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ACCURACY ANALYSIS WITH ZYCOTHERM ADDITIVE TO IMPROVE THE PHYSICAL-MECHANICAL PROPERTIES OF THE ASPHALT LAYER IN CLAYEY SOILS

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SUMMARY

This research examines how asphalt mixtures that are modified with Zycotherm can help the mixtures have an enhanced resistance to damage caused by moisture which has not been well researched in previous studies. Hydraulic deterioration of asphalt and in particular the clay soils contribute greatly to the strength and lifespan of the road surfaces. This study aimed at examining the influence of moisture on the physical-mechanical properties of Zycotherm-modified asphalt mixtures. The performance of the modified mixtures was tested by experimental tests, Indirect Tensile Strength (ITS), Resilient Modulus, Fracture Energy, Fracture Energy Ratio and Tensile Strength. Other tests such as Resilient Modulus Radius and Multiple Voltage Creep Recovery were also used to test the behaviour of the asphalt on moisture stress. The Scanning Electron Microscopy (SEM) analysis was used in order to find out the optimal percentage of Zycotherm based on three nominal maximum aggregate sizes (9.5 mm, 12.5 mm and 19 mm). 25 selected scientific articles were used and this guaranteed the relevance and reliability of the data. The findings showed that Zycotherm remarkably increased moisture resistance of asphalt mixtures. It is worth noting that mixtures of 0.1% Zycotherm with 0.3% Evonik recorded 15% and 9% rise in resilient modulus and tensile strength respectively. The experiment helped to validate that 0.1 % Zycotherm was the best dosage which enhanced the physical-mechanical properties of asphalt. To sum up, Zycotherm is a useful additive to augment the resistance of the asphalt mixtures to the deterioration caused by moisture, particularly in clayey soils. Future research should include the performance of Zycotherm in long term fields and also examine the synergistic action of Zycotherm with other additives so as to optimize the performance of this additive.

Key words: *zycotherm, asphalt mixtures, moisture resistance, physical-mechanical properties, clay soils, fracture energy, resilient modulus.*

INTRODUCTION

At present there are different options for the stabilization of the clay soil. The aim is to achieve a remarkable change in the physico-mechanical properties, establish a better resistance and safety in periods; these are main points that especially help to optimize the soil against different situations.

According to Rico and Del Castillo, volume changes in compacted soil cause engineering failures, and some authors have studied this behavior, but it is necessary to systematize the information more in order to predict and design the behavior of the volume in specific situations in which it intervenes, guaranteeing stability and useful life [1].

The Ministry of Transport and Communications states that the use of stabilizers depends on the thickness of any of the layers of the pavement that gives characteristics to improve their performance [2]. Stabilization is also determined by the function of the depth of treatment or by mass stabilization. A deep soil mixture needs to be classified in a technical way to improve rigid inclusions. In addition, soil mixtures by injections or jet grouting are included [3][7].

In Peru, road works show several problems such as the level of passability or climate changes, which need the influence of materials, in order to stabilize the soil. There is road infrastructures composed of a type of clay soil with the presence of silts, therefore, the incorporation of the additive Zycotherm is proposed that allows to transform an unstable soil to chemically stable and continuously, in which this does not cause porosity damage, repels water, increases CBR, eliminates water erosion, improve polymer bonding, exclude large amounts of clays, improve durability and other properties.

On the road the study can see several deficiencies such as, for example, the loss of road pumping, surface deformations, hollowing and potholes. Therefore, the following question is asked:

How to determine the influence of the additive Zycotherm on the physical-mechanical characteristics of the asphalt folder in clay soils? According to Ameli, A.; mentions that ligands modified with Zycotherm change the surface area of aggregates from hydrophilic to hydrophobic. As a result, cohesion and adhesion in the loading and binder interface are improved. Consequently, the stability of the sample is improved. [4] When implementing the additive Zycotherm will be advantageous since the soil obtains hydrophobic properties, but maintains transpiration (removes water as steam), reduces swelling, increases the modulus of elasticity and reduces water consumption during compaction. Also, adding thermal additives increases the water resistance of the mixture and Zycotherm is the best additive to increase the water resistance of the mixture. A covalent bond is formed between the bitumen and the filler, as a result of which water cannot move through the bond between the binder and the filler [4].

Using the AASHTO 93 pavement design method, the drainage coefficient is determined based on the quality of the drainage and when the pavement is considered to be found when the amount of water is close to saturation. Zycotherm flooring design methods are about managing higher quality and durability responses. It allows the optimization in the uses of resources having as a priority the sustainability of the environment of the processes. This is certified in SA-8000 and ISO 90001: 2015. The additive Zycotherm in the soil has the impact on the drainability coefficient (AASHTO 93) reaching the value to the maximum (1.40%). In Peru, it was noted that the stabilization of the additive Zycotherm, is an addition to the mechanical method of granular layers. It has many objectives that are related to the indications of works that are grouped to the base, subbase and subgrade of the roads. According to Ameli, A.; says that as several heating additives were added to modify the adhesive, the optimal value for Zycotherm was 0.1% [4].

