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Investigating the use of concrete and RCC instead of HMA in highway pavement in hot regions

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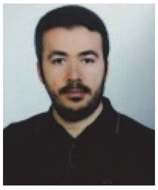

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Research Paper

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Investigating the use of concrete and RCC instead of HMA in highway pavement in hot regions

This study examines the impact of temperature on the Cizre-Silopi highway's bituminous hot mix asphalt (HMA) pavement, focusing on rutting issues exacerbated by high temperatures, which can reach up to 50 °C in the region. Despite rapid deterioration, especially under heavy truck traffic, the HMA pavement exhibited significant stability and flow resistance loss (approximately 52 %) between 20 and 50 °C. Concrete (C25) and roller-compacted concrete (RCC) pavements displayed minimal strength reductions under the same temperature conditions. These findings suggest that given the prevalent high temperatures and heavy axle loads in the region, concrete (C25) or RCC should be prioritised over HMA for pavement construction to enhance resistance against wheel rutting and temperature-induced damage. The observed rutting issues, even in the initial summer post-construction, underscore the urgency of adopting more temperature-resistant materials for road infrastructure under specified climatic conditions.

Key words:

asphalt pavement, pavement damages, concrete road, roller-compacted concrete (RCC), temperature effect

Prethodno priopćenje

Sedat Özcanan, Turan Fırat, Özgür Özcan

Istraživanje upotrebe betona i uvaljanog betona umjesto vruće bitumenske mješavine pri izgradnji kolnika autoceste u regijama s visokim temperaturama

Ovo istraživanje ispituje utjecaj temperature na kolnik autoceste Cizre – Silopi od vruće bitumenske mješavine (engl. hot mix asphalt – HMA), usredotočujući se na poteškoće s kolotrazima pogoršane visokim temperaturama koje mogu doseći i do 50 °C u regiji. Unatoč brzome propadanju, posebno pod utjecajem teškoga teretnog prometa, kolnik od vruće bitumenske mješavine pokazao je znatan gubitak stabilnosti i otpora stvaranju deformacija (približno 52 %) pri temperaturnome rasponu od 20 °C do 50 °C. Betonski kolnici (C25) i kolnici od uvaljanog betona (engl. roller-compacted concrete – RCC) pokazali su minimalno smanjenje čvrstoće pod istim temperaturnim uvjetima. Dobiveni rezultati upućuju na to da, s obzirom na prevladavajuće visoke temperature i velika osovinska opterećenja u regiji, za konstrukciju kolnika prednost treba dati betonu (C25) ili RCC-u u odnosu na HMA kako bi se povećala razina otpornosti na kolotrage i oštećenja uzrokovana temperaturom. Uočeni problemi s kolotrazima, čak i početkom ljeta nakon izgradnje, upućuju na hitno usvajanje materijala za cestovnu infrastrukturu koji su otporniji na temperaturu u navedenim klimatskim uvjetima.

Ključne riječi:

asfaltni kolnik, oštećenja kolnika, betonski kolnik, kolnik od valjanog betona (RCC), učinak temperature

1. Introduction

Asphalt remains the most widely used material for road pavements worldwide. However, considering asphalt is derived from petroleum, it contributes significantly to greenhouse gas emissions and causes adverse environmental impacts [1–4]. In recent years, highway authorities have become inclined towards environmentally friendly alternatives to conserve natural resources and promote sustainability. This study aims to reduce the carbon footprint of petroleum and its derivatives. Therefore, new asphalt mixture technologies and recycled materials are being explored to find more eco-friendly solutions [5–7]. However, asphalt remains the primary material used and has its own drawbacks.

The two most influential factors affecting pavements are traffic load and environmental effects [8–13]. While traffic load effects can be controlled by taking the necessary precautions, environmental effects are beyond our control. Although measures have been taken to address rainfall through drainage systems, temperature is the most significant environmental factor. Even though asphalt, used in road pavements, is sensitive to temperature [14–19], temperature is generally neglected in asphalt pavement design. In recent years, studies have been conducted to utilise temperature more effectively in asphalt pavement design, along with a few methods that consider temperature factors [20–22]. Although the temperature factor is considered in asphalt pavement design, asphalt material exhibits viscoelastic behaviour at high temperatures [9, 13, 14, 18]. Temperature is the most crucial factor determining the damage that affects asphalt performance, including rutting, thermal cracks, and fatigue [23–25]. Rutting is the damage most affected by temperature [26–30]. Although significant research and technologies exist regarding self-healing cracks in asphalt pavement [31, 32], repair rutting damage is not possible. While modifiers [33] enhance rutting resistance simply by improving bitumen quality, they do not completely eliminate rutting formation. A solution to this problem lies in exploring and using alternative materials (such as concrete), particularly in hot regions. However, the factors of damage detection and management of maintenance processes in both hot mix asphalt (HMA) and concrete with accurate estimations affect pavement performance [34, 35]. However, studies [36–39] have shown that concrete pavements have high performance despite faults, structural weaknesses, and environmental negativities.

