FlexMAT™ Asphalt Pavement Analysis Tools Summary and FlexMAT Specified Data Structure for Cyclic Fatigue Test

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FLEXMAT ASPHALT PAVEMENT ANALYSIS TOOLS

FlexMAT for Cracking is a Microsoft® Excel-based analysis tool for characterizing dynamic modulus and cracking of asphalt pavement mixtures from Asphalt Mixture Performance Tester (AMPT) test results. This includes determining the 2S2P1D dynamic modulus mastercurve coefficients and time-temperature shift factors. It analyzes the AMPT cyclic fatigue test results (AASHTO TP133) to provide inputs to FlexPAVE™ cracking evaluation. These inputs include damage characteristic curve coefficients, failure criteria coefficients, ageing parameters, and the coefficient of thermal contraction. The analysis also supports balanced mix design and production evaluation by calculating the S_{app} index cracking parameter from the test data.

Additional information can be found in the TechBrief, *Cyclic Fatigue Index Parameter (Sapp) for Asphalt Performance Engineered Mixture Design,* 2019. (FHWA-HIF-19-091; https://www.fhwa.dot.gov/pavement/pubs/hif19091.pdf.)

1. "FlexMAT Cracking v2.1.xlsm" (file): Actual FlexMAT v2.1 file, cracking analysis version, ready for testing using the new universal data structure format requirement.

FlexMAT for Rutting is an Excel-based analysis tool for characterizing rutting of asphalt pavement mixtures from AMPT test results. This includes analyzing the AMPT stress sweep rutting (SSR) test results (AASHTO TP134) to provide shift permanent deformation model coefficients to FlexPAVE rutting evaluation. The analysis also supports balanced mix design and production evaluation by calculating the Rutting Strain Index (RSI) parameter from the test data.

Additional information can be found in the TechBrief*, Rutting Strain Index (RSI) Parameter for Asphalt Balanced Mixture Design*, published in 2021. (FHWA-HRT-21-044; https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/21044/index.cfm)

2. "FlexMAT Rutting v2.1.xlsm" (file): Actual FlexMAT v2.1 file, rutting analysis version, ready for testing using the new universal data structure format requirement.

CLIMATIC DATA FILES

Use .csv files with the FlexMAT Rutting v2.1 analysis tool to successfully perform the asphalt pavement rutting analysis. This set of files includes an expanded MERRA2 temperature database from 2,798 locations across the United States, and 20 yr (1996–2015) of temperature information.

3. "Rutting Climate Files.zip" (files): Contains the updated temperature database required for RSI calculations in FlexMAT v2.1 for Rutting.

Extract the .csv files within the .zip file into a folder. If the folder is inside the same overarching folder as the FlexMAT Rutting v2.1 file, it will be automatically identified. If not, the user will be prompted to identify the folder's location.

DATA STRUCTURE REQUIREMENT DOCUMENTS

Use these three documents to understand the AMPT test data and universal format required for FlexMAT to successfully import the test data and conduct the analysis. Each document will show the required data format the equipment manufacturers must use and report from their test equipment. These universal requirements allow the test data to be directly imported into FlexMAT from the equipment. If your equipment is not reporting data in the specified format, use these documents to verify requirements with the manufacturer:

4. "AMPT-DM v1.0_final.docx" (file): Contains the FlexMAT specified data structure for the dynamic modulus test using the AMPT. The test data output must follow the data structure for import to FlexMAT.
5. "AMPT-Fatigue v1.0_final.docx" (file): Contains the FlexMAT specified data structure for the cyclic fatigue test using the AMPT. The test data output must follow the data structure for import to FlexMAT.
6. "AMPT-Rutting v1.0_final.docx" (file): Contains the FlexMAT specified data structure for the stress sweep rutting test using the AMPT. The test data output must follow the data structure for import to FlexMAT.

Upon exporting files from the equipment, users should not open or modify the files using text editors or Microsoft® Excel because such operations may corrupt the files and make them unreadable in FlexMAT.

EXAMPLE TEST DATA REPORT FILES

Use these files as examples of test data output files from the equipment that adhere to the universal data structure requirements to successfully use and analyze the data in FlexMAT.

7. "Input Examples" (folder): Contains dummy examples of Dynamic Modulus, Cyclic Fatigue, and SSR tests in new (universal) formats (compatible with FlexMAT v2.1).

