Chapter 3
RESEARCH METHODOLOGY

3.1 Prologue

This chapter summarizes the study's research methodology and the experimental plan's brief layout. The whole study has been divided into five different phases ranging from material acquisition to determining the optimum filler-binder ratio as stated below:

Phase I: Material collection and characterization **Error! Reference source not found.**(Figure 3 .1)

Phase II: Fabrication of asphalt mastics, aging, and evaluation of LVE limits (Figure 3.2)

Phase III: Selection of alternate fatigue test and appropriate testing geometry (Figure 3.3 and 3.4)

Phase IV: Fatigue analysis of bituminous materials (Figure 3.5)

Phase V: Fatigue performance evaluation of the asphalt mixtures and selection of optimum filler content (Figure 3.6)

3.2 Phase I: Material Collection and Characterization

The asphalt mixture can be visualized as a composite of aggregates, fillers, binders, and air voids. The aggregates of Dolomite origin were collected from the stone quarry in the form of different stockpiles. The aggregates were washed and oven dried to avoid unwanted deleterious materials. A total of six waste fillers, namely red mud (RM), marble dust (MD), limestone(LS), granite (GR), basalt (BA), and quartz (QZ), were utilized in this study out of which RM and QZ were the industrial wastes, MD and LS were acquired as the dimensional stone waste, GR and BA were the quarry waste. All the fillers were sieved from a 75µ sieve to get the uniform size of fillers, i.e., less than 75µ. There were two types of binders used in the study, i.e., neat or unmodified viscosity graded, 30 (VG-30) binder and the polymer modified binder, 40 (PMB-40). The aggregates were tested as per MoRTH-13 specifications to check their suitability for use in the asphalt mixtures. These tests include the Los Angeles abrasion (LAA) test, aggregate impact value (AIV) test, shape tests (flakiness and elongation), specific gravity test, and water absorption test. The fillers were also characterized by physical, chemical, and morphological tests such as Rigden voids (RV), specific gravity, particle size distribution, specific surface area, X-ray diffraction, scanning electron microscope, etc. The consistency tests of binders, such as penetration, softening point, and viscosity, along with performance grading, were employed to test binders.

3.3 Phase II: Fabrication of Asphalt Mastics, Aging, and Evaluation of LVE Limits

The asphalt mastics can be acknowledged as the real binder which coats the aggregates and binds them together. The mastics were fabricated by mixing preheated filler and binder using manual stirring under the action of heat. The mixing was done at three filler-binder ratios of 10, 20, and 30% filler volume with respect to the binder.

The specific gravity, the ratio of the weight of material with respect to its volume, was used to facilitate the weight-volume conversions. The filler to binder ratios were chosen with respect to volume to discard the inconsistencies related to varying specific gravity of the filler, which can cause non-uniform distribution of filler within the mastic. The mixing time was increased from 10 minutes to 30 minutes for PMB based mastics due to the higher stiffness. The binders and mastics were the short term and long term aged following a similar protocol by the western research institute (WRI) [245] where the draft oven was utilized for the aging of materials. The

LVE limits of the aged binders and mastics were determined using the amplitude sweep test corresponding to 95% of the initial complex modulus. A relationship between the LVE limit and the corresponding |G*|, known as linear viscoelastic complex modulus (LVEM), was obtained for both binders and the corresponding mastics independent of the testing conditions. The observed relationship was compared with the SHRP binder LVE criteria to check its validity in the case of asphalt mastics.

