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Investigation of Crack Growth Behavior in Heterogeneous Asphalt Concrete Using FEM Modeling Based on Random Aggregate Generation and Distribution Algorithms

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ABSTRACT

This study investigates the fracture behavior of asphalt concrete by modeling it as a multiphase material composed of aggregates and mastic. A series of two-dimensional finite element models was developed using a random aggregate generation and distribution algorithm to simulate the heterogeneous microstructure of asphalt mixtures. The generated specimens were analyzed in ABAQUS software, focusing on the evaluation of Mode I and Mode II stress intensity factors (SIFs) and stress distribution in single-edge notched beam (SENB) configurations. The simulation results demonstrate that the spatial distribution of aggregates plays a significant role in determining both the mode and magnitude of SIFs. While the Poisson ratios of the constituents had a negligible effect, their elastic moduli showed a considerable influence on fracture response. As the crack length increased, the stress field became more localized, indicating a shift from distributed elastic deformation to concentrated fracture. Additionally, regions with lower stiffness acted as stress amplifiers, guiding the crack path through weaker zones and intensifying local stress concentrations. These findings underscore the importance of accounting for microstructural heterogeneity in the fracture analysis and design of asphalt mixtures.

1. Introduction

Cracking is a major distress mechanism in asphalt pavements that compromises structural integrity and shortens service life. One critical form of cracking occurs under vehicle loading at low temperatures, where asphalt mixtures exhibit increased stiffness and reduced ductility. Under these conditions, the pavement becomes more brittle and is prone to load-induced cracking, even under standard traffic loads [1-4].

At low temperatures, the ability of the asphalt binder to dissipate energy decreases, leading to the accumulation of tensile and shear stresses under repeated loading. This makes the pavement more susceptible to crack initiation and propagation. To effectively analyze and predict this type of damage, fracture mechanics provides a robust framework. In particular, stress intensity factors (SIFs) offer a means to characterize the stress field at the tip of a crack and assess its potential to grow under given loading conditions.

Asphalt concrete is a heterogeneous material composed of mineral aggregates and asphalt binder. The fracture behavior of such mixtures is influenced by the distribution, size, and mechanical properties of aggregates, as well as the temperature-sensitive behavior of the binder. Consequently, the values of stress intensity factors, and thus the fracture resistance, depend heavily on the microstructural characteristics of the mixture. This highlights the importance of accounting for material heterogeneity when

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evaluating the low-temperature fracture performance of asphalt pavements under traffic loading.

Numerous studies have been carried out to investigate the fracture behavior of asphalt mixtures using heterogeneous modeling approaches. These studies aim to more accurately capture the effects of microstructural features such as aggregate distribution, shape, and the mechanical properties of both aggregates and mastic. By explicitly representing the heterogeneous nature of asphalt concrete, these models provide deeper insights into crack initiation and propagation mechanisms. In the following, several key studies in this area are briefly reviewed.

Teng et al. [5] performed finite element simulations of single-edge notched asphalt concrete beams using a novel random heterogeneous model calibrated with the Kalman filter. Results showed that lower temperatures led to more vertically inclined cracks, decreased mode I fracture proportion, and increased crack propagation speed in the mastic.

Chen et al. [6] developed a CZM-based finite element model using 3D image-aided heterogeneous structures to investigate asphalt concrete fracture behavior. The model was validated through SCB tests and used to study the effects of temperature, loading rate, aggregate geometry, and fracture properties. Results showed that lower temperatures and angular aggregates increase damage, while higher fracture energy improves load capacity and crack resistance.

Shi et al. [7] developed discrete element models based on 3D-scanned aggregate contours to analyze the meso-mechanical behavior of recycled asphalt mixtures. Their findings showed that RAP content had little effect on skeleton contact points but significantly impacted interfacial stresses and crack development. Shear cracks occurred mainly at RAP interfaces, while tensile cracks dominated in asphalt mortar and aggregate contacts, with higher RAP content reducing rutting resistance.

Zhang et al. [8] investigated the cracking behavior of Semi-Flexible Pavement (SFP) using three-point bending tests and finite element simulations based on a meso-scale heterogeneous model. The study found that increasing the tensile strength of asphalt mortar and asphalt–aggregate interfaces enhanced load capacity but accelerated crack propagation. Higher fracture energy delayed crack growth with diminishing effect, and optimal parameter ranges were recommended to improve SFP crack resistance.

Chen et al. [9] developed a high-resolution 2D finite element model using X-ray CT data and Cohesive Zone Modeling (CZM) to simulate fracture behavior in asphalt mixtures. The model embedded zero-thickness cohesive elements in both asphalt mastic and aggregate interfaces, and accurately predicted crack initiation and growth under fatigue loading. Results showed that crack behavior depends on temperature and material heterogeneity, with cracks initiating in the mastic at 25 °C and at binder–aggregate interfaces at 5 °C.

Lu et al. [10] developed a discrete element method (DEM) model with a novel contact law to simulate the rate- and time-dependent behavior of asphalt concrete. The model integrates viscoelastic and elastoplastic damage mechanisms and naturally captures crack initiation and growth. It was validated against experimental tests such as creep, relaxation, and SCB. The approach offers new insights into the transition from diffuse to localized failure under complex loading.

In another study by Wu et al. [11] the effects of moisture damage on asphalt mixtures were investigated using pull-off tests, SCB tests, and finite element modeling with cohesive zone models. Results showed that water immersion significantly reduced adhesion strength and fracture resistance, leading to earlier crack initiation and increased damage at binder–aggregate interfaces. The combined lab and numerical approach effectively captured moisture-induced degradation across macro and meso scales.

Xue et al. [12] developed a heterogeneous fracture simulation approach using the Discrete Element Method (DEM) and a novel algorithm to model asphalt concrete in SCB tests. A bilinear cohesive model captured crack initiation and propagation, with simulations validated against experiments at various temperatures and NMAS levels. Results showed that aggregate strength, NMAS, and temperature significantly influence crack behavior, with tensile forces being the primary failure mechanism.

Gao et al. [13] studied mix-mode fracture in asphalt concrete using ASCB tests and meso-scale finite element simulations with random aggregates. Results showed that cracks follow paths of least energy, with higher shear proportions increasing strength but reducing crack connectivity. The study revealed detailed meso-scale crack evolution and quantified tensile and shear failure contributions.

