CRACKING RESISTANCE OF NANO-MODIFIED BITUMEN-FILLER MASTICS

Banreddy Harish[1], Dr. C. Sashidhar[2]*, Dr. C. Ramachandrudu Chittar[3]

1   Research Scholar, Department of Civil Engineering, JNTUA, Ananthapuramu , Andhra Pradesh.

2   Professor, Department of Civil Engineering, JNTUA College of Engineering, Ananthapuramu, Andhra Pradesh.

3   Principal, CRIT, Ananthapuramu, Andhra Pradesh.

Abstract:

The IDEAL-CT test was conducted on bitumen–filler mastics incorporating granite filler (GF), limestone filler (LSF), and marble powder filler (MPF) at different filler–binder ratios and testing temperatures. Cylindrical specimens measuring 50 mm in diameter and 20 mm in thickness were used to assess the cracking resistance under various conditions. A constant displacement rate of 1 mm/min was maintained throughout the testing to ensure consistent loading across all mixtures. An unmodified VG30 binder was used. The study presented cracking resistance in terms of fracture energy and cracking tolerance index of nano-modified bitumen-filler mastics prepared with VG30 unmodified binder. The results showed a significant influence of filler content and temperature of cracking resistance of bitumen-filler mastics with different nano-modifiers and fillers. The marble powder filler resulted in a superior performance

Keywords: nano-modifiers, bitumen-filler mastic, marble powder filler, fracture energy, cracking tolerance index.

Background:

Nanotechnology has developed into a transformative area of science concerned with studying and controlling materials at dimensions ranging from 1 to 100 nanometers (1 nm = 10^{-9} m) (Sankaranarayannan and Jagadesan, 2016). Progress in this domain has been projected to revolutionize the understanding and utilization of both conventional and innovative materials, offering new functionalities across chemistry, physics, biology, and material sciences. In civil and structural engineering, nanotechnology emerged as a promising approach to address

durability and performance issues in infrastructure systems. The development of nanomaterials characterized by extremely high surface area, improved stability, catalytic capability, enhanced fatigue and rutting resistance, greater tensile strength, and resistance to environmental effects has shown remarkable benefits when dispersed at the nanoscale (Sabaraya et al., 2018).

Asphalt binder, which is a viscoelastic medium used to glue mineral aggregates in flexible pavements, has traditionally been modified with additives such as polymers, resins, and rubber to enhance its functional properties (Yao et al., 2012; Sabaraya et al., 2018). The incorporation of nanoparticles in relatively small amounts provides further improvements because of their distinct characteristics, including their very high surface-to-volume ratio, confinement effects, and high percentage of atoms at the surface (Yang and Tighe, 2013). Such nano-modification improves binder performance in terms of viscosity, complex shear modulus, phase angle, ductility, rutting resistance, thermal cracking resistance, oxidative aging, and even changes in SARA fractions (saturates, aromatics, resins, asphaltenes). Additionally, certain nanoparticles, such as titanium dioxide, impart photocatalytic properties that contribute to better resistance against environmental degradation and extend the durability of asphalt binders (Al-Taweel and Saud, 2016).

Research findings indicate that incorporating organic montmorillonite (OMMT) in the range of 3–6 % by binder weight significantly improves the performance of asphalt mixtures (Jahromi & Khodaii, 2009; Hossain et al., 2015; Abdullah et al., 2016). Laboratory evaluations on fatigue and rutting resistance have shown that the 6 % OMMT dosage delivers the highest improvement in resistance to cracking and permanent deformation (Abdullah et al., 2016; Ashish et al., 2017). The modification mechanism depends on whether the clay layers stay intercalated with asphalt molecules or are exfoliated into single platelets; in both cases, the binder becomes more elastic and better able to recover under repeated traffic loading, which enhances fatigue durability (Jahromi, 2015). Furthermore, the platelet structure forms a protective shield against oxygen and ultraviolet radiation, delaying oxidative aging and helping to maintain binder flexibility over extended service life (Wang et al., 2021). Practicality in handling is retained, as viscosity measurements indicated only a slight reduction when mixing temperatures were raised from 130 °C to 165 °C, suggesting that existing production temperatures remain suitable (Ezzat et al., 2016). In warm climatic zones, careful selection of OMMT grade has been shown to elevate the binder softening point, thus enhancing high-temperature stability (Zare-Shahabadi et al., 2010). Rheological testing through dynamic shear analysis also confirms that OMMT-modified binders achieve higher complex modulus (G*)

and reduced phase angle (δ), signifying lower rutting susceptibility under heavy loading (Hassan et al., 2023; Mahdi, 2013).

