advanced testing for Unbound Granular Materials**, January 21 and 22, 1999, Lisboa (Correia eds.), Balkema, pp. 17-61.

Tatsuoka, F., Correia, A. G., Ishihara, M. and Uchimura, T., 1999c, "Non-linear Resilient Behaviour of Unbound Granular Materials Predicted by the Cross-Anisotropic Hypo-Quasi-Elasticity Model", **Proc. of Workshop on Modelling and Advanced testing for Unbound Granular Materials**, January 21 and 22, 1999, Lisboa (Correia eds.), Balkema, pp. 197-204

Tatsuoka, F., Santucci de Magistris, F., Hayano, K., Momoya, Y. and Koseki, J., 2000, "Some new aspects of time effects on the stress-strain behaviour of stiff geomaterials", Keynote Lecture, **The Geotechnics of Hard Soils-Soft Rocks, Proc. of Second Int. Conf. on Hard Soils and Soft Rocks**, Napoli, 1998 (Evangelista and Picarelli eds.), Balkema, Vol. 2, pp. 1285-1371.

Thaisri, K., Youwai, S. and Kongkitkul, W., 2008, "Behavior of reinforced flexible pavement under monotonic loading condition", **Proc. of the 13th National Convention on Civil Engineering**, pp. 344-347.

Wang, L. B., Hoyos, L. R., Wang, J., Voyiadjis, G., and Abadie, C., 2004, "Anisotropic Properties of Asphalt Concrete: Characterization and Implementation in Pavement Design and Analysis", **The 83rd Transportation Research Board Annual Meeting**.

Wood, D. M., 1990, **Soil behavior and critical state soil mechanic**, Cambridge University Press, New York.

Yildirim Y. (2007). "Polymer modified asphalt binders", **Construction and Building Materials**, Vol. 21, pp. 66–72.

ชยรัตน์ พรหมสร, 2541, "การศึกษาคุณสมบัติทางวิศวกรรมของยางแอสฟัลต์และวัสดุผสมแอสฟัลต์คอนกรีตที่ปรับปรุงคุณภาพด้วยสารโพลีเมอร์", รายงานฉบับที่ วพ. 166 ศูนย์วิจัยและพัฒนางานทางกรรมทางหลวง, กรกฎาคม 2541

วัชรินทร์ วิทยกุล และสุรชัย สุนันทพงษ์ศักดิ์, 2538, “การทดสอบคุณสมบัติของโพลีเมอร์โมดิไฟด์แอสฟัลต์คอนกรีตในงานสร้างทางหลวงของประเทศไทย”, การประชุมทางวิชาการของมหาวิทยาลัยเกษตรศาสตร์ ครั้งที่ 33, 30 มกราคม- 1 กุมภาพันธ์ 2538, กรุงเทพฯ, หน้า 310-320

วัชรินทร์ วิทยกุล, 2549, “เทคโนโลยียางมะตอย (Asphalt Road Technology)”, สำนักพิมพ์มหาวิทยาลัยเกษตรศาสตร์, กรุงเทพมหานคร.



APPENDIX A

Equivalent elastic modulus, E_{eq} (E_v and E_h) and

Equivalent Poisson's ratio, ν_{eq} (ν_{vh} and ν_{hv})

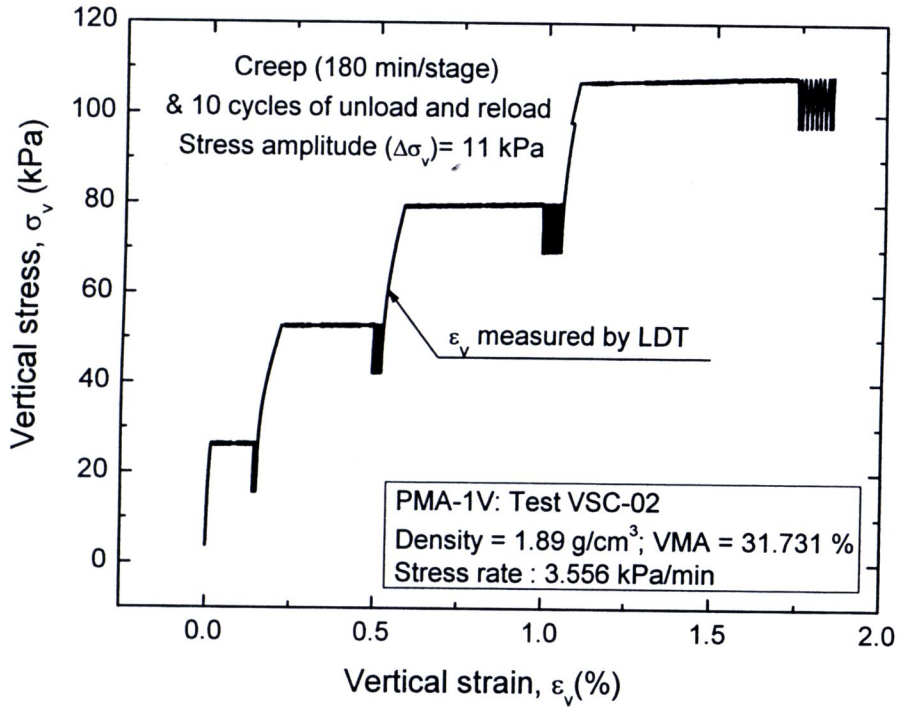


Figure A.1(a) Relationship between vertical stress and vertical strain obtained from minute cyclic loading test on PMA-1V from test VSC-02, density = 1.89 g/cm³ and VMA = 31.731 %

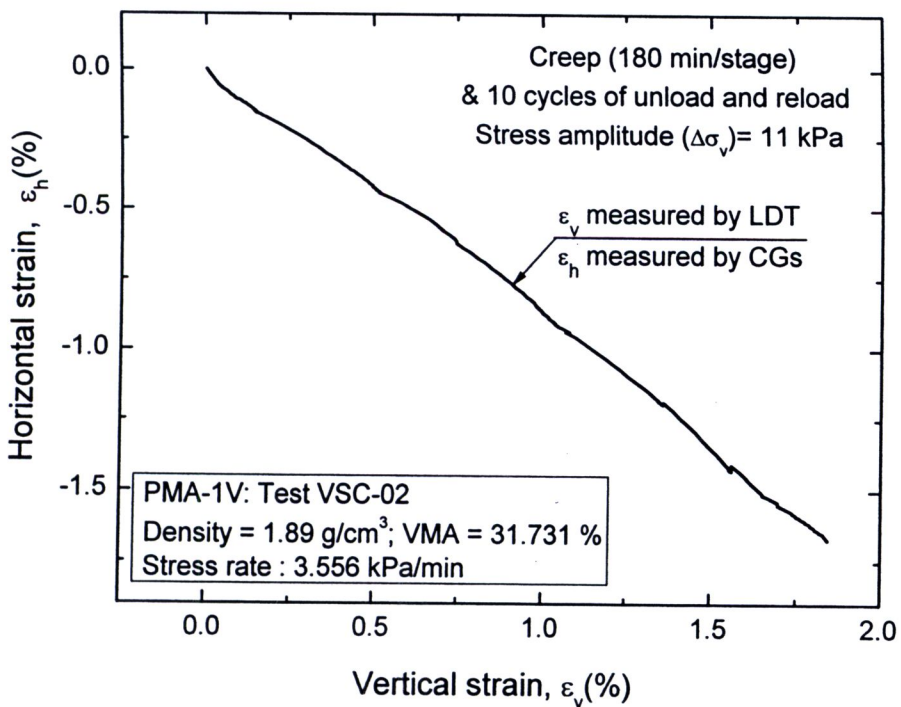


Figure A.1(b) Relationship between horizontal strain and vertical strain obtained from minute cyclic loading test on PMA-1V from test VSC-02, density = 1.89 g/cm³ and VMA = 31.731 %

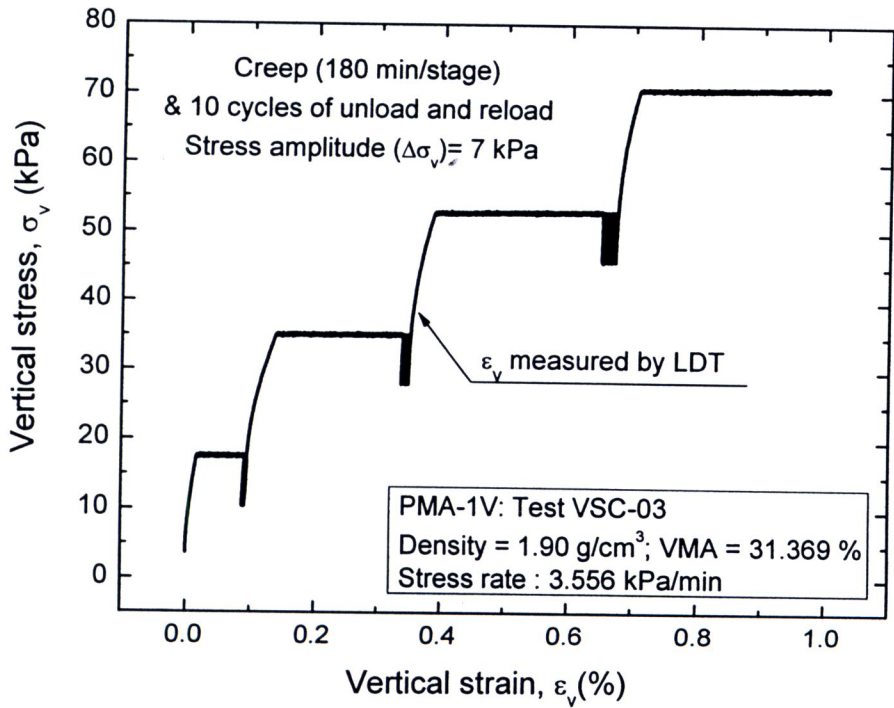


Figure A.2(a) Relationship between vertical stress and vertical strain obtained from minute cyclic loading test on PMA-1V from test VSC-03, density = 1.90 g/cm³ and VMA = 31.369 %