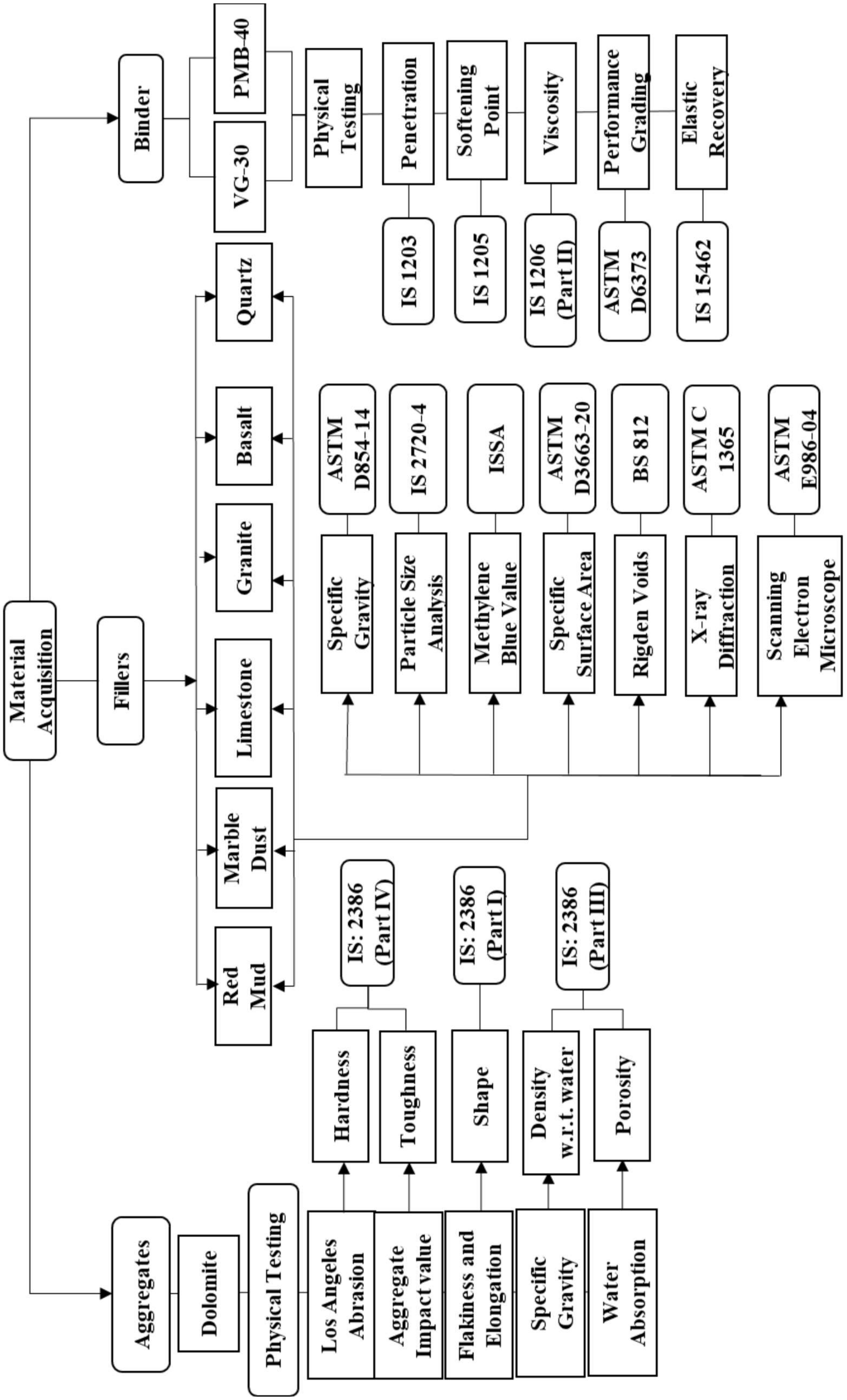

Figure 3.1 Material collection and characterization

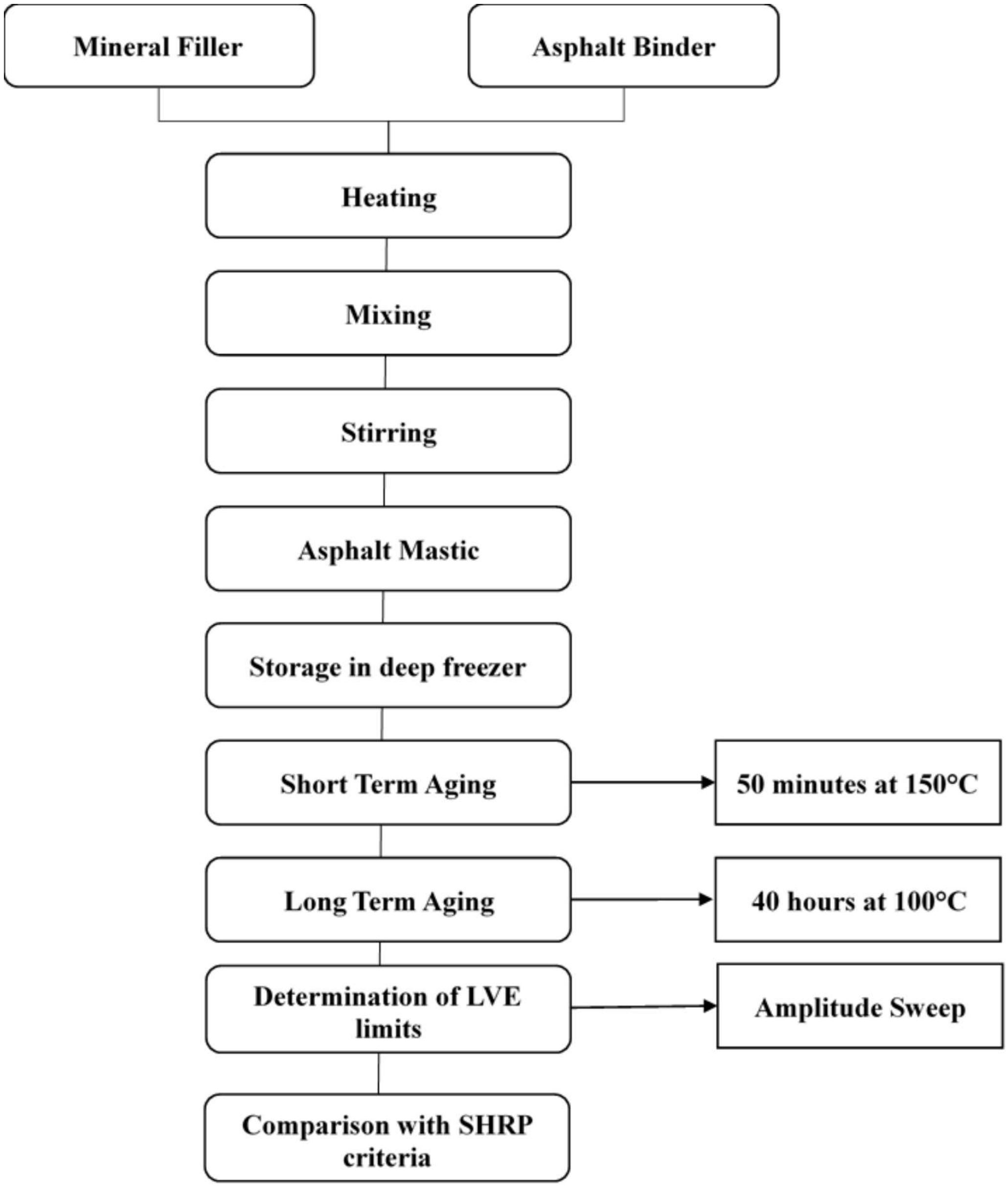

Figure 3.2 Fabrication of asphalt mastics, aging, and evaluation of LVE

3.4 Phase III: Selection of Alternate Fatigue Test and Appropriate Testing Geometry

The time sweep test is accredited to be the most accurate of all the existing binder fatigue tests. The TS test simulates the field conditions better than other tests by applying a predefined strain at a certain frequency. The liberty of choosing the strain and frequency similar to the field and traffic conditions makes it the most precise fatigue test among the existing protocols. But it's been criticized from time to time due to the longer testing times and low repeatability. The research community is in search of an alternate test that can not only characterize the fatigue properties of the material with similar efficacy but also be completed in a reasonable amount of time. Therefore, the LAS test, an accelerated test conducted within a few minutes, has been used in the study to assess its suitability as a surrogate fatigue test. The test has a bi-fold testing procedure, including frequency sweep and amplitude sweep tests. The FS test is conducted within the LVE zone at a strain rate of 0.1% with varying frequencies, whereas the AS test imparts linearly increasing strains at a frequency of 10 Hz.