Materials and Methodology

Indirect Tensile Asphalt Cracking Test (IDEAL-CT) was performed on cylindrical specimens to assess their resistance to cracking. In this test, a compressive load was applied along the vertical diametrical axis of the specimen at a constant rate of 1.0 mm/min, and the procedure was carried out at three different temperatures: 15 °C, 25 °C, and 35 °C, following ASTM D8225-19 guidelines. 50 mm diameter and 20 mm thick mastic specimens were subjected to vertical line loads and the plots between vertical displacement and applied load were analysed to compute the fracture energy and cracking tolerance index. A constant displacement rate of 1.0 mm/min was applied. The CT_{Index} was derived from the load-displacement data by assessing several parameters, including fracture energy (G_f in J/m²), specimen thickness (t in mm), diameter (D in mm), and the slope of the post-peak segment at 75% of the peak load ($|m_{75}|$ in N/m). The displacement at which this 75% peak load occurred (l_{75} in mm) was also required. The CT_{Index} was computed using the following expression:

$$CT_{Index} = \frac{t}{62} \frac{l_{75}}{D} \frac{G_f}{|m_{75}|} \times 10^6$$

To evaluate the slope at the 75% post-peak load ($|m_{75}|$), the corresponding loads at 85%, 75%, and 65% of the peak load (P_{85}, P_{75}, and P_{65}) and their respective displacements (Δ_{85}, Δ_{75}, and Δ_{65}) were used. The slope was then calculated as:

$$m_{75} = \frac{|P_{85} - P_{65}|}{|\Delta_{85} - \Delta_{65}|}$$

The fracture energy (G_f) was obtained by dividing the work of fracture (W_f in J) by the product of the thickness (t) and diameter (D) of the specimen:

$$G_f = \frac{W_f \times 10^6}{tD}$$

The work of fracture (W_f) was computed as the area under the load-displacement curve, representing the total energy absorbed by the material before complete failure.

Results and discussions

Fracture energy of bitumen-filler mastics with nano-modifiers

The fracture energy of GF-based bitumen-filler mastics increased with both temperature and filler–binder ratio (as presented in figure 1). It indicates an improved crack resistance at higher filler contents and elevated temperatures. Among the three nano-modifiers, NS consistently exhibited the highest fracture energies, followed by NC and NT, across all conditions. At 15 °C, values ranged from 1105 to 1805 N/m, while at 35 °C they increased further, reaching up to 1865 N/m. This demonstrates that both filler content and nano-modifier type significantly influenced fracture resistance, with NS providing the most effective enhancement in performance.
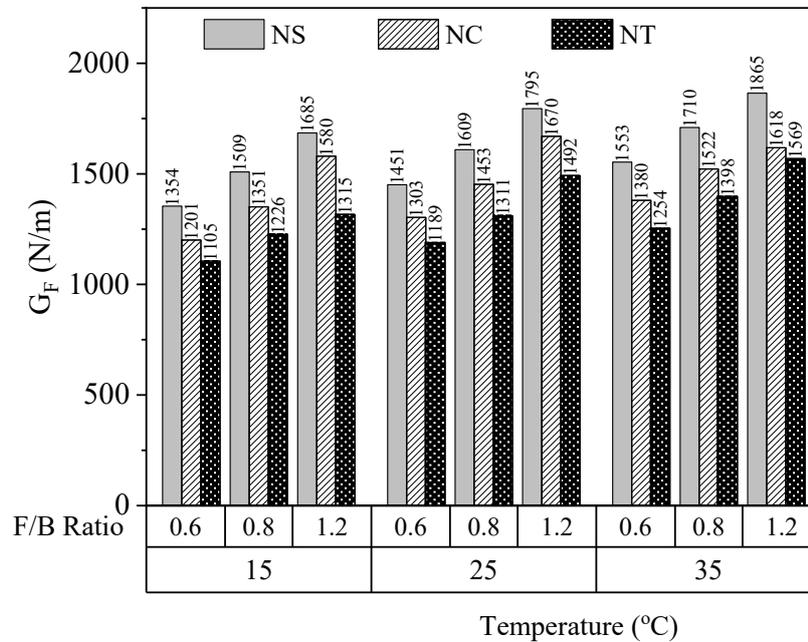

