Performance of rubber bituminous asphalt mixes at hot and warm production temperatures

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Abstract
In the production of asphalt mixtures, the possibility of recycling rubber grits has appeared for decades. A rubber bituminous mixture appearing as a special Hungarian patent greatly reduced the viscosity problems of rubber bitumen mixtures, resulting in a bitumen type that is easily transportable and does not require special equipment, The asphalt mechanical properties of the MOL rubber bituminous mixture are excellent both in the field of plastic deformation, cold behavior, and fatigue properties, so they are real competitors to polymer-modified bituminous mixtures. New research possibilities have emerged for use at reduced production temperatures, as a so-called WMA asphalt mix, in which case the first experimental – wheel tracking and cold behavior test - results are also encouraging.
Keywords: rubber grid, rubber bitumen mixture, WMA mixture, asphalt mixture performance
Kulcsszavak: gumiőrlemény, gumi bitumen keverék, WMA keverék, aszfaltkeverék teljesítmény

1. Introduction

The use of rubber bituminous binder, i.e., rubber-modified bitumen, has been present in asphalt production for decades. The purpose of rubber bitumen is twofold, since on the one hand it aims to recycle tire waste and, on the other hand, it seeks to use the beneficial properties of rubber during mixing with bitumen. However, its spread was not a complete breakthrough in the asphalt industry, which may be due to problems of production technology, quantity and quality. At the same time, rubber bitumen developed by the Hungarian Oil Industry Company (MOL) eliminated and reduced production technology problems to an acceptable extent, resulting in rubber-modified bitumen whose use in asphalt mixtures rivals the mechanical properties of polymer-modified bituminous asphalt mixes. Asphalt mixes made with domestic MOL rubber bitumen have appeared on the expressway network since last year, not only for wear layer installations, but also for bonding and base layer applications. Due to the increased energy costs, the application possibilities of asphalts made at reduced production temperatures have come to the fore again, accordingly, it is also possible to produce moderately warm asphalt mixtures in the production of rubber bituminous asphalt mixes. The purpose of publishing this article is to briefly summarize the most important asphalt mechanical experiences of mixtures made with rubber bitumen developed in Hungary and to discuss the production possibilities of moderately warm mixtures.

2. Production technologies of rubber bitumen

Advances in manufacturing technology have made it possible to recycle tyre materials (shredering). By refining grinding technologies, the tyre's main components could now be separated into rubber groats, steel and fabric. The technologies developed for the use of rubber powder are now widespread, in a very simple way the literature distinguishes between the so-called dry and wet process and their technologically modified versions. The addition of rubber granules and grits to asphalt mixtures appeared already in the 1950s and 60s in the USA and Sweden [2]. In addition to cold technologies (pressed glued rubber mats), experiments have been conducted since the 1960s to explore the application possibilities of warm technologies. MacDonald's experiments have already aimed to turn rubber-doped bitumen into rubber bitumen, i.e., to increase the rate of use from 3% to a minimum of 15% [3].

An engineer from Arizona thought it was worth mixing the rubber grist with bitumen and letting the two materials react with each other for about 1 hour, because in this case we get a new material with engineered advantageous properties. He named the material rubber asphalt, and the process is called the "water process" in scientific language.

In the dry process, rubber ground is added to the heated mineral additive, and only then mixed with bitumen during the preparation of asphalt. In this case, the rubber powder must be activated beforehand to achieve optimal particulate swelling. In the wet process, the rubber grist is first mixed with bitumen and then mixed with the stone frame. During the wet process, bitumen contains the aromatic douching oils necessary for the activation of rubber. Already early rubber bitumen studies showed that the grain size of the rubber groats, the mixing temperature and the duration of mixing are closely related to the properties of the final product [2]. The swelling and subsequent dissolution of crumb rubber can be demonstrated through rheological characteristics, e.g., the change in viscosity (*Fig. 1*) [3].

Due to its high viscosity, rubber bitumen produced by wet process requires a special asphalt recipe and asphalt production conditions, moreover, it requires a special mineral framework for the manufacture of the mixture. Despite the difficulties, asphalts and built asphalt roads mixed with the use of rubber bitumen produced in this way resulted in significant quality and durability improvements compared to asphalts and roads manufactured with normal road construction bitumen [3].