The fatigue testing was done using both TS and LAS tests under similar conditions, i.e., three filler volume concentrations, three intermediate temperatures, and six different fillers. The two most popular fatigue analysis approaches, i.e., dissipated energy and pseudo strain energy approach, were used for the analysis of LAS testing results, whereas the dissipated energy ratio (DER) approach was used in the case of time sweep testing analysis. The testing was done on both the geometries, and the correction factor was applied to the results of hyperbolic geometry. The fatigue performance of the materials was also quantified by the conventional Superpave fatigue parameter, i.e., |G*|.sinδ obtained by the LAS test. The upper threshold of 5000 kPa was suggested by the SHRP for a long term aged binder to be considered as crack-resistant material. However, no such value was recommended in the case of asphalt mastics. The difference in the stiffness of binder and mastics is very high such that the complex modulus of asphalt mastics may vary from 3 to 6 times the binder [17]. Hence, the same value of 5000 kPa cannot be used with the mastics. Due to this issue, no limit of |G*|.sinδ was employed on the materials to categorize them as good or bad. Rather, the respective values were compared as it is, and the material has a lower value of |G*|.sinδ was considered superior in terms of fatigue performance. The idea was to derive a correlation between both the fatigue tests in terms of the number of cycles to failure to find out the suitability of the LAS test as an alternate fatigue test irrespective of any variable. In addition to the correlation analysis, the ranking analysis and the discrepancy analysis were also used to better quantify the behavior of mastics.

After this, the comparative analysis between the conventional cylindrical geometry and newly introduced hyperbolic geometry was done to check the efficacy of hyperbolic geometry (HG) as a superior replacement for cylindrical geometry (CG). The advantage of HG lies in the predefined point of failure, due to which the true cohesion failure was guaranteed, which is a major drawback in CG. Also, no separate setup is needed for the HG, unlike TC or vane shear geometry, and it can be fabricated in the same setup just by using a mold. The discrepancy between the test results from both geometries was investigated with the variation in pseudostiffness of the materials as a result of applied loading. The geometry which can better characterize the fatigue behavior of asphalt binder and asphalt mastics was chosen and the remaining analysis was done on the results produced from that geometry.

