Maintenance and Rehabilitation

New thin layer surface treatment with very quick opening to traffic

Álvaro Gutiérrez[1], Marta Vila[2], Agustí Bueno[2], Luis Lozano[2]
[1]Quimikao SA de CV, [2]Kao Corporation SA

Abstract

The durability of an asphalt pavement depends on many factors that range from a good design of its structure (based on the amount, type and loads of traffic it will support) to the care of the road surface with surface treatments applied in the right time to prevent a specific type of damage. The objective of the present work is a new surface treatment consisting of applying a warm mix asphalt (one centimeter thick already compacted) being able to manufacture with a great variety of aggregates and without the need to use a polymer modified bitumen. A bitumen with a high softening point and low viscosity at temperatures between 100 ° and 160 ° C is obtained, offering a correspondingly lower traffic opening to the corresponding mixture at 30 minutes after being placed. This treatment can be applied at any time of the day or night using any model of hot asphalt paver spreader. In order to implement this treatment a package of three additives is needed. First additive will improve the lubricity aggregate-bitumen at more than 110ºC increasing significantly compaction time. Second additive will increase Softening Point of the bitumen at minimum 95ºC increasing significantly durability of mixture and prevents from rutting problems. Third additive is a fluxant that prevents from cracking at lower temperatures. .

This paper was first published in 2020 in version 1.0 of the proceedings of the 7th E&E Congress. This second edition (version 1.1.) of the proceedings is published in June 2021. The content of this paper has not changed, but the author(s) may have provided additional information in the form of an annex.

1. INTRODUCTION

Surface treatments provide an efficient remediation and prevention of damages caused by natural elements and the stress of the traffic. The choice of the right surface treatment will depend on the specific problem to be solved or prevented. It will also depend on the moment of the degradation of the road surface. Traditionally, cold techniques have been broadly used for surface treatments. However, hot techniques have also gained importance in this field, leading to the development of Asphalt Ultra Thin Layers (AUTL) and related techniques [1], [2].

Thin and ultra thin hot mix layers have shown many advantages for surface treatment such as a quick opening to traffic, as soon as the mixture cools down, with no need of a curing time. However, many drawbacks have also been reported, especially related to the fact that layer thinness makes it very prone to cool down below workability temperatures very quickly [3]. This quick cooling limits the possibility of compaction and correction of eventual application defaults. For the same reason, weather conditions may affect the success of paving operations with ultra thin layers.

Apart from a very accurate execution of the works, operating with an increased temperature of the mixture might be a way to broaden the operating time and conditions for AUTL. However, operating at increased temperatures means a higher energy consumption and CO_2 release and it can also cause an excessive oxidation of the binder which turns into a degradation of its original mechanical properties.

Another strategy is to modify the viscosity of the bitumen in order to make the asphalt mixture workable in a wider range of temperatures than usual [3]. In that case, the limitations due to a quick cooling would be mitigated. This would eventually provide a wider time window to apply, compact and correct defaults of applied AUTL. However, the additives which increase the workability of the asphalt mixture at application temperatures may also have side effects on the mechanical behaviour of the asphalt mixture at traffic temperatures. Some of these side affects may affect negatively the performance of the asphalt layer, or by the contrary may be beneficious. This is why an accurate selection of such additives and an accurate dosage of the same is a critical factor to get a successful AUTL application.

Previous publications describe a package of chemical modifiers to provide a solution for AUTL compliant with this double requirement. A first version of such additive package included three ingredients whose combination furnished satisfactory results both in laboratory tests and its successful application in Guadalajara-Colima highway (Mexico) [4].

The present work describes the development of a similar package of additives and its successful field test in Europe. The individual contribution of each component is shown, in some cases comparative examples of commonly used additives with similar performance are provided.

Since the rheological behaviour of bitumen and asphalt mix may vary significantly from one case to another, the aim of the present work is to introduce a new package and to show the effectiveness of its components to modify such behaviour, provided that the dosages of the additives have to be optimized for each practical case. Also, a practical field application is described.

2. EXPERIMENTAL METHODOLOGY

2.1 Materials

Bitumen (penetration 25°C: 50/70 mm/10, EN 1426; softening point: 46-54°C, EN-1427)
Mineral filler, passing 0.063 mm sieve
Paraffin wax (par)
Amide wax (ami)
Synthetic oil (flux)
Mineral oil (oil)
Surfactant (surf)

2.2 Laboratory Methods

Rheological experiments were conducted with a Haake Rheostress RS 6000 rheometer equipped with a plate-plate probe Ø = 20 mm unless other value is specified, gap was set at 1 mm.

·Viscosity measurements of bitumen started after a pre-conditioning time (10 min) at 170ºC, viscosity measurements were done at CR = $20s^{-1}$ at such temperature and along a cooling ramp (-1ºC/min) till 110ºC.

·Dynamic complex shear modulus (G*) and phase angle (δ) of bitumen measurements for traffic in warm weather conditions were done by oscillatory measurements at CD $\gamma = 0.12$, $\omega = 10$ rad/s (f=1.592 Hz). For every specimen, measurements started at 46 ºC, further measurements were done after temperature increases of 6ºC with conditioning time of 10 min at every step.