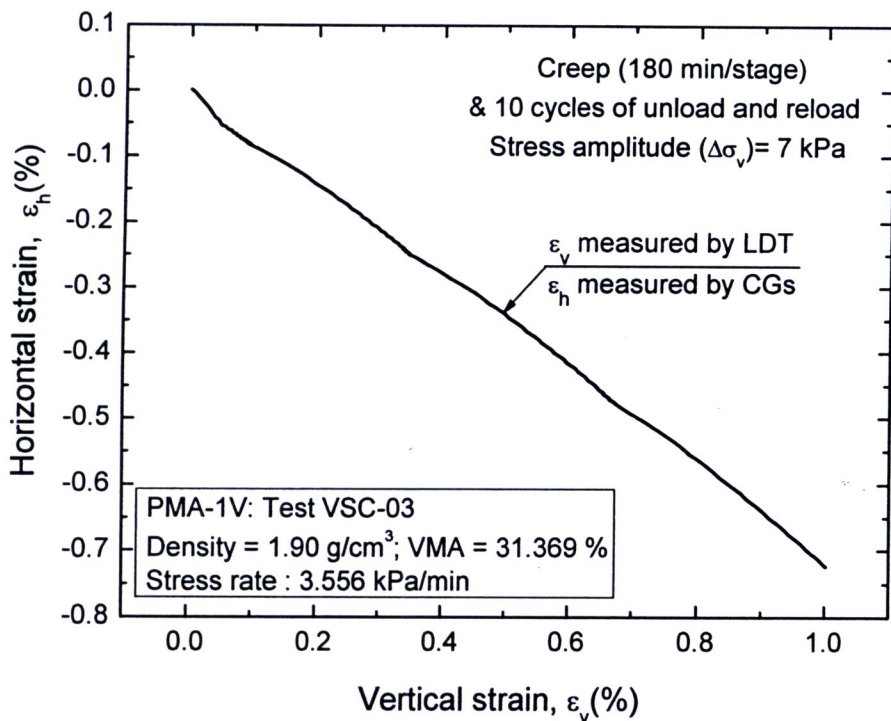


Figure A.2(b) Relationship between horizontal strain and vertical strain obtained from minute cyclic loading test on PMA-1V from test VSC-03, density = 1.90 g/cm³ and VMA = 31.369 %

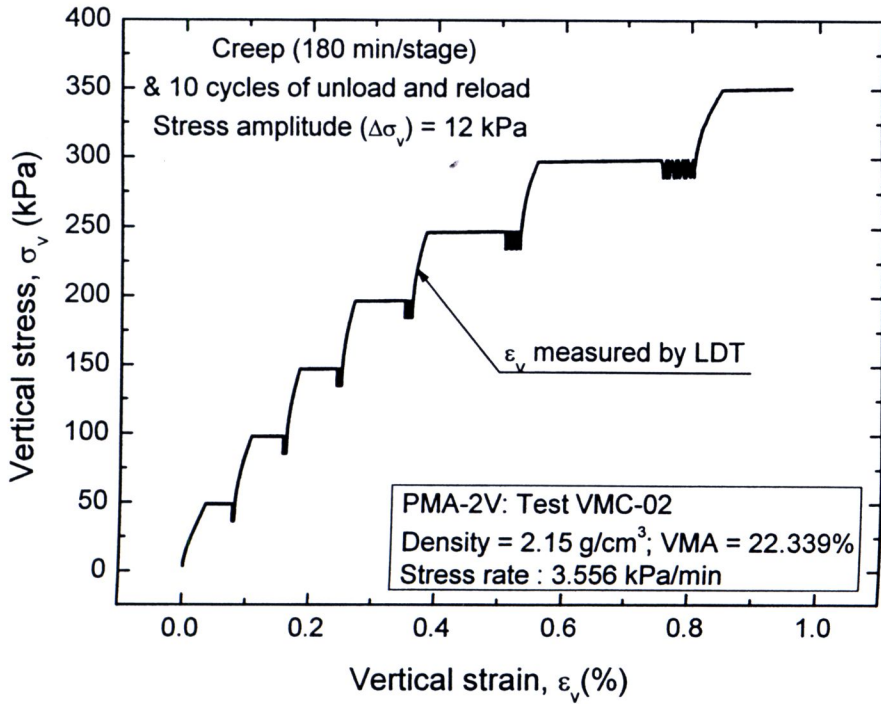


Figure A.3(a) Relationship between vertical stress and vertical strain obtained from minute cyclic loading test on PMA-2V from test VMC-02, density = 2.15 g/cm³ and VMA = 22.339 %

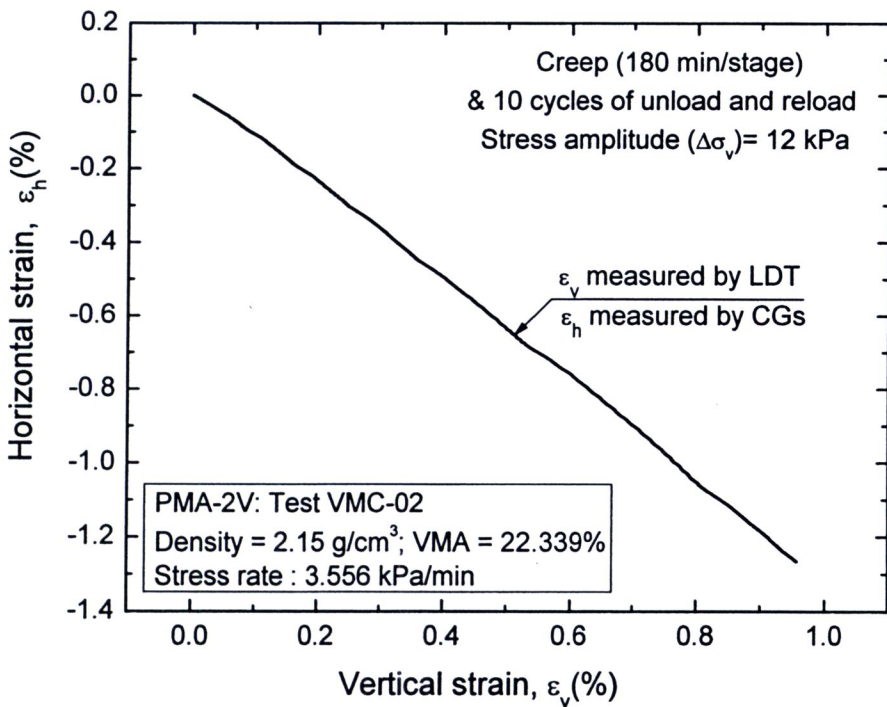


Figure A.3(b) Relationship between horizontal strain and vertical strain obtained from minute cyclic loading test on PMA-2V from test VMC-02, density = 2.15 g/cm³ and VMA = 22.339 %

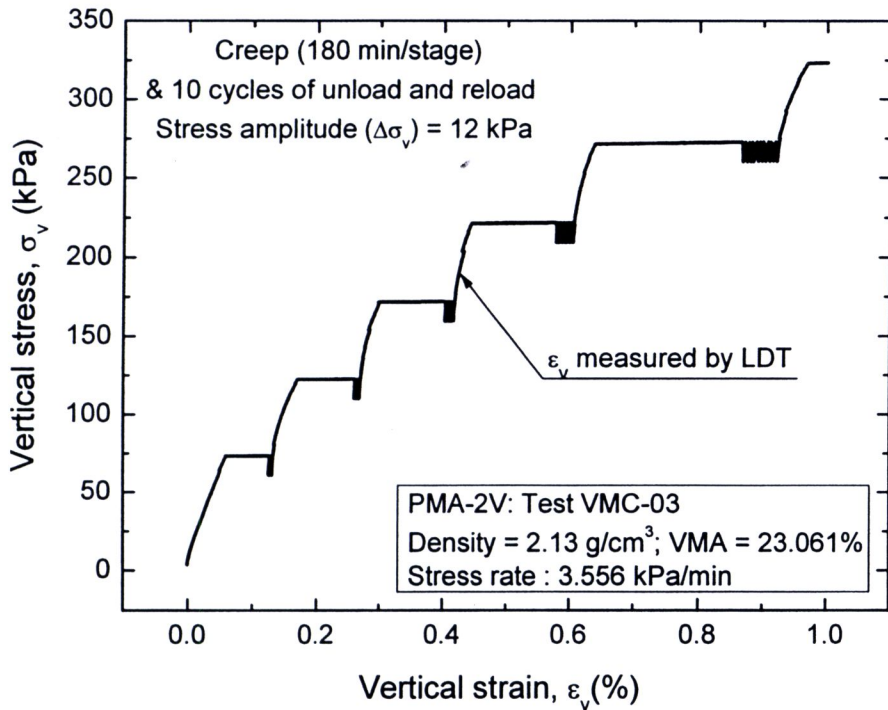


Figure A.4(a) Relationship between vertical stress and vertical strain obtained from minute cyclic loading test on PMA-2V from test VMC-03, density = 2.13 g/cm³ and VMA = 23.061 %