CONTACT

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FLEXMAT SPECIFIED DATA STRUCTURE FOR CYCLIC FATIGUE TEST

GENERAL DATA STRUCTURE ITEMS

- The data files must be in ASCII text format. No specific file extension or file naming convention is required. FlexMAT will browse all the files in selected folder to identify relevant file(s).
- The informational items (those that are not used by FlexMAT) and data (FlexMAT required) are separated by sections. Sections have unique and defined key words enclosed in square brackets ([ ]).
- The comment character is an exclamation point (!).
- Any comments or nondata items within required sections must be preceded by the comment character (!) as the first character in the line. Blank lines are acceptable within any of the sections and will be skipped when reading.
- Section headers are not case-sensitive, but it is recommended to use upper-case letters for ease of readability and consistency.
- The decimal point or period (".") must be the decimal separator symbol in numeric data fields.
- Within the test data, a comma, space, or tab must be used as field separator. Consecutive field separators (comma and space, for example) will be treated as a single-field separator.
- The positive (+) and negative (–) signs must apply to all loads, actuator displacements, and linear variable differential transformer displacements, and must be shown as:
  - Loads: Compression positive (+), Tension negative (–).
  - Displacements: Extension positive (+), Retraction negative (–).
  - Pressures positive (+), Vacuum negative (–).
- The current version of FlexMAT can accept input of both SI and U.S. units; however, the fatigue analysis and output are based on SI units. SI units should be considered for all data items and units indicated in Section G [UNIT].

FATIGUE TEST FILE LOCATION

The program input requires a separate folder for each specimen. Within that folder, the program looks for the file with keyword "AMPT-FT" in the first line.

Note of Caution: If the folder contains any redundant or surplus files in the specified data format, the program uses data from the first read file in the calculation. Therefore, the folder must have only one file in the specified data format. However, there can be any number of files in other data formats or file types within the folder.

DATA STRUCTURE—FATIGUE TEST DATA

ITEM	DATA	DESCRIPTION
A	AMPT-FT	**A** - Required. First line in the file must have this key word for this data file. FlexMAT browses the files in the folder to identify files to read.
B	[VERSION] 1.0	**B** - Required. Must have this section completed and only data item is the version number, currently 1.0, of the file format. Used to track version of file when data format is updated in the future. Not to be confused with FlexMAT version. Any informational item in this section must start with comment character (!).
C	[SUPPLEMENTARY INFORMATION] Project name, device name, device software version, operator, target temperature, or any other test related information	**C** - Optional. Optional section to document supplementary information. Not required but recommended to include project name, device name, device software version, and operator as a minimum. Can contain any information and not used in the analysis. If available, FlexMAT will read and include it in the report section for reference.
D	[SPECIMEN INFORMATION] Dimensions, conditioning time, properties, or any other specimen-related information	**D** - Optional. Optional section to document specimen information. Can be included or excluded and can contain any information. FlexMAT does not read and skips this section.
E	[SPECIMEN IDENTIFICATION]	**E** - Required. Must have this section completed. Only data item is the specimen ID. Any

! Specimen identification number (maximum 80 characters)

ABCDEFG

| F | [FIELD SEPARATOR] | **F** - Required. Must have this section completed. Only data item is the character type used as the field separator (delimiter) to separate fields (numeric data values) in each input record (line). Any informational item in this section must start with comment character (!). |

! 0=comma (","), 1=space (" "), 2=tab

! If comma and space are used together, please select 0 (comma)

! If tab and space are used together, please select 2 (tab)

0

G [UNIT]

! 0 = U.S. Units, 1 = SI Units

! U.S.: Modulus in ksi, Temperature in F, Pressure in psi, Axial Stress in psi, Load in kips, Displacement in mils

! SI: Modulus in MPa, Temperature in C, Pressure in kPa, Axial Stress in kPa, Load in kN, Displacement in mm

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G - Required. Must have this section completed. Only data item is the unit type used. Must be 0 (U.S. Units - Modulus in ksi, Temperature in F, Pressure in psi, Axial Stress in psi, Load in kips, Displacement in mils), or 1 (SI Units - Modulus in MPa, Temperature in C, Pressure in kPa, Axial Stress in kPa, Load in kN, Displacement in mm). For the selected unit type, the parameters should be reported in the stated magnitude. For example, if SI units is selected, Modulus should be reported in MPa not kPa. Any informational item in this section must start with comment character (!).

H [TEST PARAMETERS]

Frequency, Target Temperature, Axial Gauge Length, Dynamic Modulus Fingerprint Test Parameters, Target On-Specimen Peak-To-Peak Microstrain, or any other test parameters.

H - Optional. Optional section to document test parameters. Can be included or excluded and can contain any information. FlexMAT does not read and skips this section.

The informational item in this section must start with comment character (!).

I   [TEST DATA]

Supplemental test data such as complete Dynamic Modulus Fingerprint Test including parameters like Modulus, Cycle Count, Phase Angle, Stress, Microstrain, Temperature, or any other test data.

I - Optional. Optional section to document supplemental test data. Can be included or excluded and can contain any information. FlexMAT does not read and skips this section.

J   [PID TUNING QUALITY PARAMETER]

! Machine Compliance Factor, Target on Specimen Peak to Peak Strain

1.833, 420

J - Required. Must have this section completed. Only two data items are included, separated by comma, space, or tab with the following sequence: Machine Compliance Factor (MCF) and the Target On-Specimen Peak-to-Peak strain (microstrain). Any informational item in this section must start with comment character (!).