·Dynamic complex shear modulus (G*) and phase angle (δ) of bitumen measurements for traffic in cold weather conditions were done by linear frequency sweep (CD $\gamma = 0.001$). (f = 0.2, 0.4, 0.6, 0.8, 1.0, 2, 4, 6, 8, 10, 20, and 30 Hz). Same experiment was run by descending the temperature 6ºC at every step.

·Mastics were prepared by pouring 30 g of bitumen at 140ºC over 70 g of filler at 160ºC, and mixing them with a spatula, keeping the temperature around 140 ºC until a homogeneous mixture is obtained. The mixture is poured on a thermostable plastic sheet on a flat support. 2mm thick mechanical stops are situated besides the poured mastic. Next, a second sheet of thermostable plastic is put on, and finally a second hard flat surface on top. A load is placed onto the upper surface in such a manner that, when cooling down, the mastic forms a 2 mm thick layer. Once cold, 20 mm diameter samples are cut from this layer, which will be used for rheological measurements.

·Viscosity measurements of mastics were done with the above mentioned rheometer and probe. Gap was set to 0.4 mm. After pre-conditioning time of 10 minutes at 110 ºC viscosity was measured at CR = 1s^{-1} successive measurements were done along a heating ramp (+~0.9 ºC/min) until 165ºC.

3. EXPERIMENTAL WORKS AND DISCUSSION

3.1Technical purpose

As mentioned in the introduction, the purpose of the present research is to facilitate the application of AUTL in terms of good workability at feasible temperatures, and at the same time obtain an excellent performance of the same layer under traffic conditions. The use of additives or modified paving techniques may lead to undesirable side effects on the finished layer. One undesirable side effect is an excessive softening of the asphalt mixture under traffic conditions; another side effect to be avoided is an increased fragility of the asphalt at low temperatures.

The required mechanical behaviour of the asphalt mix varies depending on the scenario. For one side, paving operations (mixing, application, compaction) require workable mixtures, this is, low values for viscoelasticity. For another side, moderately high viscoelasticity values are required once the road is open to traffic. Extremely high values of viscoelasticity under traffic conditions would lead to brittle asphalt, prone to crack. Therefore, an appropriate temperature range is defined for each of the two above mentioned scenarios.

Taking into account the variation of the viscoelastic behaviour of bitumen and asphalt mixture towards temperature, one should distinguish two well different regions. Ideally, we should find a hot region with low viscoelasticity, which allows mixing, spreading and compaction operations. A flat and relatively wide plateau in this region would provide a high tolerance to temperature deviation. This would mitigate the risks associated to a quick cooling [3]. Also, a second thermal region for traffic conditions should be defined for lower temperatures, with clearly high viscoelasticity values. Again, the viscoelastic behaviour of asphalt along this region should be as constant as possible. It is desirable to keep a relatively high modulus at top temperatures of this region, which avoids excessive deformations of the asphalt layer with warm weather. It is also desirable not to have a peak in modulus at lower temperatures which prevents from asphalt cracking in cold weather. Unfortunately, this “Ideal Asphalt” behaviour is quite distant from the typical behaviour, where transition and fragility regions are present, which are convenient neither for paving nor for traffic.

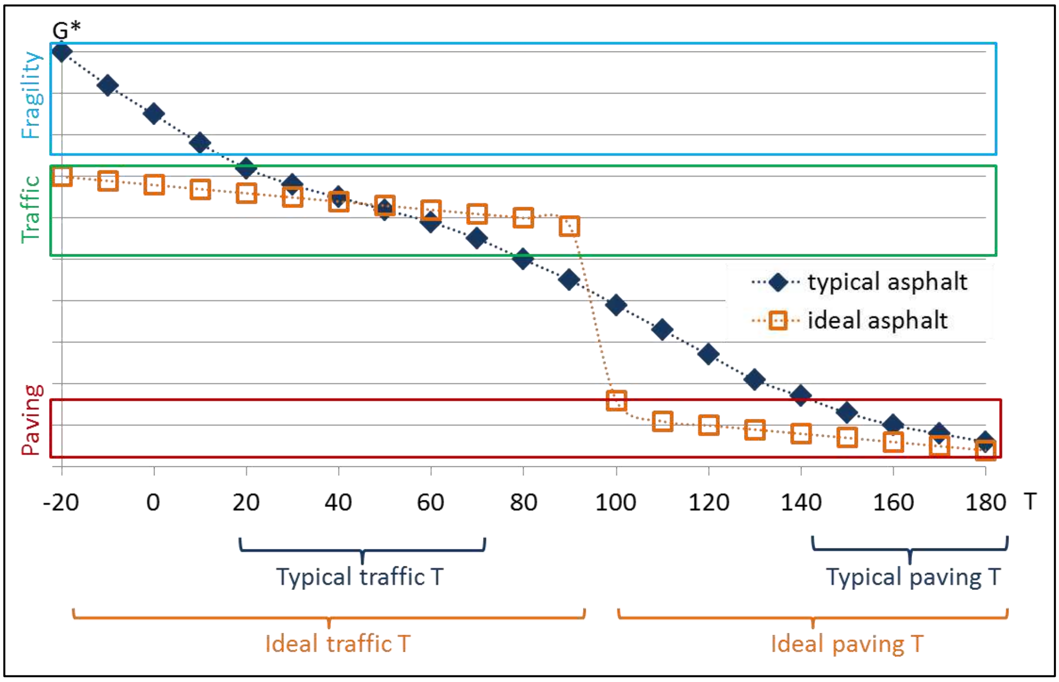

Figure 1: ideal viscoelastic behaviour of asphalt mixtures compared with typical behaviour.