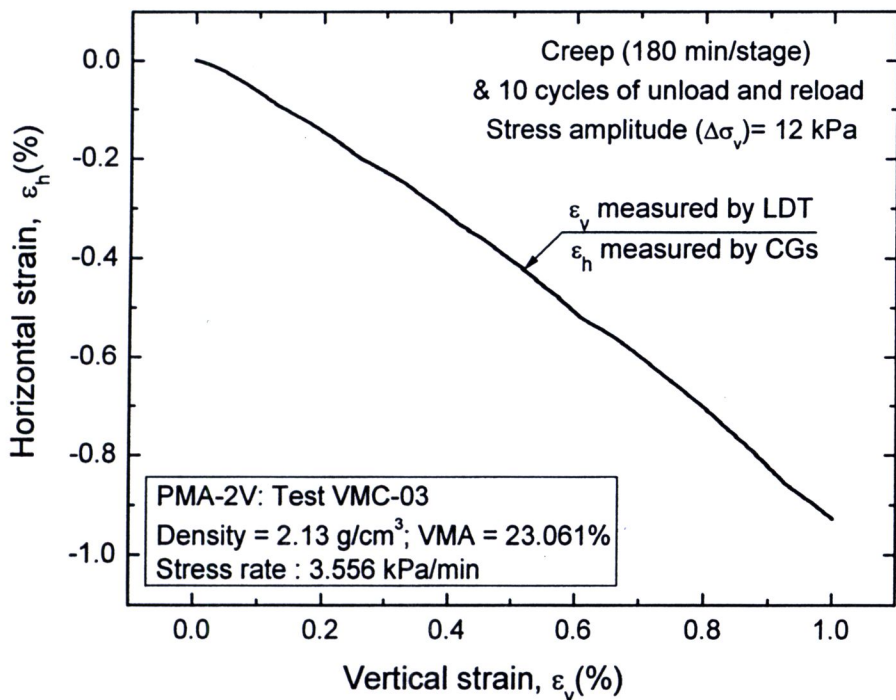


Figure A.4(b) Relationship between horizontal strain and vertical strain obtained from minute cyclic loading test on PMA-2V from test VMC-03, density = 2.13 g/cm³ and VMA = 23.061 %

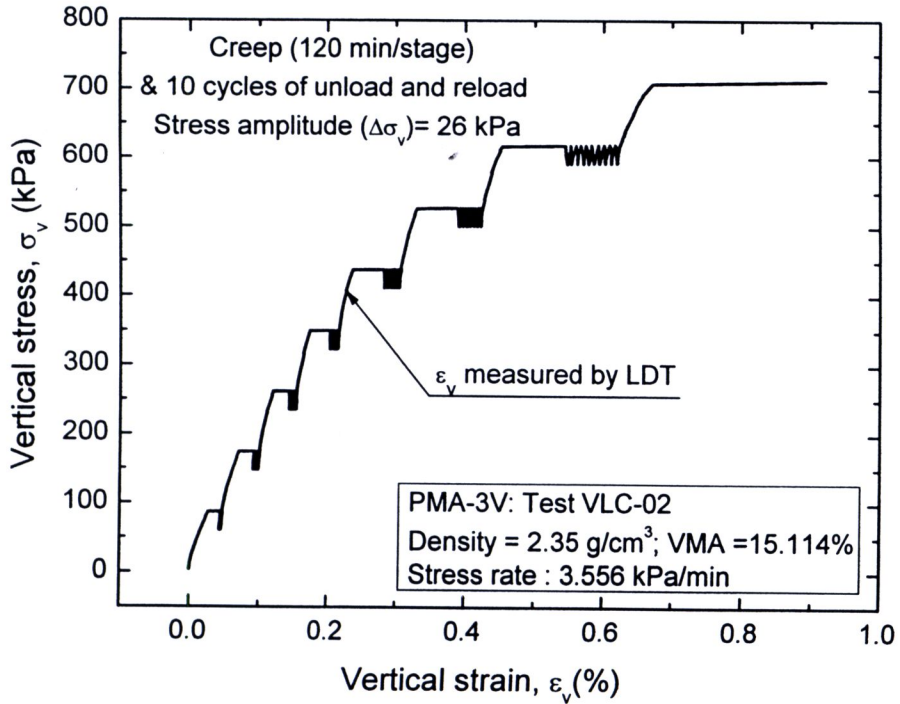


Figure A.5(a) Relationship between vertical stress and vertical strain obtained from minute cyclic loading test on PMA-3V from test VLC-02, density = 2.35 g/cm³ and VMA = 15.114 %

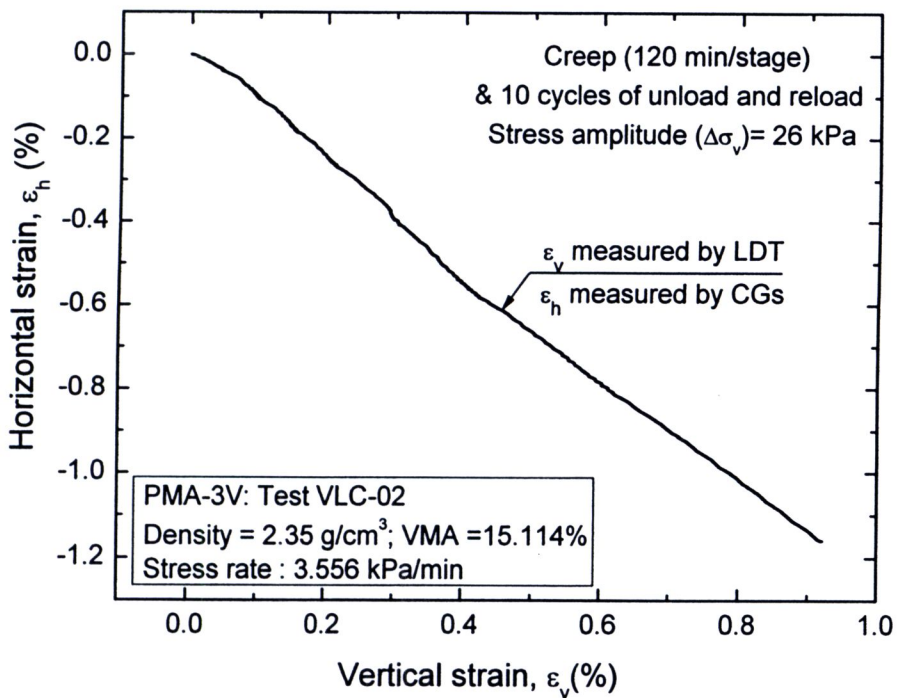


Figure A.5(b) Relationship between horizontal strain and vertical strain obtained from minute cyclic loading test on PMA-3V from test VLC-02, density = 2.35 g/cm³ and VMA = 15.114 %

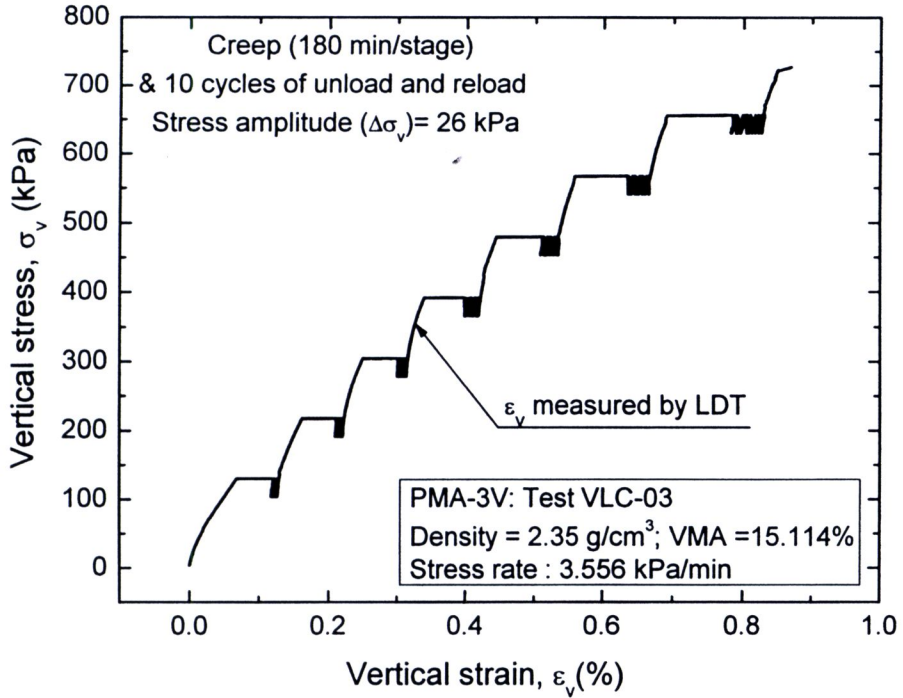


Figure A.6(a) Relationship between vertical stress and vertical strain obtained from minute cyclic loading test on PMA-3V from test VLC-03, density = 2.35 g/cm³ and VMA = 15.114 %

