STARASPHALT spa

ADHESION PROMOTERS
RAP REJUVENATORS
WARM-MIX ASPHALT

"You change and the world changes,
you live and the world lives,
you dance and the world dances,
you are the world…"
Filomena Falvo

To my daughter…

"The road to pursuing change is impervious, fraught, long, wide and bumpy, like the path of life. For a strange game of destiny the Star Asphalt has always dealt with roads and now, through the Filomena Falvo Foundation, its mission merges with the human spirit to create a single purpose. Roads finally become paths, paths become objectives. "

This work is the result of the collaboration between Star Asphalt S.p.A., a leading company in the production of special additives for bitumen and bituminous conglomerates, and the "Falvo Filomena" Foundation. Together, we are developing totally eco-friendly and green industrial systems. All Star Asphalt products have the certifications required by the Reach legislation and have been created with a particular focus on respect for the environment. In collaboration with the "Falvo Filomena" Foundation, we aim to continue the constant work of experimentation and innovation to achieve goals that are consistent with truth and clarity, peculiar virtues of my daughter Filomena, to whom this writing is dedicated.

President Prof. Rosario Giovanni Falvo

Summary

Adhesion Promoters

RAP Rejuvenators

Warm-Mix Asphalt

ADHESION PROMOTERS

Registration of ***Star Asphalt S.p.A.*** to **REACH Regulation N. 1907/2006 G.U.E. L396 of 30 December 2006 Effective from 1 June 2007 and with registration deadline to 31 May 2018**

STARDOPE® 130P

REACH REGISTRATION NUMBER

01-2119896587-13-0015

STARDOPE® 386G

REACH REGISTRATION NUMBER

01-2119492546-27-0004

ADHESION PROMOTERS

INTRODUCTION

The duration of a road pavement depends basically on adhesion between bitumen and aggregates; a good binding-aggregate adhesion is the result of the bitumen's ability to withstand static and dynamic stress caused by traffic and atmospheric agents such as air (oxygen), light and especially water. Bitumen cohesion and the adhesion between bitumen and aggregates are among the key properties that characterize the resistance of a bituminous conglomerate over time under the effect of vehicular traffic. Bitumen cohesion is an intrinsic property of this material and it is verified by numerous well-tested tests; on the other hand, adhesion between the binder and the inerts is more difficult to ensure and it is also a more complex phenomena to be investigated.

Around 95% of a bituminous conglomerate, designed to make road pavements, consists of a mixture of "stone aggregates" with a given granulometric curve, the choice of aggregates depends on the technical requirements that have to be achieved related to the features of the final result. Analyzing the inerts from a chemical point of view, they can be acidic or basic, respectively attracting negative or positive charges respectively.

Fig. 1. Types of inerts.

Usually, an asphalt mix consists of 5% by weight of bituminous binder. Bitumen is a complex mixture of chemicals. The adhesive properties of the bitumen are closely related to the presence of acidic groups, therefore a bitumen with a high acidity has better adhesion than a neutral bitumen. Bitumen/inert adhesion is basically characterized by two phases:

• The bitumen's ability to fully cover aggregates;

• Bitumen’s ability to remain attached to aggregate’s surface for the entire working life of the road.

Bitumen generally has low chemical affinity with aggregates, while aggregates have high affinity with water. For this reason, bitumen adhesion can be compromised by the presence of water/moisture.

Bitumen and aggregates affinity can be improved by adding a small amount of additives called StarDope®. These chemicals have the function of modifying the surface tension between bitumen and aggregates, reducing their contact angle.

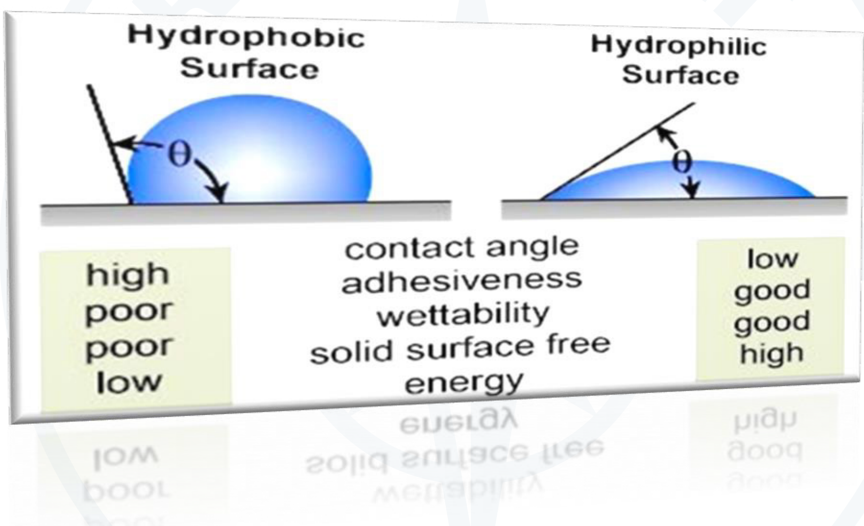


Fig. 2. Contact angle.

The use of StarDope® additives during the packing of the asphalt mix has the following benefits:

• Higher bitumen/inert adhesion;

• Increased resistance to stripping;

• Improved durability of bituminous mixtures.

Fig. 3. Section of a sample: on the left, a section of the sample made with adhesion promoter, on the right a section of the sample made without adhesion promoter.

The use of StarDope® gives greater ease of use to the asphalt mix , in particular:

• At low temperatures;

• In the presence of humidity.

StarDope® imparts to the pavements greater resistance to aging, slowing down the oxidation process. As a result of oxidation, bitumen's viscosity increases until it completely loses its flexibility, becoming fragile and prone to breakage. Our products are formulated with the aim of ensuring a suitable and durable adhesive bond between bitumen and inert with low mutual affinity.

The perfect co-operation between the binder and the stone elements prevents the water from settling between the two materials, leading to an early aging of the bituminous mixture and anticipating the initiation of disadvantages leading to floor loss.

The dosage has to be mandatory specified in the study of the mixture and may vary depending on the conditions of use, the nature of the aggregates and the characteristics of the product. The choice of the type and the additive dosage should be established in such a way to impart the features of cracking strength and durability to water action. In any case, the chosen adhesion activator must exhibit stable chemical features over time even if subjected to high temperature (T=150°C) for long periods (15 days). The addition of surfactants into bitumen has to be made with suitable equipment, such as to guarantee the exact dosage and their perfect dispersion in bituminous binder.

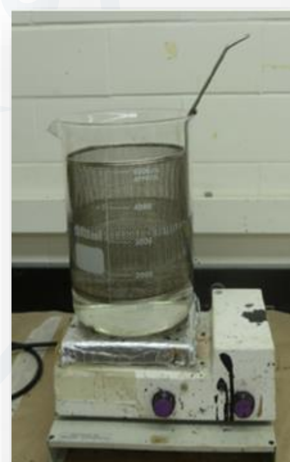
OUR SOLUTIONS

In our laboratories the variations of the characteristics of bituminous mixtures have been studied with and without the addition of special adhesion promoters called StarDope®, with the aim of determining and appreciating their performances.
Different types of aggregates are compared by testing all our specific additives to the portfolio, in order to evaluate the bitumen/aggregate adhesion; the asphalt mix produced with their addition have a better internal cohesion but above all a very high resistance to "stripping" in the detachment of the bitumen film covering the aggregate. In the experimental studies that follow, the resistance to high temperatures (T=180°C) for long periods of time (5 days) was determined by infrared spectroscopic investigation.

EXPERIMENTAL ACTIVITY REPORT

The experimental activity develops in three phases:

1. During the first phase, bitumen samples were made to which our additives have been added, in particular, 0.3% on the weight of the bituminous binder for StarDope® 130P and StarDope® 386G products, and 0.1%, 0.05% and 0.03% for the StarDope® 510 product. The prepared samples were evaluated by spectroscopic investigation investigated by Fourier transform infrared technique (FT-IR), in order to determine the bands characteristics of the additives and verify if they remain after heat treatment at 180°C, this indicates the thermo-stability of the same.



2. During the second phase, reference mixtures were made with different types of aggregates, in order to evaluate the performance of bitumen only. Similarly, samples made with additive bitumen were made.

3. During the third phase the efficiency of the additives as "adhesion promoters" was evaluated according to three different techniques: "Boiling Water Stripping Test" as required by the International regulations (ASTM D3625), "Rolling Bottle Test" according to European legislation (UNI EN 12697-11), and stripping resistance test according to Russian Standard (GOST 12.801-98) and Ukraine (ISO BV 2.7-89-99): in all these tests the aggregates are first hot-coated with additivated bitumen and not, and after appropriate cooling tested.
The first technique involves immersion in boiling water for a fixed period of time, evaluating visually, as a complete test, the degree of bitumen coating, expressed as a percentage. The covered surface, after 10 minutes of testing, must be typically over 80% in order to ensure a good durability of the mixture to the action of the water.

The second technique involves placing test samples inside glass containers filled with water at room temperature. These containers are rotated and shaken for a variable period of time (up to 24 hours) and inspected every 6 hours giving a visual assessment of the degree of bitumen coverage, as a percentage of the aggregates.

The third technique involves covering 3 single large stones, immersed in water at a temperature between 90 and 95°C for 10 minutes. At the end of the test the aggregates are evaluated visually, assigning a variable coverage class between 1 and 5. Typically values above the class 3 are considered valid.

StarDope® 130 P → REACH REGISTRATION NUMBER: 01-2119896587-13-0015

- <u>*Boiling Water Stripping Test (ASTM D3625).*</u>

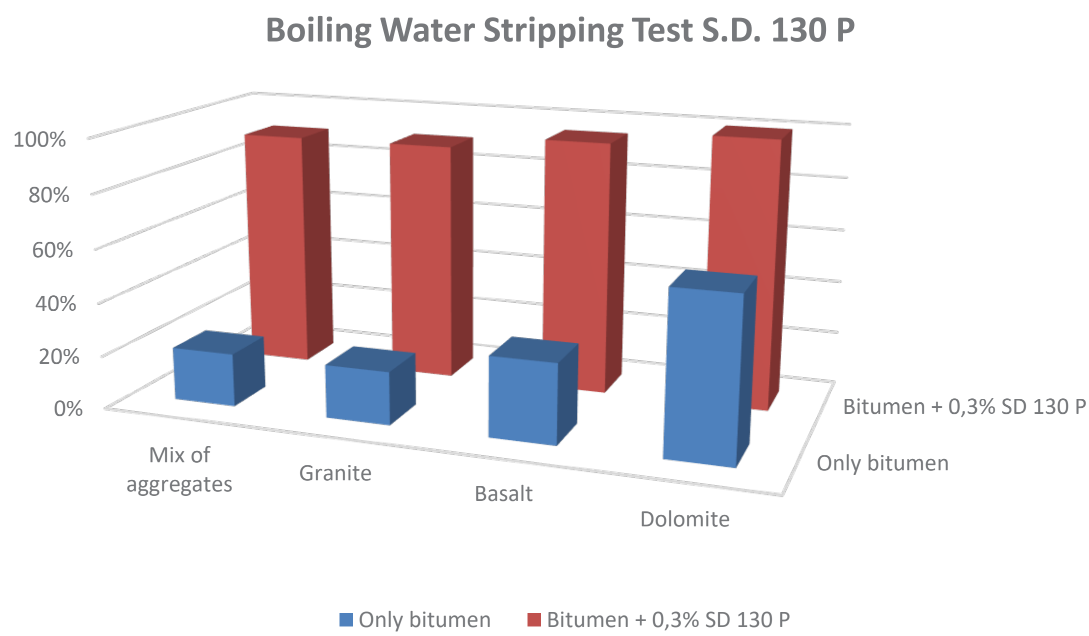
Figure 4a. Results Boiling Water Stripping Test basalt aggregates: left bitumen without additive, right bitumen with the addition of 0.3% StarDope® 130 P.

Figure 4b. Results Boiling Water Stripping Test inert granites: left bitumen without additive, right bitumen with the addition of 0.3% of StarDope® 130 P.

Figure 4c. Results Boiling Water Stripping Dolomites inert tests: left bitumen without additive, on the right bitumen with the addition of 0.3% of StarDope® 130 P.

Figure 4d. Results Boiling Water Stripping Test aggregate mix: left bitumen without additive, right bitumen with the addition of 0.3% StarDope® 130 P.

• *Boiling Water Stripping Chart Test StarDope® 130 P Overall vs Non-Additive.*



• *Rolling Bottle Test (EN 12697-11 part A).*

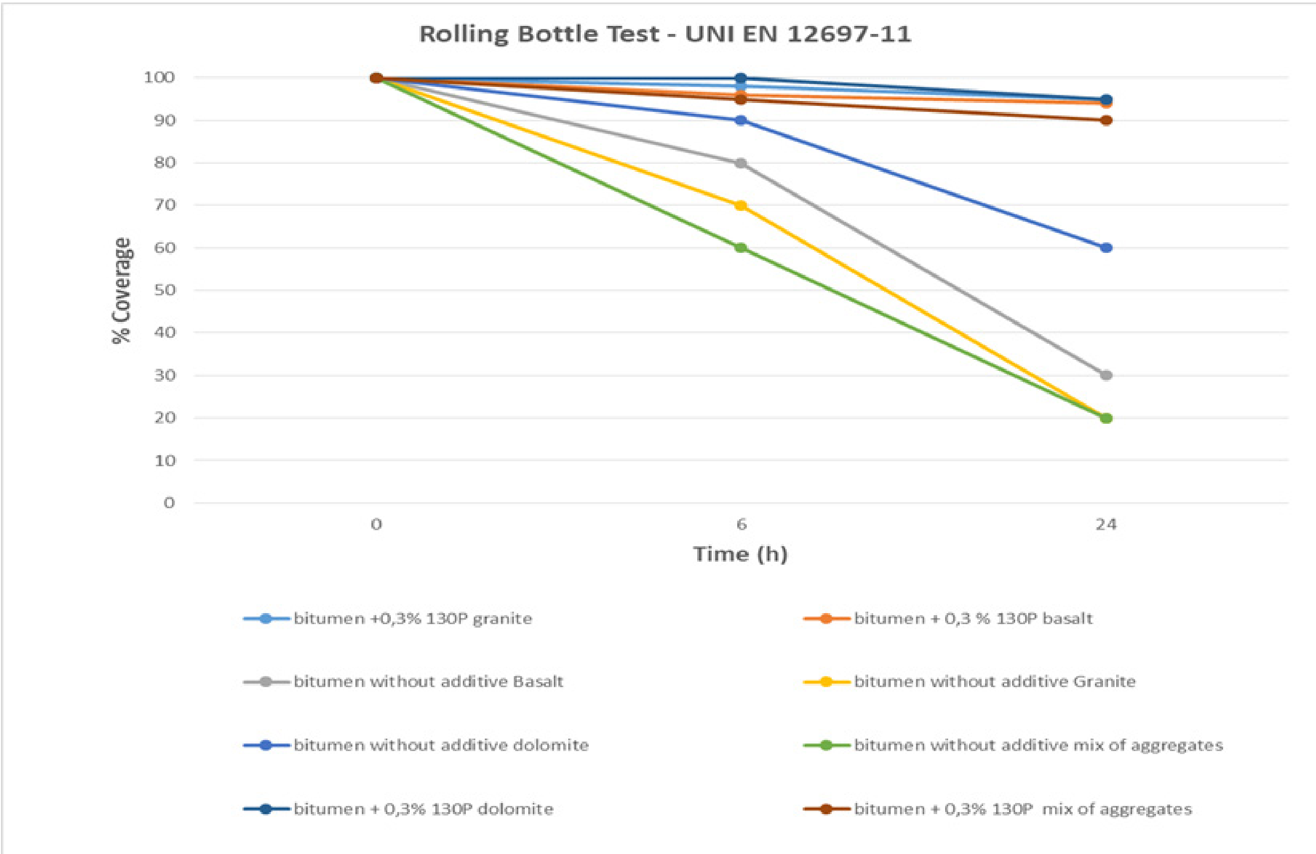
Figure 4e. Results Rolling Bottle Test inert basalt: on the left bitumen without additive, on the right bitumen with the addition of 0.3% of StarDope® 130 P.

Figure 4f. Results Rolling Bottle Test inert granites: on the left bitumen without additive, on the right bitumen with the addition of 0.3% of StarDope® 130 P.

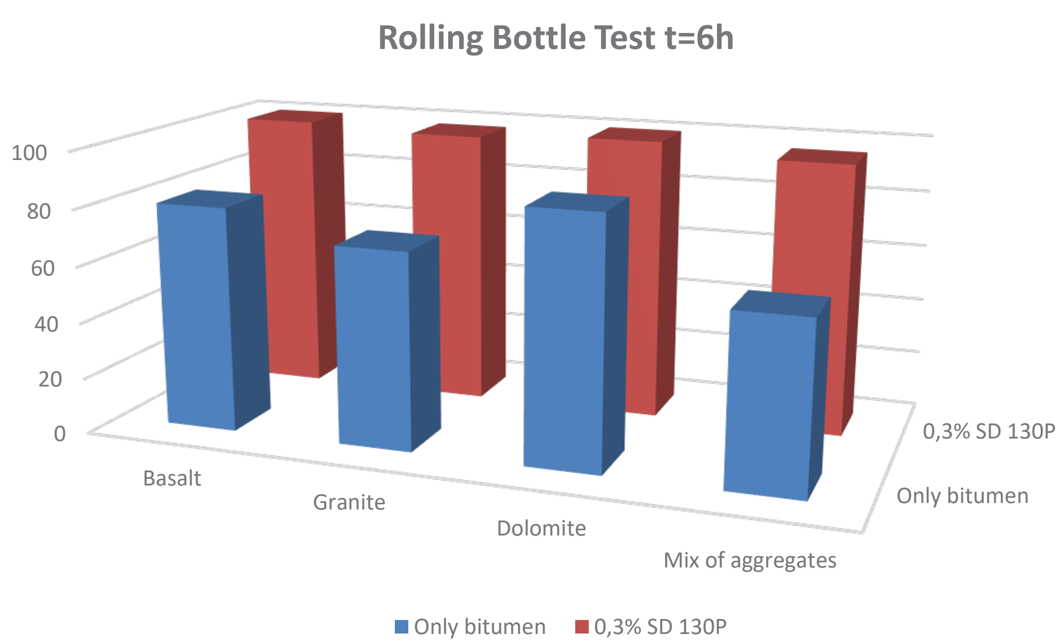
Figure 4g. Rolling Bottle Results Inert dolomitic tests: left bitumen without additive, on the right bitumen with the addition of 0.3% of StarDope® 130 P.

Figure 4h. Results Rolling Bottle Test aggregate mix: left bitumen without additive, right bitumen with the addition of 0.3% StarDope® 130 P.

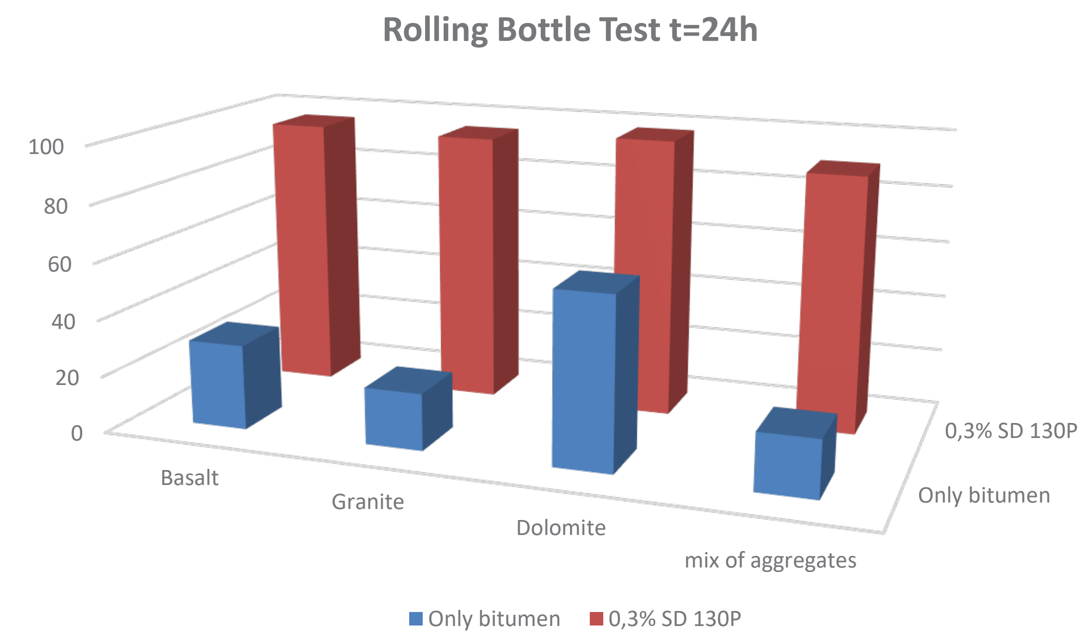
* *Rolling Bottle Total Test Chart StarDope® 130 P vs Non-Additive.*



* *Rolling Bottle Test Chart StarDope® 130 P vs Non-Additive at t = 6h.*



• <u>*Rolling Bottle Test Chart StarDope® 130 P vs Non-Additive at t = 24h.*</u>



• <u>*Test stripping resistance according to Russian law (GOST 12.801-98) and Ukraine (ISO BV 2.7-89-99).*</u>

Figure 4i. Results Granitic inert tests: left bitumen without additive, on the right bitumen with the addition of 0.3% of StarDope® 130 P.

- *Analysis FT-IR.*

The FT-IR analysis was carried out on a sample of bitumen as such, on the samples of all Star Asphalt adhesion promoters as such and the samples of bitumen added with the adhesion promoters; the comparison analysis of the bitumen spectrum as such and of the additives as they clearly show how the bitumen-additive mixture essentially results from the overlapping of the spectra of the individual components. In fact, the characteristic peaks of the bitumen and those of the StarDope® additives are clearly identifiable in the spectra below. The thermal stability of the bitumen-additive system was verified by keeping the mixture in stove at T=180°C for 5 days, simulating, approximately, an aging at T=150°C for 15 days. The spectral analysis on the bitumen-additive mixtures treated showed a high stability of the same, since the FT-IR spectra acquired after treatment at 180°C do not show significant qualitative or quantitative differences with respect to the corresponding spectra acquired on the samples that do not have immediately heat treatment.

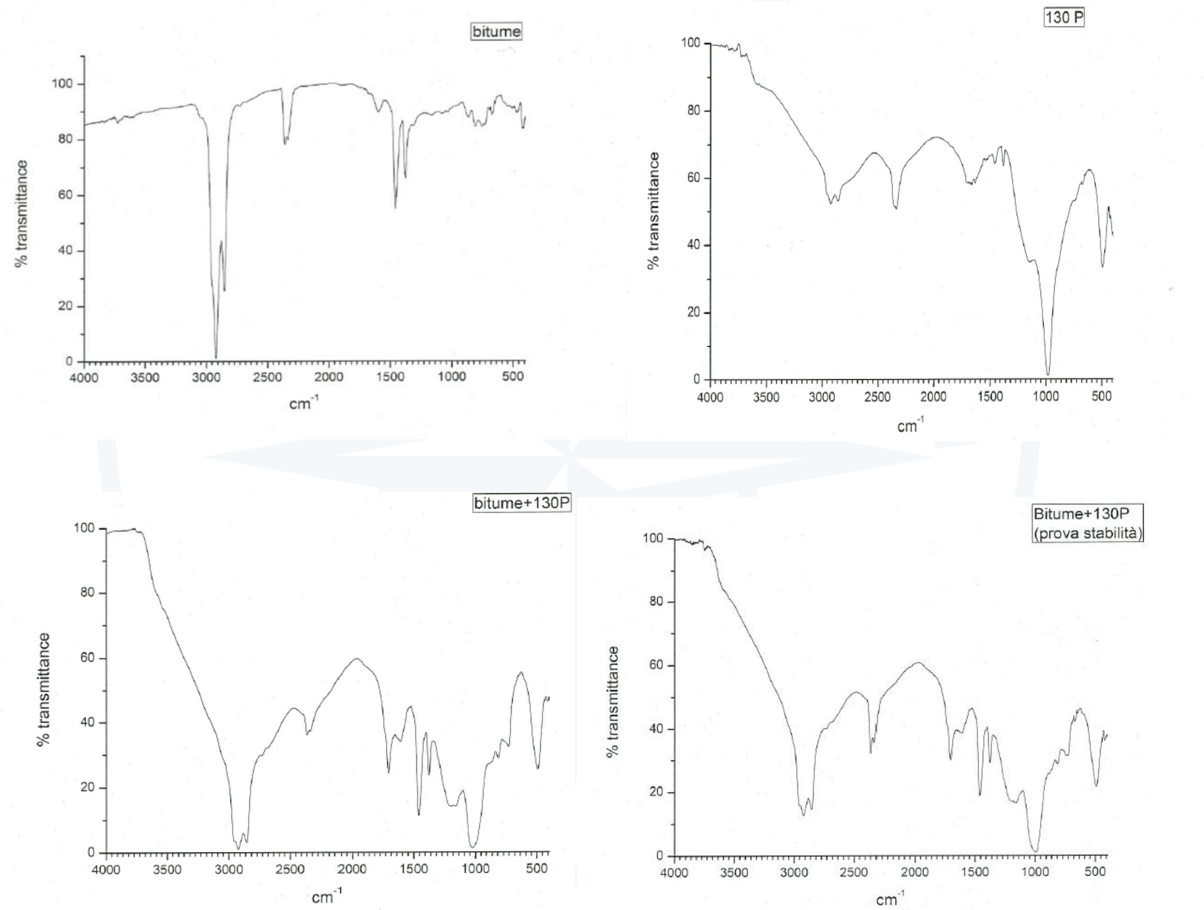


Figure 4l. Infrared spectrum acquired in transmittance by Fourier Transform Infrared Spectrometer in the frequency range between 4000 and 400 cm^{-1}.

At the top on the left, the characteristic peaks of a sample of bitumen as such, in the upper right corner the characteristic ones of the StarDope® 130 P additive, on the lower left the overlap of the characteristic peaks of a sample of bitumen with the addition of 0.3% of StarDope® 130 P, lower right peaks of the stability test at T=180°C at 5 days of the bitumen sample with the addition of 0.3% of StarDope® 130 P: presenting a similar spectrum with respect to that of the bitumen as such, in the presence of the additive, the thermostability of the adhesion promoter can be observed.

StarDope® 386 G → REACH REGISTRATION NUMBER: 01-2119492546-27-0004

- <u>*Boiling Water Stripping Test (ASTM D3625).*</u>

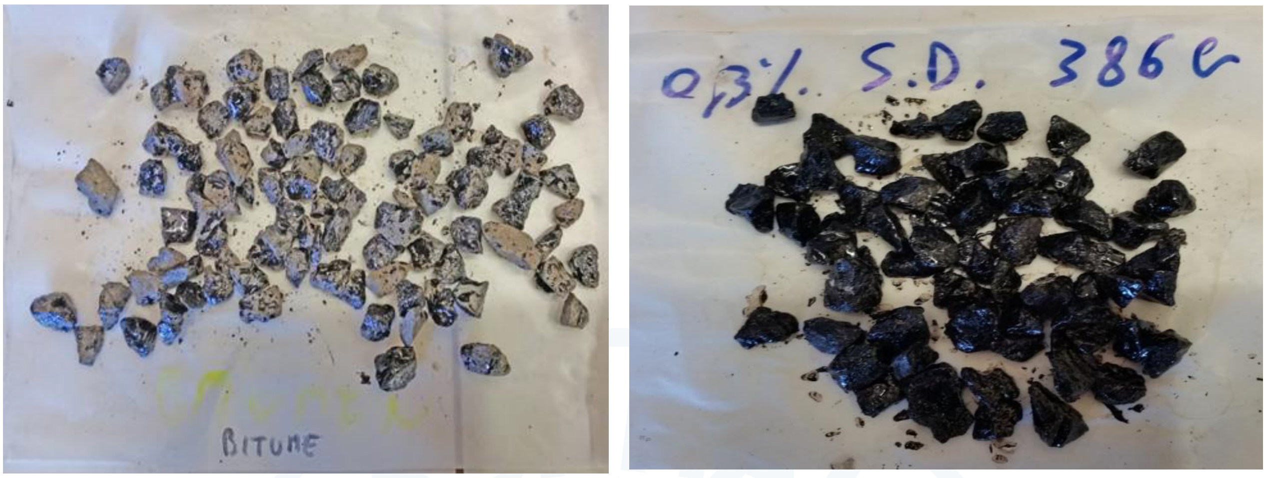


Figure 5a. Results Boiling water stripping Test basalt aggregates: left bitumen without additive, on the right bitumen with the addition of 0.3% of StarDope® 386 G.

Figure 5b. Results Boiling water stripping Test inert granites: left bitumen without additive, on the right bitumen with the addition of 0.3% of StarDope® 386 G.

Figure 5b. Results Boiling water stripping Test inert granites: left bitumen without additive, on the right bitumen with the addition of 0.3% of StarDope® 386 G.

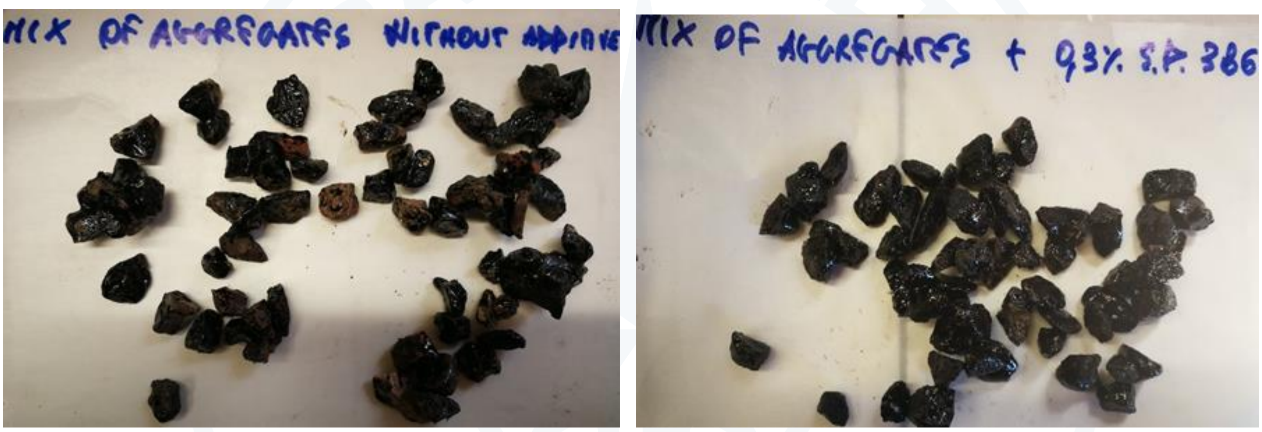
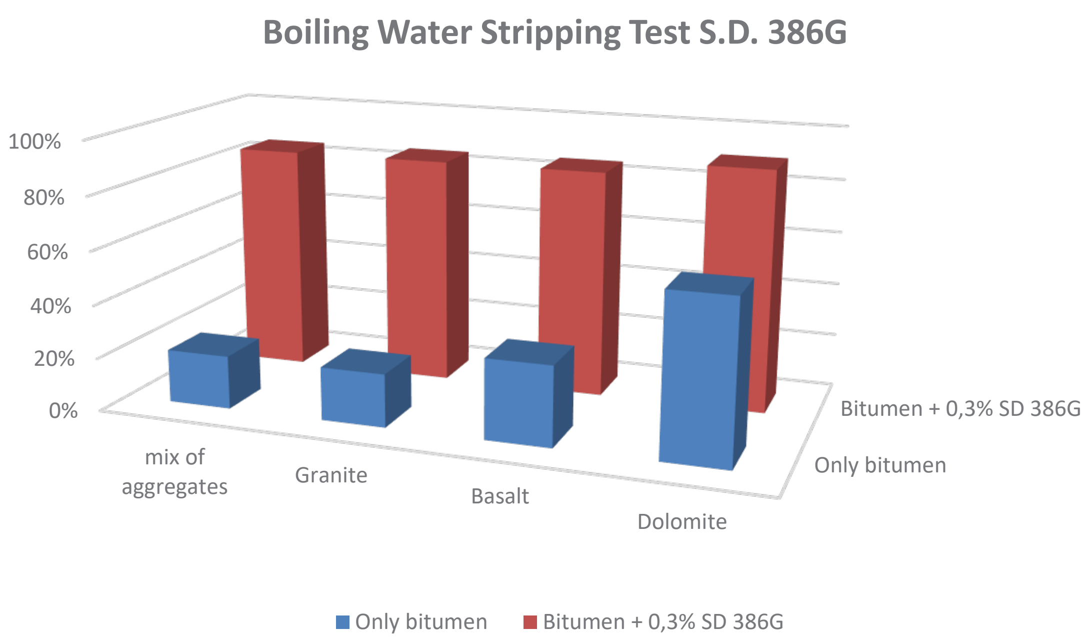


Figure 5d. Results Boiling water stripping Test aggregate mix: left bitumen without additive, on the right bitumen with the addition of 0.3% of StarDope® 386 G.