Flexible pavements undergo significant damage owing to the temperature factor, with rutting damage being the most important factor. Rutting can damage both the pavement and other layers under the pavement. The most significant advantage of rigid pavements is the absence of rutting damage. Although detailed studies on the damages that occur in the pavement owing to the temperature factor remain limited, some associated studies have been conducted. The temperature effect is a factor used in pavement design [40]. Marshall et al. [41] explored the seasonal variation in the temperature of flexible pavements in Tennessee and its effect on pavement performance. They concluded that changes in temperature, particularly in winter and summer, significantly impact pavement distress, such as cracking and rutting. Park et al. [42] proposed an effective layer-temperature prediction model and temperature correction using falling-weight deflectometer (FWD) deflections. The results suggest that the proposed model can effectively predict pavement temperature profiles. The effects of various environmental factors on flexible pavements, including temperature, moisture, and traffic loading, have been investigated [43]. This study demonstrated that temperature significantly impacts pavement performance, particularly in cold regions, and can result in pavement distress and damage. Kang et al. [44] studied the temperature-field distribution rules of asphalt pavements using a regression analysis of actual temperature measurements, with the results indicating that the temperature distribution within the asphalt pavement was influenced by various factors, including solar radiation, wind speed, and air temperature. Gang et al. [45] investigated the effect of environmental factors, including temperature, on the predicted service life of flexible pavements. Research has shown that temperature significantly impacts pavement performance and can lead to increased pavement distress and reduced service life. Antonio and Maria [46] analysed the influence of temperature on flexible pavement deflection and concluded that high temperatures lead to increased deflection in pavement structures. Breakah et al. [47] examined the effects of accurate climatic conditions on mechanistic-empirical pavement design. These results suggest that using accurate climatic conditions can improve the accuracy of pavement design. A previous study [48] investigating the temperature field of an asphalt concrete pavement indicated that the temperature profile of the pavement was affected by several factors, including solar radiation, air temperature, and pavement thickness. Abu El-Maaty [49] investigated fatigue and rutting lives in flexible pavements, with the results suggesting that the pavement structure and traffic loading significantly impact pavement performance. Some studies analysed the sensitivity of MEPDG flexible pavement performance prediction to climatic factors [50, 51], with the results indicating that temperature and precipitation had the most significant influence on pavement performance. Li et al. [52] studied the potential impacts of climate change on pavement performance and design. Research has shown that climate change can significantly impact pavement performance, particularly in areas that experience extreme weather conditions, such as high temperatures or heavy precipitation. Moreover, Flavio and Leandro [53] investigated the effect of temperature on the mechanical properties of asphalt pavements, specifically considering the thermo-viscoelastic behaviour of the material. Research has shown that temperature significantly affects the stiffness and strength of asphalt pavements, which can ultimately affect their service life. Sascha and Frohmut [54] examined the effect of surface temperature on the fatigue damage of asphalt pavements.

They concluded that high surface temperatures could increase the risk of fatigue damage in asphalt pavements, particularly in areas with high traffic volumes. Another study [55] investigated the effects of climatic factors on flexible pavement performance and service life, with the results indicating that temperature and precipitation significantly impacted pavement performance, whereas wind speed and humidity had a smaller effect. Maha et al. [56] developed a mathematical model to evaluate the impact of Egyptian climatic conditions on flexible pavement performance. The results showed that high temperatures and solar radiation are the main factors affecting pavement performance. Similarly, Mohammad and Medhat [57] developed a mathematical model for the distribution of heat through pavement layers on Makkah Road. The results indicated that the pavement structure and climatic conditions significantly impact the distribution of heat through the pavement layers. Saha et al. [58] evaluated the effects of Canadian climate conditions on the MEPDG predictions of flexible pavement performance. They concluded that the predicted pavement performance under Canadian climate conditions was lower than that under the default MEPDG climate conditions. Fajing et al. [59] reviewed and provided a summary of research on flexible pavement temperature profiles, with the results suggesting that the temperature profiles of flexible pavements are affected by various factors, including solar radiation, air temperature, and pavement thickness.

The rapid deterioration of the asphalt pavement of the Cizre-Silopi road, i.e., the subject of this study, is primarily caused by heavy traffic congestion and the high-temperature effect. Considering this highway is an international trade route, the road experiences heavy truck traffic. While precautions have been taken to address the traffic impact through axle load limits and control measures, implementing preventive measures against temperatures reaching up to 50 °C in the region is not possible. Temperature is considered the primary trigger for deterioration in both newly constructed and existing sections of roads. Therefore, this study investigates the stability and flow resistance performance of asphalt pavements with respect to temperature. The temperature performances of concrete (C25) and roller-compacted concrete (RCC), more environmentally friendly alternatives to HMA, were also investigated and compared with those of asphalt. Section 2 provides a literature review that forms the background for this study. Section 3 presents the Cizre-Silopi Road and traffic composition, temperature conditions in the region, experimental procedures, and sample preparation details as a case study. Section 4 examines the damage caused by temperature in HMA pavement on the road, the experimental determination of the performance of HMA, concrete (C25), and RCC based on temperature effects, and presents the results. The final section summarises the results and provides recommendations.

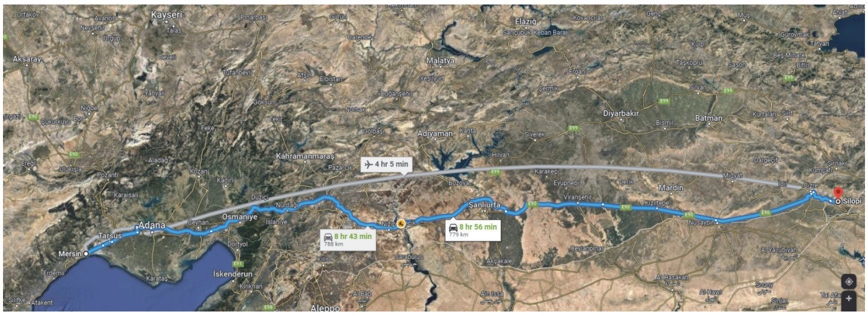
2. Case study, materials and methods

2.1. Cizre-Slopi highway and its traffic composition

Cizre and Silopi, indicated in Figure 1, are two districts located in the Şırnak province of Turkey. Şırnak is a province situated in the southeastern region of Turkey, sharing borders with both Syria and Iraq. Being located at a significant point due to its bordering position with the two countries, Şırnak gains particular importance, especially with the Habur border gate located in Silopi, which serves as a major trade route between Turkey and Iraq. Most of the trade between Turkey and Iraq is conducted via road transportation. The Cizre-Silopi Highway, depicted in Figure 2, represents the final section where the aforementioned trade logistics converge.

Figure 1. Cizre and Silopi locations from Google Earth [60]

Figure 2. Cizre and Silopi highway from Google Maps [61]



Slika 3. Figure 3. Mersin-Adana-Gaziantep-Şanlıurfa-Habur Highway (O.52) from Google Maps [61]

Table 1. 2022 AADT values for the Cizre-Silopi highway [62]

Vehicle type	Number	Percentage [%]
Car	5465	53.31
MCV*	696	6.79
Bus	66	0.64
Truck	230	2.25
Trailer	3794	37.01
AADT -T otal	**10251**	**100**
*Medium commercial vehicle, AADT - Annual Average Daily Traffic		

Figure 4. Cizre-Silopi highway platform and pavement view from Google Earth [60]

The road, as shown in Figure 3, is an extension of the Mersin-Adana-Gaziantep-Şanlıurfa-Habur (O.52) highway and serves as a significant route for logistics coming from Istanbul, Ankara, and Izmir, reaching Cizre via Diyarbakır Mardin and continuing to the border. Consequently, this road is subjected to substantial truck traffic.