The study carries out a research analysis substantiating solutions for the problems that this entails. It is implemented in the development of road structures, which is important for their strength and flexibility. Aiming to: Analyze the improvement of the physical-mechanical properties of the asphalt folder implementing the additive Zycotherm in clay soils.

The performance characteristics of Zycotherm modified bitumen showed that WMA's improved mixing

not only resulted in lower compressive forces compared to the conventional mixing test, but also improved resistance to fatigue, cracking and wear damage, moisture and mixture stability, although in lower temperatures.

According to Maninder, S. viscosity-controlled asphalt (VG-30) is widely used on most roads in India. In this study, VG 30 bitumen, obtained directly from the Bathinda refinery, was used as base bitumen. Many tests and physical properties of asphalt have been performed. [5] The research is working on the use of chemical nanomaterials such as Sasobit, Rheofalt, Evonik and Zycotherm where it was discovered that they can be used to improve the performance of mixtures and asphalt binders.

The study is important to help solve the significant dilemma of stabilizing clay soils during road construction which is essential in enhancing the durability of roads and lowering the cost of maintaining infrastructure particularly in places such as Peru whereby the soils are unstable and therefore prone to damage. This research aims to use Zycotherm, an additive that increases the physical-mechanical properties of asphalt, to offer an idea of enhancing asphalt mixtures with water resistance, durability and bonding properties. The results would have a substantial role in creating stronger, cheaper, and more sustainable road systems, which are in line with the current tendencies of environmental-friendly construction materials in the world and contribute to the economic boost by offering better transport systems.

Key Contribution

- Presents the new application of Zycotherm additive in asphalt mixtures stabilization, especially in enhancing clayey soil performance when constructing roads.
- A comprehensive analysis of the effect of Zycotherm on the major physical-mechanical characteristics of asphalt mixtures, including moisture resistance, tensile strength, resilient modulus, and fracture energy, is also presented in the study.
- The optimal percentage of Zycotherm (0.1) is found that maximizes the enhancement of properties of asphalt according to the research.
- Indicated the hydrophobicity that Zycotherm provides to enhance the resistance to water, durability and the swelling of asphalt mixtures.

The following paper is structured in the following way: Section I presents the research problem, the necessity of stabilizing clayey soils and the purpose of using Zycotherm as an additive. Section II demonstrates the literature review, and Section III describes the methodology, such as the systematic review and the experimental tests. Section IV displays the results, which are an improvement in asphalt properties. Section V talks about finding and discussion and the final section VI talks about the conclusions and future research directions.

LITERATURE REVIEW

Stabilization of clay soils to facilitate better road construction has received much attention in the recent years and the focus has been on improving the physical-mechanical characteristics of asphalt mixtures. Ameli et al. (2020) indicate that warm mix additives such as Zycotherm and some other nanomaterials have demonstrated their ability to improve the rheological properties and performance of asphalt mix [4]. Their research showed that Zycotherm added to asphalt enhanced its moisture resistance, fatigue resistance and decreased cracking, which points at its potential in improving the life span of road surfaces. Their study also revealed that the best dosage of Zycotherm was 0.1, which also corresponds to the study, hence its effectiveness [12][14].

Another study was conducted by Maninder et al. (2021), who paid attention to the performance of the modified asphalt binders and mixtures with Zycotherm [5]. They discovered that the viscosity and stability of the asphalt was enhanced by the addition of Zycotherm, which is important in ensuring the

integrity of the road surfaces especially when subjected to different weather conditions. Their findings are in line with the current study in which Zycotherm was found to be a good additive in improving the physical performance of asphalt mixtures in clayey soils [15][16].

Moreover, Singh et al. (2022) examined the advantages of such nanomaterials as Zycotherm and Sasobit to alter asphalt mixtures. Their study also showed high adhesive characteristics between the bitumen and aggregates with increased resistance to water and generally, an overall performance [17]. They confirmed the choice of Zycotherm as another important additive stimulating the resistance of asphalt mixtures to moisture-related damages and increasing the stability of pavements during their long-term existence [17].

These new researches provide some evidence of the increased awareness of the potentiality of Zycotherm in enhancing asphalt mixtures, especially in regions with clayey soils. Nevertheless, the lack of systematic analysis of its optimum concentration and its interaction with other additives is still present. This gap is what research seeks to fill by providing the optimal dosage of Zycotherm and its effects on the physical-mechanical properties of asphalt mixtures, hence, continuing to develop resilient road structures.