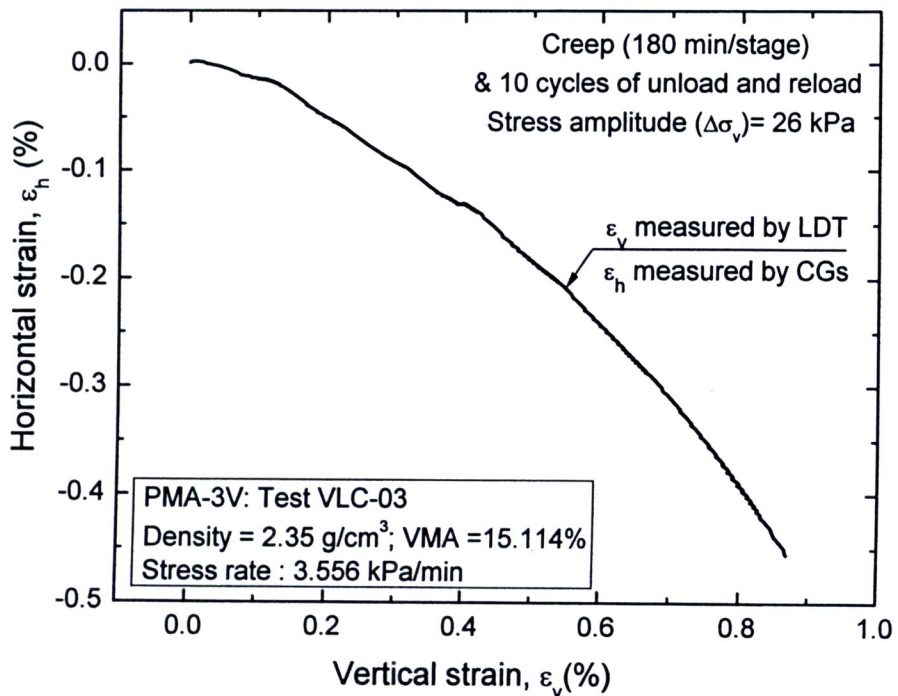


Figure A.6(b) Relationship between horizontal strain and vertical strain obtained from minute cyclic loading test on PMA-3V from test VLC-03, density = 2.35 g/cm³ and VMA = 15.114 %

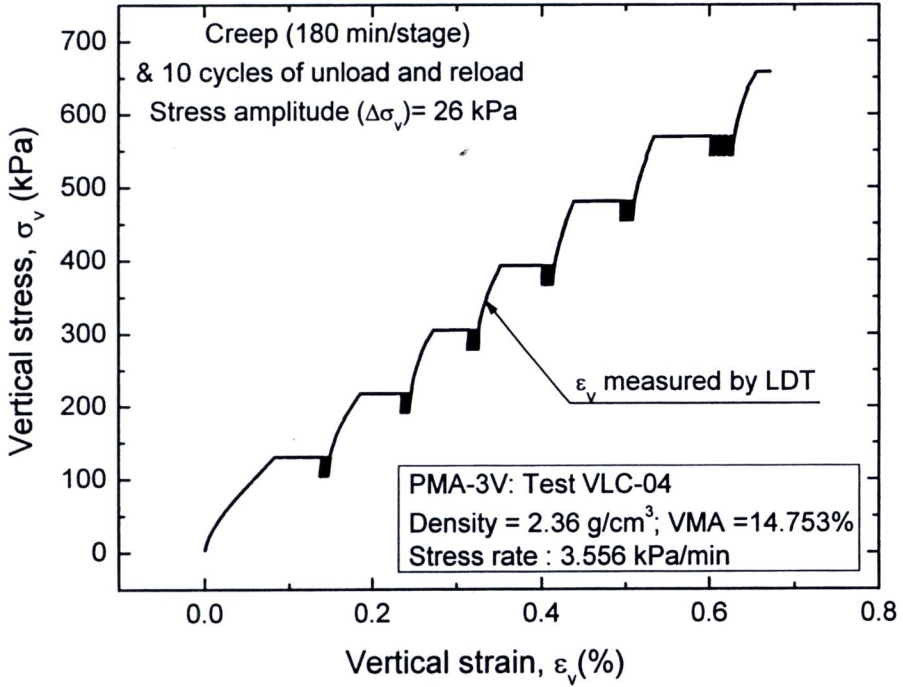


Figure A.7(a) Relationship between vertical stress and vertical strain obtained from minute cyclic loading test on PMA-3V from test VLC-04, density = 2.36 g/cm³ and VMA = 14.753 %

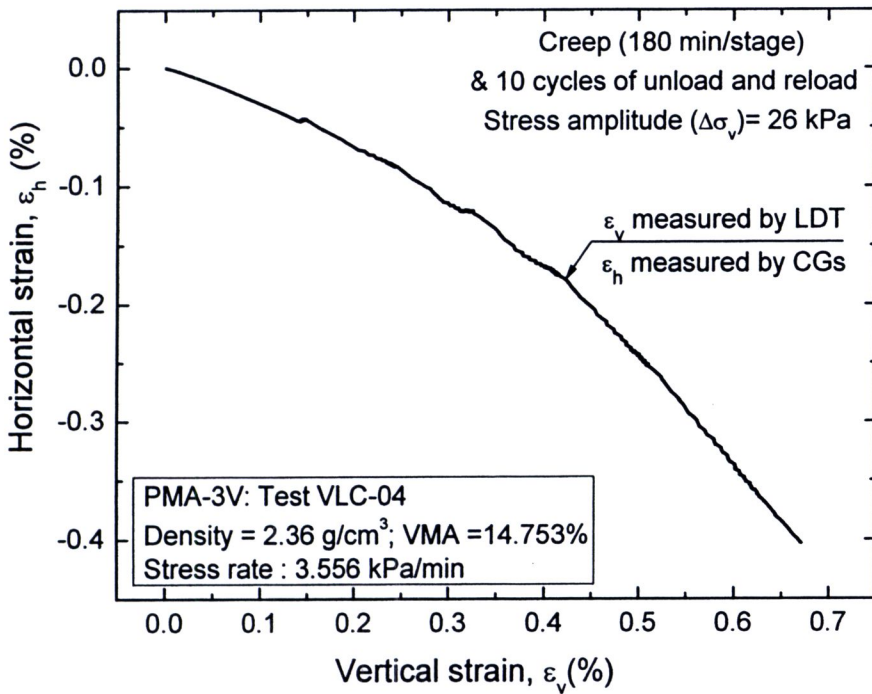


Figure A.7(b) Relationship between horizontal strain and vertical strain obtained from minute cyclic loading test on PMA-3V from test VLC-04, density = 2.36 g/cm³ and VMA = 14.753 %

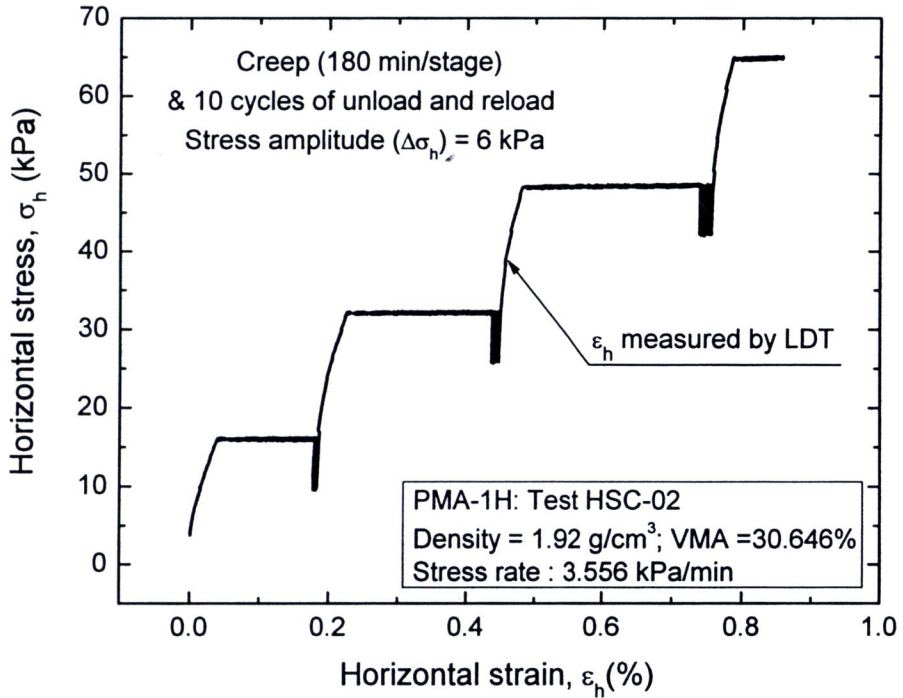


Figure A.8(a) Relationship between horizontal stress and horizontal strain obtained from minute cyclic loading test on PMA-1H from test HSC-02, density = 1.92 g/cm³ and VMA = 30.646 %

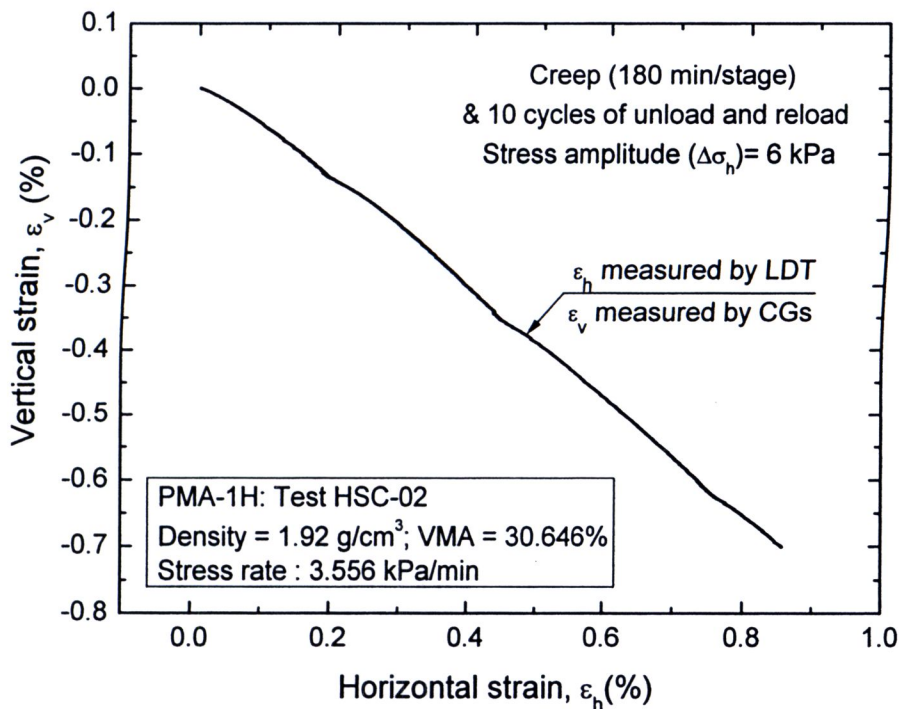


Figure A.8(b) Relationship between vertical strain and horizontal strain obtained from minute cyclic loading test on PMA-1H from test HSC-02, density = 1.92 g/cm³ and VMA = 30.646 %