Given the significance of these highways, there are significant deficiencies in both infrastructure and pavement structures, resulting in traffic safety problems. The high traffic volume and predominance of trucks have exacerbated the issues associated with this road. Table 1 provides the annual average daily traffic (AADT) for 2022 [62]. As shown in the table, 39.26 % of the traffic on the road consisted of trucks and trailers. When buses were included, heavy vehicles accounted for nearly 40 % of the traffic, significantly higher than the average value, posing a serious axle load issue for pavements.

A section of the Cizre-Silopi road, where infrastructure analysis was conducted based on the temperature factor, is shown in Figure 4. As shown in the figure, the road is divided into a central median and consists of two platforms. The road had four lanes, with two lanes in each direction (2 × 2). Additionally, damage, such as longitudinal-transverse thermal cracks, fatigue cracks (alligator cracking), and wheel tracks, can be observed on the superstructure. A detailed analysis of the damage occurring in the relevant superstructures is presented in Section 4.1.

2.2. Temperature situation in the region

The most important aspect of this study is the temperature performance of existing road infrastructure with HMA pavements. In this study, the effects of temperature on asphalt (HMA), Concrete (C25), and roller-compacted concrete (RCC) were investigated. Therefore, considering the temperature conditions in the region, especially during the summer months, as well as the annual average temperatures, is important.

The average hourly temperature values over the past 30 years in the Cizre region are shown in Figure 5. As seen from the figure, the temperature remained above 25 °C from April to November. Silopi exhibits a parallel pattern with Cizre, with an average temperature difference of approximately 1 °C lower. For a year, the maximum average temperature is around 27 °C for Cizre and approximately 26 °C for Silopi [63].

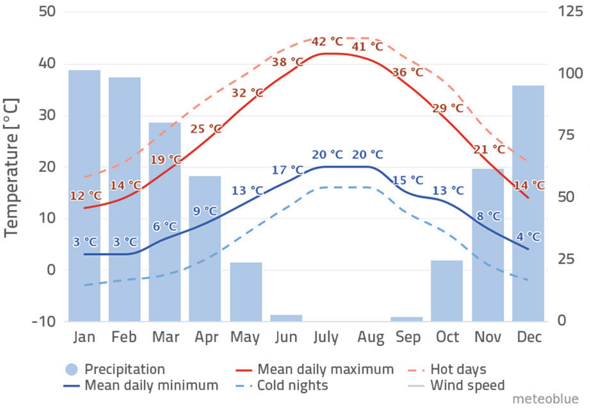


Figure 5. Average temperatures of Cizre [63]

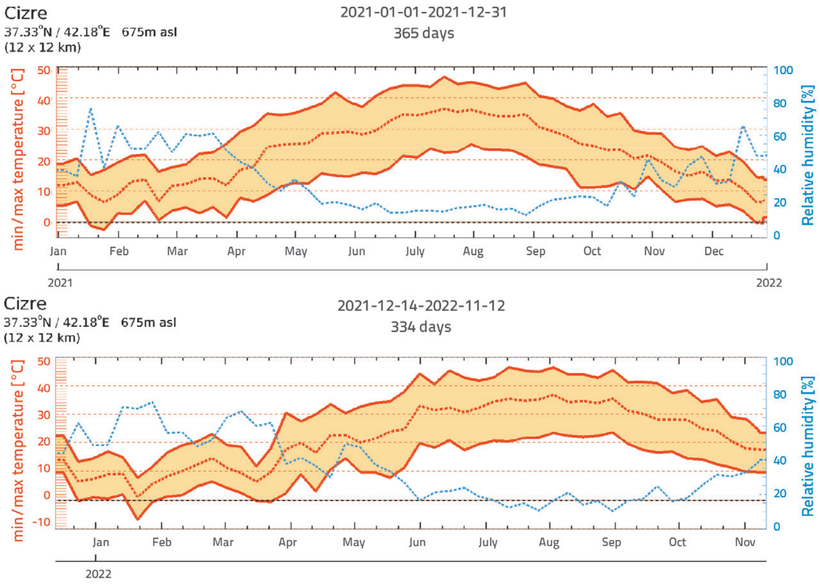


Figure 6. 2021–2022 min/max temperatures of Cizre [63]

As shown in Figure 6, in 2021 and 2022, the highest maximum temperature in Cizre was observed to be around 50 °C in July/August [63]. This temperature was also recorded in Turkey.

In the Introduction, the negative effects of temperature on asphalt pavements are discussed. The temperature conditions in the region where the study was conducted were as described above. At this point, noting the change in the surface temperature of the asphalt depending on the air temperature is useful. In particular, asphalt pavements absorb sunlight, causing it to heat more than the surrounding air. Owing to its dark colour and low reflectivity, asphalt retains its energy. As a result, the surface temperature of asphalt can be several degrees higher than the air temperature, particularly in summer. In a study conducted in summer [64], the temperature difference between the air and asphalt surfaces during the daytime is shown in Figure 7.

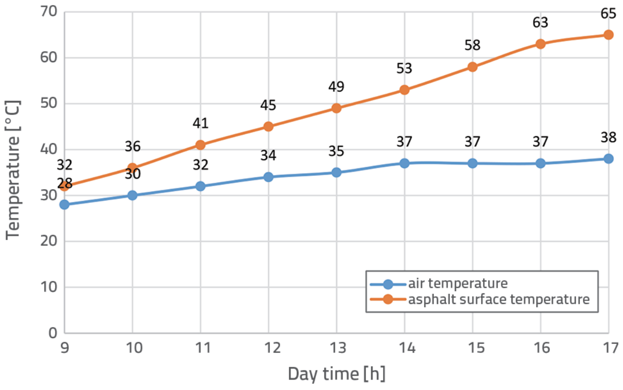


Figure 7. Air temperature vs. asphalt surface temperature

As shown in the graph, the asphalt surface temperature was above the air temperature throughout the day, and the temperature difference increased as the air temperature increased. Asphalt surface temperature exceeds 70 °C at points where the temperature reaches 40–50 °C. The sensitivity of asphalt to heat and its tendency to warm up significantly more than the air temperature adversely affect its mechanical properties. This characteristic is the underlying cause of the deterioration of asphalt pavements. In addition to the negative effects of temperature on the mechanical properties of asphalt, particularly in city centres, heated asphalt radiates heat to its surroundings, thereby contributing to the urban heat island effect. This phenomenon causes temperatures in city centres to be higher than those in rural areas [64].

