Indirect Tensile Fatigue Test Analysis of VG - 40 Binder by Varying Temperature

Shreyas. K[1], Dr. l. Manjesh[2], Sumanth. S[3]

[1]Research Scholar, Dept. of Civil Engineering, UVCE, Bangalore
[2]Professor & Chairman, Dept. of Civil Engineering. UVCE, Bangalore
[3]Research Scholar, Dept. of Civil Engineering, UVCE, Bangalore

Abstract
This paper conducted an assessment of the physical and engineering characteristics of binders with 2% cement as mineral filler. The study aimed to determine the repetition of wheel loads for both Grade - I & Grade - II aggregates. The specimens have been cast to measure the fatigue cycles with stress levels ranging from 10% to 40%.

Keywords: Stability, VG – 40 grade binder, fatigue cycle of modified binders.

1. INTRODUCTION

Fatigue Test

Fatigue cracking is a significant form of damage that occurs in asphalt concrete pavements. This type of discomfort occurs due to the frequent application of traffic loading, leading to failure in flexible pavements. Fatigue cracking can be classified as either bottom-up fatigue cracking or top-down fatigue cracking, depending on the dominating mechanisms and the location of the crack start.

These fissures not only reduce the load distribution capacity of bituminous layers, but also enable water to infiltrate into the base and subgrade, so hastening the total deterioration of the pavement. Repeated loading on bituminous pavement over extremely resilient soils leads to fatigue failure.

The fatigue life of bituminous concrete pavements is influenced by various factors, including the stiffness of the mix, bitumen content, softening point of bitumen, viscosity of bitumen, grading of aggregate, building technique, traffic, and climate. The overall shape of an aggregate also has an indirect impact on fatigue performance through its influence on the applied strain.

The fatigue life of bituminous concrete mixtures was assessed by the indirect tensile fatigue test. The measurement of horizontal deformation during the indirect tension fatigue test is recorded as a function of the load cycle. The test specimen is exposed to varying levels of stress in order to conduct a regression analysis on a range of values. This analysis helps establish the relationship between the number of cycles at failure (NF) and the initial tensile strain (εt) on a logarithmic scale. The fatigue life (Nf) of a specimen refers to the number of cycles required for failure of a bituminous concrete mix.

Aggregates:

The shape and surface characteristics of the coarse aggregate have a direct impact on the elastic modulus of asphalt mixes. While the changes in overall size did not have a significant impact on the connection between the shape of the coarse aggregate and the elastic modulus, decreasing the maximum nominal aggregate size from 19 mm (with a layer thickness of 50 mm) to 9.5 mm showed a growing positive effect of aggregate shape on the elastic modulus of asphalt mixtures. Aggregates that exceed a specific size exhibit linear elastic behaviour, leading to effective elastic characteristics.

Analysis of elastic modulus characteristics:

The modulus of elasticity is utilised to define the behaviour of pavement materials when subjected to different loading situations that do not lead to the failure of the pavement system. Granular material is a type of material that becomes harder and less deformed as stress increases, resulting in a higher stiffness or modulus of elasticity. On the other hand, fine-grained or subgrade soils are known as stress-softening materials, meaning that as stress increases, their stiffness or modulus of elasticity decreases. As the amount of asphalt grows, the proportion of empty spaces in the material decreases. During the process of mixing and compaction, a portion of the asphalt gets assimilated by the mineral aggregates. The impact of this absorption on the physical characteristics of the mixture is minimal compared to the qualities at the interface between asphalt and aggregate, as well as the asphalt film. If the modulus exceeds the upper limit of this range, the mixture will be excessively rigid, potentially leading to fatigue and/or thermal cracking issues. If the consistency of the mixture is excessively pliable and the correlation between the modulus of elasticity and temperature falls below the lower threshold, the mixture is deemed excessively pliable and consequently fails to sufficiently safeguard the underlying layers or may be prone to deformation. Furthermore, it has been observed that the modulus of elasticity at low temperatures is partly correlated with cracking. Mixtures with higher modulus of elasticity (higher MR) are more susceptible to breaking at low temperatures compared to mixtures with lower modulus of elasticity (lower MR). Furthermore, the modulus of elasticity experiences a significant fall as the temperature rises, primarily because the asphalt binder becomes softer at higher temperatures.

Test procedure for conducting Fatigue test

1. The prepared Marshall specimens were kept in water bath maintained at the desired temperature 25°C & 35°C for about 2 hours before testing.
2. The specimen was placed in the testing mould on the bottom-loading strip. The holding bolts were tightened so that the specimen was held properly. The linear bearing was placed over the specimen.
3. LVDT's were fixed to measure horizontal and vertical deformation of the specimen under loading.
4. The load cell of the repeated loading machine was brought in contact with the linear bearing by operating the offset knob.
5. The visual basic program was opened and details of the test and specimen dimensions were entered and it was run.
6. The fatigue tests were carried out on VG- 40 grade mixes at 10%, 20%, 30% and 40% stress level at test temperature of 25°C & 35°C for a frequency of 4.0 Hz, 3.0 Hz, 2.0 Hz & 1.0 Hz by using half sine waveform to evaluate the fatigue characteristics of CRMB mixes.

The data provided by the software in an excel format was analysed to determine Resilient Modulus, Tensile stress, and Initial Tensile Strain for all the specimens tested using the following equations.

2. LITERATURE REVIEW

D.N. Little, E.tal This project aimed to create many methods for evaluating the modulus of asphalt concrete. These methods will allow the Department to conduct testing that supports design processes and verifies non-destructive field testing. Efforts were undertaken to create an efficient testing methodology, as well as adaptable methodologies that can easily integrate new research and procedures centred around mechanistic design methods. Two test configurations were chosen for development, and the uniaxial compression test with sinusoidal loading is applicable to various materials and stress situations. A technique was devised for the analysis of field cores of very limited length. The diametrical indirect tensile test can be efficiently conducted on compact, graded asphalt concrete sample measuring two inches in length. The capacity to measure both Poisson's ratio and modulus of elasticity was established for both test configurations (1).

Amir Modarres, E.tal The modulus of elasticity of bituminous mix, ascertained by the ASTM D4123-04 method, is a stress-strain measurement employed to assess the elastic characteristics of this mixture. It is widely recognised that the majority of road building materials are not elastic, but instead experience persistent deformation with each load. Nevertheless, if the load is significantly smaller than the material's strength and occurs repeatedly, the deformation experienced during each load repetition is nearly fully reversible and directly proportional to the load. This deformation can be regarded as elastic.

The formula for MR is given by $MR = [\{P*(\mu + 0.27)\} / \{(t * \delta h)\}]$.

The variables in the equation are defined as follows: P represents the maximum dynamic load in Newtons (N), μ represents the Poisson's ratio assumed to be 0.35, t represents the length of the specimen in millimetres (mm), and δh represents the total horizontal recoverable deformation in millimetres (mm). The loading frequency in the MR test was set to 1 Hz, with 0.1 s allocated for loading and 0.9 s for recovery. Both the Infrared Thermal Sensing (ITS) and Magnetic Resonance (MR) tests were conducted at a temperature of 20 degrees Celsius. Moreover, the stress level in the Mr test was chosen to be 20% of ITS. (2).