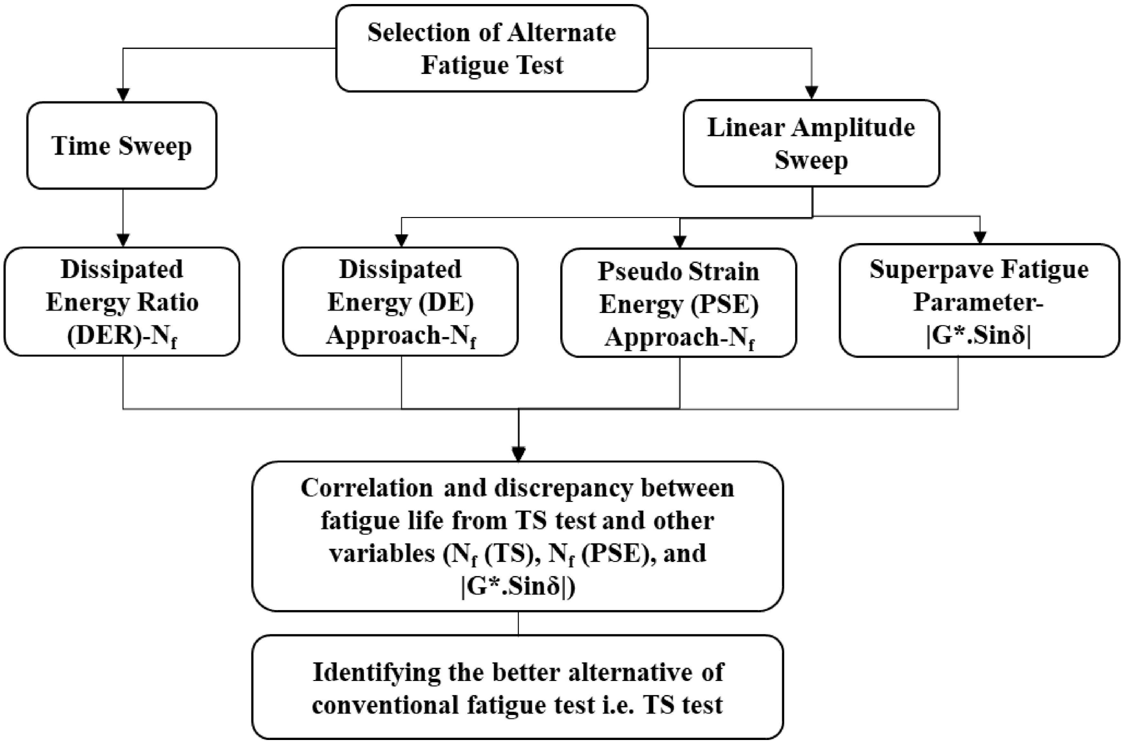

Figure 3.3 Selection of alternate fatigue test

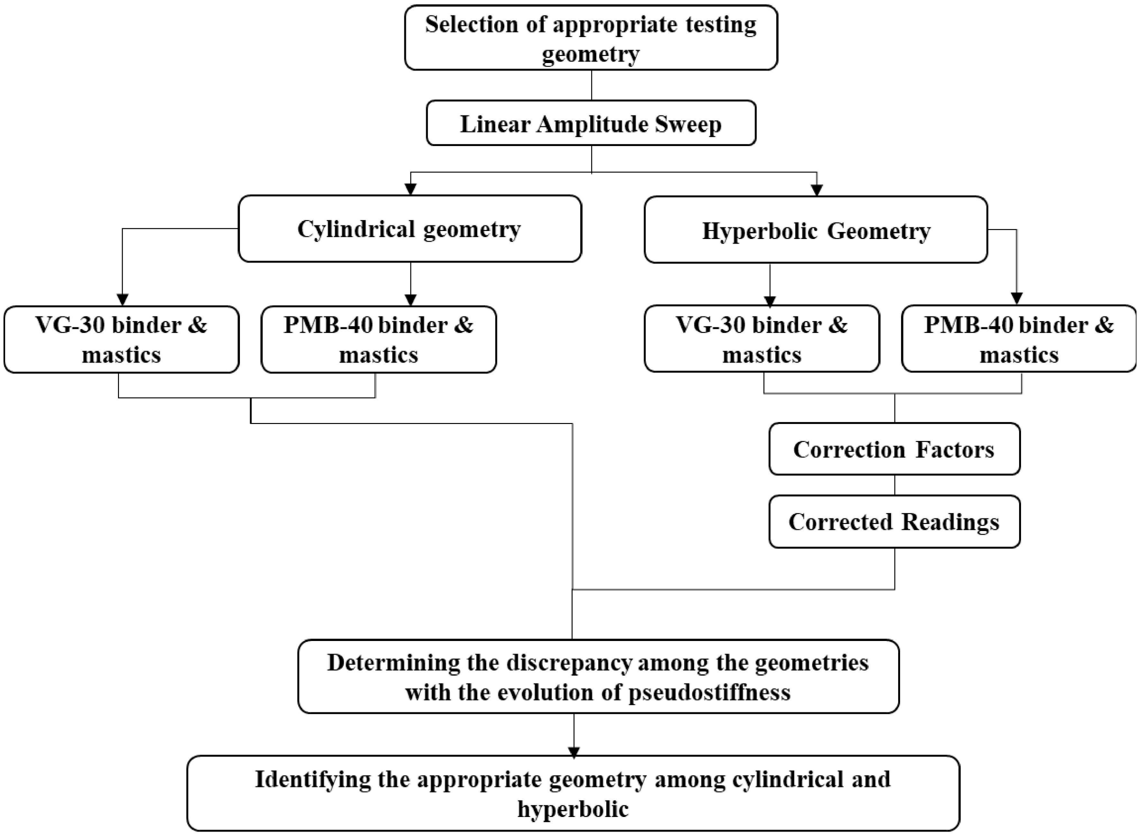

Figure 3.4 Selection of appropriate testing geometry

3.5 Phase IV: Fatigue Analysis of Asphalt Binders and Asphalt Mastics

This section is dedicated to the fatigue analysis of asphalt binders and asphalt mastics. The effect of all the affecting factors is studied in detail. The factors include intermediate testing temperatures (5, 15, and 25°C), filler volume concentrations (10, 20, and 30% by volume), type of binder (VG-30 and PMB-40), strain levels (0.1, 1, 2.5, 5, and 10%), and the type of filler (RM, MD, LS, GR, BA, and QZ). The effect of the other three factors, i.e., geometry, type of test, and analysis approach, has already been discussed in phase III. Different studies have pointed out different factors that influence fatigue behavior depending on their research domain. Therefore, a comprehensive study that can cover all the variables can only conclude the true reason behind the behavior of the materials. Several researchers have used the Glower-Rowe parameters as a cracking indicator [246,247]. It was also used in this study to check its applicability in the case of asphalt mastics. The ranking of different fillers was obtained as per the G-R parameter and the fatigue life, followed by the comparative analysis.

3.6 Phase V: Fatigue Performance Evaluation of the Asphalt Mixtures

