Asphalt mixture performance and testing

Laboratory and site validation of a regeneration oil for recycled asphalt mixtures

Ian Michael Lancaster, Dennis Day, Jukka Laitinen
Nynas UK AB

Abstract

The addition of Recycled Asphalt (RA) into asphalt mixtures has been common practice for many years. This can be both environmentally and commercially desirable if managed properly and care is taken to ensure the subsequent asphalt mixture remains compliant with prevailing performance specifications. With additions of up to 10% RA little is required in amendments to production procedures to ensure full compliance. However, the current trend of increased RA content mixtures requires more careful consideration of both the constituent materials and the asphalt production method. To manufacture asphalt mixtures with RA contents above 20% the addition of a soft bitumen may be sufficient to maintain performance. However, at increased RA levels or for mixtures targeting a softer penetration grade based asphalt an alternative approach of using a regeneration oil is necessary. A wide range of materials are available which may be employed as a regenerating agent for RA mixtures. However, to produce a finished asphalt with equivalent short and long term performance to a virgin asphalt mixture far fewer suitable materials are available. Nynas technical centres in Belgium, Finland, Sweden and UK, working in cooperation with their customers throughout Europe, identified a non-hazardous hydrocarbon regeneration oil and this paper details its laboratory and site verification.

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1. INTRODUCTION

A well-designed asphalt pavement will provide sufficient load bearing capacity for the road's traffic volumes, will be resistant to deformation and cracking and will produce a surface that with appropriate levels of maintenance should have a service life of at least 15 to 25 years. Refined bitumen is a complex mixture of hydrocarbons and over time the lighter components evolve leading to a slow hardening of the bitumen and eventually resulting in the requirement to remove and replace the asphalt layer. This is typically removed by planing the road prior to resurfacing, with the resultant planings referred to as Recycled Asphalt (RA). A wide range of potential asphalt surfacing designs are in use and therefore the quantity of bitumen contained in RA may vary, although it is typically found to be between 3 and 7%. Whilst small quantities of RA may also be generated during utility maintenance works in relatively fresh asphalt, the majority arises from asphalt at the end of its service life and the bitumen contained in the RA usually has a needle penetration at 25°C of between 10 and 30 dmm. Approximately 50 million tonnes of RA are produced annually in Europe (EAPA 2017) which are 100% recyclable (EAPA 2014) as even though the bitumen in the RA is relatively hard it will still add to the total bitumen content of the any new asphalt it is added into.

1.1. Addition of RA to asphalt mixtures

As is well known the needle penetration of a blend of two penetration grade bitumens can be determined using blending charts or calculated using the formula

$$\log P = \frac{AlogP_a + BlogP_b}{100}$$

Where P is the penetration of the blend, Pa is the penetration of component a, Pb is the penetration of component b, A is the % of component a in the blend, and B is the % of component b in the blend.
Therefore, once the penetration of the binder in the RA is known, it is straightforward to calculate the penetration of bitumen within a RA/virgin bitumen asphalt mixture. Whilst Road Note 43 (Carswell et al 2010) demonstrated that it was possible to include at least 30% RA into thin surfacing materials the current UK practice described in PD6691 (BSI 2015) recommends that the amount of RA added to a mixture shall not exceed 10% for surface courses and 50% for all other materials. The provision for higher quantities of RA on a case-by-case basis is allowed, although this is not common.

1.2. Limitations of penetration grade bitumen additions

At low RA addition levels the impact of the harder penetration RA is slight, and with small amendments to the fresh bitumen additions to the mixture it is straightforward to produce a compliant material. However, at higher RA levels this is more difficult to achieve. Figure 1 shows the effect of increasing levels of RA, with a penetration of 18dmm and binder content of 6.0%, added to a mixture with a target binder content of 5.3%.