A. Patel, E.tal The elastic properties of dense asphalt concrete and semi-dense asphalt concrete were investigated by experimental research, which involved extracting core samples from the pavements. The cores were fully characterised as part of the proposed method for determining MR. Samples were extracted from the top layers and binding layers of the runways' pavements. The cores were subjected to density-space analysis, Marshall stability, and yield value testing, following the guidelines established in ASTM D6927 [14]. The obtained results are now presented. The Marshall stability values for the DAC and SDAC samples were measured as 765 kg and 725 kg, respectively, at a temperature of 60°C. The yield value of the SDAC samples exhibited a greater magnitude in comparison to that of the DAC samples. The mean bulk densities of the DAC and SDAC samples were 2.36 and 2.33 g/cm3, respectively. The stiffness modulus of the mix was calculated using the shell nomograms, taking into account the mix parameters (density, air voids, aggregate voids filled with bitumen, and bitumen content), the bitumen properties (penetration, softening point, temperature susceptibility, penetration index, and specific gravity), and the aggregate properties (specific gravity)(3).

Kalhan Mitra, E.tal The binder mixture specimens undergo an indirect tensile test, in which a load is supplied at a consistent rate of deformation. The empirical data obtained from the binder mixture experiments is utilised to calibrate the suggested computational model of the binder mixture. The asphalt mixture specimens are subjected to an indirect tensile test, where they are tested under continual deformation. A mixture of asphalt that consists of 5% (by weight) asphalt binder in relation to the total weight of the mixture is frequently known as a "5% asphalt mix." Indirect tensile tests are conducted on asphalt and binder mix samples using an Instron equipment. The experimental force-time curves exhibit significant heterogeneity among samples for all binder contents ranging from 5.5% to 6.5% (4).

H. Di Benedetto E.tal. These features can only be introduced if the material's behaviour is linear. An assessment of the linear viscoelastic range of bituminous mixes is conducted by analysing the logarithmic (base 10) relationship between the strain amplitude and the number of cycles applied. The conclusions drawn from the inter laboratory tests conducted by 15 laboratories focused on improving the repeatability and reproducibility of testing the stiffness properties of bituminous mixtures under cyclic loading. These conclusions specifically addressed the test equipment, sample preparation, testing, and calibration procedures [(5)].

David H. Timm Offers an in-depth examination of the different layers that make up the pavement, with a specific emphasis on the composition of the materials and the mechanical characteristics of those materials. The laboratory performed triaxial elasticity and dynamic modulus tests and furnished a summary of the findings. The laboratory and field data underwent statistical analysis, and models were developed to illustrate the relationships between relevant pavement properties and mechanistic material traits. The analysis determined that factors such as air voids, binder grade, gradation, and asphalt content had no substantial influence. The influence of cracking on modulus values was notably evident in the Hot Mix Asphalt (HMA) layer [(6)]**.**

Ramprasad.D.S,E.tal According to reports, the specifications for bituminous binders in India are determined using empirical experiments that provide inconclusive results on their performance characteristics. This paper provides a description of the physical and rheological properties of commonly used bituminous binders in India, focusing on their performance qualities at high and medium field temperatures. When analysing the behaviour of bituminous binders, we take into account the impact of temperature fluctuations, loading rate, and loading amount. The study reports changes in the characteristics of commonly used bitumens (60-70) in both their unaltered form and when modified with rubber crumb. Marshall The properties and ratio of indirect tensile strength are compared for the specimens that were manufactured with the optimal amount of binder for bituminous concrete with a grain size of 2. Bitumen that has been enhanced with crumb rubber demonstrates increased Marshall Stability, decreased flow, elevated Indirect Tensile Strength (ITS), and enhanced rheological characteristics that are associated with resistance to rutting. CRMB requires a slightly higher amount of binder compared to regular bitumen, but it shows improved strength in terms of increased Marshall Stability and lower yield value[(7)].

Moe Aung Lwin E.tal, By incorporating crumb rubber tyres into bituminous pavement, the recycling rate may be increased and the cost of incineration can be minimised. Five distinct types of open-graded pavement (OGW) samples were created using the dry-mixing method, with each sample weighing 1.15 kg. Each OGW mixture consisted of 4% to 6% Bitumen Pen 60/70 and 1% rubber tyres, resulting in 14% to 20% rubber tyres in the bituminous samples. The addition of 20% crumb rubber tyres to Bitumen Pen 60/70 resulted in a blend that exhibited the qualities of PG 76 bitumen. The physical characteristics of OGW produced from crumb rubber modified bitumen (CRMB) were superior to those of regular bitumen. The OGW (Open Graded Wearing) mix was chosen for this investigation due to its versatility in various road conditions and several benefits it provides [(8)].

Nabin Rana Magar, The rheology of CRMB is influenced by various internal elements, including the quantity, type, particle size, source, and composition of pure bitumen. Additionally, external factors such as mixing time, temperature, and the technique of mixing (dry or wet) also play a role. The objective of this study is to examine the practical effectiveness of bitumen that has been enhanced with 15% by weight of crumb rubber, while also considering variations in the size of the rubber particles.

Crumb rubber is divided into four size categories: coarse (1 mm - 600 µm), medium (600 µm - 300 µm), fine (300 µm - 150 µm), and superfine (150 µm - 75 µm). The modified bitumen is subjected to standard laboratory tests using various sizes of crumb rubber, and subsequently analysed. The Marshall stability approach is employed for the purpose of mix design. Crumb rubber modified bitumen (CRMB) is manufactured(9).

Ambika Kuity, E.tal All the materials, asphalt binders, and fillers utilised in this study were sourced from local suppliers. The current study has used bituminous concrete (BC) as the asphalt mix in accordance with Indian requirements. The BC samples are produced using a medium gradation. This research presents a thorough investigation of the performance of five distinct fillers, specifically brick dust, fly ash, lime dust, recycled concrete waste dust, and ordinary stone dust, when employed in asphalt mix. The asphalt concentration was established at 5.66% based on the weight of the aggregates, excluding fillers. In this paper, a volume proportioning technique was implemented to replace the stone dust fillers with a new type of fillers, taking into account their varied densities(10).

Georges A.J. Mturi, E.tal Rheological analyses using a dynamic shear rheometer (DSR) enable improved characterisation. Nonetheless, the diverse structure of CRM bitumens poses difficulties in testing using existing procedures and equipment. DSR When conducting tests on CRM bitumens, it is necessary to modify the distance between the plates to prevent any disruption caused by the presence of rubber particles. In order to achieve this objective, the impact of adjusting the DSR plate gap setting on the measured linear visco-elastic characteristics of the binder was observed. A matched gap was chosen to conduct rheological measurements in order to analyse the qualities of CRM bitumen as it ages. Due to the heterogeneous composition of CRM bitumen, it is not feasible to extract the binder as a singular element from surface sealants or asphalt mixes. The recovery process yields two distinct components: the rubber crumb and the solvent-soluble fraction that contains the base binder. The solvent extraction technique disrupts the chemical equilibrium of the CRM bitumen mixture (11).

BasharTarawnehE.tal The determination of the MR should be conducted by the repetition of triaxial loading (RTL) experiments in a laboratory setting. Nevertheless, this examination necessitates highly skilled workers and costly laboratory apparatus. Furthermore, it is regarded as relatively laborious in terms of time. Thus, the estimation of MR is accomplished by correlating it with different in-situ test results and material index features. The regression analysis demonstrated that employing linear elastic software for back-calculation of the FWD module yielded a more accurate forecast of the laboratory-measured elastic modulus compared to utilising the AASHTO or Florida equations (12).