2.3. Experiments and test procedure

2.3.1. Concrete mixer pan type

The concrete mixer is used to prepare materials such as concrete, which consists of various inputs such as cement, water, and aggregates in a laboratory environment. The materials were mixed in this device until they reached a specific consistency and were then used later. This process can be used to prepare concrete (C25) and RCC materials.

2.3.2. Core drilling machine

Concrete coring machines are devices used to obtain samples more easily, quickly, and without damage from concrete columns, beams, and slabs, as well as from materials such as asphalt pavement or rock stone. In this study, the samples were extracted from an HMA pavement constructed in situ. The cylindrical samples obtained using the core drilling method were subsequently subjected to Marshall testing.

2.3.3. Slump test

A slump test was conducted to determine the followability or consistency of the materials, particularly in the case of concrete. In this study, the slump test was used to test the consistency of the concrete (C25) and RCC samples. Specifically, for the RCC samples, a slump of zero is desired. After a homogeneous mixture was obtained in the mixing machine, the slump of the RCC material was measured before preparing the samples. The necessary adjustments were made to achieve a slump value of zero before the samples were prepared.

2.3.4. Compression test

A compressive strength test, commonly used to assess concrete strength, was conducted to measure the strength of the material under axial loading. In this study, compressive strength tests were conducted on cubic samples of concrete (C25) and RCC to determine their compressive strengths and related mechanical properties. Samples with different temperatures, such as 20, 30, 40, and 50 °C, will be subjected to this test to calculate the compressive strength and other mechanical values.

2.3.5. Marshall stability test

The Marshall test was conducted to determine the load and flow values of the asphalt pavement. In this study, it will be specifically used to measure the change and stability of the mechanical behaviour of HMA core samples that have been stored for 24 hours at different temperatures such as 20, 30, 40, and 50 °C. Instead of conducting a pressure test on an asphalt sample obtained from the field using a core device, the Marshall test is preferred for evaluating the stability, load, and flow values. This study aimed to investigate the changes in the mechanical performance of HMA, concrete (C25), and RCC samples at various temperatures. Considering different materials and constructions are involved, the influence of temperature on the mechanical behaviour is considered significant, rather than conducting tests under the same conditions. The main objective of this study is to examine the strength losses associated with temperature.

In addition to the Marshall stability test, two other tests have recently been widely used to simulate permanent deformations in asphalt pavements. These tests were wheel-tracking and cyclic compression tests.

- Wheel Tracking Tests: These provide a direct simulation of wheel loading and are often easier to relate to field performance, making them valuable for routine mix design and quality control.
- Cyclic Compression Tests offer detailed insights into fundamental material properties and behaviour under cyclic loading-essential for advanced material characterisation and model development.

However, considering this study aims to compare the effects of different temperatures on various materials, such as HMA, concrete, RCC, the simpler and more widely used Marshall test is preferred for asphalt analysis.

2.3.6. Laboratory oven

In this study, an oven was used to heat the samples to different temperatures to investigate the effect of temperature. HMA, concrete (C25), and RCC samples were placed in the oven at different temperatures such as 20, 30, 40, and 50°C for 24 h before undergoing mechanical testing. The samples were then removed from the oven and immediately subjected to mechanical testing.

2.4. Preparation of samples

The material compositions and ratios of the HMA, concrete (C25), and RCC samples are listed in Table 2. HMA content represents the applied material content of the respective roads. Obtaining HMA samples from the field rather than prepare them in the laboratory is preferable because the field sample would better represent actual applications. Figure 8 illustrates the preparation of the samples. In 8.a, the extraction of HMA samples from the field using a core drilling machine can be observed. As shown in 8.b, the core sample was cylindrical with a diameter of 100 mm and length of 150 mm. The preparation of the concrete (C25) and 150 x 150 x 150 mm cube samples is presented in 8.c. The preparation of the RCC mixture is shown in 8.d, where compaction was performed using a roller in the RCC application, resulting in a dense mixture and an approximately zero slump value, as demonstrated in the slump test 8.e. The 150 x 150 x 150 mm RCC samples are shown in 8.f.

Table 2. Material contents and combination ratios of HMA (Hot Mix Asphalt), concrete (C25), and RCC (Roller Compacted Concrete) samples

HMA		**Concrete (C25)**		**RCC [65]**	
Density	2420 kg/m^3	Cement	285 kg/m^3	Cement	250 kg/m^3
Bitumen	4.05 %	Water	213,5 l/m^3	Water	95.5 l/m^3
Aggregate 0-5 mm	48 %	Sand	615 kg/m^3	Sand	735 kg/m^3
Aggregate 5-12 mm	22 %	Aggregate 5-10 mm	415 kg/m^3	7-14 mm	810 kg/m^3
Aggregate 12-19 mm	14 %	Aggregate 10-20 mm	825 kg/m^3	Aggregate 14-20 mm	420 kg/m^3
Aggregate 19-25 mm	16 %				

Figure 8. a) HMA core cutting; b) HMA core samples; c) Concrete (C25) mix preparation and samples; d) RCC preparation in mixer; e) Slump test; f) RCC samples

3. Analyses and results

3.1. Analysis of highway deterioration and temperature effect

Visuals related to the damage occurring in the existing (old) and newly constructed asphalt pavements, based on on-site inspections conducted on the road where the study was conducted, are presented in Figure 9. In the top row, the visuals depict the damage observed in the existing (old) asphalt pavement. Here, (a) shows the wheel rutting damage and undulation, (b) shows the wheel rutting damage, fatigue cracks, and severe potholes, and (c) shows the wheel rutting damage, fatigue, block cracks, and alligator cracking. Wheel rutting is the most common problem observed in existing (old) asphalt pavements. Continuous wheel-rutting damage was observed along the entire Cizre-Silopi route. In the bottom row, visuals related to the newly constructed asphalt pavements on the respective roads are provided. As seen in (d, e, f) of the figure, despite being newly constructed, the pavement had already developed wheel-rutting damage and undulation in the first summer. Similar to the existing (old) pavement, the fundamental problem of the newly constructed pavement is wheel rutting damage.