- *Boiling Water Stripping Chart Total Test StarDope® 386 G vs Non-Additive.*



- *Rolling Bottle Test (EN 12697-11 part A).*

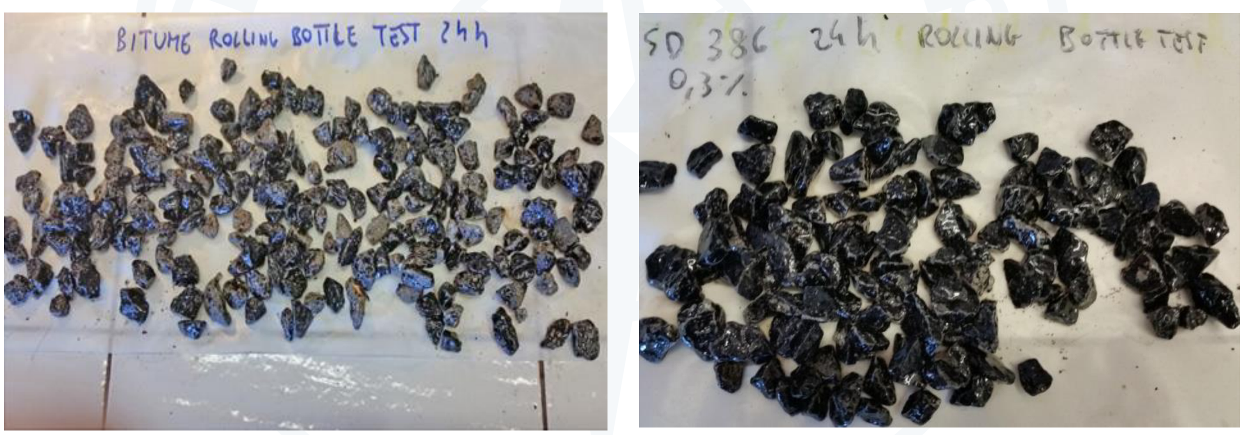


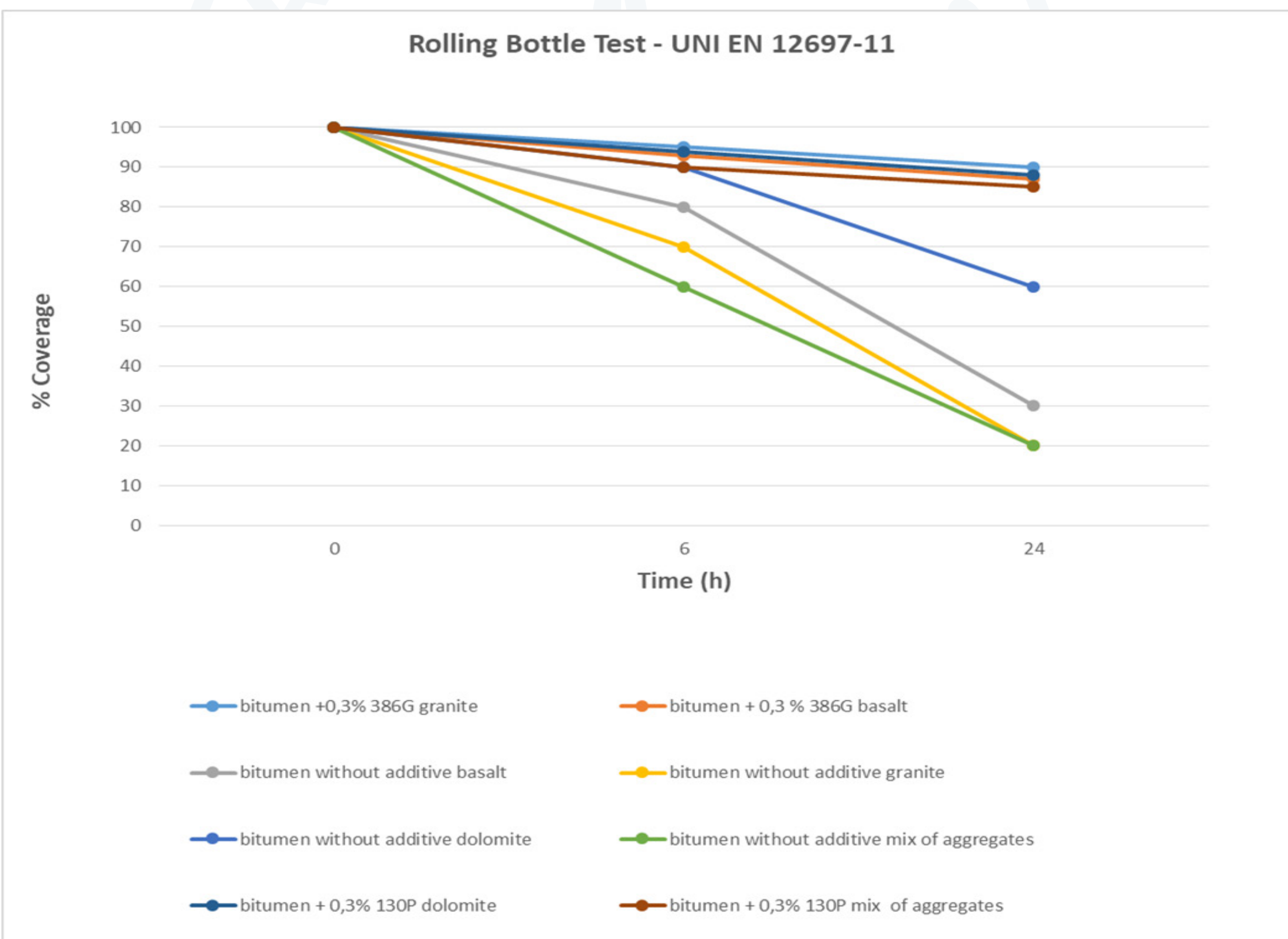
Figure 5e. Results Rolling Bottle Test inert basalt: on the left bitumen without additive, on the right bitumen with the addition of 0.3% of StarDope® 386 G.

Figure 5f. Results Rolling Bottle Test inert granites: left bitumen without additive, on the right bitumen with the addition of 0.3% of StarDope® 386 G.

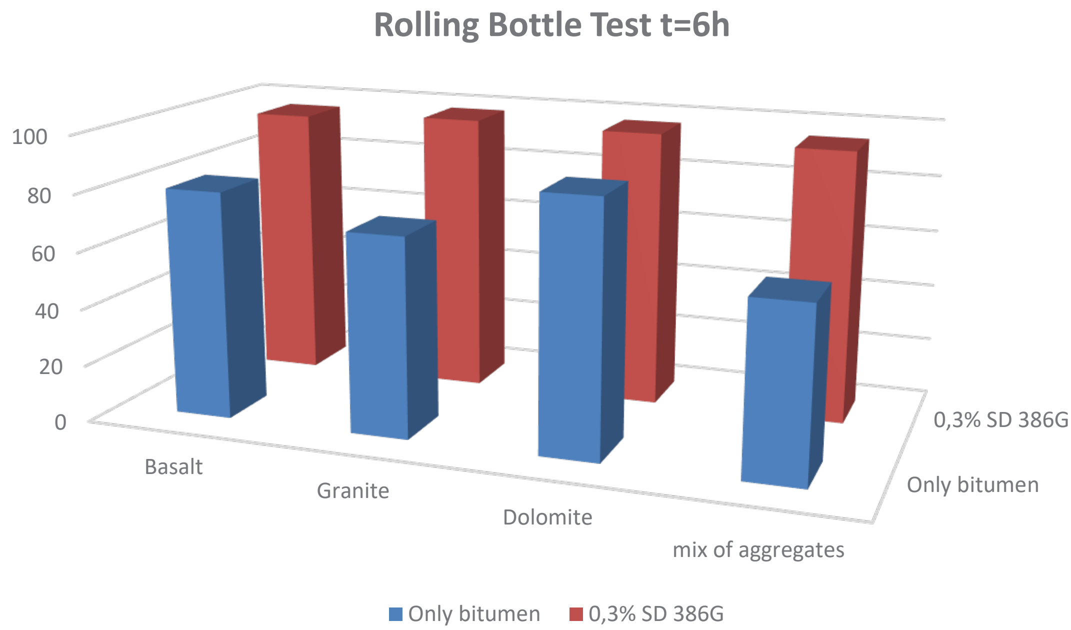
Figure 5g. Results Rolling Bottle Test inert dolomitics: left bitumen without additive, on the right bitumen with the addition of 0.3% of StarDope® 386 G.

Figure 5h. Results Rolling Bottle Test aggregate mix: left bitumen without additive, on the right bitumen with the addition of 0.3% of StarDope® 386 G.

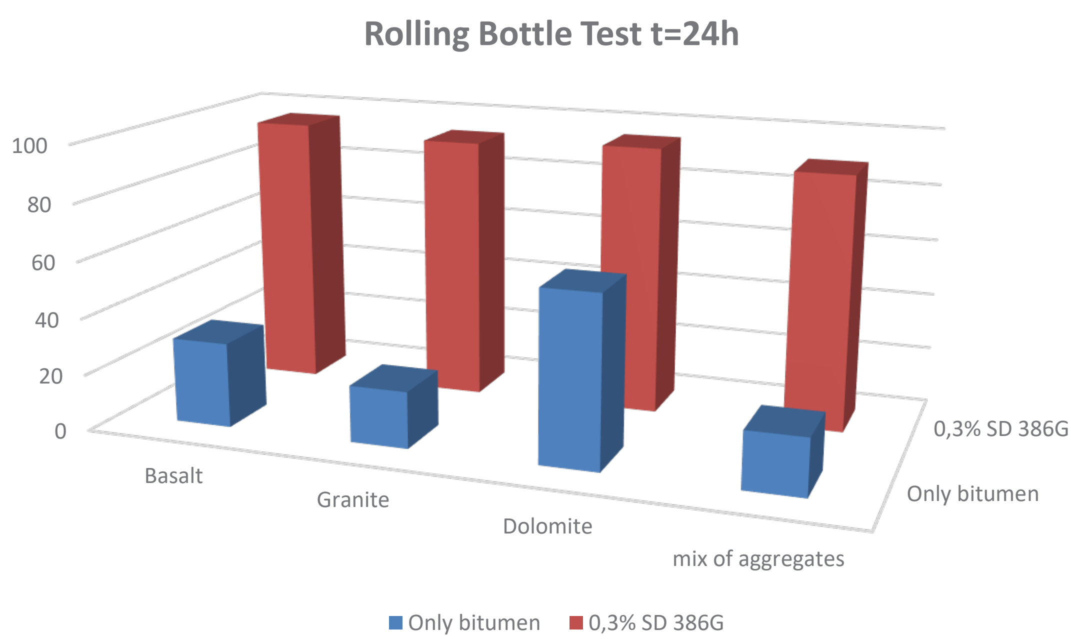
• <u>*Total Rolling Bottle Test Chart StarDope® 386G vs Non-Additive.*</u>



• ***Rolling Bottle Test Chart StarDope® 386G vs Non-Additive at t = 6h.***



• ***Rolling Bottle Test Chart StarDope® 386G vs Non-Additive at t = 24h.***



- <u>*Analysis FT-IR.*</u>

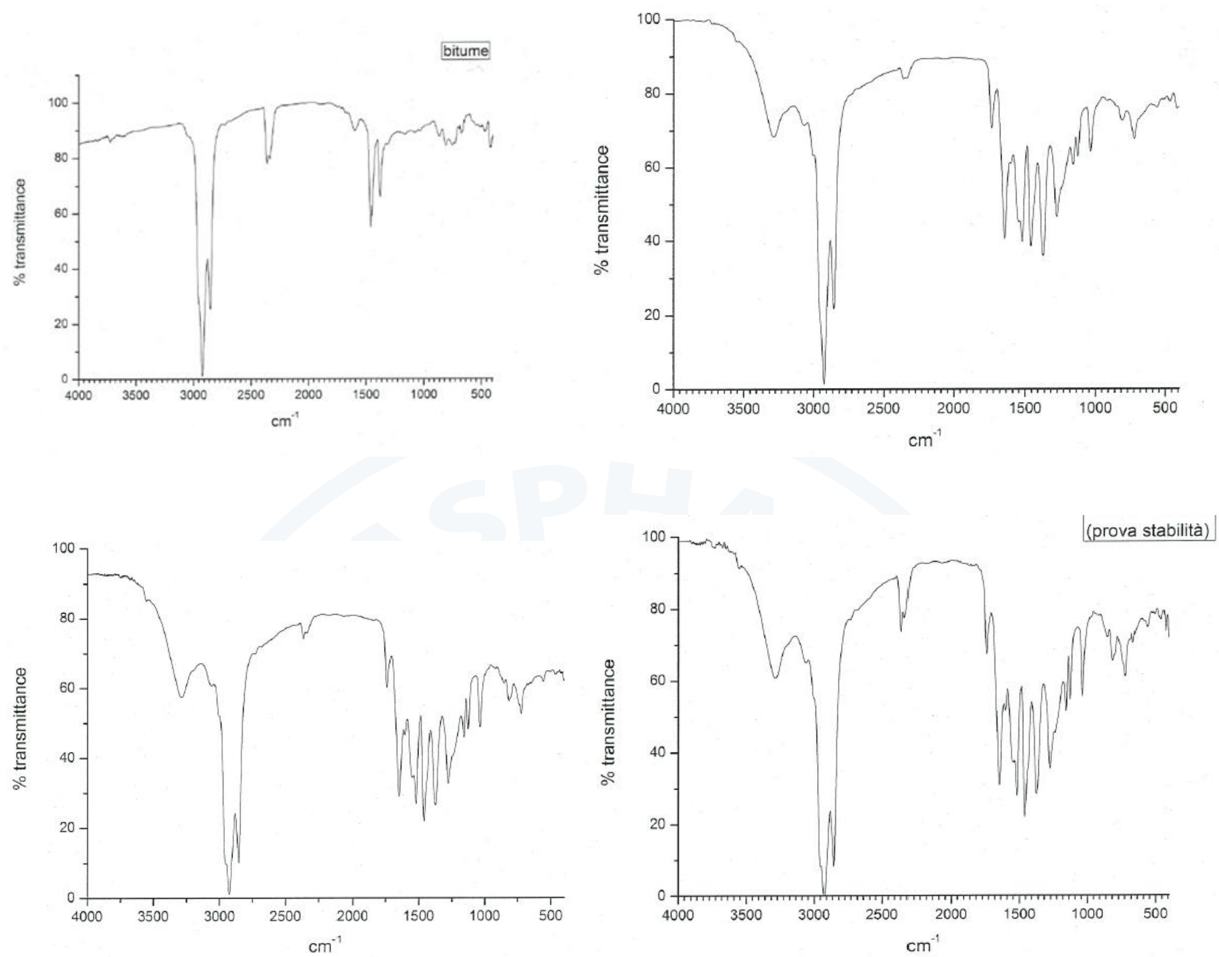


Figure 5i. Infrared spectrum acquired in transmittance by Fourier Transform Infrared Spectrometer in the frequency range between 4000 and 400 cm^{-1}. At the top on the left, the characteristic peaks of a sample of bitumen as it is, in the upper right corner those of the StarDope® 386 G additive, on the lower left the overlap of the characteristic peaks of a sample of bitumen with the addition of 0.3 % of StarDope® 386 G, lower right the T=180°C at 5 days of the bitumen sample with the addition of 0.3% of StarDope® 386 G: having a similar spectrum compared to that of the bitumen as such in the presence of the additive it is possible to ascertain the thermostability of the adhesion promoter.

StarDope® 510

- <u>*Boiling Water Stripping Test (ASTM D3625).*</u>

Figure 6a. Results Boiling Water Stripping Test basalt aggregates: left bitumen without additive, on the right bitumen with the addition of 0.1% of StarDope® 510.

Figure 6b. Results Boiling Water Stripping Test inert granites: left bitumen without additive, on the right bitumen with the addition of 0.1% of StarDope® 510.

Figure 6c. Results Boiling Water Stripping Dolomites inert tests: left bitumen without additive, on the right bitumen with the addition of 0.1% of StarDope® 510.

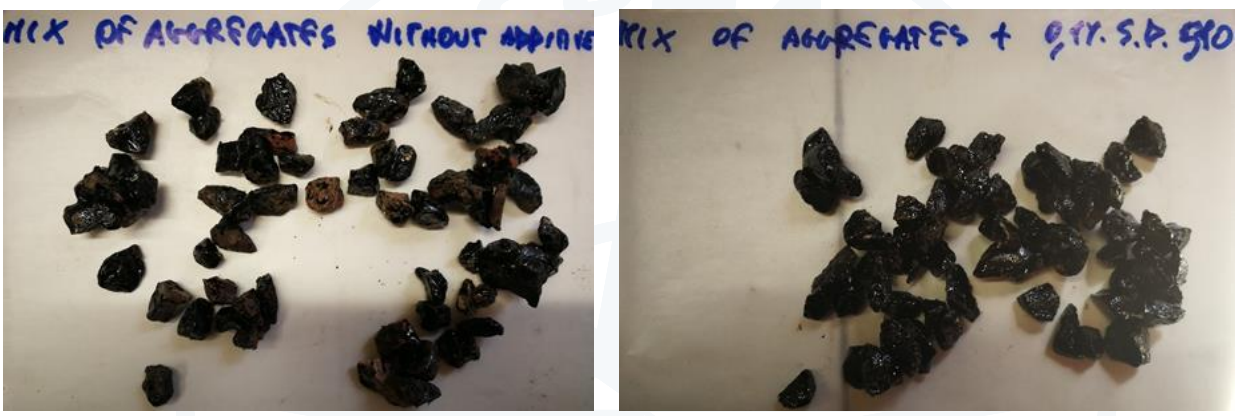
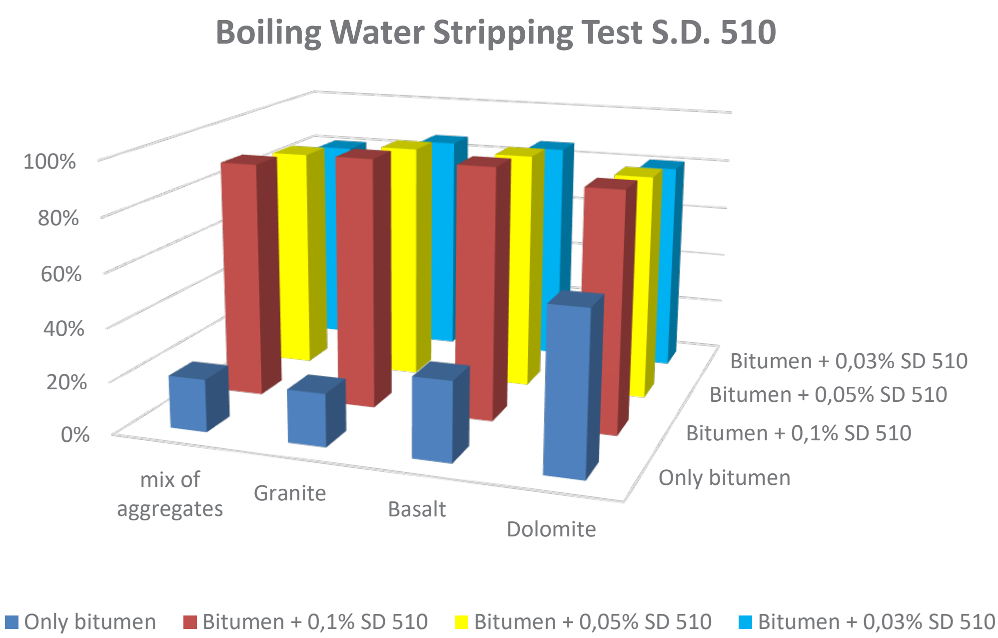


Figure 6d. Results Boiling Water Stripping Test aggregate mix: left bitumen without additive, right bitumen with the addition of 0.1% StarDope® 510.

- *Boiling Water Stripping Chart Total Test StarDope® 510 vs Non-Additive.*



- *Rolling Bottle Test (EN 12697-11 part A).*

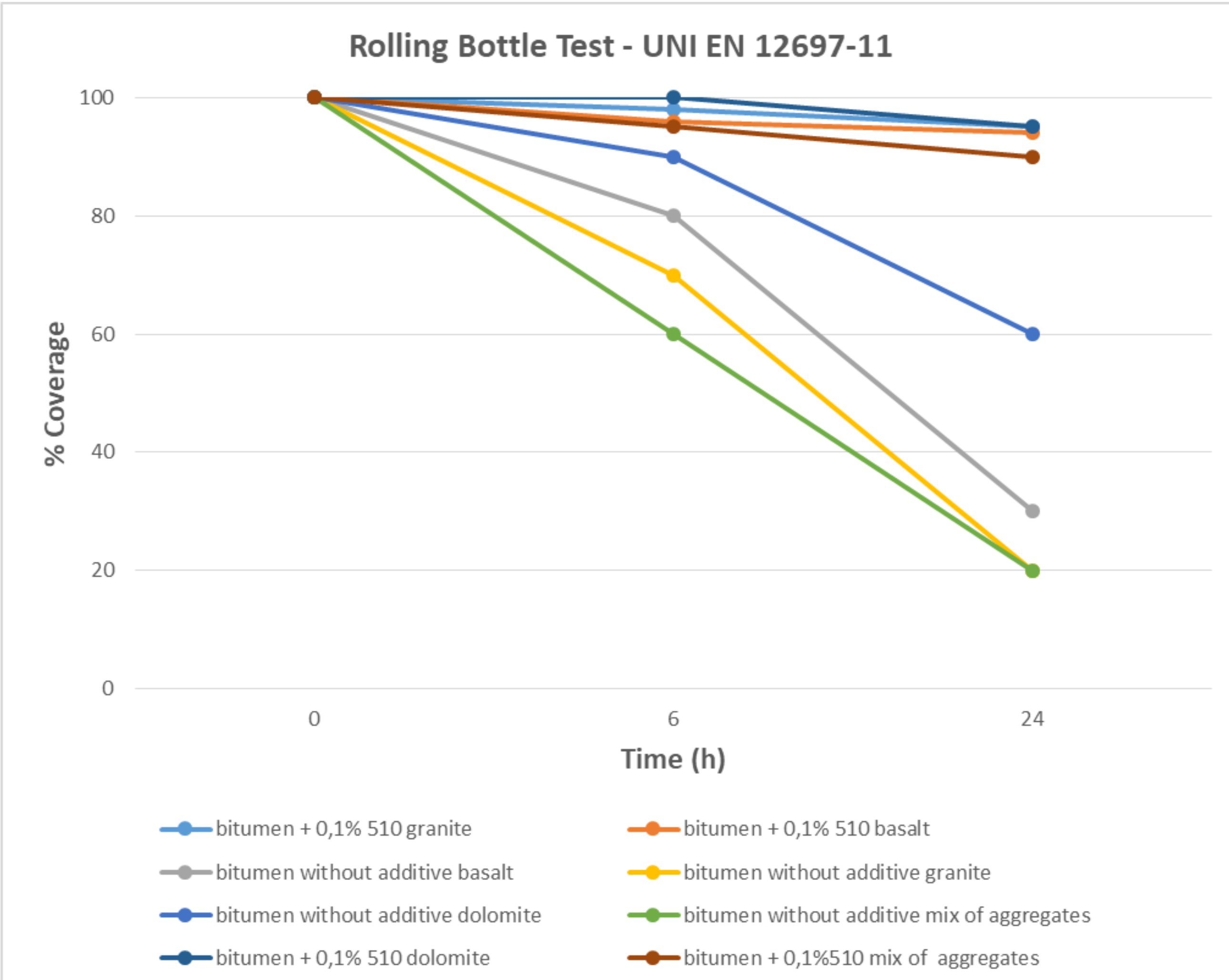
Figure 6e. Results Rolling Bottle Test inert basalt: on the left bitumen without additive, on the right bitumen with the addition of 0.1% of StarDope® 510.

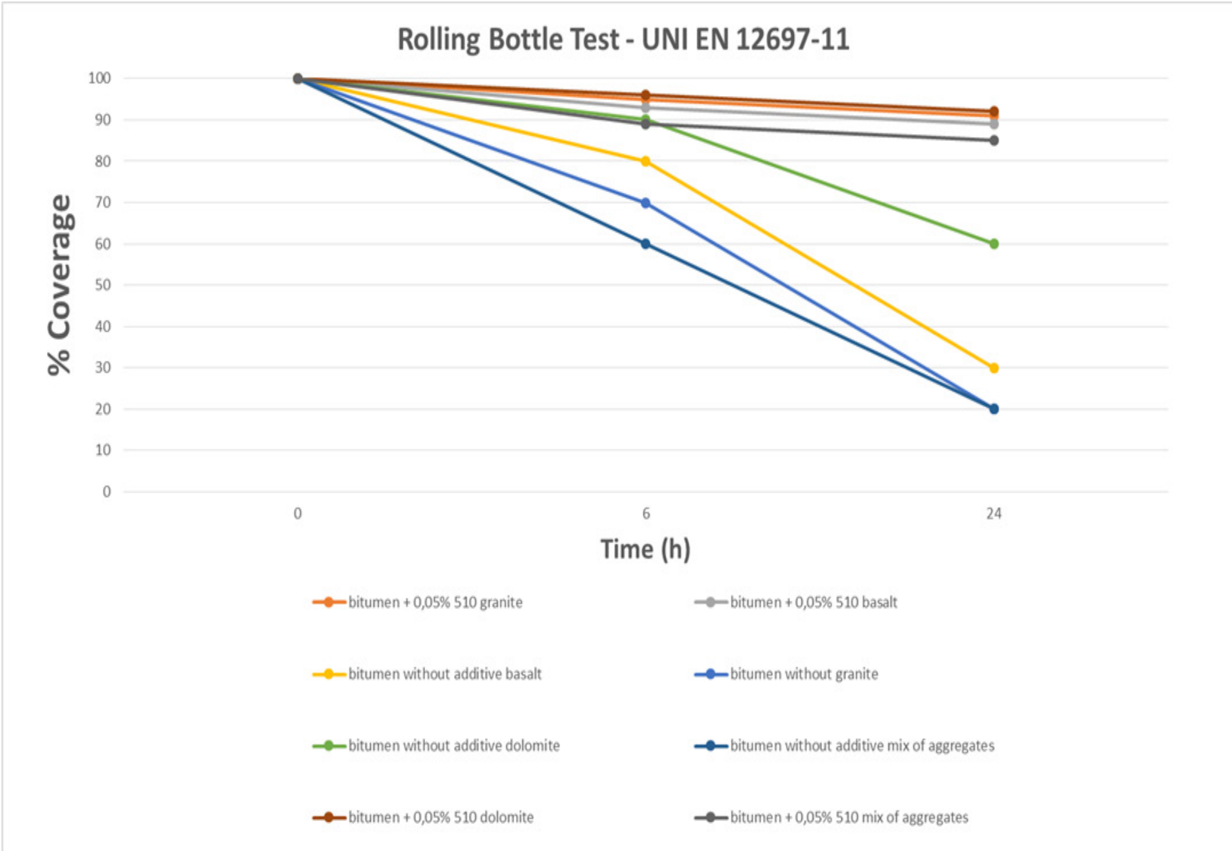
Figure 6f. Results Rolling Bottle Test inert granites: on the left bitumen without additive, on the right bitumen with the addition of 0.1% of StarDope® 510.

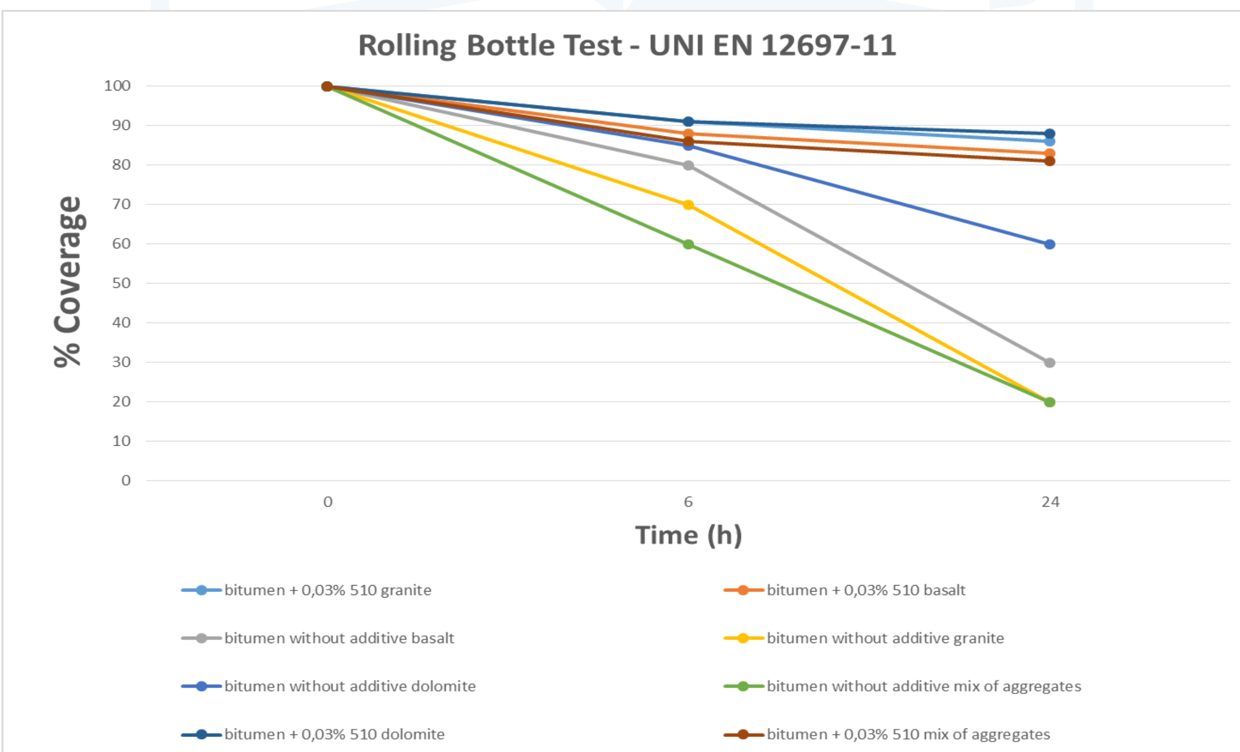
Figure 6g. Results Rolling Bottle Test inert dolomitic: left bitumen without additive, on the right bitumen with the addition of 0.1% of StarDope® 510.

Figure 6h. Results Rolling Bottle Test inert mix: left bitumen without additive, on the right bitumen with the addition of 0.1% of StarDope® 510.

