Causes for the Detrimental Effect of REOB in Asphalt Binder

IAPA Scholarship Report

Javier J. García Mainieri

January 2021

Acknowledgement

Firstly, I would like to express my gratitude to the Illinois Asphalt Pavement Association (IAPA) for their support during this 2020-2021 academic year. I am honored and grateful for having been selected as a recipient of the IAPA scholarship and look forward to collaborating with the asphalt industry in Illinois.

The contents of this report reflect the view of the author, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of Illinois Center for Transportation (ICT). This report does not constitute a standard, specification, or regulation.

Introduction

The use of asphalt binders with a performance grading (PG) of 58-28 for new and rehabilitation road construction in Illinois is surpassing that of the stiffer PG 64-22 binders (Trepanier 2020). Softening stiffer binders using additives might be more economical than producing softer binders (Kriz et al. 2019). Therefore, it is expected that soon the Illinois Department of Transportation (IDOT) will allow the use of softening or recycling agents.

A modifier type that has been commonly used to soften asphalt binders is re-refined engine oil bottoms (REOB). However, asphalt pavement's premature cracking or poor durability have been associated with the presence of REOB (Ozer et al. 2016; Reinke et al. 2016). It is thus important to understand the characteristics of this modifier type and investigate the causes of such adverse effects on pavements.

The objective of this report is to identify the characteristics of REOB-type modifiers that might be detrimental to asphalt binder quality leading to cracking in pavements.

Rheological Characteristics

Singhvi et al. (2020) and García Mainieri et al. (2021) studied the effects of blending a PG 64-22 binder with softening modifiers, one of which was of the REOB type. The findings from this study are highlighted in this section.

Superpave PG grading

REOB is capable of softening the binder; i.e., lowering the high and low temperature PG grade of the binder. The low temperature PG grade is affected in a minor way even when REOB dose is increased (Ozer et al. 2016). Singhvi et al. (2020), provided a detailed explanation for this phenomenon. As shown in Figure 1, with increasing dose of REOB, the modulus of the binder decreases and therefore so does the High and Intermediate PG grades. This is also clearly depicted in the BBR stiffness measurements. As the shear modulus decreases, the bending stiffness of the BBR specimens did as well, thus leading the Low Temperature PG grade -as determined by stiffness – to become larger (in negative value). On the other hand, the Low Temperature PG grade -as determined by the m-value or relaxation indicator – remained stable indicating that the REOB was not effective at increasing the capacity of the binder to relax quickly enough when subjected to a constant load. This is of particular importance for pavements during low temperature seasons, where a soft asphalt mix is needed for low resistance shrinkage as temperature goes down over night.