As mentioned in the introduction, asphalt is a temperature-sensitive material [14–19], exhibits viscoelastic behaviour at high temperatures [9, 13, 14, 18]. In addition, temperature is one of the most important factors influencing asphalt performance in terms of wheel rutting damage, thermal cracks, fatigue, and other damages [23–25], with wheel rutting damage being particularly affected by temperature [26–30]. In this context, when examined, the main causes of the wheel rutting damage occurring in both the existing (old) and newly constructed asphalt pavements are primarily the heavy vehicles such as trucks, which account for nearly 40 % of the traffic composition on this road (Table 1), and most importantly, the record high temperatures reaching up to 50 °C during the summer months in the region (Figure 6).

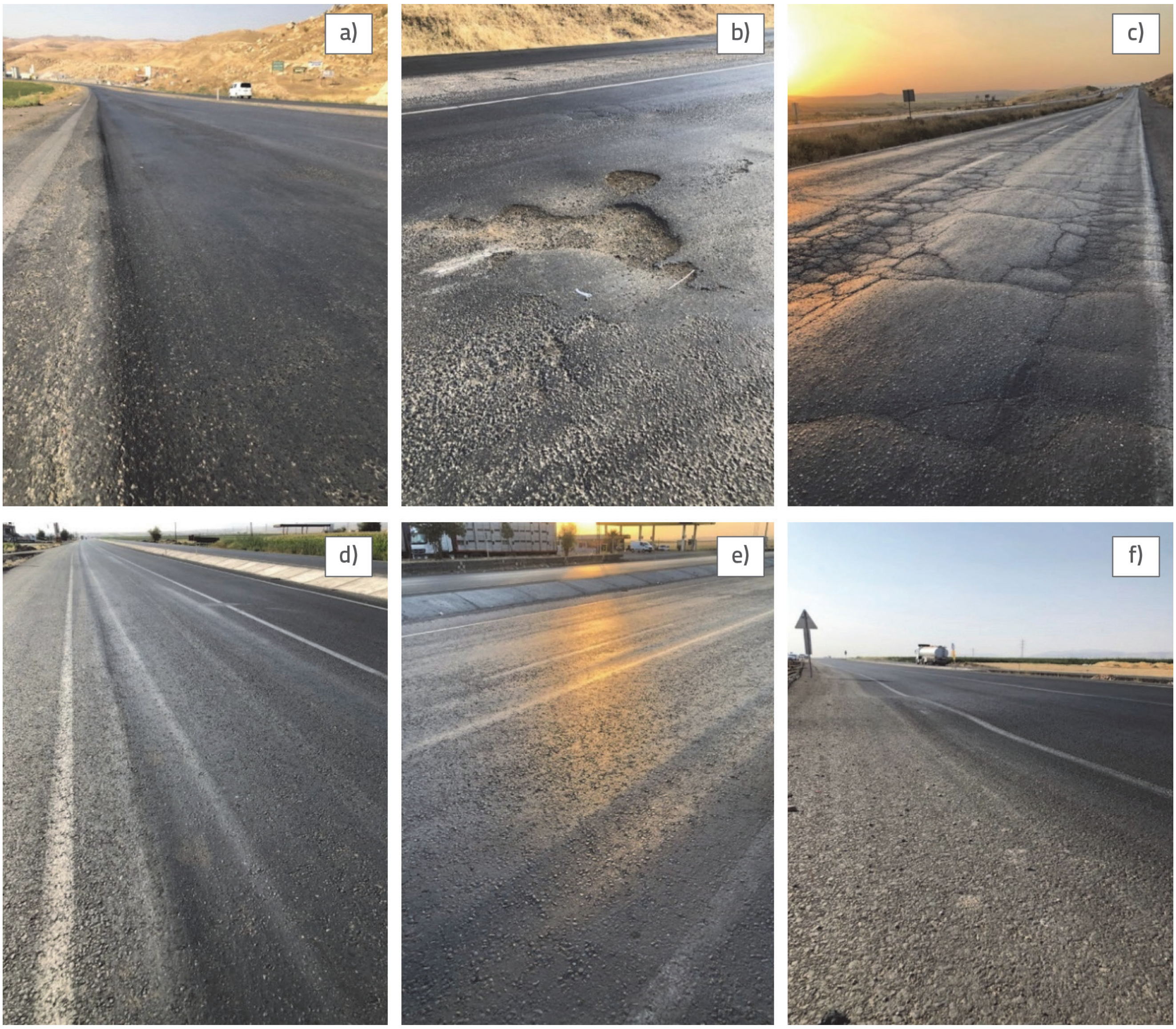


Figure 9. Damages in the old asphalt pavement: a) rutting and undulation; b) rutting, fatigue cracks and potholes; c) rutting, fatigue and block cracks, alligator cracks, damages in the new asphalt pavement; d, e, f) rutting damage and corrugation

3.2. Mechanical properties of HMA samples at different temperatures

Asphalt materials are sensitive to temperature. In this study, considering the temperature range from the average temperature (20 °C) to the maximum temperature reached during the summer months in the Cizre-Silopi regions (50 °C), the stability and flow resistance performance of the asphalt material were investigated using the Marshall Stability test for temperature values of 20, 30, 40, and 50 °C. For this purpose, the samples obtained from the field using the core-drilling machine were kept in a drying oven for 24 h, as shown in Figure 10.a). Subsequently, the samples were

Table 3. Mechanical behaviour changes in HMA (Hot Mix Asphalt) sample depending on temperature

Temperature [°C]	**Stability** [kN]	**Load** [kN]	**Stress** [MPa]	**Yield** [mm]
20	20.83	4.11	5.23	5.37
30	13.80	2.72	3.47	6.64
40	11.56	2.28	2.90	7.19
50	10.01	1.99	2.53	7.69

tested in a Marshall apparatus, as shown in Figure 10.b, to determine the stability and flow resistance of the asphalt material under temperature variations. Figure 10.c shows the obtained flow and stability data, and an example of the shape change of an asphalt specimen based on the test results is shown in Figure 10.d.