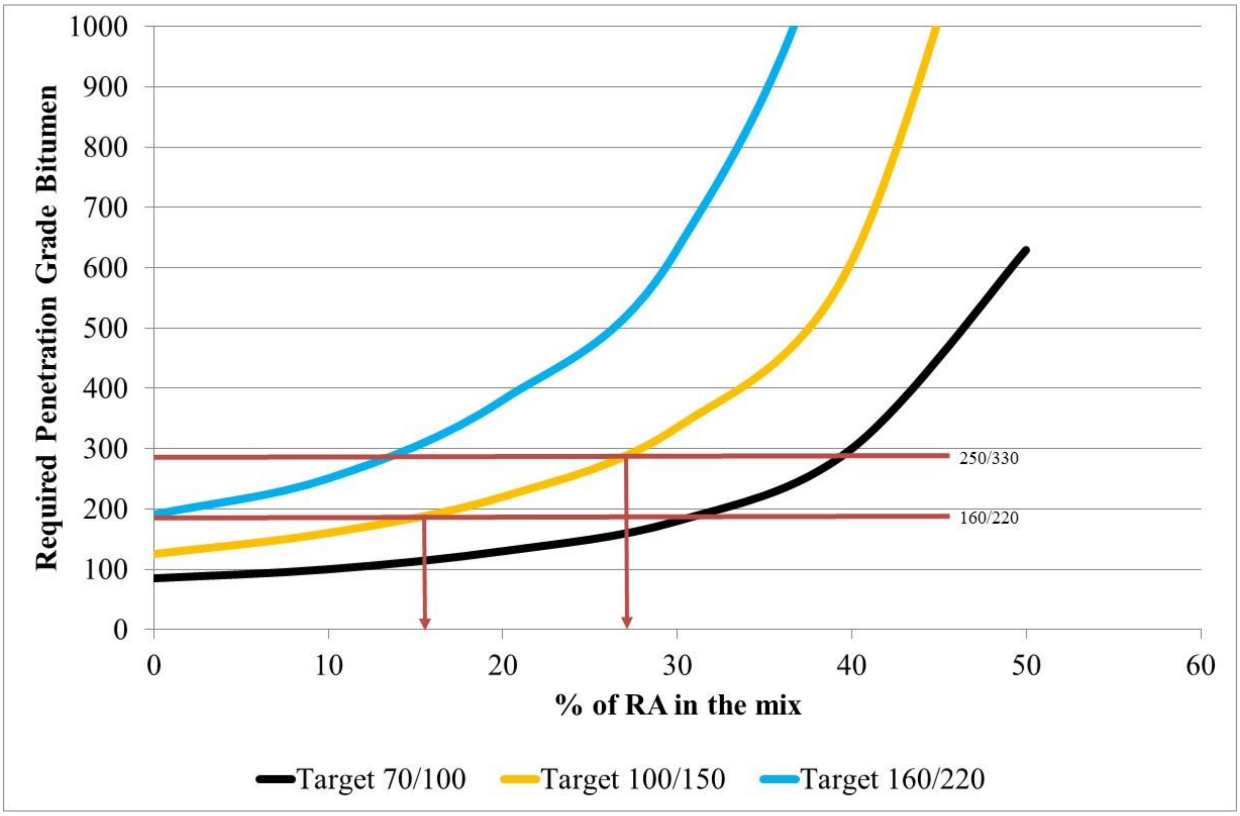

Figure 1: Effect of %RA on the bitumen penetration required to produce a specified asphalt

In this mixture to produce a 100/150 penetration mixture the maximum amount of RA that can be added is around 16% if 160/220 is used as the fresh bitumen component, and around 28% if 250/330 is used. In some countries the range of available bitumen grades may be limited and particularly so for grades softer than 160/220. Furthermore, the number of bitumen storage tanks at many asphalt plants are limited and therefore using a tank to store a very soft bitumen grade may not always be practical.