The asphalt mixtures were prepared as per MoRTH-13 guidelines following DBM-2 gradation with a NMAS of 26.5 mm. The fractionation method was used for the gradation to avoid the discrepancies associated with stockpiling method or job mix formula. The fillers were used at 3, 5, and 7% representing low, average, and high filler content. The change in filler content was adjusted by varying only the aggregates retained on the 4.75 mm sieve to maintain uniformity in the gradation at different filler contents. The mixing and compaction temperature of the virgin and polymer-modified binders were obtained through rotational viscometer and DSR, respectively, prior to the mixture fabrication. The asphalt mixtures were prepared by mixing the required quantity of aggregates, filler, and binder at the corresponding mixing temperature. After mixing, the loose mixture was subjected to conditioning for 2 hours at compaction temperatures (MS-2) to account for the binder absorption. The OBCs were calculated at 4% air voids (Asphalt Institute MS-2) at each filler content for both binders. Hence, a total of 3*3*2=18 OBCs were obtained.

The fatigue performance evaluation of the asphalt mixtures was analyzed using the fracture test known as the SCB test. The test utilized the SCB specimen of 57 mm height and 95 mm diameter with pre-defined notch lengths of 15 mm and 30 mm prepared at 7% air voids. The test measured load and deformation based on which the strain energy is evaluated by calculating the area under the curve. The rate of change of strain energy with respect to notch length is calculated as J_c, known as the critical energy release rate. Finally, a methodology for selecting the optimum filler dosage from the properties of fillers and the binder was suggested, which can exhibit higher fatigue performance and requires a lesser quantity of binder.