The stability, load limit, flow values, and stress limit behaviours of the HMA specimens are provided in Table 3 and Figure 11, considering the temperature dependency. As shown in the table and figure, the mechanical behaviour and properties of the HMA specimen underwent significant changes with increasing temperature. As the temperature rises from 20 °C to 50 °C, it leads to capacity losses of up to 52 % in stability, load, flow, and stress/pressure values. Considering the graphs in the figure, the most critical temperature range is between 20 °C and 30 °C. Within this range, the values dropped sharply, and after 30 °C, the downward trend decreased. In particular, the flow value of the asphalt material exhibits a significant increase of approximately 43 % with increasing temperature. As the temperature increases, the asphalt becomes more fluid and viscous.

Using a material easily influenced by temperature, especially in regions like Cizre-Silopi where temperatures reach 50 °C and on roads exposed to heavy traffic, can create significant handicaps for the infrastructure. Despite being newly constructed, the occurrence of damage, such as wheel rutting and undulations, in the pavement during the first summer indicates the effects of temperature and heavy vehicle traffic on the service life of the pavement, as evidenced from the abovementioned results and relevant tables and figures.

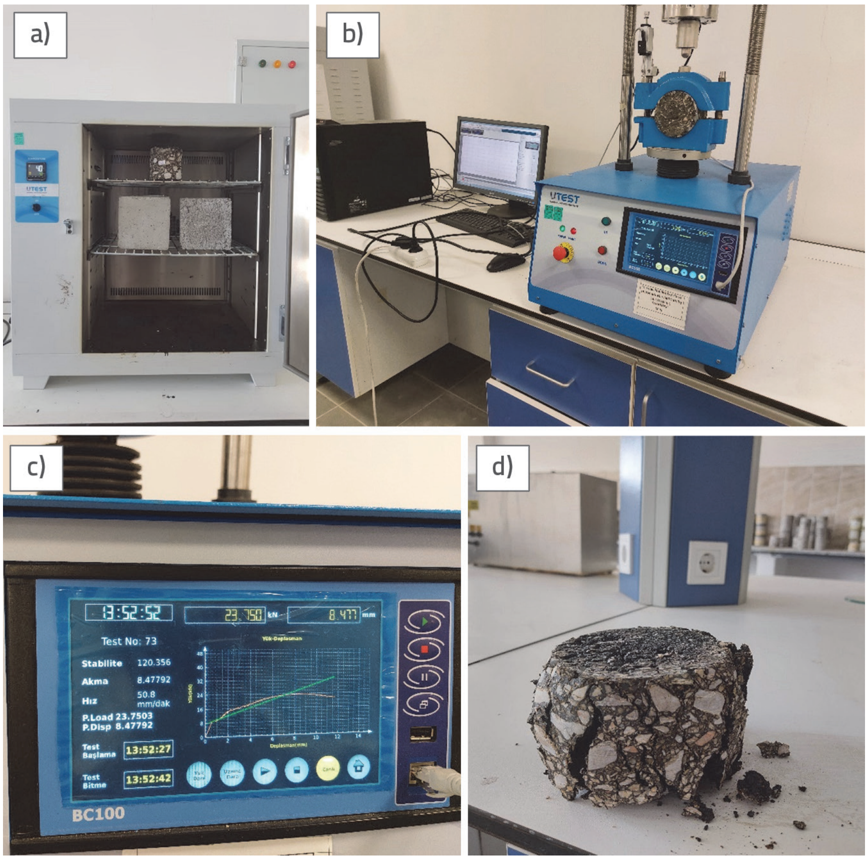


Figure 10. a) Heating the samples in the oven; b) Marshall stability machine; c) Analysis status and data obtained; d) HMA sample as a result of the test

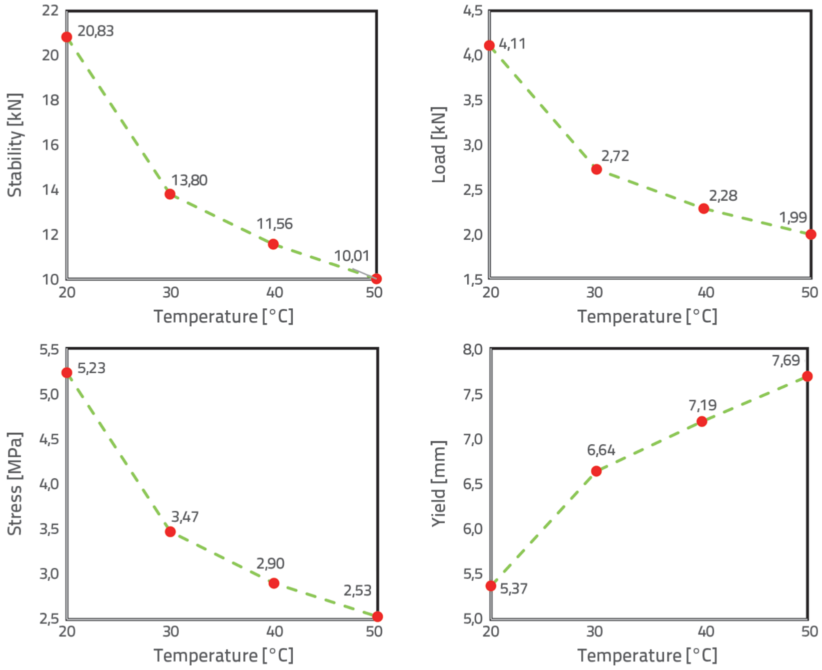


Figure 11. Graphical illustration of mechanical behaviour changes in HMA samples depending on temperature

3.3. Mechanical properties of concrete (C25) samples at different temperatures

The concrete (C25) samples were tested based on their compressive strength after curing and drying for seven days.