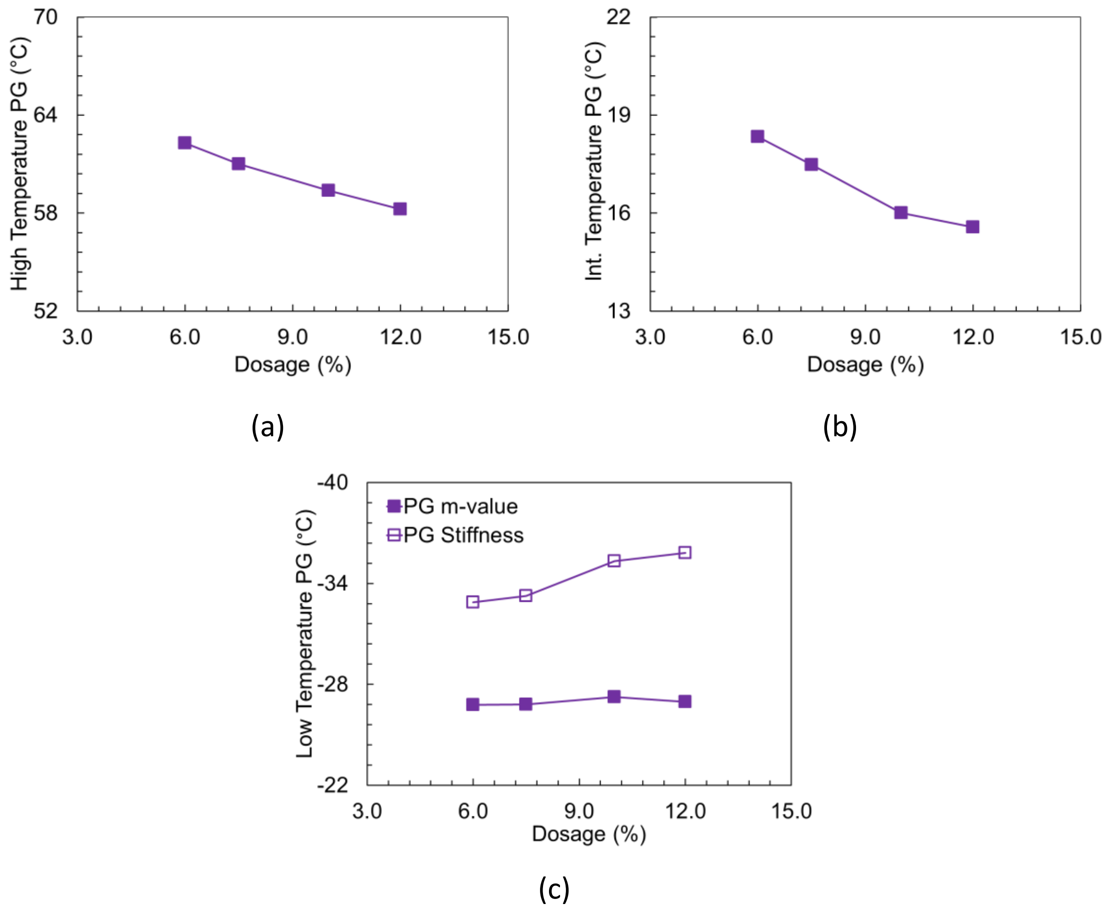

Figure 1. PG of 64-22 binder with increasing dose of REOB. (a) High PG, (b) Intermediate PG, and (c) Low PG. From Singhvi et al. 2020

Aging, Composition, and Other Parameters

As stated before, REOB could aid in lowering the stiffness of an asphalt binder. However, it is worth to note that this softener-modified asphalt binder (SMAB) could pass a PG specification but still have an undetected detrimental effect on the asphalt binder. Singhvi et al. (2020) provide parameters obtained from frequency sweep testing in a dynamic shear rheometer (DSR) and bending beam rheometer (BBR) testing that help to distinguish REOB from other softeners and make REOB-modified binder stand out because of a lower expected performance when compared to a benchmark unmodified binder. These are presented in Figure 2.

The Glover-Rowe parameter (GR) is related to low-temperature cracking. It is proportional to the modulus |G*| and inversely proportional to the phase angle. A higher GR brings the binder near onset and severe cracking potential, as per FIGURE 3 (a). The ΔT_c parameter is a difference between the stiffness and relaxation critical temperatures obtained from the BBR test (Asphalt Institute, 2019). A more negative value of ΔT_c parameter is related to low-temperature cracking also. Both ΔT_c and GR illustrate how the effect of oxidation – provided by laboratory aging procedures of increasing intensity: RTFO, PAV, 2PAV and 3PAV, respectively – seem to be accelerated for the binder modified with REOB. As per Figure 2 (b), the phase angle of the REOB-modified binder is lower for any value of |G*|. The phase angle follows the trend of the ratio of the elastic component to the viscous component of |G*|, a lower value – or a high elastic predominance – is indicative of a brittle behavior.