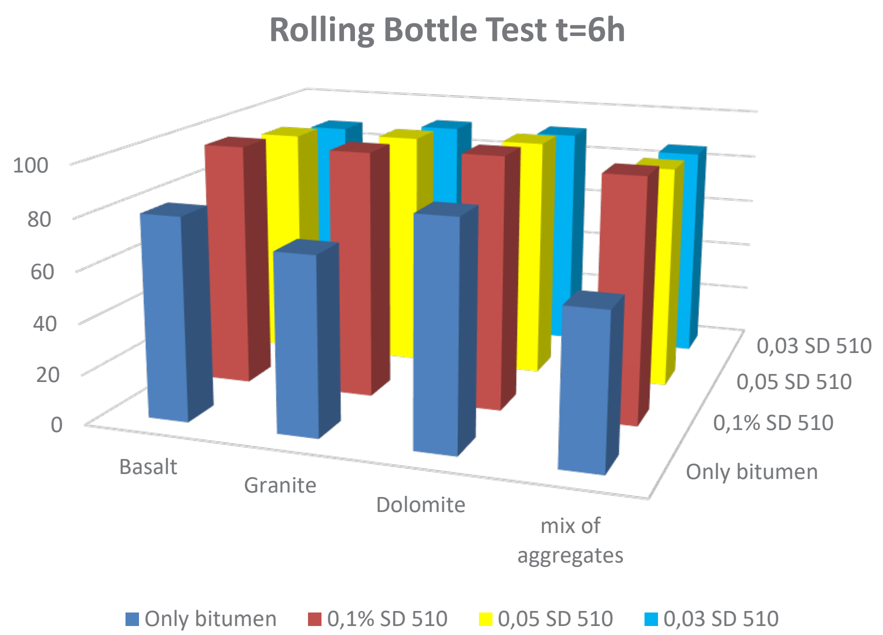
- *Rolling Bottle Total Test Chart StarDope® 510 vs Non-Additive.*



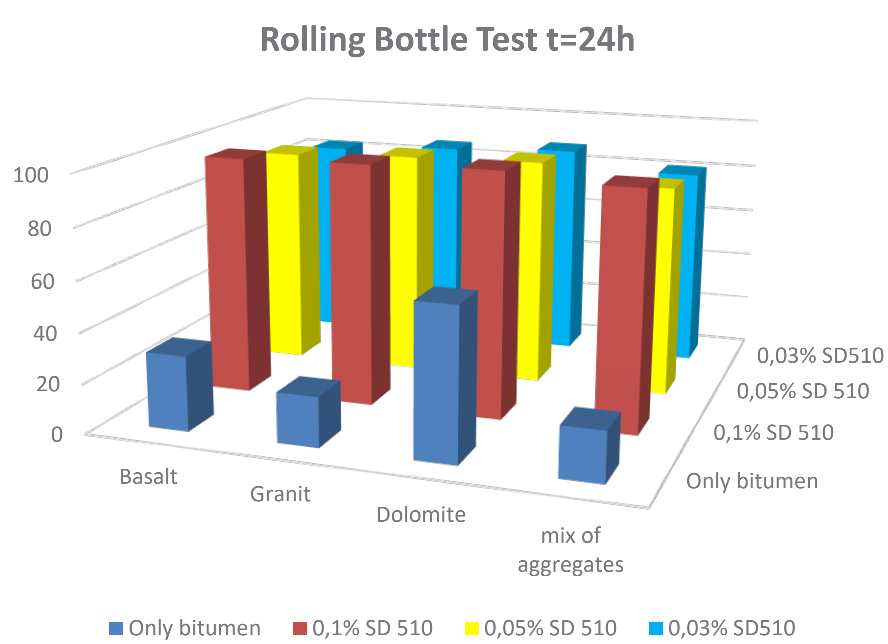

Rolling Bottle Test - UNI EN 12697-11
% Coverage
100
90
80
70
60
50
40
30
20
10
0
0
6
24
Time (h)
bitumen + 0,05% 510 granite
bitumen + 0,05% 510 basalt
bitumen without additive basalt
bitumen without granite
bitumen without additive dolomite
bitumen without additive mix of aggregates
bitumen + 0,05% 510 dolomite
bitumen + 0,05% 510 mix of aggregates


Rolling Bottle Test - UNI EN 12697-11
% Coverage
100
90
80
70
60
50
40
30
20
10
0
0
6
24
Time (h)
bitumen + 0,03% 510 granite
bitumen + 0,03% 510 basalt
bitumen without additive basalt
bitumen without additive granite
bitumen without additive dolomite
bitumen without additive mix of aggregates
bitumen + 0,03% 510 dolomite
bitumen + 0,03% 510 mix of aggregates

• *Rolling Bottle Test Chart StarDope® 510 vs Non-Additive at t = 6h.*



• *Rolling Bottle Test Chart StarDope® 510 vs Non-Additive at t = 24h.*



• *<u>Test stripping resistance according to Russian law (GOST 12.801-98) and Ukraine (ISO BV 2.7-89-99).</u>*

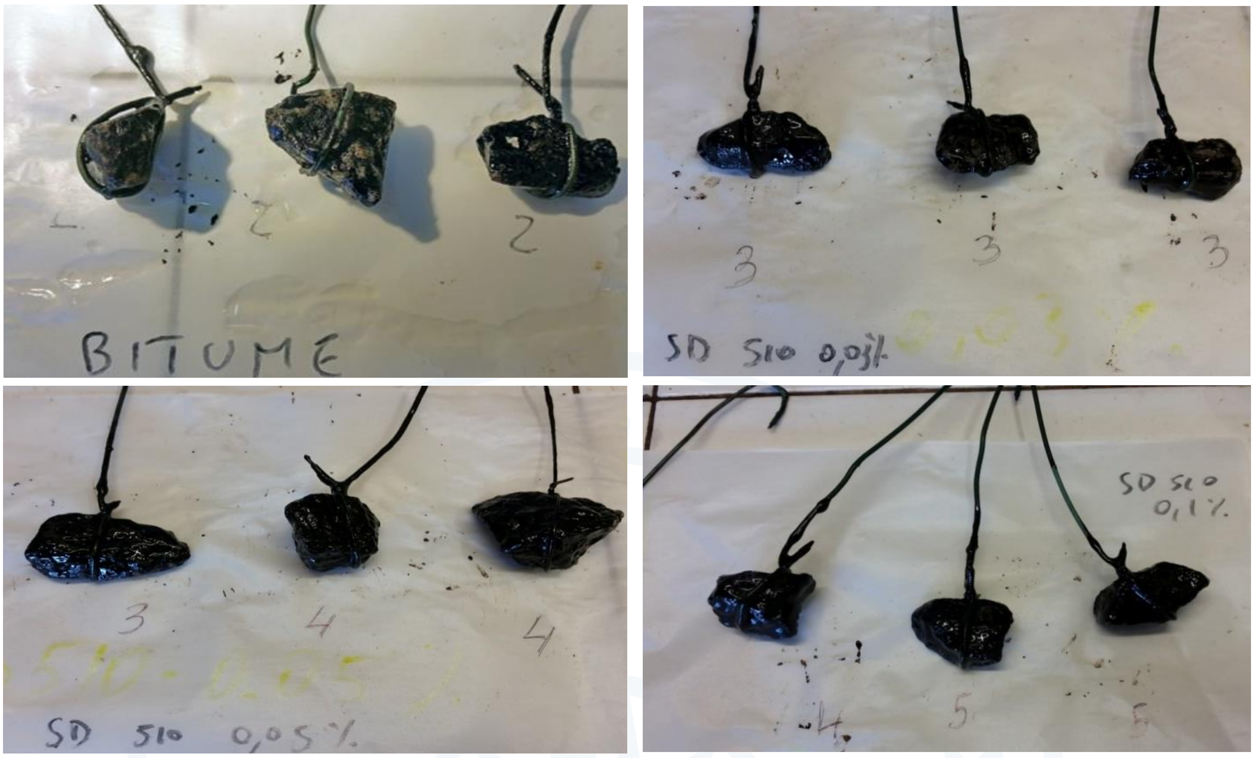


Figure 6i. Results Granitic inert tests: top left bitumen without additive, top right bitumen with the addition of 0.03% of StarDope® 510, lower left bitumen with the addition of 0.05% of StarDope® 510 , in the lower right bitumen with the addition of 0.1% of StarDope® 510.

* <u>*Analysis FT-IR.*</u>

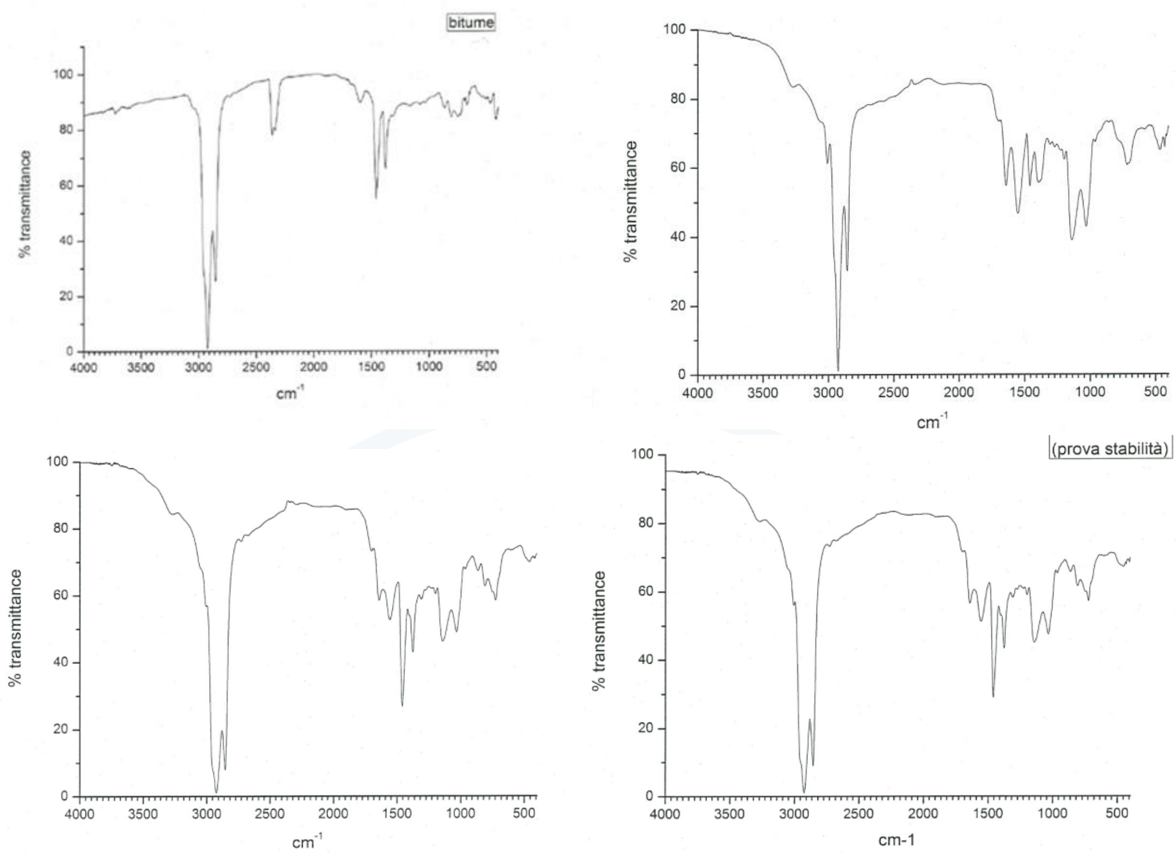
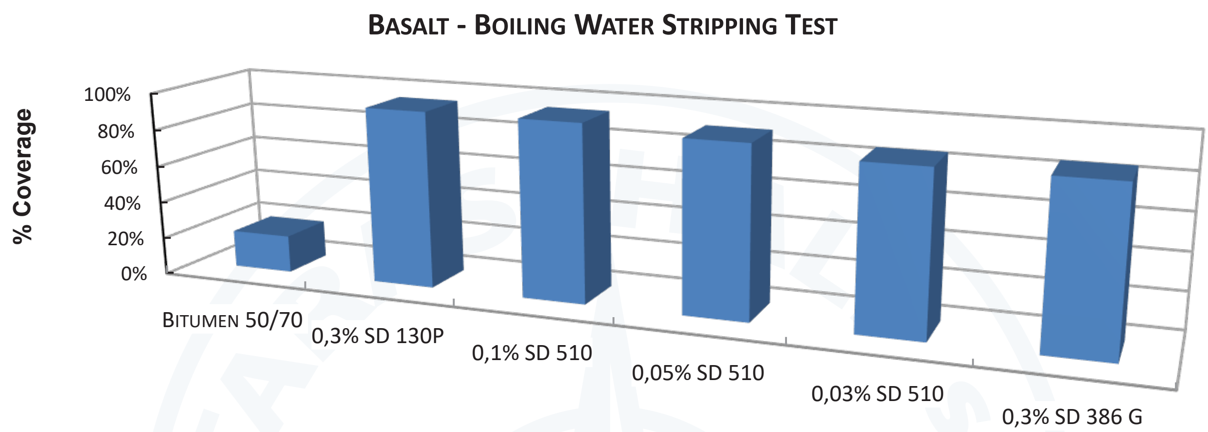


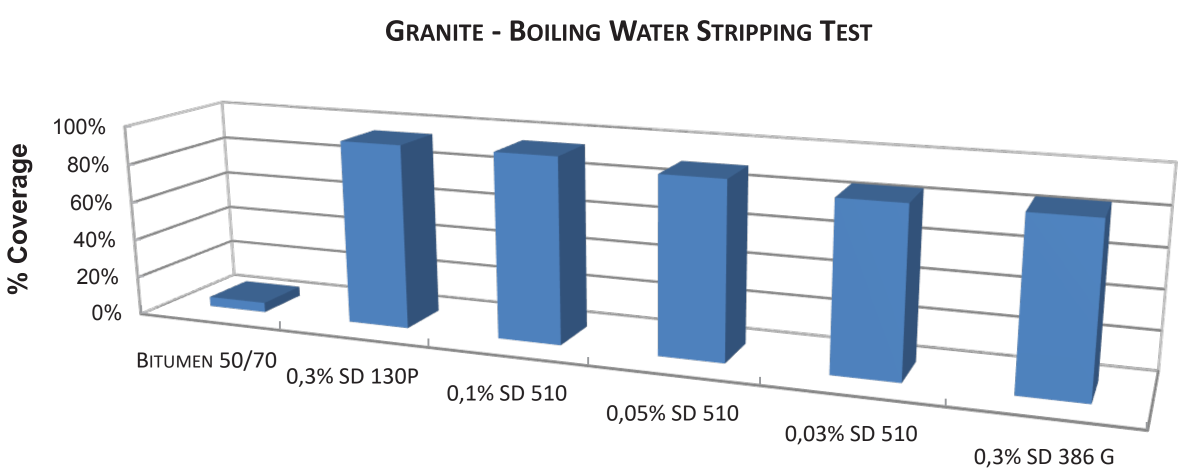
Figure 6l. Infrared spectrum acquired in transmittance by Fourier Transform Infrared Spectrometer in the frequency range between 4000 and 400 cm^{-1}.
At the top left are the characteristic peaks of a sample of bitumen as it is, in the upper right-hand corner of the StarDope® 510 additive, at the bottom left the overlap of the characteristic peaks of a sample of bitumen with the addition of 0.1% of StarDope® 510, lower right the T=180°C stability test at 5 days of the bitumen sample with the addition of 0.1% of StarDope® 510: presenting a similar spectrum compared to that of bitumen as such, in the presence of the additive, the thermostability of the adhesion promoter can be observed.

DISCUSSION OF RESULTS AND CONCLUSIONS

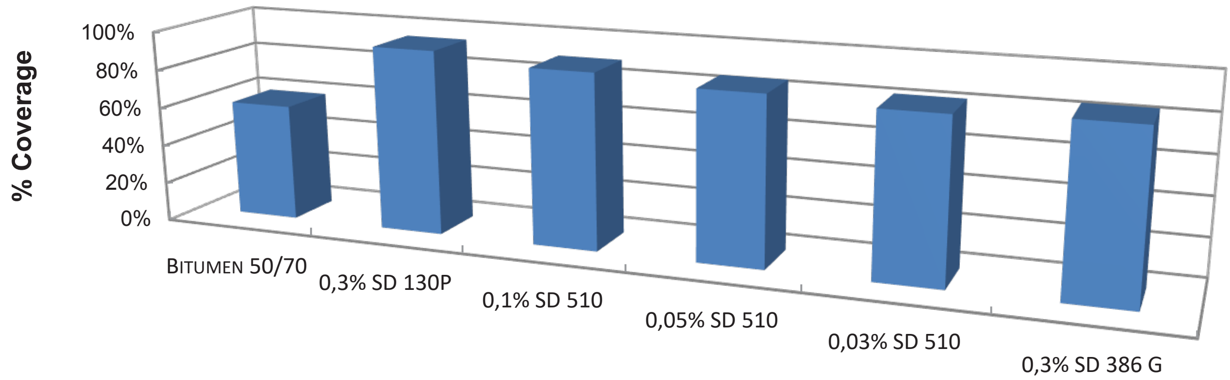
For a global view of the performance of StarDope® additives, the overall experimental results obtained are shown in graph:

- *Boiling Water Stripping Test (ASTM D3625).*

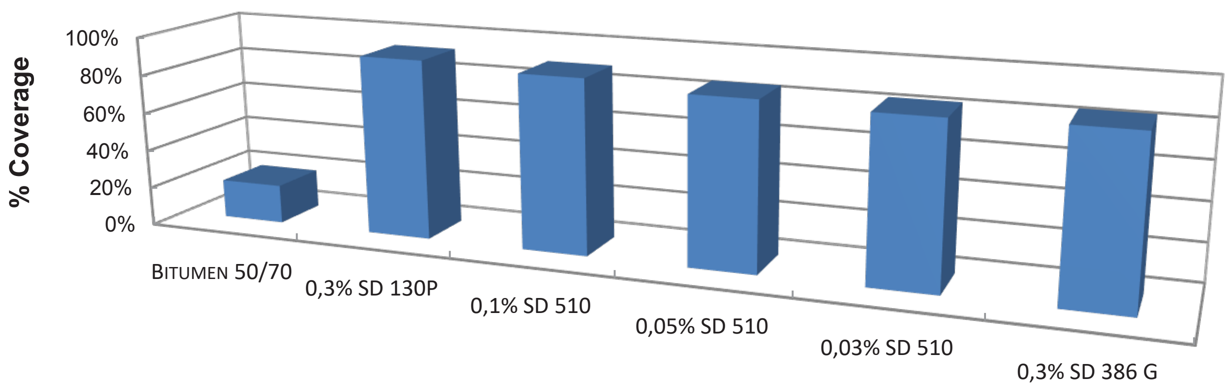




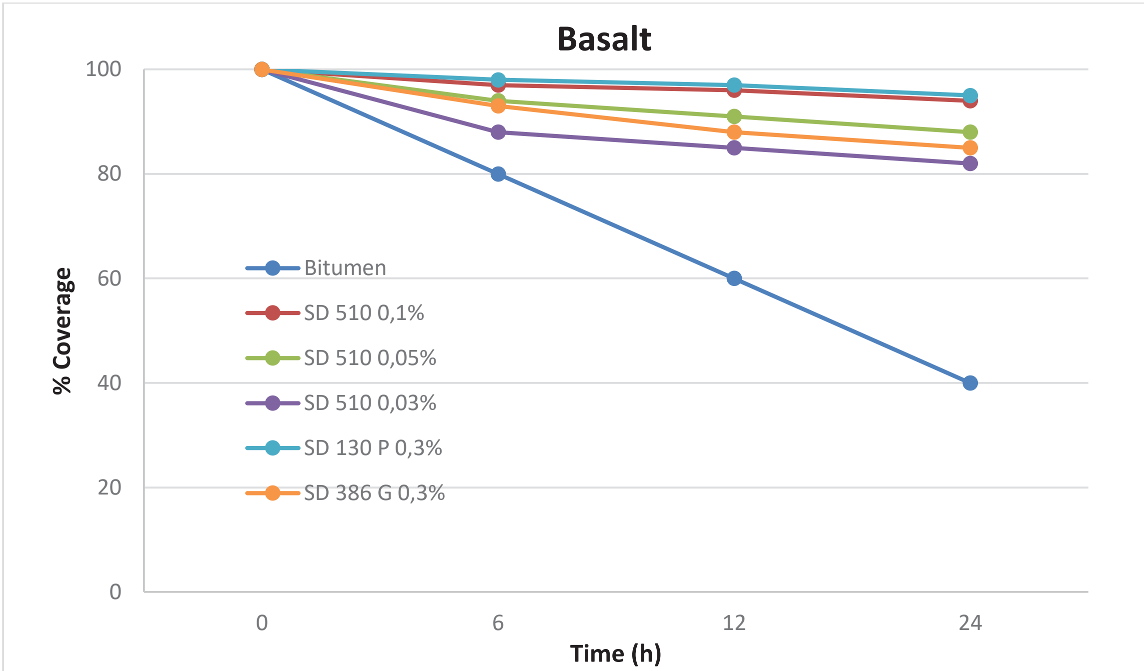
Dolomite - Boiling Water Stripping Test

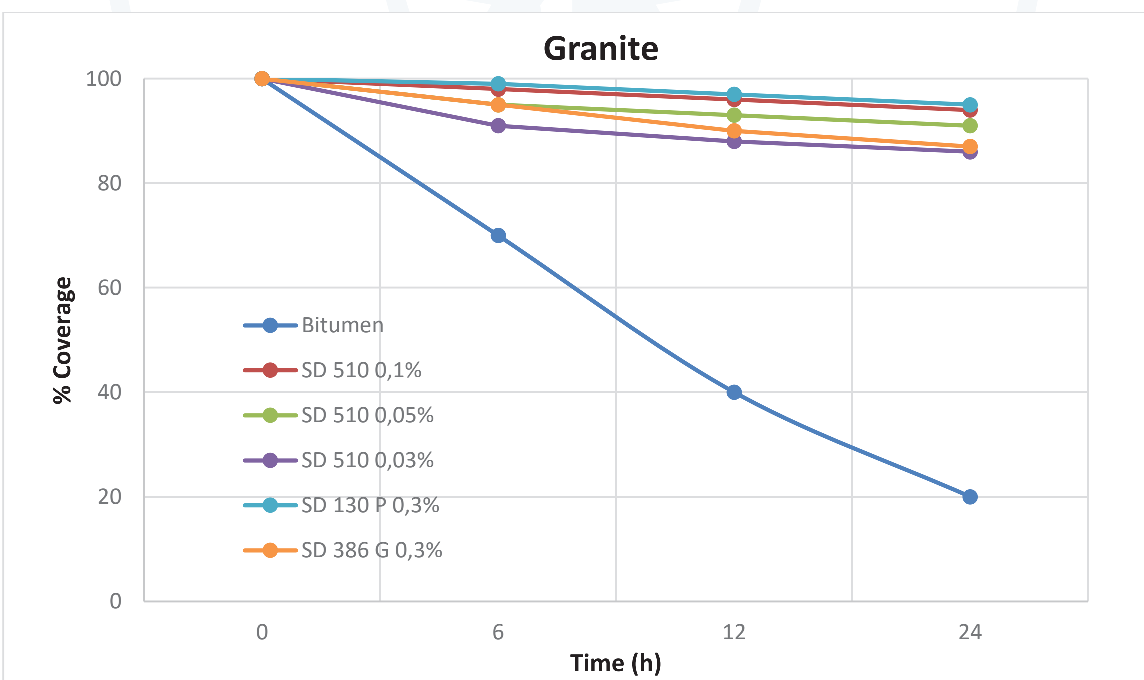


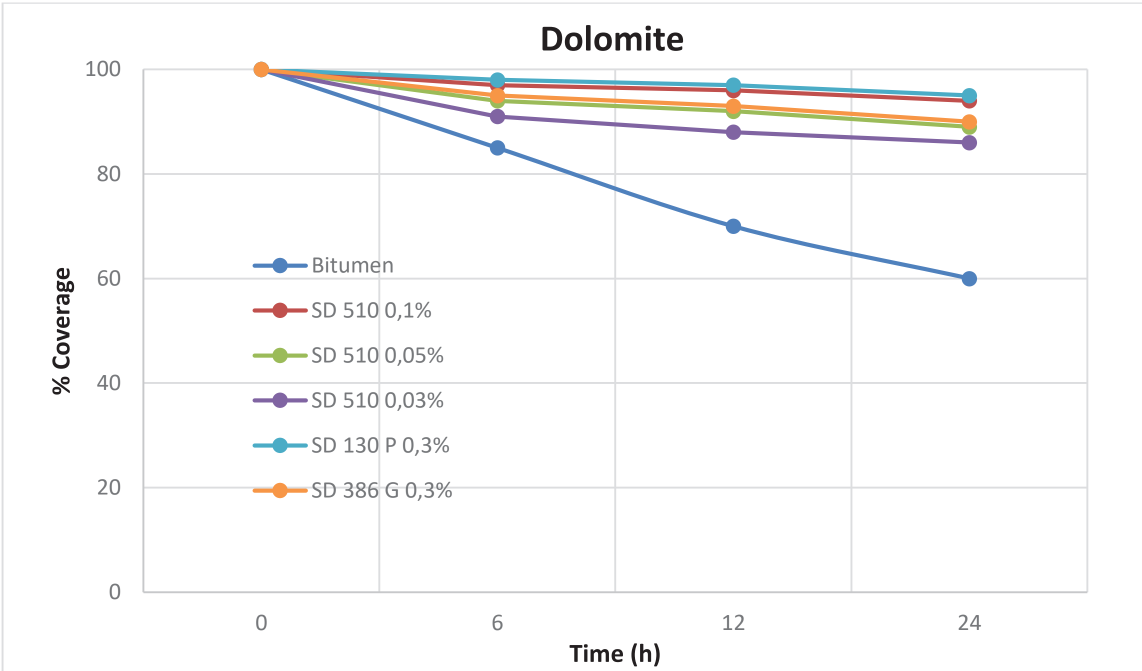
Mix of Aggregates - Boiling Water Stripping Test



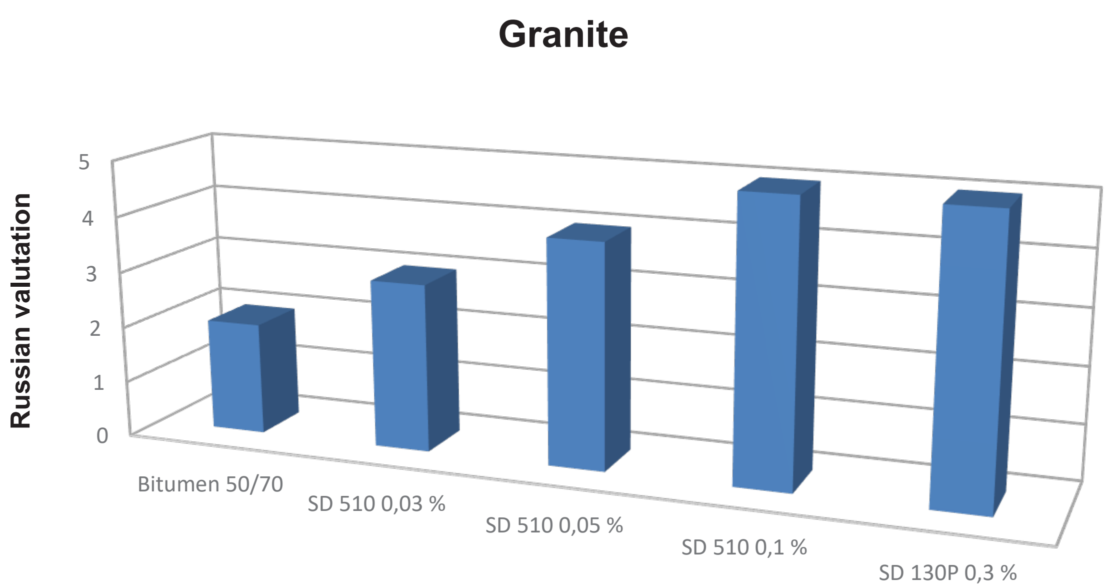
- *Rolling Bottle Test (EN 12697-11 part A).*







- *Test stripping resistance according to Russian law (GOST 12.801-98) and Ukraine (ISO BV 2.7-89-99).*



From the analysis of the experimental results obtained it is possible to state that the use of additives called StarDope®:

- ✓ Significantly increase the adhesion of the bitumen to the inerts;
- ✓ They guarantee a perfectly stable bond between bitumen and inerts, both acid and basic;
- ✓ Improve the resistance of bituminous conglomerates to water action.

These additives give the road pavement improved properties in terms of:

- ✓ Degree of coverage of aggregates during the mixing and production phase. This action is called "active adhesion": the bitumen, even in the presence of water and humidity, perfectly covers the aggregates.
- ✓ Resistance to the stripping of the bitumen film covering the inert, perfectly stable and long lasting. This action defines "passive adhesion" and represents the ability of bitumen to remain attached to the surface of aggregates throughout the useful life of the road pavement.

Furthermore, in order to verify the thermal stability of our additives, FT-IR spectroscopic analysis was performed on the bitumen as it is, on individual additives and on bitumen-additive mixtures; the comparison analysis clearly shows that the spectra of the bitumen-additive mixture essentially result from the overlapping of the spectra of the individual components. In fact, the characteristic peaks of the bitumen and those of the additive are clearly identifiable in the resulting spectra.

The thermal stability of the bitumen-additive system has been verified under conditions of high oxidative stress (T=180°C). The spectral analysis on the bitumen-additive mixtures showed a high stability of the same, since the FT-IR spectra acquired after treatment at T=180°C do not show significant qualitative or quantitative differences with respect to the corresponding spectra acquired on the samples that do not have undergone heat treatment, as shown by the spectra attached to this work.

In conclusion, the various tests carried out show a high efficiency as well as a high thermal stability of the StarDope® additives, guaranteeing long-lasting performance.

RAP REJUVENATORS

Registration of *Star Asphalt S.p.A.* to REACH Regulation N. 1907/2006 G.U.E. L396 of 30 December 2006

Effective from 1 June 2007 and with registration deadline to 31 May 2018

ACF WARM-MIX® 2G, ACF WARM-MIX® 4G,
ACF WARM-MIX® 40, ACF WARM-MIX® 50 PLUS

Complex mixtures of polymers and adhesion promoters registered to the REACH Regulation

REACH REGISTRATION NUMBER

01-2119492546-27-0004

RAP REJUVENATORS

INTRODUCTION

The useful life of a road paving is characterized by various events that limit its duration over time, accelerating its deterioration:

- The increase in heavy traffic;
- The lift of the background;
- environmental conditions;
- The natural aging of the binder;
- The quality of the materials used.

It is therefore necessary to carry out maintenance operations which, in most cases, involve the removal of a part of the thickness of the bituminous asphalt package, thus obtaining waste material, the so-called "RAP" (RAP: Recycled Asphalt Pavement) . In recent years there has been an evident accumulation of RAP material, which requires technologies to maximize recycling.

Large-scale recycling of waste products from various industrial sectors can be considered one of the main objectives of the modern world. The reasons that support the need to recycle are many and all equally important, as is well summarized the general outline of the document "Recycling for road improvements" published by the OECD in 1997:

• Reduction in the use of raw materials;

• Reduction of land to be disposed of as landfill;

• Contain pollution of soil and atmosphere due to transport and incineration of waste;

• Energy conservation;

• Affordability;

• Technical advantages.

In order to recycle milled material (RAP), it is necessary to recreate the lost chemical and physical characteristics of the binder.
The recycling of asphalt pavement is obtained by adding a functional additive to the rejuvenation of the binder. Currently many use fluxing additives, which are not functional to the rejuvenation of the additive, but only break down its viscosity; a regenerating agent, on the other hand, must restore the Asphaltene/Maltene ratio, ensuring mechanical performance of the final binder mixture, comparable to a virgin binder. Over time, various additives have been tested, typically with dosages of 5 to 10% on the weight of the oxidized binder. In flooring made with the addition of flux-type additives, problems of molding and cracking resistance, as well as adhesion and cohesion between binder and aggregates were found. Many of the current additives currently on the market suffer from these problems, the Star Asphalt, after careful and targeted studies, has formulated functional chemical additives able to really regenerate the oxidized binder.
Using RAP material in asphalt mix involves a study that can be synthesized in several steps:

• Definition of the characteristics of the milled material (bitumen content, granulometric curve);

• Composition of the granulometric curve containing a variable percentage of RAP in

function of the type of asphalt mix to be made;

• Determination of the percentage of new bitumen to be added, considering the addition

of the regenerated bitumen in the RAP;

• Study of the mechanical and volumetric behavior of the mixture.

The introduction of the RAP material indirectly involves difficulties due to the increase in viscosity of the asphalt mix , since the viscosity of the pavement bitumen to be regenerated is very high:

• The milled sole has a very high viscosity, even undetectable at temperatures below 80 °C, and its addition in a percentage of 30% significantly increases the viscosity of the final asphalt mix;
• The addition of ACF on the bitumen, leads to a reduction in viscosity with a consequent increase in workability, adhesion to aggregates, compacting of the asphalt mix and a possibility of decreasing the mix and spread temperatures compared to an asphalt made without ACF, with savings on fuel consumption and reduced emissions of polluting gases into the atmosphere.

OPERATIVE TECHNIQUES FOR RAP MATERIAL RE-USE

To add RAP material to an asphalt mix, the following operating procedure must be performed:

1. Identify the type of the asphalt mix to be obtained: base, binder or wear. It is noted that the mix obtained with the RAP material is identical to that produced using virgin aggregates; therefore, depending on the desired layer, reference can be made both as a granulometric curve and as a total bitumen content to the technical requirements for the various layers.

2. Analyze in advance the RAP material to be used, determining: granulometric curve, content and quality of the contained bitumen. It is advisable to use milled material with a particle size distribution that is as homogeneous as possible; for this purpose it is suggested to use a plant that shatters, selects and produces a milled material with a maximum particle size of 10/12 mm.

3. In the formulation of the final mixture, the milled material is considered as an aggregate. Therefore, once the quantity of RAP material to be used has been established, the overall granulometric curve is created, adding the virgin aggregates necessary to satisfy the requirements of the prescriptions.

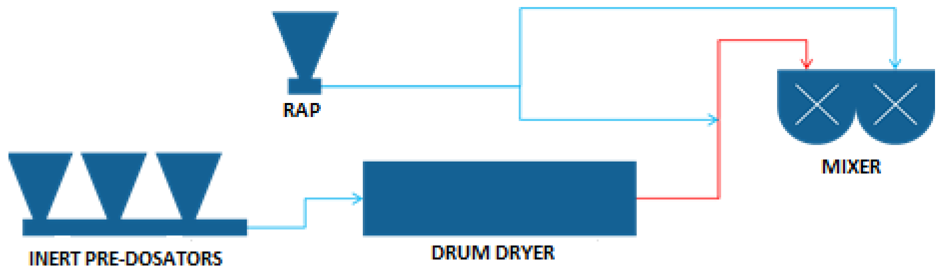
4. The evaluation of the quantity of new bitumen to be added is deducted by subtracting from the total content of binder, potentially to be added, the quantity of bitumen contained in the RAP material present in the mixture.

5. The evaluation of the amount of ACF to be used is deducted according to the percentage of new bitumen to be added in the mixture, according to the criterion that the viscosity of the total binder in mixture (old bitumen + new bitumen + ACF) at the temperature of 60°C must be less than 400 Pa·s.

The production process of the MIX with the addition of the RAP material depends on the type of plant used and the equipment that the system has. The method of introducing the milled material into the mixture can be carried out in two ways: "cold" and/or "hot".

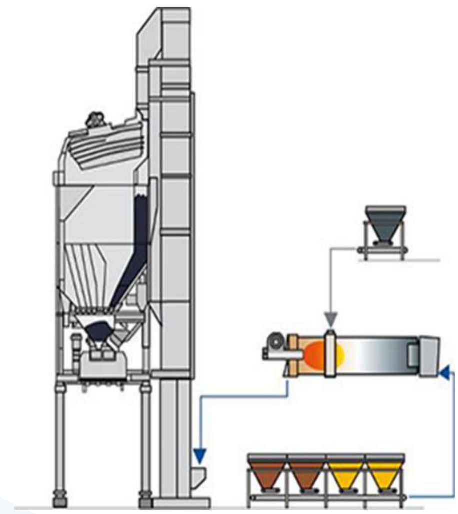
Cold mix asphalt technique

The milled material is added, at room temperature and therefore probably also humid, to the dried inerts. The addition can take place directly in the mixer or in the bucket elevator, after exiting the dryer cylinder, or with both solutions.



The choice of the addition mode substantially conditions the percentage of RAP material that can be used; in any way, it is mandatory that the final temperature of the mixture, coming out of the mixer, reaches at least 150°C. To this end, virgin aggregates must be overheated up to about 200÷250°C in addition to being dried.
The heat deviation between aggregate temperatures and that of the mixes at the outlet of the mixer depends on:
• The percentage of milled material used;
• From the ambient temperature and environmental climatic conditions;
• From the water content present in the RAP material.
The "cold" method, however, places a limit on the recycling percentage, in the order of 20-30%, in relation to the homogeneity of the RAP material and to the capacity of the system for the disposal of gases and vapors that are formed during the productive phase.

Hot mix asphalt technique



The "hot" addition of the RAP material is the most advantageous technique from a technical and economic point of view. A specific asphalt production plant is required or in any case with technical options that allow it to be made. There are three possible ways.