Du et al. [14] developed a multiscale finite element model integrating asphalt mixture microstructure and pavement macrostructure to investigate cohesive and adhesive damage in asphalt pavements. The study revealed that heterogeneity causes stress concentrations leading to cracking, and lower adhesive strength at binder-aggregate interfaces significantly contributes to surface-initiated “top-down” cracks.

In another study by Sun et al. [15] developed a microstructure-based multiscale finite element method to analyze the impact of temperature fields on damage initiation in asphalt pavements under traffic loading. Incorporating thermal radiation, convection, and conduction, the model links global pavement and local mixture scales using digital image processing and cohesive zone modeling. Results highlight the critical role of temperature variation in pavement damage and demonstrate the method’s potential for improving performance prediction and pavement design.

Although several previous studies have modeled the fracture behavior of asphalt concrete, many have relied on homogenized or idealized representations of the material microstructure. These approaches often overlook the influence of aggregate morphology, spatial distribution, and localized interactions near the crack tip. The present study addresses this gap by employing a random aggregate generation algorithm to construct heterogeneous SENB specimens and analyze their fracture behavior through finite element modeling. The novelty of this work lies in its systematic investigation of the combined effects of aggregate distribution, crack location, and constituent material properties, particularly under low-temperature conditions, on both Mode I and Mode II stress intensity factors. By explicitly modeling microstructural heterogeneity, this research provides new insights into the fracture resistance mechanisms of asphalt mixtures, offering a more realistic basis for performance prediction and material design.

2. Methodology

Although aggregates are irregularly shaped polygons in reality, modeling and meshing these complex geometries is highly challenging. To overcome this issue, the aggregates in this study were assumed to be circular in shape to simplify the meshing process and reduce computational complexity.

Table 1 presents the gradation of the aggregates used in the asphalt concrete specimens. While the weight percentage of fine aggregates is lower than that of coarse aggregates, the number of fine particles is significantly higher. Therefore, modeling all individual fine aggregates is impractical. To address this, many researchers have modeled only the coarse aggregates explicitly, while representing the fine aggregates, binder, and air voids as a homogeneous mastic phase. For example, Kim et al. [16-18] considered particles larger than 2.36 mm as coarse aggregates. Similarly, Li and Metcalf John [19] defined particles smaller than 4.75 mm as fine aggregates. In this study, aggregates larger than 2.36 mm were considered coarse and were explicitly modeled, while finer particles were included within the mastic matrix. This approach provides a reasonable balance between modeling accuracy and computational efficiency.

MATLAB software was used for the generation and distribution of aggregates. Fig. 1 illustrates the algorithm developed for the random generation and placement of aggregates. In this algorithm, each gradation range from the aggregate gradation table is defined as a separate group. Based on the custom-written MATLAB code, the algorithm first generates a circular aggregate with a random radius according to the specified gradation limits. Then, the generated particle is checked to ensure that it does not overlap with previously placed aggregates and is fully located within the SENB specimen boundaries.

Table 1. Aggregate gradation for asphalt mixture.

Percent passing	Sieve size (mm)
100	19
100-90	12.5
77-44	4.75
58-28	2.36
21-5	0.3
10-2	0.075

3. Geometry

The geometry of the SENB specimen consists of a rectangular asphalt concrete beam with a single notch introduced on one edge. The typical dimensions of the specimen include a length L and height H. In the standard configuration, a notch of length a is centrally located on one edge of the specimen. However, to induce mixed-mode fracture conditions, the notch is shifted horizontally from the mid-span by a distance d, resulting in an asymmetric crack location.

The beam is supported on two rollers placed symmetrically at a span S, and a vertical load is applied at the top surface of the specimen. Due to the eccentric notch, the crack tip experiences both normal (tensile) and tangential (shear) stresses, facilitating the study of combined Mode I/II fracture behavior. The degree of mode mixity is controlled by the notch eccentricity d, notch length a, and the overall dimensions of the specimen.

This geometric modification allows for a relatively simple yet effective experimental setup to investigate the fracture performance of asphalt mixtures under realistic service-like loading conditions. A schematic illustration of the off-center notched SENB specimen is shown in Fig. 2.

4. Modeling

To apply boundary conditions, the vertical movement of the support was constrained, and a vertical load of P = 100 N was applied to the SENB specimen. As shown in Fig. 3, the asphalt mixture was modeled as a composite of coarse aggregates embedded in a mastic matrix. The aggregates were considered to behave as linearly elastic materials, while the mechanical behavior of mastication is known to be temperature-dependent. At elevated temperatures, mastic exhibits viscoelastic behavior, and rutting becomes the dominant mode of pavement failure. Conversely, at subzero temperatures, mastic behaves predominantly as an elastic material, and cracking becomes the principal distress mechanism in asphalt mixtures.

To investigate the influence of the mechanical properties of aggregates and mastic on the crack tip fracture parameters, a two-dimensional meso-structured (two-phase) model was developed and simulated using ABAQUS software. Approximately 250,000 2D CPE8R elements were used to discretize the aggregates and mastic phases. As illustrated in Fig. 4, a refined mesh and singular elements were employed near the crack tip to accurately capture the stress field singularity.

