Effects of Grain Bag Waste Plastic on the Mechanical Performance of Asphalt Mixtures and the Role of Undergraduate Research in Engineering Education

Kaylee Cunning[1], Jamilla E. S. L. Teixeira[2], Joseph Tighi[1], Isabela M. Bueno[3], Jessica Deters[4]

1: Civil and Environmental Engineering Department, University of Nebraska – Lincoln; 2: Mechanical and Materials Engineering Department, University of Nebraska – Lincoln

Abstract

This study addresses the global need for sustainable solutions and the preparedness of the future STEM workforce by integrating undergraduate research and mentorship in engineering education. One of the current environmental challenges is to reduce the amount of mismanaged or landfilled waste plastics. In this context, this research aims to verify the feasibility of using one type of waste plastic generated in rural areas, grain bag waste plastics (GBWP), in the production of asphalt concrete (AC). Various laboratory tests were conducted to assess the overall performance of the AC, including the Indirect Tensile Asphalt Cracking Tests (IDEAL-CT) and the Hamburg Wheel Tracking Test (HWTT). ANOVA statistical analysis was performed to determine the significance of differences in some of the obtained performance-based parameters. The results showed significant improvements in AC's rutting and moisture resistance. However, considering the materials and proportions used, the cracking resistance decreased with the addition of GBWP. Additionally, the educational impact of undergraduate research experiences, emphasizing the importance of mentorship, particularly from female role models, in engaging and retaining students in engineering. Reflections from a participant in the University of Nebraska-Lincoln's Undergraduate Creative Activities & Research Experiences Program (UCARE) and leading author of this study demonstrate how hands-on research and strong role models enhance practical skills, critical thinking, and confidence. This dual-focused approach underscores the benefits of integrating research and education, showing how undergraduate research advances technical knowledge and enriches the educational experience. It also calls for increased investment in research opportunities to prepare a diverse and capable future engineering workforce, addressing real-world environmental and engineering challenges. By promoting sustainability and inclusivity, this study contributes to the development of innovative solutions and the empowerment of the next generation of engineers.

Keywords

Undergraduate research experience; waste plastics; asphalt research; sustainable infrastructure; hot mix asphalt; engineering education; engineering role models

Introduction

Considering the global needs to ensure a safer and sustainable planet, a recent ABET brief report [1] discusses the necessity of preparing students to advance sustainable solutions for pressing environmental challenges. The brief report highlights the importance of firsthand experiences in STEM programs. Specifically in civil engineering undergraduate programs, it is critical to promote different initiatives besides conventional education styles, such as traditional lectures, rote memorization, and reliance on textbooks, and give opportunities to our future engineers to think critically to broaden student perspectives beyond the classroom [2]. Role models and mentorship in engineering can play a big role in students' success, and having female leaders can further foster the engagement of female students in research and higher education [3].

The involvement of undergraduate students in research studies that address global needs brings impactful benefits to society. A current environmental challenge is related to the growing volume of plastic waste generated, and a great part of it being landfilled. Its persistent nature and low biodegradability lead to long-term pollution in landfills and natural environments [4]. In 2019, the United States managed approximately 44 million tons (Mt) of plastic waste, which accounted for about 13.7% of the total municipal solid waste (MSW) managed that year. Among the various types of plastic waste, Low-Density Polyethylene (LDPE) and Linear Low-Density Polyethylene (LLDPE) represented a significant portion, making up about 34% of the total plastic waste managed. Specifically, 15,139 kilotons (kt) of LDPE/LLDPE waste were generated, with 13,290 kt landfilled, 1,524 kt combusted, and 325 kt recycled. Other types of plastic waste included Polyethylene Terephthalate (PET) (5,986 kt), High-Density Polyethylene (HDPE) (7,910 kt), Polypropylene (PP) (8,189 kt), Polyvinyl Chloride (PVC) (699 kt), Polystyrene/Expanded Polystyrene (PS/EPS) (3,094 kt), and other resins (3,115 kt), with varying proportions being landfilled, combusted, or recycled [8][9]. To address this pressing issue, it is critical to develop more sustainable solutions to divert the influx of plastic waste polluting our environment.

Moreover, the early involvement of undergraduate students in studies that aim to look for alternative recycling strategies for waste plastic use is beneficial to prepare our future engineering workforce to work on environmental challenges. Opportunities for undergraduate research continue to grow, as these experiences not only improve retention but also increase the likelihood that students will pursue graduate level degrees [10]. Undergraduate research experiences (UREs) continue to evolve, including National Science Foundation (NSF) funded programs that foster the participation of undergraduate students in early research initiatives, such as the NSF Research Experiences for Undergraduates (REU) and the NSF International Research Experiences for Students (IRES) programs. Course-based UREs have grown in prevalence, but the most enduring model of undergraduate research is the apprenticeship-model, where students work directly under the mentorship of a faculty member[10].

The University of Nebraska-Lincoln established the Undergraduate Creative Activities & Research Experiences Program (UCARE) in 1998. UCARE provides $1,000,000 in stipends annually for approximately 300 to 350 undergraduate students across all majors. UCARE participants showcase their primary outcomes in a yearly Undergraduate Research Symposium. Programs such as UCARE allow students to work alongside faculty members, engaging in hands-on research and creative projects, enhancing their academic and professional development.

Cunning et al. (2024) presented a reflection of three undergraduate students involved in UCARE and NSF-REU programs in 2023, and the impacts of this opportunities to develop their self-identity, critical thinking, adaptability, and a holistic understanding of sustainable engineering practices. As a follow-up, this study highlights how integrating research and education is beneficial to prepare our future engineering workforce to work on environmental challenges.

More than that, this paper presents a reflection on how the inspiration sparked by female role models in the field can broaden the participation of female students in male-dominant fields.

Thus, this research study conducted under the UCARE program emphasizes the importance of hands-on research in the educational experience, allowing students to apply theoretical knowledge to practical challenges. By investigating the performance of asphalt mixtures containing locally sourced GBWP, this study not only contributes to sustainability efforts by reducing agricultural plastic waste but also enhances road durability, benefiting the broader community. Engaging in such research projects equips students with valuable skills and knowledge, preparing them for future professional and academic pursuits while addressing pressing environmental issues.