The first consists in heating the RAP material by direct contact with the virgin aggregates: the heating of the virgins allows the evaporation of the water present in the cold milled in order to reach, subsequently, the correct temperature in the final mixture. It is also possible to distinguish solutions in which the milled product is introduced upstream of the mixing step inside the rotating dryer cylinder and in this case a specific arrangement is required on the cylinder for introducing the RAP material and a dedicated feeding line consisting of a dosing hopper and a dedicated conveyor belt, recommending the use of the screen (note the fraction of milled material to be introduced), or directly in the final mixing phase without having to give up the use of the screen.

The second heating mode envisages a pre-treatment of the RAP material, which is dried and heated in a dedicated drum, as is the case for virgin aggregates, allowing extremely precise weighting and a regular and controlled heating of the material to be recycled.

OUR RECYCLING SOLUTIONS

In our laboratories, additives called ACF have been developed that allow to re-use the milled material, guaranteeing high performance and limiting the phenomenon of the rutting. There are two lines studied and proposed based on the functionality and the regenerating power of each additive:

- Hot regenerating: to be used at the traditional production temperatures of bituminous conglomerates.
- Multifunctional warm regenerating: some can be used at "luke-warm" production temperatures up to a maximum of 30% of milling. Others to allow the recycling of high quantities of milled material (>30%) favoring the regeneration of the oxidized bitumen contained in the milled material, the low temperature workability of the resulting bituminous conglomerate and the tight adhesion of the bitumen film covering the aggregate.

REJUVENATORS FOR HOT MIX ASPHALT

ACF ECO

It is an additive specifically designed to heat regenerate the oxidized bitumen contained in the RAP material; it consists of chemical components of different nature, each of which allows to reduce the viscosity of the bituminous mixture containing the RAP material, and reintegrate the volatile components of the binder. Its correct dosage allows to restore the properties of the binder to the typical values of a mixture without the RAP material. It is recommended for applications requiring the reuse of RAP quantities up to 30%. The percentage of product to be dosed can vary from 0.2% to 0.3% on the weight of the milled material used, depending on the working conditions and the type of RAP used.

STARDOPE® ACF 100

It is an additive with dual function, regenerating the oxidized bitumen contained in the the RAP material, and moreover, due to the presence of the adhesion promoter, there will be a better quality of the final asphalt, due to the establishment of a perfectly stable bond between bitumen and virgin aggregates, and because of greater flexibility in the use of asphalt mix, particularly in the presence of moisture. The percentage of product to be dosed can vary from 0.2% to 0.3% on the weight of the RAP material used, depending on the working conditions and the type of RAP.

POLYFUNCTIONAL REJUVENATORS FOR WARM-MIX ASPHALT

ACF WARM-MIX® 2G → <u>Complex mixture of products registered to the REACH regulation</u>

It is an additive with a regenerating function of the oxidized bitumen contained in the milled material; moreover it allows to be able to compact and spread the asphalt mix at lower temperatures than those traditionally used, favoring a good bitumen/aggregate adhesion. This peculiarity allows to improve the workability of the mixtures without compromising the degree of compaction. The percentage of product to be dosed can vary from 0.2% to 0.3% on the weight of the milled material used, depending on the working conditions and the type of RAP.

ACF WARM-MIX® 4G → <u>Complex mixture of products registered to the REACH regulation</u>

It is an additive with a triple function, in fact, the mix packed with the addition of Warm-Mix ACF 2G have mechanical characteristics similar to those produced using only virgin aggregates and new bitumen. Its presence allows to reduce the working temperatures of 20-40°C compared to those traditionally used and also ensures better workability of the mix and an excellent bitumen / inert adhesion. The percentage of product to be dosed can vary from 0.1% to 0.3% on the weight of the milled material used, depending on the working conditions and the type of milling.

ACF WARM-MIX® 40 → **Complex mixture of products registered to the REACH regulation**

It is a multifunctional additive, which allows to reuse high RAP percentages, in the order of 40/50%; with the use of this additive it is possible to implement both hot and warm recycling techniques, obtaining an asphalt mix with physical-mechanical characteristics similar to those of the asphalt mix produced by using aggregates and virgin bitumen, limiting the phenomenon of rutting. The additive makes it possible to: regenerate old bitumen, improve workability, improve adhesion inerts/bitumen and above all be able to spread and compact at temperatures lower than those traditionally used.

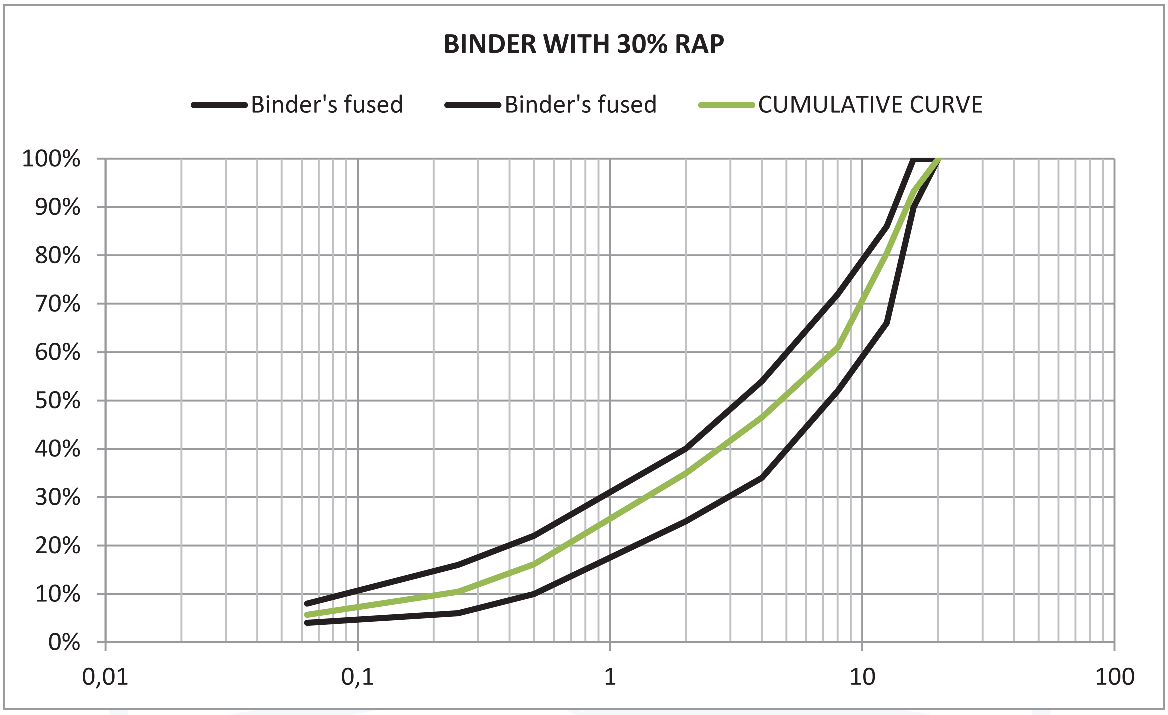
ACF WARM-MIX® 50 PLUS → **Complex mixture of products registered to the REACH regulation**

It is a multifunctional additive, which allows the reuse of high milling percentages, with the possibility of working with modified bitumen. The use of this additive guarantees the correct workability by implementing the warm mix recycling technique, obtaining a mixs with physical-mechanical characteristics similar to those of an asphalt produced using inerts and virgin bitumen, limiting the phenomenon of the rutting.

PHASE 1: REALIZATION OF ASPHALT MIX

Granulometric curves

BINDER ANAS spindle, made with 30% of 0-10 mm milling:



Preparation of mixtures

The mixtures, both the reference one (without addition of additives) and the one with the addition of the additive, consist of bituminous type B conglomerates packed with 50/70 bitumen (penetration: 55 dmm; R&B: 47°C).

The mixtures were packaged in the laboratory by means of a thermostatic mixer for bituminous conglomerates (Infratest), using a total percentage of binder of 4.5% by weight referred to the inerts (old + new bitumen). 30% rap were made, dosing the additive to 0.2 and 0.3% respectively on the weight of the milled product.

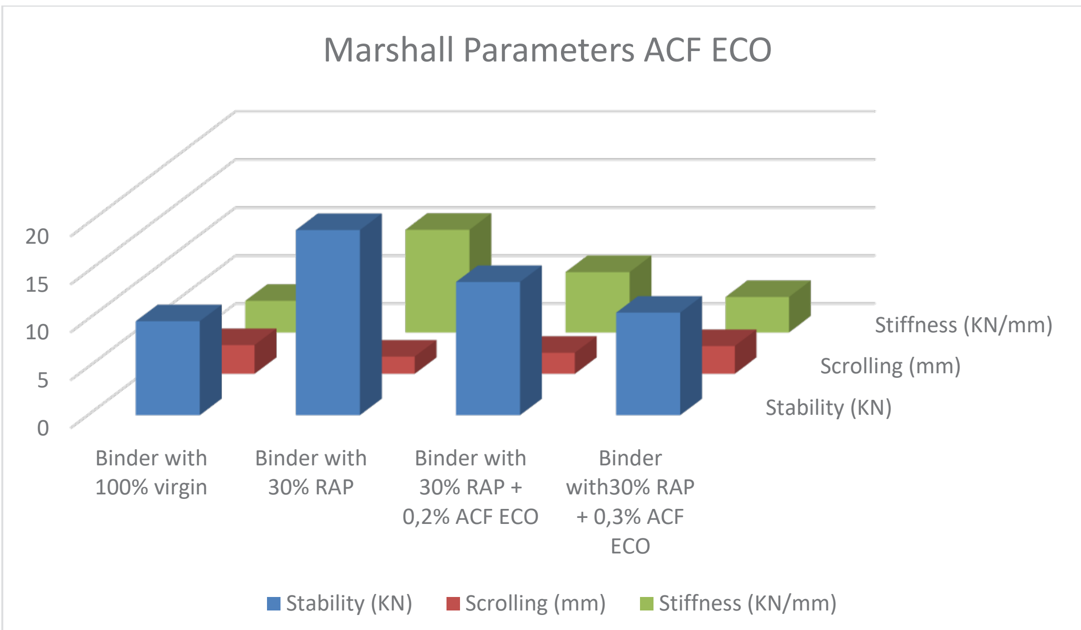
The mixing was performed at the temperature of 160°C.

Realization of the specimens and analysis of the results

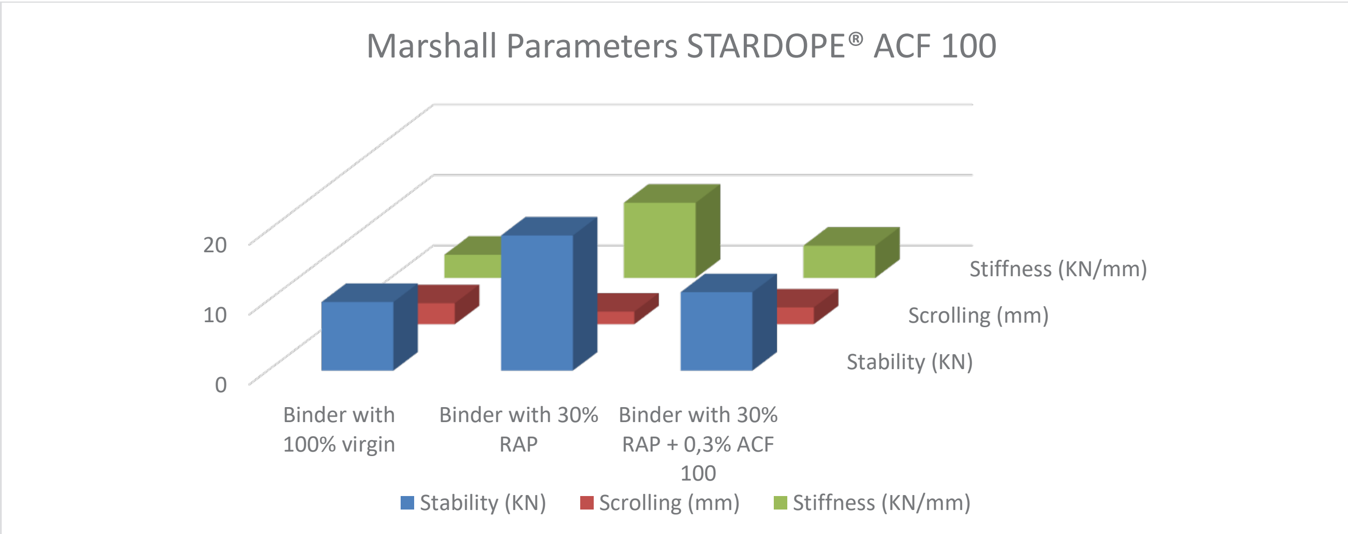
The specimens were packaged at a temperature of 150°C and compacted to the Marshall compactor to evaluate the mechanical properties of the mixtures.

ACF ECO e STARDOPE® ACF 100

- **Marshall Test**



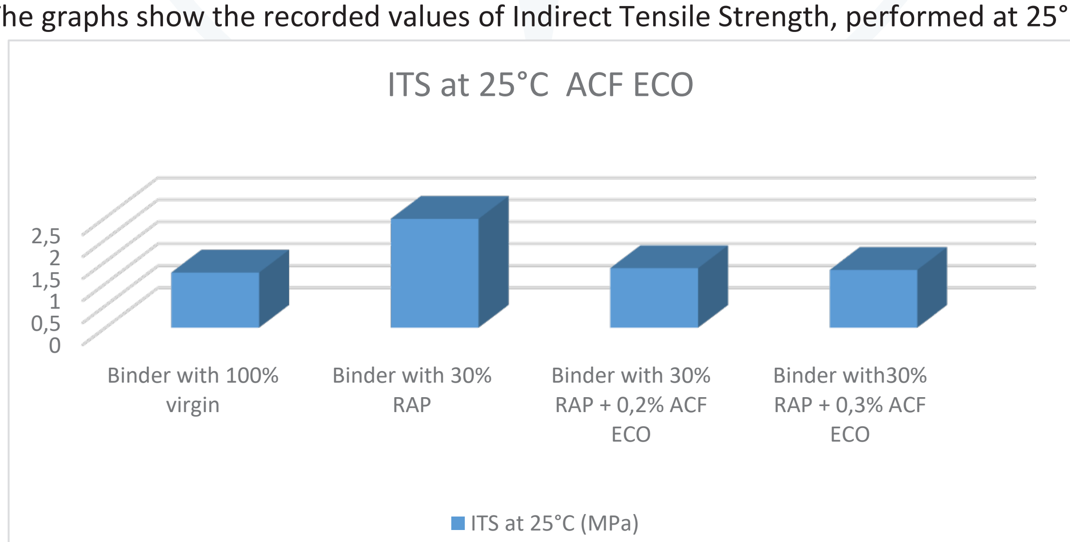
Asphalt Mix	*Stability (KN)*	*Scrolling (mm)*	*Stiffness (KN/mm)*
Binder with 100% Virgin	*9,8*	*3,0*	*3,3*
Binder with 30% RAP	*19,3*	*1,8*	*10,7*
Binder with 30%RAP + 0,2% ACF ECO	*13,9*	*2,2*	*6,3*
Binder with 30%RAP + 0,3% ACF ECO	*10,7*	*2,9*	*3,7*



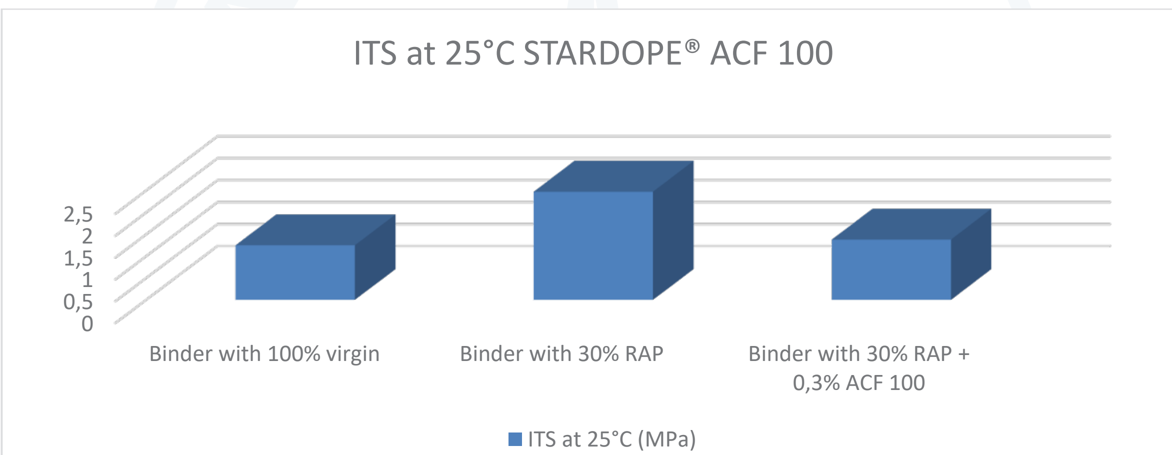
Asphalt Mix	*Stability (KN)*	*Scrolling (mm)*	*Stiffness (KN/mm)*
Binder with 100% Virgin	*9,8*	*3,0*	*3,3*
Binder with 30% RAP	*19,3*	*1,8*	*10,7*
Binder with 30%RAP + 0,3% STARDOPE® ACF 100	*11,1*	*2,5*	*4,4*

- **Indirect Tensile Strength**

The graphs show the recorded values of Indirect Tensile Strength, performed at 25°C.



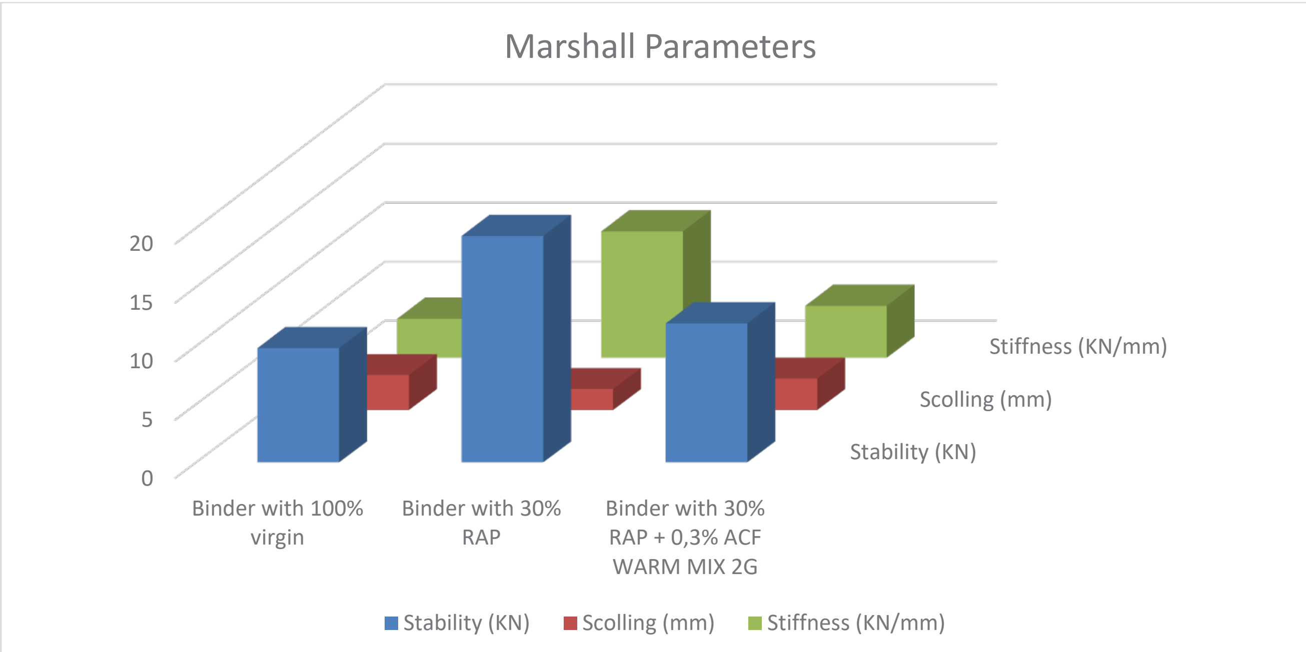
Asphalt Mix	ITS at 25°C (MPa)
Binder with 100% Virgin	*1,25*
Binder with 30% RAP	*2,47*
Binder with 30%RAP + 0,2% ACF ECO	*1,35*
Binder with 30%RAP + 0,3% ACF ECO	*1,31*
Reference ANAS	*0,7-1,4*



Asphalt Mix	ITS at 25°C (MPa)
Binder with 100% Virgin	*1,25*
Binder with 30% RAP	*2,47*
Binder with 30%RAP + 0,3% STARDOPE® ACF 100	*1,38*
Reference ANAS	*0,7-1,4*

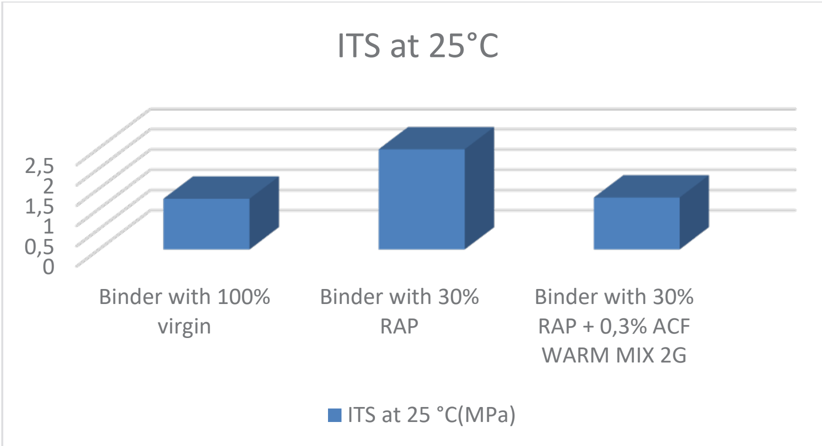
ACF WARM-MIX® 2G

- **Marshall Test**



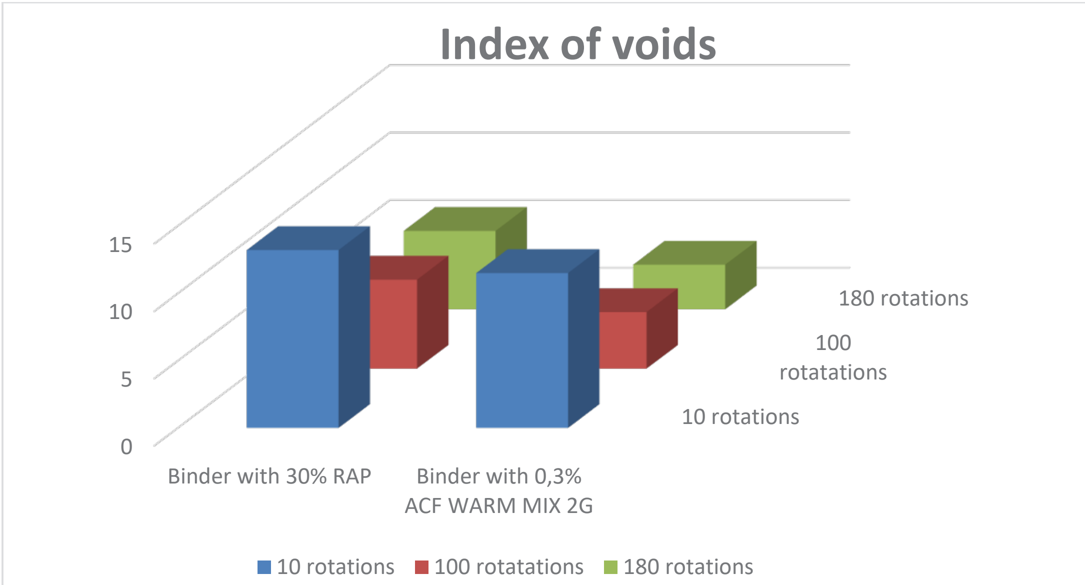
Asphalt Mix	*Stability (KN)*	*Scrolling (mm)*	*Stiffness (KN/mm)*
Binder with 100% Virgin	*9,8*	*3,0*	*3,3*
Binder with 30% RAP	*19,3*	*1,8*	*10,7*
Binder with 30% RAP + 0,3% ACF WARM MIX® 2G	11,9	2,7	4,4

• **Indirect Tensile Strength**



Asphalt Mix	*ITS at 25°C (MPa)*
Binder with 100% Virgin	*1,25*
Binder with 30% RAP	*2,47*
Binder with 30% RAP + 0,3% ACF WARM MIX® 2G	*1,28*
Reference ANAS	*0,7-1,4*

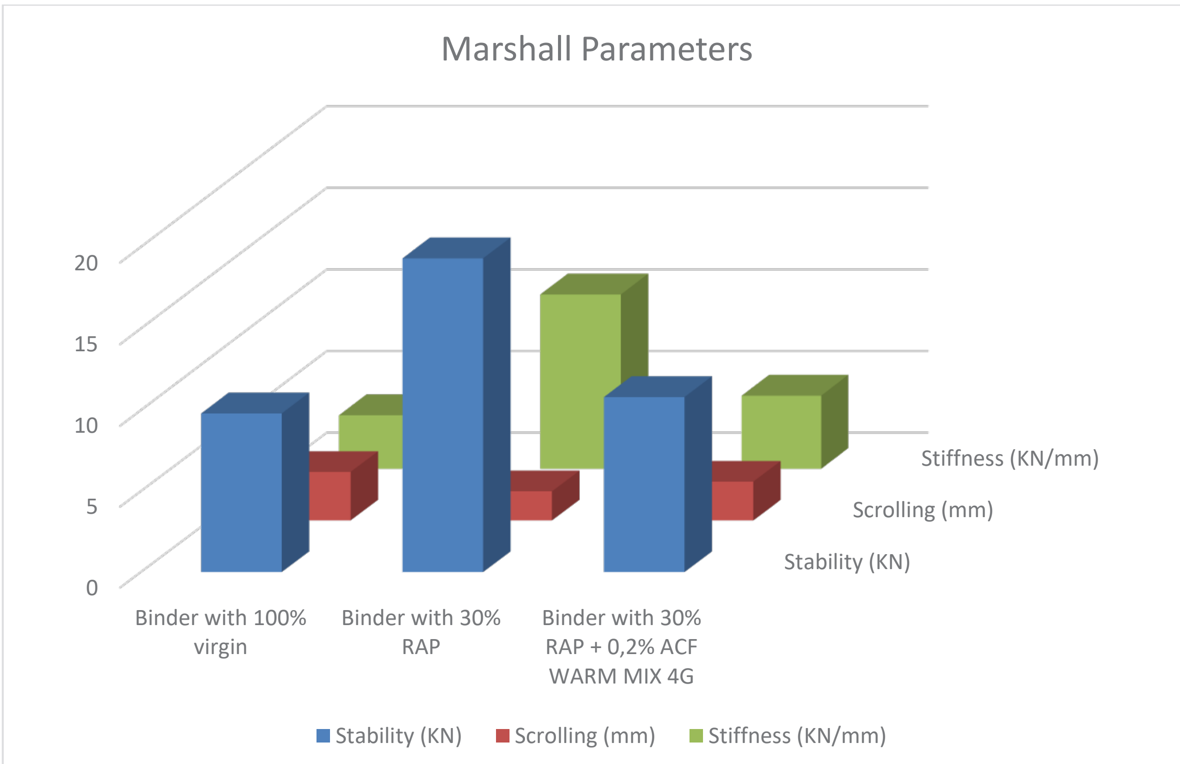
- **Index of voids**



Compaction at 120°C	*10 rotations*	*100 rotations*	*180 rotations*
Reference Results of asphalt mix 30% RAP	*13,2*	*6,6*	*5,8*
Results of asphalt mix ACF WARM MIX® 2G	*11,5*	*4,2*	*3,3*
Reference ANAS	*11-15*	*3-6*	*≥2*

ACF WARM-MIX® 4G

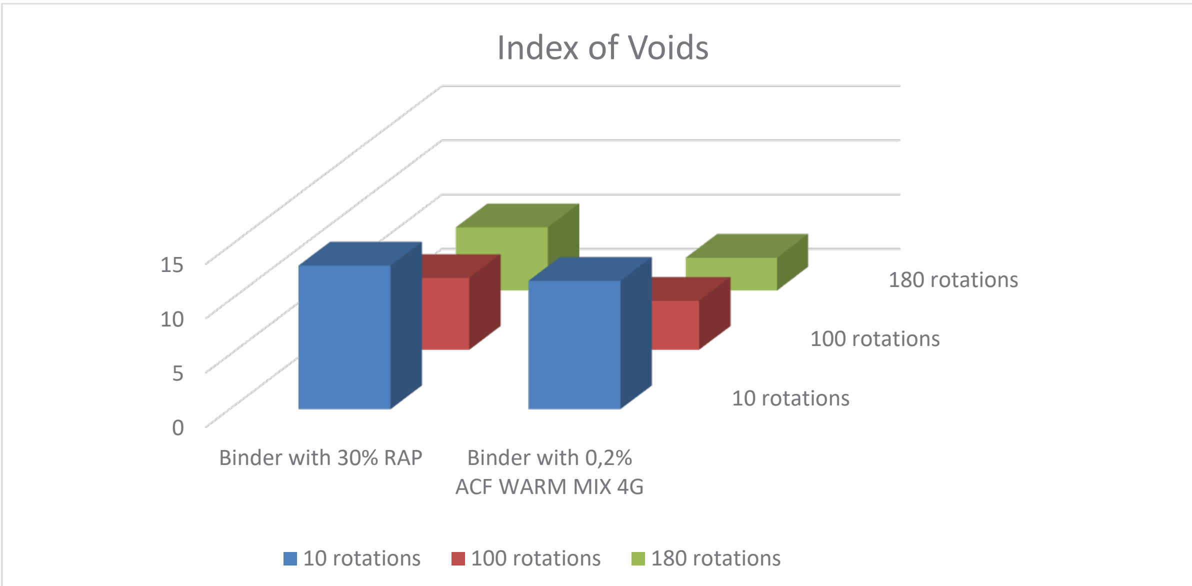
- **Marshall Test**



Asphalt Mix	*Stability (KN)*	*Scrolling (mm)*	*Stiffness (KN/mm)*
Binder with 100% Virgin	*9,8*	*3,0*	*3,3*
Binder with 30% RAP	*19,3*	*1,8*	*10,7*
Binder with 30% RAP + 0,2% ACF WARM MIX® 4G	*10,8*	*2,5*	*4,3*

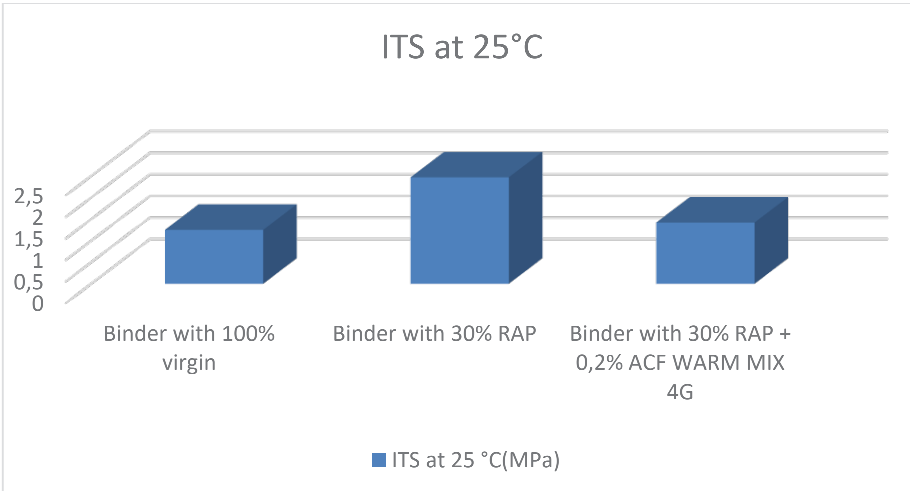
- **Index of voids**

The graph shows the values recorded on the specimens packaged at 120°C with rotary compactor.



Compaction at 120°C	*10 rotations*	*100 rotations*	*180 rotations*
Reference Results of asphalt mix 30% RAP	*13,2*	*6,6*	*5,8*
Results of asphalt mix ACF WARM MIX® 4G	*11,8*	*4,5*	*3,0*
Reference ANAS	*11-15*	*3-6*	*≥2*

- **Indirect Tensile Strength**



Asphalt Mix	*ITS a 25°C (MPa)*
Binder with 100% Virgin	*1,25*
Binder with 30% RAP	*2,47*
Binder with 30% RAP + 0,2% ACF WARM MIX® 4G	*1,32*
Reference ANAS	*0,7-1,4*

PHASE 2: BINDER QUALIFICATION

BITUMINOUS BINDER	PENETRATION (dmm)	SOFTENING (°C)
Bitumen 50/70	*68*	*51*
Bitumen Extract -Binder with 0% RAP	*50*	*60*
Bitumen Extract -Binder with 30% RAP	*44*	*63*
Bitumen Extract -Binder with 30% RAP + 0,2% ACF ECO	*52*	*61*
Bitumen Extract -Binder with 30% RAP + 0,3% ACF ECO	*59*	*55*

PHASE 3: CHARACTERISTICS OF ADDITIVE BINDERS

This type of study was conducted at the laboratories of the chemistry department of the University of Calabria, in order to verify the presence of the adhesion promoter and the thermo-stability. FT-IR analysis was carried out on non-additived bitumen samples, and samples were added with: STARDOPE®ACF 100, ACF WARM-MIX® 2G, ACF WARM-MIX® 4G and ACF WARM-MIX® 50 PLUS. From the comparison analysis it is possible to show how the spectra of the bitumen-additive mixture result from the overlapping of the spectra of the individual components, as shown in the following spectra. The thermal stability of the bitumen-additive system was also evaluated by keeping the sample additivated in a stove at T=180°C for 5 days, simulating the heat treatment at T=150°C for about 15 days. Spectral analysis on bitumen-additive mixtures showed a high stability, since the FT-IR spectra acquired after treatment at 180 ° C, do not show significant variations.