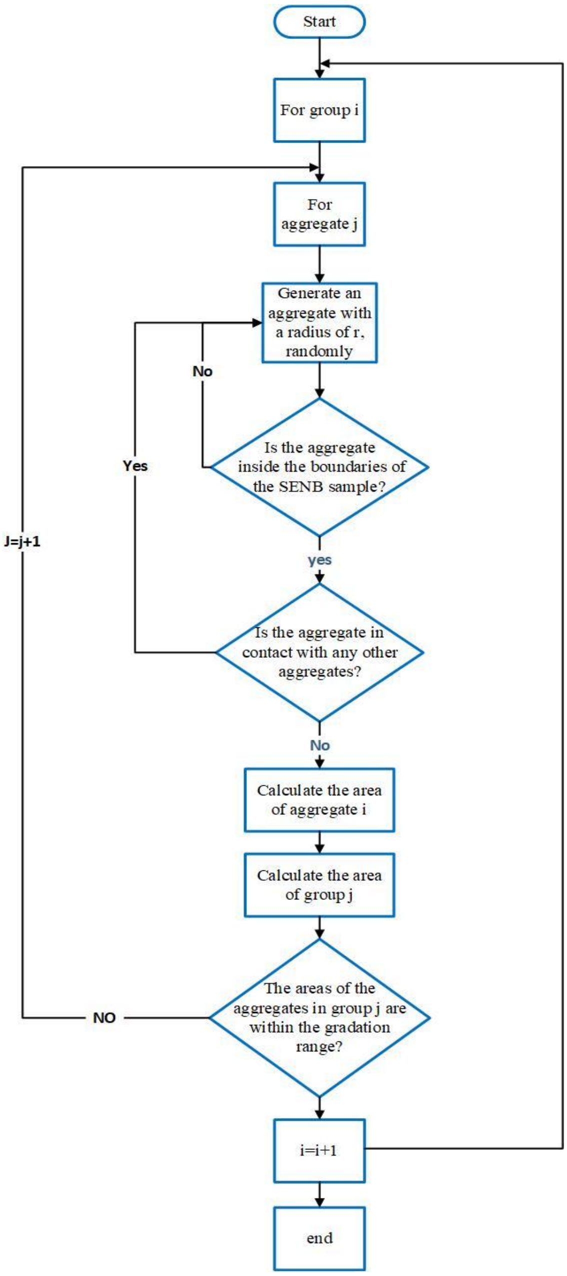


Fig. 1. Flowchart of the aggregate generation and packing algorithm used in asphalt mixture modeling.

Since the focus of this study is on the low-temperature fracture behavior of asphalt mixtures, both aggregate and mastic phases were assumed to behave as linear elastic materials. This assumption is consistent with AASHTO TP105-13 [20] and is widely used in literature for evaluating the critical stress intensity factor (KIC) of cracked asphalt specimens. The mechanical properties used for the aggregate and mastic phases in this study are presented in Table 2 [21-24]. A perfect bond between the two phases was assumed.

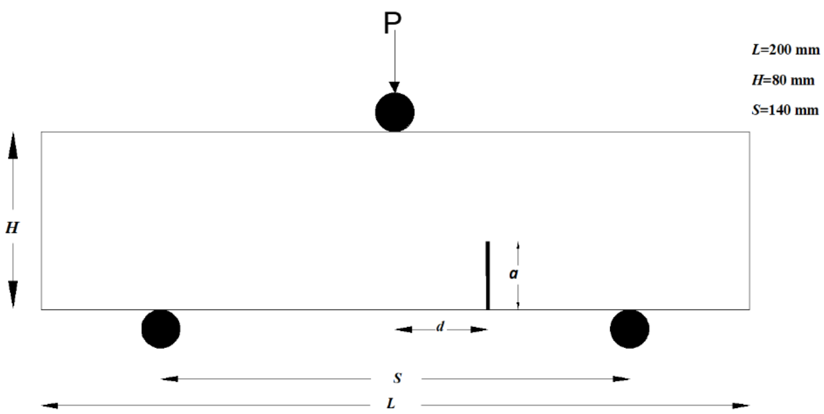


Fig. 2. Single edge notch bending (SENB) specimen subjected to three-point bending load.

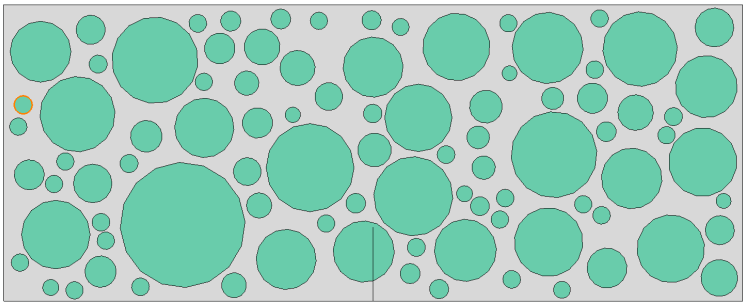


Fig. 3. The generated SENB specimen consisting of two-phase coarse aggregates (green) and mastic matrix (gray).

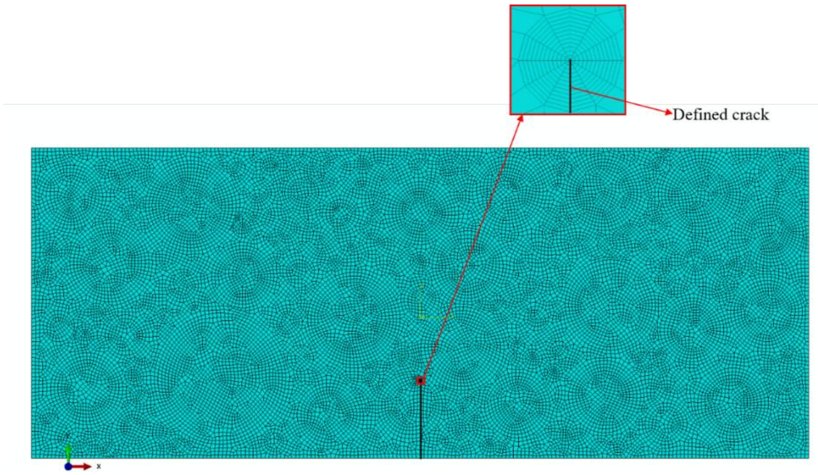


Fig. 4. Finite element representation of the SENB specimen.

Table 2. Different materials are considered as asphalt mixture components at low temperatures

Material	Young's modulus (*E*) (MPa)	Poisson's ratio (*ν*)
Coarse aggregates	30000, 50000, 80000	0.05, 0.25, 0.45
Mastic	5000, 10000, 15000, 20000	0.15, 0.25, 0.35

5. Fracture parameters

Williams [25] proposed a series of equations to describe the stress field in the vicinity of a crack tip under mixed-mode loading conditions. The stress components in polar coordinates near the crack tip are expressed as follows:

$$\sigma_{rr} = \frac{1}{\sqrt{2\pi r}}\cos\frac{\theta}{2}\ [K_I\left(1+\sin^2\frac{\theta}{2}\right)+\frac{3}{2}K_{II}\sin\theta - 2K_{II}\tan\frac{\theta}{2} \tag{1}$$

$$\tau_{r\theta} = \frac{1}{2\sqrt{2\pi r}}\cos\frac{\theta}{2}\ [K_I\sin\theta + K_{II}(3cos\theta - 1) \tag{2}$$

$$\sigma_{\theta\theta} = \frac{1}{\sqrt{2\pi r}}\cos\frac{\theta}{2}\ [K_I\cos^2\frac{\theta}{2} - \frac{3}{2}K_{II}\sin\theta] \tag{3}$$

Here, *r* and *θ* represent the radial distance and angular position relative to the crack tip, respectively. The terms *KI* and *KII* are the mode I and mode II stress intensity factors, which characterize the intensity of the stress field near the crack tip under different loading modes.