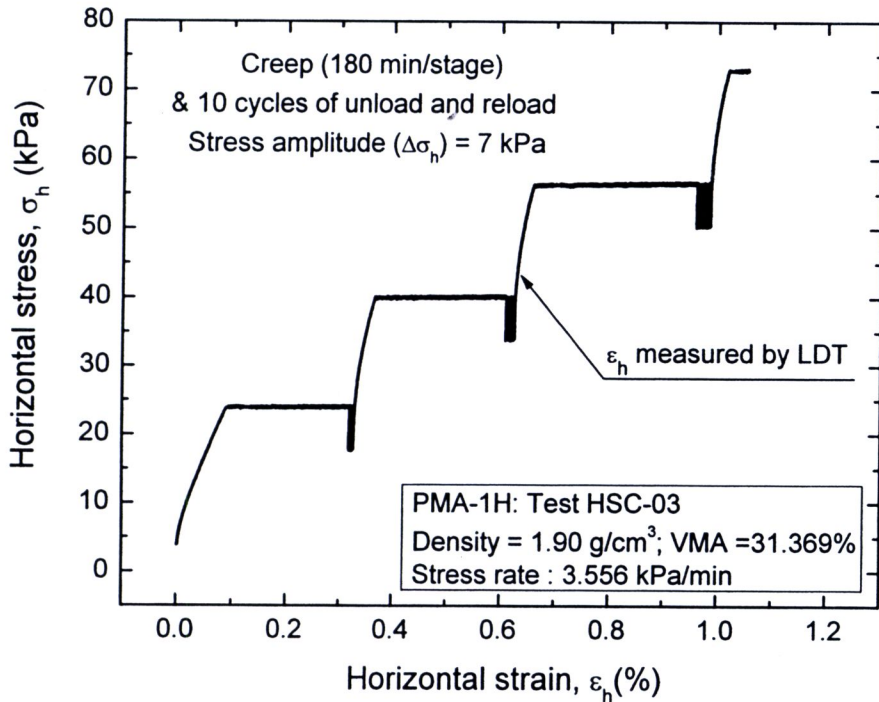


Figure A.9(a) Relationship between horizontal stress and horizontal strain obtained from minute cyclic loading test on PMA-1H from test HSC-03, density = 1.90 g/cm³ and VMA = 31.369 %

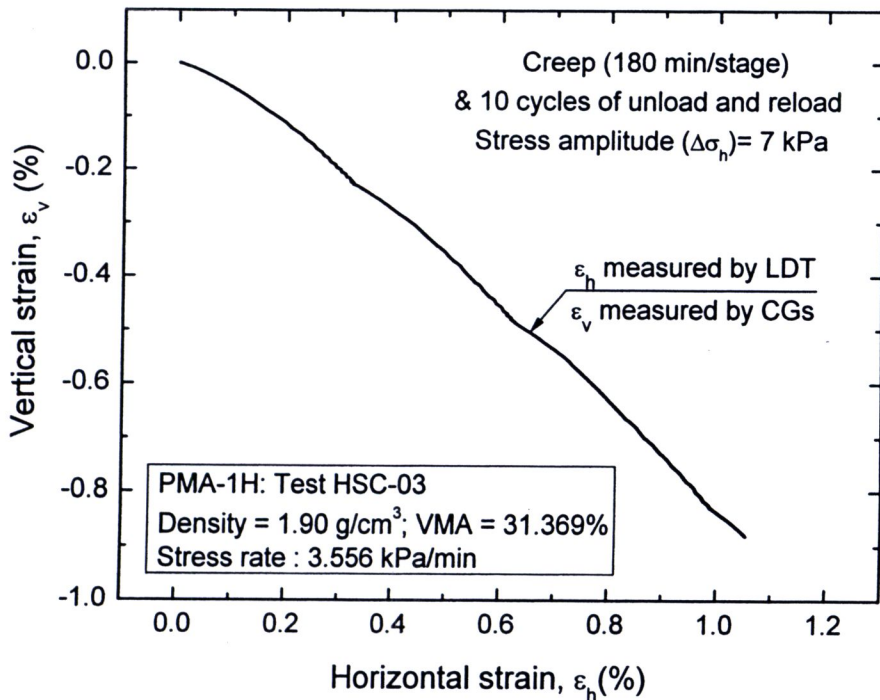


Figure A.9(b) Relationship between vertical strain and horizontal strain obtained from minute cyclic loading test on PMA-1H from test HSC-03, density = 1.90 g/cm³ and VMA = 31.369 %

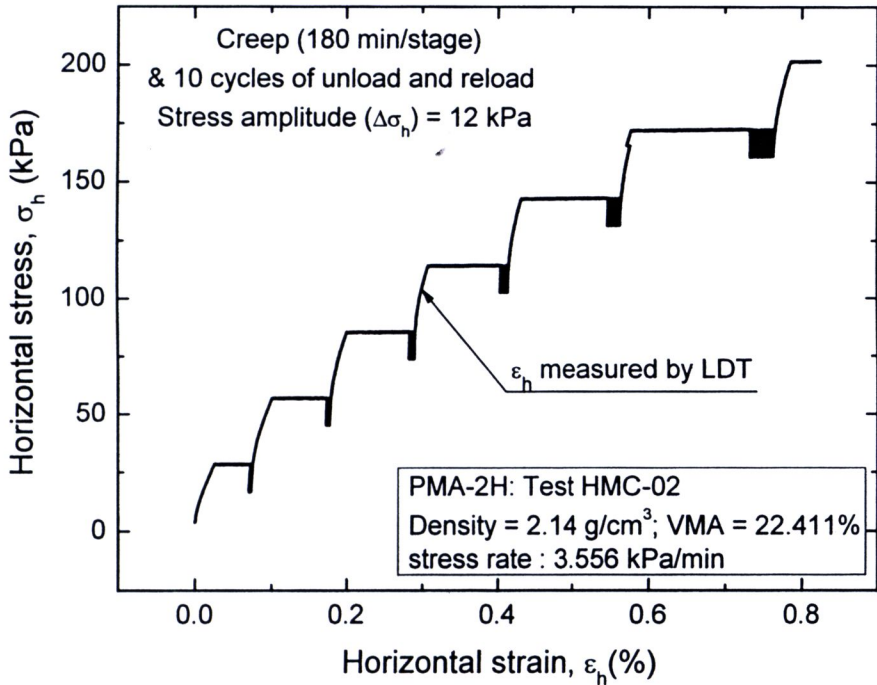


Figure A.10(a) Relationship between horizontal stress and horizontal strain obtained from minute cyclic loading test on PMA-2H from test HMC-02, density = 2.14 g/cm³ and VMA = 22.411 %

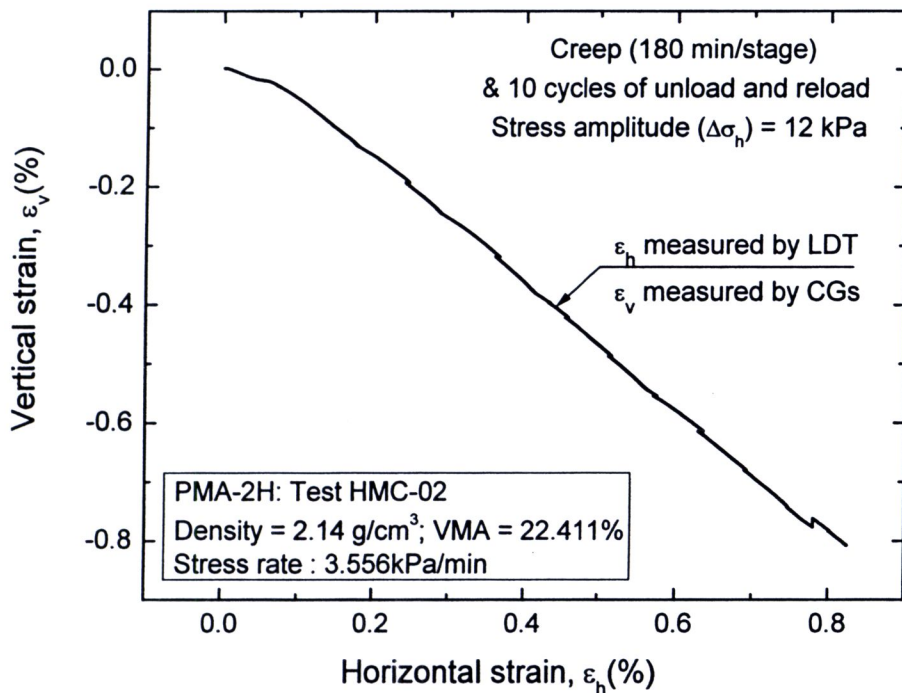


Figure A.10(b) Relationship between vertical strain and horizontal strain obtained from minute cyclic loading test on PMA-2H from test HMC-02, density = 2.14 g/cm³ and VMA = 22.411 %