2. DEVELOPMENT OF A REGENERATION OIL

The addition of fluxes to bitumen to soften the bitumen is well known, but in order to use such a material to accurately adjust a mixture's characteristics containing high levels of RA is more challenging and not straightforward. A more appropriate route to correcting the properties of the finished asphalt mixture is to employ a specially designed regeneration oil and, therefore, Nynas technical centres throughout Europe collaborated in developing a suitable product. The first stage of the development was to assess the full range of available materials that could be used as a regeneration oil, such as those shown in Figure 2, including highly refined mineral oils of different viscosities, vegetable oil, and recycled oil.

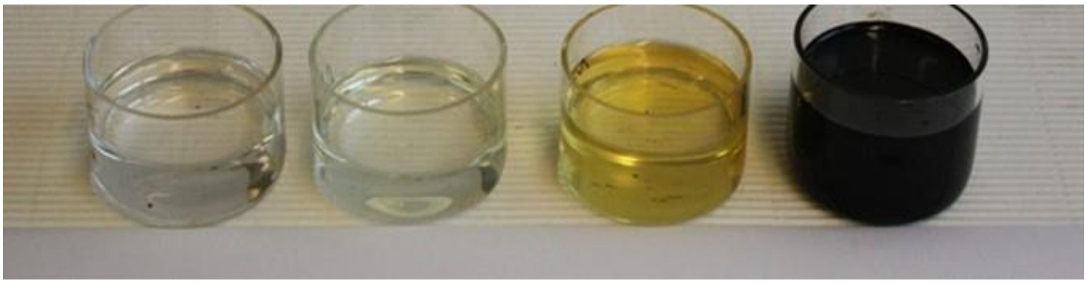

Figure 2: Typical materials available for potential use as regeneration oils

The initial consideration for any material was that it must be safe to use. Therefore, the majority of oils available were quickly discounted as being toxic, irritants, carcinogenic or environmentally hazardous. The next stage was to consider the safety of the oil during its intended use and it was, therefore, essential that any regenerating oil should have a flash point in excess of the temperatures it could encounter during mixing with aggregate, RA and bitumen. There were also further practical operational factors to consider as some materials have a relatively high pour point which would limit their use to summer months or require heated tanks.

Once all the safety considerations had been addressed the effectiveness of the oils as a bitumen regenerator could be explored. The first step of the assessment was to determine the oil's ability to achieve the required penetration of the asphalt blend. Figure 3 shows the effect of 3 refined mineral oils with different viscosities on the addition rates of regenerating oil and fresh 160/220 to the same mixture used in Figure 1. As an example, highlighted by the red lines, a mixture containing 20% RA and oil 3 would require 3.74% fresh 160/220 and 0.36% oil.