The stress distribution around the crack tip is strongly influenced by the material's elastic properties, loading conditions, and crack location. These parameters play a crucial role in predicting crack initiation and propagation directions. For a more accurate assessment of crack growth, factors such as material heterogeneity and aggregate distribution should also be considered.

6. Result

The stress intensity factors (SIFs) for Mode I (*KI*) and Mode II (*KII*) fracture modes were evaluated for several non-homogeneous asphalt specimens with a single-edge notch bending (SENB) configuration. The SIFs were calculated as a function of crack offset distance d from the center of the specimen.

Fig. 5 illustrates the variation of *KI* with respect to crack offset d. It is observed that all heterogeneous samples exhibit a significant dependency on the crack location. In general, *KI* values peak when the crack is located near the center or slightly off-center, and gradually decrease as the crack moves toward the edge of the specimen. Sample 2 shows the highest initial *KI* value, while Sample 3 presents a smoother decline. The homogeneous specimen, in contrast, displays a more consistent and linear reduction in *KI* as d increases, indicating more predictable fracture behavior.

Fig. 5 presents the corresponding *KII* values. The results show that Mode II SIFs are relatively smaller in magnitude compared to Mode I and fluctuate around zero. This suggests the presence of minor shear contributions due to material heterogeneity and crack asymmetry. Samples 1 and 2 show oscillatory trends in *KII*, with peaks and troughs that imply localized shear stress concentrations. Sample 3 maintains values closer to zero, indicating predominantly Mode I behavior. The homogeneous specimen again exhibits the most stable response, with minimal variation in *KII*.

These findings confirm that material heterogeneity significantly influences the fracture behavior of asphalt specimens, particularly affecting Mode I crack propagation. Crack positioning relative to material inhomogeneities plays a crucial role in determining the fracture path and intensity.

According to this figure, the numerical results show significant differences, ranging from 20% to 90%, between the heterogeneous and homogeneous modeling approaches, depending on the type of sample (i.e., the spatial distribution of aggregates within the SENB specimen) and the crack length (i.e., the relative distance between the crack tip and nearby aggregates).

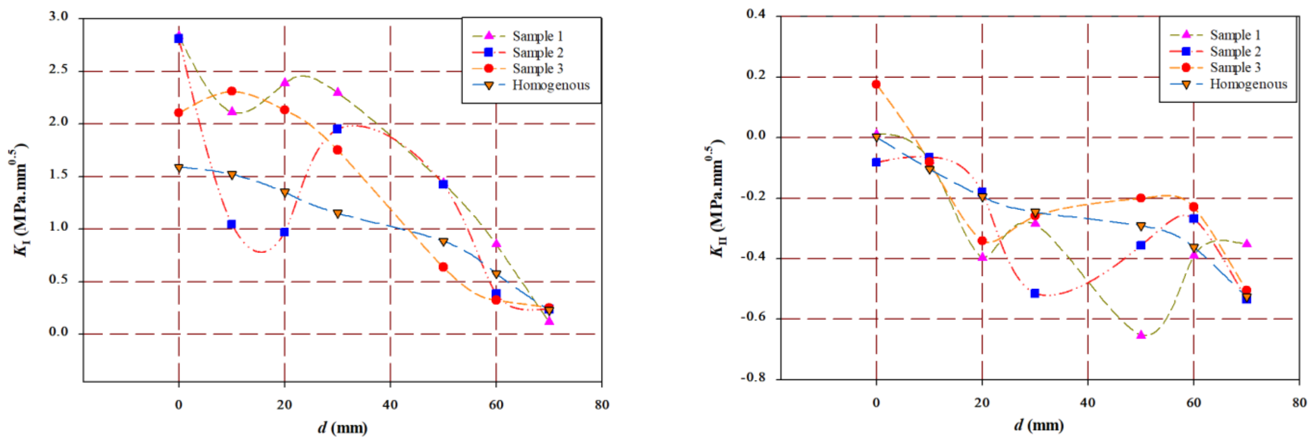


Fig. 5. Stress intensity factor variations (Mode I and Mode II) for a crack located at a distance d from the center of an SENB specimen under different aggregate distributions.

Fig. 6 shows the variation of mode I and mode II stress intensity factors for an SENB (Single Edge Notch Bending) asphalt specimen with varying elastic moduli (*E* = 30, 50, and 80 GPa) of coarse aggregates. The crack offset distance from the center of the specimen, denoted by d, is represented on the horizontal axis, while the corresponding stress intensity factor is plotted on the vertical axis.

It is evident from the figures that for non-homogeneous specimens, as the modulus of elasticity of the aggregates increases, the mode I stress intensity factor (*KI*) increases as well. This behavior is attributed to the fact that aggregates with higher stiffness generate higher stress concentrations around the crack tip. As discussed by Anderson [26] and Lawn [27], the presence of stiff inclusions in a softer matrix leads to an intensification of the stress field near the crack tip, which raises the value of *KI*. In contrast, the homogeneous specimen, which lacks such elastic discontinuities, exhibits the lowest values of *KI*, indicating a more uniform stress distribution [28].

In the case of mode II (*KII*), shown in Fig. 6, the values remain generally lower than mode I but exhibit fluctuations depending on the crack position and the modulus of the aggregates. These fluctuations are caused by mixed-mode interactions and are highly sensitive to the stiffness mismatch, which alters the local shear stress distribution. Similar observations were reported in earlier studies on fractures in heterogeneous materials.

Fig. 7 depicts the influence of Poisson's ratio of the aggregates (0.05, 0.25, and 0.45) on *KI* and *KII*. As Poisson's ratio increases, the *KI* values also increase, particularly when the crack tip is near the center of the specimen. According to Christensen [29], a higher Poisson's ratio results in greater lateral expansion under uniaxial stress, which leads to increased confinement and elevated normal stress near the crack tip, thereby increasing *KI*.

Furthermore, the observed fluctuations in *KII* values with respect to Poisson's ratio can again be linked to the induced local shear stresses and their redistribution around the crack path in a heterogeneous medium. These effects become more pronounced when the crack is located away from the symmetry axis, where asymmetric interactions between the aggregates and the surrounding matrix occur.

These results clearly demonstrate that both the elastic modulus and Poisson's ratio of aggregates significantly influence the stress intensity factors in asphalt mixtures. Therefore, accounting for such heterogeneities is critical in accurately evaluating the fracture behavior of asphaltic composites.