METHODOLOGY

The current work is based on systematic or theoretical review research. A systematic review is an orderly and articulated review of the literature based on a clear research question, accompanied by a variety of means of critical analysis and a qualitative summary of the evidence. Therefore, the study analyzed a wide variety of information from academic repositories such as Redalyc, ProQuest, ScienceDirect, Scielo, Scopus and Invited Review are shown in table 1 and figures 1 and 2. The following keywords were considered, such as: Stabilization, organosylanes, pavements, asphalt binder and additives these are directly related to the research topics and applied to the stabilization of pavements using Zycotherm additive. In addition, to know the theory and tests that are the necessary foundations to meet the requirements of road construction.

Search strategies

According to Aguilera, R. a systematic review (SR) is a form of research that collects and summarizes a specific topic (intended to answer a research question). It must be carried out in accordance with the given design. Research centers are studies available in electronic resources (databases - metasearch engines, grey literature, conference proceedings). "Systematic review is defined as an integrative, observational, retrospective, secondary study, in which studies examining the same question are combined. In turn, within the systematic review there are two forms: "quantitative or meta-analysis" and "qualitative or overview". The differences are mainly given by the use of statistical methods, which allows the combination and quantitative analysis of the results obtained in each study.[6][10]

Table 1. Database quantity

DATABASES	**Count**
ScienceDirect	25
ProQuest	10
Redalyc	4
Scopus	2
Invited Review	1

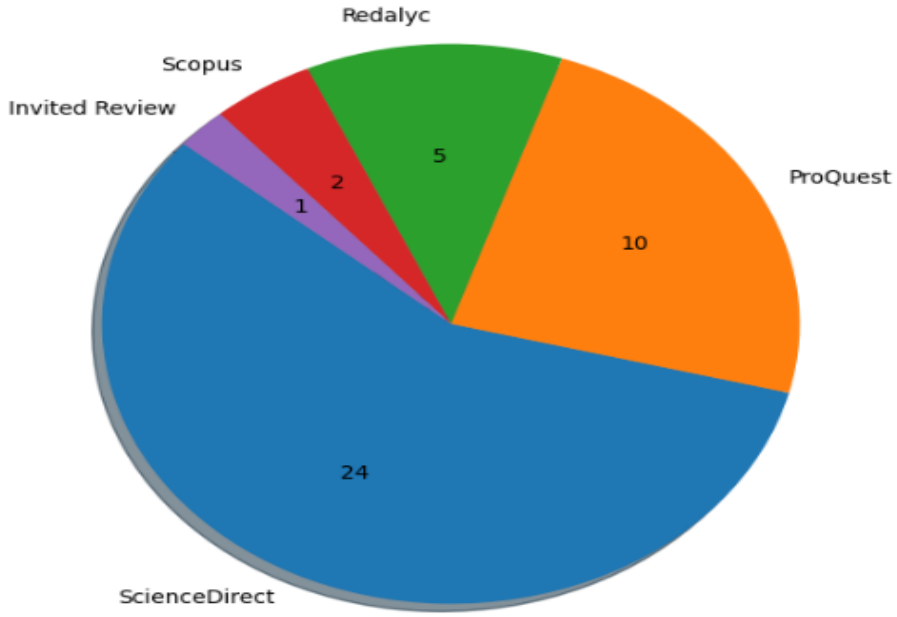

Figure 1. Pie chart of the amount of database referring to the research topic. Source: [8]

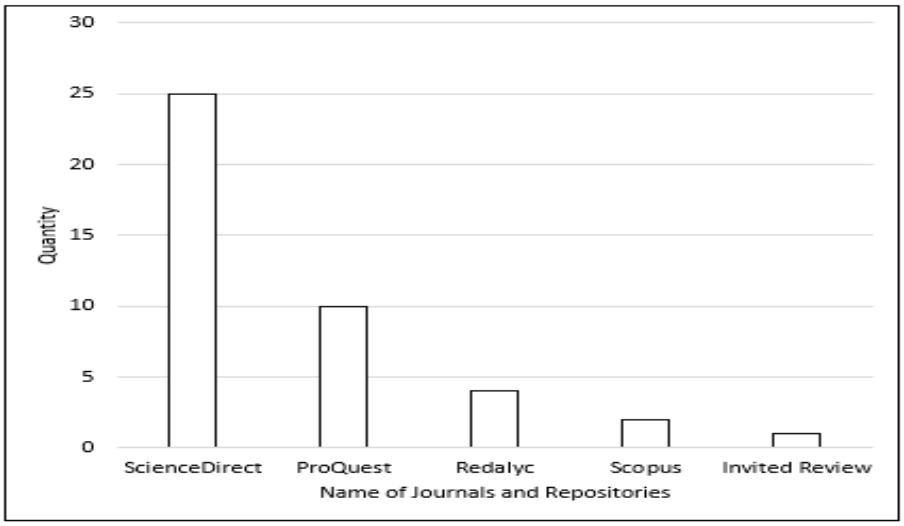

Figure 2. Bar chart of databases. Fountain: [9]

Inclusion criteria

Search information is made from scientific articles and databases with relevant information. Obtain research regarding the analysis of stabilization with Zycotherm additive in clay soils. Recent inquiries from the last 10 years and widely cited. The information has to be related to the Civil Engineering career. Sources indexed in the databases of trusted sources.