Objectives and Scope

This paper aims to present how the integration of undergraduate research and education is a powerful tool to develop our future workforce, presenting evidence of enriched skillsets, increased confidence, and a broader perspective on engineering's societal role in the case of one student. In particularly, a case study examines the research experience of an UCARE undergraduate researcher showing her technical skills' gain and confidence to conduct research and her reflection on the motivator factors (female role model and sustainability topic) and impacts of this experience on her heir career trajectory. The UCARE student worked on a project for 3 months on the topic of using rural area waste materials for sustainable infrastructure under the supervision of a faculty mentor. Through this apprenticeship-style URE [11], the student and her advisor elaborated an individualized mentoring plan (IMP) and had lab-based research in a multicultural group of undergraduate and graduate students. The results we present are two-fold. First, we present the experimental research that students conducted on the use of rural waste plastics (i.e., GBWP) in asphalt mixtures and the technical outcomes of that research. Second, we present a reflection from the undergraduate student in this experimental research, including her main motivations to engage in research extracurricular activity, her learning outcomes, and the impact of this experience in her career trajectories.

Accordingly, two major goals (Research and Education) and deliverables are included in this paper:

- **Research Goal:** *User-Inspired Research: Exploring the Use of Rural Waste Plastic in Sustainable Infrastructure.* This goal focuses on providing experimental evidence regarding the effectiveness of GBWP in enhancing asphalt concrete properties such as resistance to rutting, cracking, and moisture damage. By assessing the impact of GBWP on the durability and performance of asphalt mixtures, the study aims to contribute to sustainability efforts by reducing local agricultural plastic waste and improving road durability.

- **Education Goal:** *Reflection on The Role of Undergraduate Research Experiences in Engineering Education:* To evaluate the impact of undergraduate research experiences on engineering education. This goal involves assessing how participation in this hands-on research project enhances undergraduate engineering students' practical skills, knowledge, and overall educational experience. By involving undergraduates in the research on GBWP in HMA, the study aims to demonstrate the importance of undergraduate research in engineering education and its effectiveness in preparing students to address real-world environmental and engineering challenges.

These objectives guide the research methodology, data collection, and analysis, ensuring a comprehensive exploration of both the technical benefits of using GBWP in asphalt and the educational value of engaging undergraduates in meaningful research projects.

Research Goal: Exploring Waste Plastic from Rural Areas for Sustainable Infrastructure

Brief Literature Review

Recent studies have shown promising results in incorporating waste plastics into asphalt mixtures to improve performance [12],[13]. There are two main methods for incorporating waste plastic into asphalt mixtures: the wet method and the dry method. The wet method involves melting the plastic and mixing it with the binder before adding it to the aggregates. The dry method involves adding the plastic directly to the heated aggregates before the binder is added. This approach is simpler and more easily integrated into current production processes without extensive changes [13].

The GBWP is made with a UV repellent additive to protect the rural products, which make it less susceptible to heat degradation and melting. Considering the difficulty of melting GBWP, the wet process might not be ideal. Incorporating GBWP might be an alternative way to recycle this material and enhance some properties of asphalt concrete. Recent studies indicate that incorporating waste plastics into asphalt can improve its resistance to rutting, cracking, and moisture damage [7],[16][12],[13]. Numerous studies have investigated the incorporation of LDPE waste plastic (LDPE WP) into asphalt concrete (AC), with early results from 1989 demonstrating that adding 5% LDPE WP to AC significantly improved its resistance to rutting and fatigue cracking [17]. Other studies show that adding LDPE improves Marshall stability, resilient modulus, fatigue life, and moisture susceptibility of AC mixtures [18],[19]. One study incorporated LDPE recycled from agricultural greenhouses into AC mixtures, resulting in improved behavior associated with water sensitivity and rutting resistance [20].

A significant challenge in incorporating waste plastics into asphalt is ensuring the plastic does not adversely affect the asphalt's performance. The effects of waste plastic on asphalt concrete can differ depending on properties such as melting point. Studies have shown that adding waste plastic increases asphalt concrete stiffness when using the dry process with LDPE, HDPE, PP, and PET [21],[8]. The GBWP's UV repellent additive prevents it from melting at typical mixing temperatures, which might alter expected outcomes. The dry method of incorporating GBWP into HMA is advantageous because it simplifies the process and minimizes the need for additional equipment or extensive process changes. By preheating the aggregates and then adding the GBWP, the method leverages existing production capabilities, making it easier to adopt at a larger scale. This approach can potentially strengthen the asphalt mixture by acting as a flexible fiber, thus improving its durability.

Given that GBWP is expected to retain its solid form and not melt, it is hypothesized herein that this material might function as an additional component in the asphalt mixture, potentially acting like a plastic fiber. This could enhance cracking resistance, depending on the size of the GBWP used. Studies have shown notable improvements in the performance of asphalt mixtures, particularly in terms of durability and resistance to deformation and cracking, when plastic fibers are incorporated [22],[23]. This suggests that the inclusion of GBWP, due to its fiber-like behavior when not melted, could similarly boost the cracking resistance of the asphalt mixture. To verify this hypothesis, we conducted different performance tests such as Hamburg Wheel Tracking Test (HWTT) and Indirect Tensile Asphalt Cracking Test (IDEAL CT).

Materials and Methods

<u>Binder and Aggregates</u>

The asphalt mixtures were produced by blending virgin binder with aggregates and GBWP. The asphalt binder was a PG 64-28. The PG system classifies binders based on their suitability for specific climatic conditions. The "64" indicates that the binder can withstand high temperatures up to 64°C without becoming excessively soft, which is crucial for preventing rutting during hot weather. The "-28" denotes that the binder remains flexible at low temperatures down to -28°C, which helps in preventing cracking during cold weather. According to its viscosity, the selected binder has a mixing temperature of 156°C (313°F) and a compaction temperature of 143°C (290°F). This binder was selected for its compatibility with the local climatic conditions in Nebraska and its suitability for use in Hot Mix Asphalt (HMA). The aggregates were sourced locally and include limestone and 47B (gravel) aggregates. The limestone aggregates were divided into three fractions: screenings, manufactured sand (man sand), and coarse aggregates. The 47B aggregates were sieved to ensure uniform particle size distribution. The mixture composition (by weight) consisted of 80% of limestone screenings, 10% of man sand limestone, 5% of coarse limestone, and 5% of 47B aggregates. The combined aggregate gradation met the Superpave nominal maximum aggregate size (NMAS) 9.5mm requirements, as illustrated in **Figure 1**. This blend of aggregates is designed to provide a well-graded mix that meets the specifications of the Nebraska Department of Transportation (NDOT) for HMA.