Figure 1. Fracture energies of GF based bitumen-filler mastics with VG30 binder

Figure 2 provides the fracture energy data for LSF-based bitumen-filler mastics using VG30 binder. Results confirm an increasing trend with temperature and filler-binder ratio. At the lowest condition of 15 °C and 0.6 ratio, fracture energy varied between 1250 N/m and 1516 N/m. With temperature raised to 35 °C at the same filler-binder ratio, values reached between 1379 N/m and 1725 N/m. The maximum energy absorption was recorded at 1.2 ratio and 35 °C, ranging from 1726 N/m to 2069 N/m. These findings suggest that LSF fillers enhance fracture energy compared with GF, particularly at higher binder proportions and test temperatures.
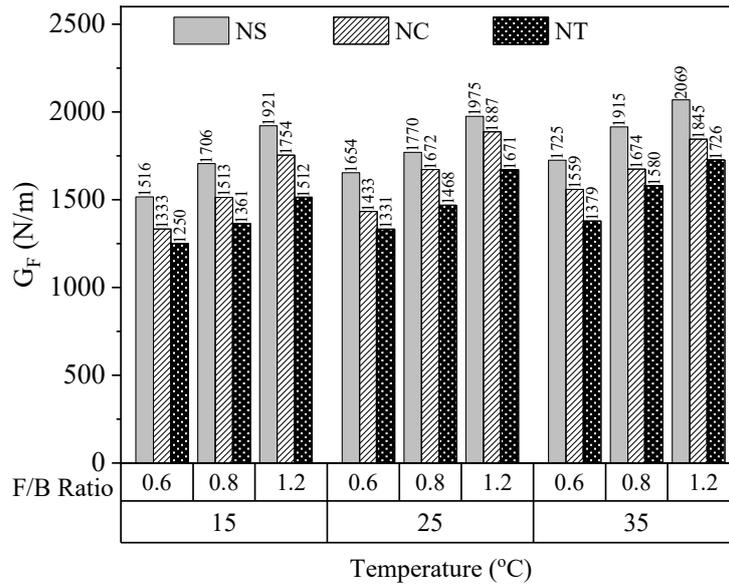
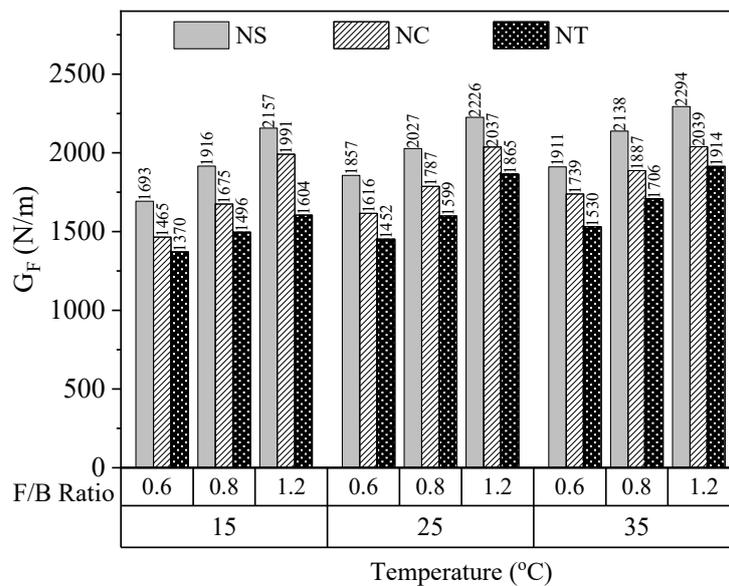**Figure 2.** Fracture energies of LSF based bitumen-filler mastics with VG30 binder

Figure 3. Fracture energies of MPF based bitumen-filler mastics with VG30 binder

Figure 3 illustrates the fracture energies of MPF-based mastics incorporating VG30 binder. At 15 °C and a 0.6 filler-binder ratio, fracture energy values ranged between 1370 N/m and 1693 N/m. Increasing the test temperature to 35 °C elevated the values to 1530 N/m to 1911 N/m. With a 0.8 filler-binder ratio, the range expanded further, with maximum values of 1706 N/m at 35 °C. The highest fracture resistance was achieved at a filler-binder ratio of 1.2 and 35 °C, reaching between 1914 N/m and 2294 N/m. These results show that MPF fillers consistently provide superior fracture energies compared to GF and LSF systems, highlighting their effectiveness in improving crack resistance under IDEAL-CT testing.