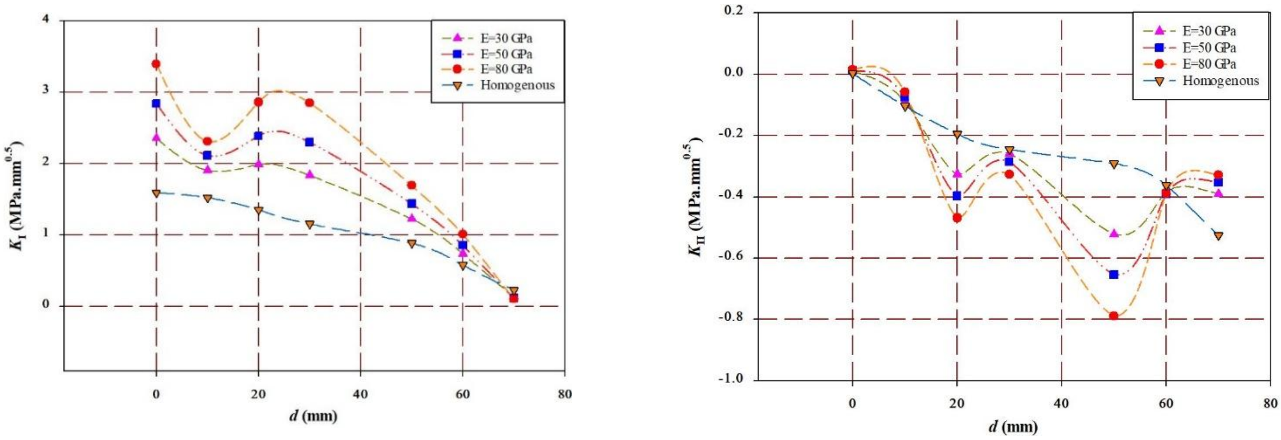


Fig. 6. Effect of aggregate elastic modulus on Mode I and Mode II stress intensity factors.

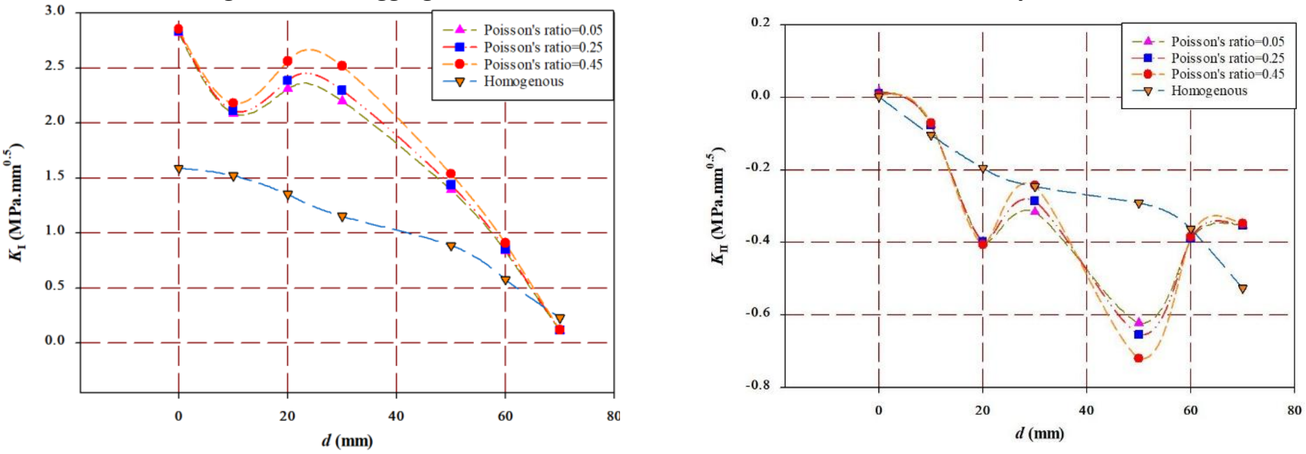


Fig. 7. Effect of Poisson's ratio of aggregates on Mode I and Mode II stress intensity factors.

Fig. 8 displays the variations of *KI* and *KII*, respectively, for mastic elastic moduli of 5, 10, 15, and 20 GPa, compared to a homogeneous model. As shown in Fig. 8, *KI* reaches its maximum near the notch (at $d = 0$) and gradually decreases with increasing distance from the crack tip. Decreasing the mastic modulus leads to a significant increase in Mode I SIF. For example, the peak *KI* for $E = 5$ GPa is approximately twice as high as that for the homogeneous case, indicating that softer mastic phases intensify tensile stress concentration at the crack tip. In contrast, as seen in Fig. 8, *KII* demonstrates an oscillatory pattern with both positive and negative values. Lower elastic modulus results in more pronounced deviations in shear stress, with increased amplitude of *KII* along the crack front. The homogeneous model exhibits a more stable and less fluctuating shear response. These results underscore the substantial role of stiffness mismatch in modulating both tensile and shear stress distributions near the crack tip.

In Fig. 9, the variation of *KI* shows that Poisson's ratio has a relatively moderate effect on Mode I SIF. Although the general trend remains similar across the three values, slightly higher ν values tend to reduce *KI* marginally in the central part of the specimen. This can be attributed to the enhanced lateral contraction resistance in mastics with higher Poisson's ratios.

Fig. 9 reveals that Mode II SIFs are more sensitive to changes in ν. Increasing Poisson's ratio leads to larger fluctuations in *KII*, especially at intermediate distances from the notch. This behavior reflects the impact of transverse strain on shear stress development, indicating that mastic with higher ν values amplifies the nonuniform shear field near the crack tip.

