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EVALUATION OF STIFFNESS TO PREDICT FATIGUE LIFE OF HOT-MIX ASPHALT – A CANADIAN CASE STUDY

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Abstract: This study reports the relationship between the stiffness and fatigue life of hot-mix asphalt. Six different types of hot-mix asphalt mixtures were produced. The Superpave mix design method was followed for five mixtures; the remaining one mixture was designed using the Marshall method. The asphalt mixtures were tested for stiffness and fatigue life. The stiffness was measured with respect to resilient modulus and dynamic modulus. The dynamic modulus test was carried out at six different loading frequencies (0.1, 0.5, 1.0, 5.0, 10.0 and 25 Hz) and five different temperatures (-10, 4.4, 21.1, 37.8, and 54.4 ^{0}C). The fatigue life was determined by conducting the repeated flexural bending test. The regression analyses were performed to examine the relationships of resilient modulus and dynamic modulus with fatigue life. The results of regression analyses based on the data obtained through laboratory testing showed that resilient modulus did not have a strong relationship with fatigue life. In contrast, dynamic modulus showed a strong relationship with fatigue life for a number of loading frequencies and testing temperatures. It is also notable that the strong relationship between dynamic modulus and fatigue life was observed at higher testing temperatures of 37.8 and 54.4 ^{0}C. The overall findings suggest that the dynamic modulus at 5.0–25.0 Hz and 37.8 ^{0}C can be used to predict the fatigue life of hot-mix asphalt mixture.

1. INTRODUCTION

Hot-Mix Asphalt (HMA) is a time-dependent and stress-dependent pavement material, comprising fine and coarse mineral aggregates, asphalt cement or binder, and air voids. It exhibits elastic, plastic, viscoelastic, and viscoplastic responses when subjected to repeated loading (Ahmad et al. 2011, Safiuddin et al. 2012). Repeated loading also causes fatigue in HMA. The HMA used in flexible pavements should provide the desired service life with good fatigue resistance under expected traffic loads and climatic conditions. An HMA mixture can undergo fatigue failure if it is not properly designed and placed. The in-service performance of HMA depends on a number of mixture properties including fatigue resistance (TDOT 2011, Tighe et al. 2007). When fatigue resistance is not adequately maintained, HMA can undergo fatigue cracking leading to structural failure of the pavement.

Fatigue cracking is linked with different mix variables and stiffness of the asphalt mixture. Fatigue life increases with lower stiffness at low temperatures (Ddamba 2011, Islam 2011). Neto et al. (2009) reported that the type of asphalt cement influences the stiffness of asphalt, and thus the fatigue life of HMA mixture. The fatigue life of HMA is also influenced by aggregate type, aggregate gradation, asphalt cement content, and air voids (NCHRP 2010, Harvey and Tsai 1996). Asphalt cement content and air voids produce more significant effect than aggregate factors (NCHRP 2010). Harvey and Tsai (1996) reported that the fatigue resistance of HMA substantially increases with lower air voids and higher asphalt content. Moreover, the type and amount of mineral filler influence the fatigue life of HMA. A certain amount of mineral filler is beneficial to increase fatigue life; however, excessive filler content enhances fatigue cracking (Al-Suhaibani et al. 1992, NCHRP 2006).

Most of the aforementioned studies accentuated the effects of different factors on both the stiffness and fatigue life of HMA mixture. However, none of the above studies highlighted the relationship between stiffness and fatigue life. The literature search revealed that limited research has been conducted to study the relationship between the fatigue life and stiffness of HMA mixture. The present paper aimed at investigating the correlation between the stiffness and fatigue life of different HMA mixtures. Six different HMA mixtures were produced and tested for stiffness and fatigue life. The dynamic modulus and resilient modulus tests were carried out to determine the stiffness. The fatigue life was measured from the repeated flexural bending test. Based on the overall test results, the regression analyses were performed to observe the relationship between fatigue life and resilient/dynamic modulus.