JorgeB.Sousa,Etal Rutting, which refers to the permanent deformation of asphalt pavements, has a substantial influence on the overall performance of the pavement. Ruts diminish the longevity of the pavement and pose significant dangers to drivers by compromising driving performance. The progress of highway engineers in developing rut-resistant materials has been hindered by the limitations of current empirical methods used to test and evaluate asphalt-aggregate mixtures. These approaches do not offer a dependable measure of how well the materials will function in real-world conditions. Rutting is mostly attributed to recurrent shear deformation under traffic pressure, but mix compaction (volume change) does have some impact. The extent of rutting is influenced by factors such as tyre load level and pressure, traffic volume, heat condition, and varied mix properties. Aggregate features, such as rough surface texture, angularity, and dense aggregate, play a crucial role in resisting permanent deformation among the relevant mix properties. The quantity and rigidity of the asphalt or modified asphalt binder are crucial factors, as lower asphalt contents and more rigid binders offer superior resistance to permanent deformation.[13]

1. Tensile stress, $\sigma_x = \frac{2 \times P}{(\pi \times d \times t)} Mpa$

   Where,
   P = applied repeated load in Newton.
   d = diameter of the specimen in mm.
   t = thickness of the specimen in mm.

2. Resilient Modulus, MR $= \frac{P(0.27 + \mu)}{(HR \times t)} Mpa$

   Where,
   HR = Resilient Horizontal Deformation
   μ = Resilient Poisson's Ratio (@ 25^0C & 35^0C μ = 0.35 as per TRL)

3. Initial tensile strain, $\varepsilon = \frac{\sigma_x(1+3\mu)}{MR}$

3. MATERIALS AND METHODOLOGY

Materials

- Viscous Grade – 40 (VG – 40) has been obtained from Mangalore Refineries & Petro-Chemicals Limited – MRPL.
- Aggregates are obtained from Bangalore where in the stone quarry situated in Bidadi for the analysis.

Methodology:

- Evaluation of fatigue test of specimens casted with grade – I aggregate & grade – II aggregates with VG – 40 as binder.

TABLE – 1: Results of Indirect Tensile Fatigue Test with 25^0C temperature at 10%, 20%, 30%, and 40% stress level using VG - 40 grade with Grade-I aggregates (Frequency – 4.0 Hz)

Specimen Name (A-VG-40-2)	Stress Level, %	Load, N	Height of specimen, mm	Tensile Stress, MPa	Resilient Horizontal Deformation, mm	Resilient Modulus, MPa	Initial Tensile strain, Micro strain	Fatigue Life, No. of cycles
VG-40-1	10	1630	64	0.159	0.00483	3256.56	102.61	8312
VG-40-2	10	1630	62	0.164	0.00496	3277.83	101.94	8356
VG-40-3	10	1630	62	0.164	0.00495	3284.98	101.72	8367
VG-40-4	20	3260	64	0.319	0.0121	2607.58	256.29	7535
VG-40-5	20	3260	63	0.324	0.0122	2625.13	254.58	7513
VG-40-6	20	3260	62	0.327	0.0123	2625.84	254.51	7587
VG-40-7	30	4890	63	0.474	0.0198	2368.46	423.25	6812

VG-40-8	30	4890	64	0.474	0.0197	2379.75	421.24	6834
VG-40-9	30	4890	63	0.482	0.0199	2397.35	418.15	6897
VG-40-10	40	6520	63	0.642	0.0291	2182.81	612.33	5976
VG-40-11	40	6520	63	0.647	0.0295	2169.58	616.06	5934
VG-40-12	40	6520	63	0.640	0.0291	2174.95	614.54	5912

TABLE – 2 Results of Indirect Tensile Fatigue Test with 25^{0}C temperature at 10%, 20%, 30%, and 40% stress level using VG - 40 grade with Grade-I aggregates (Frequency – 3.0 Hz)

Specimen Name (B-VG-40-2)	Stress Level, %	Load, N	Height of specimen, mm	Tensile Stress, MPa	Resilient Horizontal Deformation, mm	Resilient Modulus, MPa	Initial Tensile strain, Micro strain	Fatigue Life, No. of cycles
VG-40-1	10	1630	62	0.165	0.00558	2917.38	114.54	7623
VG-40-2	10	1630	63	0.162	0.00551	2905.31	115.01	7689
VG-40-3	10	1630	63	0.162	0.00549	2914.97	114.63	7643
VG-40-4	20	3260	64	0.316	0.0135	2315.12	288.67	6734
VG-40-5	20	3260	62	0.328	0.0138	2353.59	283.95	6729
VG-40-6	20	3260	63	0.322	0.0134	2377.24	281.12	6798
VG-40-7	30	4890	65	0.468	0.0222	2083.41	481.16	5832
VG-40-8	30	4890	63	0.486	0.0229	2097.15	478.01	5876
VG-40-9	30	4890	62	0.485	0.0235	2042.96	490.69	5832
VG-40-10	40	6520	63	0.648	0.0339	1891.57	706.61	4967
VG-40-11	40	6520	62	0.659	0.0344	1894.43	705.54	4923
VG-40-12	40	6520	64	0.639	0.0345	1830.51	730.18	4954

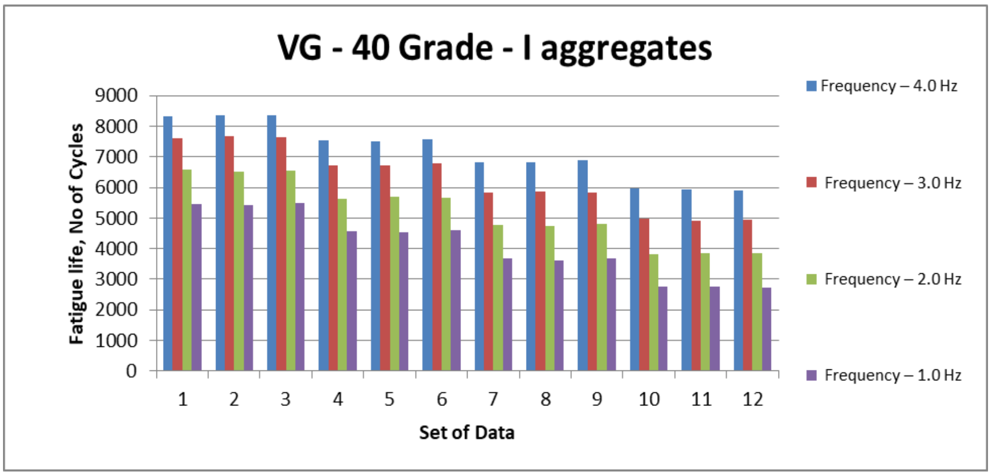
TABLE – 3: Results of Indirect Tensile Fatigue Test with 25^{0}C temperature at 10%, 20%, 30%, and 40% stress level using VG - 40 grade with Grade-I aggregates (Frequency – 2.0 Hz)

Specimen Name (C-VG-40-2)	Stress Level, %	Load, N	Height of specimen, mm	Tensile Stress, MPa	Resilient Horizontal Deformation, mm	Resilient Modulus, MPa	Initial Tensile strain, Micro strain	Fatigue Life, No. of cycles
VG-40-1	10	1630	64	0.158	0.00616	2536.86	131.72	6587
VG-40-2	10	1630	62	0.164	0.00629	2581.84	129.42	6512
VG-40-3	10	1630	63	0.161	0.00614	2594.06	128.81	6545
VG-40-4	20	3260	65	0.312	0.0149	2069.43	322.94	5623
VG-40-5	20	3260	63	0.322	0.0152	2092.43	319.39	5698
VG-40-6	20	3260	63	0.321	0.0154	2062.33	324.05	5667
VG-40-7	30	4890	62	0.493	0.0273	1787.75	560.73	4765