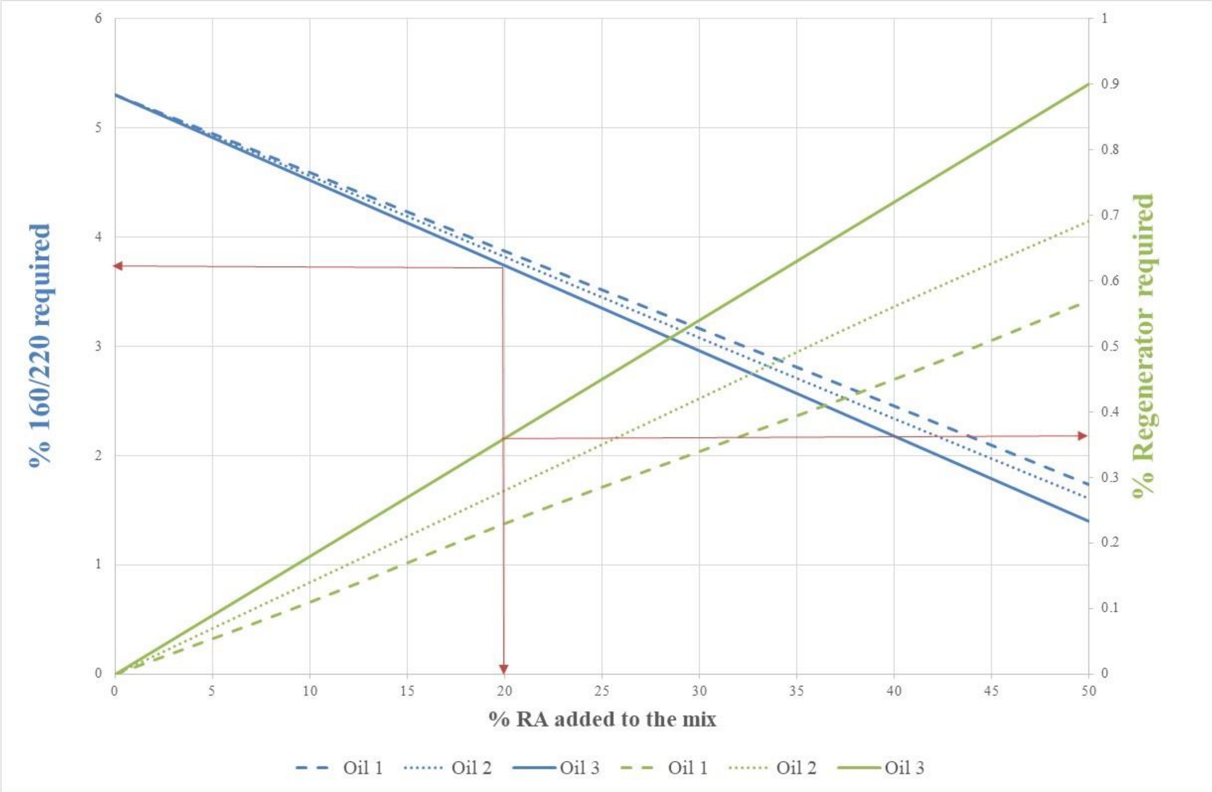

Figure 3: Effect of three different oils on the addition rates of regeneration oil and bitumen

This also demonstrates that the impact of the oils can be significant both in terms of the required addition levels of fresh bitumen, and the tolerances necessary to maintain good control of the asphalt properties especially at high RA contents. The effect of the grade of oil used has been studied by other researchers using a wide range of materials, bitumens and mixture types. Artamendi et al (2011) investigated the used vegetable oils in mixtures with up to 60% RA, whilst Zaumanis et al (2013) studied nine different additives, and found their softening efficacy ranged by a factor of twelve. Ongel and Hugener (2015) assessed three different additives in 100% RA mixtures with Cao et al (2019) and Ganter et al (2019) both successfully demonstrating that an aged polymer modified bitumen could also be regenerated.

The required dosage rate of regenerating oil is primarily a function of its viscosity, with lower viscosity oils having a greater softening effect on the RA. However, lower viscosity oils are usually more costly and also tend to have lower flash points which, as discussed earlier, must be judged as a primary consideration when selecting the oil. Therefore, the choice of regeneration oil is a balance between safety, efficacy and cost, and following this screening process a suitable material was chosen for further assessment and scale up trials, with typical properties of the oil shown in Table 1.

Table 1. Typical properties of the selected regeneration oil

Test description	Test method	Typical value
Density at 15°C	EN 15326	0.917 kg/dm3
Viscosity at 20°C	EN 12595	530 mm2/s
Flash Point (PM)	EN ISO 2719	212 °C
Pour Point	ASTM D 97	-30 °C
Sulphur	ASTM D 2622	0.06 %
Total Acid Number	ASTM D 974	< 0.01 mg KOH/g

2.1. Binder durability assessment

Whilst obtaining the desired initial mixture properties is essential for compliance purposes, to be a truly effective additive the regeneration oil must also maintain the same levels of durability as found in mixtures produced using fresh bitumen. If the oil is too volatile or is prone to oxidation then the finished asphalt will be less durable and could fail prematurely. At a microstructural scale the regeneration oil and the RA must be chemically and physically compatible or, as shown by Nahar et al (2014), this could also lead to early failures.