K   [FINGERPRINT TEST DATA]

! Time, Axial Stress, Actuator Strain, Axial Strain #1, Axial Strain #2 …

5.000, 32.29, 8.323, 9.046, 6.989, 9.864, 18.05, 0.036621, 0.000916

5.001, 17.76, 4.161, 7.302, 5.463, 9.210, 18.05, 0.020142, 0.000458

5.002, 4.305, 8.323, 5.777, 5.245, 4.632, 18.05, 0.004883, 0.000916

….

K - Required. Must have this section completed. Test data from the fingerprint dynamic modulus test in the units specified in the [UNIT] section, one line per time increment, data items separated by comma, space, or tab, with the following sequence per line: Time (sec), Axial Stress (kPa or psi), Peak to Peak Actuator Strain (microstrain), LVDT Axial Strain #1 (microstrain), LVDT Axial Strain #2 (microstrain), LVDT Axial Strain #3 (microstrain), Temperature (C or F), Load (kN or kips), Actuator Displacement (mm or mils), LVDT Displacement #1 (mm or mils), LVDT Displacement #2 (mm or mils), LVDT Displacement #3 (mm or mils). Any informational item in this section must start with comment character (!).

L   [FINAL FINGERPRINT DYNAMIC MODULUS]

! Units should be based on the selection made in [UNIT] header.

L - Required. Must have this section completed. Only data item is the Final Fingerprint Dynamic Modulus reported in the units specified in the

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[UNIT] section. Any informational item in this section must start with comment character (!).

M   [FATIGUE INITIAL CYCLES TEST DATA]

! Time, Axial Stress, Actuator Strain, Axial Strain #1, Axial Strain #2 …

0.0000, -0.29, 6.93, 0.41, 0.62, 0.27, 15.04, -0.02, 0.001, 0.009, 0.0044, 0.0019

0.0010, 0.18, 000, 0.19, -0.02, -0.16, 15.04, 0.0916, 0.00,0.013, -0.002, -0.0011

0.0020, 0.413, 3.46, 0.19, 0.19, 0.49, 15.05, 0.003, 0.0004, 0.0013, 0.0013, 0.0034

….

M - Required. Must have this section. Test data from fatigue initial cycles in the units specified in the [UNIT] section, one line per time increment, data items separated by comma, space, or tab, with the following sequence per line: Time (sec), Axial Stress (kPa or psi), Peak to Peak Actuator Strain (microstrain), LVDT Axial Strain #1 (microstrain), LVDT Axial Strain #2 (microstrain), LVDT Axial Strain #3 (micro-strain), Temperature (C or F), Load (kN or kips), Actuator Displacement (mm or mils), LVDT Displacement #1 (mm or mils), LVDT Displacement #2 (mm or mils), LVDT Displacement #3 (mm or mils). Any informational item in this section must start with comment character (!).

N   [FATIGUE TEST DATA]

! Cycle, Dynamic Modulus, Phase Angle, Peak to Peak Stress, Maximum Stress ….

10, 4708.6, 28.052, 1139.1, 272.4, -875.4, 1594.8, 241.9, 263.5 ….

20, 4646.4, 28.108, 1194.5, 374.9, -818.2, 1603.0, 257.1, 283.2 ….

….

N - Required. Must have this section completed. Test data from fatigue test in the units specified in the [UNIT] section, one line per reported load cycle (every 10th cycle), data items separated by comma, space, or tab, with the following sequence per line: Cycle, Dynamic Modulus (MPa or ksi), Phase Angle (Degrees), Peak to Peak Stress (kPa or psi), Maximum Stress (kPa or psi), Minimum Stress (kPa or psi), Peak to Peak Actuator Strain (microstrain), Peak to Peak Average Strain (microstrain), LVDT Peak to Peak Strain #1 (microstrain), LVDT Peak to Peak Strain #2 (microstrain), LVDT Peak to Peak Strain #3 (microstrain), Maximum Actuator Strain (microstrain), Minimum Actuator Strain

(microstrain), LVDT Maximum Strain #1 (microstrain), LVDT Minimum Strain #1 (microstrain), LVDT Maximum Strain #2 (microstrain), LVDT Minimum Strain #2 (microstrain), LVDT Maximum Strain #3 (microstrain), LVDT Minimum Strain #3 (micro-strain), Temperature (C or F), Peak to Peak Load (kN or kips), Maximum Load (kN or kips), Minimum Load (kN or kips), Peak to Peak Actuator Displacement (mm or mils), LVDT Peak to Peak Displacement #1 (mm or mils), LVDT Peak to Peak Displacement #2 (mm or mils), LVDT Peak to Peak Displacement #3 (mm or mils), Maximum Actuator Displacement (mm or mils), Minimum Actuator Displacement (mm or mils), LVDT Maximum Displacement #1 (mm or mils), LVDT Minimum Displacement #1 (mm or mils), LDVT Maximum Displacement #2 (mm or mils), LVDT Minimum Displacement #2 (mm or mils), LVDT Maximum Displacement #3 (mm or mils), LVDT Minimum Displacement #3 (mm or mils). Any informational item in this section must start with comment character (!).