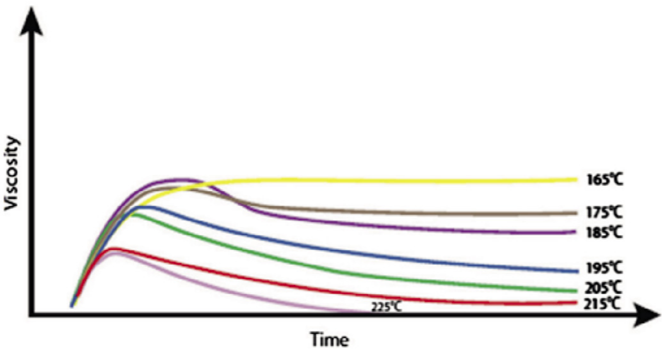

Fig. 1 Change of rubber bitumen viscosity as a function of blending temperature and duration
1. ábra A gumibitumen viszkozitásának változása a keverési hőmérséklet és idő függvényében

3. Modified wet process, or MOL technology

The joint research and development activities of MOL and the University of Pannonia in the field of rubber bitumens started in the early 2000s. The objective was to produce a rubber bitumen product that has the advantages of already known rubber bitumen products but eliminates or at least reduces to an acceptable extent the problems of their production and/or use, and it was also an important goal to make the new production technology feasible in the oil refinery. This will make it possible that the production of rubber bitumen does not require a special rubber-bitumen mixing plant at the site of asphalt production, and the product is transported, used in asphalt manufacturing and road construction similarly to polymer-modified bitumens. As a result of the successful research and development activity, a patent-protected technology and product (HU226481) was developed [4]. The technology described by the patent is the so-called "technology". Modified wet process and the manufactured product is chemically stabilized rubber bitumen [4]:

- In the first technological step of the modified wet process, the rubber grist is added to high-temperature bitumen (210-250 °C) and subjected to intensive stirring, resulting in swelling and partial dissolution of the rubber grit.
- In the next technological step, during mixing at a lower temperature (140-180 °C), the partially dissolved rubber powder is stabilized, and the split carbon-sulfur and sulphur-sulfur bonds are partially rebuilt (revulcanized).
- A multifunctional, self-developed and manufactured additive is also used in MOL, which improves the dissolution of rubber grits in bitumen and the compatibility of the rubber-bitumen system, and on the other hand, due to its viscosity reducing function, it also plays a significant role in improving the applicability of the product (pumpability at asphalt mixing stations, atomization, compressibility).

The complete dissolution of the rubber powder does not take place even during the modified wet process developed by MOL and the University of Pannonia, as complete dissolution would be at the expense of the quality of the manufactured product. 50-60% by weight of the rubber grist used dissolves, so a significantly higher proportion than in the previously applied wet rubber bitumen production technologies. Polymers that enter bitumen by the dissolution of rubber as active modifying agents improve the properties of bitumen. The undissolved rubber grains, swollen by the binding of the oily components of bitumen, partially retain their elastic properties. As a consequence, the fatigue and low-temperature properties of the binder improve, which also results in a significant improvement in the quality of asphalt [5].

4. Experience and tests of rubber bitumen installation in Hungary

Rubber bituminous test sections were already built in Hungary before 2010 on a test basis, and the first laboratory asphalt mechanical tests started during this period.

The opening of MOL's rubber bitumen manufacturing plant in Zalaegerszeg created a new opportunity for the production of rubber bitumen mixtures, and since 2012 rubber bituminous asphalt mixtures have been integrated into Hungarian road technical regulations. Between 2012 and 2021, more than 110 km of road sections made using rubber bituminous asphalt mixture were created or renovated in Hungary. On the affected road sections, they were typically built mostly in wear and bonding layers, but after 2018 the base layers were also built with rubber bitumen mixtures (RMB), and from this year these modern mixtures were also installed on some Hungarian expressways.

Budapest University of Technology and Economics' (BUTE) Department of Highway and Railway Engineering has been involved in the investigations of RMB almost since the beginning of the development. Tests have already been carried out on mixtures made according to the previous technical specification in 2009, with encouraging results. The asphalt mechanical properties (fatigue, resistance to deformation, etc.) of the RMB mixture have been shown to be superior to those made with conventional road construction bitumen; some of its characteristics were found to be close to, and sometimes even precede those of polymer-modified bitumen binder (PMB) asphalt mixes.

It is clear that rubber bitumen is not a competitor to conventional asphalt mix, but to polymer-modified bituminous mixture. It is becoming clear that the cold-side behavior and fatigue resistance are significantly better when comparing rubber bituminous mixtures with polymer-modified bituminous mixtures, in the case of plastic deformation – and so far, this has been confirmed by the small number of triaxial tests – there is no significant difference between the two mixtures, and the stiffness test results favor PMB mixtures.

The researchers of BUTE's Department of Highway and Railway Engineering compared the traditional, polymer-modified and rubber-bituminous asphalt track structures built with an unbound base structure using the dimensioning procedure of the road structure, and the results concluded that under the same load conditions, asphalt thicknesses up to 1.5 cm thinner than PMB mixtures may be sufficient to withstand loads [5].