Several additive families may be use to make the behaviour of the asphalt close to the ideal profile. Viscosity of melt bitumen may be reduced by adding fluxing agents. However, fluxing agents may turn bitumen too soft under traffic conditions. This would seriously endanger the bearing capacity of the pavement once open to traffic. Therefore, the use of fluxing agents to facilitate the application of AUTL doesn’t seem a fully satisfactory strategy unless this excessive softness at traffic temperatures is compensated somehow.

Waxes have also the ability to reduce the viscosity of the melt bitumen [3], [5]. The choice of a wax with an appropriate melting point will prevent from excessive softness of the bitumen at traffic temperatures. However, the use of waxes has two limitations: one is that a high amount of wax may be required to soften bitumen at reduced mixing and spreading temperatures, the other is an embrittlement of the bitumen at low temperatures, which can lead to winter fragility of the pavement.

Surfactants don't modify the rheological properties of the bitumen in a significant extent [5]. However, an appropriately chosen surfactant acts at the interface enhancing the wettability of the aggregate by the bitumen, and increasing the plasticity of the asphalt mixture [6]. As a result, the use of such surfactant may contribute to keep the workability of the asphalt mixture at a temperature significantly below the reference one.

On a previous publication, an ideal viscoelastic and thermal profile of bitumen was obtained by doping it with 3.5% of an amide wax, 1% of a rejuvenating agent (fluxing oil), and 0.5% of a surfactant. [4]. RTFO tests with this modified package showed a reduced ageing effect, according to complex modulus and phase angle measurements of the additivated bitumen after RTFO. Further research has furnished alternative fluxing oil and surfactant. These new modifiers have a very similar effect on bitumen as those described in the past. This is why the present work, takes the dosages referred in previous works [4] as a starting point for the development of this renewed AUTL additive package. Laboratory studies include the effect of additives separately alone and combined. During the laboratory development phase, the benefit on the workability of the asphalt mix is studied by viscosity measurements of the doped bitumen and by viscosity measurements of doped mastic. Laboratory studies of the effect of additives on the performance at traffic temperatures are based on complex modulus and phase angle of the doped bitumen. For comparative purposes a paraffin wax and a mineral oil are included in some of the described experiments. In some cases, the laboratory studies have been conducted at a deliberately increased dosage of some components in order to amplify their effect during the laboratory studies. Laboratory results are used as a guide to adjust a final dosage of same additives for a further field test.

3.2 Effect on the viscosity of melt bitumen

Viscosity of blank and doped bitumen was measured at a temperature range around the mixing applying and compacting temperatures. At this stage, low viscosity is required. Results are summarized in the table 1:

Table 1: viscosity of blank and additivated bitumen in cps vs. Temperature.

	170°C	160°C	150°C	140°C	130°C	120°C	110°C
blank	86,9	129	199	315	543	945	1773
1% ami	79,3	116	175	277	470	827	1508
2% ami	76,6	109	166	257	428	749	1417
4% ami	69,3	103	152	234	374	666	2032
1% par	85,6	125	194	305	513	904	1689
2% par	82,9	119	180	290	491	861	1582
4% par	74,7	107	162	255	424	727	1342
0.5% surf	88,2	133	207	323	557	989	1844
3% oil	70,8	107	157	246	406	704	1279
3% flux	78,9	112	166	256	419	713	1295
4% ami 3%flux	52,6	75,9	113	173	282	476	1340
4% par 3%flux	65,7	96,8	140	212	340	571	1017
4% ami 3% oil	59,7	85,1	121	188	298	520	1641
3% ami 1% flux 0,5% surf	70,7	102	149	229	390	658	1658

An overall view shows that all additives reduce significantly the viscosity of the bitumen. As expected, the flowing effect of the additive increases as the dosage is increased. Comparison among waxes shows that amide wax is more efficient in reducing viscosity than paraffin wax at all dosages. Comparison between mineral oil and synthetic oil doesn't show dramatic differences in terms of viscosity reduction. Combinations of waxes and fluxing agents provide a more dramatic decrease of bitumen viscosity. Again, preference for amide wax instead of paraffin is confirmed also in combination with oils. One can also notice that combination of synthetic oil and amide wax is more efficient than mineral oil and amide wax. Notice that surfactant has no reduction of bitumen viscosity, on the contrary, a slight increase is detected.

Selected results are plotted in Figures 2 (only one additive) and 3 (combinations of wax and fluxing agents) for a detailed analysis. A shift of the viscosity curve to lower temperatures indicates that the corresponding asphalt mixture will be more tolerant to quick cooling in terms of ease to spread and compact, than blank bitumen.