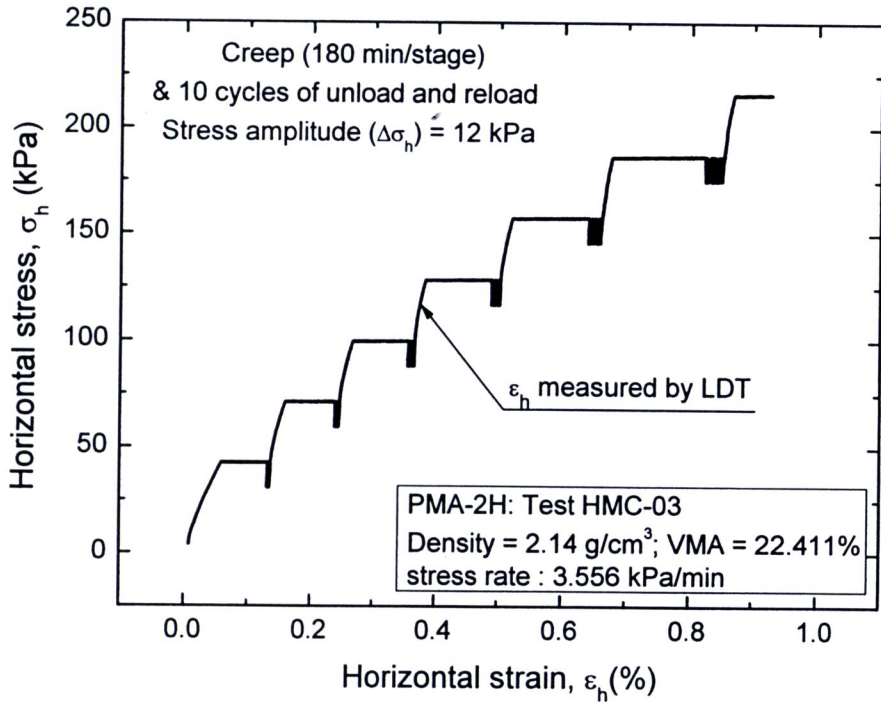


Figure A.11(a) Relationship between horizontal stress and horizontal strain obtained from minute cyclic loading test on PMA-2H from test HMC-03, density = 2.14 g/cm^3 and VMA = 22.411 %

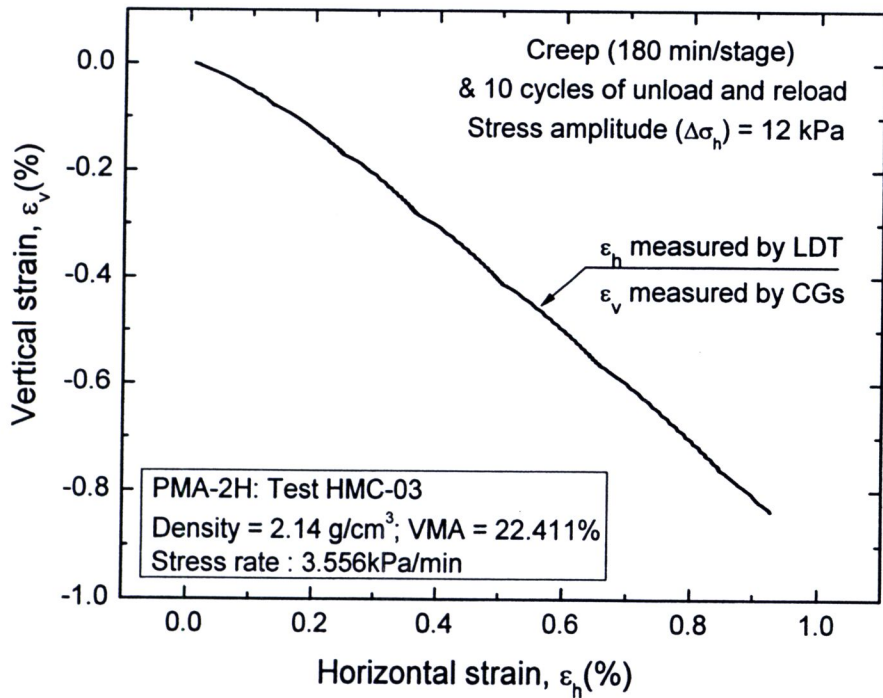


Figure A.11(b) Relationship between vertical strain and horizontal strain obtained from minute cyclic loading test on PMA-2H from test HMC-03, density = 2.14 g/cm^3 and VMA = 22.411 %

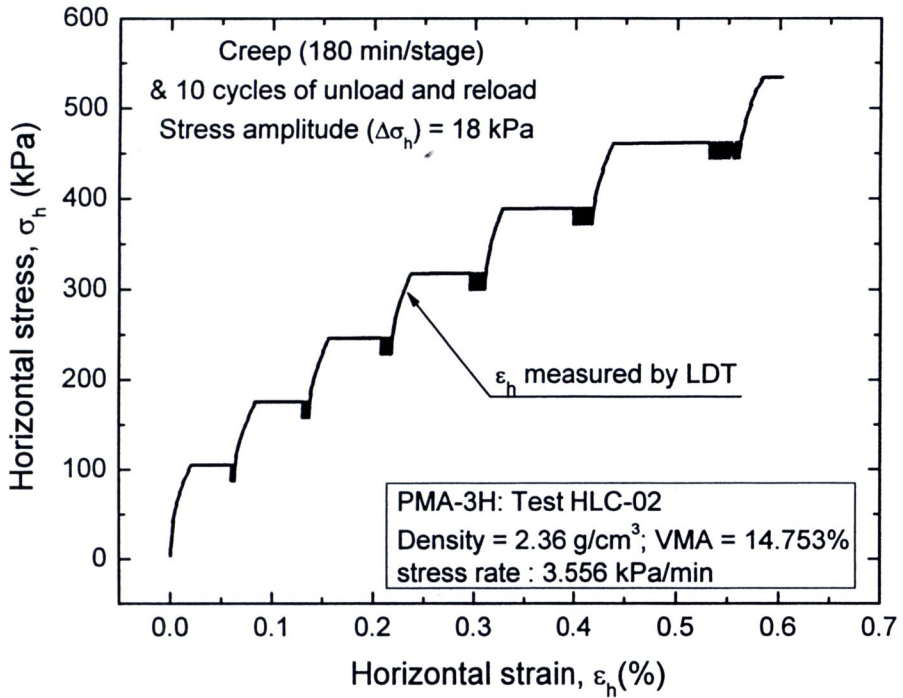


Figure A.12(a) Relationship between horizontal stress and horizontal strain obtained from minute cyclic loading test on PMA-3H from test HLC-02, density = 2.36 g/cm³ and VMA = 14.753 %

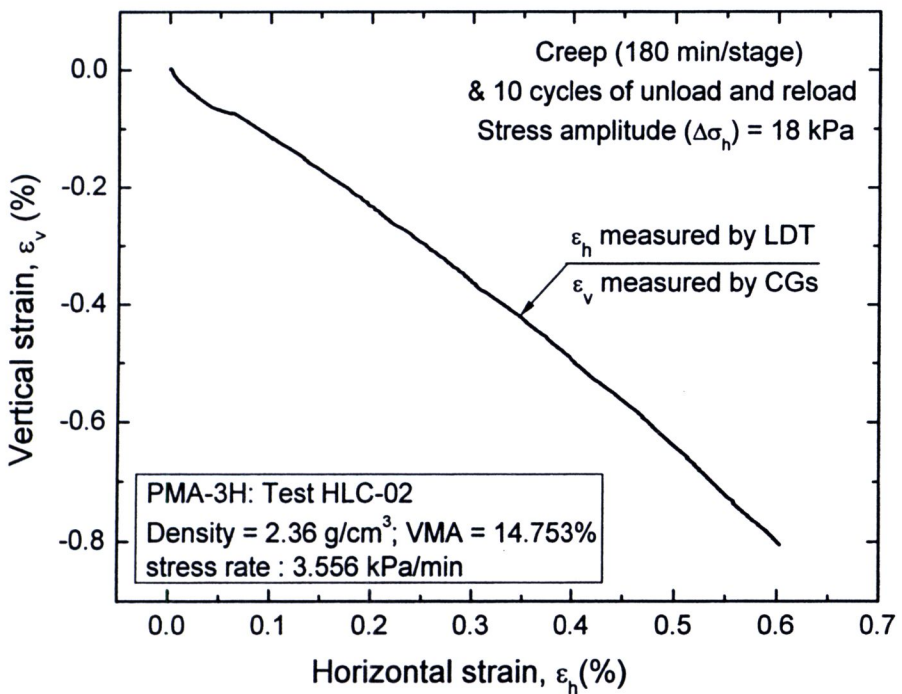


Figure A.12(b) Relationship between vertical strain and horizontal strain obtained from minute cyclic loading test on PMA-3H from test HLC-02, density = 2.36 g/cm³ and VMA = 14.753 %

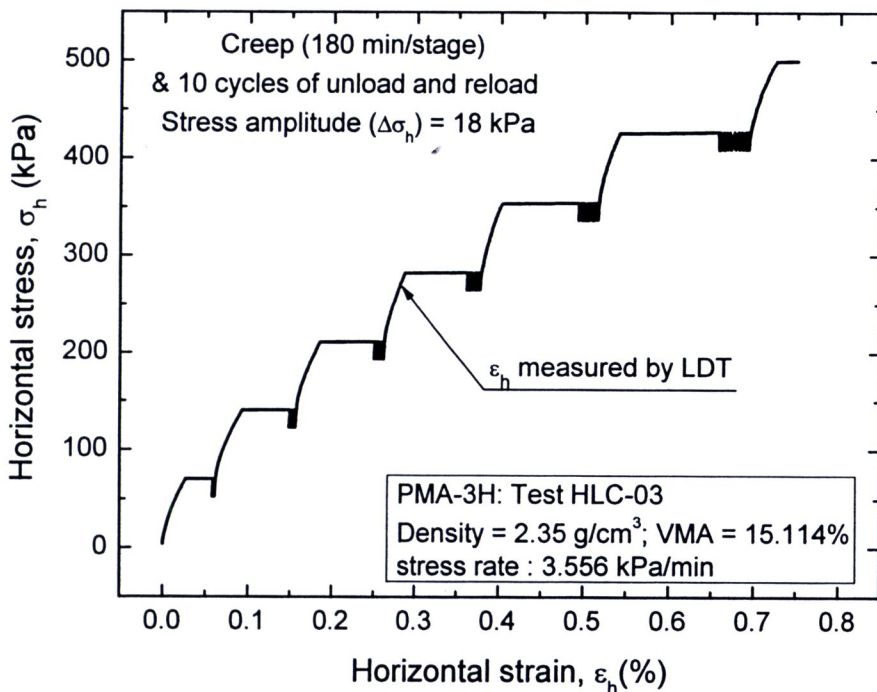


Figure A.13(a) Relationship between horizontal stress and horizontal strain obtained from minute cyclic loading test on PMA-3H from test HLC-03, density = 2.35 g/cm³ and VMA = 15.114 %