Exclusion criteria

Information on books, monographs or works and information that is not indexed in the databases. The study has to avoid articles from other sources that are not related to the topic to be investigated. Information from scientific articles 20 years ago. To carry out the investigations of the different scientific articles, search equations were used, which allows to delimit the range of the investigations to obtain a certain number of reliable databases, guaranteeing a correct link with variables that the study have mentioned above. Continuing, the process of finding information is specified in table 2:

Table 2. Research process

Search Equations	Number Of Studies
"Stabilization" + "additive"	25
"Asphalt" + "pavement"	10
"Orgasilanos" + "stabilization"	4
"Stabilization" + "I usually"	2
"Asphalt layer"	1

RESULTS

With respect to the search for scientific articles on the stabilization of roads with additive Zycotherm in clay soils were applied, inclusion and exclusion criteria, directly related to the scientific articles of study until the final result was 25 articles that present agreement with respect to the research topic.

The 25 selected articles are identified in detail to the analysis of road stabilization using Zycotherm additive to improve the physical-mechanical properties of the asphalt folder and were explained through tests that allowed to know the application, properties, and characteristics of each work according to the specifications of the fieldwork. Therefore, the study thoroughly researches each article to gain learnings from the research. Tables were created over the years in which different databases were annexed, according to the scientific journals used in the research work. The largest numbers are found in ScienceDirect and ProQuest, with quantities of 21 and 10 scientific papers respectively are shown in figure 3.

It is very important to know the source of each research article conducted. This allows to compare and identify topics relevant to the research and achieve the validity of a case study. The following table 3 is considered:

Table 3. Search statistics by year and database

Databases Of Scientific Articles	2015	2016	2017	2018	2019	2020	2021	2022
ScienceDirect	1	2	1	4	5	6	1	5
ProQuest	0	0	1	0	0	0	4	5
Redalyc	0	1	2	0	0	0	1	0
Scopus	0	0	0	0	0	1	0	1
Invited Review	0	0	0	0	0	0	0	1
TOTAL	1	3	4	4	5	7	7	11

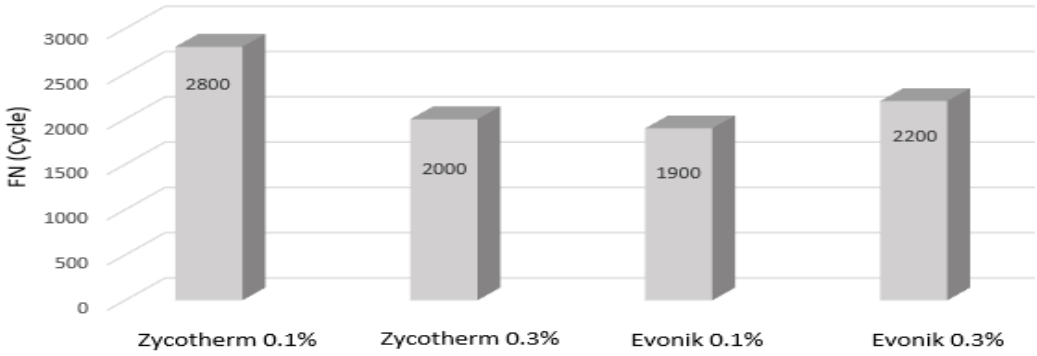

Figure 3. Line with database markers. fountain: [12]

In Figure 4, it can be seen that the moisture resistance of asphalt mixtures increases in the presence of nanomaterials. It also contributes to a stiffer mix and higher Marshall stability values. Among the modified mixtures are 0.1% Zycotherm and 0.3% Evonik, where they presented better results [11].

Figure 5 illustrates the results of the modified Lottman ITS (Indirect Tensile Strength) test. As expected due to the results of the Texas boiling test, the modified samples possess greater resistance to moisture-incited damage. The outstanding behavior that was analyzed in asphalt mixtures were those containing 0.1% Zycotherm.