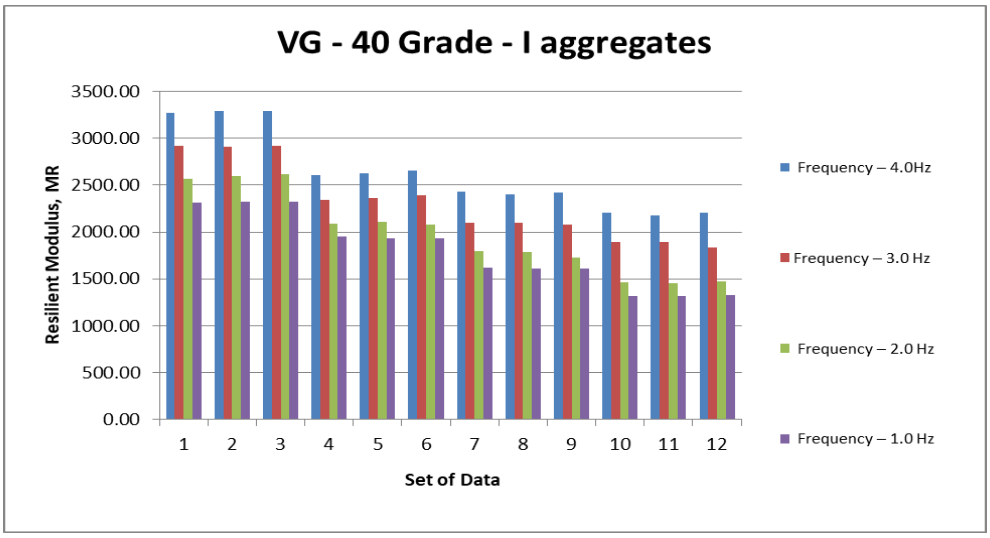
VG-40-8	30	4890	63	0.480	0.0269	1764.62	568.08	4732
VG-40-9	30	4890	64	0.476	0.0275	1713.51	585.03	4798
VG-40-10	40	6520	64	0.630	0.0432	1442.49	926.59	3823
VG-40-11	40	6520	64	0.637	0.0434	1452.63	920.12	3856
VG-40-12	40	6520	64	0.632	0.0430	1454.13	919.18	3867

TABLE – 4: Results of Indirect Tensile Fatigue Test with 25^{0}C temperature at 10%, 20%, 30%, and 40% stress level using VG - 40 grade with Grade-I aggregates (Frequency – 1.0 Hz)

Specimen Name (D-VG-40-2)	Stress Level, %	Load, N	Height of specimen, mm	Tensile Stress, MPa	Resilient Horizontal Deformation, mm	Resilient Modulus, MPa	Initial Tensile strain, Micro strain	Fatigue Life, No. of cycles
VG-40-1	10	1630	64	0.160	0.00682	2313.53	144.43	5467
VG-40-2	10	1630	64	0.159	0.00681	2309.72	144.67	5423
VG-40-3	10	1630	62	0.164	0.00701	2319.26	144.08	5498
VG-40-4	20	3260	62	0.329	0.0167	1947.38	343.18	4567
VG-40-5	20	3260	62	0.329	0.0169	1924.03	347.34	4521
VG-40-6	20	3260	65	0.314	0.0161	1927.54	346.71	4589
VG-40-7	30	4890	63	0.487	0.0298	1614.64	620.85	3687
VG-40-8	30	4890	64	0.478	0.0295	1603.82	625.04	3621
VG-40-9	30	4890	65	0.468	0.0289	1600.41	626.37	3665
VG-40-10	40	6520	63	0.646	0.0487	1312.35	1018.48	2756
VG-40-11	40	6520	63	0.642	0.0488	1301.64	1026.86	2743
VG-40-12	40	6520	64	0.633	0.0476	1314.21	1017.04	2721



Graph – 1: Fatigue Life Vs Different loading period



Graph – 2: Resilient Modulus Vs Different loading period

TABLE – 5: Results of Indirect Tensile Fatigue Test with 25^{0}C temperature at 10%, 20%, 30%, and 40% stress level using VG - 40 grade with Grade-II aggregates (Frequency – 4.0 Hz)

Specimen Name (A-VG-40-1)	Stress Level, %	Load, N	Height of specimen, mm	Tensile Stress, MPa	Resilient Horizontal Deformation, mm	Resilient Modulus, MPa	Initial Tensile strain, Micro strain	Fatigue Life, No. of cycles
VG-40-1	10	1545	64	0.151	0.00472	3168.04	99.97	7230
VG-40-2	10	1545	63	0.154	0.00478	3176.88	99.70	7256
VG-40-3	10	1545	63	0.154	0.00479	3173.77	99.79	7289
VG-40-4	20	3090	64	0.302	0.0112	2669.38	237.30	6378
VG-40-5	20	3090	64	0.300	0.0111	2668.85	237.35	6316
VG-40-6	20	3090	62	0.312	0.0113	2727.91	232.21	6385
VG-40-7	30	4635	62	0.468	0.0187	2477.41	383.54	5623
VG-40-8	30	4635	64	0.454	0.0186	2413.69	393.66	5689
VG-40-9	30	4635	62	0.468	0.0189	2449.22	387.95	5610
VG-40-10	40	6180	63	0.614	0.0287	2114.77	599.07	4876
VG-40-11	40	6180	63	0.614	0.0287	2114.10	599.26	4892
VG-40-12	40	6180	64	0.599	0.0281	2108.49	600.86	4821

TABLE – 6: Results of Indirect Tensile Fatigue Test with 25^{0}C temperature at 10%, 20%, 30%, and 40% stress level using VG - 40 grade with Grade-II aggregates (Frequency – 3.0 Hz)

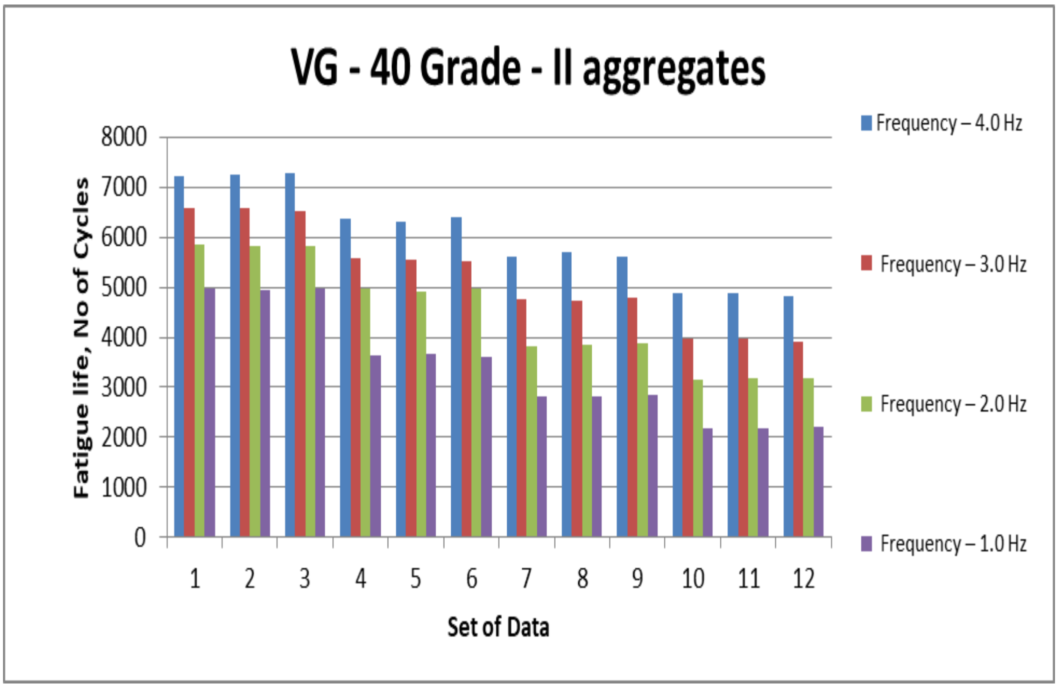
Specimen Name (B-VG-40-1)	Stress Level, %	Load, N	Height of specimen, mm	Tensile Stress, MPa	Resilient Horizontal Deformation, mm	Resilient Modulus, MPa	Initial Tensile strain, Micro strain	Fatigue Life, No. of cycles
VG-40-1	10	1545	63	0.153	0.00545	2785.00	113.73	6578
VG-40-2	10	1545	62	0.155	0.00549	2788.13	113.60	6589
VG-40-3	10	1545	62	0.156	0.00553	2787.56	113.62	6512
VG-40-4	20	3090	64	0.302	0.0127	2352.63	269.25	5576
VG-40-5	20	3090	64	0.300	0.0124	2389.79	265.07	5563
VG-40-6	20	3090	62	0.311	0.0132	2332.26	271.60	5523
VG-40-7	30	4635	64	0.449	0.0221	2011.32	472.41	4765
VG-40-8	30	4635	65	0.449	0.0222	2001.64	474.70	4721
VG-40-9	30	4635	62	0.467	0.0224	2061.55	460.90	4789
VG-40-10	40	6180	63	0.611	0.0341	1770.90	715.40	3976
VG-40-11	40	6180	64	0.605	0.0342	1748.91	724.39	3967
VG-40-12	40	6180	63	0.614	0.0343	1770.90	715.40	3912