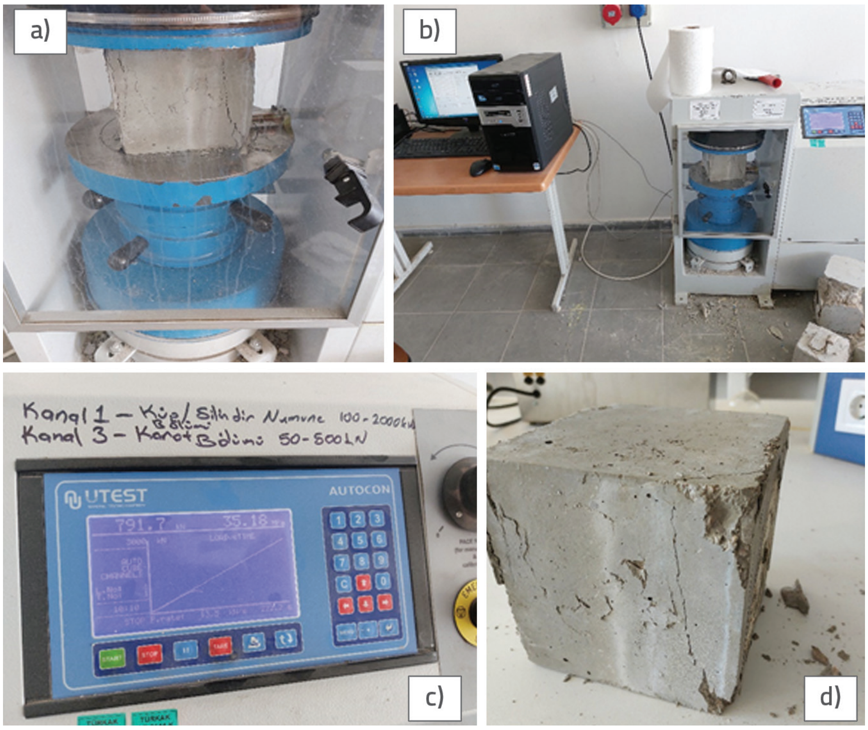


Figure 12. a) Compression test machine; b) and c) Analysis status and data obtained; d) Concrete (C25) sample as a result of the test

Table 4. Mechanical behaviour changes in Concrete (C25) sample depending on temperature

Temperature [°C]	**Compressive strength** [MPa]	**Load capacity** [kN]
20	36.42	819.50
30	35.18	791.65
40	36.58	823.04
50	35.99	809.70

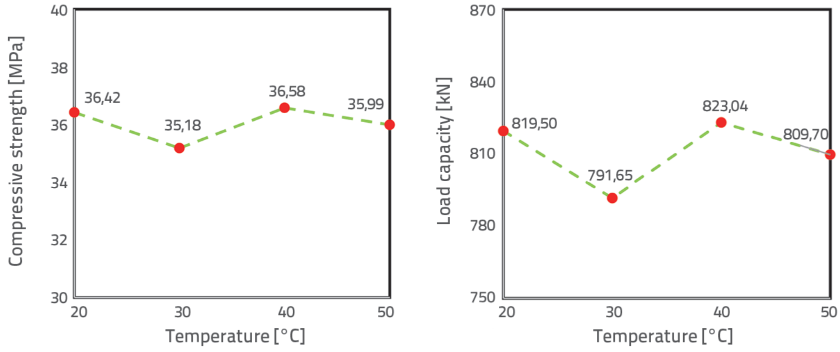


Figure 13. Graphical illustration of mechanical behaviour changes in Concrete (C25) samples depending on temperature

As shown in Figure 10.a, the samples were subjected to a 24-h curing process in an oven at temperatures of 20, 30, 40, and 50 °C before being tested for compressive strength. Figure 12 illustrates the compression testing apparatus (a), analysis and data collection (b, c), and an example of the test result (d). The mechanical properties of HMA samples were determined using the Marshall test. The concrete samples were subjected to a compressive strength test to evaluate their load-bearing capacities. The main objective is to determine how the mechanical properties of HMA and concrete change with temperature. Therefore, the focus is on the changes in the mechanical properties with temperature rather than on the specific methods used.

Compressive strength is the primary consideration in the use of concrete in structural design. Additionally, knowledge of the compressive strengths of concrete and RCC samples, unlike that of HMA samples, can provide an indication of their other mechanical properties. There is a correlation between the compressive and flexural strengths of concrete, and a high compressive strength indicates low permeability and high durability.

The compressive strengths and load capacities of the concrete specimens depending on the temperature are listed in Table 4 and shown in Figure 13. Unlike the HMA material, the mechanical properties of concrete remain independent of temperature. Despite the increase in the temperature, the compressive strength and load capacity of the specimens remained approximately constant. HMA is known that HMA is sensitive to temperature, as confirmed by the above results. In regions such as Cizre-Silopi, where the average temperature is around 26–27 °C throughout the year and reaches 45–50 °C in summer, concrete should be used as the pavement material instead of temperature-sensitive HMA, which has high compressive strength and is less affected by temperature. Concrete, which does not undergo changes in its mechanical properties with temperature and has a high compressive strength, does not suffer from wheel-tracking damage in road pavements. Concrete pavements can be an alternative solution to these problems, particularly wheel rutting damage and undulation caused by high axle loads and pressure owing to heavy vehicle traffic in HMA pavements.

3.4. Mechanical properties of RCC samples at different temperatures

The Roller Compacted Concrete (RCC) specimens, similar to the concrete (C25) specimens, were tested based on their 7-d compressive strength after curing. Before testing, the RCC specimens were kept in an oven at 20, 30, 40, and 50 °C for 24 h and then subjected to compressive testing. Figure 14 illustrates the compressive testing apparatus (a), analysis and data collection (b, c), and an example of the test results (d). The compressive strengths and load capacities of RCC specimens were determined. The RCC has the same composition as traditional concrete; however, the mixture proportions are different. RCC, a rigid and dry mixture laid as a road pavement and compacted with a roller, does not require joints, dowels, or steel reinforcement, such as concrete, and can be opened to traffic without a setting time. These characteristics make RCC pavements simpler, faster, and more cost-effective than concrete pavements.