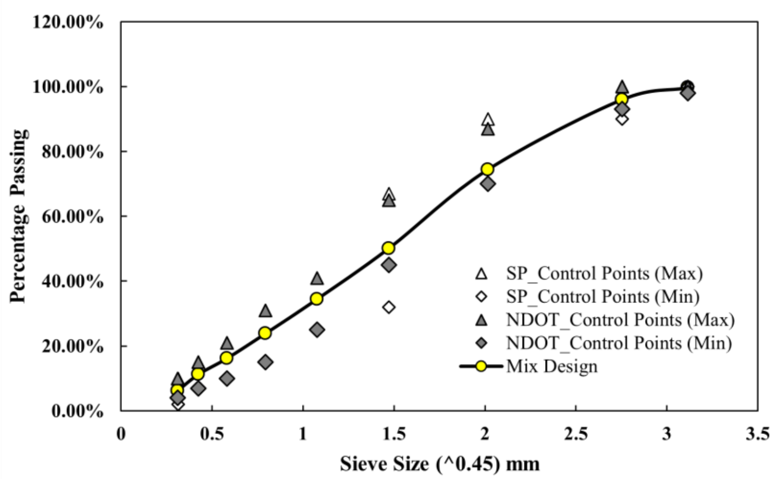

Figure 1. Selected aggregate gradation and NDOT control points

Waste Plastic Samples

Grain bag waste plastic (GBWP), the primary focus of this study, is sourced from First Star Recycling in Omaha, who collects the bags from local farmers. These grain bags, primarily composed of Low-Density Polyethylene (LDPE) with UV-repelling additives, are cleaned and shredded into small flakes to facilitate uniform distribution within the asphalt mixture. The GBWP flakes vary in size from approximately 4mm to 40mm and can be either long and thin or rectangular in shape. The particle size of the shredded GBWP is controlled to ensure consistent incorporation during the mixing process. **Figure 2** shows the variation in GBWP flake sizes.

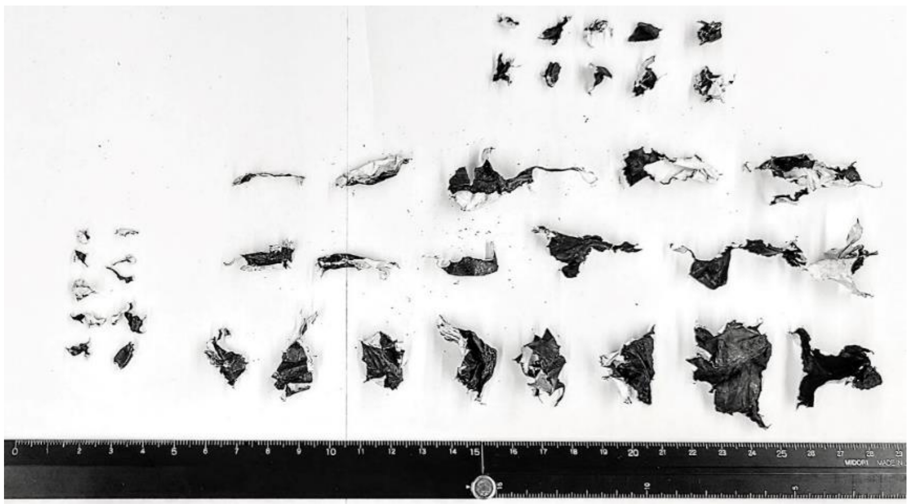

Figure 2. Size variation of the grain bag waste plastic flakes used in this study

It was necessary to experimentally determine the melting point of the WP samples to establish how we expect the plastic to integrate at mixing temperature. To verify the melting point of the plastic, each sample underwent two heating cycles using Differential Scanning Calorimetry (DSC). The peaks shown in **Figure 3** represent the melting temperature for each cycle. As observed, the melting point for the GBWP samples appears to be around 118.3˚C which aligns with values reported in similar studies [24],[25].

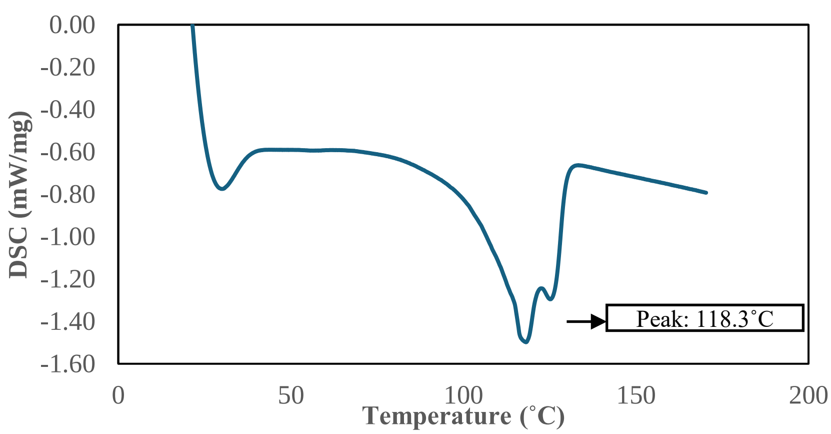

Figure 3. DSC test results for GBWP

Sample Preparation

In this study, the aggregates were preheated to 313°F (156°C) for 1 hour and GBWP flakes, constituting 1% by weight of the aggregates, were added. These flakes were mixed thoroughly with the heated aggregates, curling up but not melting, and distributed evenly throughout the mixture, resembling fibers.