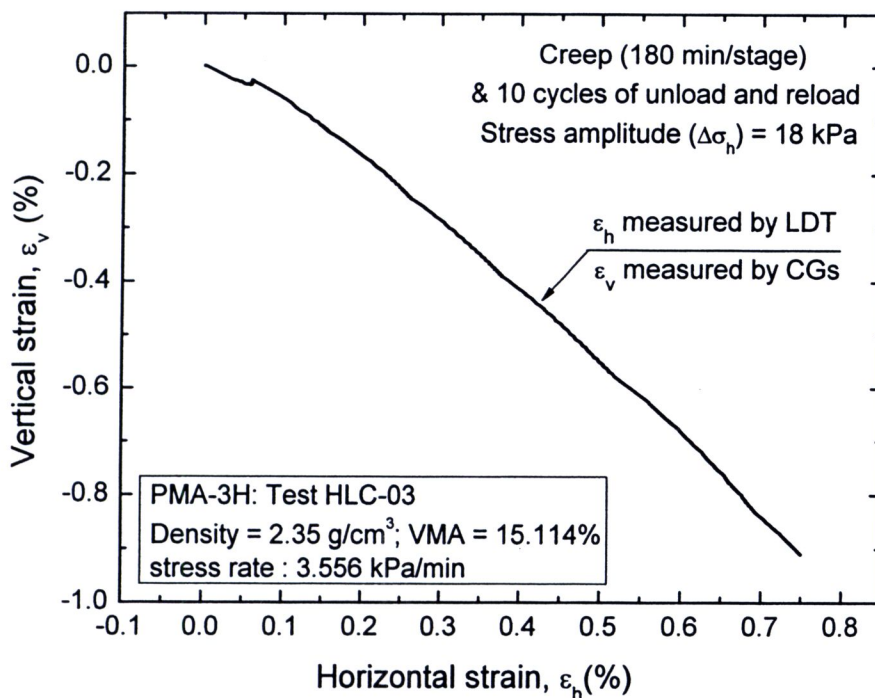


Figure A.13(b) Relationship between vertical strain and horizontal strain obtained from minute cyclic loading test on PMA-3H from test HLC-03, density = 2.35 g/cm³ and VMA = 15.114 %

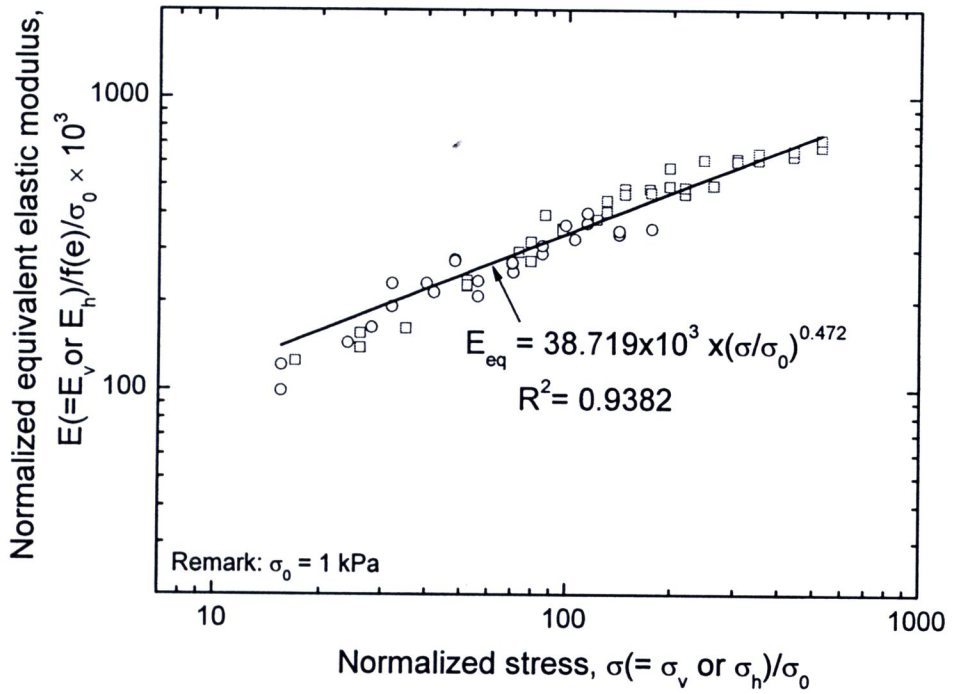


Figure A.14(a) Equivalent elastic modulus for all densities and direction as a function of normalized stress (Assumed isotropic behaviors)

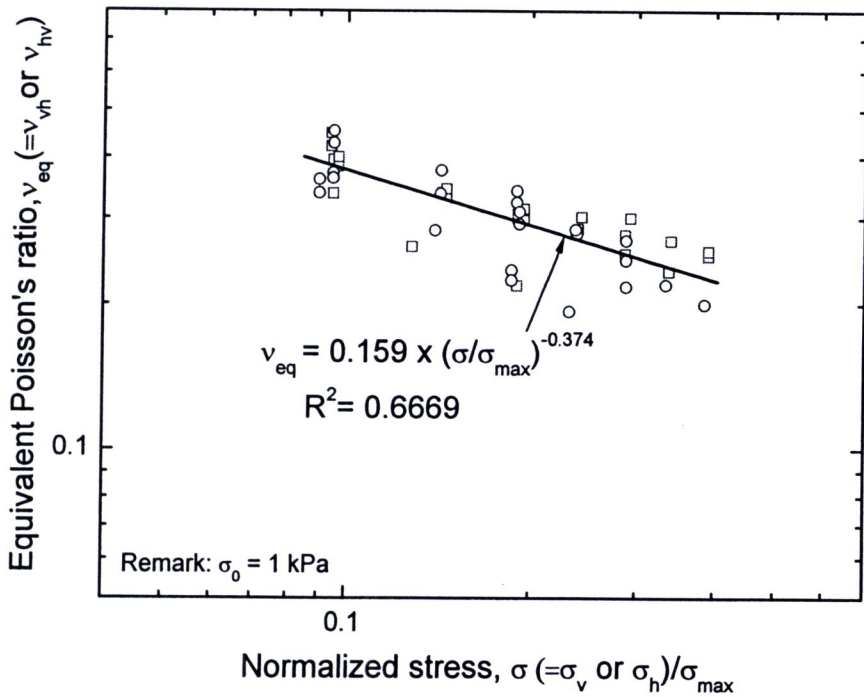


Figure A.14(b) Equivalent Poisson's ratio for all densities and direction as a function of normalized stress (Assumed isotropic behaviors)

APPENDIX B

Calculation of voids in mineral aggregate for PMA-1, PMA-2 and PMA-3

Calculation of voids in mineral aggregate for PMA-1V, PMA-1H, PMA-2V, PMA-2H, PMA-3V and PMA-3H

Asphaltic cement content (P_B) = 5 %

Asphaltic absorption (P_{BA}) = 0.38 %

Relative density of aggregate ($RD_{\text{aggregate}}$) = 2.63

Relative density of asphaltic ($RD_{\text{asphaltic}}$) = 1.037

PMA-1V and PMA-1H: Density = 1.90 g/cm³

Solⁿ	Assume: $V = 1 \text{ m}^3$				
	M	$=$	ρV	$=$	$1,900 \times 1 = 1,900 \text{ kg}$
	M_B	$=$	$(P_B / 100 \times M)$	$=$	$(5 / 100) \times 1,900 = 95 \text{ kg}$
	M_G	$=$	$M - M_B$	$=$	$1,900 - 95 = 1,805 \text{ kg}$
	M_{BA}	$=$	$(P_{BA}/100) \times M_G$	$=$	$(0.38 / 100) \times 1,805 = 6.859 \text{ kg}$
	M_{BE}	$=$	$M_B - M_{BA}$	$=$	$95 - 6.859 = 88.14 \text{ kg}$
	V_G	$=$	$M_G / (RD_{\text{aggregate}} \times \rho_w)$		
		$=$	$1,805 / (2.63 \times 1,000)$		
		$=$	0.686 m^3		
	V_{BE}	$=$	$M_{BE} / (RD_{\text{asphaltic}} \times \rho_w)$		
		$=$	$88.14 / (1.037 \times 1,000)$		
		$=$	0.085 m^3		
	V_A	$=$	$V - (V_G + V_{BE})$		
		$=$	$1 - (0.686 + 0.085)$		
		$=$	0.228 m^3		
	$\therefore \text{VMA}$	$=$	$[(V_{BE} + V_A) / V] \times 100$		
		$=$	$[(0.085 + 0.228) / 1] \times 100$		
		$=$	31.369%		