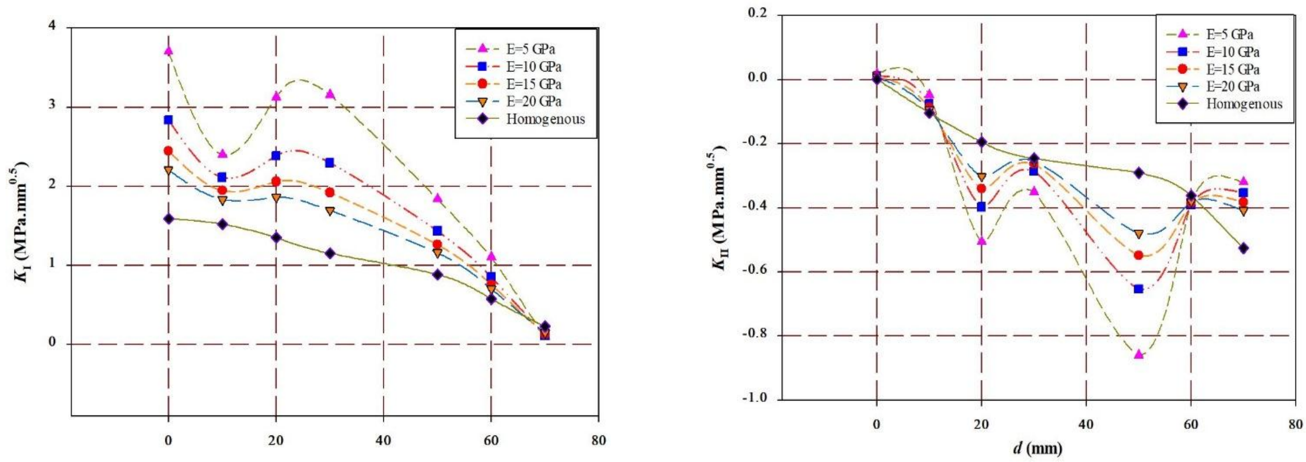


Fig. 8. Effect of mastic elastic modulus on Mode I and Mode II stress intensity factors.

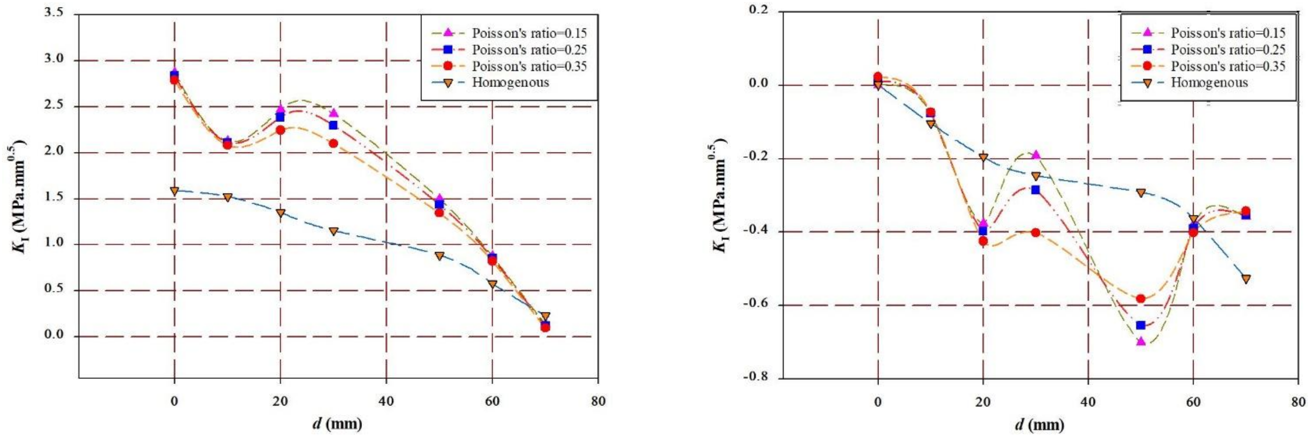
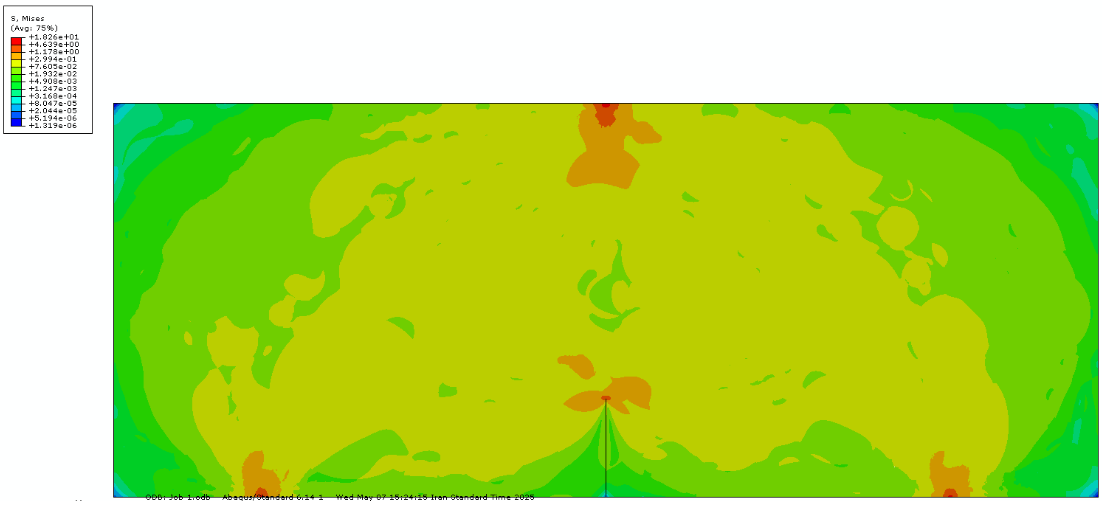


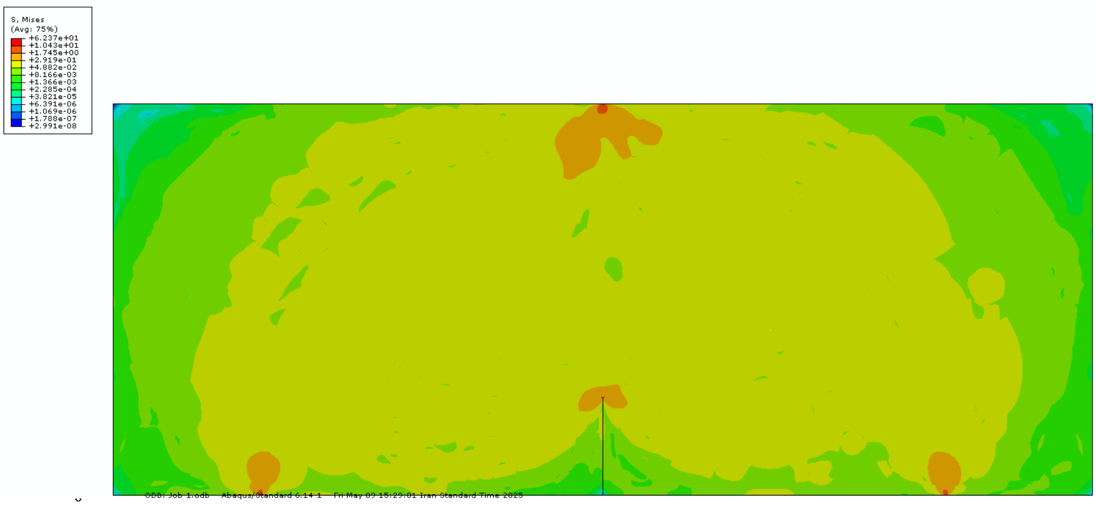
Fig. 9. Effect of Poisson's ratio of mastic on Mode I and Mode II stress intensity factors.