CT_INDEX of bitumen-filler mastics with nano-modifiers

CT_{index} values varied between 99,014 and 199,668 at 15 °C and a 0.6 ratio. With temperature rising to 35 °C at the same ratio, the range expanded significantly from 184,922 to 450,871. The highest CT_{index} was noted at 1.2 ratio and 35 °C, where values reached 246,738 to 551,478. This confirms that higher binder content and elevated test temperatures substantially improve crack tolerance in GF-based systems.
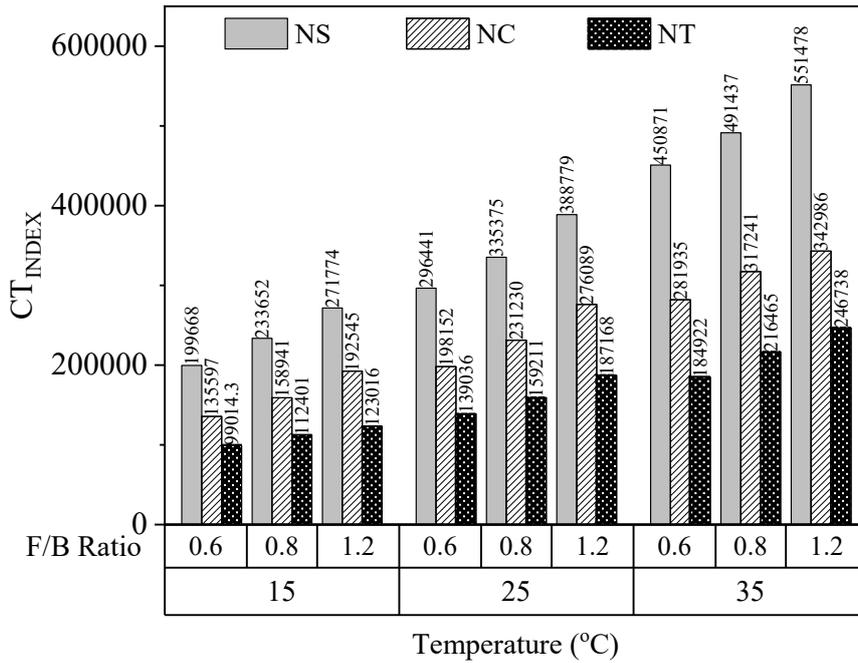

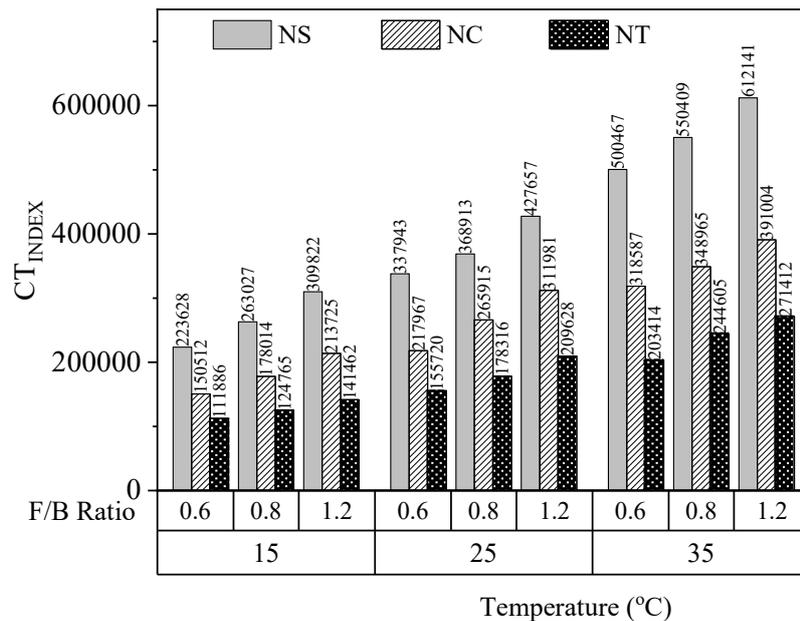**Figure 4.** Cracking tolerance indices of GF based bitumen-filler mastics with VG30 binder