PMA-2V and PMA-2H: Density = 2.15 g/cm³

Solⁿ	Assume: $V = 1 \text{ m}^3$				
	M	$=$	ρV	$=$	$2,150 \times 1 = 2,150 \text{ kg}$
	M_B	$=$	$(P_B / 100 \times M)$	$=$	$(5 / 100) \times 2,150 = 107.5 \text{ kg}$
	M_G	$=$	$M - M_B$	$=$	$2,150 - 107.5 = 2,042.5 \text{ kg}$
	M_{BA}	$=$	$(P_{BA}/100) \times M_G$	$=$	$(0.38 / 100) \times 2,042.5 = 7.762 \text{ kg}$
	M_{BE}	$=$	$M_B - M_{BA}$	$=$	$107.5 - 7.762 = 99.739 \text{ kg}$
	V_G	$=$	$M_G / (RD_{\text{aggregate}} \times \rho_w)$		
		$=$	$2,042.5 / (2.63 \times 1,000)$		
		$=$	0.777 m^3		
	V_{BE}	$=$	$M_{BE} / (RD_{\text{asphaltic}} \times \rho_w)$		
		$=$	$99.739 / (1.037 \times 1,000)$		
		$=$	0.096 m^3		
	V_A	$=$	$V - (V_G + V_{BE})$		
		$=$	$1 - (0.777 + 0.096)$		
		$=$	0.127 m^3		
	$\therefore \text{VMA}$	$=$	$[(V_{BE} + V_A) / V] \times 100$		
		$=$	$[(0.096 + 0.127) / 1] \times 100$		
		$=$	22.339%		

PMA-3V and PMA-3H: Density = 2.37 g/cm³

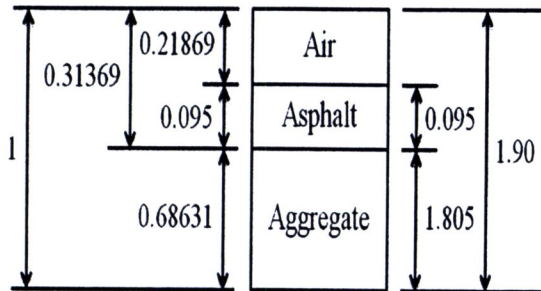
$$\begin{aligned}
 \text{Sol}^n \quad & \text{Assume: } V = 1 \text{ m}^3 \\
 M &= \rho V = 2,370 \times 1 = 2,370 \text{ kg} \\
 M_B &= (P_B / 100 \times M) = (5 / 100) \times 2,370 = 118.5 \text{ kg} \\
 M_G &= M - M_B = 2,370 - 118.5 = 2,251.5 \text{ kg} \\
 M_{BA} &= (P_{BA} / 100) \times M_G = (0.38 / 100) \times 2,251.5 = 8.556 \text{ kg} \\
 M_{BE} &= M_B - M_{BA} = 118.5 - 8.556 = 109.94 \text{ kg} \\
 V_G &= M_G / (RD_{\text{aggregate}} \times \rho_w) \\
 &= 2,251.5 / (2.63 \times 1,000) \\
 &= 0.856 \text{ m}^3 \\
 V_{BE} &= M_{BE} / (RD_{\text{asphaltic}} \times \rho_w) \\
 &= 109.944 / (1.037 \times 1,000) \\
 &= 0.106 \text{ m}^3 \\
 V_A &= V - (V_G + V_{BE}) \\
 &= 1 - (0.856 + 0.106) \\
 &= 0.038 \text{ m}^3 \\
 \therefore \text{VMA} &= [(V_{BE} + V_A) / V] \times 100 \\
 &= [(0.106 + 0.038) / 1] \times 100 \\
 &= 14.392 \%
 \end{aligned}$$

Calculation of voids ratio (e_0) for PMA

Asphaltic cement content = 5 %

PMA-1V and PMA-1H: Density = 1.90 g/cm³

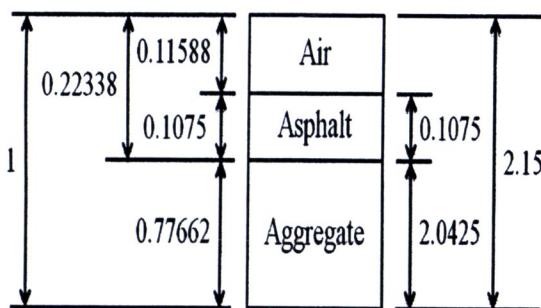
Voids in mineral aggregate (VMA) = 31.369 %



$$\begin{aligned}
 e_0 &= (V_{\text{air}} + V_{\text{asphalt}}) / V_{\text{aggregate}} \\
 &= (V_A + V_{BE}) / V_G \\
 &= 0.31369 / 0.68631 = 0.4571
 \end{aligned}$$

PMA-2V and PMA-2H: Density = 2.15 g/cm³

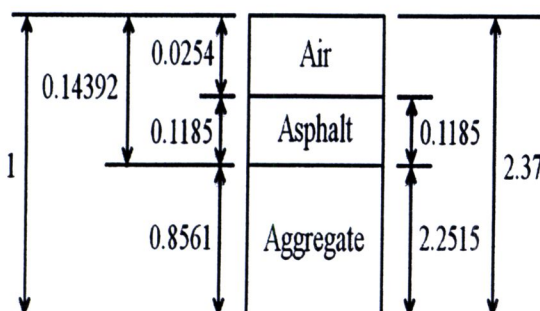
Voids in mineral aggregate (VMA) = 22.338 %



$$\begin{aligned}
 e_1 &= (V_{\text{air}} + V_{\text{asphalt}}) / V_{\text{aggregate}} \\
 &= (V_A + V_{BE}) / V_G \\
 &= 0.22338 / 0.77662 = 0.2876
 \end{aligned}$$

PMA-3V and PMA-3H: Density = 2.37 g/cm³

Voids in mineral aggregate (VMA) = 14.392 %



$$\begin{aligned}
 e_1 &= (V_{\text{air}} + V_{\text{asphalt}}) / V_{\text{aggregate}} \\
 &= (V_A + V_{BE}) / V_G \\
 &= 0.14392 / 0.8561 = 0.1681
 \end{aligned}$$

APPENDIX C

The coefficient of determination (R^2) of equivalent stiffness

Table C.1 Summary of determination (R^2) of equivalent stiffness for the vertical and horizontal of PMA at different densities

Stiffness type	Series name	Density (g/cm ³)	VMA (%)	R ²
Vertical equivalent elastic modulus, $E_{v,eq}$	PMA-1V	1.90	31.369	0.9532
	PMA-2V	2.15	22.339	0.9445
	PMA-3V	2.37	14.392	0.9389
Horizontal equivalent elastic modulus, $E_{h,eq}$	PMA-1H	1.90	31.369	0.9546
	PMA-2H	2.15	22.339	0.9424
	PMA-3H	2.37	14.392	0.9653
Vertical-horizontal Poisson's ratio, $\nu_{vh,eq}$	PMA-1V	1.90	31.369	0.8720
	PMA-2V	2.15	22.339	0.9701
	PMA-3V	2.37	14.392	0.9526
Horizontal-vertical Poisson's ratio, $\nu_{hv,eq}$	PMA-1H	1.90	31.369	0.9769
	PMA-2H	2.15	22.339	0.8374
	PMA-3H	2.37	14.392	0.9744

APPENDIX D

The density of PMA specimen (ρ)

Table D.1 Summary of density (ρ) of the vertical and horizontal of PMA at different densities for monotonic loading test

Series name	Test name	Density (g/cm ³)	VMA (%)	e
PMA-1V	VSM-01	1.91	31.007	0.449
	VSM-02	1.91	31.007	0.449
	VSM-03	1.91	31.007	0.449
PMA-2V	VMM-01	2.15	22.339	0.288
	VMM-02	2.15	22.339	0.288
	VMM-03	2.14	22.699	0.294
PMA-3V	VLM-01	2.36	14.753	0.173
	VLM-02	2.36	14.753	0.173
	VLM-03	2.35	15.114	0.178
PMA-1H	HSM-01	1.90	31.369	0.457
	HSM-02	1.90	31.369	0.457
	HSM-03	1.89	31.731	0.465
PMA-2H	HMM-01	2.14	22.699	0.294
	HMM-02	2.15	22.339	0.288
	HMM-03	2.15	22.339	0.288
PMA-3H	HLM-01	2.35	15.114	0.178
	HLM-02	2.36	14.753	0.173
	HLM-03	2.36	14.753	0.173

Table D.2 Summary of density (ρ) of the vertical and horizontal of PMA at different densities for cyclic loading test

Series name	Test name	Density (g/cm ³)	VMA (%)	e
PMA-1V	VSC-01	1.90	31.369	0.457
	VSC-02	1.89	31.731	0.465
	VSC-03	1.90	31.369	0.457
PMA-2V	VMC-01	2.15	22.339	0.288
	VMC-02	2.15	22.339	0.288
	VMC-03	2.13	23.061	0.300
PMA-3V	VLC-01	2.37	14.392	0.168
	VLC-02	2.35	15.114	0.178
	VLC-03	2.35	15.114	0.178
	VLC-04	2.36	14.753	0.173
PMA-1H	HSC-01	1.90	31.369	0.457
	HSC-02	1.92	30.646	0.442
	HSC-03	1.90	31.369	0.457
PMA-2H	HMC-01	2.15	22.339	0.288
	HMC-02	2.14	22.699	0.294
	HMC-03	2.14	22.699	0.294
PMA-3H	HLC-01	2.37	14.392	0.168
	HLC-02	2.36	14.753	0.173
	HLC-03	2.35	15.114	0.178

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
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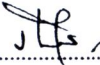
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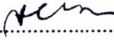
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