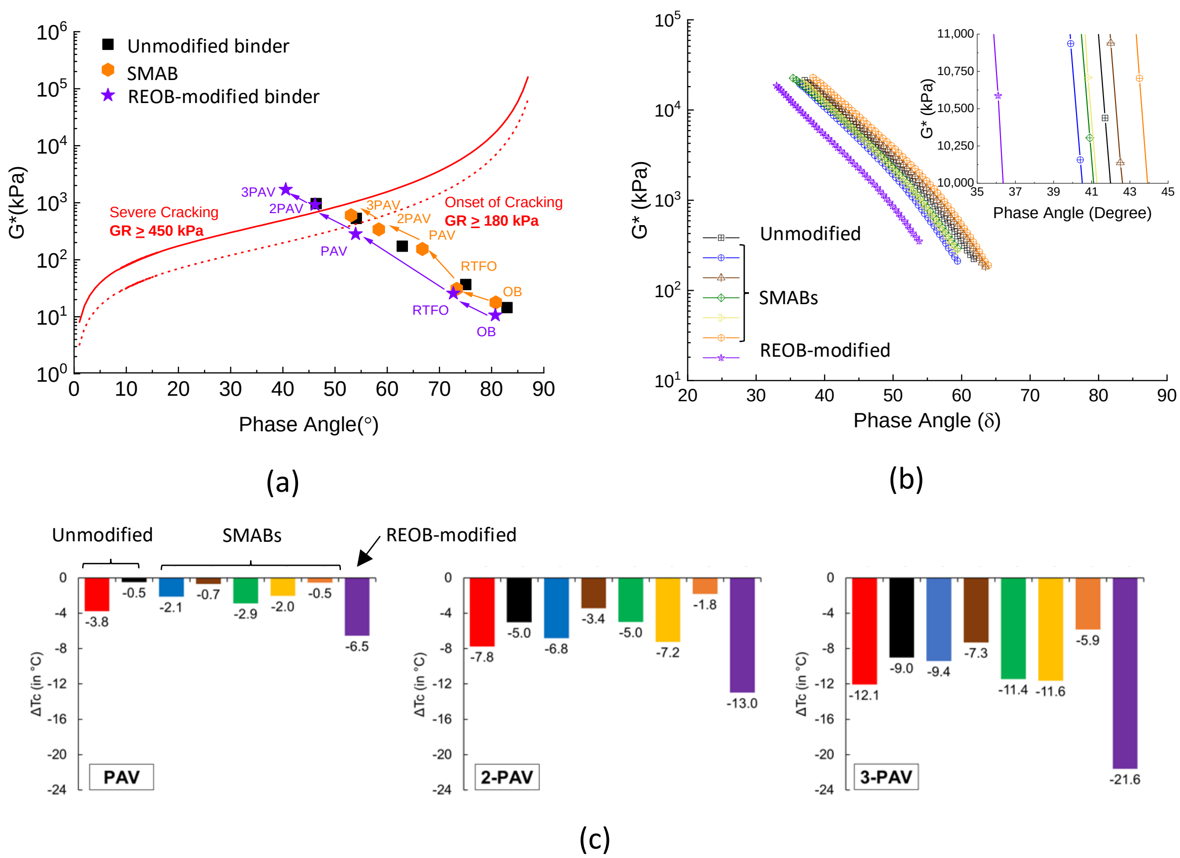

Figure 2. (a) GR, (b) Phase Angle at PAV aging condition, and (c) Tc results. From Singhvi et al. 2020. Modified

García Mainieri et al. (2021), provide a practical parameter ($\Delta|G^*|_{peak\ \tau}$ or Delta G) to assess the fatigue tolerance of asphalt binder using the linear amplitude sweep (LAS) in a DSR. The REOB-modified binder, as per Figure 3, had poor performance when compared to the other SMABs and the unmodified counterparts. This was associated to the quick and sudden initiation of cracks during testing on the REOB-modified binder.

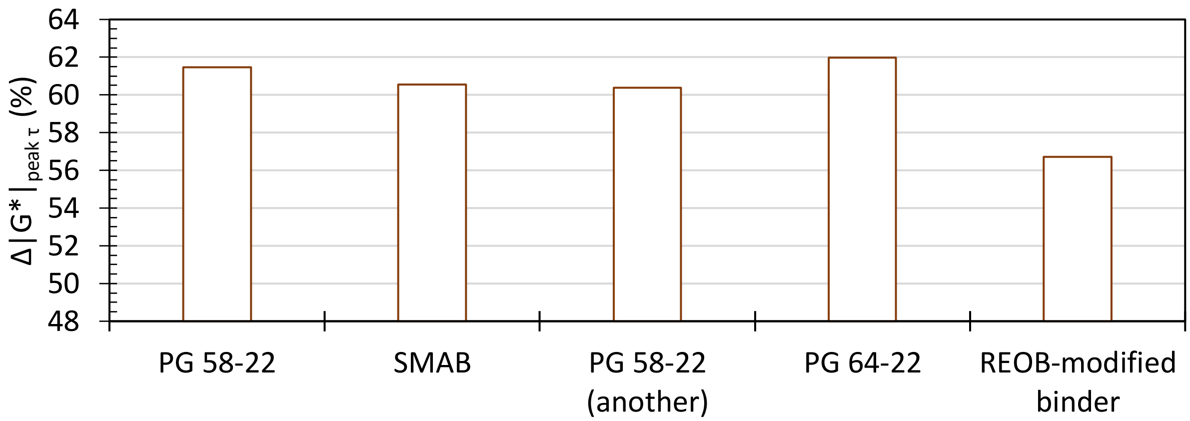

Figure 3. Delta G results at PAV aging condition from García Mainieri et al. 2021. Modified