Type of asphalt mechanical test	Normal asphalt mix	Polymer modified asphalt mix	Rubber bituminous asphalt mix
Wheel tracking test	+	++	++
Fatigue resistance test	+	++	+++
IT-CY stiffness test	+	+++	++
Cold behaviour test	+	++	+++
Note: The difference between the + signs represent the positions of the test results of each mixture relative to each other			

Fig. 2 Comparison of asphalt mechanical tests carried out over the last ten years for each type of mixture (+++: indicates best performance) [6]
2. ábra Az elmúlt tíz évben az egyes keveréktípusokon elvégzett aszfaltmechanikai vizsgálatok összehasonlítása (+++: a legjobb teljesítményt jelzi) [6]

5. Rubber bitumen as moderately warm asphalt

The production temperature of hot mix asphalt mixes (HMA) is between 160 °C and 180 °C. Various viscosity reduction processes can be used to produce „Warm Mix Asphalt" (WMA) between 100 °C and 150 °C and semi-warm asphalt mixtures between 60 °C and 100 °C [7]. The purpose of the high temperature is to temporarily reduce the viscosity of bitumen enough to coat the grains and be transported to the work area for installation. At the same time, the viscosity of bitumen can be reduced by various processes, foaming, or by adding chemical and organic substances.

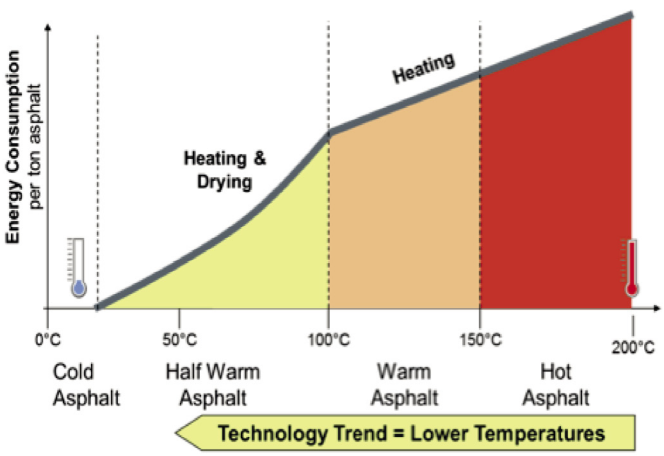

Fig. 3 Types of asphalt depending on production temperature: cold asphalt, half warm asphalt, warm asphalt, and hot asphalt [7]
3. ábra Az aszfalt típusai a gyártási hőmérséklettől függően: hideg aszfalt, félig meleg aszfalt, meleg aszfalt és forró aszfalt [7]

By reducing the viscosity of bitumen, WMA mixtures can be produced at temperatures up to 30-60 °C lower than conventional asphalt. Thus, by reducing the energy required for heating, direct fuel savings of up to 30-50% can be achieved, which can be easily and immediately realized during asphalt production. Another important aspect is that the coating of the aggregate frame with bitumen is not damaged and thus its compactability is not inferior to WMA asphalt compared to conventional asphalt mixes [8].

International research has also proven that by adding an additional organic or chemical additive, it is possible to create a mixture that meets the mechanical properties of the original rubber bituminous asphalt mix as WMA asphalt, since the modulus values of indirect tensile stress, wheel track formation resistance and elasticity practically did not differ in the case of the WMA mixture compared to the „normal" rubber bituminous mixture representing the reference mixture [9]. A Spanish study looked at how the WMA-RMB mixture performed. Four mixtures were tested, the control mixture was made with bitumen PMB 45-80-65 and the rubber bituminous mixture was made with 20% by weight of rubber powder added to bitumen 70/100. During the WMA process, a paraffinic organic substance (Sasobit) and a surface activating chemical additive (Zycotherm®®) were used. The mixture itself was BBTM 11A, produced at different temperatures. Based on the stiffness measurements carried out according to EN 12697-26, rubber bituminous mixtures performed better than polymeric mixtures at all test temperatures except chemical additive mixtures, with paraffin additive achieving best results. The wheel tracking test result of this mixture was practically identical to that of the PMB mixture [5, 10].

As a moderately warm asphalt mix, the rubber bituminous mixture developed by MOL was also tested in spring 2023. Two types of WMA additives were used mixed with RMB:

- GMB: wax (paraffin) type additive containing 2339-B/22 WMA additive-1, has a viscosity reducing effect at high temperatures, thereby reducing the temperature of asphalt mixing. However, when cooled to 50-70 °C, there is no softening effect, it brings about the quality parameters of the unadditive binder or asphalt, possibly it may have a stiffness/modulus increasing effect in the range of the road surface usage temperature.
- 2340-B/22: GMB containing WMA additive-2: surfactant, the mechanism of action of which is that bitumen wets the mineral more easily by reducing surface tension. As a result, at lower temperatures, rock wetting, that is, asphalt mixing, can be carried out.