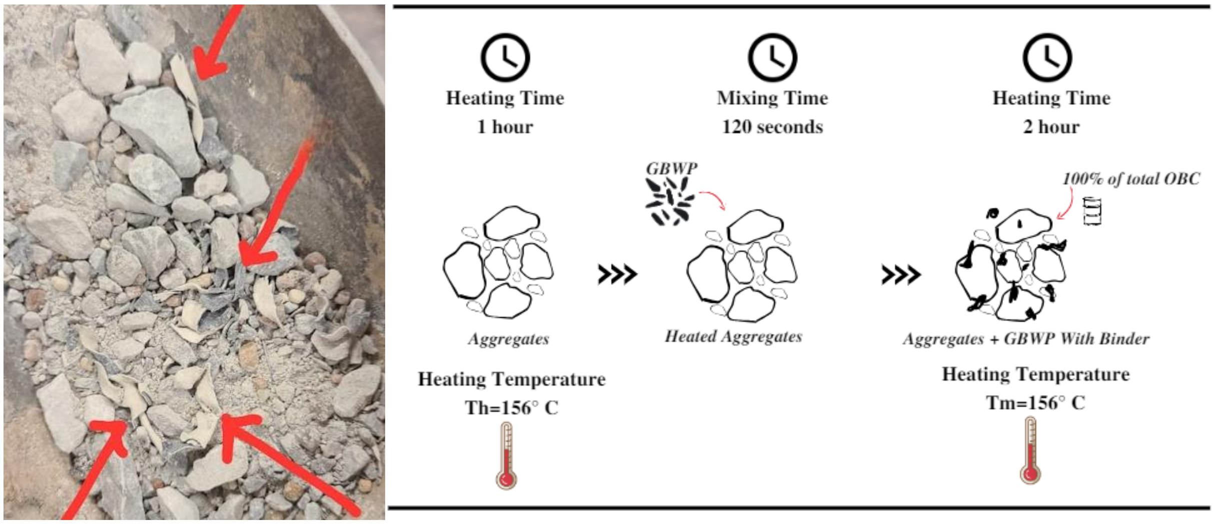

Figure 4. GBWP incorporated into aggregate mixture and mixing procedure

After the GBWP was thoroughly mixed with the preheated aggregates, the next step in the HMA mixing procedure was the addition of the asphalt binder. The asphalt content was previously determined (Ref) as 5% for a reference mixture with no GBWP but using the same aggregate and material's proportions as in this study. The binder mixing and compaction temperature were 156°C (313°F) and 143°C (290°F), respectively. The mixing process continued until all components were uniformly combined, resulting in a homogeneous asphalt mixture. This mixture was then subjected to short-term aging to simulate the aging process during asphalt production according to the AASHTO R 30 [26]. The mixture was aged for 4 hours at 275°F (135°C), mixing every hour to ensure uniform aging.

The study examined three mixtures: AC1 (reference mixture at the preliminary OBC), AC2 (reference mixture with binder content adjusted based on performance test results), and GBWP (AC1 with the addition of grain bag waste plastic as a mixture addition), as shown in **Figure 4**. Five specimens of each AC mixture and seven of GBWP were compacted at 143°C in the laboratory using the Superpave gyratory compactor, with a diameter of 150mm and a height of 62 ± 1mm, targeting 7 ± 0.5% air voids as recommended by the performance test standard procedures.

Rutting and Moisture Damage Assessment

The rutting and moisture susceptibility of all mixtures were assessed using the Hamburg Wheel Tracking Test (HWTT) in accordance with AASHTO T 324-22 [27]. For this test, two cylindrical specimens from each mixture were prepared and then submerged in water maintained at 50°C. The test continued for 20,000 cycles or until a deformation of 25mm was achieved. During the test, a steel wheel with a load of 703±4.5 N rolled back and forth across the surface of the specimens, making 52 ± 2 passes per minute. At the conclusion of the test, a graph plotting load cycles against rut depth was generated. This graph provides important parameters such as the stripping inflection point (SIP), which indicates the mixture's resistance to moisture damage, and the number of cycles used for the pass-fail criteria, typically based on an accumulation of a maximum rut depth of 12.5 mm [27],[28],[29]. **Figure 5** illustrates the HWTT equipment used.

Figure 5. HWTT equipment post-test loaded with the GBWP mixture

<u>Cracking Assessment.</u>

The cracking resistance at intermediate temperature for all asphalt mixtures was evaluated using the IDEAL-CT test, following ASTM D8225 guidelines [24]. Three specimens from each mixture were tested. The specimens were conditioned at 25°C for 2 hours before testing. Each sample was placed in the center of a specific fixture while a compression load was applied to maintain a constant load-line displacement (LLD) at a rate of 50±2mm/min, as depicted in **Figure 6a**. This compression load generated a tensile load at the center of the specimen. Upon completion of the test, a graph plotting load against LLD was created, and the Cracking Tolerance (CT) index was calculated. The CT index incorporates factors such as the failure energy, the displacement at 75% of the peak load post-peak, the absolute value of the post-peak slope, and the specimen’s thickness, as seen in **Figure 6b**. Generally, a higher CT index indicates better resistance to cracking [28],[30],[31].

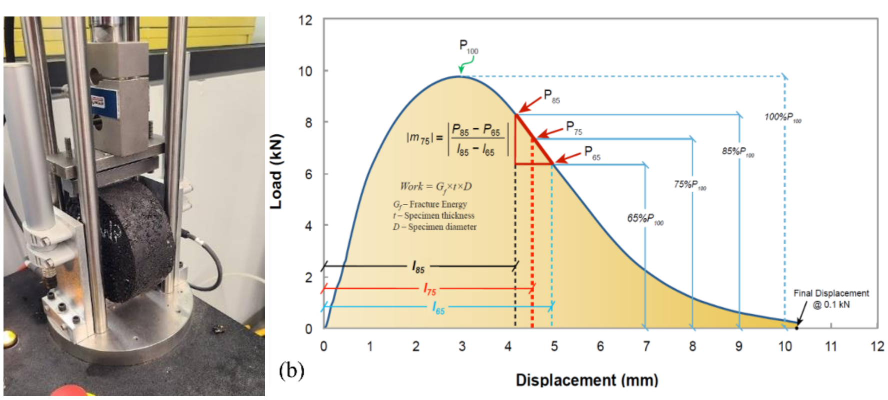

Figure 6. IDEAL-CT test: a) Apparatus; b) Sample Load x LLD curve. Zhou et al. [32]

Other than the CT index, it is important to analyze the entire load-displacement curve to gain insights into the material's response characteristics. The initial slope of the curve is indicative of the material's initial stiffness when there is minimal damage to the specimen. This initial stiffness can be correlated with the material's rutting resistance, as some energy dissipation due to deformation is expected. The post-peak behavior of the curve, represented by the post-peak slope, indicates the rate of crack propagation within the mixture. A steeper post-peak slope suggests that cracks propagate more rapidly, implying that the mixture has a lower resistance to cracking propagation and, consequently, a lower CT index [33].

Results

Figure 7 displays the curves obtained from the Hamburg Wheel Tracking Test. From this we can observe and gather values relating to the rutting and moisture resistance, further elaborated in **Figure 8**.