Samples of bitumen recovered from RA were mixed with 160/220 and regeneration oil at a laboratory scale. The binders were stored and blended at 160°C and the regeneration oil added at ambient temperature, with each mixture stirred for 15 minutes using a low shear mixer to ensure homogeneity. These were then aged using short and long term methods and their properties reassessed as shown in Table 2.

Table 2. Effect of 160/220 and regeneration oils to RA on binder durability

	35/50	RA + 160/220	RA + Regeneration Oil
Penetration (25°C, 5s, 100g), EN1426	43 dmm	48 dmm	43 dmm
Softening Point, EN1427	52.1°C	50.7°C	52.2°C
After short term ageing, EN12607-1			
Retained Penetration, EN1426	74%	73%	81%
Increase in Softening Point, EN1427	4.9°C	4.1°C	3.7°C
After long term ageing, EN14769			
Retained Penetration, EN1426	49%	58%	72%
Increase in Softening Point, EN1427	10.8°C	8.0°C	5.0°C

As can be seen from these results the addition of regeneration oil to RA produces a binder with ageing properties at least as good as those of virgin binder and mixtures of RA and 160/220, indicating that asphalt produced using RA will have acceptable durability performance.

2.2. Asphalt plant mixing considerations

The blending of RA and regeneration oil is depicted schematically in Figure 4.

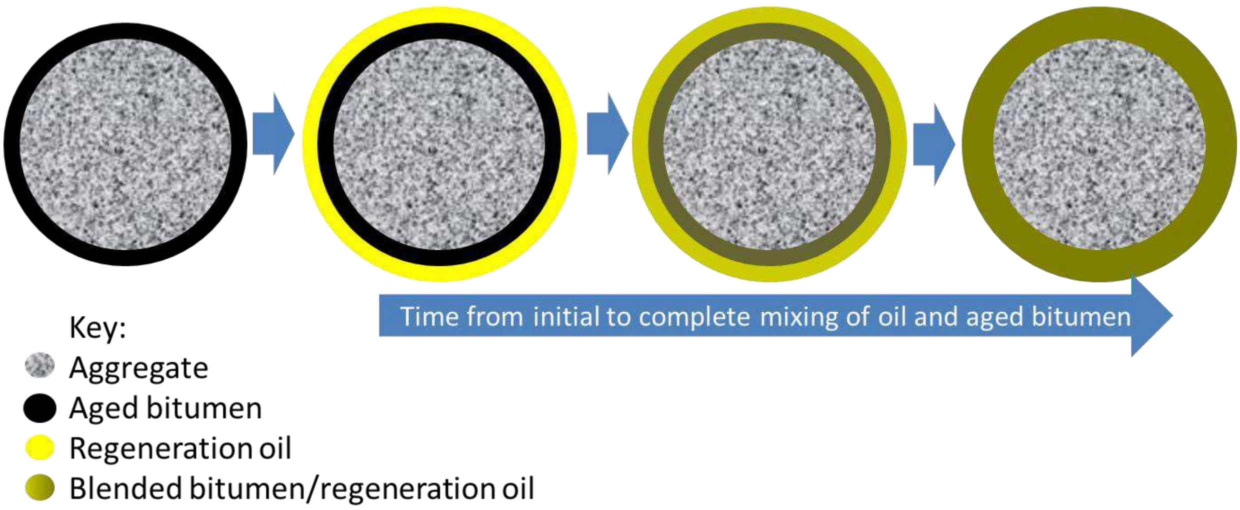

Figure 4: Schematic of RA and regeneration oil mixing

The aim of any process is to achieve complete blending of the RA and regeneration oil. However, as shown by Karlsson & Isacsson (2003) if this takes place at ambient temperatures then oil will simply coat the RA and whilst diffusion between the two materials will occur it will only be at a very slow rate.
In order to achieve mixing the RA needs to be heated to reduce the bitumen's viscosity and allow the regeneration oil to blend with it. Incomplete mixing could lead to an asphalt that is difficult to lay, flushes, or has a stiffness that is not compliant with the specified asphalt.
At a plant scale the mixing times and temperatures must be adjusted to ensure that substantially complete blending takes place (Van der Kooij & Verburg 1996, Navaro et al 2012). Mixing trials are necessary as each plant has its own characteristics and, therefore, its own mixing times and temperature, although it would be anticipated that a small increase in mixing times would initially be advised when compared to 100% virgin aggregate mixtures.