2. EXPERIMENTAL PROCEDURE

2.1. Design of HMA Mixtures

A conventional Hot Laid 3 (HL 3) dense-graded Marshall surface course mixture, three dense-graded Superpave (SP) surface course mixtures, and two dense-graded SP binder course mixtures were produced. Reclaimed Asphalt Pavement (RAP) and/or Recycled Asphalt Shingles (RAS) from demolished residential or commercial roofs were incorporated in the asphalt mixtures. The HL 3 asphalt mixture was designed based on the Marshall methodology to meet the requirements of Ontario Provincial Standard Specification (OPSS) 1150 (MTO 2010). The SP asphalt mixtures were designed based on the Superpave methodology (AI 2003) to meet the requirements of OPSS 1151 (MTO 2007). The mix compositions and constituent materials of different HMA mixtures are provided in Table 1. Two major nominal maximum sizes of 12.5 and 19 mm were used in designing the aggregate structure of HMA. The gradations of aggregate structure for different HMA mixtures are given in Table 2. The volumetric properties of different HMA mixtures are presented in Table 3.

2.2. Preparation of HMA Mixtures

Fine and coarse mineral aggregates, Performance-Graded Asphalt Cement (PGAC), RAP and/or RAS were mixed thoroughly to produce the HMA mixtures. The control mixture HL 3 was provided by a local contractor, Steed and Evans Ltd. The remaining five mixtures were produced in the Centre for Pavement and Transportation Technology (CPATT) laboratory at the University of Waterloo. A mechanical revolving drum-type mixer was used in the mixing operation. The mixing time was 2 to 3 minutes depending on the amount of RAP and RAS incorporated into the mixture. Once mixed, the loose asphalt mixture was poured into cardboard boxes and stored at room temperature.

2.3. Fabrication of Test Specimens

The specimen preparation for testing of the HMA mixtures for stiffness and fatigue life was performed in the CPATT laboratory. The loose asphalt mixtures were oven-conditioned following the specified conditioning time and compaction temperature. The cylinder specimens of Ø150 (diameter) × 170H (height) mm size were produced using the conditioned asphalt mixtures. These specimens were compacted using a Superpave Gyratory Compactor (SGC). The cylinder specimens of Ø100 × 150H mm size were cored from Ø150 × 170H mm cylinders for use in the dynamic modulus test. Also, the cylinder specimens of Ø150 × 50H mm size for use in the resilient modulus test were obtained by cutting the required number of Ø150 × 170H mm cylinders. Moreover, the conditioned asphalt mixtures were compacted by using an Asphalt Vibratory Compactor (AVC) to form 390L (length) × 73W (width) × 70H (height) mm beam specimens. These specimens were cut to prepare 380L × 63W × 50H mm beam specimens for use in the flexural fatigue test. The air voids of the primary and processed specimens were checked based on the bulk and maximum relative densities of the asphalt mixtures.