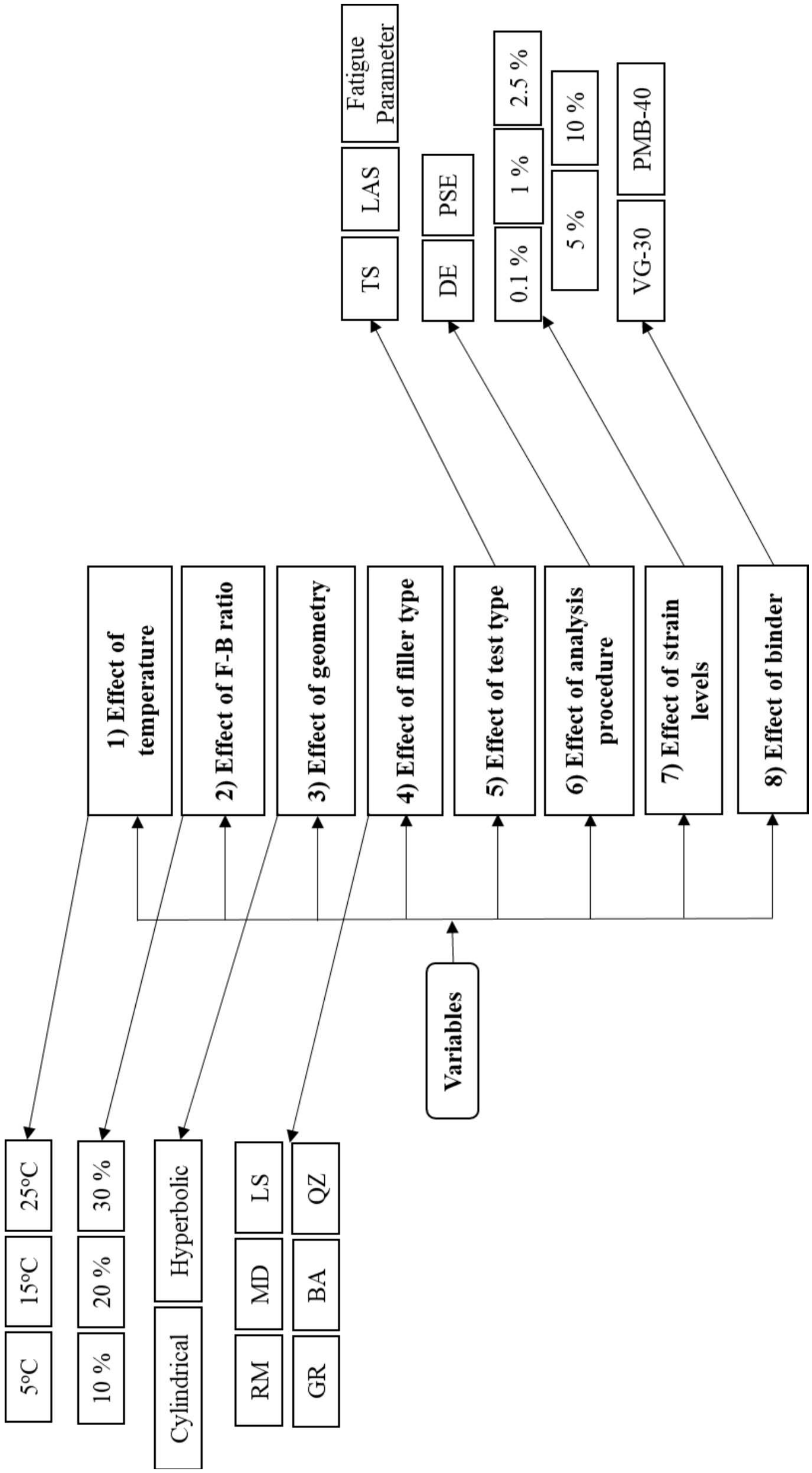

Figure 3.5 Factors considered for the fatigue analysis of asphalt binders and mastics