Figure 5. Cracking tolerance indices of LSF based bitumen-filler mastics with VG30 binder

Figure 5 presents the CT_{index} results for LSF-based mastics with VG40 binder. At the lower test condition of 15 °C and 0.6 ratio, the index ranged from 111,886 to 223,628, whereas at 35 °C, it rose considerably to between 203,414 and 500,467. With increased filler-binder ratios, CT_{index} values improved further, with the maximum range recorded at 1.2 and 35 °C, varying between 271,412 and 612,141. These outcomes indicate that LSF fillers enhance the cracking tolerance compared to GF, particularly at high binder ratios.
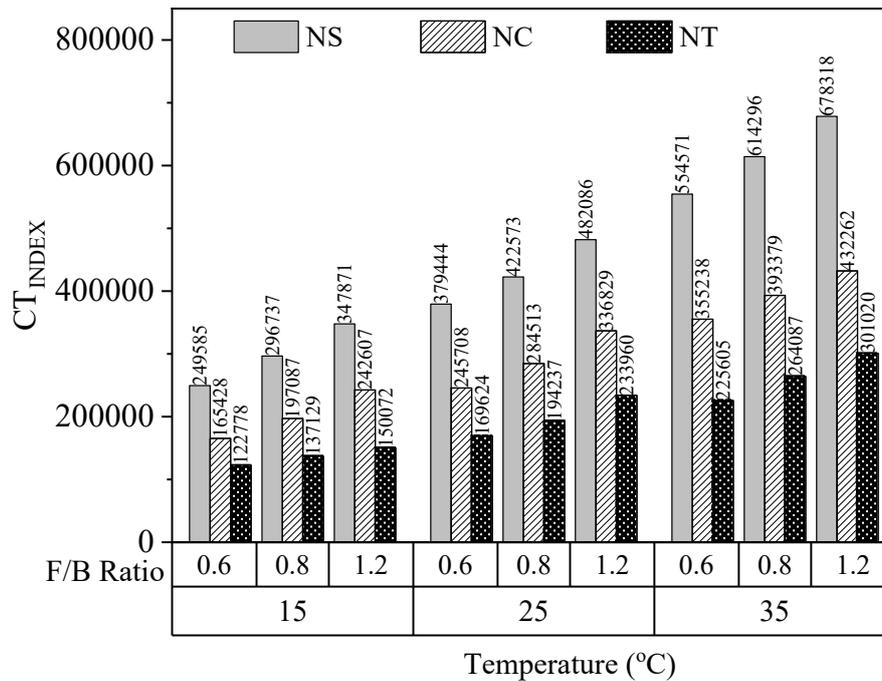

Figure 6. Cracking tolerance indices of MPF based bitumen-filler mastics with VG30 binder

Figure 6 displays the CT_{index} of MPF-based mastics using VG40 binder. At 15 °C and 0.6 ratio, the values ranged between 122,778 and 249,585, while at 35 °C under the same ratio, the range extended to 225,605–554,571. A further increase was observed at higher ratios, with the maximum index occurring at 1.2 and 35 °C, where values reached 301,020–678,318. This suggests that MPF fillers provide the highest improvement in cracking tolerance among the three filler systems, making them more effective in resisting crack propagation under IDEAL-CT loading conditions.

Summary

In summary, the fracture energy results of GF-, LSF-, and MPF-based bitumen-filler mastics with VG30 binder revealed a clear dependence on both temperature and filler–binder ratio. GF systems showed fracture energy rising from 1105–1805 N/m at 15 °C to as high as 1865 N/m at 35 °C, with NS modifiers consistently outperforming NC and NT. LSF mastics displayed

higher fracture energy than GF, ranging from 1250–1516 N/m at 15 °C and 0.6 ratio to 1726–2069 N/m at 1.2 ratio and 35 °C, highlighting the benefit of limestone fillers at elevated conditions. MPF fillers delivered the highest fracture resistance, beginning at 1370–1693 N/m for 15 °C and 0.6 ratio, and reaching 1914–2294 N/m at 1.2 ratio and 35 °C, confirming their superior role in resisting crack growth under IDEAL-CT loading.