TABLE – 7: Results of Indirect Tensile Fatigue Test with 25^{0}C temperature at 10%, 20%, 30%, and 40% stress level using VG - 40 grade with Grade-II aggregates (Frequency – 2.0 Hz)

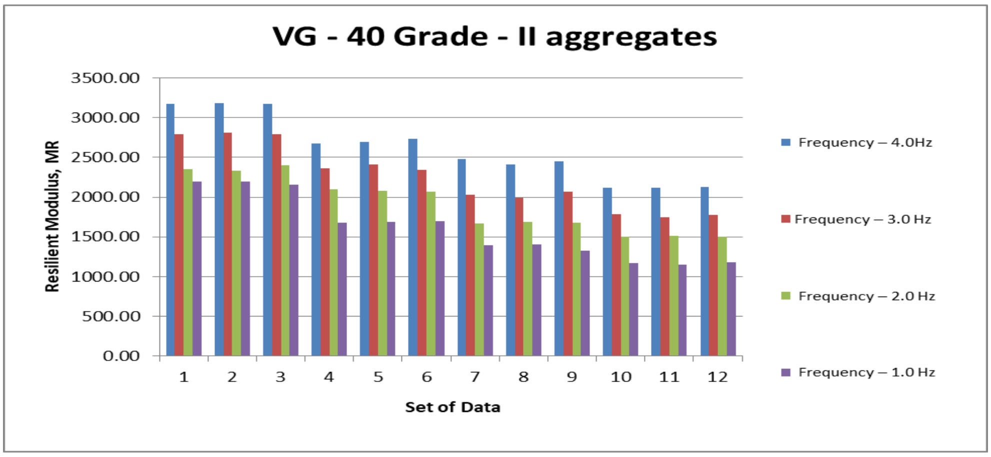
Specimen Name (C-VG-40-1)	Stress Level, %	Load, N	Height of specimen, mm	Tensile Stress, MPa	Resilient Horizontal Deformation, mm	Resilient Modulus, MPa	Initial Tensile strain, Micro strain	Fatigue Life, No. of cycles
VG-40-1	10	1545	62	0.156	0.00657	2350.46	134.75	5854
VG-40-2	10	1545	64	0.151	0.00641	2334.61	135.67	5832
VG-40-3	10	1545	62	0.156	0.00644	2395.98	132.19	5821
VG-40-4	20	3090	63	0.307	0.0145	2092.89	302.67	4976
VG-40-5	20	3090	63	0.307	0.0146	2077.90	304.85	4921
VG-40-6	20	3090	64	0.300	0.0145	2043.05	310.05	4965
VG-40-7	30	4635	63	0.460	0.0273	1667.94	569.67	3826
VG-40-8	30	4635	62	0.464	0.0274	1675.93	566.95	3845
VG-40-9	30	4635	62	0.468	0.0276	1675.56	567.08	3876
VG-40-10	40	6180	64	0.604	0.0399	1497.66	845.92	3145
VG-40-11	40	6180	64	0.599	0.0397	1492.87	848.64	3178
VG-40-12	40	6180	63	0.611	0.0404	1494.75	847.57	3167

TABLE – 8: Results of Indirect Tensile Fatigue Test with 25^{0}C temperature at 10%, 20%, 30%, and 40% stress level using VG - 40 grade with Grade-II aggregates (Frequency – 1.0 Hz)

Specimen Name (D-VG-40-1)	Stress Level, %	Load, N	Height of specimen, mm	Tensile Stress, MPa	Resilient Horizontal Deformation, mm	Resilient Modulus, MPa	Initial Tensile strain, Micro strain	Fatigue Life, No. of cycles
VG-40-1	10	1545	63	0.154	0.00691	2197.61	144.12	4965
VG-40-2	10	1545	63	0.154	0.00692	2196.87	144.17	4935
VG-40-3	10	1545	64	0.151	0.00693	2157.07	146.83	4976
VG-40-4	20	3090	64	0.300	0.0178	1664.28	380.61	3645
VG-40-5	20	3090	62	0.312	0.0183	1684.45	376.06	3658
VG-40-6	20	3090	62	0.312	0.0182	1696.98	373.28	3612
VG-40-7	30	4635	64	0.454	0.0321	1398.58	679.38	2829
VG-40-8	30	4635	62	0.468	0.0331	1398.50	679.43	2821
VG-40-9	30	4635	63	0.460	0.0345	1319.43	720.14	2856
VG-40-10	40	6180	63	0.614	0.0521	1164.58	1087.86	2164
VG-40-11	40	6180	63	0.614	0.0529	1147.69	1103.87	2178
VG-40-12	40	6180	62	0.619	0.0525	1166.23	1086.32	2198



Graph – 3: Fatigue Life Vs Different loading period



Graph – 4: Resilient Modulus Vs Different loading period

TABLE – 9: Results of Indirect Tensile Fatigue Test with 35⁰C temperature at 10%, 20%, 30%, and 40% stress level using VG - 40 grade with Grade-I aggregates (Frequency – 4.0 Hz)

Specimen Name (A-VG-40-2)	Stress Level, %	Load, N	Height of specimen, mm	Tensile Stress, MPa	Resilient Horizontal Deformation, mm	Resilient Modulus, MPa	Initial Tensile strain, Micro strain	Fatigue Life, No. of cycles
VG-40-1	10	1395	63	0.139	0.00924	1485.78	192.48	3891
VG-40-2	10	1395	64	0.137	0.00952	1419.54	201.46	3835
VG-40-3	10	1395	63	0.139	0.00956	1436.04	199.14	3854
VG-40-4	20	2790	62	0.282	0.0221	1262.44	453.05	3382
VG-40-5	20	2790	63	0.278	0.0222	1236.81	462.44	3378
VG-40-6	20	2790	64	0.273	0.0228	1185.44	482.48	3351
VG-40-7	30	4185	64	0.410	0.0358	1132.46	757.57	3077
VG-40-8	30	4185	65	0.404	0.0353	1130.83	758.67	3028
VG-40-9	30	4185	64	0.410	0.0352	1151.77	744.88	3069
VG-40-10	40	5580	63	0.555	0.0521	1054.02	1085.28	2738
VG-40-11	40	5580	62	0.564	0.0523	1066.92	1072.15	2782
VG-40-12	40	5580	63	0.555	0.0521	1054.02	1085.28	2767