Table 1: Constituent Materials and Mixture Composition of Different HMA Mixtures

Type of Asphalt Mixture		Material	Aggregate Composition	Asphalt Mixture Composition
Surface Course Mixtures	Mix 1: HL 3 (RAP+RAS)	Crushed stone (coarse aggregate)	40.3%	38.70%
		Asphalt sand (fine aggregate)	36.7%	35.24%
		Screenings (fine aggregate)	8.0%	7.68%
		RAP	13.5%	12.97%
		RAS	1.5%	1.44%
		New asphalt cement (PG 58-28)	-	3.97%
	Mix 2: SP 12.5E FC1 (RAP+RAS)	Crushed stone (coarse aggregate)	26.5%	25.63%
		Aggregate chips (coarse aggregate)	20.0%	19.35%
		Screenings (fine aggregate)	8.0%	7.74%
		VFA sand (fine aggregate)	25.5%	24.67%
		RAP	17.0%	16.44%
		RAS	3.0%	2.90%
		New asphalt cement (PG 52-34)	-	3.27%
	Mix 3: SP 12.5E FC2 (RAP+RAS)	Crushed stone (coarse aggregate)	25.7%	24.86%
		Aggregate chips (coarse aggregate)	20.0%	19.35%
		Screenings (fine aggregate)	14.0%	13.54%
		Manufactured sand (fine aggregate)	25.3%	24.47%
		RAP	12.0%	11.61%
		RAS	3.0%	2.90%
		New asphalt cement (PG 52-34)	-	3.27%
	Mix 4: SP 12.5E FC2 (RAS)	Crushed stone (coarse aggregate)	35.6%	34.33%
		Aggregate chips (coarse aggregate)	14.0%	13.50%
		Screenings (fine aggregate)	15.0%	14.45%
		Manufactured sand (fine aggregate)	29.4%	28.35%
		RAS	6.0%	5.79%
		New asphalt cement (PG 52-40)	-	3.58%
Binder Course Mixtures	Mix 5: SP 19E (RAP+RAS)	Crushed stone (coarse aggregate)	25.1%	24.37%
		Aggregate chips (coarse aggregate)	17.1%	16.61%
		Manufactured sand (fine aggregate)	16.1%	15.64%
		IKO sand (fine aggregate)	13.7%	13.30%
		RAP	25.0%	24.28%
		RAS	3.0%	2.91%
		New asphalt cement (PG 52-34)	-	2.89%
	Mix 6: SP 19E (RAS)	Crushed stone (coarse aggregate)	39.5%	38.20%
		Aggregate chips (coarse aggregate)	13.8%	13.35%
		Manufactured sand (fine aggregate)	28.8%	27.86%
		IKO sand (fine aggregate)	11.9%	11.51%
		RAS	6.0%	5.80%
		New asphalt cement (PG 52-40)		3.28%

2.4. Laboratory Testing

2.4.1. Resilient Modulus Test

Resilient modulus provides a means to analyze the stiffness of materials under different conditions. The resilient modulus of the HMA mixtures was determined using the CPATT Materials Testing System (MTS) in accordance with ASTM D7369-11 (ASTM 2011). The resilient modulus test was performed in the CPATT laboratory using triplicate Ø150 × 50 mm cylinder specimens. The air voids of the specimens were 7 ± 1% and the test temperature was 23 ± 2 ^{0}C. The specified load (10% of the maximum load) consisting of haversine pulse with a frequency of 1 Hz was applied on the specimens for a duration of 0.1 s followed by a rest period of 0.9 s at each loading cycle.

Table 2: Gradation of Aggregate Blends for Different HMA Mixtures

Sieve Size (mm)	Cumulative Percent Passing					
	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
26.5	100.0	100.0	100.0	100.0	100.0	100.0
19	100.0	100.0	100.0	100.0	100.0	99.8
16	100.0	100.0	100.0	100.0	96.1	92.4
13.2	99.0	100.0	100.0	100.0	89.7	82.3
9.5	82.7	90.0	90.2	86.4	83.6	74.1
6.7	64.8	76.6	77.7	72.1	73.1	63.7
4.75	55.0	62.6	64.0	60.0	65.9	59.3
2.36	43.7	44.6	43.4	44.3	48.3	48.0
1.18	30.3	38.7	28.6	29.5	36.2	36.0
0.6	20.2	35.0	19.6	20.1	28.1	27.3
0.3	11.5	29.4	13.1	13.4	12.5	13.2
0.15	6.8	13.2	7.6	7.5	7.5	8.4
0.075	4.6	4.4	4.2	4.0	5.2	6.4