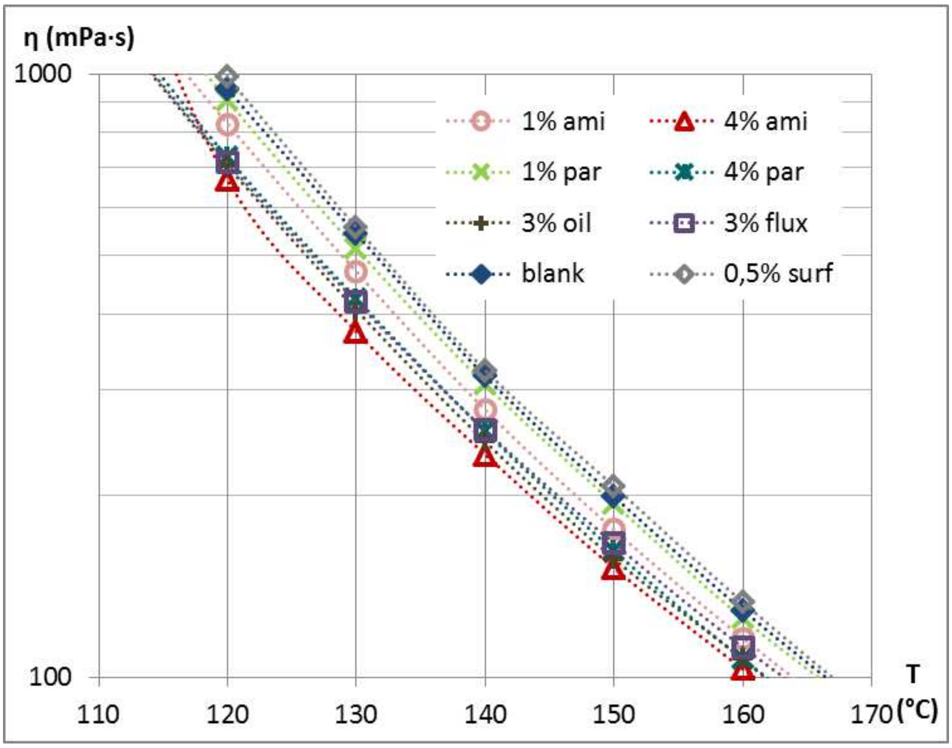

Figure 2: bitumen viscosity vs. temperature, single additive.

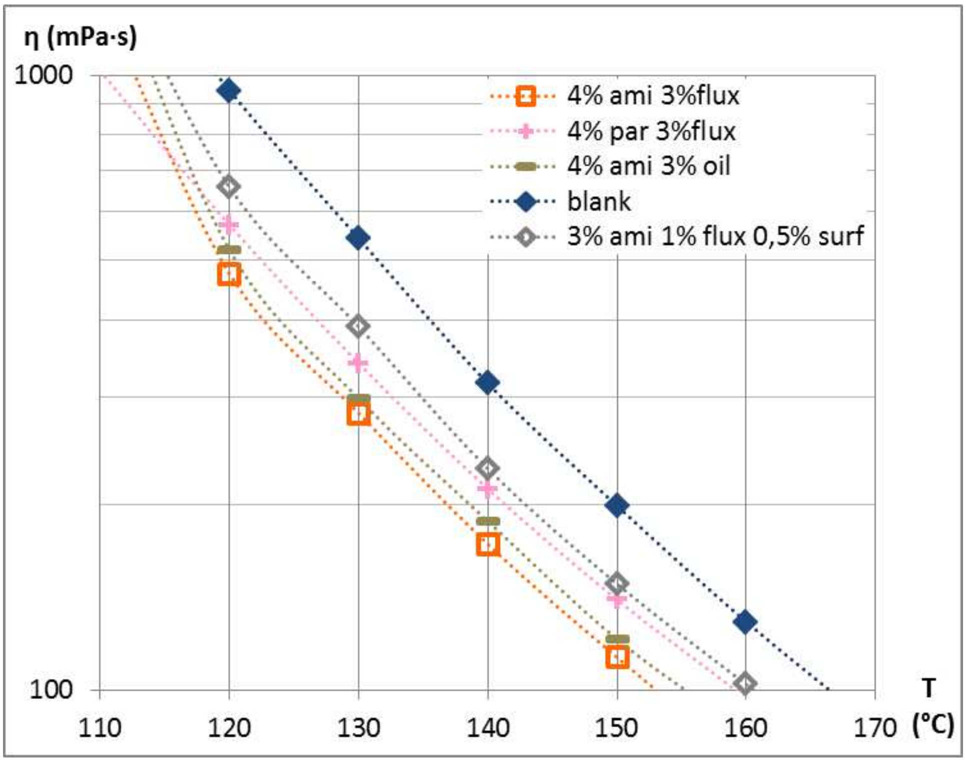

Figure 3: bitumen viscosity vs. temperature, combinations of additives.

Regarding single additives, waxes dosed at 4% over bitumen provide a reduction of equiviscosity temperature around 6-7 °C. Amide wax provides a slightly better fluxing effect than paraffin wax. Oils also provide a comparable fluxing effect. Notice that surfactant has any significant effect on the viscosity of the bitumen.