TABLE – 10: Results of Indirect Tensile Fatigue Test with 35⁰C temperature at 10%, 20%, 30%, and 40% stress level using VG - 40 grade with Grade-I aggregates (Frequency – 3.0 Hz)

Specimen Name (B-VG-40-2)	Stress Level, %	Load, N	Height of specimen, mm	Tensile Stress, MPa	Resilient Horizontal Deformation, mm	Resilient Modulus, MPa	Initial Tensile strain, Micro strain	Fatigue Life, No. of cycles
VG-40-1	10	1395	64	0.137	0.00993	1360.93	210.13	3227

VG-40-2	10	1395	63	0.139	0.00992	1383.93	206.64	3287
VG-40-3	10	1395	64	0.137	0.00991	1363.68	209.71	3238
VG-40-4	20	2790	62	0.282	0.0237	1177.22	485.85	2822
VG-40-5	20	2790	63	0.278	0.0238	1153.66	495.77	2871
VG-40-6	20	2790	65	0.269	0.0234	1137.28	502.91	2898
VG-40-7	30	4185	63	0.416	0.0387	1064.23	806.15	2557
VG-40-8	30	4185	63	0.416	0.0386	1066.99	804.06	2538
VG-40-9	30	4185	64	0.410	0.0387	1047.60	818.94	2552
VG-40-10	40	5580	63	0.555	0.0574	956.69	1195.68	2367
VG-40-11	40	5580	64	0.547	0.0579	933.61	1225.24	2358
VG-40-12	40	5580	62	0.564	0.0574	972.13	1176.70	2366

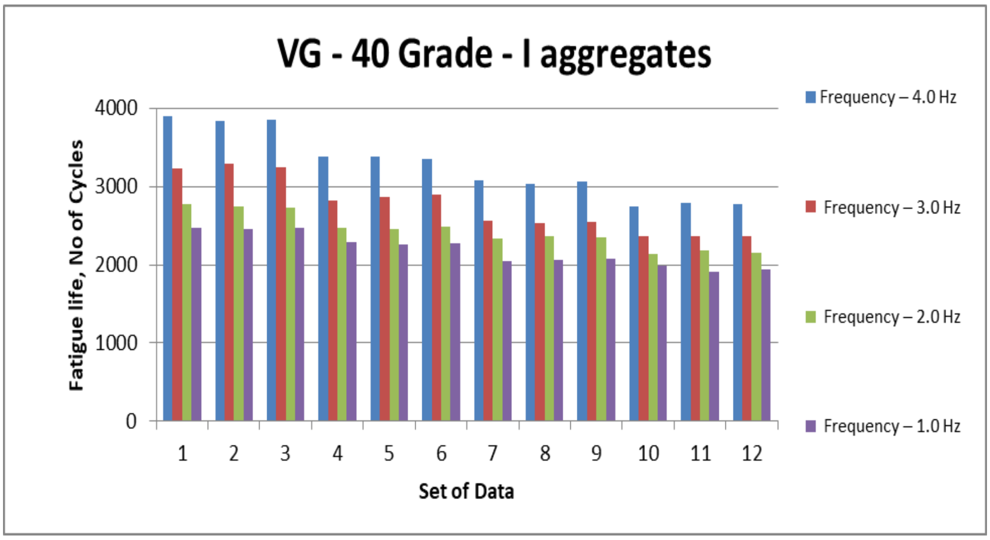
TABLE – 11: Results of Indirect Tensile Fatigue Test with 35^{0}C temperature at 10%, 20%, 30%, and 40% stress level using VG - 40 grade with Grade-I aggregates (Frequency – 2.0 Hz)

Specimen Name (C-VG-40-2)	Stress Level, %	Load, N	Height of specimen, mm	Tensile Stress, MPa	Resilient Horizontal Deformation, mm	Resilient Modulus, MPa	Initial Tensile strain, Micro strain	Fatigue Life, No. of cycles
VG-40-1	10	1395	64	0.137	0.0108	1251.30	228.54	2767
VG-40-2	10	1395	62	0.141	0.0113	1234.51	231.65	2738
VG-40-3	10	1395	62	0.141	0.0111	1256.76	227.55	2722
VG-40-4	20	2790	62	0.282	0.0276	1010.87	565.80	2469
VG-40-5	20	2790	63	0.278	0.0271	1013.18	564.51	2452
VG-40-6	20	2790	65	0.269	0.0272	978.39	584.58	2488
VG-40-7	30	4185	64	0.410	0.0419	967.59	886.66	2329
VG-40-8	30	4185	62	0.423	0.0463	903.89	949.15	2369
VG-40-9	30	4185	64	0.410	0.0468	866.29	990.35	2349
VG-40-10	40	5580	62	0.564	0.0669	834.08	1371.45	2144
VG-40-11	40	5580	63	0.555	0.0662	829.52	1378.99	2178
VG-40-12	40	5580	64	0.547	0.0663	815.33	1402.99	2155

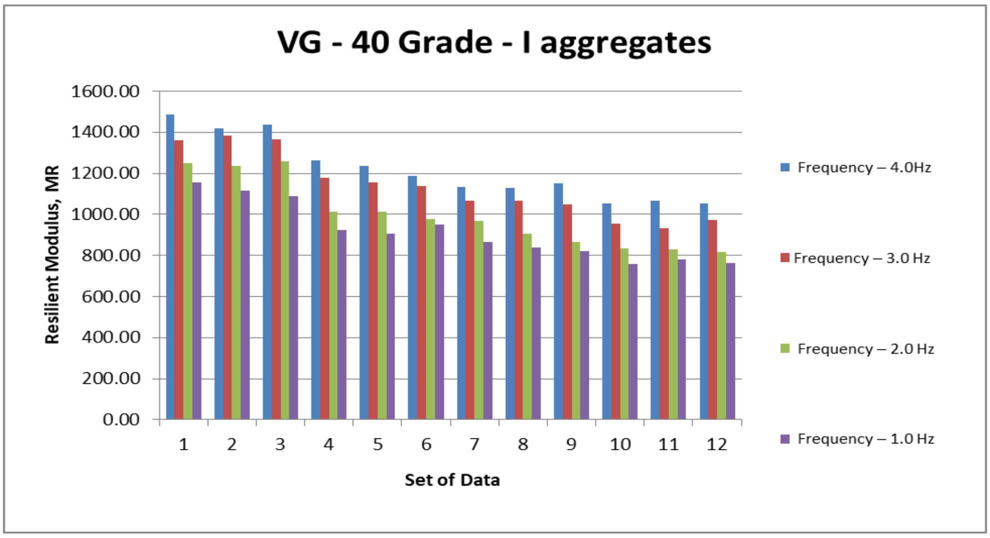
TABLE – 12: Results of Indirect Tensile Fatigue Test with 35^{0}C temperature at 10%, 20%, 30%, and 40% stress level using VG - 40 grade with Grade-I aggregates (Frequency – 1.0 Hz)

Specimen Name (D-VG-40-2)	Stress Level, %	Load, N	Height of specimen, mm	Tensile Stress, MPa	Resilient Horizontal Deformation, mm	Resilient Modulus, MPa	Initial Tensile strain, Micro strain	Fatigue Life, No. of cycles
VG-40-1	10	1395	63	0.139	0.0119	1153.66	247.88	2466