The CT_{index} results followed a similar trend of improvement with rising filler–binder ratio and temperature across all filler systems. GF mastics showed values from 99,014–199,668 at 15 °C and 0.6 ratio, which increased sharply to 246,738–551,478 at 1.2 ratio and 35 °C, indicating significant enhancement in crack tolerance. LSF systems recorded CTindex values of 111,886–223,628 at the lowest condition, progressing to 271,412–612,141 at the highest, confirming their stronger performance compared to GF. MPF mastics exhibited the most pronounced improvement, with values beginning at 122,778–249,585 at 15 °C and 0.6 ratio and peaking at 301,020–678,318 under the maximum condition, demonstrating their superior crack resistance and tolerance under increased load and temperature.

References:

- Abdullah, M. E., et al. (2016). "Engineering Properties of Asphalt Binders Containing Nanoclay and Chemical Warm-Mix Asphalt Additives." Construction and Building Materials, 112, 232–240. doi:10.1016/j.conbuildmat.2016.02.089.

- Ashish, P. K., Singh, D., and Bohm, S. (2017). "Investigation on Influence of Nanoclay Addition on Rheological Performance of Asphalt Binder." Road Materials and Pavement Design, 18(5), 1007–1026. doi:10.1080/14680629.2016.1201522.

- Ezzat, H., et al. (2016). "Evaluation of Asphalt Binders Modified with Nanoclay and Nanosilica." Procedia Engineering, 143, 1260–1267. doi: 10.1016/j.proeng.2016.06.119

- Hassan, M. M., Hossain, Z., and Baumgardner, G. (2023). "Impact of Nanoclays on Chemical Fractions and Mechanical Performance of Asphalt Binders." Journal of Materials in Civil Engineering, 35(6), 04023117.

- Hossain, Z., et al. (2015). "Evaluation of Moisture Susceptibility of Nanoclay-Modified Asphalt Binders Through the Surface Science Approach." Journal of Materials in Civil Engineering, 27(10), 04014261. doi:10.1061/(ASCE)MT.1943-5533.0001228.

- Jahromi, S. G. (2015). "Effect of Carbon Nanofiber on Mechanical Behavior of Asphalt Concrete." International Journal of Sustainable Construction Engineering and Technology, 6(2), 57–66.

- Mahdi, L. M. J. (2013). "Effect of Short Term Aging on Organic Montmorillonite Nanoclay Modified Asphalt." Indian Journal of Science and Technology, 6(11), 1–9. doi:10.17485/ijst/2013/v6i11.13

- Sabaraya, I. V., A. Filonzi, R. Hajj, D. Das, N. B. Saleh, and A. Bhasin. 2018. "Ability of Nanomaterials to Effectively Disperse in Asphalt Binders for Use as a Modifier." *J. Mater. Civ. Eng.*, 30 (8): 1–8. https://doi.org/10.1061/(asce)mt.1943-5533.0002315.

- Sankaranarayannan, S. S., and Jagadesan, J. R. (2016). "Comparison of High-Performance Fly Ash Concrete Using Nano Silica Fume on Different Mixes." Circuits and Systems, 7, 1259–1267.

- Wang, D., et al. (2021). "Thermal Oxidative and Ultraviolet Ageing Behaviour of Nano-Montmorillonite Modified Bitumen." Road Materials and Pavement Design, 22(1), 121–139.

- Yang, J., and Tighe, S. (2013). "A Review of Advances of Nanotechnology in Asphalt Mixtures." Procedia – Social and Behavioral Sciences, 96, 1269–1276.

- Yao, H., et al. (2012). "Performance of Asphalt Binder Blended With Nonmodified and Polymer-Modified Nanoclay." Construction and Building Materials, 35, 159–170. doi:10.1016/j.conbuildmat.2012.02.056.

- Zare-Shahabadi, A., Shokuhfar, A., and Ebrahimi-Nejad, S. (2010). "Microstructure and Properties of Nanoclay Reinforced Asphalt Binders." Defect and Diffusion Forum, 297–301, 579–583. doi:10.4028/www.scientific.net/ddf.297-301.579.