It is noteworthy that amide wax shows a unique effect in comparison with other additives studied, at temperatures below 120°C, the flowing effect tends to disappear, providing viscosity values closer to the blank reference. Even when combined with oils, amide wax decreases its fluxing ability below 120°C.

3.3 Effect on the viscosity of hot mastic

According to literature, the flowing effect of some additives on melt bitumen may be more evident when monitored in a bitumen-filler mastic instead of pure bitumen. Under such conditions, in addition of the modification of the viscosity of the bulk of the bitumen face, the effects at the aggregate-bitumen interface become evident [6].

Mastics of mineral filler were prepared with blank bitumen and doped examples and submitted to viscosity measurements as described in point 5.2. The results are plotted in figure 4. Notice that viscosity is expressed in Pa·s since obtained values are higher than those obtained when measuring melt bitumen.

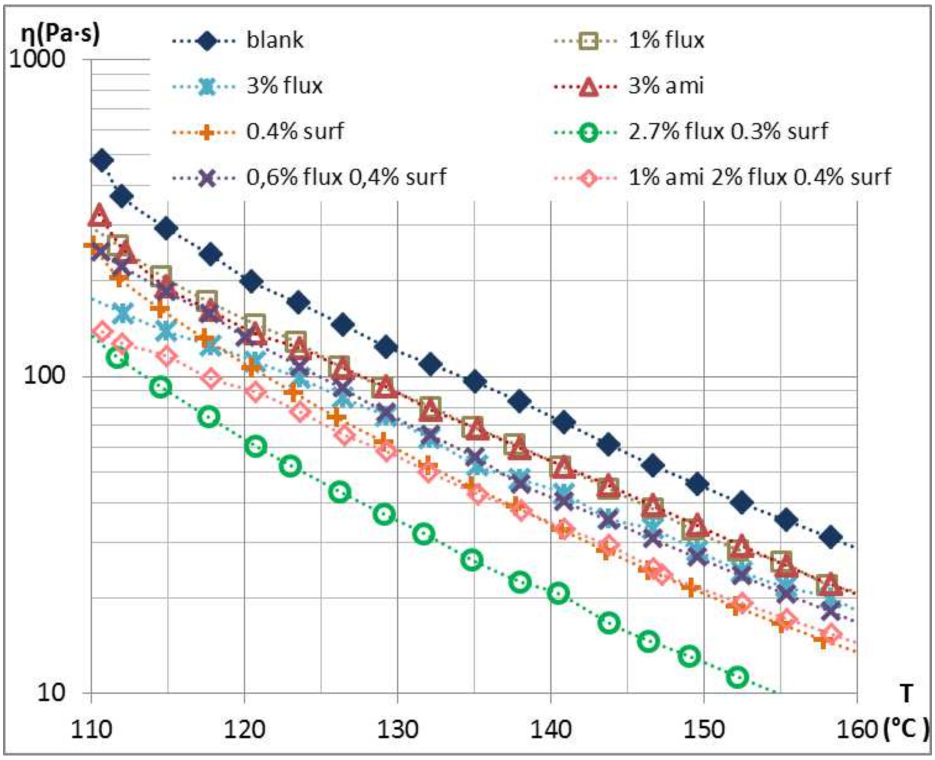

Figure 4: viscosity of mastics (bitumen + mineral filler) vs. temperature.

Here, amide provides a similar equiviscosity temperature reduction (~7°C) than when measured in melt bitumen. However, the effect of oil is more noticeable when monitored on mastic than when monitored in bitumen (equiviscosity temperature reduced 10-12°C with respect to the blank). However, the most outstanding effect is detected for the surfactant, which had little or no effect on the viscosity of the melt bitumen but has a clear effect on the viscosity of the mastic, even at lower dosages than other additives.

A dramatic decrease of the viscosity of the mastic is noticed when combining additives, e.g. oil + surfactant. As mentioned before, literature explains such effect by the activity of surfactants at the aggregate-bitumen interface.

3.4 Effect on the mechanical properties of bitumen at high temperature traffic conditions.

The upper temperature operational limit for the bitumen may be illustrated by measuring the complex shear modulus and the phase angle at increasing temperatures along the 46-100°C range. Norms based on this methodology set a critical value of $G^*/\sin(\delta)$ of 1000 Pa, assuming that lower quotients correspond to a such a soft bitumen that it provides a poor bearing capacity to the asphalt mixture [7]. Whereas on points 6.1 and 6.2 a softening effect was wished, here, an excess of fluxing oil could have a negative impact, turning the bitumen too soft to provide a suitable bearing capacity. One can expect that this excessive softening may become more evident under warm weather conditions. Thus, the goal for the present point is to obtain same or higher values of $G^*/\sin(\delta)$ than the blank bitumen.

The measurements done in the present work are plotted in Figure 5.