VG-40-2	10	1395	63	0.139	0.0123	1116.14	256.22	2461
VG-40-3	10	1395	65	0.135	0.0122	1090.67	262.20	2477
VG-40-4	20	2790	64	0.273	0.0293	922.46	620.03	2289
VG-40-5	20	2790	64	0.273	0.0298	906.98	630.61	2251
VG-40-6	20	2790	62	0.282	0.0294	948.98	602.70	2267
VG-40-7	30	4185	63	0.416	0.0476	865.25	991.54	2049
VG-40-8	30	4185	62	0.423	0.0499	838.68	1022.95	2066
VG-40-9	30	4185	64	0.410	0.0495	819.03	1047.48	2083
VG-40-10	40	5580	65	0.538	0.0703	757.11	1510.88	1983
VG-40-11	40	5580	63	0.555	0.0702	782.25	1462.31	1916
VG-40-12	40	5580	64	0.547	0.0707	764.59	1496.10	1934



Graph – 5: Fatigue Life Vs Different loading period



Graph – 6: Resilient Modulus Vs Different loading period

TABLE – 13: Results of Indirect Tensile Fatigue Test with 35^{0}C temperature at 10%, 20%, 30%, and 40% stress level using VG - 40 grade with Grade-II aggregates (Frequency – 4.0 Hz)

Specimen Name (A-VG-40-1)	Stress Level, %	Load, N	Height of specimen, mm	Tensile Stress, MPa	Resilient Horizontal Deformation, mm	Resilient Modulus, MPa	Initial Tensile strain, Micro strain	Fatigue Life, No. of cycles
VG-40-1	10	1365	62	0.138	0.00945	1444.44	193.73	3610
VG-40-2	10	1365	63	0.136	0.00931	1442.89	193.93	3623
VG-40-3	10	1365	63	0.136	0.00929	1446.00	193.52	3638
VG-40-4	20	2730	63	0.272	0.0199	1350.08	414.53	3143
VG-40-5	20	2730	62	0.276	0.0195	1400.00	399.75	3186
VG-40-6	20	2730	64	0.267	0.0192	1377.44	406.30	3121
VG-40-7	30	4095	62	0.414	0.0332	1233.43	680.60	2838
VG-40-8	30	4095	63	0.407	0.0327	1232.42	681.16	2876
VG-40-9	30	4095	64	0.401	0.0326	1216.88	689.86	2856
VG-40-10	40	5460	63	0.543	0.0491	1094.37	1022.78	2427
VG-40-11	40	5460	63	0.543	0.0493	1089.93	1026.95	2487
VG-40-12	40	5460	64	0.535	0.0481	1099.66	1017.86	2422

TABLE – 14: Results of Indirect Tensile Fatigue Test with 35^{0}C temperature at 10%, 20%, 30%, and 40% stress level using VG - 40 grade with Grade-II aggregates (Frequency – 3.0 Hz)

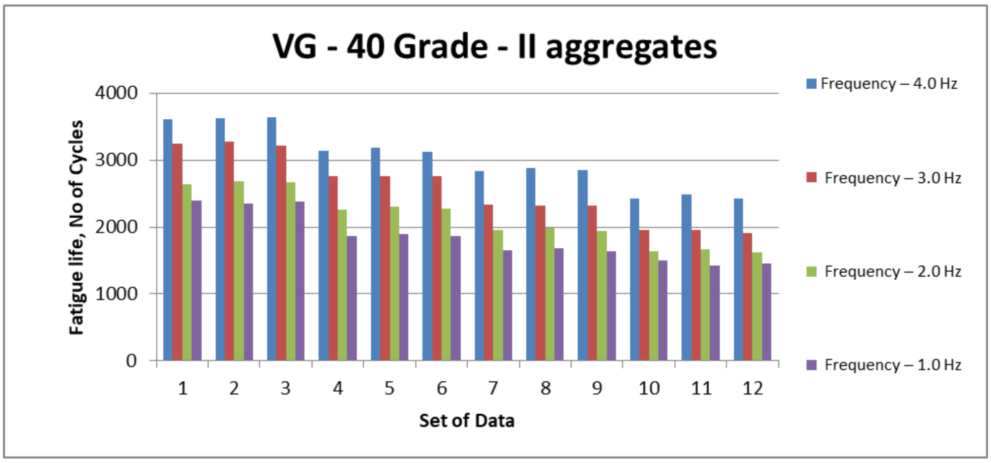
Specimen Name (B-VG-40-1)	Stress Level, %	Load, N	Height of specimen, mm	Tensile Stress, MPa	Resilient Horizontal Deformation, mm	Resilient Modulus, MPa	Initial Tensile strain, Micro strain	Fatigue Life, No. of cycles
VG-40-1	10	1365	65	0.132	0.00992	1312.50	213.20	3244
VG-40-2	10	1365	64	0.134	0.00991	1334.35	209.71	3277
VG-40-3	10	1365	65	0.132	0.00994	1309.86	213.63	3221
VG-40-4	20	2730	65	0.263	0.0215	1211.16	462.08	2756
VG-40-5	20	2730	62	0.276	0.0216	1263.89	442.80	2765
VG-40-6	20	2730	65	0.263	0.0215	1211.16	462.08	2754
VG-40-7	30	4095	65	0.395	0.0357	1094.12	767.26	2329
VG-40-8	30	4095	63	0.407	0.0369	1092.14	768.65	2326
VG-40-9	30	4095	63	0.407	0.0367	1098.09	764.48	2326
VG-40-10	40	5460	63	0.543	0.0544	987.75	1133.19	1951
VG-40-11	40	5460	62	0.552	0.0549	994.54	1125.45	1955
VG-40-12	40	5460	62	0.552	0.0544	1003.68	1115.20	1906

TABLE – 15: Results of Indirect Tensile Fatigue Test with 35^{0}C temperature at 10%, 20%, 30%, and 40% stress level using VG - 40 grade with Grade-II aggregates (Frequency – 2.0 Hz)

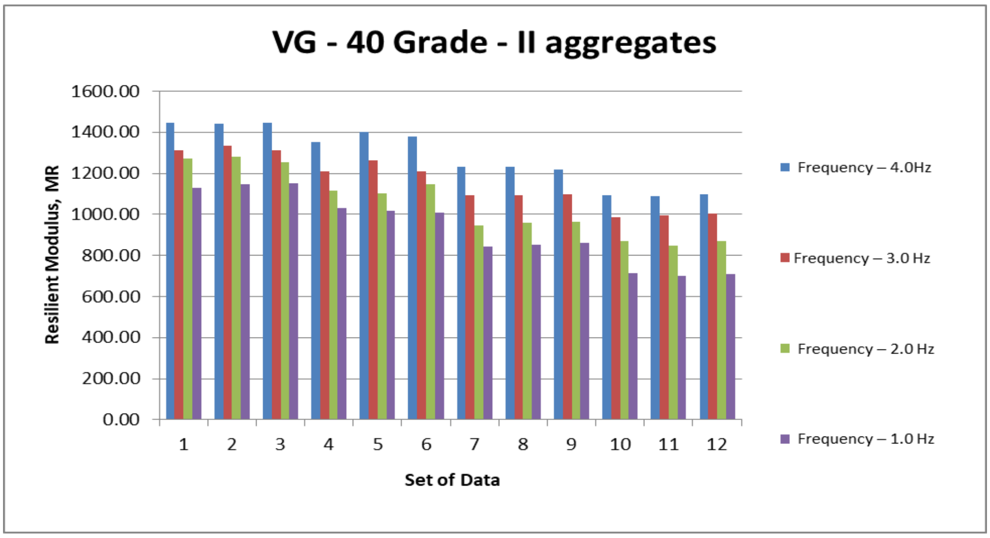
Specimen Name (C-VG-40-1)	Stress Level, %	Load, N	Height of specimen, mm	Tensile Stress, MPa	Resilient Horizontal Deformation, mm	Resilient Modulus, MPa	Initial Tensile strain, Micro strain	Fatigue Life, No. of cycles
VG-40-1	10	1365	64	0.134	0.0104	1271.48	220.08	2632
VG-40-2	10	1365	63	0.136	0.0105	1279.37	218.72	2678
VG-40-3	10	1365	63	0.136	0.0107	1255.45	222.89	2665
VG-40-4	20	2730	64	0.267	0.0237	1115.90	501.52	2257
VG-40-5	20	2730	65	0.263	0.0236	1103.39	507.21	2298
VG-40-6	20	2730	62	0.276	0.0238	1147.06	487.90	2266
VG-40-7	30	4095	64	0.401	0.0419	946.79	886.66	1949
VG-40-8	30	4095	62	0.414	0.0426	961.27	873.30	1978
VG-40-9	30	4095	63	0.407	0.0418	964.11	870.72	1938
VG-40-10	40	5460	63	0.543	0.0619	868.07	1289.42	1634
VG-40-11	40	5460	65	0.527	0.0616	845.45	1323.90	1665
VG-40-12	40	5460	62	0.552	0.0629	868.04	1289.45	1615