The effect of REOB with binders having different composition may vary (Johnson and Hesp 2014). In turn, the effect of REOB having different composition might also vary. In the case of the REOB used by Singhvi et al. (2020) and García Mainieri et al. (2021), the presence of Sulphur was identified in the modifier. Sulphur, being available to react with oxygen, could have promoted the formation of Sulfoxides. Sulfoxides are a functional group commonly identified in oxidized asphalt binder. The attachment of oxygen might have increased the average molecular size of the asphalt binder. According to Singhvi et al. (2020), increased average molecular size might be related to the embrittlement of asphalt binders. The studied REOB also had high residue (heptane insoluble components) measured with Saturate-Aromatic-Resin-Asphaltene fractionation, which can be another reason for increase brittleness (Singhvi et al. 2020).

Cracking Characteristics

The Illinois Flexibility Index Test (I-FIT) has been used to evaluate REOB as an additive in the mixture level (Ozer et al. 2016, Al-Qadi et al. 2019). I-FIT provides an indication of the cracking potential of asphalt mixtures by the means of an index, termed as Flexibility Index (FI). The FI depends on the fracture energy of the material and the slope of the post-peak loaddeformation curve of the test, which is indicative of the speed of the propagation of a fully formed crack.

Ozer et al. (2016), indicate – along with Figure 4 – that decreasing effect on modulus/stiffness caused by the REOB decreased once the material was aged. According to Ozer et al. (2016), overall, their results were indicating brittleness and higher potential for damage with aging in the field, for mixes with higher percentages of REOB.

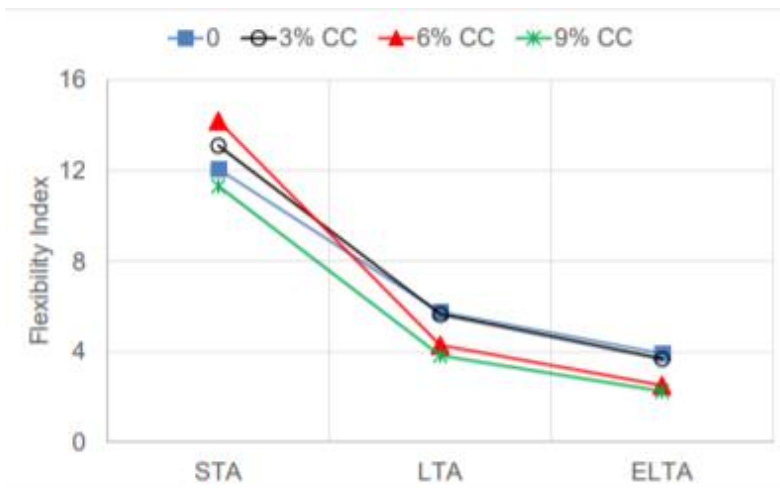

Figure 4. Impact on the FI of aging under different aging conditions (Short Term Aging [STA], Long-Term Aging [LTA], and Extralong-Term Aging [ELTA]) for mixes prepared with control and CC-type ReOB. From Ozer et al. 2016.

Al-Qadi et al. (2019), verified that aging affects mixes with REOB in an increased way with the data presented in Figure 5. Mix LM7, contains 9% (by binder weight) of REOB. When its Unaged FI and m-value (obtained at PAV aging condition are compared to the rest of the mixes, the performance achieved is the one of a ductile mix containing a soft binder. It is evident that after 1 day aging at an oven at 95˚C the FI has decreased considerably; after 3-day aging (95˚C) and 5-day (85˚C) aging FI values are comparable to the worst performing mixes and are close to the proposed minimum threshold long-term aging threshold of 4.0.