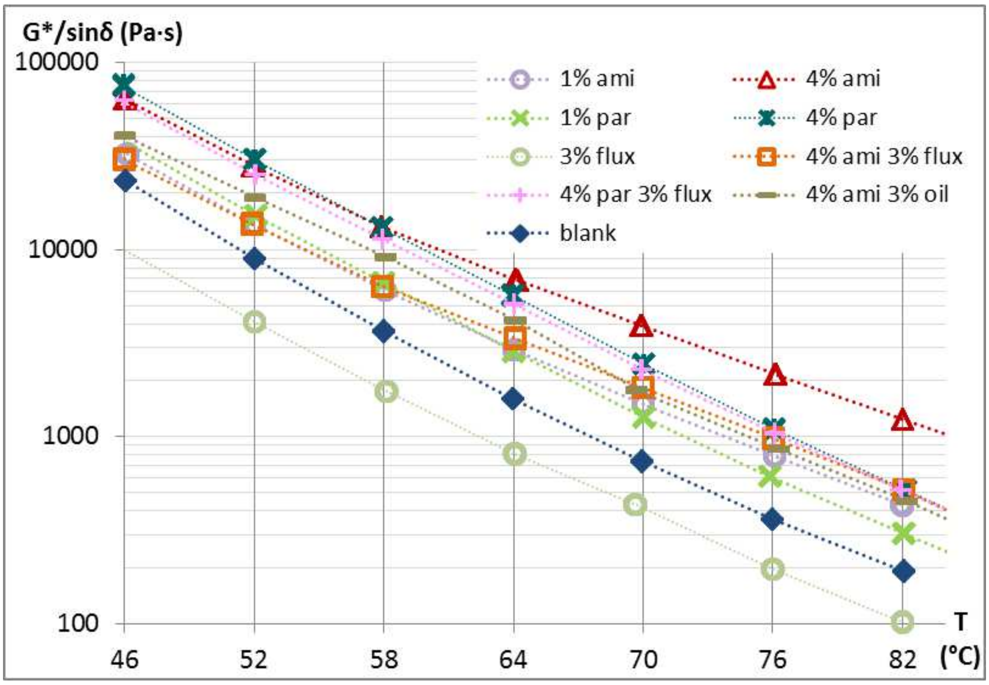

Figure 5: Complex shear modulus of bitumens vs. temperature

Both waxes provide a significant increase of the hardness of the bitumen at this temperature range. Notice that both have a similar effect at moderate temperatures, whereas as temperature rises, bitumen doped with paraffin has a bigger drop in hardness than the one doped with amide wax. This difference between amide and paraffin wax at higher traffic temperatures in figure 5 is quite in good agreement with the observed viscosity peak for amide doped bitumen below 120 ºC in figures 2 and 3.

Notice that, as expected, the use of flux oil alone provides a drop of the G*/sin(δ) values. So, although their enhance the workability of the asphalt mixture, they increase the risk of excessive plastic deformations at traffic temperatures.

However, even when mixed with oils, waxes provide higher values of G*/sin(δ) than blank bitumen. This points that higher dosages of fluxing oil would be admitted keeping a good bearing capacity for the asphalt mixture, as long as the dosage of amide wax is big enough to compensate any excessive softening under traffic conditions.

3.5 Effect on the mechanical properties of bitumen at low temperature traffic conditions

The modulus of bitumen increases and phase angle decreases as temperature decreases. In other words, bitumen becomes brittle at temperatures. This effect makes the pavement more prone to crack under traffic stress at low temperatures. The use of waxes can even increase this embrittlement at low temperatures. One goal of the present work is to prevent the excessive embrittlement of bitumen caused by waxes, or even keep better plasticity at low temperatures than blank bitumen.

The variation of complex modulus and phase angle in front of the temperature at 2 Hz of the studied bitumen samples are plotted in figure 6. As expected, at low temperatures both waxes have an embrittlement effect on the bitumen. This is noticed by higher values of G* and lower values of δ for bitumen doped with only wax. The plasticizing effect of fluxing oil is also evident for both parameters. The embrittlement caused by the amide wax is efficiently compensated by the fluxing oil providing a very similar behaviour to the original bitumen. However, the Embrittlement caused by the paraffin wax although reduced is not fully compensated by the same dosage of fluxing oil.