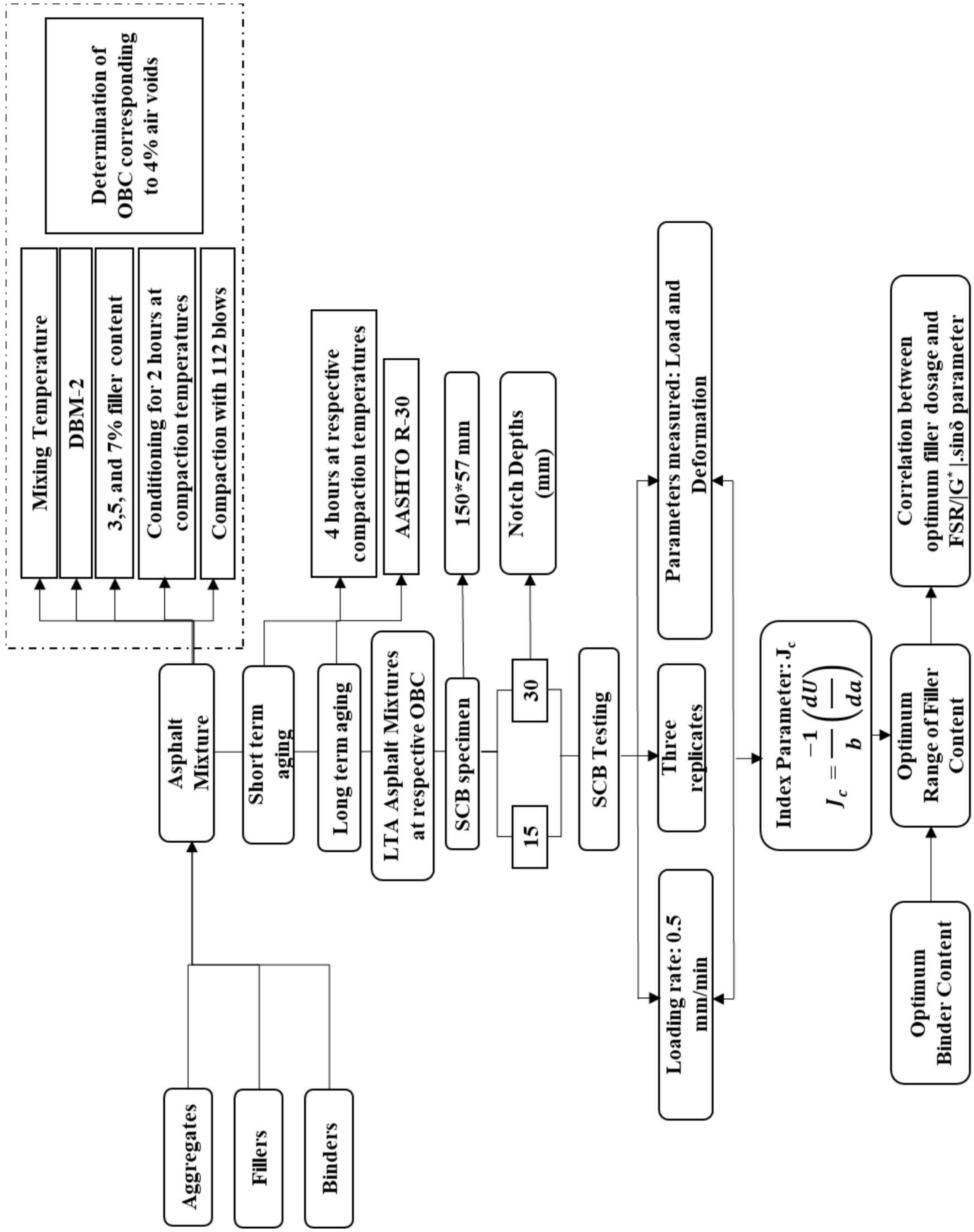

Figure 3.6 Fatigue performance evaluation of the asphalt mixtures and selection of optimum filler