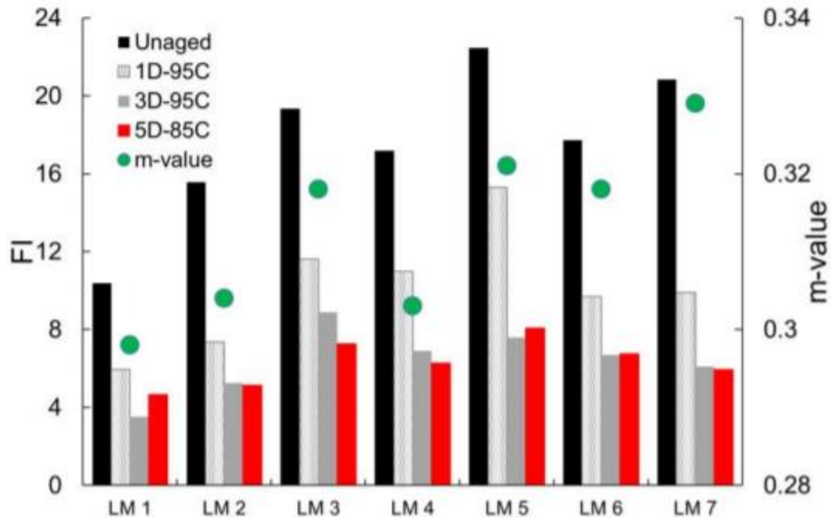

Figure 5. FI and binder m-value for mixes and respective binders. From Al-Qadi et al. 2019

Conclusion

The REOB modifiers used in the mentioned studies embrittle asphalt binder making it more prone to suddenly crack. The softening effect of REOB appears to vanish when aging in the mixture or binder level are applied. Laboratory oxidation seems to affect a binder with REOB in a more accelerated way than an unmodified one. The presence of Sulphur or residues (heptane insoluble) in REOB might be associated with accelerated oxidation effects and embrittlement.

References

Asphalt Institute. Use of the Delta Tc Parameter to Characterize Asphalt Binder Behavior IS-240; Asphalt Institute: Lexington, KY, USA, 2019

Al-Qadi, I.L.; Ozer, H.; Zhu, Z.; Singhvi, P.; Ali, M.U.; Sawalha, M.; Luque, A.E.F.; García Mainieri, J.J.; Zehr, T.G. Development of Long-Term Aging Protocol for Implementation of the Illinois Flexibility Index Test (I-FIT); Illinois Center for Transportation: Rantoul, IL, USA, 2019.

García Mainieri, J.J.; Singhvi, P.; Ozer, H.; Sharma, B.K.; Al-Qadi, I.L. 2021. Fatigue Tolerance of Aged Softener-Modified Asphalt Binders Using Linear Amplitude Sweep. In Proceedings of the 100th Transportation Research Board Conference, Online, January 2021.

Johnson, K., and S. Hesp. 2014. Effect of Waste Engine Oil Residue on the Quality and Durability of SHRP MRL Binders. Paper #14-0529. Proceedings of the 93rd Transportation Research

Board, Transportation Research Board, National Research Council, National Academies, Washington, DC.

Kriz, P.; Noel, J.; Quddus, M.; Maria, S. Rheological Properties of Phase-Incompatible Bituminous Binders. In Proceedings of the 56th Peterson Asphalt Research Conference, Laramie, WY, USA, 14–17 July 2019.

Ozer, H.; Renshaw, G.; Hasiba, K.; Al-Qadi, I.L. Evaluation of the Impacts of Re-Refined Engine Oil Bottoms (ReOB) on Performance Graded Asphalt Binders and Asphalt Mixtures, Report No. FHWA-ICT-16-006; Illinois Center for Transportation: Rantoul, IL, USA, 2016.

Reinke, G.; Hanz, A.; Anderson, R.M.; Ryan, M.; Engber, S.; Herlitzka, D. Impact of re-refined engine oil bottoms on binder properties and mix performance on two pavements in Minnesota. In Proceedings of the E&E Congress 2016, 6th Eurasphalt & Eurobitume Congress, Prague, Czech Republic, 1–3 June 2016.

Singhvi, P.; García Mainieri, J.J.; Ozer, H.; Sharma, B.K.; and Al-Qadi, I.L. Effect of Chemical Composition of Bio- and Petroleum-Based Modifiers on Asphalt Binder Rheology. Applied Sciences, 2020. 10: 10.1061/9780784482469.028.

Trepanier, J. IDOT HMA Tech Briefs. In Proceedings of the 61st Illinois Bituminous Paving Conference, Champaign, IL, USA, December 2020