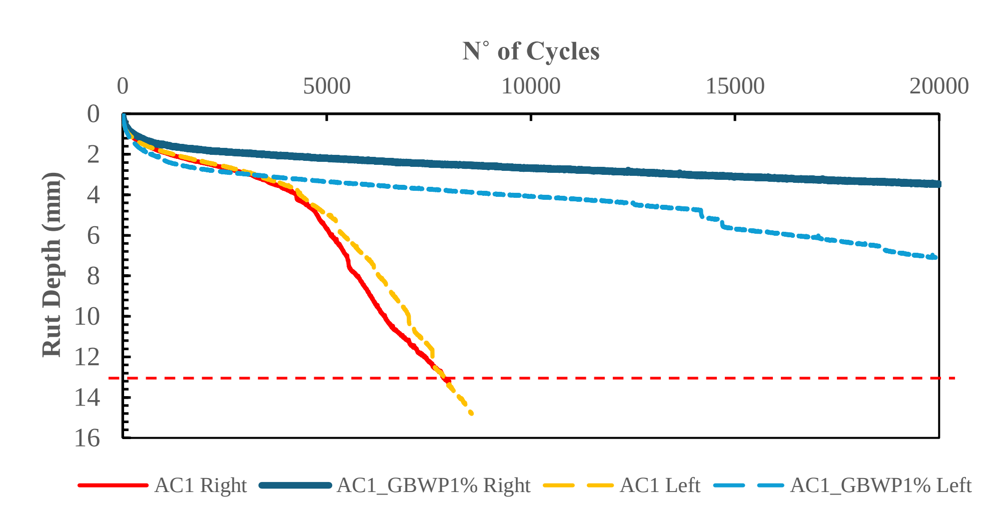

Figure 7. HWTT curves for each studied mixture

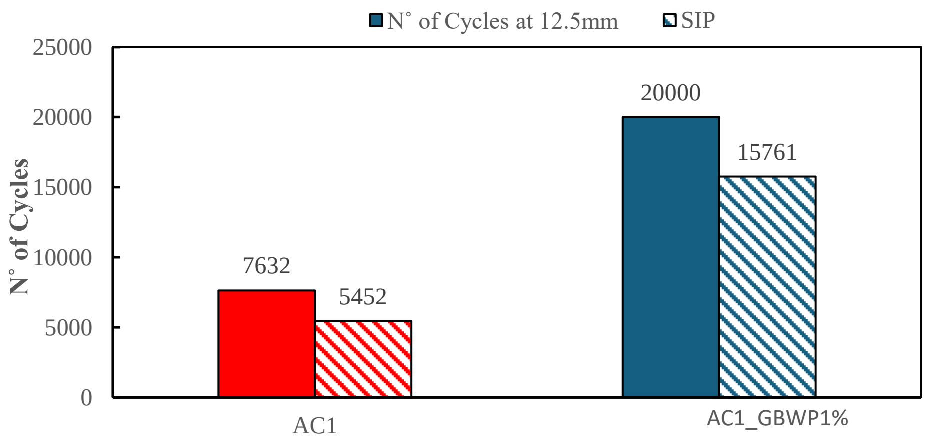

Figure 7. Rutting resistance and moisture susceptibility of each studied mixture

Compared to the reference mixture AC1, the incorporation of GBWP resulted in a 162% enhancement in rutting resistance and an 189% increase in moisture resistance. Previous studies using alternative evaluation methods have indicated that the addition of waste plastic (WP) can increase mixture stiffness, which correlates with the observed enhancement in rutting resistance [34],[35],[36]. This improvement may be attributed to the GBWP functioning as a reinforcing fiber within the mixture, contributing to its structural integrity. In terms of moisture resistance, the increased resistance may result from the fibrous nature of WP, which enhances the overall homogeneity and adhesion of the mixture, thereby mitigating moisture damage.

Figure 9 presents the load versus LLD (Load-Load Displacement) graphs for each mixture. The post-peak behavior of these curves indicates the cracking propagation resistance of the mixtures, which can be evaluated by analyzing the post-peak slope. A steeper slope implies a faster rate of crack propagation, suggesting lower resistance to cracking and a subsequently lower CT index [33]. The average CT index for all studied mixtures is shown in **Figure 10**.

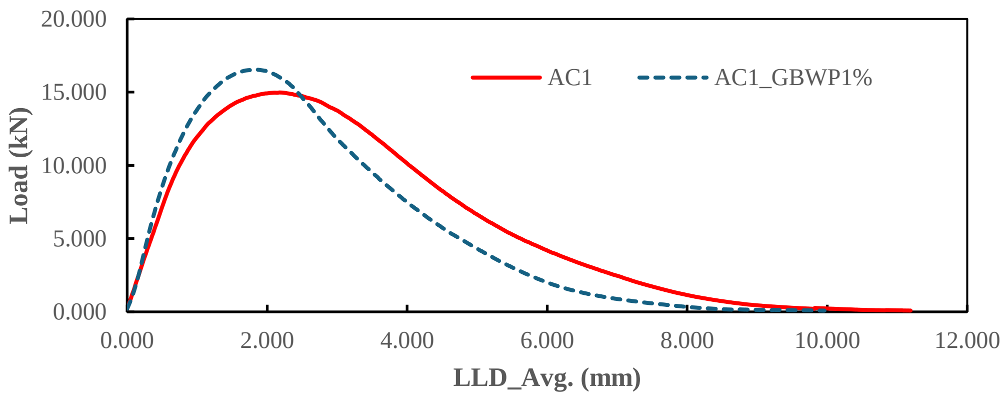

Figure 8. Average Load x LLD curve of each studied mixture

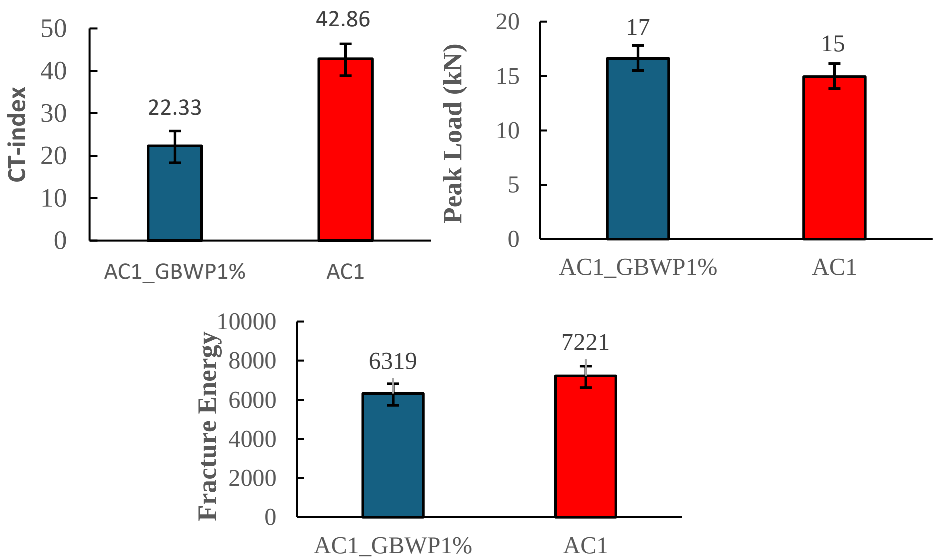

Figure 9. a) Average CT index for each mixture. b) Peak Load. c) Fracture Energy

From **Figure 10a**, it is apparent that AC1_GBWP1% exhibits a markedly lower CT Index, spanning approximately 22 to 25 with a median value around 23, in contrast to AC1, which ranges from roughly 40 to 47 with a median value around 43. This diminution in the CT Index signifies a reduction in crack tolerance for the modified mix. Nevertheless, AC1_GBWP1% demonstrates a lower coefficient of variation (COV) of 7.1%, compared to 16.6% for AC1, indicating enhanced consistency in performance.