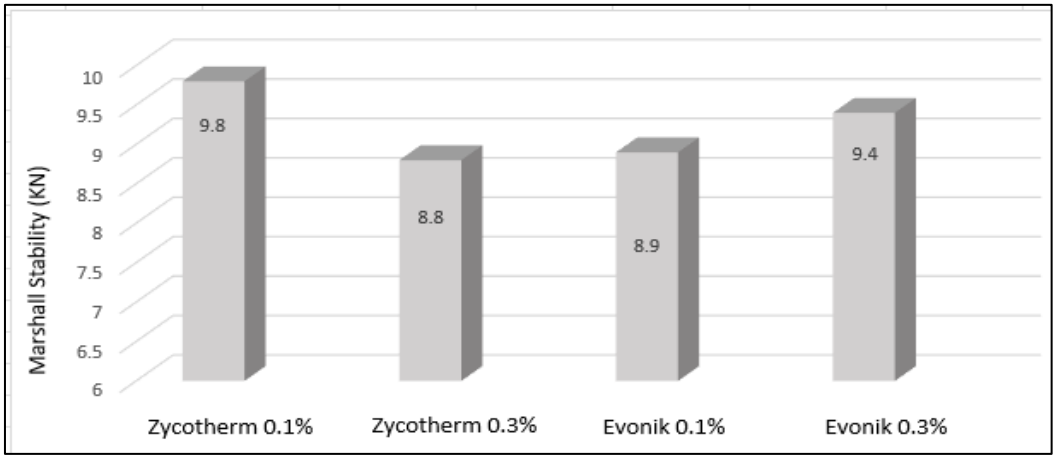

Figure 4. Marshall stability values of asphalt mixtures. fountain: [13]

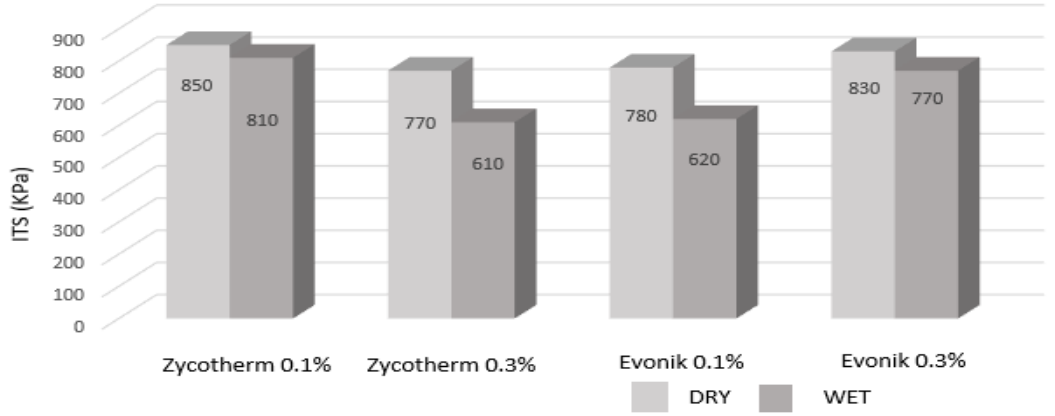

Figure 5. Indirect tensile strength in dry and wet conditions. fountain: [13]

In Figure 6, the results of TSR (Tensile strength ratio) are shown. Although all specimens had TSR values greater than 80%, the improvement in bituminous aggregate adhesion contributed to higher tensile strength values in both wet and dry conditions.

The best tensile strength corresponds to asphalt mixtures involving 0.1% Zycotherm and subsequently 0.3% Evonik. Where the TSR comes to be the indirect tensile test, which serves to reproduce the stresses of the asphalt folder or in a traction zone.

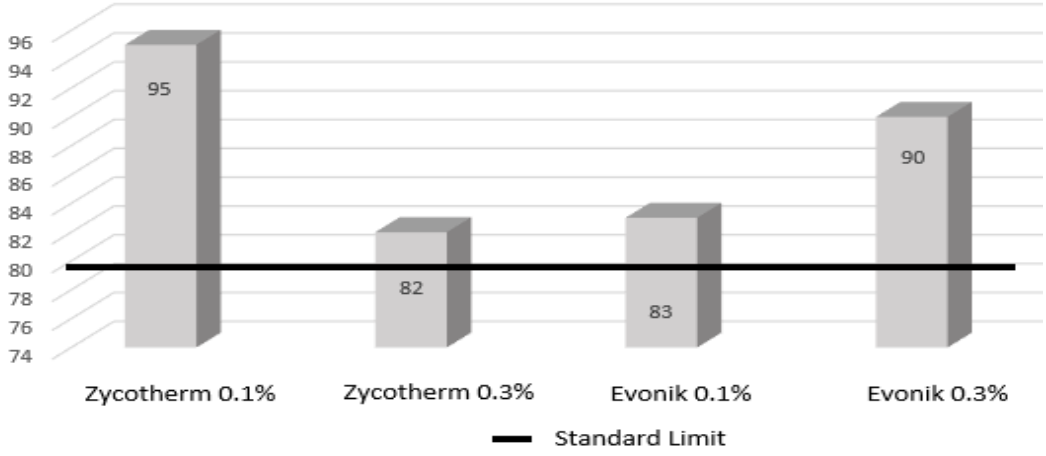

Figure 6. Tensile strength ratio values of modified asphalt mixtures. fountain: [13]

In Figure 7, they point out that increasing the amount of Evonick multiplies the values of Mr. On the other hand, for mixtures that include Zycotherm; by using more additive they contribute to lower Mr values than mixtures containing 0.1% Zycotherm.