TABLE – 16: Results of Indirect Tensile Fatigue Test with 35^{0}C temperature at 10%, 20%, 30%, and 40% stress level using VG - 40 grade with Grade-II aggregates (Frequency – 1.0 Hz)

Specimen Name (D-VG-40-1)	Stress Level, %	Load, N	Height of specimen, mm	Tensile Stress, MPa	Resilient Horizontal Deformation, mm	Resilient Modulus, MPa	Initial Tensile strain, Micro strain	Fatigue Life, No. of cycles
VG-40-1	10	1365	63	0.136	0.0119	1128.85	247.88	2398
VG-40-2	10	1365	63	0.136	0.0117	1148.15	243.72	2354
VG-40-3	10	1365	64	0.134	0.0115	1149.86	243.35	2376
VG-40-4	20	2730	65	0.263	0.0253	1029.25	543.75	1856
VG-40-5	20	2730	62	0.276	0.0268	1018.66	549.40	1887
VG-40-6	20	2730	64	0.267	0.0262	1009.42	554.43	1859
VG-40-7	30	4095	63	0.407	0.0478	843.10	995.70	1654
VG-40-8	30	4095	63	0.407	0.0472	853.81	983.21	1678
VG-40-9	30	4095	62	0.414	0.0475	862.11	973.75	1643
VG-40-10	40	5460	64	0.535	0.0743	711.89	1572.28	1492
VG-40-11	40	5460	65	0.527	0.0744	700.00	1599.00	1423
VG-40-12	40	5460	64	0.535	0.0747	708.08	1580.75	1456



Graph – 7: Fatigue Life Vs Different loading period



Graph – 8: Resilient Modulus Vs Different loading period

4. RESULTS AND DISCUSSION

Results of Fatigue test

1. The Resilient Modulus of VG - 40 grade with Grade-I aggregates at 25 degrees are in the range of 3256.56 to 1314.21 N/mm^2.
2. The Resilient Modulus of VG - 40 grade with Grade-II aggregates at 25 degrees are in the range of 3168.04 to 1166.23 N/mm^2.
3. The Resilient Modulus of VG - 40 grade with Grade-I aggregates at 35 degrees are in the range of 1485.78 to 764.59 N/mm^2.
4. The Resilient Modulus of VG - 40 grade with Grade-II aggregates at 35 degrees are in the range of 1444.44 to 708.08 N/mm^2.

Sample calculation of Fatigue test-

$$\sigma_x = \frac{2 \times P}{(\pi \times d \times t)} Mpa$$

Tensile Stress At 35^0C i.e. Unconditioned specimen Repeated Load, P = 1365 N Average height of the Marshall specimen, t = 63 mm Diameter of the Marshall specimen, D = 101.6 mm Tensile Stress, σx = 0.136 N/mm^2

$M_R = \frac{P(0.27+\mu)}{(HR \times t)} Mpa$ = [{1365 (0.27 + 0.35)} / {(0.0119*63.0)}] = 1128.85 Mpa

μ = Resilient Poisson's Ratio (@ 35^0C μ = 0.35 as per TRL)

Initial tensile strain, $\varepsilon = \frac{\sigma_x(1+3\mu)}{MR}$ = [{0.136 (1 + 3*0.35)} / 1128.85] = 247.88 Micro strain.

REFERENCES

1. D.N Little, E.tal, "Resilient modulus of asphalt concrete", Texas transportation institute, Research Report, November, 1991.
2. Amir Modarres, Morteza Rahmanzadeh, Application of coal waste powder as filler in hot mix asphalt, Construction and Building Materials 66 (2014) 476–483, Elsevier publications.
3. A. Patel, E.tal, "A methodology for determination of Resilient modulus of asphaltic concrete", Article ID 936395 Hindawi Publishing Corporation, Advances in Civil Engineering, Volume 2011.
4. Kalhan Mitra, Animesh Das, Sumit Basu, Mechanical behavior of asphalt mix: An experimental and numerical study, Construction and Building Materials 27 (2012) 545–552, Elsevier publications.
5. H. Di Benedetto, M. N. Partl, L. Francken and C. De La Roche Saint André, Stiffness testing for bituminous mixtures RILEM TC 182-PEB PERFORMANCE TESTING AND EVALUATION OF BITUMINOUS MATERIALS, *Materials and Structures/Matériaux et Constructions*, Vol. 34, March 2001, pp 66-70.
6. David H. Timm, Angela L. Priest, "Material Properties of the NCAT Test Track Structural Study", National centre for asphalt technology NCAT Report 06-01, April 2006.
7. Ramprasad.D.S, Umesha.T.S, Dinesh.S.V, Dattatreya.J.K, COMPARISON OF PHYSICAL AND RHEOLOGICAL PROPERTIES OF PLAIN AND CRUMB RUBBER MODIFIED BITUMEN, IJRET: International Journal of Research in Engineering and Technology eISSN: 2319-1163 | pISSN: 2321-7308.
8. Moe Aung Lwin, Handojo Djati Utomo, Crumb Rubber Modified Bitumen in Open Graded Wearing Course of Flexible Pavement, ISSN Online: 2164-3172, Open Journal of Civil Engineering, 2017, 7, 165-176.
9. Nabin Rana Magar, A Study on the Performance of Crumb Rubber Modified Bitumen by Varying the Sizes of Crumb Rubber, International Journal of Engineering Trends and Technology (IJETT) – Volume 14 Number 2 – Aug 2014.
10. Ambika Kuity, Sandhya Jayaprakasan, Animesh Das, Laboratory investigation on volume proportioning scheme of mineral fillers in asphalt mixture, Construction and Building Materials 68 (2014) 637–643, Elsevier publications.
11. Georges A.J. Mturi, Johan O'Connell, Salah E. Zoorob and Morris De Beer, A study of crumb rubber modified bitumen used in South Africa, Article in Road Materials and Pavement Design · May 2014.
12. Bashar Tarawneh/ Munir D.Nazzal, Optimization of resilient modulus prediction from FWD results using artificial neural network, periodica polytechnic Civil Engineering 58/2 (2014) 143–154 doi: 10.3311/PPci.2201 http://periodicapolytechnica.org/ci Creative Commons Attribution.

13. Jorge B. Sousa, Joseph Craus, Carl L. Monismith, Summary Report on Permanent Deformation in Asphalt Concrete, Institute of Transportation Studies University of California Berkeley, California, SHRP-A/IR-91-104.
14. AASHTO guide for design of pavement structures, American Association of Transport Officials, Washington.D.C, 1993.