Table 3: Volumetric Properties of Different HMA Mixtures

Property	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
Air Voids,%	4.0	4.0	4.0	4.0	4	4
N_{design} - Gyrations	N/A[1]	125	125	125	125	125
VFA[2] (%)	73.2	74.2	74.9	75.1	70.3	64.4
VMA[3] (%)	15	15.5	16.0	16.0	13.3	12.9
Dust Proportion	0	0	0	0	0.5	3
Tensile Strength Ratio (%)	N/A	>=80	>=80	>=80	>=80	>=80
Stability	16750	N/A	N/A	N/A	N/A	N/A
Flow (0.25 mm)	10.5	N/A	N/A	N/A	N/A	N/A
New AC (%)	3.97	3.27	3.27	3.58	2.89	3.28
Total Recycled AC (%)[4]	1.03	1.83	1.93	1.62	2.01	1.62
Total AC Content (%)	5.0	5.1	5.2	5.2	4.9	4.9

[1]Not Applicable, [2]Voids Filled with Asphalt, [3]Voids in Mineral Aggregate, [4]AC from RAP and RAS

2.4.2. Dynamic Modulus Test

Dynamic modulus is a measure for the stiffness of materials. The dynamic modulus of different HMA mixtures was determined by MTS according to AASHTO TP 62-07 (AASHTO 2007). The dynamic modulus test was carried out in the CPATT laboratory using triplicate Ø100 × 150H mm cylinder specimens. The air voids of the specimens were 7 ± 1%. The test was carried out at six loading frequencies (0.1, 0.5, 1.0, 5.0, 10.0, and 25 Hz) and five temperatures (-10, 4.4, 21.1, 37.8, and 54.4 ^{0}C). The test specimen was placed in an environmental chamber to allow it reach the specified testing temperature within the tolerance of ±0.3°C. For each testing temperature, a repetitive, compressive, and sinusoidal load was applied on the test specimens. The deformation of the test specimens was measured by two linear variable differential transducers (LVDTs).

2.4.3. Fatigue Test

The flexural beam fatigue test was performed in CPATT lab using MTS to determine the fatigue life of different HMA mixtures. The test was carried out in accordance with the procedure given in ASTM D7460-08 (ASTM 2008). Triplicate 380L × 63W × 50H mm beam specimens were used in this test. The air voids of the specimens were 7 ± 1% for the surface layer mixtures (Mix 1, Mix 2, Mix 3, and Mix 4). In contrast, the air void content of the specimens was about 10% for the binder layer mixtures (Mix 5 and Mix 6). The test beams were subjected to a cyclic haversine load in a four-point bending frame. The loading frequency was 10 Hz. The strain level of 800 microstrains was selected to allow the specimen undergo a minimum of 10,000 load cycles before its stiffness is reduced to at least 50% of the initial stiffness. The initial stiffness was estimated based on the technique depicted in ASTM D7460-08 (ASTM 2008). The test was performed at the temperature of 23 ± 2 ^{0}C.

3. TEST RESULTS AND ANALYSIS

3.1. Resilient Modulus Test Results

The average results of the resilient modulus test are provided in Table 4. The resilient modulus values were obtained at the loading frequency of 1 Hz and testing temperature of 23 ± 2 ^{0}C. The average resilient modulus varied in the range of 1013–2889 MPa. Mix 1 (HL 3 containing 1.5% RAS and 13.5% RAP) was found to have the highest total and instantaneous resilient modulus values. The lowest total and instantaneous resilient modulus values were obtained for Mix 4 (SP 12.5E FC2 containing 6% RAS). Table 4 also shows that the surface layer SP mixtures (Mix 2, Mix 3, and Mix 4) had a lower resilient modulus than the binder layer SP mixtures (Mix 5 and Mix 6). This indicates that the three surface layer mixtures, Mix 2 to Mix 4, should have a higher fatigue life than the binder layer mixtures, Mix 5 and Mix 6. This is because an asphalt mixture possessing a lower stiffness generally exhibits a higher fatigue life (Islam 2011), which was indeed observed from the results of the flexural fatigue test.