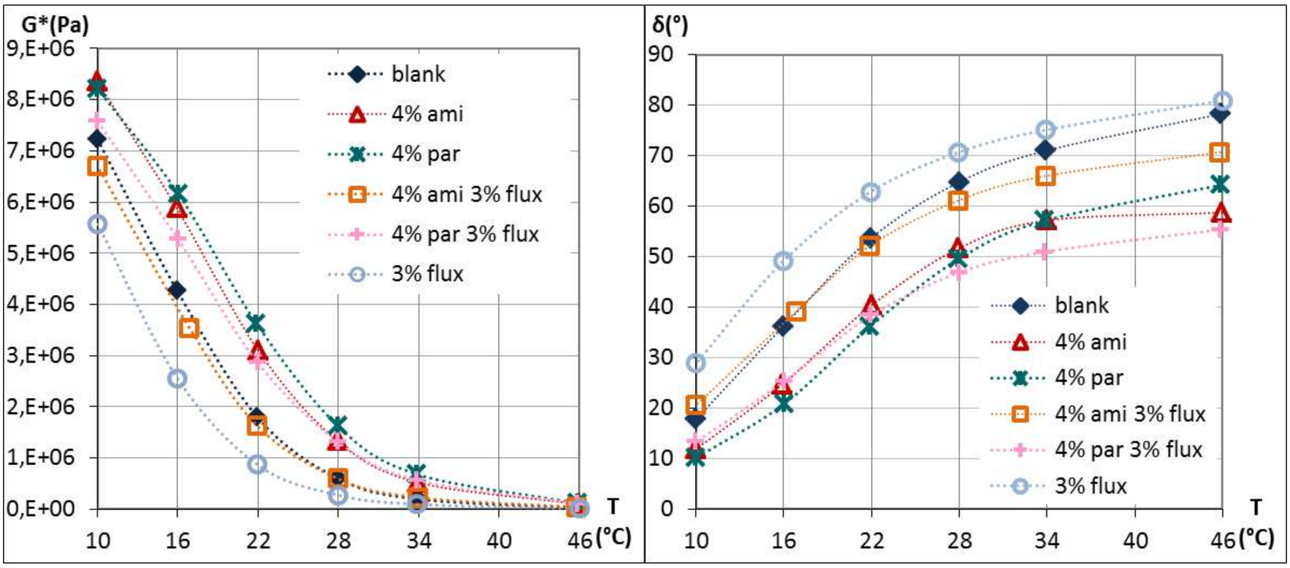

Figure 6: complex shear modulus (left), and phase angle (right) vs. temperature, at 2 Hz.

At higher deformation frequencies, differences are clearer at intermediate temperatures (see figure 7). Again, a more brittle behaviour is observed for bitumen doped with paraffin wax, and even more difficult to be compensated with fluxing oil.

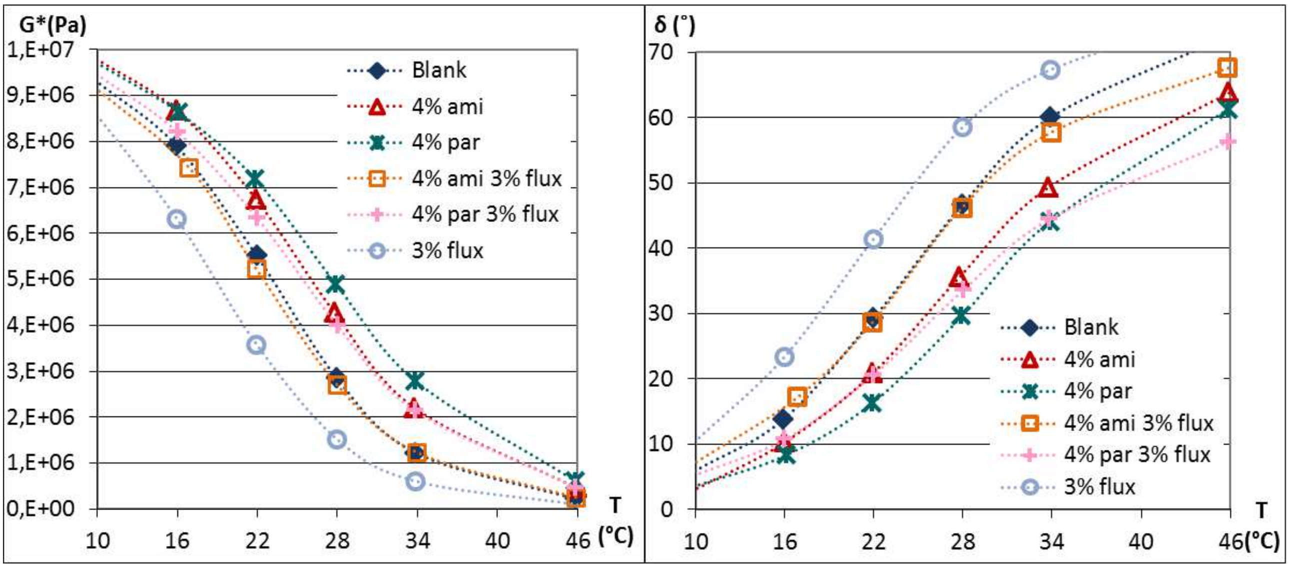

Figure 7: complex shear modulus (left) and phase angle (right) vs. temperature, at 20 Hz.

4. FIELD APPLICATION

Field test of this application was done in a local road on March 2019 in Imola (Italy), with a total area of 2500 m^2. The original pavement was moderately cracked (transversally and longitudinally) showing some losses of material. Slight traffic deformations and some marks presumably due to construction defaults were also visible. No signs of damage in lower layers were found.

Figure 8: old pavement surface. Right: detail of mark, after tack coat spraying.

For this operation, an asphaltic mixture was designed using an aggregate following the grading curve of the figure 9.

