Abstract

Name of the student: **Shivam Tripathi** Roll No: **231030054**

Degree for which submitted: **M.Tech.** Department: **Civil Engineering Department**

Thesis title: **Understanding the Role of Ageing and Moisture Damage to Asphalt Mixture using Laboratory based Evaluation of Fine Aggregate Matrix**

Thesis supervisors: **Dr. Prabin Kumar Ashish.**

Month and year of thesis submission: **June 2026**

Different forms of failures occur in asphalt pavements during its service life, including rutting, moisture damage and fatigue. Among these, moisture damage is considered one of the major distress type, as it weakens the bond between asphalt binder and aggregates, leading to stripping, stiffness reduction, ravelling, and loss of fatigue resistance. The problem is more severe in thin asphalt layer based applications such as micro-surfacing. Water can easily penetrate through pores and interfacial zones, weakening the adhesive bond between binder and aggregates and accelerating pavement deterioration. Such moisture damage based deterioration increases further because of aging to asphalt binder in the asphalt layer during construction phase and subsequently over the survice life.

Several laboratory methods at the Hot Mix Asphalt (HMA) scale, including Marshall Retained Stability,tensile strength ratio, and Wheel Tracking tests, are commonly used to evaluate moisture susceptibility. However, these methods require large specimen sizes, extensive materials. Material-level approaches either on binder or aggregate do not fully represent the behaviour of asphalt mixtures under rheological conditions. Alternatively, assesement may be made at potentially intermediate level using Fine Aggregate Matrix (FAM), which consist of binder, filler, fine aggregates, and air voids, provides an intermediate-scale approach for evaluating asphalt behaviour. FAM testing requires less material, improves experimental repeatability, and offers better sensitivity in understanding the combined effects of moisture and ageing, thereby bridging the gap between individual material-level characterization and full HMA-scale performance.

Therefore, the present study aims to systematically quantify the coupled effects of oxidative ageing and moisture conditioning on FAM using a comprehensive suite of rheological tests on FAM specimens, thereby providing insight into asphalt layer durability and performance. Maximum size of Aggregate 2.36 mm was taken based on prior research demonstrating its suitability in replicating actual FAM behaviour. Binder content was found using surface area method, and FAM mixtures were designed for 7% air void. Specimens were fabricated using core cutting method to ensure geometric uniformity and compatibility with Rheometer testing. Prepared FAM specimens were subjected to controlled moisture conditioning for different durations—1 day, 4 days, and 7 days.

Short term and Long term ageing protocols was applied to capture time-dependent oxidative hardening phenomena. The viscoelastic responses of the FAM was characterized using strain sweep, frequency sweep and time sweep tests. Frequency sweep tests evaluated rate-dependent stiffness, complex modulus evolution, and phase angle changes under different ageing and conditioning states. Time-sweep experiments captured fatigue damage progression and changes in material integrity under repeated cyclic loading.

Results reveal that ageing substantially increases stiffness and reduces phase angle, indicating a shift toward more elastic and brittle behaviour of the FAM. In contrast, moisture conditioning leads to a progressive reduction in complex modulus and a contraction of the linear viscoelastic LVE region, highlighting the weakening of the binder–aggregate interaction and reduced strain tolerance. The strain sweep results demonstrate a clear shift of the LVE limit toward lower strain levels with increasing moisture exposure, indicating earlier damage , particularly for LTA specimens. Frequency sweep analysis shows a consistent reduction in stiffness across the entire frequency spectrum with moisture conditioning, with a more pronounced effect observed in LTA mixtures, suggesting increased moisture susceptibility due to ageing-induced brittleness. Time sweep results further confirm that fatigue life decreases significantly with increasing strain level, moisture conditioning duration, and ageing severity, with LTA wet-conditioned specimens exhibiting the lowest fatigue resistance. The combined ageing–moisture interaction therefore reflects a coupled mechanism of oxidative hardening and moisture-induced degradation, resulting in accelerated stiffness loss and early fatigue failure. These findings demonstrate that while ageing enhances initial stiffness, it significantly increases vulnerability to moisture damage, and the resulting interaction governs the overall deterioration behaviour of FAM mixtures. The study highlights the effectiveness of FAM-based rheological characterization in capturing these mechanistic degradation pathways and providing reliable insights into mixture-level performance.

The study shows that while ageing enhances stiffness, it critically increases moisture susceptibility, and the combined ageing–moisture interaction governs accelerated damage evolution, which can be effectively captured using FAM-based rheological characterization.