In addition to the mixture with the two additives, two reference mixtures were prepared, a rubber bituminous AC 16 binding course (mF) (RMB 45/80-55 reference) and a polymer-modified AC 16 binding course (mF) (PMB 25/55-65 reference) mixture. The two reference mixtures were mixed according to MSZ EN 12697-35 and compacted at 170 °C, but the two WMA additive mixtures were mixed 20 °C lower.

Experiments were carried out to determine wheel traces (MSZ EN 12697-22 /9.3.2.) and cold behaviour, i.e., cracking temperatures, on the above-mentioned mixtures. Based on the results, it can be clearly seen that the surface-active additive rubber bituminous mixture mixed at a temperature lower than 20 °C gave the same results in terms of plastic deformation resistance as the reference PMB and RMB mixtures (*Fig. 4)*.

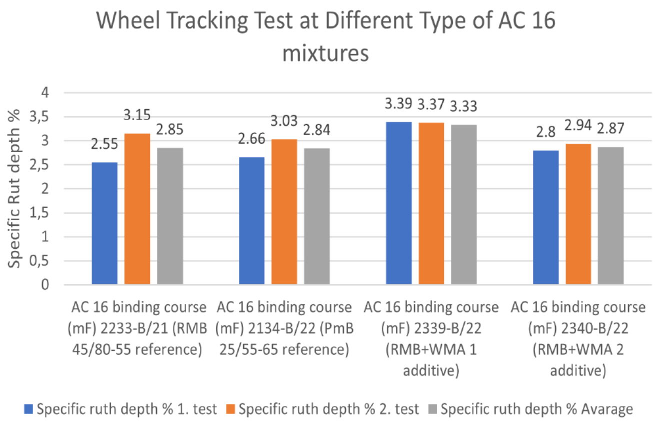

Fig. 4 Wheel tracking properties of rubber bituminous and "conventional" mixtures with WMA additive
4. ábra Gumi bitumenes és "hagyományos" keverékek keréknyomképződési tulajdonságai WMA adalékanyaggal

In terms of cracking temperature, the same mixture prepared with an active surface additive exceeded the cracking temperature result of the PMB reference mixture and yielded the level of the reference RMB mixture (*Fig. 5*).

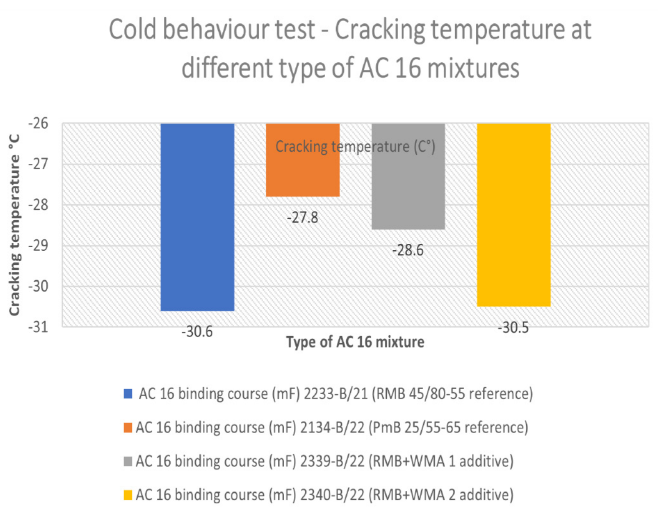

Fig. 5 Cracking temperature of rubber bituminous and "conventional" mixtures with WMA additive (Cold behavior)
5. ábra Gumi bitumenes és "hagyományos" keverékek repedési hőmérséklete WMA adalékkal (hideg viselkedés)

6. Conclusion

The use of rubber bitumens has been present in road construction for almost 50 years. Despite the beneficial properties, the application of the material could not spread to the desired extent, mainly due to manufacturing technology problems. MOL's chemically stabilized rubber bitumen product has successfully eliminated these technological problems of production and transportation and has created a favorable material that can be successfully used as a binder for any asphalt mix. In recent years, numerous asphalt mechanical tests have proven the application of domestically developed rubber bitumen, and rubber bituminous mixtures have finally appeared on the expressway network as well. In the current situation, in order to spread rubber bitumen domestically and internationally, it is necessary to examine how the scope of application of rubber bitumen can be extended.

Based on the test results presented above and international examples, it would be worthwhile to examine the possibility of using rubber bitumen in the case of WMA asphalts as well, and further studies should be carried out on the application of rubber bituminous mixtures in the binding and upper base layers regarding the overall track structure behavior.

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