STARDOPE® ACF 100

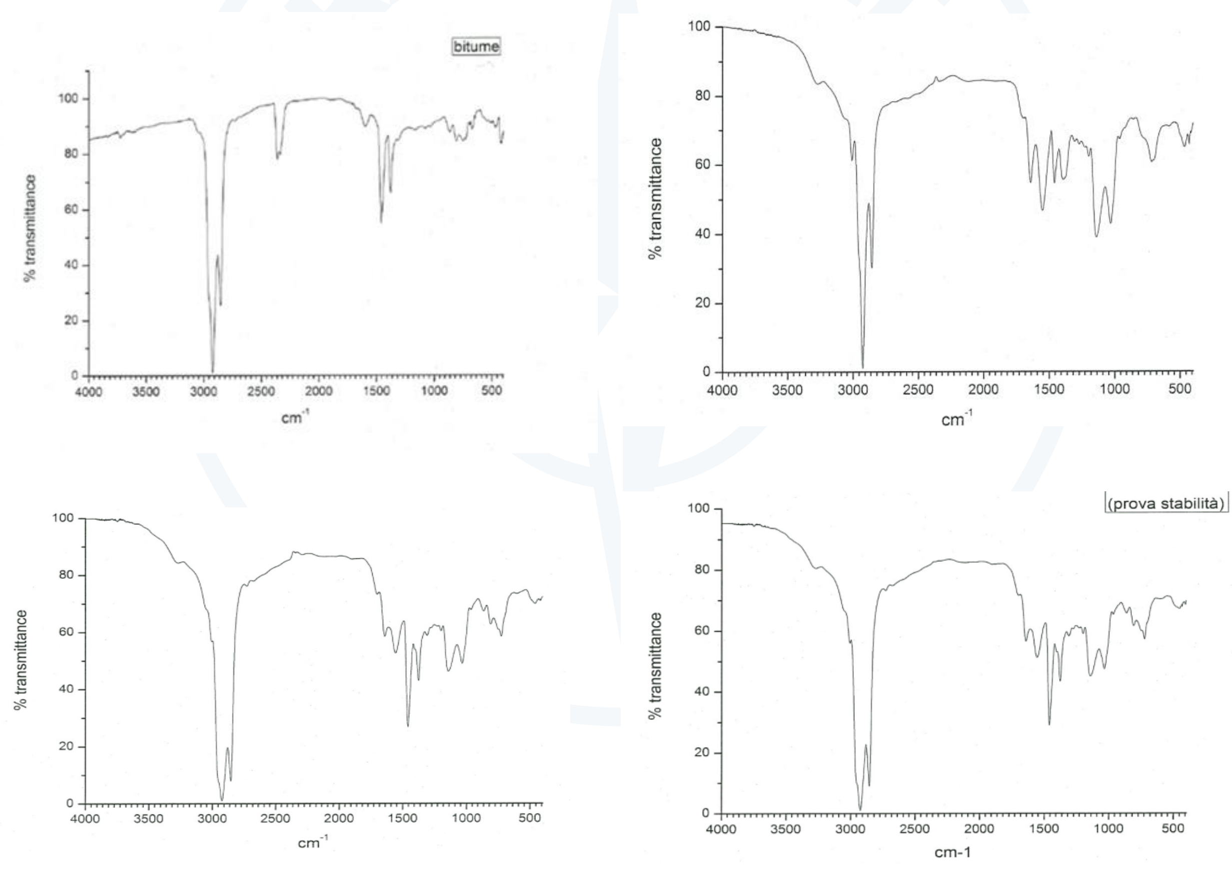


Figure 1. Infrared spectrum acquired in transmittance by Fourier Transform Infrared Spectrometer in the frequency range between 4000 and 400 cm^{-1}. In the upper left corner, the characteristic peaks of a sample of non-mixed bitumen, in the upper right corner of those with an added bitumen, on the left the overlap of the characteristic peaks of a sample of bitumen with the addition of the additive, at the bottom right the stability test at T=180°C at 5 days of the bitumen sample with the addition of the additive.

ACF WARM-MIX® 2G

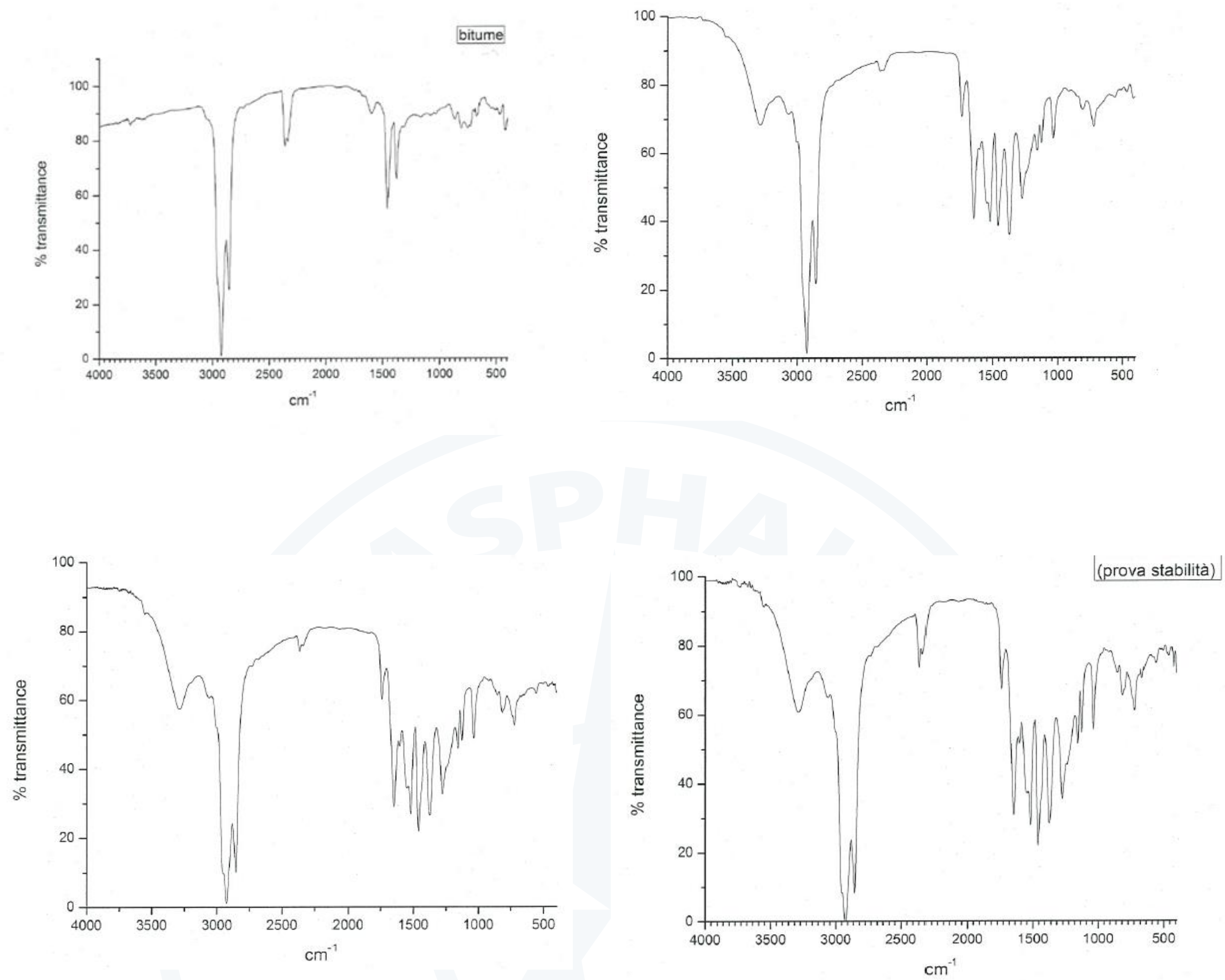


Figure 2. Infrared spectrum acquired in transmittance by Fourier Transform Infrared Spectrometer in the frequency range between 4000 and 400 cm^{-1}. In the upper left corner, the characteristic peaks of a sample of non-mixed bitumen, in the upper right corner of those with an added bitumen, on the left the overlap of the characteristic peaks of a sample of bitumen with the addition of the additive, at the bottom right the stability test at T=180°C at 5 days of the bitumen sample with the addition of the additive.

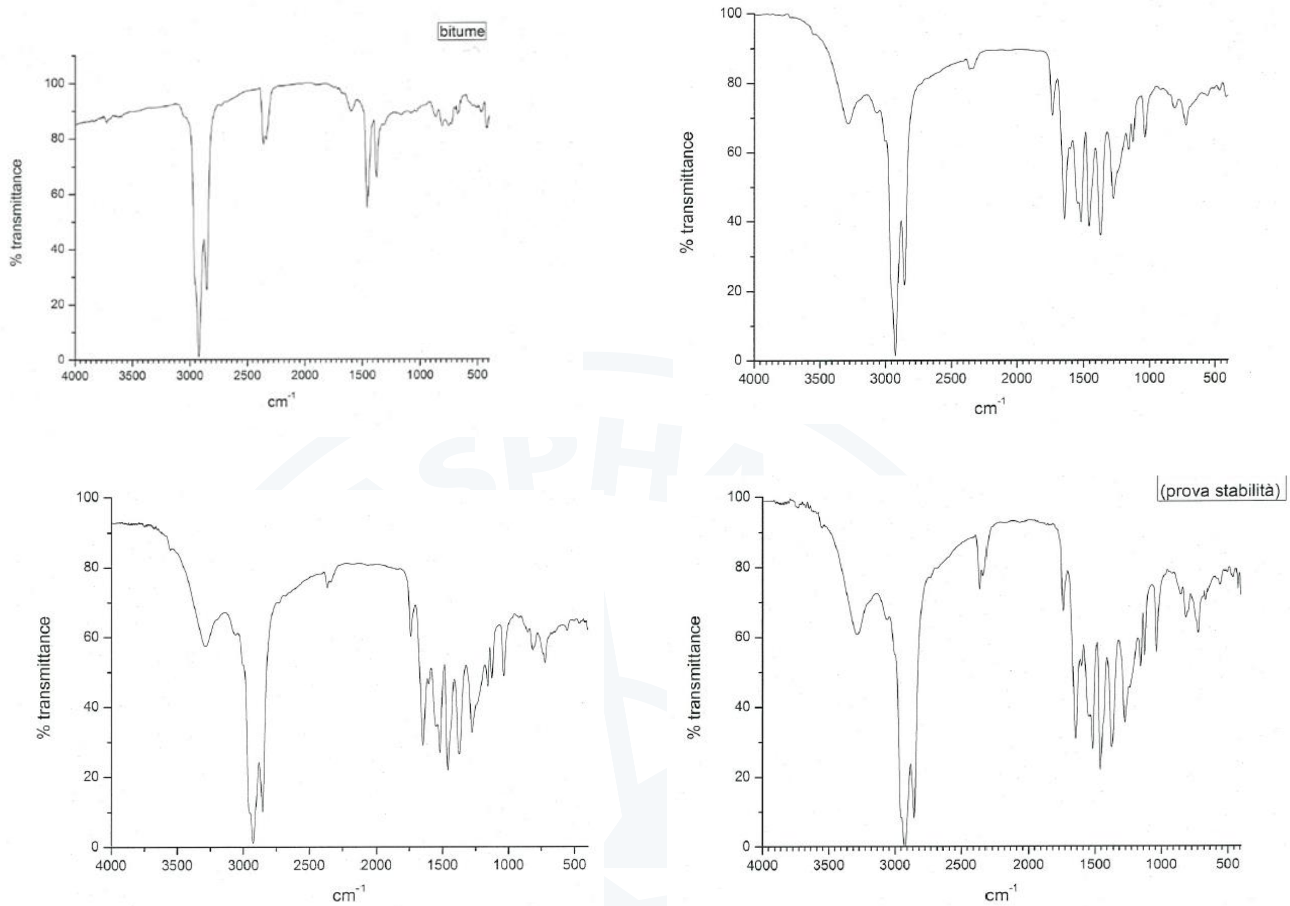


Figure 3. Infrared spectrum acquired in transmittance by Fourier Transform Infrared Spectrometer in the frequency range between 4000 and 400 cm^{-1}. In the upper left corner, the characteristic peaks of a sample of non-mixed bitumen, in the upper right corner of those with an added bitumen, on the left the overlap of the characteristic peaks of a sample of bitumen with the addition of the additive, at the bottom right the stability test at T=180°C at 5 days of the bitumen sample with the addition of the additive.

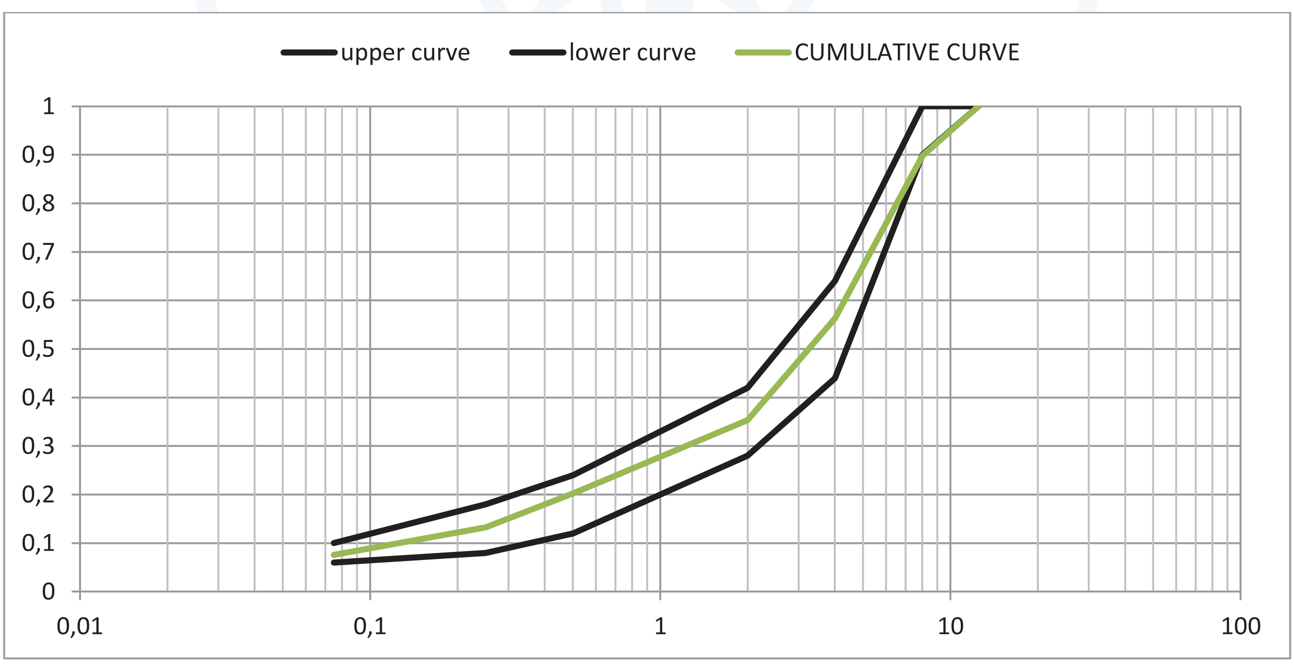
RE-USE OF HIGH RAP PERCENTAGES

ACF WARM-MIX® 40

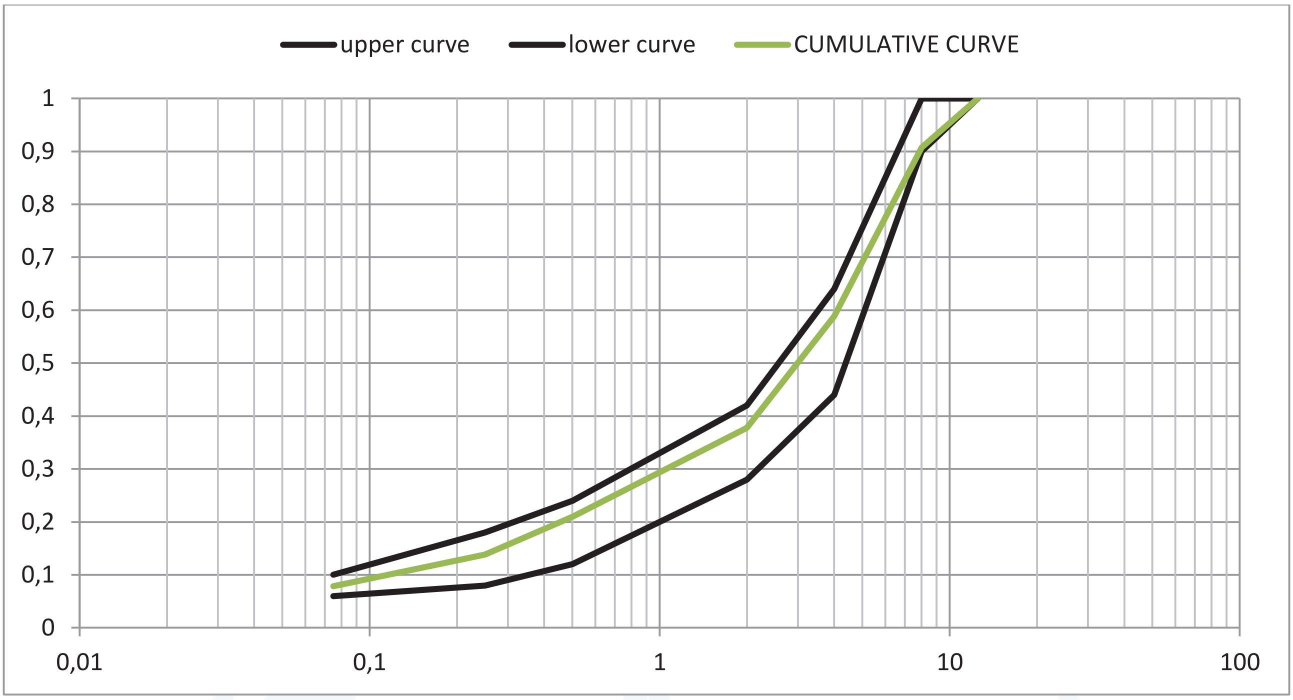
The study was carried out by evaluating the mechanical and volumetric properties of bituminous mixtures made using 40 and 50% RAP, and an ANAS type B wear reference spindle. Moreover, the binder was rheologically characterized in order to evaluate its properties, and to avoid any problems related to the resistance of the same.

Granulometric curve

Wear-resistant ANAS B-type, made with 40% of 0-10 mm RAP:



Wear-resistant ANAS B-type, made with 50% of 0-10 mm RAP:



Preparation of mixtures

The mixtures, both the reference one (without addition of additives) and the one with the addition of the additive, consist of bituminous type B conglomerates packed with 50/70 bitumen (penetration: 55 dmm; R&B: 47°C).

The mixtures were packaged in the laboratory by means of a thermostatic mixer for bituminous mixtures (Infratest), using a total percentage of 5% by weight binder referred to inerts (old + new bitumen). 40% and 50% milled bituminous conglomerates were made, dosing the additive ACF WARM-MIX® 40 to 0.37% and 0.41% respectively on the weight of the milled material.

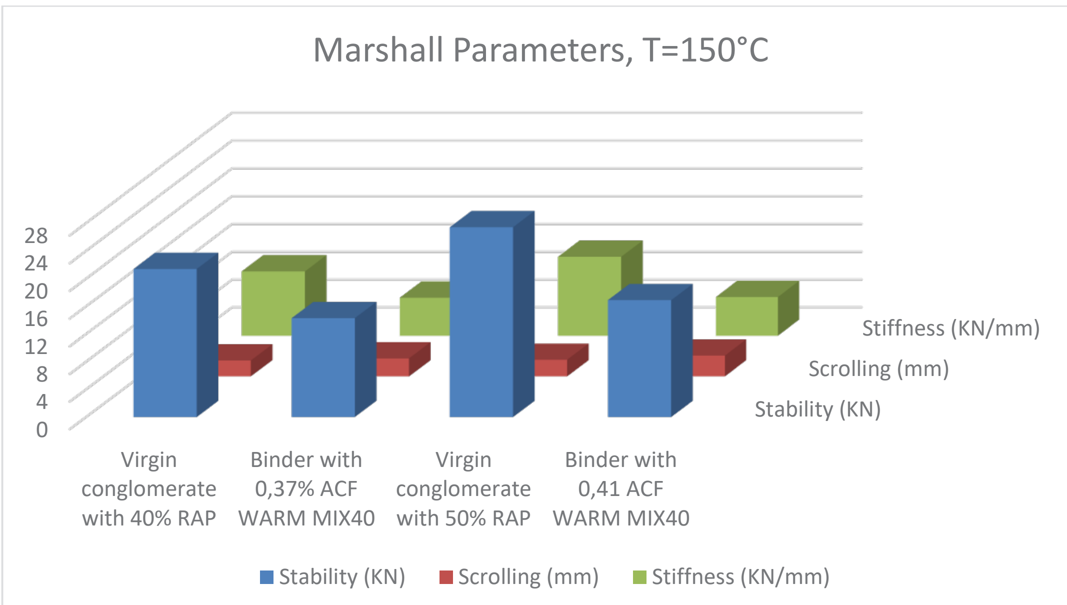
The mixing was performed at the temperature of 160°C.

Realization of the specimens and analysis of the results

The specimens were packaged respectively at the temperature of 150 and 110°C, compacted to the Marshall compactor to evaluate the mechanical properties of the mixtures, and at 10, 100, 180 rotations to the rotary compactor, to evaluate the volumetric properties.

- **Marshall Test**

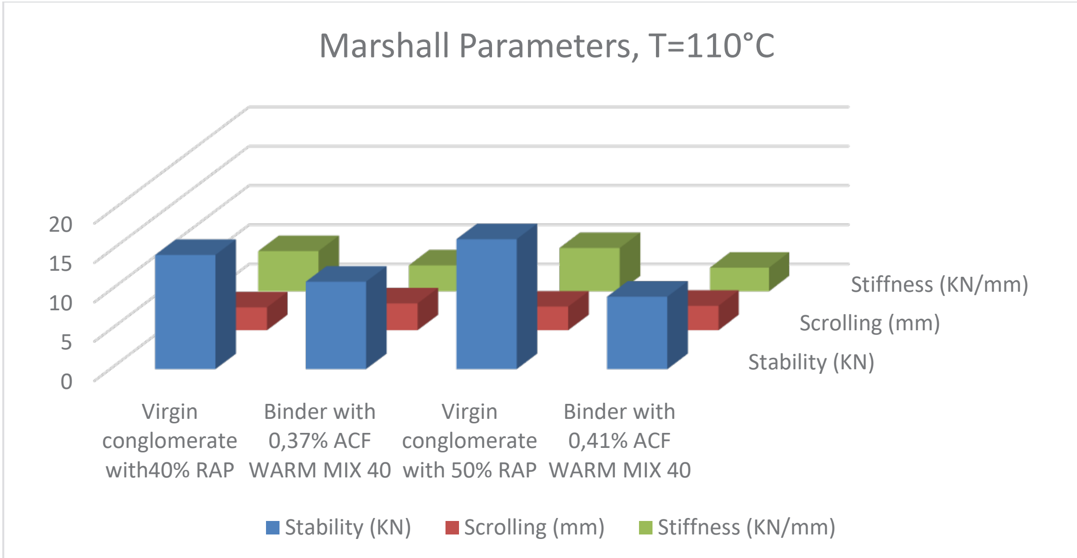
The graph shows the values recorded on specimens packed with Marshall compactor at 150°C.



Compaction at T=150°C	*Stability (KN)*	*Scrolling (mm)*	*Stiffness (KN/mm)*
Reference Results of asphalt mix 50% RAP	*27,4*	*2,4*	*11,4*
Results of asphalt mix ACF WARM MIX® 40	*16,9*	*3,0*	*5,6*

Compaction at T=150°C	*Stability (KN)*	*Scrolling (mm)*	*Stiffness (KN/mm)*
Reference Results of asphalt mix 40% RAP	*21,4*	*2,3*	*9,3*
Results of asphalt mix ACF WARM MIX 40	*14,3*	*2,6*	*5,5*

The graph shows the values recorded on specimens packed with Marshall compactor at T=110°C.

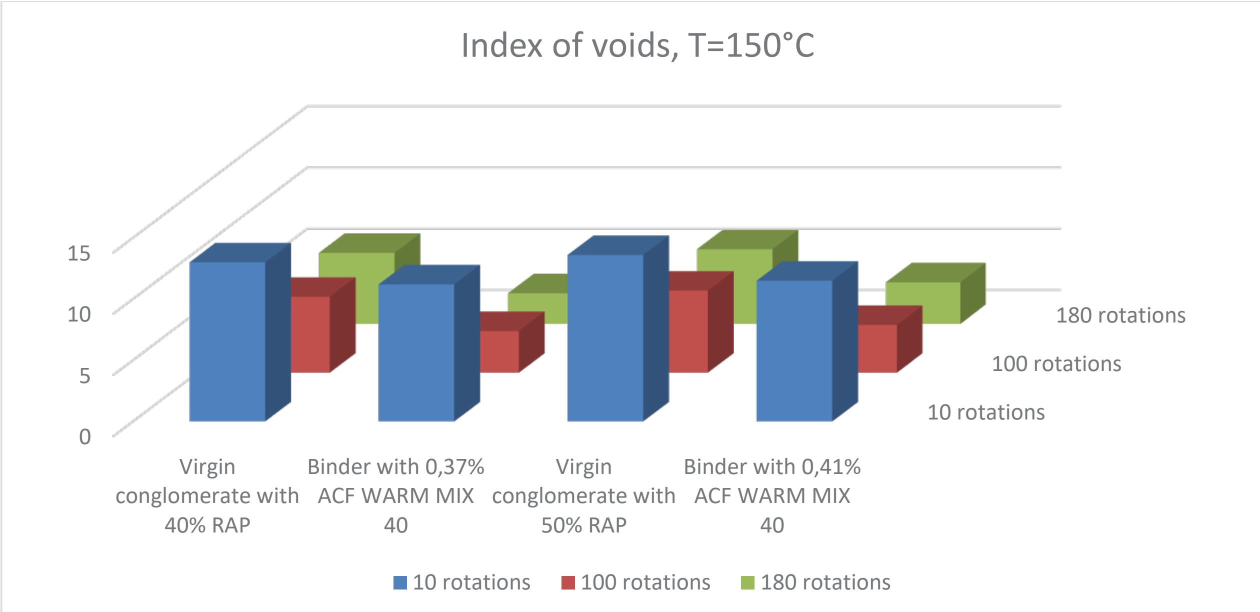


Compaction at T= 110°C	*Stability (KN)*	*Scrolling (mm)*	*Stiffness (KN/mm)*
Reference Results of asphalt mix 50% RAP	*16,5*	*3,0*	*5,5*
Results of asphalt mix ACF WARM MIX® 40	*9,2*	*3,1*	*3,0*

Compaction at T= 110°C	*Stability (KN)*	*Scrolling (mm)*	*Stiffness (KN/mm)*
Reference Results of asphalt mix 40% RAP	*14,5*	*2,9*	*5,1*
Results of asphalt mix ACF WARM MIX® 40	*11,1*	*3,4*	*3,3*

- **Index of voids**

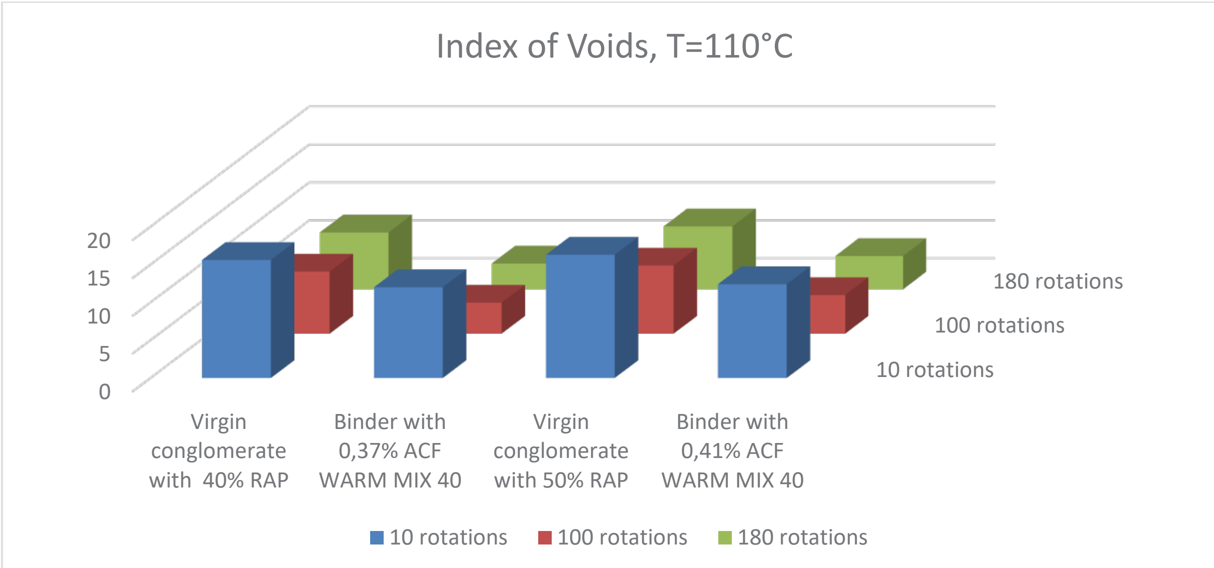
The graph shows the values recorded on specimens packaged at T=150°C with rotary compactor.



Compaction at T=150°C	*Voids at 10 rotations (%)*	*Voids at 100 rotations (%)*	*Voids at 180 rotations (%)*
Reference Results of asphalt mix 50% RAP	*13,6*	*6,7*	*6,1*
Results of asphalt mix ACF WARM MIX® 40	*11,5*	*3,9*	*3,4*
Reference ANAS	*11-15*	*3-6*	*≥2*

Compaction at T=150°C	*Voids at 10 rotations (%)*	*Voids at 100 rotations (%)*	*Voids at 180 rotations (%)*
Reference Results of asphalt mix 40% RAP	*13,0*	*6,2*	*5,8*
Results of asphalt mix ACF WARM MIX® 40	*11,2*	*3,4*	*2,5*
Reference ANAS	*11-15*	*3-6*	*≥2*

The graph shows the values recorded on specimens packaged at T=110°C with rotary compactor.

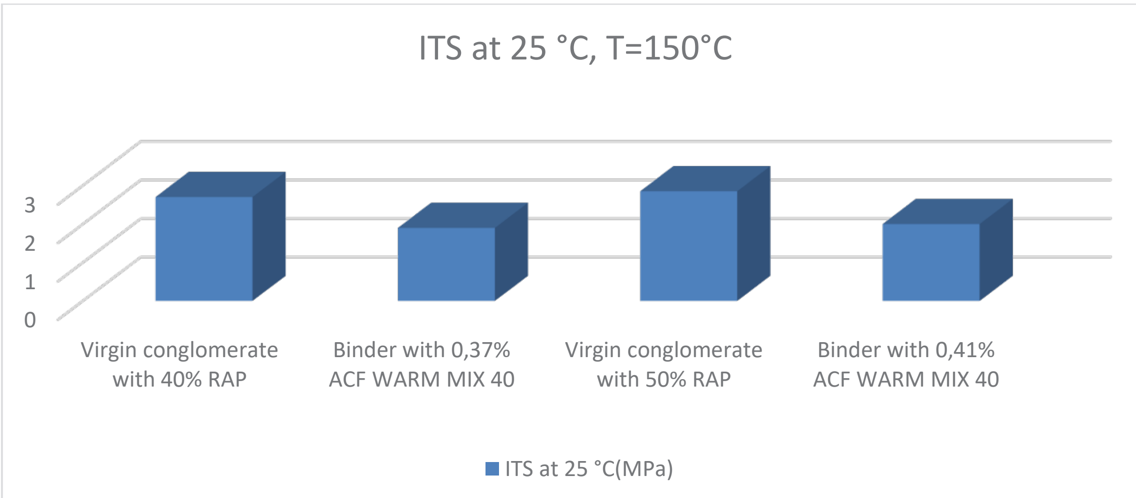


Compaction at T=110°C	*Voids at 10 rotations (%)*	*Voids at 100 rotations (%)*	*Voids at 180 rotations (%)*
Reference Results of asphalt mix 40% RAP	*16,3*	*9,0*	*8,3*
Results of asphalt mix ACF WARM MIX® 40	*12,4*	*5,1*	*4,4*
Reference ANAS	*11-15*	*3-6*	*≥2*

Compaction at T=110°C	*Voids at 10 rotations (%)*	*Voids at 100 rotations (%)*	*Voids at 180 rotations (%)*
Reference Results of asphalt mix 40% RAP	*15,6*	*8,2*	*7,5*
Results of asphalt mix ACF WARM MIX® 40	*12,0*	*4,1*	*3,4*
Reference ANAS	*11-15*	*3-6*	*≥2*

- **Indirect Tensile Strength**

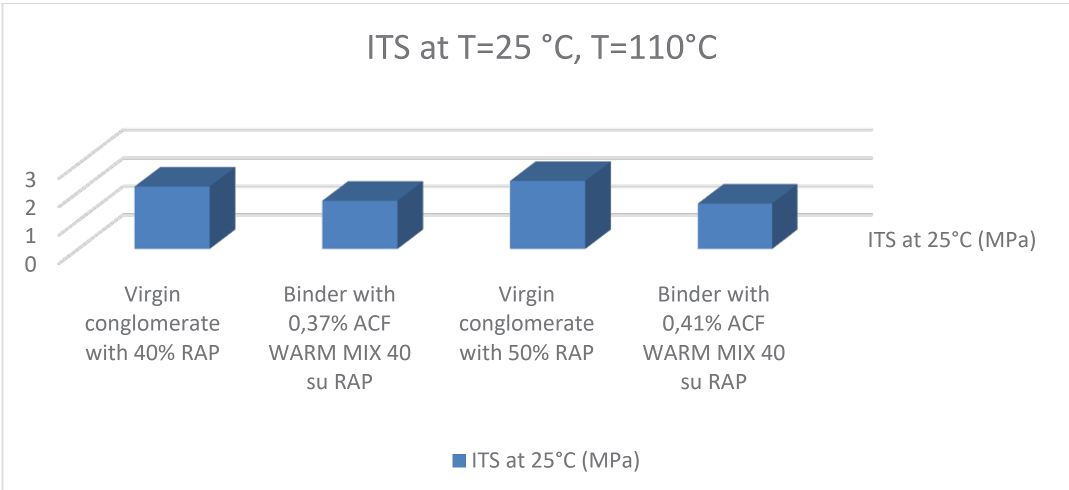
The graph shows the recorded values of Indirect Tensile Strength, of specimens packaged at T=150°C.