Table 4: Average Resilient Modulus Test Results for Different HMA Mixtures

Asphalt Mixture	Total Resilient Modulus (MPa)	Instantaneous Resilient Modulus (MPa)
Mix 1	2,889	2,728
Mix 2	1,376	1,374
Mix 3	1,162	1,157
Mix 4	1,013	1,049
Mix 5	1,482	1,472
Mix 6	1,709	1,728

3.2. Dynamic Modulus Test Results

The average results of the dynamic modulus test are presented in Table 5. The dynamic modulus varied in a wide range of 309–29,006 MPa. These dynamic modulus values were obtained for six different loading frequencies (0.1, 0.5, 1.0, 5.0, 10.0, and 25 Hz) and five different temperatures (-10, 4.4, 21.1, 37.8, and 54.4^{0}C). Mix 6 provided the highest dynamic modulus; the lowest dynamic modulus was obtained for Mix 1 (Table 5). The overall test results obtained reveal that the dynamic modulus values depended on both loading frequencies and temperatures. A lower dynamic modulus was achieved at a higher testing temperature whereas a higher dynamic modulus was obtained for a greater loading frequency (Table 5). A lower dynamic modulus at low temperatures is desirable to reduce fatigue cracking (Islam 2011, Ddamba 2011). At low temperatures, Mix 3 (SP 12.5E FC2 containing 3% RAS and 12% RAP) and Mix 6 (SP 19E containing 6% RAS) had the highest dynamic modulus among surface layer and binder layer mixtures, respectively. Thus, these two asphalt mixtures indicated higher fatigue cracking susceptibility. At low temperatures, Mix 1 (HL 3 containing 1.5% RAS and 13.5% RAP), a surface layer mixture and Mix 5 (SP 19E containing 3% RAS and 25% RAP), a binder layer mixture had the lowest dynamic modulus. Hence, these two asphalt mixtures indicated lower fatigue cracking susceptibility.

3.3. Fatigue Test Results

The average flexural fatigue test results are provided in Table 6. Among the surface layer mixtures, Mix 1 (HL 3 containing 1.5% RAS and 13% RAP) had the highest susceptibility to fatigue failure whereas Mix 2

(SP 12.5E FC1 containing 3% RAS and 17% RAP) had the highest resistance to fatigue failure. Mix 4 (SP 12.5E FC2 containing 6% RAS) performed better than Mix 3 (SP 12.5E FC2 containing 3% RAS and 12% RAP). For the two binder layer mixtures (Mix 5 and Mix 6), the fatigue results were lower than expected and likely been impacted by the high air void content. The air void content of Mix 5 and Mix 6 was about 10%; the fatigue resistance is generally reduced at higher air voids (Harvey and Tsai 1996).

Table 5: Average Dynamic Modulus Test Results for Different HMA Mixtures

Asphalt Mixture	Frequency (Hz)	Dynamic Modulus (MPa)				
		-10°C	4.4°C	21.1°C	37.8°C	54.4°C
Mix 1	25	16,294	12,003	5,985	3,016	826
	10	16,133	11,579	5,343	2,473	643
	5	15,739	11,157	4,812	2,095	550
	1	14,098	9,111	3,603	1,494	409
	0.5	13,435	8,381	3,223	1,323	370
	0.1	11,838	6,652	2,398	1,038	309
Mix 2	25	24,373	14,985	7,088	2,413	868
	10	23,041	13,380	5,999	2,045	702
	5	21,893	11,977	5,355	1,779	613
	1	19,071	9,294	4,117	1,414	498
	0.5	17,827	8,234	3,737	1,295	463
	0.1	15,180	6,472	2,924	1,074	403
Mix 3	25	26,599	14,749	7,405	2,345	868
	10	25,392	13,288	6,381	2,159	685
	5	24,125	12,316	5,608	1,892	601
	1	21,045	9,634	4,198	1,423	458
	0.5	19,927	8,721	3,737	1,288	418
	0.1	17,012	6,941	1,316	1,067	356
Mix 4	25	25,387	14,459	7,071	2,650	1044
	10	24,382	13,310	6,272	2,313	850
	5	22,784	12440	5,619	2,023	721
	1	20,701	9,639	4,199	1,504	548
	0.5	18,767	8,902	3,790	1,330	503
	0.1	16,782	7,019	2,973	1,140	413
Mix 5	25	24,888	16,700	9,272	4,045	1339
	10	24,106	14,412	8,188	3,431	1119
	5	23,278	13,879	7,584	3,054	957
	1	20,764	12,789	5,735	2,978	710
	0.5	19,665	10,598	5,118	2,074	645
	0.1	17,412	9,023	4,060	1,565	527
Mix 6	25	29,006	20,157	7,721	5,558	2203
	10	27,600	19,557	6,272	4,890	1822
	5	26,453	18,621	5,619	4,298	1500
	1	23,787	15,293	4,199	3,211	1075
	0.5	22,730	13,818	3,790	2,783	988
	0.1	20,136	12,012	2,973	2,169	748