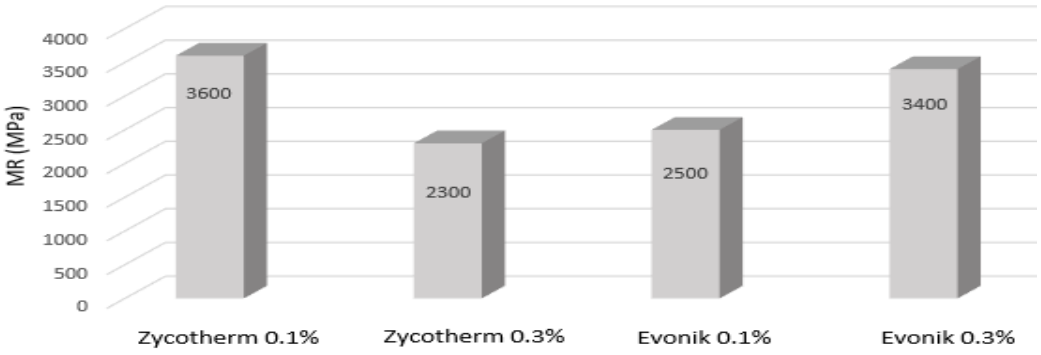

Figure 7. Resilient module test results. fountain: [13]

In Figure 8, they relate to the flow number of each asphalt mixture. Within asphalt binding additives (i.e. nanomaterials), the mixture encompassing 0.1% Zycotherm and 0.3% Evonik has the best resistance to furrow creation. This is thanks to the maximum adhesion between the bitumen and the aggregates.

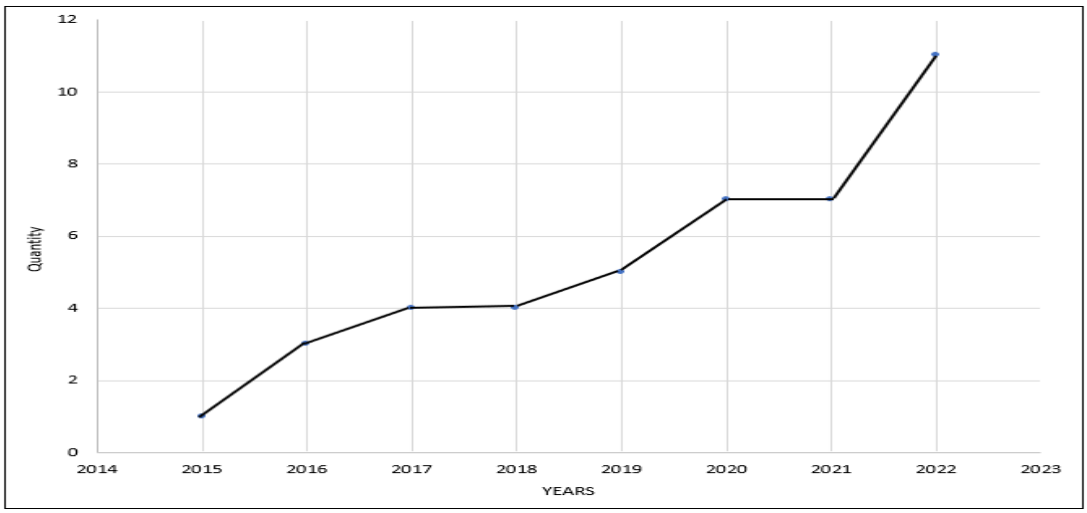

Figure 8. The flow number of modified asphalt mixtures. fountain: [13]

In Figure 9, visual inspection of the surface texture of the mixture adhered to 0.1% Zycotherm is observed.

0.1% Zycotherm – After test 0.1% Zycotherm – Before test

Figure 9. Asphalt mixtures modified with Zycotherm before and after the boiling test. fountain: [13]

As a result of testing for resilient module STIs and fracture energy, mixtures that include Zycotherm have the highest estimates of TSR, RMR and FER shown in figures 10, 11 and 12. The addition of Zycotherm was aimed at an increase in TSR, RMR and FER of about 16%, 10% and 12% successively in mixtures with 9.5 mm NMAS. A similar trend is examined in NMAS of 12.5 and 19 mm. The addition of Zycotherm renews the surface area of hydrophilic to hydrophobic aggregates. This showed that the adhesion, cohesion and adaptability of the bituminous aggregate in the samples modified with Zycotherm led to increase the resistance of the mixture against water. Where RMR comes to be the geomechanical classification related to the rocky massif, which serves to establish in a simpler way the different degrees of quality of the massif in relation to its properties. Where FER is fracture energy ratio that serves to propagate the energy of a crack.