Compaction at T=150°C	*ITS (MPa)*
Reference Results of asphalt mix 50% RAP	*2,9*
Results of asphalt mix ACF WARM MIX® 40	*2,0*

Compaction at T=150°C	*ITS (MPa)*
Reference Results of asphalt mix 40% RAP	*2,7*
Results of asphalt mix ACF WARM MIX® 40	*1,9*

The graph shows the recorded values of Indirect Tensile Strength, of the specimens packaged at T=110°C.



Compaction at T=110°C	*ITS (MPa)*
Reference Results of asphalt mix 50% RAP	*2,4*
Results of asphalt mix ACF WARM MIX® 40	*1,6*

Compaction at T=110°C	*ITS (MPa)*
Reference Results of asphalt mix 40% RAP	*2,2*
Results of asphalt mix ACF WARM MIX® 40	*1,7*

Preparation of the binder mixture.

In order to carry out the tests on the binder, a 50% mixture composed of 50/70 type asphalt (Penetration: 55 dmm; R&B: 47°C), the same used for the realization of bituminous conglomerates, and for 50% oxidized bitumen. The corresponding amount of ACF WARM-MIX® 40 has been added to this mixture, which is equal to 3.5% of the weight of the total binder. The binder was tested with DSR technique in simulation of: pre-mixing, post-mixing and spreading (after aging RTFO) and finally after long-term aging (PAV). On the other hand, the same procedure was applied to the "virgin" bitumen, previously mentioned.

The initial viscosity of the binders was also evaluated with a Brookfieeld viscometer.

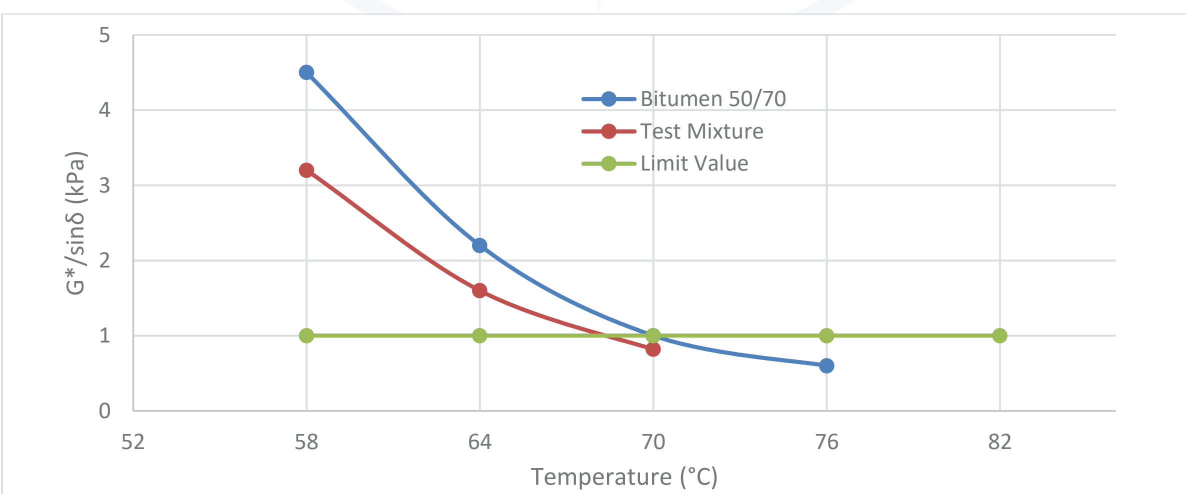
Principles of the DSR method

This method makes it possible to evaluate the resistance of the binder to the striking and cracking; in particular, the standard specifies the limits within which the binder maintains its optimal characteristics. In particular, the test simulates the action exerted by vehicular traffic at a speed of 90-100 Km/h. The tests were carried out on two bituminous mixtures: a reference mixture, virgin bitumen of the 50/70 type and a test mixture, composed of 50% of virgin type 50/70 bitumen and 50% of bitumen of the type 50/70 oxidized, with the addition of 3.5% by weight (referred to the mixture) of the polyfunctional additive called ACF WARM-MIX® 40.

- **Analysis of the results**

Pre-mixing binder

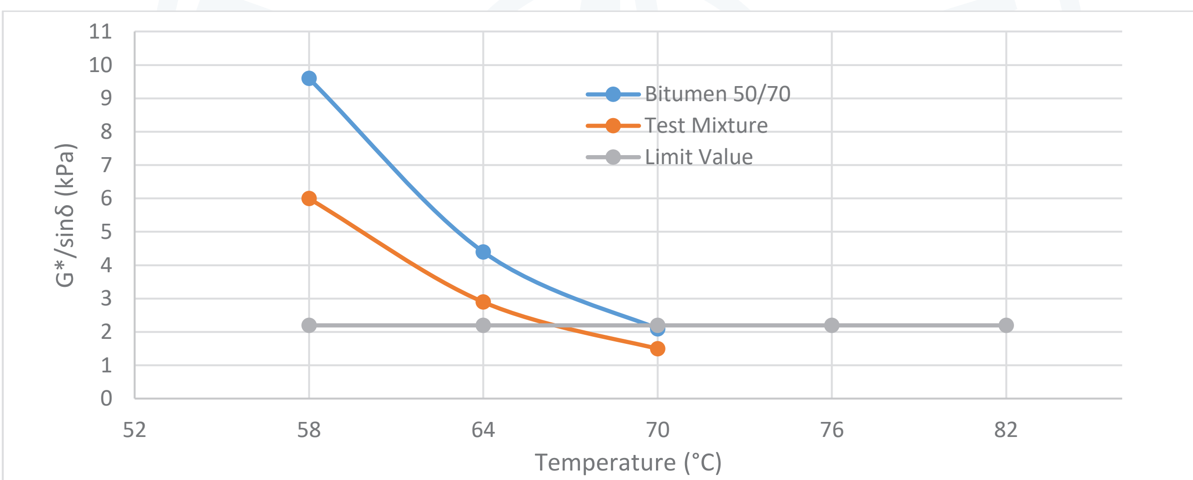
To qualify a "virgin" bitumen, the SHRP system imposes the control of the viscoelastic parameter G*/sinδ; the value of this parameter must not be less than 1 kPa.



	Bitumen 50/70	Testing mixtures
G/sinδ 58°C (KPa)*	*4,5*	*3,2*
G/sinδ 64°C(KPa)*	*2,2*	*1,6*
G/sinδ 70°C (KPa)*	*1,0*	*0,82*
G/sinδ 76°C (KPa)*	*0,6*	*-*

- **Post-mixing and spreading binder (RTFO aging)**

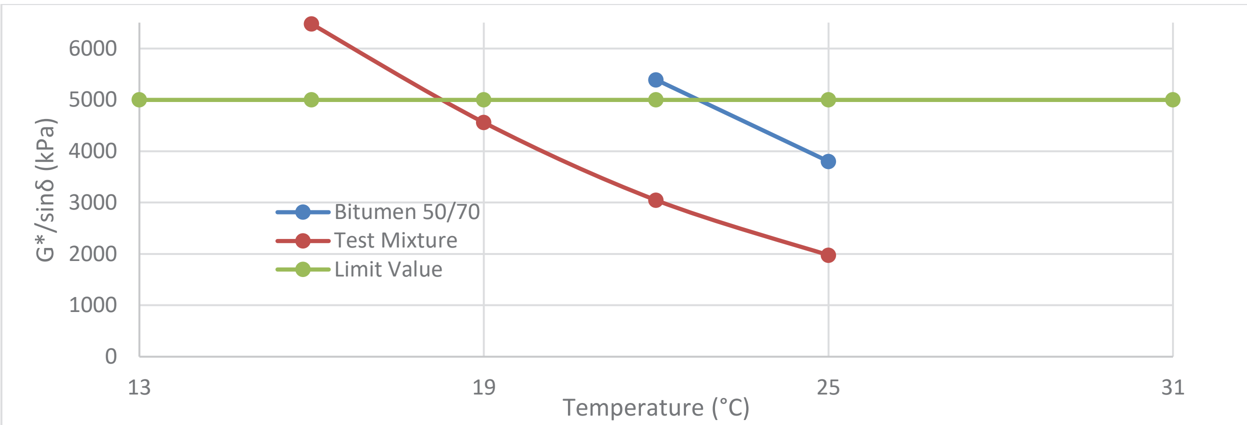
To qualify a bitumen in terms of rotting, after post mixing and spreading, the SHRP system imposes the control of the viscoelastic parameter G*/sinδ, which as a result of the packaging and spreading process (aging RTFO) must not be less than 2.2 kPa.



	Bitumen 50/70	Testing mixtures
G/sinδ 58°C (KPa)*	*9,6*	*6,0*
G/sinδ 64°C (KPa)*	*4,4*	*2,9*
G/sinδ 70°C (KPa)*	*2,1*	*1,5*

• **Long-term evaluation (after PAV)**

To qualify a bitumen in terms of fatigue (cracking), or to simulate the stress conditions that the flooring undergoes in the long term, the binders have been subjected to PAV aging. The SHRP system imposes the control of the viscoelastic parameter G*·sinδ, in order to evaluate the progress of the life process of the pavement from 5 to 10 years, which must be less than 5000 kPa.



	Bitumen 50/70	*Testing mixture*
G·sinδ 25°C (kPa)*	*3808*	*1975*
G·sinδ 22°C (kPa)*	*5390*	*3045*
G·sinδ 19°C (kPa)*		*4558*
G·sinδ 16°C (kPa)*		*6477*

- **Binder viscosity T=60°C**

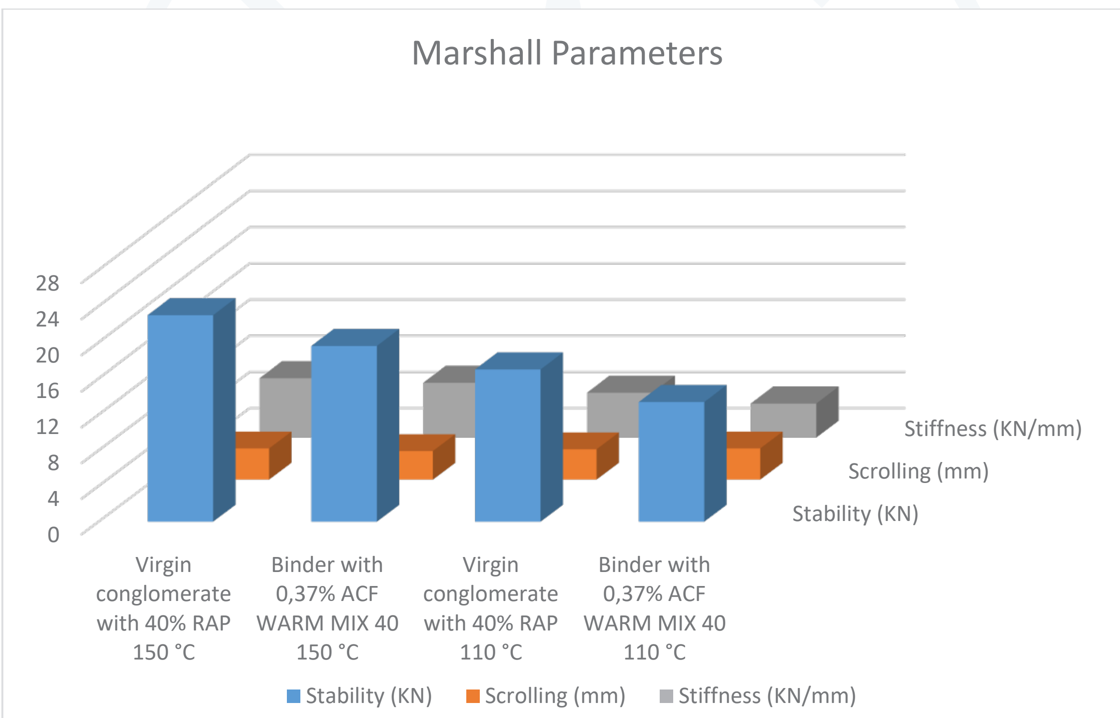
	Bitumen 50/70	*Testing mixture*
Viscosity in Pa·s	*205*	*270*
Value for bitumen 50/70 Pa·s	*≥ 145*	
Value for bitumen 35/50 Pa·s	*≥ 225*	

Mixture with modified bitumen

An additional study was carried out on an ANAS type B wear mat using as binder a modified bitumen with SBS (hard modification) (Penetration: 42 dmm; R&B: 78°C) in the percentage of 5% by weight referred to aggregates (old + new bitumen), 40% RAP with 0-10 mm granulometry and ACF WARM-MIX® 40 in the percentage of 0.37% on the weight of the milled product added to the mixture. The mixing was carried out again at the temperature of 160°C, the specimens were packaged respectively at the temperature of 150 and 110°C, compacted to the Marshall compactor to evaluate the mechanical properties of the mixtures, and at 10, 140, 230 rotations to the rotary compactor , to evaluate the volumetric properties.

- **Marshall Test**

The graph shows the values recorded on specimens packed with Marshall compactor at T=150 and 110°C.

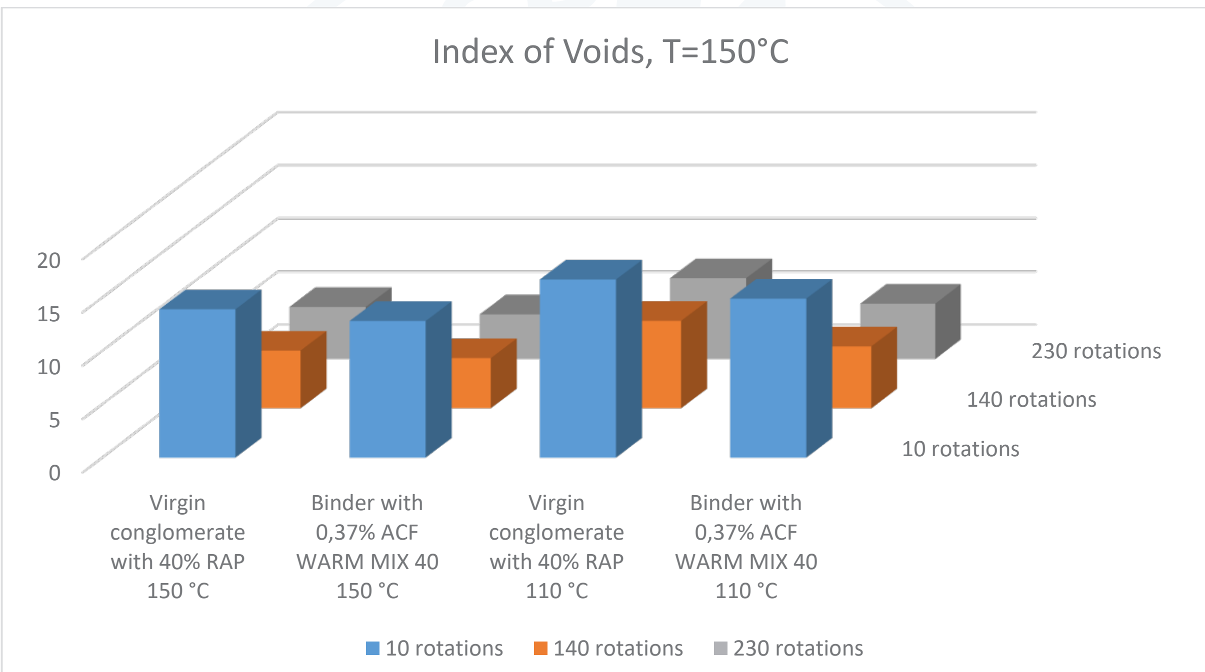


Compaction at T=150°C	*Stability (KN)*	*Scrolling (mm)*	*Stiffness (KN/mm)*
Reference Results of asphalt mix 40% RAP	*23,0*	*3,5*	*6,6*
Results of asphalt mix ACF WARM MIX® 40	*19,6*	*3,2*	*6,1*

Compaction at T=110°C	Stability (KN)	Scrolling (mm)	Stiffness (KN/mm)
Reference Results of asphalt mix 40% RAP	*17,0*	*3,4*	*5,0*
Results of asphalt mix ACF WARM MIX® 40	*13,4*	*3,5*	*3,8*

- **Index of voids**

The graph shows the values recorded on specimens packed at T=150 and 110°C with rotary compactor.

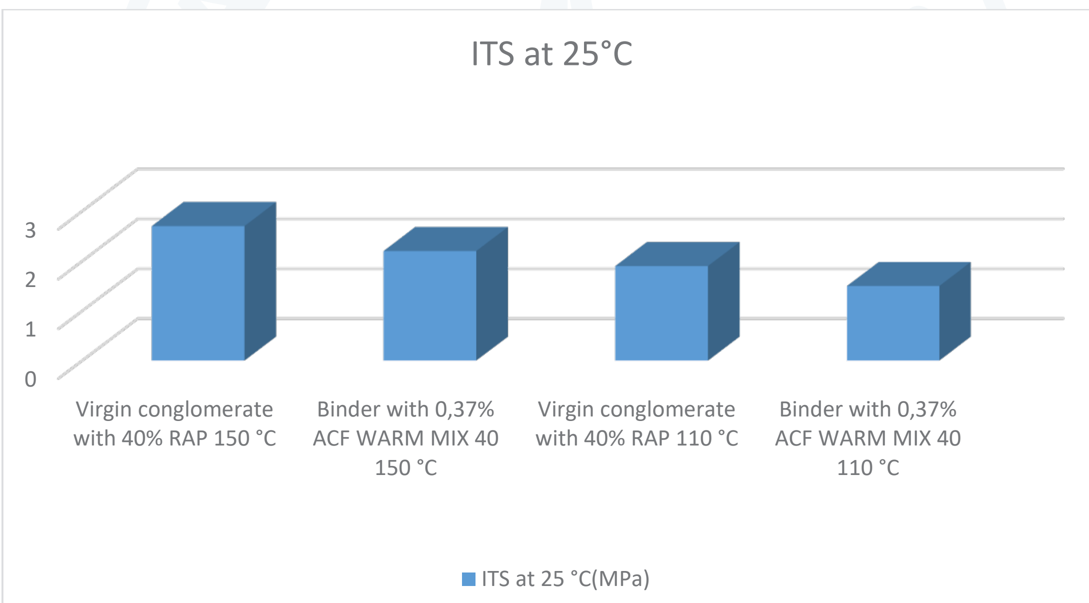


Compaction at T=150°C	Voids at 10 rotations (%)	Voids at 140 rotations (%)	Voids at 230 rotations (%)
Reference Results of asphalt mix 40% RAP	*13,9*	*5,4*	*4,9*
Results of asphalt mix ACF WARM MIX® 40	*12,8*	*4,7*	*4,2*
Reference ANAS	*11-15*	*3-6*	*≥2*

Compaction at T=110°C	*Voids at 10 rotations (%)*	*Voids at 140 rotations (%)*	*Voids at 230 rotations (%)*
Reference Results of asphalt mix 40% RAP	*16,7*	*8,2*	*7,6*
Results of asphalt mix ACF WARM MIX 40	*14,9*	*5,8*	*5,2*
Reference ANAS	*11-15*	*3-6*	*≥2*

- **Indirect Tensile Strength**

The graph shows the recorded values of indirect tensile strength, of specimens packaged at T=150 and 110°C.



Compaction at T=150°C	*ITS (MPa)*
Reference Results of asphalt mix 40% RAP	*2,7*
Results of asphalt mix ACF WARM MIX® 40	*2,2*
Reference ANAS	*0,95-1,7*

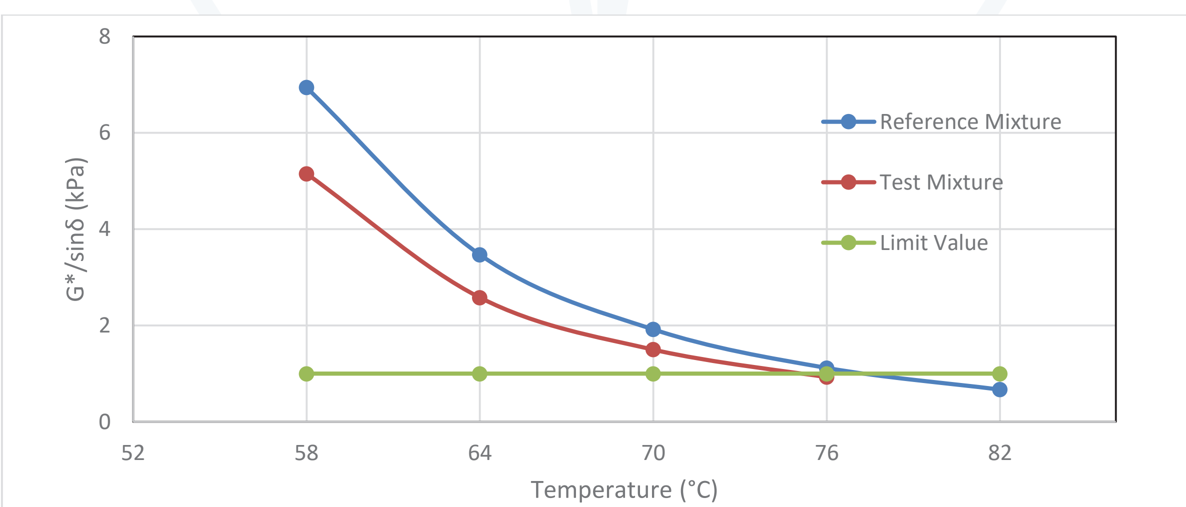
Compaction at T=110°C	ITS(MPa)
Reference Results of asphalt mix 40% RAP	1,9
Results of asphalt mix ACF WARM MIX® 40	1,5
Reference ANAS	0,95-1,7

Preparation of the binder mixture

The tests were carried out on two bituminous mixtures: a reference mixture, 60% composed of bitumen modified with SBS (hard modification) and 40% of bitumen of the 50/70 virgin type, and a test mixture, composed of 60% from modified bitumen with SBS (hard modification) and from 40% from oxidized type 50/70 bitumen, with the addition of 3% by weight (referred to the mixture) of the polyfunctional additive called ACF WARM-MIX® 40 The binder was tested with DSR technique in pre-mixing simulation, post mixing and spreading (after RTFO aging) and, finally, after long-term aging (PAV).

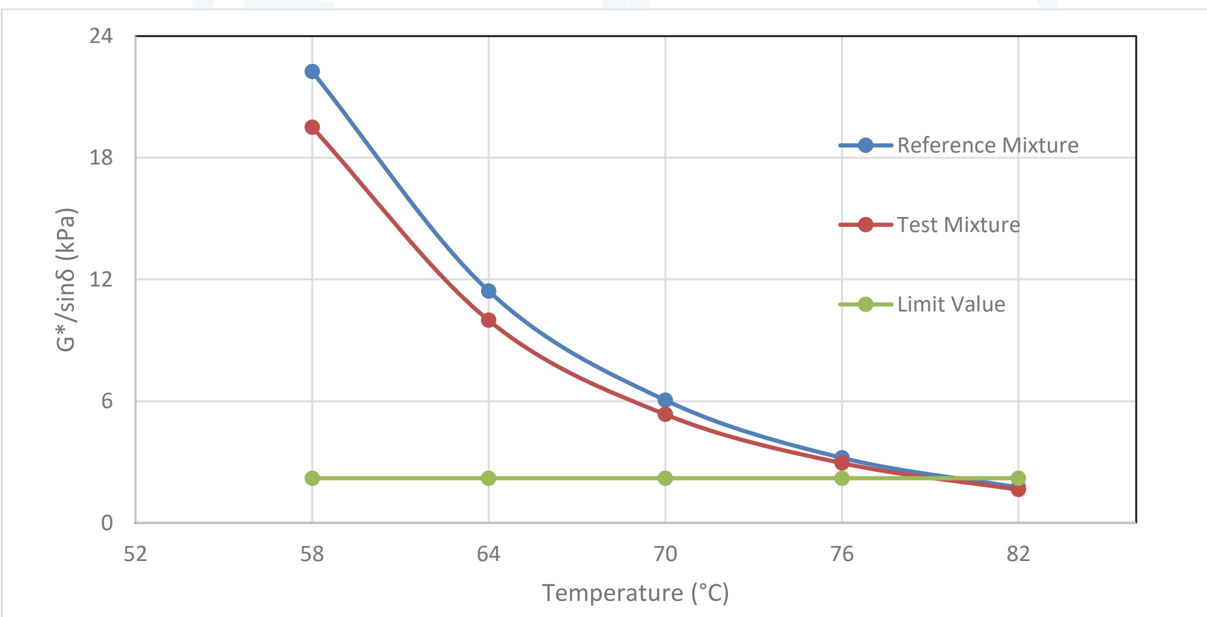
Analysis of the results

- **Pre-mixing binder**



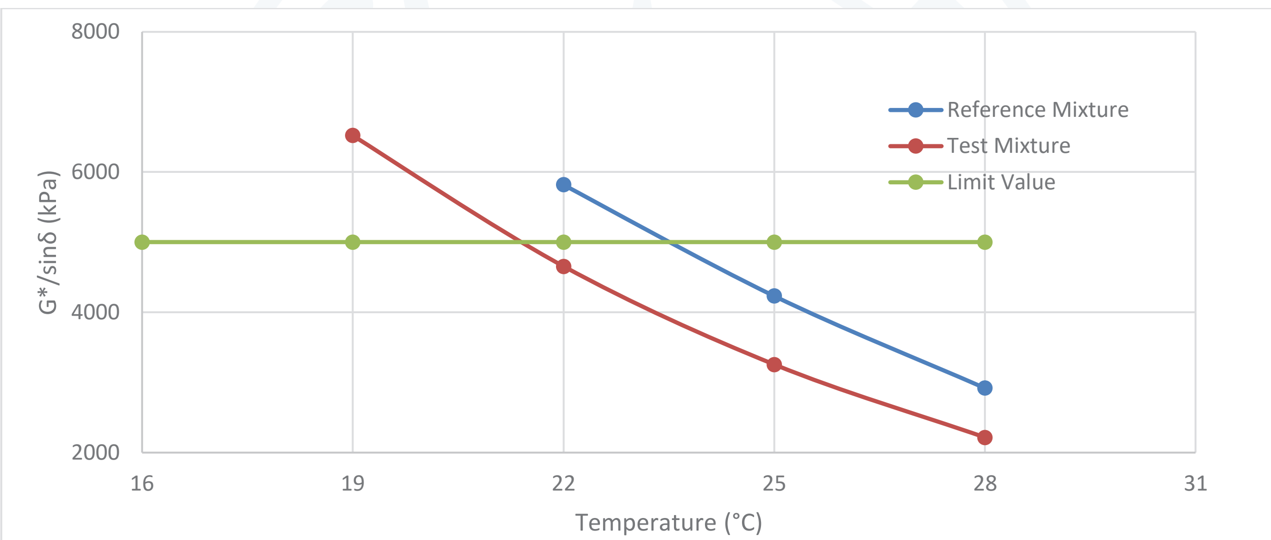
	Reference mixtures	*Testing mixtures*
G/sinδ 58°C (KPa)*	*6,94*	*5,15*
G/sinδ 64°C(KPa)*	*3,47*	*2,58*
G/sinδ 70°C (KPa)*	*1,92*	*1,50*
G/sinδ 76°C (KPa)*	*1,12*	*0,93*
G/sinδ 82°C (KPa)*	*0,67*	*-*

- **Post-mixing and spreading binder (RTFO aging)**



	Reference mixtures	Testing mixtures
G*/sinδ 58°C (KPa)	22,25	19,50
G*/sinδ 64°C (KPa)	11,43	9,98
G*/sinδ 70°C (KPa)	6,05	5,35
G*/sinδ 76°C (KPa)	3,21	2,95
G*/sinδ 82°C (KPa)	1,75	1,64

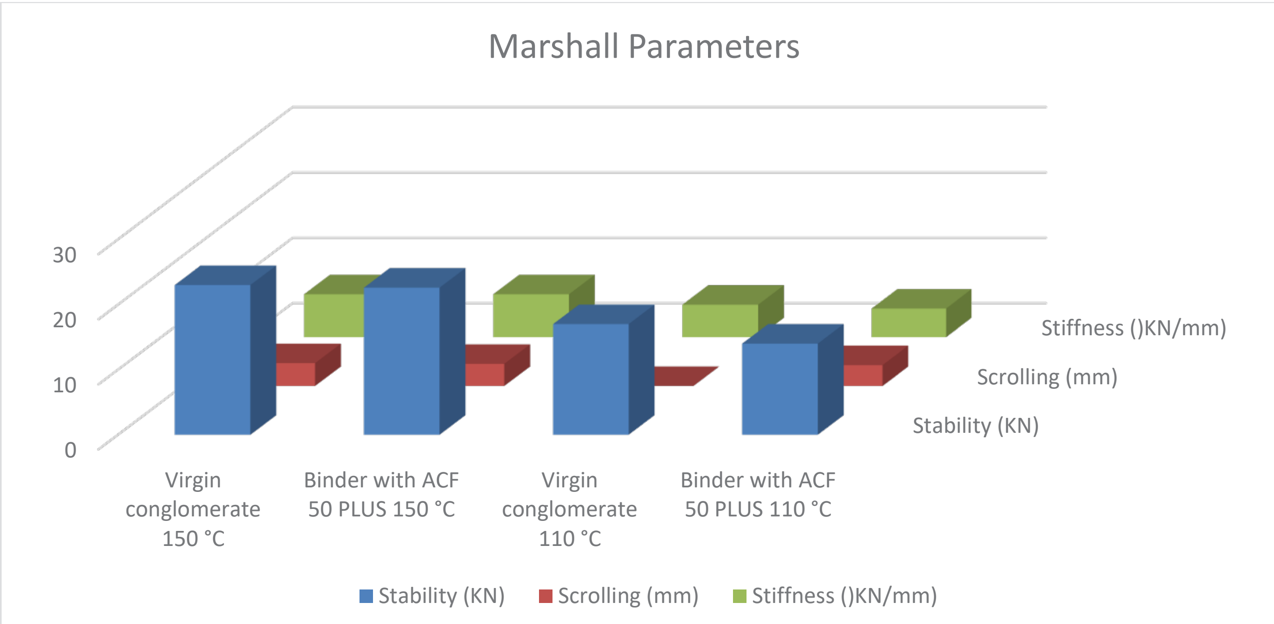
- **Long-term evaluation (after PAV)**



	Reference mixtures	Testing mixtures
G*·sinδ 28°C (kPa)	2921	2215
G*·sinδ 25°C (kPa)	4233	3255
G*·sinδ 22°C (kPa)	5818	4655
G*·sinδ 19°C (kPa)	-	6520

ACF WARM-MIX® 50 PLUS

The graph shows the values recorded on specimens packed with Marshall compactor at T=150 and 110°C.