3.4. Regression Analyses

The regression analyses were carried out for all asphalt mixtures to examine the correlations of fatigue life with resilient modulus and dynamic modulus. The effects of different loading frequencies and testing temperatures on the correlations were perceived.

Table 6: Average Flexural Fatigue Test Results for Different HMA Mixtures

Asphalt Mixture	Fatigue Life (Cycles)
Mix 1	23,900
Mix 2	79,850
Mix 3	37,500
Mix 4	70,300
Mix 5	21,000
Mix 6	9,900

3.4.1. Correlation between Resilient Modulus and Fatigue Life

The results of regression analyses revealed that no good correlation exists between resilient modulus and fatigue life. The goodness of the relationship was determined using the criteria shown in Table 7. The characteristics of the best-fit relationship are given in Table 8. The type of the best-fit line was polynomial. The relationship was fair with a correlation coefficient of 0.67. Both the resilient modulus and fatigue tests were conducted at the same testing temperature of 23 ± 2 ^{0}C. However, the loading frequency for resilient modulus test and fatigue test was different. Perhaps, this is why the correlation between resilient modulus and fatigue life was not good.

Table 7: Criteria for Goodness of Statistical Relationship (Adapted from Tran and Hall 2005)

Goodness of Fit	Coefficient of Correlation (R)
Excellent	≥ 0.95
Good	0.84 – 0.94
Fairly good	0.73 – 0.83
Fair	0.63 – 0.72
Poor	0.45 – 0.62
Very poor	≤ 0.44

3.4.2. Correlation between Dynamic Modulus and Fatigue Life

The results of regression analyses revealed that dynamic modulus showed good correlation with fatigue life for a number of loading frequencies. The goodness of the correlation was determined based on the criteria given in Table 7. The characteristics of the best-fit relationships are shown in Table 8. The correlation between dynamic modulus of elasticity and fatigue life varied with testing temperature and loading frequency (Table 8). The relationship of dynamic modulus with fatigue life was very poor to poor for all loading frequencies (0.1–25.0 Hz) at 21.1 ^{0}C (Table 8). The correlations were fair to fairly good for all loading frequencies at -10 and 54.4 ^{0}C. In contrast, at the lower loading frequencies of 0.1, 0.5 and 1.0 Hz, the correlations were fairly good to good at 4.4 and 37.8 ^{0}C (Table 8, Figure 1). The correlation coefficient ranged from 0.79 to 0.86 in these cases. The good correlations between dynamic modulus and fatigue life were indeed attained for the loading frequencies of 5.0, 10.0, and 25.0 Hz at 37.8 ^{0}C (Figure 1). In these cases, the best-fit lines were power with a correlation coefficient greater than 0.84. This suggests that the fatigue life of HMA mixture can be predicted by determining its dynamic modulus at 37.8 ^{0}C using a loading frequency in the range of 5.0–25.0 Hz. At this testing temperature and loading frequency range, a lower dynamic modulus indicates a higher fatigue life, that is, a lower susceptibility to fatigue cracking in HMA pavement.