2.3. Asphalt plant mixing addition point trials

Once the mixing times and temperatures are optimised then the addition point for the regeneration oil is less critical. Asphalt plant trials assessed several addition methods as shown in Figure 5 below labelled as
① With the RA feed to the recycling drum
② Into the RA addition screw to the mixer

③ Directly into the mixer box
④ Added to the bitumen via the weigh kettle

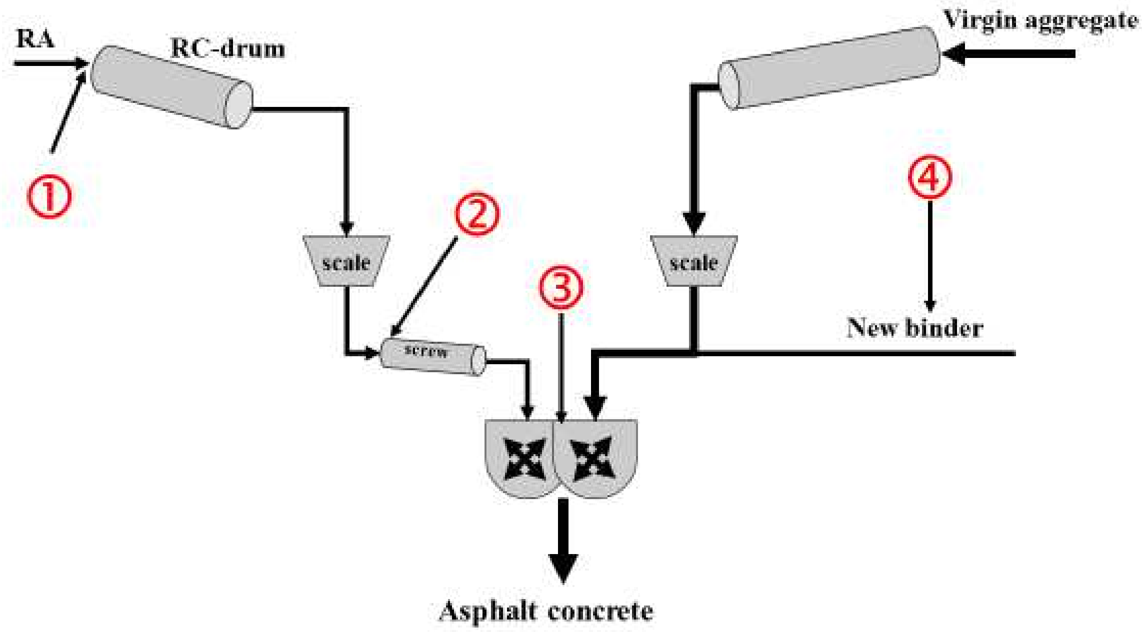

Figure 5: Potential addition methods for regeneration oils to a typical asphalt plant

In addition a further method ⑤ was also assessed where the RA and regenerator were mixed at ambient temperature. This mixture ⑤ was stockpiled for a month and fed to the plant via the heated drum when required for production.

Samples of asphalt were produced using 40% RA and methods ②, ③, and ⑤ along with a reference 0% RA mixture using 150 dmm bitumen. Whilst recovering the bitumen from these mixtures would confirm the ratio of RA to regeneration oil was correct the recovery process would by its nature completely homogenise the components so this approach could not be used to determine mixing efficiency. Instead samples of each asphalt were compacted and their stiffness at 10°C determined after 1, 7 and 28 days as shown in Figure 6.