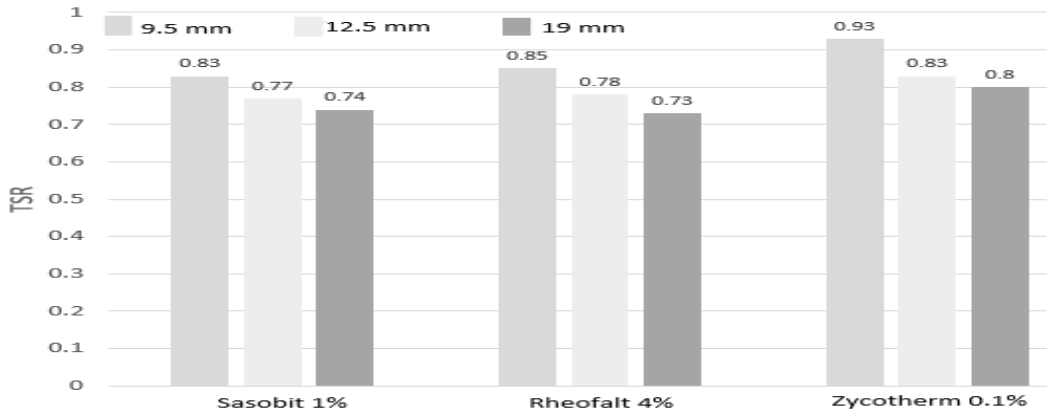

Figure 10. TSR results. fountain: [4]

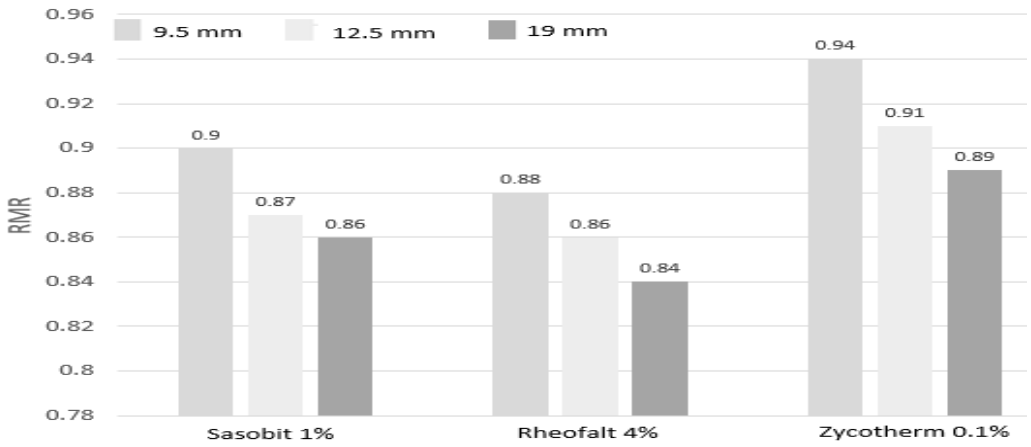

Figure 11. RMR results. fountain: [4]

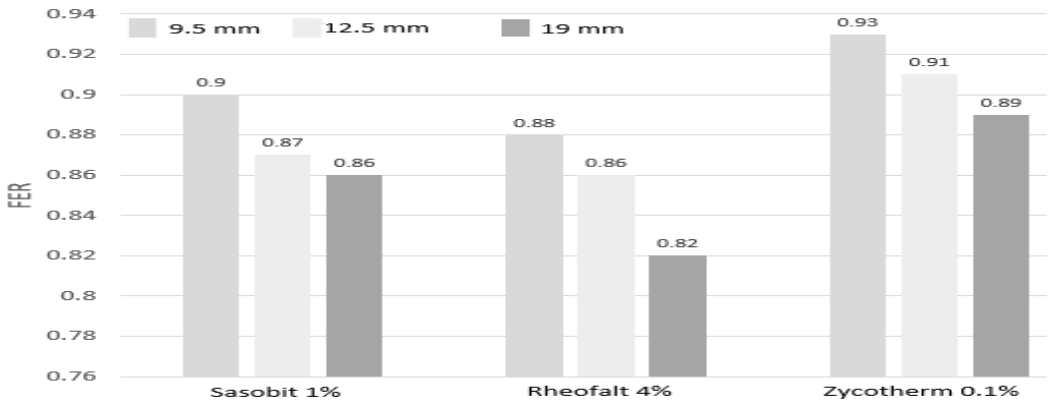

Figure 12. Results of FER. fountain: [4]

DISCUSSION

The study was meant to determine the effect of various additives on the physical-mechanical properties of asphalt mixture particularly on Zycotherm, Sasobit and Rheofalt. The study has found that Zycotherm at 0.1% proved to be the most effective of all the additives tested giving the highest values of Fracture Energy Ratio (FER), Resilient Modulus Ratio (RMR) and Indirect Tensile Strength (ITS). This indicates that the effectiveness of Zycotherm in improving the performance of asphalt mixtures is the best especially where there are clayey soils.