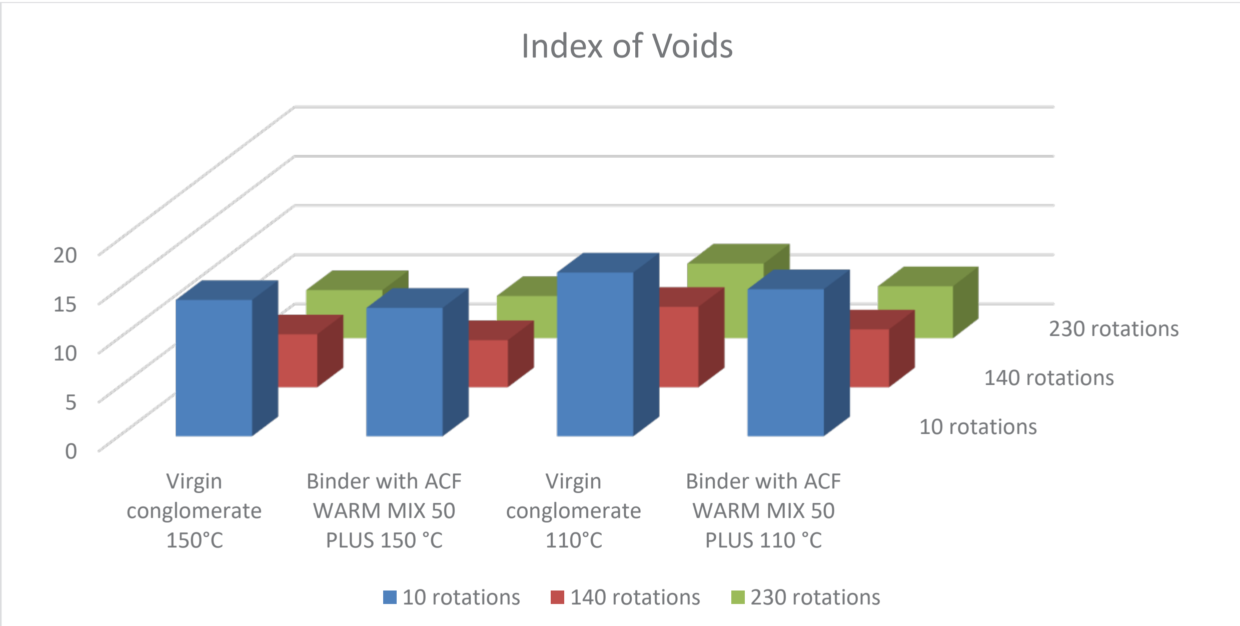


Compaction at T=150°C	*Stability (KN)*	*Scrolling (mm)*	*Stiffness (KN/mm)*
Reference Results of asphalt mix	23,0	3,5	6,6
Results of asphalt mix + ACF WARM MIX® 50 PLUS	22,6	3,4	6,6

Compaction at T=110°C	*Stability (KN)*	*Scrolling (mm)*	*Stiffness (KN/mm)*
Reference Results of asphalt mix	17,0	3,4	5,0
Results of asphalt mix + ACF WARM MIX® 50 PLUS	14,0	3,2	4,4

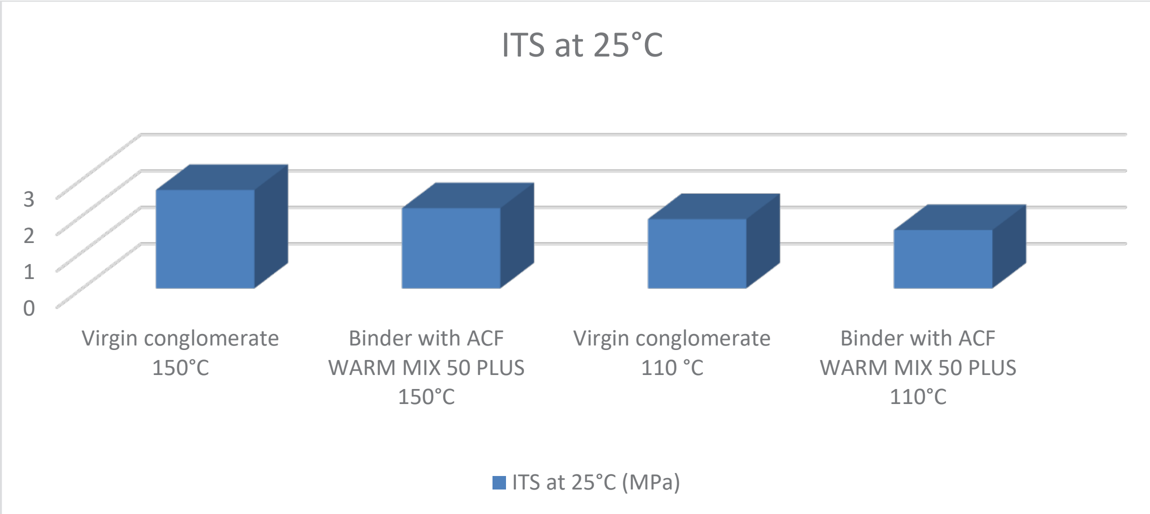
- **Index of voids**

The graph shows the values recorded on specimens packaged at T=150°C with rotary compactor.



Compaction at T=150°C	*Voids at 10 rotations (%)*	*Voids at 140 rotations (%)*	*Voids at 230 rotations (%)*
Reference Results of asphalt mix	13,9	5,4	4,9
Results of asphalt mix + ACF WARM MIX® 50 PLUS	13,1	4,8	4,3

Compaction at T=110°C	*Voids at 10 rotations (%)*	*Voids at 140 rotations (%)*	*Voids at 230 rotations (%)*
Reference Results of asphalt mix	16,7	8,2	7,6
Results of asphalt mix + ACF WARM MIX® 50 PLUS	15,0	5,9	5,3



Compaction at T=150°C	*ITS (MPa)*
Reference Results of asphalt mix	2,7
Results of asphalt mix + ACF WARM MIX® 50 PLUS	2,4

Compaction at T=110°C	*ITS (MPa)*
Reference Results of asphalt mix	1,9
Results of asphalt mix + ACF WARM MIX® 50 PLUS	1,6

Characteristics of the binder with additive

This type of study was conducted at the laboratories of the chemistry department of the University of Calabria, in order to verify the presence of the adhesion promoter and the thermo-stability. FT-IR analysis was conducted on non-additived bitumen samples and a sample supplemented with the additive ACF WARM-MIX® 50 PLUS. From the comparison analysis it is possible to highlight how the spectrum of the bitumen-additive mixture results from the overlap of the spectrum of the individual components, as shown in the underlying spectra. The thermal stability of the bitumen-additive system was also evaluated by keeping the sample additivated in a stove at T=180°C for 5 days, simulating the heat treatment at T=150°C for about 15 days. Spectral analysis on the bitumen-additive mixture showed a high stability, since the FT-IR spectrum acquired after treatment at T=180°C, does not show significant variations.

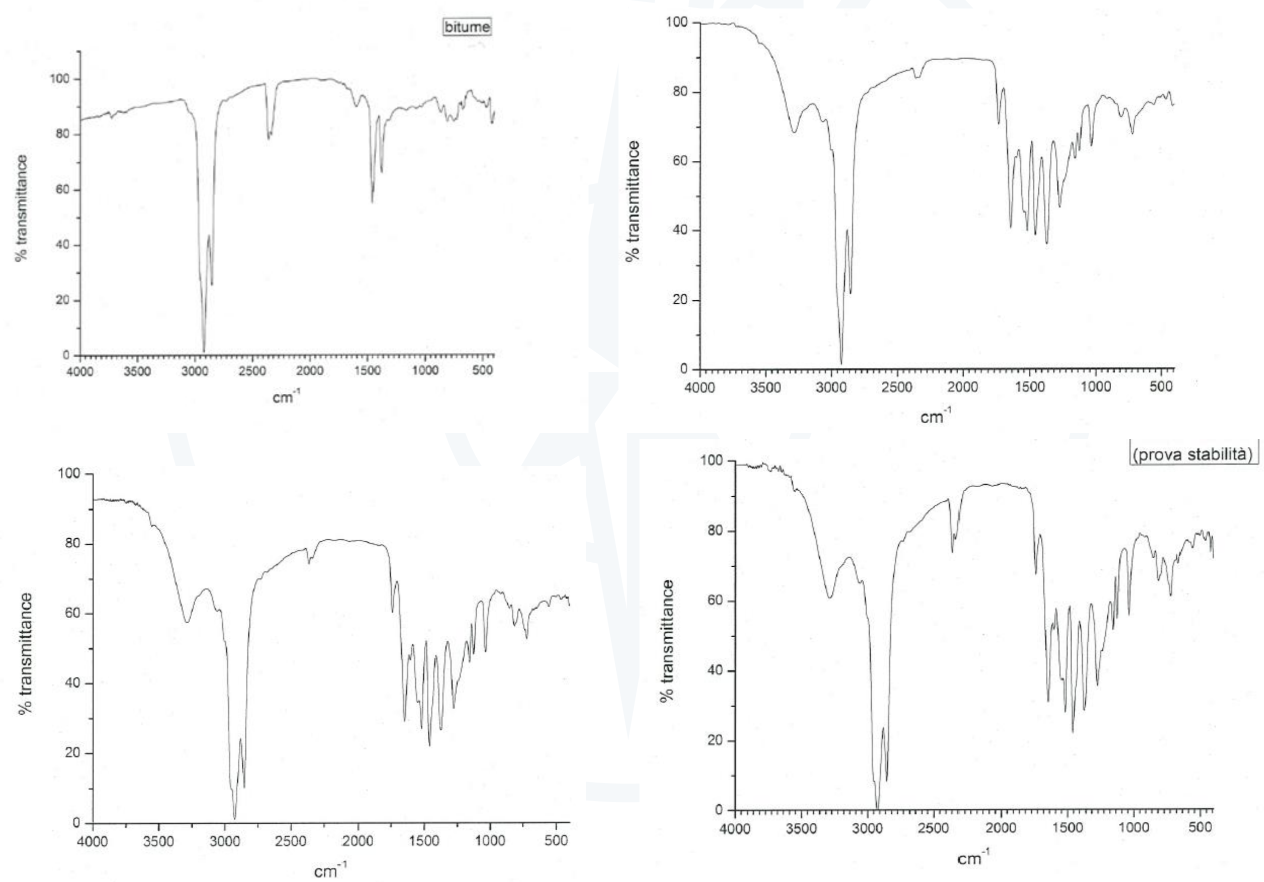


Figure 4. Infrared spectrum acquired in transmittance by Fourier Transform Infrared Spectrometer in the frequency range between 4000 and 400 cm-1. In the upper left corner, the characteristic peaks of a sample of non-mixed bitumen, in the upper right corner of those with an added bitumen, on the left the overlap of the characteristic peaks of a sample of bitumen with the addition of the additive, at the bottom right the stability test at T=180°C at 5 days of the bitumen sample with the addition of the additive.

DISCUSSION OF RESULTS AND CONCLUSIONS

The bitumen contained in the milled material undergoes, by oxidation, chemical-physical changes, therefore, a decrease in the value of penetration, an increase in the softening point and viscosity. Therefore, if a milled conglomerate is added to the milled material, in order to make a new one, a drastic increase in viscosity of the whole new conglomerate is obtained, as the average viscosity, resulting from the union of the old binder and the addition, it is very high. Mechanically, a bituminous conglomerate containing milling percentages greater than 10% causes a stiffening of the flooring, or compromises the resistance to the compressive and tensile stresses to which the roof is subjected, favoring the phenomena of cracking and cracking.

In terms of mechanical parameters, the Marshall stability increases and the sliding values decrease; the result is a more rigid flooring that can not withstand the vertical loads that generate bending stresses, traction in the lower half and compression in the upper half due to the continuous passage of vehicles, resulting in fatigue failure.

Our laboratories have developed a wide range of additives called ACF (Functional Chemical Additives) that allow the re-use of the milled material while maintaining control of the mechanical performance of the asphalt. With the use of these additives, the milling recycling technique allows to obtain bituminous mixes which have physical-mechanical characteristics similar to those of bituminous conglomerates produced using inert and virgin bitumen.

Furthermore, using each regenerant according to the specific case, it is possible to:

- Increase the useful life of the road pavement;
- Reduce greenhouse gas emissions;
- Reduce the production costs of asphalt mix;
- Keep mixing and production times unchanged;
- Improve compaction at low temperatures;
- Establish a greater bitumen / aggregate interaction;
- Recycle, with specific additives, high percentages of milled material even on wear layers.

WARM-MIX ASPHALT

Registration of ***Star Asphalt S.p.A.*** to **REACH Regulation**

N. 1907/2006 G.U.E. L396 of 30 December 2006

Effective from 1 June 2007 and with registration deadline to 31 May 2018

STARDOPE® WARM-MIX 2G

Complex mixtures of polymers and adhesion promoters registered to the REACH Regulation

REACH REGISTRATION NUMBER

01-2119492546-27-0004

WARM-MIX ASPHALT

INTRODUCTION

In the last few years the road construction industry is striving for new technologies that will improve the performance of the used material and the efficiency of the works while at the same time preserving resources and reducing polluting emissions. One of the possible approaches that can contribute to achieving these goals is the reduction of the production and compacting temperature of the bituminous conglomerate of which the superstructure is made. The resulting mixture is named "Warm Mix Asphalt". In general, the blending of the blends may take place at different temperatures and this has allowed to classify them as:

- For temperatures ranging from 150 to 190°C it is defined as Hot Mix Asphalt (HMA);
- For temperatures ranging from 100 to 140°C it is defined as Warm Mix Asphalt (WMA);
- For temperatures ranging from 60 to 100°C Half-Warm Mix Asphalt (HWMA);
- For temperatures ranging from 0 a 40°C Cold mix.

The reduction of the temperature with WMA (which can reach up to 30% less than conventional asphalt mix) is the result of recent technological developments that require the use of organic additives, chemical additives and water-based or foamed processes; Such technologies, although different, have the same aim, that is to improve the workability of the bitumen at lower temperatures as well as to moderate pollutant emissions. In addition, they allow an increase in asphalt mix density and a reduction in permeability. Therefore, the benefits resulting from their use are numerous: first of all the lowering of emissions in general and in particular those of greenhouse gases, then an improvement in working conditions for the absence of harmful gases, a lower consumption of Energy for the production of the mixture, a faster re-opening to traffic after work, a stretch for greater distances and even in cold climates, a reduction in bitumen aging.

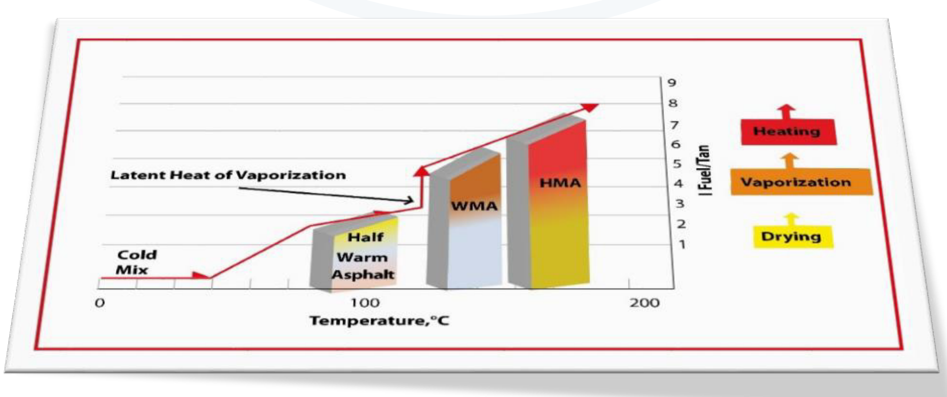


Fig. 1. Classification according to temperature range.

OUR SOLUTIONS

Our additives arise from the need to reduce emissions to the atmosphere (CO_2, NO_x, VOC, thin powders...), constantly improving performance, increasing construction efficiency, resource conservation and environmental management. Unlike the most common bitumen conglomerate production methods, the use of our Warm-Mix® can reduce the temperatures during production and compacting. Such additives are consistent with the ideals described by sustainable development.

For the use of these products it is not necessary to apply particular procedures but above all the asphalt plant must not be modified; just add them to the bituminous binder and it is possible, immediately after, to reduce the production, spread and compaction temperatures.

Our Warm-Mix® can be used with any type of asphalt plant and are compatible with all types of bitumen, both normal and modified.

It is possible to add them directly in the mixer of the production plant during the phase of packaging the bituminous conglomerate, using an automatic metering device or, alternatively, they can be added directly into the bitumen storage tank at the time of its recharge; this operation must be carried out in such a way as to add the additive as soon as the bitumen is poured into the storage tank, making sure that its dosage is terminated when the bitumen is decanted. Subsequently, the bitumen-additive mixture must be homogenized by means of a mixer or by recirculation.

WARM-MIX® L

It was the first WARM MIX® additive developed by Star Asphalt, compared to dozens of studies and field trials, winner of international awards for its high effectiveness and exceptional performance; is still very sought after all over the world for its quality. Its addition, during the asphalt packaging phase, means that the mixing, paving and compaction temperatures can be considerably lower than those traditionally used, typically up to 90°C. Its peculiar characteristic is that of improving the workability of the final asphalt mix without compromising the resistance to the rutting.

Международен панаир Пловдив International Fair Plovdiv, Bulgaria

ДИПЛОМ
DIPLOMA

Международен панаир Пловдив награждава със Златен медал и Диплом

експоната „Енергоспестяваща добавка за топъл асфалт WARM-MIX L"
Производител: Star Asphalt S.P.A., Италия
Изложител: БЕТА ПРОИНВЕСТ ЕООД, София

представен на ЕСЕНЕН ПАНАИР 2011

International Fair Plovdiv awards a Gold Medal and Diploma to

the exhibit "WARM-MIX L Energy-Saving Additive for Warm Mix Asphalt"
Manufacturer: Star Asphalt S.P.A, Italy
Exhibitor: BETA PROINVEST Ltd., Sofia

exhibited at the INTERNATIONAL AUTUMN FAIR 2011

ufi Approved Event

МЕЖДУНАРОДЕН ТЕХНИЧЕСКИ ПАНАИР INTERNATIONAL TECHNICAL FAIR

2011

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Пловдив

Председател на Съвета на директорите: (Величка Гергова)
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Спечелилият кандидат няма право да използва по какъвто и да е начин наградата "Златен медал и диплом" относно изделие, различно от посоченото в настоящия диплом
The "Gold Medal and Diploma" award may not be applied in any way to a product other than the one specified in this diploma

Fig. 2. Warm-Mix Gold Medal and Diploma L: Energy-Saving Additive for Warm-Asphalt Mix, International Fair Plovdiv Bulgaria 2011.

STARDOPE® WARM-MIX

It is a special additive that increases workability at low temperatures and the degree of coverage of bituminous mixtures. Its addition, during the asphalt packaging phase, means that the mixing, paving and compaction temperatures can be considerably lower than those traditionally used. The addition of this additive to the bituminous conglomerates, allows to use lower working temperatures, even 40°C, compared to those traditionally used.

STARDOPE® WARM-MIX 2G → <u>Complex mixture of products registered to the REACH regulation</u>

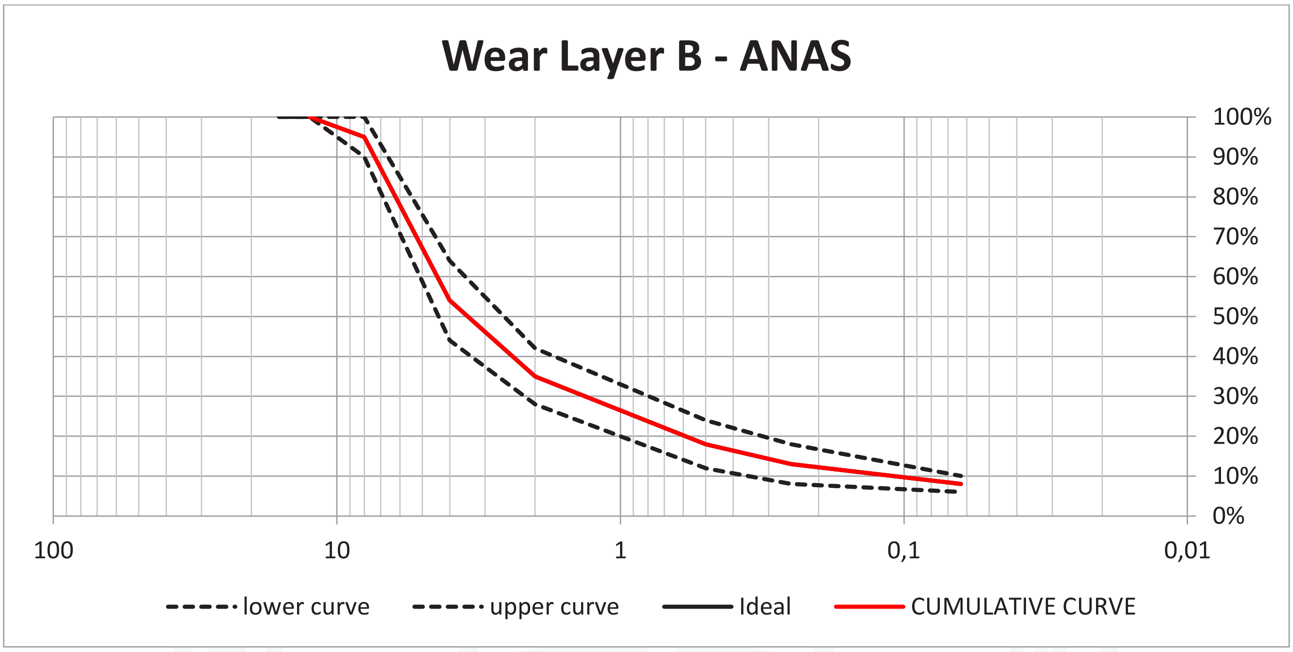
It is the last born in the Star Asphalt house, after a long phase of research and experimentation, it allows to increase the workability at low temperatures and the degree of coverage of bituminous mixtures. Its addition, during the asphalt packaging phase, means that the mixing, paving and compaction temperatures can be considerably lower than those traditionally used. The addition of this additive to the asphalt mix, allows working temperatures typically 40-50°C lower than those traditionally used; moreover, it does not modify the chemical-physical characteristics of the bituminous binder.

EXPERIMENTAL ACTIVITY REPORT

PHASE 1: REALIZATION OF ASPHALT MIX

Granulometric curves

Wear Layer ANAS type B:



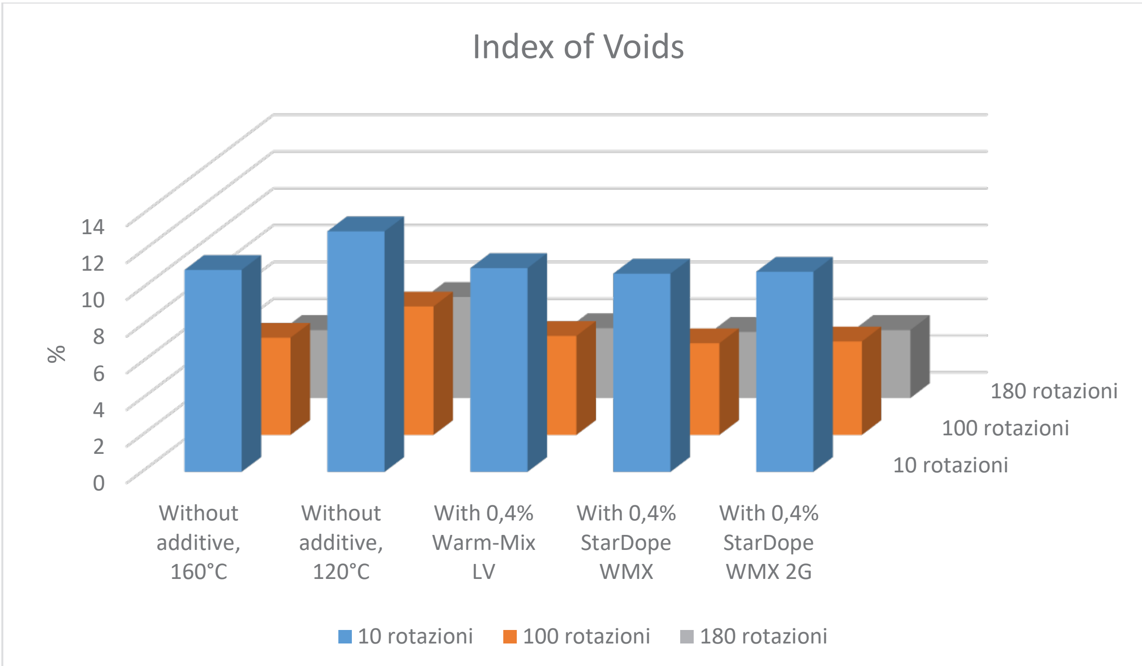
Preparation of mixtures

The mixtures, both the reference one (without addition of additives) and the one with the addition of the additive, consist of bituminous type B conglomerates packed with 50/70 bitumen (Penetration: 55 dmm; R&B: 47°C).

The mixtures were packaged in the laboratory by means of a thermostatic mixer for asphalt (Infratest), using a percentage of 5% by weight binder referred to the inerts. The Asphalt mix were made by dosing the additives in variable percentages between 0.4 and 0.6% on the weight of the binder.

The mixing was performed at a temperature of 120°C.

The graph below shows the experimental results obtained by compacting mixtures made with and without additives to the rotary compactor.



	10 rotations	100 rotations	180 rotations
Without additive, 160°C	11,0	5,3	3,7
Without additive, 120°C	13,1	7,0	5,5
With 0,4% WARM-MIX® L, 120°C	11,1	5,4	3,8
With 0,4% STARDOPE WARM-MIX®, 120°C	10,8	5,0	3,6
With 0,4% STARDOPE WARM-MIX® 2G, 120°C	10,9	5,1	3,7

The results obtained show that the dosage of small quantities of additives, called WARM-MIX®, allows a real lowering of the production temperatures, spreading and compacting the asphalt mix, of about 40 °C lower than the same mix produced without use of additives.

Tests performed at S.C. Laborator Central Constructii CCF SRL – ROMANIA

The tests were carried out on a wear conglomerate, made with 5% of 50/70 type bitumen, with and without additives at different compaction temperatures.

- **Marshall Test**

	Mixing: 165°C Compaction: 140°C	Mixing: 165°C Compaction: 100°C	Mixing: 120°C Compaction: 90°C	Acceptable value
Density [g/cm^3] 25°C	2,5	2,5	2,5	
Stability [KN] 60°C	10,4	9,0	8,7	≥ 8,0
Scrolling [mm]	4,0	3,6	3,2	2 - 4
Stiffness [KN/mm]	2,6	2,5	2,7	2 - 5

- ***Wheel tracking test, bitume 50/70***

Number	**Test method EN 12697-22**	**U.M.**	**Test Results**		**Limit Values**
			Test 1	**Test 2**	
1.	Strain rate WTS Air Wheel-tracking slope	mm/103 Load cycle	0,77	0,81	Max. 1,0
2.	Average WTS Air	mm/103 Load cycle	0,79		1,0
3.	Proportional rut depth of the PDR air Proportional Rut Depth	%	7,6	7,9	Max. 9,0
4.	Average PRD air	%	7,8		Max. 9,0
5.	Sulcus depth RD air Rut Depth	mm	3,88	3,95	-
6.	Average RD air	mm	3,92		-

- ***Bitumen 50/70 with 0,5% of WARM-MIX® L***

Number	Test method EN 12697-22	U.M.	Test Results Test 1	Test 2	Limit Values
1.	Strain rate WTS Air Wheel-tracking slope	mm/103 Load cycle	0,71	0,75	Max. 1,0
2.	Average WTS Air	mm/103 Load cycle	0,73		1,0
3.	Proportional rut depth of the PDR air Proportional Rut Depth	%	6,8	7,2	Max. 9,0
4.	Average PRD air	%	7,2		Max. 9,0
5.	Sulcus depth RD air Rut Depth	mm	3,53	3,6	-
6.	Average RD air	mm	3,57		-

Tests carried out on Roads and Bridges Ltd, Varna, D-r Pisculiev Str. 3- BULGARIA

Tests performed on an asphalt mix made of 50/70 bitumen with 0.4% of Warm Mix L on the weight of the bitumen at different compaction temperatures.

Compaction temperature: 135 °C

Parameters	Standard	value	Acceptable value	Temperature
Compaction value [g/cm³]	EN 12697-6	2,351		25°C
StabilityMarshall [KN]	EN 12697-34	10,3	≥ 8,0	60°C
Plasticity [mm]	EN 12697-34	2,9	2÷4	60°C

- *Compaction temperature: 120°C*

Parameters	Standard	value	Acceptable value	Temperature
Compaction value [g/cm³]	EN 12697-6	2,334		25°C
StabilityMarshall [KN]	EN 12697-34	9,3	≥ 8,0	60°C
Plasticity [mm]	EN 12697-34	2,8	2÷4	60°C

- *Compaction temperature:100°C*

Parameters	Standard	value	Acceptable value	Temperature
Compaction value [g/cm³]	EN 12697-6	2,303		25°C
StabilityMarshall [KN]	EN 12697-34	8,0	≥ 8,0	60 °C
Plasticity [mm]	EN 12697-34	2,2	2÷4	60°C

Field tests

Several road sections have been built, including trial fields, in various sections of the Calabrian state; all the works were inspected by ANAS, carrying out checks and sampling on site, coordinating directly with Star Asphalt S.p.A, in collaboration with the University of Calabria, over the course of three years from the same annual inspection. The work was carried out by creating wear mats using the additive WARM-MIX® L.

The roads affected are:

- Strada statale 107 Silana Crotonese
- Strada statale 183 Aspromonte-Jonio
- Strada statale 682 Jonio-Tirreno
- Strada statale 105 Belvedere Marittimo-Castrovillari
- Strada statale 106 Tratto Sibaritide
- Strada statale 278 Potame-Amantea

The results found in the field are shown below:

- ***Strada statale 107 Silana Crotonese***

It is an important road network that crosses Calabria, the Silano plateau and the mountain ranges of the coast, which connect the Tyrrhenian Sea to the Ionian Sea, Cosenza and Crotone.

	Asphalt reference after 3 year	Asphalt with WMX L after 1 year	Asphalt with WMX L after 2 year	Asphalt with WMX L after3 year
Depth of the furrow (mm)	6	2	4	4
Total length of cracks (cm)	330	30	92	92
Density (%Gmm)	96,7	97,8	97,1	97,1

- ***Strada statale 183 Aspromonte-Jonio***

Former National Road 183 Aspromonte-Jonio (SS 183); it is an Italian provincial road that connects the Aspromonte with the southern coast of the Ionian.

	Asphalt reference after 3 year	Asphalt with WMX L after 1 year	Asphalt with WMX L after 2 year	Asphalt with WMX L after3 year
Depth of the furrow (mm)	5	0	2	3
Total length of cracks (cm)	274	0	61	61
Density (%Gmm)	92,8	89,9	88,6	88,2

- ***Strada statale 682 Jonio-Tirreno***

It is an important road network that connects the Tyrrhenian coast with the Ionian coast through the Limina tunnel (length 3200 m, 74° of the Italian tunnel for length).

	Asphalt reference after 3 year	Asphalt with WMX L after 1 year	Asphalt with WMX L after 2 year	Asphalt with WMX L after3 year
Depth of the furrow (mm)	3	0	2	3
Total length of cracks (cm)	152	0	30	30
Density (%Gmm)	97	96,5	95,8	94,2

- ***Strada statale 105 Belvedere Marittimo-Castrovillari***

The Statale 105 of Castrovillari connects the Tirreno Cosentino to the valley of the Esaro and to the Pollino.

	Asphalt reference after 3 year	Asphalt with WMX L after 1 year	Asphalt with WMX L after 2 year	Asphalt with WMX L after3 year
Depth of the furrow (mm)	3	0	0	2
Total length of cracks (cm)	62	0	30	30
Density (%Gmm)	97,8	95,8	95,4	94,8

- ***Strada statale 106 - Tratto Sibaritide***

It is one of the most important and busy arteries of Calabria after the A2 motorway of the Mediterranean. 120 Km of carpet from Km 295 to Km 415 have been realized.

	Asphalt reference after 3 year	Asphalt with WMX L after 1 year	Asphalt with WMX L after 2 year	Asphalt with WMX L after3 year
Depth of the furrow (mm)	1,4	0	0,7	1,3
Total length of cracks (cm)	275	0	30	61
Density (%Gmm)	97,8	96,8	96,4	95,8

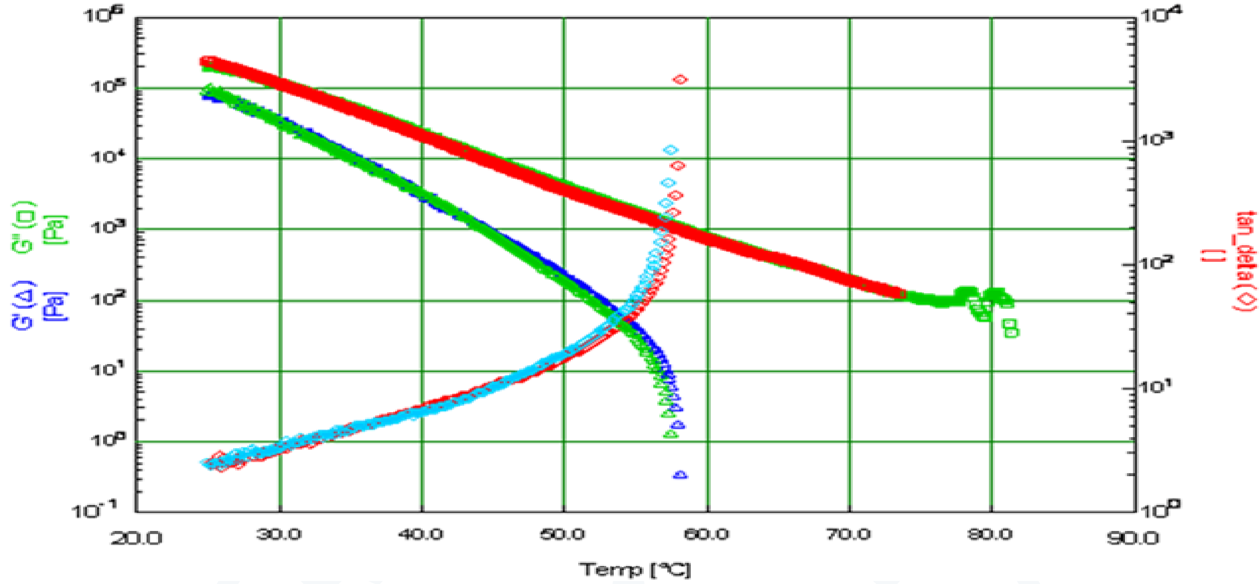
- ***Strada statale 278 Potame-Amantea***

Former highway 278 of Potame, now the provincial road 257 Cosenza-Potame-Amantea, begins in Cosenza and ends by the state road 18 Tirrena Inferiore in the city of Amantea.