Additionally, from the curves in **Figure 9**, we can see that AC1_GBWP1% had a higher peak-load and a steeper post-peak curve, indicating a more brittle behavior with faster macrocracking propagation. Figure 10 delineates that the peak load for AC1_GBWP1% is marginally higher than that of AC1, reaching approximately 16.5 kN compared to around 14.9 kN, thereby indicating an improvement in initial load-bearing capacity. However, the post-peak behavior of AC1_GBWP1% is characterized by a more precipitous decline, implying a swifter reduction in load-bearing capacity following the peak load [36],[37],[38].

These findings suggest that the incorporation of grain bag waste plastic into the mix enhances the initial mechanical strength, yet concurrently diminishes the overall crack tolerance and durability. Consequently, while the initial enhancements in strength are significant, the increased susceptibility of AC1_GBWP1% to cracking over time underscores the necessity for further optimization to achieve an optimal balance in the AC performance.

Conclusions

The incorporation of Grain Bag Waste Plastic (GBWP) into asphalt mixtures has demonstrated significant enhancements in performance metrics. Specifically, the Hamburg Wheel Tracking Test (HWTT) results showed substantial increases in both rutting resistance and moisture resistance, indicating that GBWP can effectively reinforce the structural integrity of asphalt mixtures. This improvement suggests potential for extended pavement lifespan and enhanced durability. However, while the initial load-bearing capacity of the modified asphalt mixture (AC1_GBWP1%) was higher, the Cracking Tolerance (CT) index was notably lower compared to the reference mixture. This indicates that although GBWP enhances the mixture's strength, it may also increase its susceptibility to cracking over time. Alternatives such as different binder content or the use of polymer modified binders can help to overcome the cracking issue. The authors are working on optimizing the use of GBWP in AC and follow-up results will be presented upon available.

Education Goal: Reflection on Impact of Undergraduate Research Experiences in Engineering Education.

Towards the end of the UCARE Program experience, we collected a reflection from the student about their learning journey. The goal of this reflection is to assess whether the student has achieved a deeper understanding of the research process and its impact on their academic and professional development. This reflection also aims to evaluate how well the program has enhanced their practical skills, critical thinking, and ability to apply theoretical knowledge to real-world problems. Additionally, it serves to gather insights into the student's personal growth, including their ability to work collaboratively, manage projects, and communicate their findings effectively. By analyzing these reflections, we can identify the strengths of the UCARE Program and areas for improvement, ensuring that future participants receive a comprehensive and enriching research experience that prepares them for successful careers in engineering and beyond.

What have you learned by participating in undergraduate research that you don't think you would have learned otherwise?

Participating in undergraduate research has given me invaluable insights into the infrastructure of roads, an essential yet often overlooked aspect of our society. Before this experience, I hadn't fully appreciated the complexity and importance of road engineering. We tend to notice roads only when they deteriorate and cause inconvenience, but through this research, I've learned about the meticulous work engineers do to prevent and address issues like cracking and rutting. Now, I am actively contributing to solving these problems, which has deepened my understanding of civil engineering and its real-world impact. This hands-on experience has provided me with a perspective and set of skills that I wouldn't have gained through classroom learning alone.

What role has participating in undergraduate research played in your motivation to complete and persist through your degree? Does having a female advisor help as motivator factor to pursue research as an extracurricular activity?

Participating in undergraduate research has significantly boosted my motivation to complete and persist through my degree. This hands-on, engaging experience has provided a refreshing contrast to traditional classroom learning, allowing me to apply theoretical knowledge to real-world problems. It has also given me a competitive edge in certain subjects, demonstrating firsthand where my degree can take me and how I can make a tangible impact.

Additionally, having a female advisor has been a powerful motivator. While the gender gap in engineering has improved, there is still a noticeable difference in the number of male versus female students. For women entering this field, seeing a female professor excelling is incredibly inspiring. I have been fortunate to receive direct mentorship from a strong female role model in engineering, who is dedicated to helping each of us under her guidance excel. Her support and example have been invaluable in encouraging me to pursue research and persist through the challenges of my degree.

Think about your experience with your research mentor and research group. How did your mentor and group contribute to your undergraduate research experience?

My experience with my research mentor and research group has been instrumental in shaping my undergraduate research journey. From the very beginning, my mentor and I worked closely to develop a personalized research plan as part of my UCARE proposal. These individual meetings were pivotal, as they allowed us to tailor my research activities to align with my interests and career goals. This personalized guidance not only kept me on track but also motivated me to delve deeper into the subject matter.

Our research group is incredibly diverse, comprising members from various parts of the world. This diversity has enriched my experience far beyond the technical aspects of our research. I've gained valuable insights into different cultures, traditions, and perspectives. Our group dynamic fosters an environment of friendship and emotional support, making our team feel like a second family. We often gather outside of work to share foods from our regions, exchange stories, and celebrate traditions. These moments have taught me so much about the world and have built strong, lasting bonds among us.

Working with such a diverse team has enhanced my understanding of global engineering challenges and solutions. It has also emphasized the importance of collaboration and empathy in professional settings. The friendships and emotional support from my team have been a cornerstone of my research experience, providing a sense of belonging and motivation. This holistic experience has not only broadened my technical knowledge but has also prepared me for a career in a globalized engineering environment, where cultural competence and teamwork are essential

What do you want to do when you graduate? How has your undergraduate research experience contributed to those career goals?

When I first entered engineering, my only goal was to acquire a useful degree. However, as I began my research, met new people, made connections, and heard their stories, my goals and aspirations developed alongside my research journey. Now, I am considering becoming an educator like my advisor and pursuing a master's and PhD. Alternatively, I am also contemplating a career in elementary education, where I can foster early interest in engineering.

My undergraduate research experience has been pivotal in shaping these career goals. It has opened up new doors and presented opportunities I never would have considered before. Engaging in research has shown me the impact of education and mentorship, inspiring me to potentially follow a similar path. The connections and experiences I've gained through research have broadened my perspective, helping me see the diverse possibilities within the field of engineering and beyond. This journey has been transformative, turning a once broad and undefined goal into a passion for inspiring and educating the next generation of engineers.

Concluding Remarks

The involvement of undergraduate students in this research provided them with valuable hands-on experience, enhancing their practical skills and knowledge. Programs supporting undergraduate research, like this one, play a critical role in preparing future engineers to tackle real-world challenges. These experiences not only yield meaningful research results but also significantly impact students' understanding of engineering principles and their career trajectories, bridging the gap between theoretical knowledge and practical applications.