4. CONCLUSIONS

The correlation between the stiffness and fatigue life of HMA mixtures was examined in the present study. The stiffness was determined with respect to resilient modulus and dynamic modulus. The fatigue life was evaluated from the flexural beam fatigue test. The correlations of resilient modulus and dynamic modulus with fatigue life were examined based on regression analyses.

Table 8: Correlation between Stiffness and Fatigue Life of HMA

Test Conditions				Nature of Relationship between Resilient Modulus and Fatigue Life		
RM Stiffness Test		Flexural Fatigue Test				
f (Hz)	T (^{0}C)	f (Hz)	T (^{0}C)	Best-fit Line	R	Goodness of Fit
1	23 ± 2	10	23 ± 2	PN	0.67	Fair
DM Stiffness Test		Flexural Fatigue Test		Nature of Relationship between Dynamic Modulus and Fatigue Life		
f (Hz)	T (^{0}C)	f (Hz)	T (^{0}C)	Best-fit Line	R	Goodness of Fit
0.1	- 10	10	23 ± 2	PN	0.75	Fairly good
	4.4			PW	0.83	Fairly good
	21.1			PN	0.32	Very poor
	37.8			PW	0.79	Fairly good
	54.4			EP	0.68	Fair
0.5	- 10	10	23 ± 2	PN	0.78	Fairly good
	4.4			PW	0.86	Good
	21.1			PN	0.51	Poor
	37.8			PW	0.83	Fairly good
	54.4			EP	0.71	Fair
1.0	- 10	10	23 ± 2	PN	0.75	Fairly good
	4.4			EP	0.81	Fairly good
	21.1			PN	0.46	Poor
	37.8			EP	0.81	Fairly good
	54.4			EP	0.72	Fair
5.0	- 10	10	23 ± 2	PN	0.79	Fairly good
	4.4			EP	0.74	Fairly good
	21.1			PN	0.41	Poor
	37.8			PW	0.88	Good
	54.4			EP	0.76	Fairly good
10.0	- 10	10	23 ± 2	PN	0.74	Fairly good
	4.4			EP	0.66	Fair
	21.1			PN	0.42	Very poor
	37.8			PW	0.89	Good
	54.4			EP	0.76	Fairly good
25.0	- 10	10	23 ± 2	PN	0.71	Fair
	4.4			PN	0.68	Fair
	21.1			PN	0.48	Poor
	37.8			PW	0.89	Good
	54.4			EP	0.77	Fairly good

Notation: DM = Dynamic Modulus, EP = Exponential, f = Frequency, PN = Polynomial, PW = Power, R = Coefficient of Correlation, RM = Resilient Modulus, T = Temperature

The following conclusions are drawn from the findings of the present study:

- The correlation between dynamic modulus and fatigue life of the HMA mixtures varied due to the different loading frequencies and temperatures used in the dynamic modulus test.
- The fairly good to good correlations between dynamic modulus and fatigue life were observed for lower loading frequencies (0.1–1.0 Hz) at 4.4 and 37.8 ^{0}C. At higher loading frequencies (5.0–25.0 Hz), good correlations were obtained at 37.8 ^{0}C.

- The correlation between the dynamic modulus and fatigue life of HMA mixtures was very poor to poor for all loading frequencies at 21.1 ^{0}C. The correlations were fair to fairly good for all loading frequencies at -10 and 54.4 ^{0}C.
- There was no good relationship between the resilient modulus and fatigue life of the asphalt mixtures. This suggests that the resilient modulus test cannot be used to predict the fatigue life of HMA mixtures.
- The fatigue life of HMA mixtures can be predicted based on their dynamic modulus obtained at 5.0–25.0 Hz and 37.8 ^{0}C.