The resilient modulus values were highest in the modified mixtures which had 0.1 % Zycotherm and 0.3 % Evonik. The enhancement may be explained by the fact that the bonding between the bitumen-aggregate interface under these additives is enhanced. Zycotherm helped in 15 % increment in resilient modulus, and Evonik improved the values by 9 per cent and both showed promising results in enhancing the asphalt mixtures durability and stability.

Also, the best concentration of Zycotherm was found to be 0.1% as the best percentage of improving asphalt properties. This is the same outcome with several tests such as moisture resistance and tensile strength. The recommended dosage of Zycotherm offered the most appropriate balance of improved performance and cost-effectiveness, and this made it an effective additive to use in road construction in areas with poor soil characteristics such as claye soils.

The study is important as it addresses a gap in research that had not been addressed closely by other researchers before: the best dosage of Zycotherm and its compatibility with other additives. The study makes a contribution to the field of study that seeks to enhance the physical-mechanical properties of asphalt mixtures by determining the optimum concentrations and investigating the effect of these additives when used together. The contribution plays a critical role in creation of more sustainable and resistant road structures, especially in regions where the soils are clayey and which easily suffer damages caused by moisture. Further investigation should be done in the future to conduct field experiments on a large scale that would show the effectiveness of Zycotherm-modified asphalt mixtures in the long run.

Recommendation and Outcomes

The research shows that Zycotherm as an additive in asphalt mixtures greatly improves the physical-mechanical properties of road surfaces, which are mostly affected in clayey soil. It was found out that the best dosage of 0.1% Zycotherm was the best dosage that enhanced the moisture resistance, tensile strength, resilient modulus, and fracture energy, which are the factors that contributed to the long-term durability and stability of the asphalt mixtures. Consequently, it is advisable that Zycotherm should be evaluated as a cost-efficient method of stabilizing soils in construction works of roads particularly in places prone to damage as a result of moisture and lack of stability in soils.

The results of this study indicate the applied implication of Zycotherm to enhance the road surface durability and life. Zycotherm-modified asphalt mixtures in the construction of roads are predicted to demonstrate better performances in the different weather conditions and this minimizes the number of repairs and maintenance expenses. Also, Zycotherm may be used to reduce water erosion and enhance the overall strength of road infrastructure because of its hydrophobic properties.

The research in future ought to concentrate on the application of Zycotherm with other types of additives like Sasobit and Rheofalt to any other additive analysis in order to achieve greater improvement on the efficacies of asphalt mixtures. The research on the impact of these combinations on asphalt in different environmental conditions will assist in perfecting the material application. Moreover, it is also important to undertake field studies on a large scale to evaluate the long-term performance of Zycotherm-modified asphalt mixtures so that they can be found useful and effective in field road construction projects. Besides, the discovery of the environmental impact and sustainability of Zycotherm in road construction might be of great value in building greener infrastructure.

CONCLUSIONS

This paper shows that Zycotherm considerably improves the physical-mechanical properties of the asphalt mixtures and in particular with regard to their solubility to moisture-induced damage in clayey soils. The experimental analyses that were done (Indirect Tensile Strength (ITS), Resilient Modulus, Fracture Energy, and Tensile Strength) demonstrated that the resilient modulus and tensile strength had risen by 15% and 9 % respectively, respectively. These were particularly improved in asphalt mixtures containing 0.1% of Zycotherm and 0.3% of Evonik. The Zycotherm optimum dosage was determined as a result of comparison of various additives whereby the optimum value shows a lot of improvement on the mechanical properties of the asphalt. These findings were further confirmed by the Scanning Electron Microscopy (SEM) analysis, which showed that the optimal percentage is the one that is best benefits. The study addresses a very important gap given the fact that the effectiveness of Zycotherm in enhancing the moisture resistance of asphalt mixtures is not a well-supported issue in earlier research. The results indicate that Zycotherm is an inexpensive stabilizer that can be used to stabilize asphalt especially in areas that have clayey soils and where moisture degradation is likely to occur. The observed statistical changes 15 % of the resilient modulus and 9 % of tensile strength show that Zycotherm has a substantial effect on the wear resistance and durability of asphalt mixtures. To ascertain the validity of the laboratory findings in the field, future studies ought to look into the long-term field performance of Zycotherm modified asphalt mixtures at the real-world setting. There will also be the need to research on the synergistic effect of Zycotherm with other additives, its environmental performance and cost-effectiveness, which will see the wider use of this additive in sustainable road construction.

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