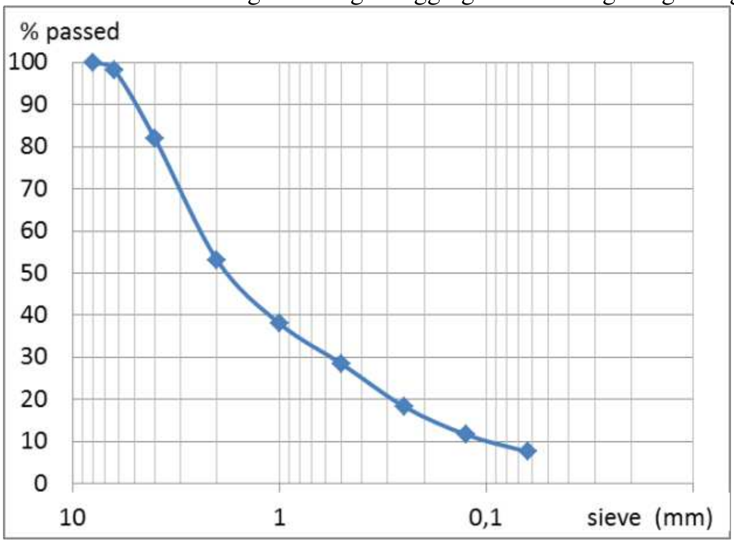

Figure 9: grading curve of aggregate for AUTL field test.

A 50/70 bitumen was selected, (different from the one used in point 6), which according to laboratory studies with this new bitumen, was doped according to the next optimized dosages:

Amide wax (ami): 30 kg/Ton
Synthetic oil (flux): 10 kg/Ton
Surfactant (surf): 5 kg/Ton

Additives were added directly to the bitumen tank at 160 ºC and allowed to homogenize for 1 hour at the same temperature using the standard recirculation system of the tank.

Doped bitumen was dosed at 54 kg /Ton of aggregate. Aggregates and doped bitumen were mixed at 145 ºC.

Paving operation was done under cold and humid weather (8 °C). Before the application of the asphalt mixture, surface was sprayed with a tack coat emulsion (C55B3, 0.5 kg/m2).

Figure 10: old surface after tack coat spraying

The asphalt mixture was applied at 125-130°C, it was compacted immediately at around 110ºC. The final thickness of the new layer was 1.2 cm.
The visual inspection 3 months after the application showed a regular surface with no defaults. More inspections along time will be recommendable to check the durability of the applied layer.

Figure 11: mixture application

Figure 12: compaction

Figure 13: visual inspection after 3 months

More inspections along time will be recommendable to check the durability of the applied layer.

5. CONCLUSIONS

- A package of additives that can modify the mechanical properties of the bitumen along all temperature range has been studied. This package combines one amide wax, a fluxing synthetic oil, and a surfactant.
- The selection of an amide wax and the synthetic fluxing oil has furnished enhanced results in comparison to standard reference waxes and oils.
- When dosed appropriately on the bitumen, this combination of additives reduces dramatically the viscosity of melt bitumen and the viscosity of hot and warm asphalt mixes.
- Simultaneously, the optimal combination of additives increases the complex shear modulus of the bitumen at the higher temperature limit for traffic conditions, this reduces the risk of excessive softness of the bitumen in warm weather.
- Such additive package has a plasticizing effect at low temperature, this avoids an increased bitumen embrittlement in cold weather.
- The effects of such combination of additives are a powerful tool to tune the mechanical properties of the bitumen, in order to fulfil the needs of every specific paving operation.
- Asphalt Ultra Thin Layers (AUTL) are a hot surface treatment, in which keeping asphalt mixture workable is a critical factor since mixture tends to cool down very quickly.
- The proposed additive package allows to spread and compact AUTL avoiding the risk of early hardening due to a quick cooling of the mixture.
- A field trial has demonstrated the effectiveness of this combination in the application of an Asphalt Ultra Thin Layer keeping the asphalt mixture at moderate temperatures during the whole operation, even under adverse weather conditions.
- The present combination of additives may be useful to modify the grade of bitumen, its ingredients have shown some advantages towards other similar materials such as mineral oils or paraffin waxes.

6. REFERENCES

[1] Sol-Sánchez, M.; García-Travé, G.; *et al.* ; Evaluating the mechanical performance of Very Thin Asphalt Overlay (VTAO) as a sustainable rehabilitation strategy in urban pavements. Mater. Construcc. 67 [327], el 32. DOI: http://dx.doi.org/10.3989/mc.2017.05016

[2] UNE-EN 13108-9:2018 Bituminous mixtures - Material specifications - Part 9: Asphalt for Ultra-Thin Layer (AUTL).

[3] Kragh, J. ; Goubert, L. , Optimization of Thin Asphalt Layers, Final Report. 2011, p41-p48. https://www.vti.se/en/Publications/Publication/optimization-of-thin-asphalt-layers-opthinal-final_674028.

[4] Gutiérrez-Muñiz, A. ; et al. Nuevo tratamiento superficial de rápida apertura al tráfico y fácil aplicación. XIII Jornada Nacional Asefma. 2018, communication 20.

[5] Reyes-Ortiz, O.J.; Pérez-Jiménez, F.E.; *et al.*el Proyecto FENIX en la UPC: mezclas semicalientes, XV Congreso Ibero-Latinoamericano del Asfalto. 2009, p. 803-812 URI: https://upcommons.upc.edu/handle/2117/6723.

[6] Gil, S.; Torrejón, A. ; Reología de Másticos semicalientes. VI Jornada Nacional Asefma, 2011, communication 32.

[7] Standard Specification for Performance graded asphalt binder AASHTO M 320.