The transformative effects of these programs call for a reconsideration of resource allocation. The tangible outcomes emphasize the need for further investment in undergraduate research opportunities. Enhancing the accessibility of such experiences could be a strategic avenue for fostering a generation of innovative engineers.

In conclusion, the revelations from this study elucidate the impact of programs supporting undergraduate research and their potential ripple effects within engineering education. By nurturing a culture of experiential learning and aligning research pursuits with critical global concerns, we can forge a path toward holistic education, innovation, and transformative change.

Acknowledgements

This research was conducted as part of a Nebraska Department of Transportation feasibility study on the use of recycled plastic in asphalt pavements, supported by the University of Nebraska–Lincoln UCARE program. We extend our sincere appreciation to First Star Recycling for providing the waste plastic used in this study.

References

[1] ABET. (2018). Sustainable engineering: An issue brief. https://www.abet.org/wp-content/uploads/2018/11/ABET_Sustainable-Engineering_Issue-Brief.pdf

[2] Suhirman, S., & Prayogi, S. (2023). Overcoming challenges in STEM education: A literature review that leads to effective pedagogy in STEM learning. *Jurnal Penelitian Pendidikan IPA*, 9(8), 432-443. https://doi.org/10.29303/jppipa.v9i8.4715

[3] Godbole, R., & Saxena, D. (2020). Strengthening the participation of women in science. Journal of the Indian Institute of Science, 100(4), 773-780. https://doi.org/10.1007/s41745-020-00195-0

[4] Lebreton, L., and A. L. Andrady. Future Scenarios of Global Plastic Waste Generation and Disposal. Palgrave Communications, Vol. 5, No. 1, 2019. https://doi.org/10.1057/s41599-018-0212-7.

[5] Environmental Protection Agency EPA. Facts and Figures about Materials, Waste and Recycling, Plastics: Material-specific Data (2023). https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data. (Accessed 17 June 2024).

[6] Yin, F., M. Fortunatus, R. Moraes, M. D. Elwardany, N. Tran, and J.-P. Planche. Performance Evaluation of Asphalt Mixtures Modified with Recycled Polyethylene via the Wet Process. Transportation Research Record, Vol. 2675, No. 10, 2021, pp. 491–502. https://doi.org/10.1177/03611981211011650

[7] Radeef, H. R., N. A. Hassan, A. R. Z. Abidin, M. Z. H. Mahmud, N. I. Md. Yusoffa, M. K. I. M. Satar, and M. N. M. Warid. Enhanced Dry Process Method for Modified Asphalt Containing Plastic Waste. Frontiers in Materials, Vol. 8, 2021. https://doi.org/10.3389/fmats.2021.700231.

[8] Taherkhani, H., and M. Tajdini. Comparing the Effects of Nano-Silica and Hydrated Lime on the Properties of Asphalt Concrete. Construction and Building Materials, Vol. 218, 2019, pp. 308–315. https://doi.org/10.1016/j.conbuildmat.2019.05.116.

[9] Milbrandt, A., Coney, K., Badgett, A., & Beckham, G. T. (2022). Quantification and evaluation of plastic waste in the United States. Resources, Conservation & Recycling, 183, 106363. https://doi.org/10.1016/j.resconrec.2022.106363

[10] Eagan, M. K., Hurtado, S., Chang, M. J., Garcia, G. A., Herrera, F. A., & Garibay, J. C. (2013). Making a difference in science education: The impact of undergraduate research programs. American Educational Research Journal, 50(4), 683-713. https://doi.org/10.3102/0002831213482038

[11] National Academies of Science, Engineering, and Medicine. (2017). Undergraduate research experiences for STEM students: Successes, challenges, and opportunities. The National Academies Press.

[12] Khurshid, M. B., N. A. Qureshi, A. Hussain, and M. J. Iqbal. Enhancement of Hot Mix Asphalt (HMA) Properties Using Waste Polymers. Arabian Journal for Science and Engineering, Vol. 44, No. 10, 2019, pp. 8239–8248. https://doi.org/10.1007/s13369-019-03748-3.

[13] Mashaan, N. S., A. Chegenizadeh, and H. Nikraz. Evaluation of the Performance of Two Australian Waste-Plastic-Modified Hot Mix Asphalts. Recycling, Vol. 7, No. 2, 2022, p. 16. https://doi.org/10.3390/recycling7020016.

[14] Chin, C., and P. M. M. Damen. Viability of Using Recycled Plastics in Asphalt and Sprayed Sealing Applications. Austrodas, 2019.

[15] Heydari, S., A. Hajimohammadi, N. H. S. Javadi, and N. Khalili. The Use of Plastic Waste in Asphalt: A Critical Review on Asphalt Mix Design and Marshall Properties. Construction and Building Materials, Vol. 309, 2021, p. 125185. https://doi.org/10.1016/j.conbuildmat.2021.125185.

[16] Vasudevan, R., A. R. C. Sekar, B. Sundarakannan, and R. Velkennedy. A Technique to Dispose Waste Plastics in an Ecofriendly Way – Application in Construction of Flexible Pavements. Construction and Building Materials, Vol. 28, No. 1, 2012, pp. 311–320. https://doi.org/10.1016/j.conbuildmat.2011.08.031.

[17] D.N. Little, Enhancement of Asphalt Concrete Mixtures to Meet Structural Requirements through the Addition of Recycled Polyethylene, in: H.F. Waller (Ed.), ASTM International, West Conshohocken, PA, 1993, pp. 210-230.

[18] M. Panda, M. Mazumdar, Utilization of reclaimed polyethylene in bituminous paving mixes, J. Mater. Civ. Eng. 14 (6) (2002) 527–530, https://doi.org/ 10.1061/(ASCE)0899-1561(2002) 14:6(527).

[19] Almeida, A., Capitão, S., Bandeira, R., Fonseca, M., & Picado-Santos, L. (2020). Performance of AC mixtures containing flakes of LDPE plastic film collected from urban waste considering ageing. Construction and Building Materials, 232, 117253. https://doi.org/10.1016/j.conbuildmat.2019.117253

[20] Martin-Alfonso, J. E., Cuadri, A. A., Torres, J., Hidalgo, M. E., & Partal, P. (2019). Use of plastic wastes from greenhouse in asphalt mixes manufactured by dry process. *Road Materials and Pavement Design*, *20*(sup1), S265-S281. https://doi.org/10.1080/14680629.2019.1588776

[21] Jahromi, S. G. Estimation of Resistance to Moisture Destruction in Asphalt Mixtures. Construction and Building Materials, Vol. 23, No. 6, 2009, pp. 2324–2331. https://doi.org/10.1016/j.conbuildmat.2008.11.007.