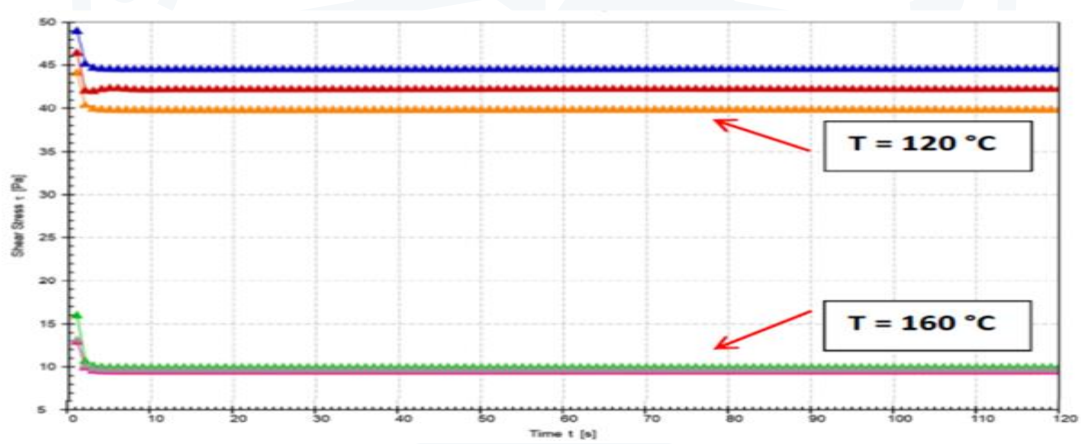
	Asphalt reference after 3 year	Asphalt with WMX L after 1 year	Asphalt with WMX L after 2 year	Asphalt with WMX L after3 year
Depth of the furrow (mm)	3,5	1,2	2,4	3,2
Total length of cracks (cm)	182	0	0	30
Density (%Gmm)	96,1	94,8	94,7	94,4

STEP 2: QUALIFICATION OF THE BINDER

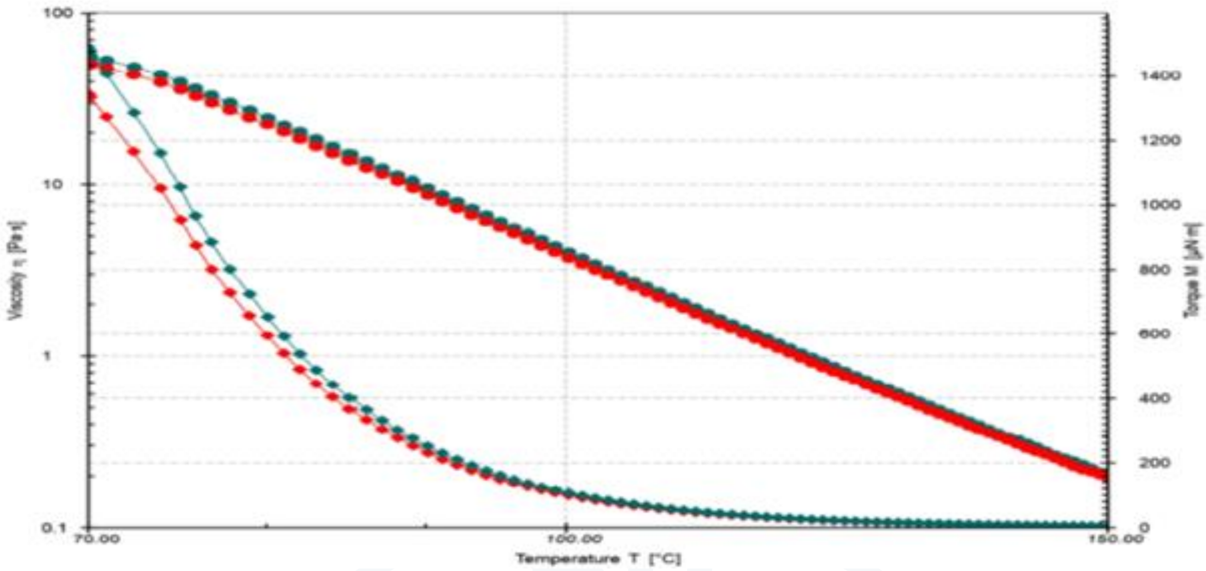
- **Rheological characterization**



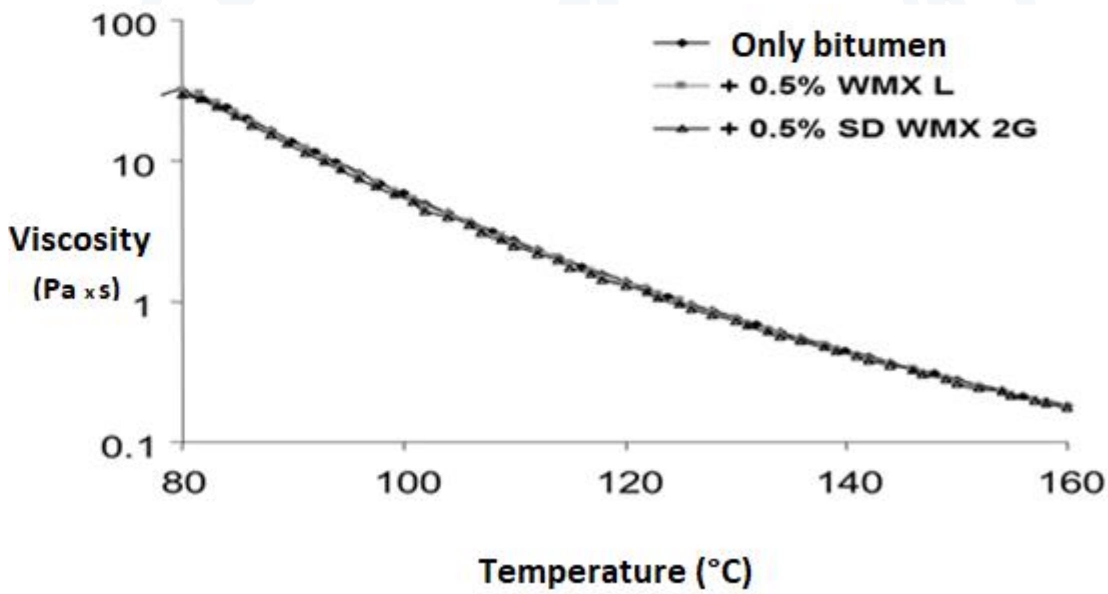
Graph 1. Storage module (G '') and loss module (G ') of a non-additive bitumen and of a bitumen additived with 0.5% of Warm-Mix® L. Department of Chemistry - UNIVERSITY OF CALABRIA - Arcavacata of Rende.



Graph 2. Overlap of "stress" curves of a sample of non-additive bitumen (blue curve), a sample of bitumen added with 0.5% of Warm-Mix® L (red curve) and a sample of bitumen admixed with 0.5% of StarDope® Warm-Mix 2G (orange curve) with deformation γ = 70%, frequency ν = 10 Hz and temperature T=120°C and T=160°C.



Graph 3. Overlap of curves of bitumen samples without additive and with 0.5% of Warm-Mix® L with shear rate = 0.5s-1 in a range of T=70-150°C.



Graph 4. Trend of the viscosity as a function of the temperature of a sample of non-mixed bitumen, a sample of bitumen with 0.5% of Warm-Mix® L and a sample of bitumen added with 0.5% of StarDope® Warm-Mix 2G: as you can see, all the curves are superimposed, indicating that there is no change in the viscosity of the bitumen as these additives do not modify the physical properties of the bituminous binder.

Penetration and Softening Point

Penetration and softening tests were performed to confirm that the dosage of the additive does not change the characteristics of the binder.

Samples	Penetration (dmm)	Softening (°C)
Bitumen 70/100	72 ± 1	48 ± 2
Bitumen 70/100 + 0,5% Warm-Mix L	74 ± 1	48 ± 2
Bitumen 70/100 + 0,5% StarDope WMX	74 ± 1	47 ± 2
Bitumen 70/100 + 0,5% StarDope WMX 2G	73 ± 1	47 ± 2

- **PHASE 3: CHARACTERIZATION OF THE ADDITIVE BINDER**

Analysis FT-IR

This type of study was conducted at the laboratories of the chemistry department of the University of Calabria, in order to verify the thermo-stability of the additives.

FT-IR analysis was conducted on a sample of non-additive bitumen, a sample of StarDope® Warm-Mix 2G, a sample of StarDope® WMX, a sample of bitumen added with the StarDope® Warm-Mix 2G and a sample bitumen added with StarDope® WMX; from the comparison analysis it is possible to show how the spectra of the bitumen-additive mixture result from the overlapping of the spectra of the individual components, as shown in the following spectra.

Consequently, the thermal stability of the bitumen-additive system was evaluated by keeping the sample additivated in a stove at T=180°C for 5 days, simulating the heat treatment at T=150°C for about 15 days.

Spectral analysis on the bitumen-additive mixture showed a high stability, since the FT-IR spectrum acquired after treatment at T=180°C does not show significant qualitative or quantitative differences with respect to the corresponding one acquired on the additive-derived bitumen sample. suffered heat stress. The additives therefore maintain their chemical structure substantially unchanged with exposure to the oxidative conditions tested; the bitumen-additive system is stable in these conditions.

STARDOPE® WARM-MIX 2G

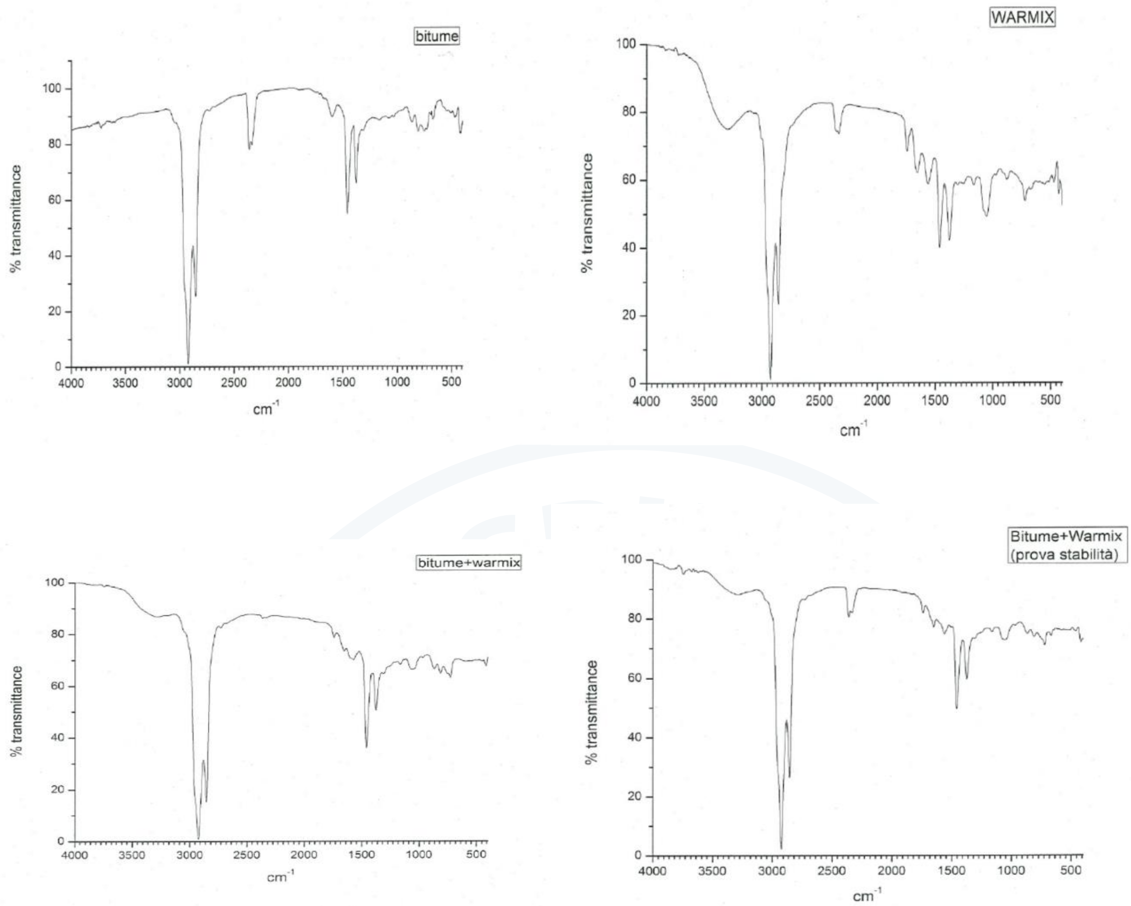


Fig. 3. Infrared spectrum acquired in transmittance by Fourier Transform Infrared Spectrometer in the frequency range between 4000 and 400 cm-1. At the top on the left, the characteristic peaks of a sample of bitumen as it is, on the top right, those of the StarDope® Warm-Mix 2G additive, on the lower left, the characteristic peaks of a sample of bitumen with the addition of 0.5 % of StarDope® Warm-Mix 2G, lower right the T=180 ° C stability test of the bitumen sample with the addition of 0.5% of StarDope® Warm-Mix 2G.

STARDOPE® WMX

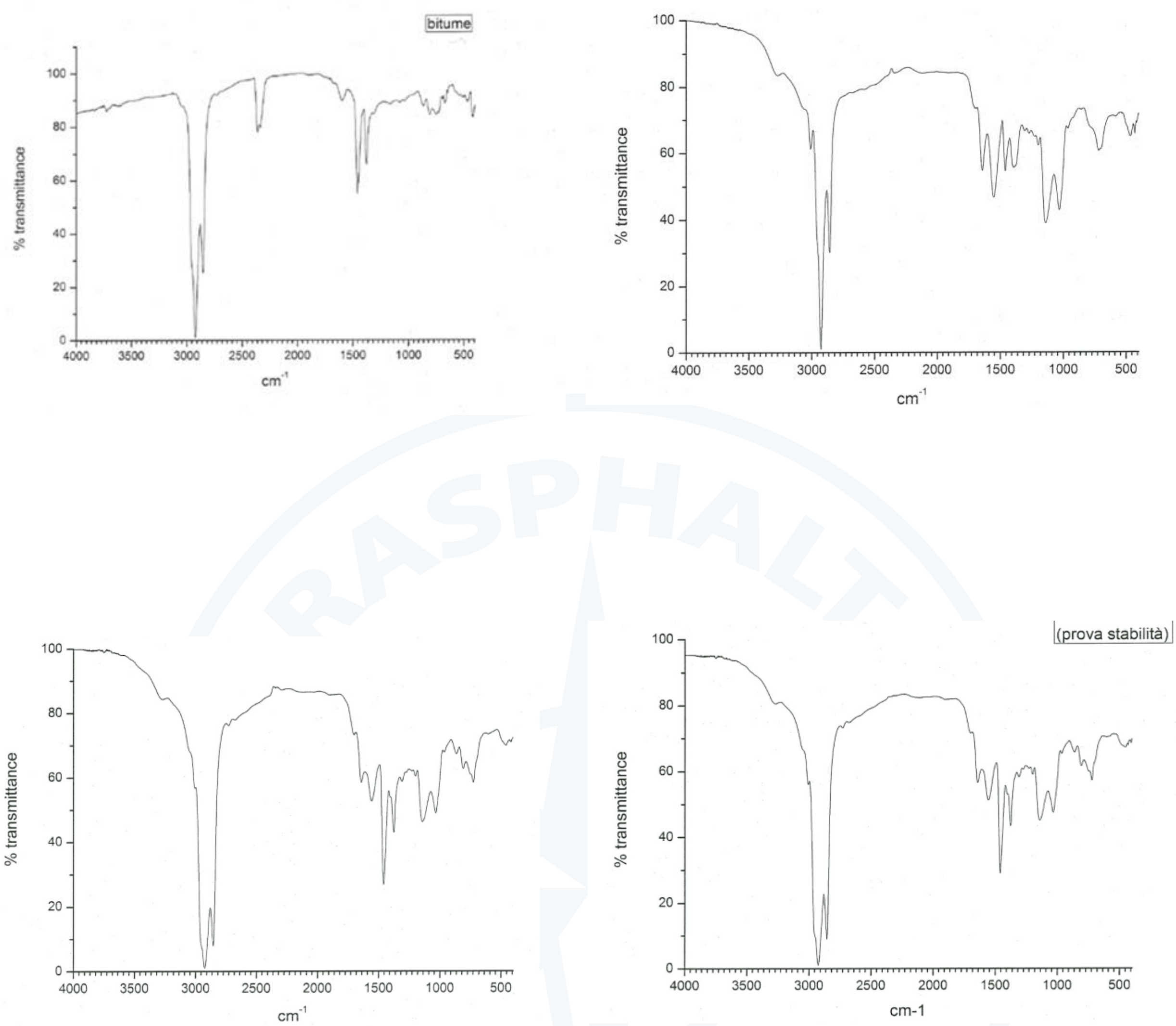


Fig. 4. Infrared spectrum acquired in transmittance by Fourier Transform Infrared Spectrometer in the frequency range between 4000 and 400 cm-1. In the upper left corner, the characteristic peaks of a sample of non-mixed bitumen, in the upper right corner of those with an added bitumen, on the left the overlap of the characteristic peaks of a sample of bitumen with the addition of the additive, at the bottom right the stability test at T =180°C at 5 days of the bitumen sample with the addition of the additive.

- **Adhesion test**

In order to highlight the potential of adhesion promoters, in addition to the warm properties of StraDope® Warm-Mix and StraDope® Warm-Mix 2G, the classic evaluation tests of the adhesion power of our range have been carried out. Warm-Mix on different types of aggregates. The results obtained show that these additives have dual functionality, from warm mix and from adhesion promoter.

I. Boiling Water Stripping Test (ASTM D3625)

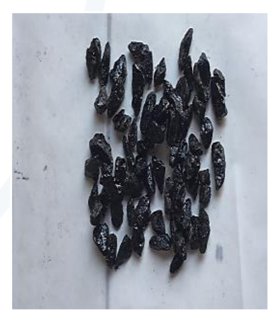
<u>**GRANITE**</u>

SAMPLES	COVERAGE RATE
Only Bitumen	F-G (20-40%)
Bitumen + 0,4% WARM-MIX® L	F-G (20-40%)
Bitumen + 0,4% STARDOPE® WARM-MIX	C (90%)
Bitumen + 0,4% STARDOPE® WARM-MIX 2G	C-D (80-90%)

Only Bitumen

Bitumen + 0,4% WARM-MIX® L

Bitumen + 0,4% STARDOPE® WARM-MIX



Bitumen + 0,4% STARDOPE® WARM-MIX 2G

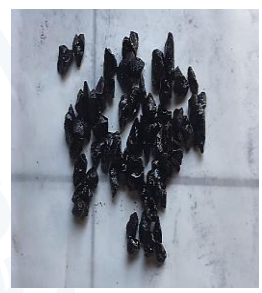
DOLOMITE

SAMPLES	COVERAGE RATE
Only Bitumen	E (60%)
Bitumen + 0,4% WARM-MIX® L	E (60%)
Bitumen + 0,4% STARDOPE® WARM-MIX	C (90%)
Bitumen + 0,4% STARDOPE® WARM-MIX 2G	C-D (80-90%)

Only Bitumen

Bitumen + 0,4% WARM-MIX® L

Bitumen + 0,4% STARDOPE® WARM-MIX



Bitumen + 0,4% STARDOPE® WARM-MIX 2G

MIX OF AGGREGATES OF DIFFERENT CHEMICAL NATURE

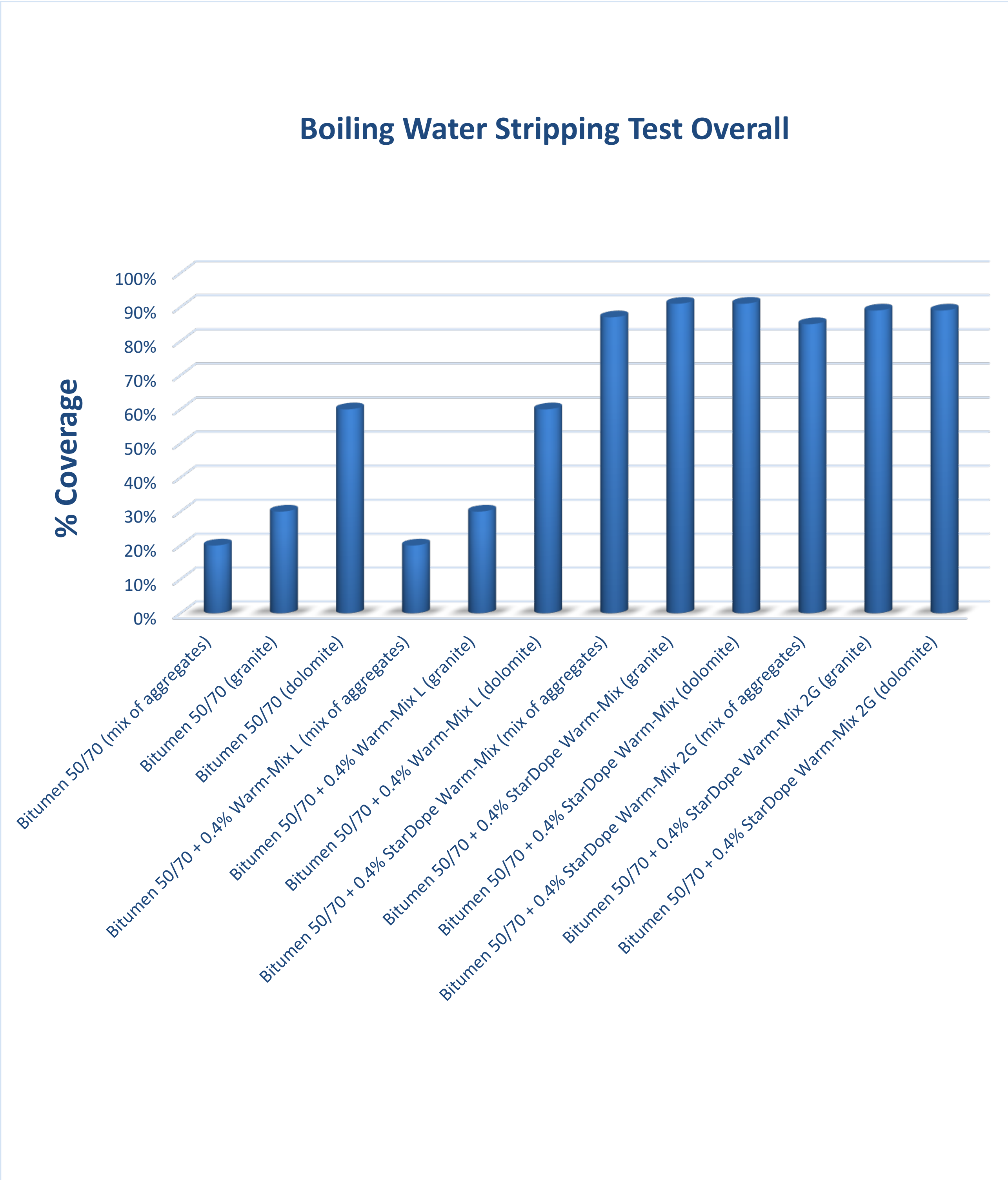
SAMPLES	COVERAGE RATE
Only Bitumen	G (20%)
Bitumen+ 0,4% WARM-MIX® L	G (20%)
Bitumen+ 0,4% STARDOPE® WARM-MIX	C-D (80-90%)
Bitumen + 0,4% STARDOPE® WARM-MIX 2G	D (80%)

Only Bitumen

Bitumen + 0,4% WARM-MIX® L

Bitumen + 0,4% STARDOPE® WARM-MIX

Bitumen + 0,4% STARDOPE® WARM-MIX 2G



Boiling Water Stripping Test Overall
% Coverage
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Bitumen 50/70 (mix of aggregates)
Bitumen 50/70 (granite)
Bitumen 50/70 (dolomite)
Bitumen 50/70 + 0.4% Warm-Mix L (mix of aggregates)
Bitumen 50/70 + 0.4% Warm-Mix L (granite)
Bitumen 50/70 + 0.4% Warm-Mix L (dolomite)
Bitumen 50/70 + 0.4% StarDope Warm-Mix (mix of aggregates)
Bitumen 50/70 + 0.4% StarDope Warm-Mix (granite)
Bitumen 50/70 + 0.4% StarDope Warm-Mix (dolomite)
Bitumen 50/70 + 0.4% StarDope Warm-Mix 2G (mix of aggregates)
Bitumen 50/70 + 0.4% StarDope Warm-Mix 2G (granite)
Bitumen 50/70 + 0.4% StarDope Warm-Mix 2G (dolomite)

I. Rolling Bottle Test (UNI EN 12697-11 Part A)

GRANITE

SAMPLES	COVERAGE RATE
Only Bitumen	F-G (20-40%)
Bitumen + 0,4% WARM-MIX® L	F-G (20-40%)
Bitumen + 0,4% STARDOPE® WARM-MIX	B (95%)
Bitumen + 0,4% STARDOPE® WARM-MIX 2G	C (90%)

Only Bitumen

Bitumen + 0,4% WARM-MIX® L

Bitumen + 0,4% STARDOPE® WARM-MIX

Bitumen + 0,4% STARDOPE® WARM-MIX 2G

DOLOMITE

SAMPLES	COVERAGE RATE
Bitumen	E (60%)
Only Bitumen + 0,4% WARM-MIX® L	E (60%)
Bitumen + 0,4% STARDOPE® WARM-MIX	C (90%)
Bitumen + 0,4% STARDOPE® WARM-MIX 2G	C (90%)

Only Bitumen

Bitumen *+ 0,4% WARM-MIX® L*

Bitumen *+ 0,4% STARDOPE® WARM-MIX*

Bitumen *+ 0,4% STARDOPE® WARM-MIX 2G*

MIX OF AGGREGATES OF DIFFERENT CHEMICAL NATURE

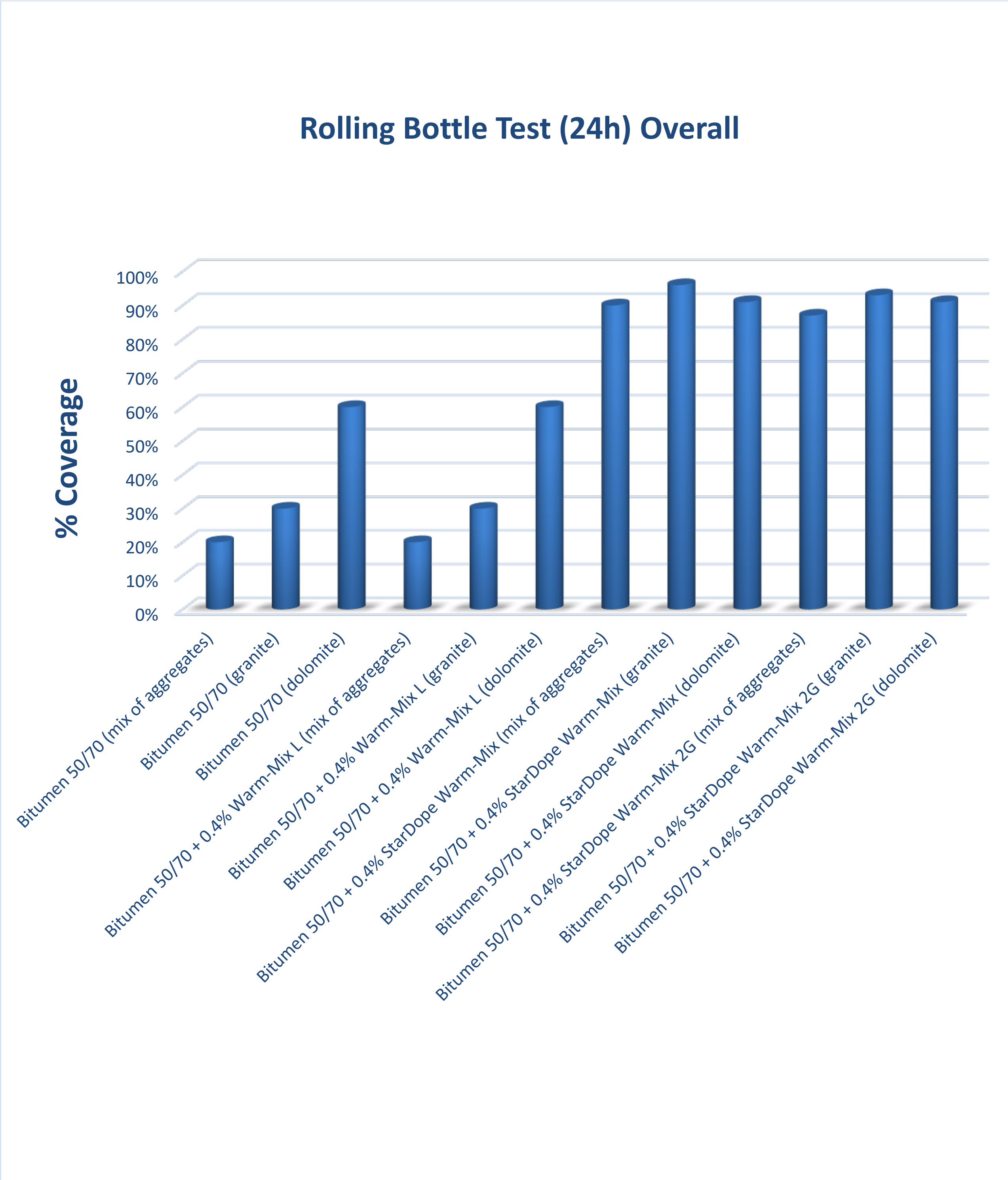
SAMPLES	COVERAGE RATE
Only Bitumen	G (20%)
Bitumen + 0,4% WARM-MIX® L	G (20%)
Bitumen + 0,4% STARDOPE® WARM-MIX	C-D (80-90%)
Bitumen + 0,4% STARDOPE® WARM-MIX 2G	D (80%)

Only Bitumen

Bitumen + 0,4% WARM-MIX® L

Bitumen + 0,4% STARDOPE® WARM-MIX

Bitumen + 0,4% STARDOPE® WARM-MIX 2G


Rolling Bottle Test (24h) Overall
% Coverage
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Bitumen 50/70 (mix of aggregates)
Bitumen 50/70 (granite)
Bitumen 50/70 (dolomite)
Bitumen 50/70 + 0.4% Warm-Mix L (mix of aggregates)
Bitumen 50/70 + 0.4% Warm-Mix L (granite)
Bitumen 50/70 + 0.4% Warm-Mix L (dolomite)
Bitumen 50/70 + 0.4% StarDope Warm-Mix (mix of aggregates)
Bitumen 50/70 + 0.4% StarDope Warm-Mix (granite)
Bitumen 50/70 + 0.4% StarDope Warm-Mix (dolomite)
Bitumen 50/70 + 0.4% StarDope Warm-Mix 2G (mix of aggregates)
Bitumen 50/70 + 0.4% StarDope Warm-Mix 2G (granite)
Bitumen 50/70 + 0.4% StarDope Warm-Mix 2G (dolomite)

DISCUSSION OF RESULTS AND CONCLUSIONS

Analyzing the experimental results obtained, it can be stated that the use of additives called Warm-Mix® guarantee:

- ✓ Environmental benefits;
- ✓ Economic benefits;
- ✓ Benefits on flooring;
- ✓ Improvements in the workability of the final bituminous conglomerate;
- ✓ Not compromising the physical properties of the bituminous binder (viscosity, penetration and softening point).

Furthermore, while the Warm-Mix®L improves the workability of conglomerates at low temperatures, the StarDope® Warm-Mix and StarDope® Warm-Mix 2G additives also favor bitumen/inert adhesion, therefore the bituminous mixes produced with their addition , will present a better cohesion but above all a very high resistance to stripping, that is to the detachment of the bitumen film covering the aggregate. In this regard, the FT-IR spectroscopic analysis was performed on the bitumen as it is, on the single StarDope® Warm-Mix 2G additive and on the bitumen-additive mixture; the comparison analysis clearly shows that the spectrum of the bitumen-additive mixture essentially results from the overlap of the spectrum of the single component. In fact, the characteristic peaks of the bitumen and those of the additive are clearly identifiable in the overlying spectra.

The thermal stability of the bitumen-additive system was verified under conditions of high oxidative stress (T=180°C for 5 days). The spectral analysis on the bitumen-additive mixture showed a high stability of the same, since the FT-IR spectrum acquired after T-treatment=180°C does not show significant qualitative or quantitative differences with respect to the corresponding spectrum acquired on the sample which did not has undergone heat treatment, as shown by the attached spectrums already discussed.

By using our Warm-Mix® it is possible, therefore:

- ✓ Use packaging temperatures below 30°C to 50°C compared to those traditionally used.
- ✓ Make a reduction in production costs and reduce the emission of greenhouse gases.
- ✓ Extend the transport, spreading and compacting times of the bituminous mixtures.
- ✓ Improve the workability of bituminous conglomerates in extreme climatic conditions.
- ✓ Improve the workability of bitumen conglomerates containing milled material.
- ✓ Improve the workability of conglomerates produced with bituminous recovery sheaths.
- ✓ Keep mixing times unchanged, leaving the production capacity of the plant constant.
- ✓ Promote a high resistance to stripping.

FINAL CONSIDERATIONS

The purpose of this "textbook" is to suggest the appropriate improvements in order to guarantee a high quality level of our roads, eliminating improvisation, coordinated with these indispensable for the managerial responsibility of the operators involved in the construction of road paving.

The StarAsphalt S.p.A. is constantly looking for innovative solutions and undisputed advantages on several fronts for the community, proposing advanced performance additives studied in its laboratories and realized in its production sites, in compliance with Regulation (EC) no. 1907/2006 concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) and the establishment of the European Chemicals Agency, resulting from the use of diversified products that are less and less harmful to humans and for the environment.

Considering the amount of the treated aspects and the continuous development of products and technological innovations, the following writing will be in continuous evolution.

NOTE

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