Fig. 10 presents the stress distribution in three different Single Edge Notch Bending (SENB) specimens composed of asphalt materials, modeled with spatial heterogeneity in their mechanical properties. Each specimen exhibits a unique stress field pattern influenced by the non-uniform distribution of stiffness and other material characteristics. The heterogeneous modeling approach captures the inherent variability present in asphalt mixtures, offering a more realistic representation of their fracture behavior.

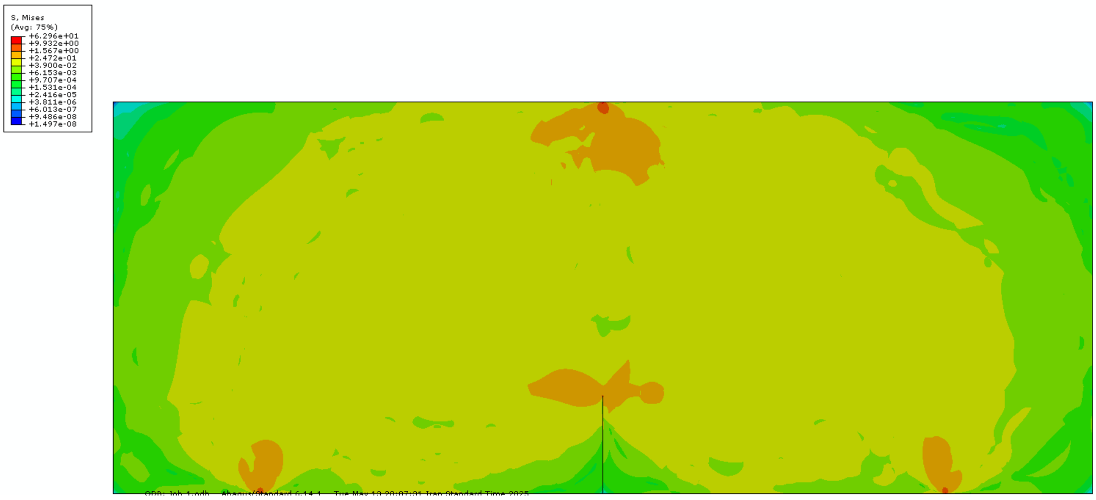
In all cases, high-stress concentrations are observed near the notch tip, as expected, but their intensity and spread vary significantly among the three configurations. Compared to the homogeneous specimen (Fig. 10), the heterogeneous models reveal more localized and asymmetric stress fields, which are driven by the internal microstructural differences. These localized stress amplifications can lead to premature crack initiation in weaker zones, demonstrating the critical role of material heterogeneity in fracture performance. Moreover, regions with lower stiffness within the heterogeneous models act as preferred paths for crack propagation, confirming that the inclusion of non-uniformity in material properties can have a considerable impact on predicting failure mechanisms in asphalt-based structures.



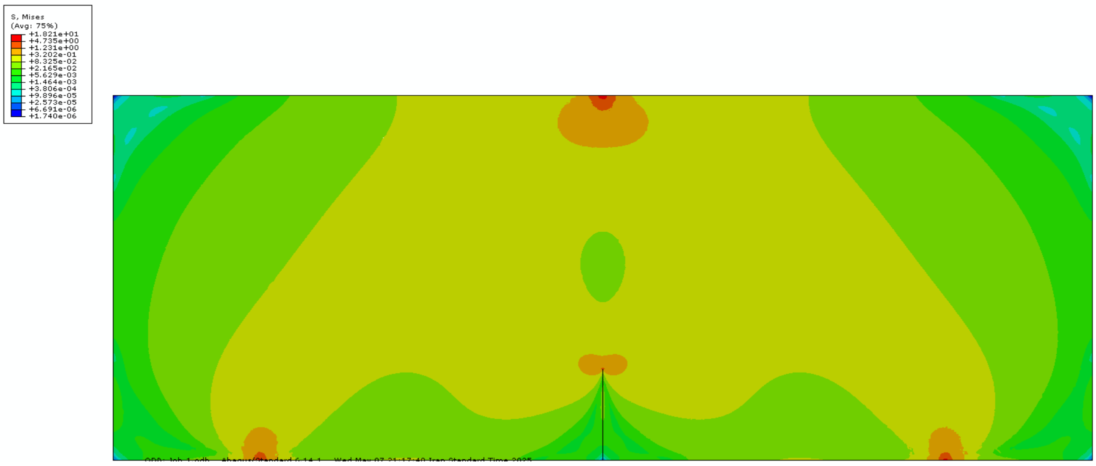
Sample 1



Sample 2



Sample 3



Homogeneous Model

Fig. 10. Stress distribution contours in heterogeneous asphalt specimens modeled using random aggregate generation and distribution algorithm.

Fig. 11 illustrates the stress distribution in a single heterogeneous asphalt SENB specimen at three stages of crack growth—corresponding to crack lengths of 20 mm, 40 mm, and 60 mm. The results reveal clear changes in both the location of stress concentration zones and the overall shape of the stress field as the crack propagates.

At the initial stage with a 20 mm crack (Fig. 11), the stress is primarily concentrated at the notch tip on the lower edge of the specimen. The distribution appears relatively symmetric and broad, indicating a more uniform load-bearing response of the surrounding material. Stress contours spread gradually around the notch, suggesting limited localization.

As the crack extends to 40 mm (Fig. 11), the stress concentration shifts forward along the crack path and becomes more pronounced. The distribution loses its symmetry, becoming elongated and skewed in the direction of crack growth. The high-stress region narrows and intensifies, especially in zones of lower stiffness within the heterogeneous material. These zones act as stress amplifiers, guiding the crack through the weaker areas.

By the time the crack reaches 60 mm (Fig. 11), the stress field becomes sharply localized near the crack tip. The distribution evolves into a narrow, high-intensity peak, reflecting a critical state close to fracture. The stress away from the tip decreases significantly, indicating a transition from distributed elastic deformation to localized failure. The stress contours now align strongly with the crack trajectory, emphasizing the dominant influence of material heterogeneity on fracture direction.