[22] Abu Abdo, A. M., & Jung, S. J. (2020). Investigation of reinforcing flexible pavements with waste plastic fibers in Ras Al Khaimah, UAE. *Road Materials and Pavement Design*, *21*(6), 1753-1762. https://doi.org/10.1080/14680629.2019.1566086

[23] Ballester-Ramos, M., Miera-Dominguez, H., Lastra-González, P., & Castro-Fresno, D. (2023). Second life for plastic fibre waste difficult to recover: Partial replacement of the binder in asphalt concrete mixtures by dry incorporation. *Materials*, *16*(3), 948. https://doi.org/10.3390/ma16030948

[24] Ma, Y., H. Zhou, X. Jiang, P. Polaczyk, R. Xiao, M. Zhang, and B. Huang. The Utilization of Waste Plastics in Asphalt Pavements: A Review. Cleaner Materials. Volume 2.

[25] Duarte, G. M., and A. L. Faxina. Asphalt Concrete Mixtures Modified with Polymeric Waste by the Wet and Dry Processes: A Literature Review. Construction and Building Materials. Volume 312.

[26] AASHTO. (2020). R 30: Standard practice for mixture conditioning of hot mix asphalt (HMA). GlobalSpec. https://standards.globalspec.com/std/13399819/aashto-r-30

[27] AASHTO T-324-22 Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Asphalt Mixtures. *American Association of State Highway and Transportation Officials.*

[28] Asphalt Institute. 2014. Asphalt Mix Design Methods. Manual Series No. 02 (MS-2) 7th Ed.

[29] Zhang, Y., and H. U. Bahia. Effects of Recycling Agents (RAs) on Rutting Resistance and Moisture Susceptibility of Mixtures with High RAP/RAS Content. Construction and Building Materials, Vol. 270, 2021, p. 121369. https://doi.org/10.1016/j.conbuildmat.2020.121369.

[30] ASTM D8225 Standard test method for determination of cracking tolerance index of asphalt mixture using the indirect tensile cracking test at intermediate temperature. American Society for Testing and Materials, 2019.

[31] Polaczyk, P., Y. Ma, R. Xiao, W. Hu, X. Jiang, and B. Huang. Characterization of Aggregate Interlocking in Hot Mix Asphalt by Mechanistic Performance Tests. Road Materials and Pavement Design, Vol. 22, No. sup1, 2021, pp. S498–S513. https://doi.org/10.1080/14680629.2021.1908408

[32] Zhou, F., S. Im, L. Sun, and T. Scullion. Development of an IDEAL Cracking Test for Asphalt Mix Design and QC/QA. Road Materials and Pavement Design, Vol. 18, No. sup4, 2017, pp. 405–427. https://doi.org/10.1080/14680629.2017.1389082.

[33] Chen, H., Y. Zhang, and H. U. Bahia. The Role of Binders in Mixture Cracking Resistance Measured by Ideal-CT Test. International Journal of Fatigue, Vol. 142, 2021, p. 105947. https://doi.org/10.1016/j.ijfatigue.2020.105947.

[34] Goli, A., B. Rout, T. Cyril, and V. Govindaraj. Evaluation of Mechanical Characteristics and Plastic Coating Efficiency in Plastic-Modified Asphalt Mixes. International Journal of Pavement Research and Technology, Vol. 16, No. 3, 2023, pp. 693–704. https://doi.org/10.1007/s42947-022-00157-y.

[35] Veerasingam, S., M. Ranjani, R. Venkatachalapathy, A. Bagaev, V. Mukhanov, D. Litvinyuk, M. Mugilarasan, K. Gurumoorthi, L. Guganathan, V. M. Aboobacker, and P. Vethamony. Contributions of Fourier Transform Infrared Spectroscopy in Microplastic Pollution Research: A Review. Critical Reviews in Environmental Science and Technology, Vol. 51, No. 22, 2021, pp. 2681–2743. https://doi.org/10.1080/10643389.2020.1807450.

[36] DeFelsko. Automatic Pull-Off Adhesion Tester Instruction Manual. 2024.

[37] Arunkumar Goli; Biswabikash; Tomsy Cyril; V. Govindaraj. Evaluation of Mechanical Characteristics and Plastic Coating Efciency in Plastic Modifed Asphalt Mixes. International Journal of Pavement Research and Technology. 693–704, 2023. https://doi.org/10.1007/s42947-022-00157.

[38] H. R. Radeef; N. A. Hassan; A. R. Z. Abidin; M. Z. H. Mahmud; C. R. Ismail; H. F. Abbas, Z. H. Al-Saffar; S. Redha. Impact of Ageing and Moisture Damage on the Fracture Properties of Plastic Waste Modified Asphalt. IOP Conf. Series: Earth and Environmental Science (2022). IOP Publishing. doi:10.1088/1755-1315/971/1/012009

[39] Yeong Jia Boom, Dai Lu Xuan, Marie Enfrin, Michael Swaney, Hassan Masood, Biplob Kumar Pramanik, Dilan Robert, Filippo Giustozzi. Engineering properties, microplastics and emissions assessment of recycled plastic modified asphalt mixtures, Science of The Total Environment. Volume 893, 2023, 164869, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2023.164869.

Kaylee Cunning

Cunning is a fourth-year undergraduate student and undergraduate research assistant at the Civil and Environmental Engineering Department at University of Nebraska-Lincoln, and member of the Institute for Electronics and Electrical Engineers.

Jamilla E. S. L. Teixeira

Teixeira is an Assistant Professor of Civil and Environmental Engineering and Geotechnical and Materials Researcher at the University of Nebraska—Lincoln. She holds her Ph.D. and M.S. in Civil Engineering from the University of Nebraska—Lincoln, and her B.S. in Civil Engineering from Federal University of Ceara- Brazil.

Joseph Tighi

Tighi is a fourth-year undergraduate student and undergraduate research assistant at the Civil and Environmental Engineering Department at University of Nebraska-Lincoln.

Isabela Bueno

Bueno is a second year M.S. student in civil engineering graduate program and graduate research assistant at the Civil and Environmental Engineering Department at the University of Nebraska-Lincoln.

Jessica Deters

Deters is an Assistant Professor of Mechanical and Materials Engineering and Discipline Based Education Researcher at the University of Nebraska—Lincoln. She holds her Ph.D. in Engineering Education and M.S. in Systems Engineering from Virginia Tech, and her B.S. in Applied Mathematics and Statistics from the Colorado School of Mines.