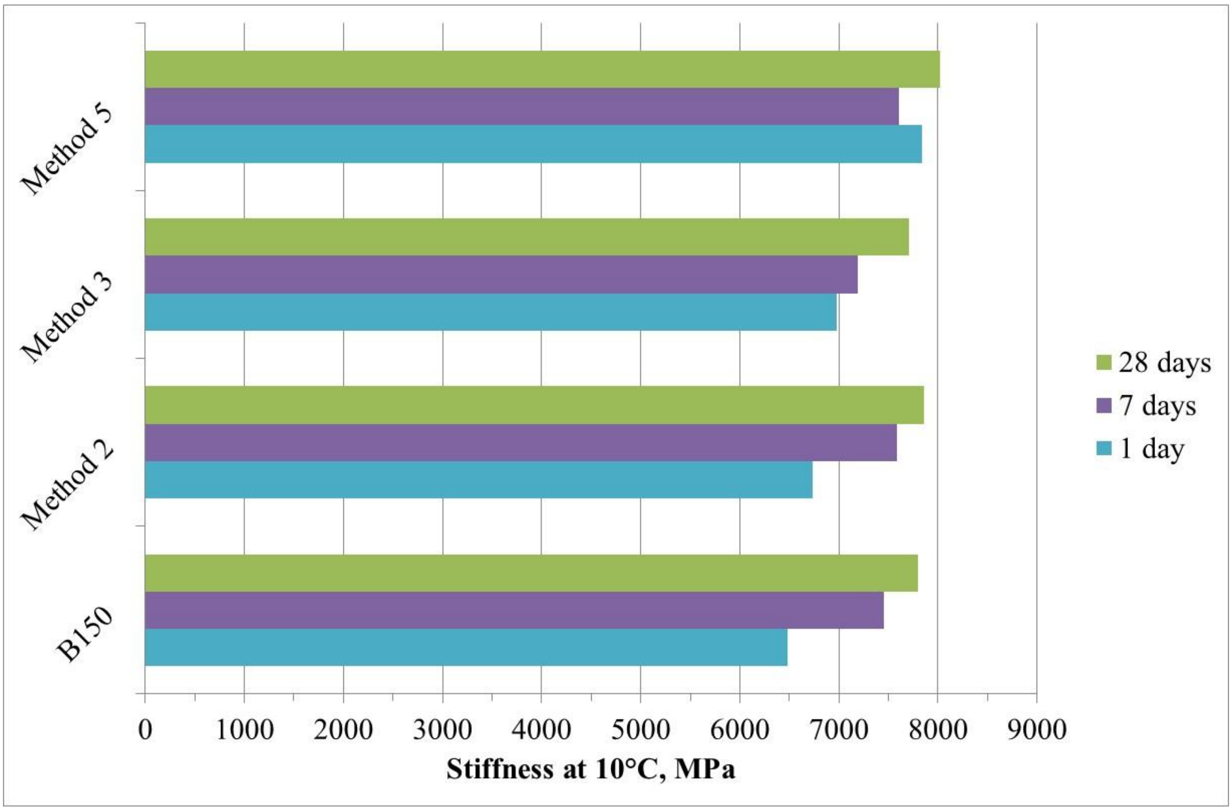

Figure 6: Stiffness evolution of asphalts produced using different regeneration oil addition methods

As can be seen all four methods produce similar stiffness mixtures, with little variation in the stiffness development over time, indicating that complete mixing has occurred.

3. CONCLUSIONS

This paper examined the steps necessary to successfully develop a material suitable to be used as a RA regeneration oil in asphalt mixtures, with its safety, dosage rates, durability, cost and practicality all considered. Full scale trials further demonstrated that the recommended regeneration oil could be effectively added into high RA content asphalt mixtures via a wide range of addition routes, and that the resulting asphalt mixture had equivalent stiffness to a 100% virgin bitumen mixture indicating complete mixing of the regeneration oil, bitumen from the RA and fresh bitumen occurred.

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