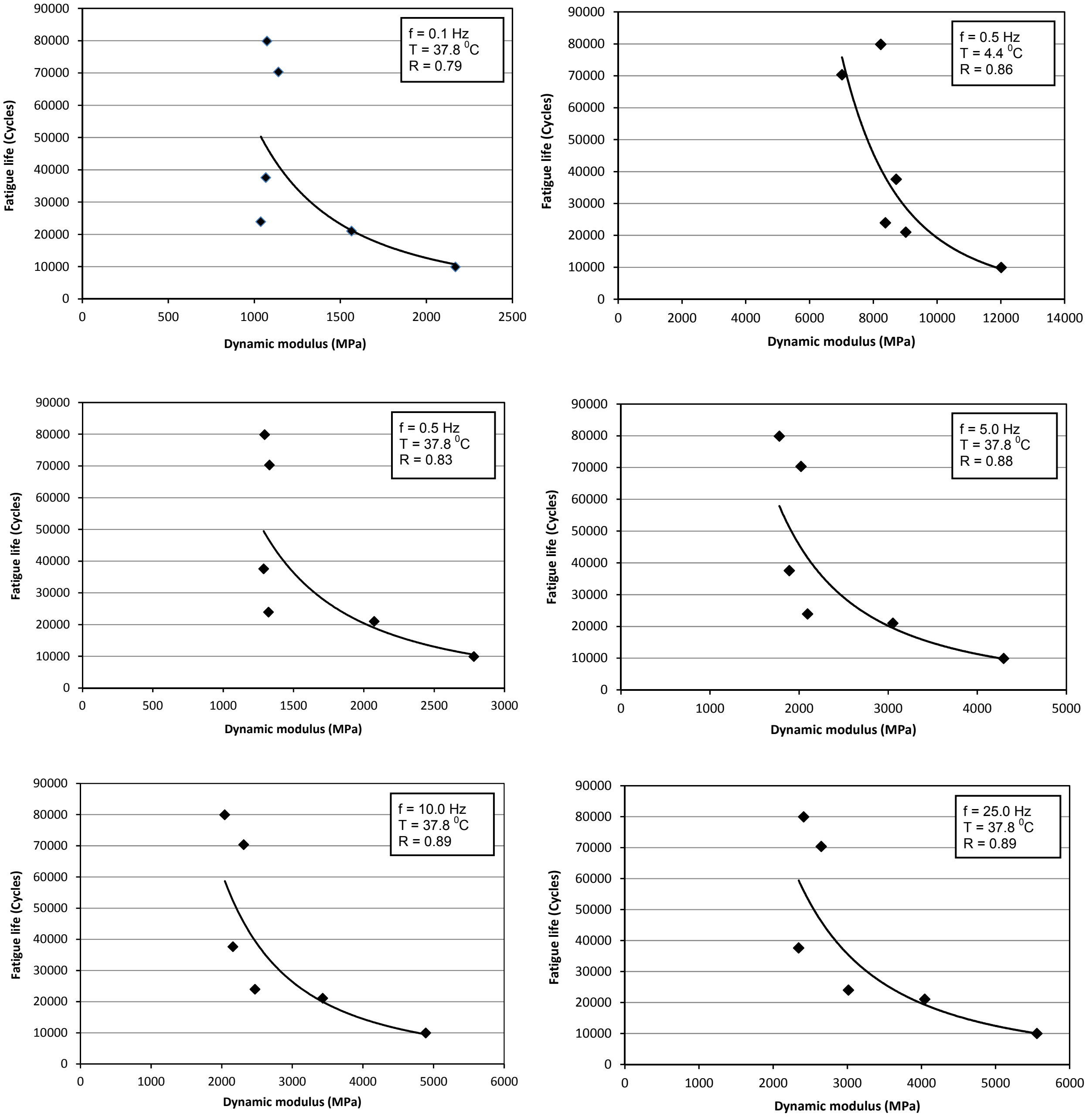

Figure 1: Correlation between Fatigue Life and Dynamic Modulus of HMA

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