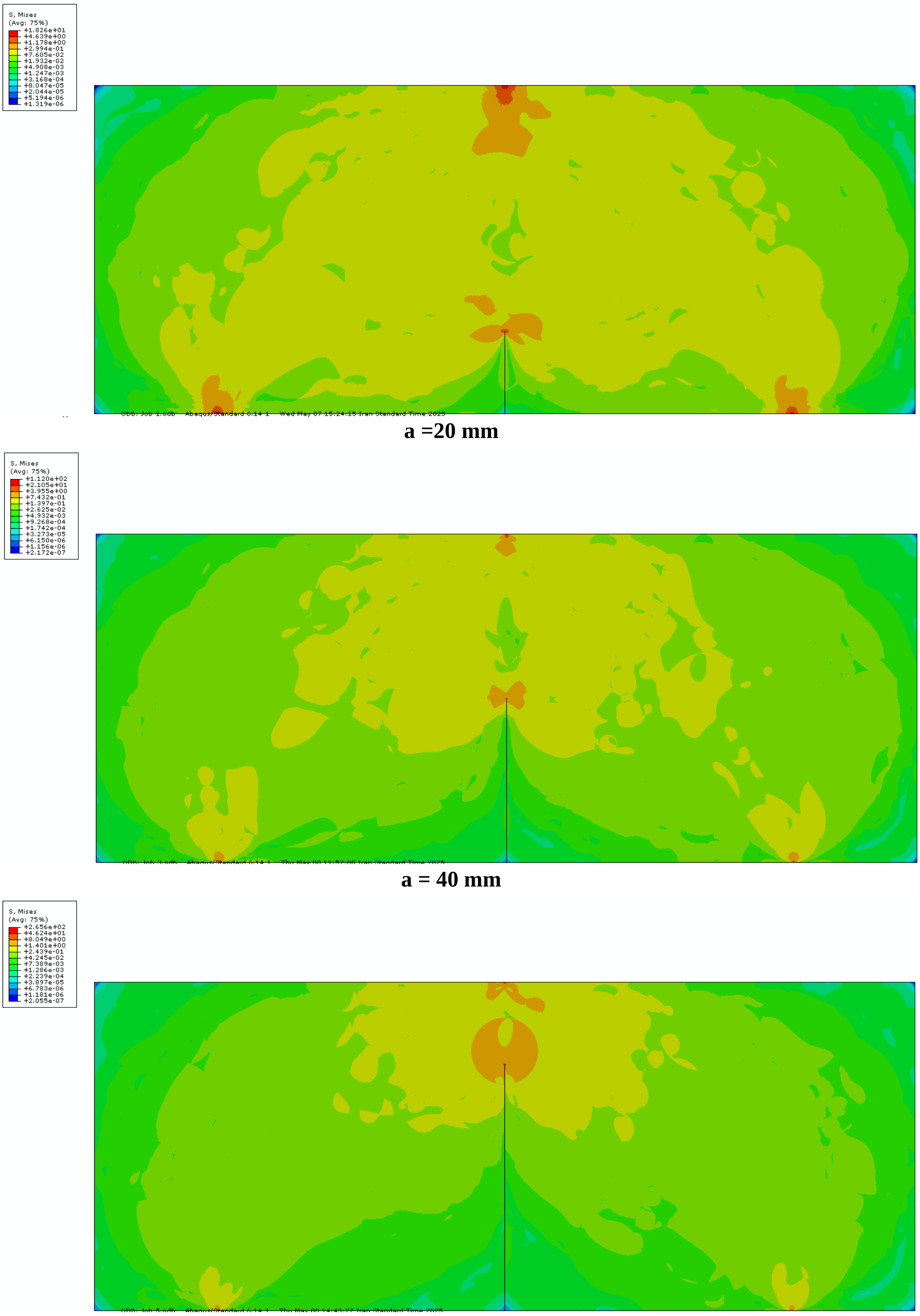


Fig. 11. Stress distribution in heterogeneous asphalt specimens for various crack lengths (20 mm, 40 mm, and 60 mm).

7. Conclusion

In this study, the asphalt mixture was modeled as a multiphase material consisting of aggregates and mastic, and its fracture behavior was investigated using a large set of two-dimensional finite element models. To this end, heterogeneous asphalt specimens were numerically generated via a random aggregate generation and distribution algorithm. These models were then analyzed using the ABAQUS finite element software. Mode I and Mode II stress intensity factors (SIFs), along with the stress distribution in a single-edge notched beam (SENB) specimen, were evaluated. Based on the results obtained from the finite element simulations, the following key findings were observed:

- The aggregate distribution significantly influences the fracture behavior of asphalt concrete, particularly the mode and magnitude of stress intensity factors.

- The Poisson ratios of both mastic and aggregates have a minor effect on the stress intensity factors, whereas their elastic moduli exhibit a significant influence.
- As the crack length increases, the stress distribution becomes increasingly asymmetric and focused, highlighting the influence of material heterogeneity on fracture evolution.
- Zones of lower stiffness act as stress amplifiers, redirecting the crack path toward weaker areas and intensifying local stress concentrations.
- With increasing crack length, stress fields evolve from broad and symmetric to narrow and highly localized forms.

Despite these findings, the study involves several simplifying assumptions that introduce limitations. The aggregates were modeled as idealized circular inclusions, which do not capture the irregular geometries of real aggregates. Moreover, a perfect bonding condition was assumed between aggregates and mastic, neglecting potential interfacial debonding or slippage. The analysis was also limited to two-dimensional models, which may not fully capture the three-dimensional stress states present in real asphalt mixtures. Future work will focus on incorporating more realistic aggregate shapes, interface modeling via cohesive zones, and extending the analysis to three-dimensional and coupled thermo-mechanical frameworks for enhanced predictive accuracy.

Statements & Declarations

Author contributions

Majid Jebalbarezi Sarbijan: Investigation, Formal analysis, Validation, Resources, Writing - Original Draft, Writing - Review & Editing.

Bahram Shirini: Investigation, Conceptualization, Methodology, Writing - Review & Editing, Writing - Review & Editing.

Hamed Rooholamini: Investigation, Conceptualization, Methodology, Writing - Review & Editing, Writing - Review & Editing.

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Data availability

The data presented in this study will be available on interested request from the corresponding author.

Declarations

The authors declare no conflict of interest.

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