Figure 14. a) Compression test machine; b) and c) Analysis status and data obtained; d) RCC sample as a result of the test

Table 5. Mechanical behaviour changes in RCC sample depending on temperature

Temperature [°C]	**Compressive strength** [MPa]	**Load capacity** [kN]
20	12.29	276.43
30	14.56	327.70
40	14.34	322.76
50	15.08	339.27

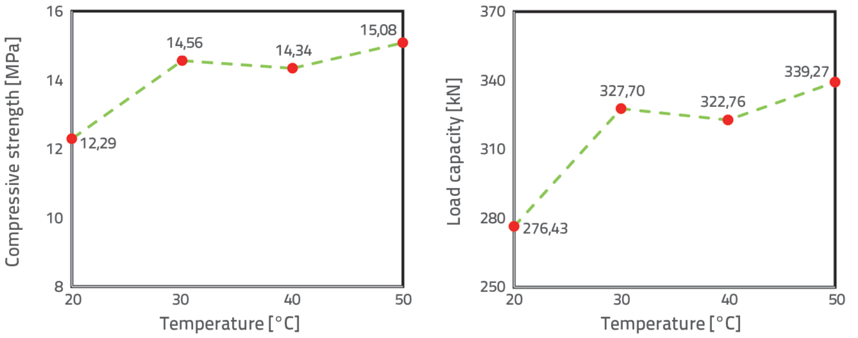


Figure 15. Graphical illustration of mechanical behaviouur changes in RCC samples depending on temperature

The changes in the compressive strength and load capacity of the RCC specimens with temperature variations are presented in Table 5 and Figure 15, respectively. While the compressive strength of the concrete (C25) reached 36 MPa, that of the RCC specimens remained constant at 15 MPa. The inherent strength of the RCC material was approximately 30 MPa because RCC has a low water content and gains strength through compaction in the field. However, in this study, the RCC material was compacted by tapping with a mallet into cubic specimens after preparation in a mixer. Therefore, the obtained compressive strength was slightly lower than that in field applications. However, in this study, the focus is not only on the strength of the RCC material, but also on its behaviour and changes with temperature. Surprisingly, the compressive and load strengths of the RCC material increased in parallel with increasing temperature. Particularly, RCC performance remarkably increased between 20–30 °C and behaved more stably between 30–50 °C. However, there was an overall improvement of 23 % in RCC performance with the temperature increase compared to 20 °C. In terms of mechanical properties, the HMA material is sensitive to temperature, whereas the concrete (C25) material exhibits stable behaviour. The advantages and reasons for preferring concrete (C25) over HMA in terms of the temperature-dependent performance are explained above. Considering its temperature performance and application advantages, RCC is a better alternative to concrete (C25). In a comparison made in a laboratory environment, RCC performed better than normal concrete (C25) in terms of mechanical properties and resistance to environmental effects [66].

3.5. Overall comparison of all results

The temperature performances of the HMA, Concrete (C25), and RCC specimens are listed in Table 6 and shown in Figure 16. A temperature value of 20 °C, close to the temperature value under normal conditions, was used as the reference value. The critical design parameter of stress/compressive strength was selected as the performance indicator. The changes between 20–50 °C are shown in the figure based on the stress strengths of the specimens at the reference temperature. As shown in the figure, HMA lost 52 % of its performance with increasing temperature. The performance of C25 concrete remained stable with temperature variations, whereas the performance of the RCC increased by 23 % with temperature. As mentioned previously, asphalt materials are sensitive to temperature. These results support the hypothesis. The critical temperature transition for asphalt occurs between 20–30 °C, indicating significant changes in behaviour above the average temperature. The asphalt material transitions from elastic to viscoelastic behaviour. High temperatures in the region and heavy vehicle traffic are the main causes of damage to HMA pavements. Although the sensitivity of asphalt to temperature and its loss of strength are evident, C25 concrete, which does not lose strength with temperature and even shows an increase in strength, and RCC materials would be a better solution for road pavements. Additionally, both C25 and RCC concrete materials exhibited high compressive strengths. The compressive strength of HMA decreases by 52 %, from 5.23 MPa to 2.53 MPa, with increasing temperature. The compressive strength of C25 was stable at 36 MPa, whereas that of RCC increased with temperature, reaching 15 MPa. In terms of compressive strength, C25 was 14 times higher than that of HMA, and RCC was six times higher. Therefore, considering heavy vehicle traffic and axle weights, C25 and RCC can better withstand pressures and loads than HMA. The superior temperature and compressive strength performances of the concrete materials compared with HMA are evident from the above results.

Table 6. Temperature performance of compressive strength of the HMA (Hot Mix Asphalt), concrete (C25), and RCC (Roller Compacted Concrete)

Temperature [°C]	HMA	Concrete (C25)	RCC
20	1.00	1.00	1.00
30	0.66	0.97	1.18
40	0.55	1.004	1.17
50	0.48	0.99	1.23

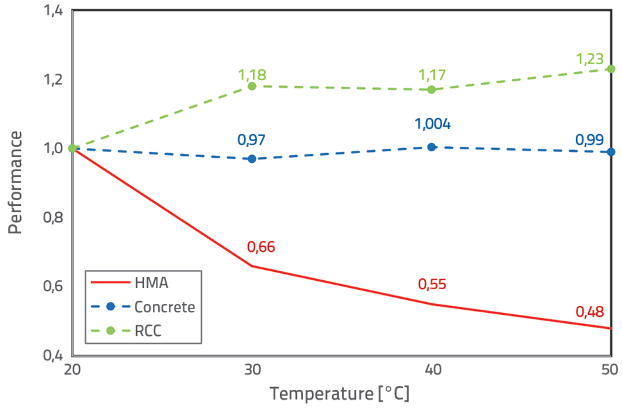


Figure 16. Temperature performance of the HMA, concrete (C25), and RCC in graphical illustration

4. Conclusion

This study investigated the causes and solutions of the problems encountered in the HMA pavement of Cizre–Silopi Road. Despite continuous repairs and renovations, the road deteriorates before a single summer passes, and the insistence of the responsible authority on using HMA in the pavement has turned the problem into a chronic issue. Both old and newly constructed road sections were studied, with the most common type of pavement damage identified. The annual average temperature in the region is around 26–27 °C, reaching record levels of up to 50 °C during the summer months. With asphalt materials sensitive to temperature, performance analyses were conducted for HMA samples taken from the newly constructed pavement and alternative concrete (C25) and RCC samples at temperature values of 20, 30, 40, and 50 °C. Furthermore, considering that 40 % of the traffic on the road consists of heavy vehicles with high axle loads and pressures, the following conclusions were drawn:

- The HMA material has lost approximately 52 % of its stability, compressive strength, and load capacity in the 20–50 °C temperature range. The flow increased by approximately 43 % and became more viscous. The critical temperature transition for asphalt occurs between 20 and 30 °C, indicating significant changes in the behaviour of asphalt above the average temperature. Asphalt materials undergo a transition from elastic to viscoelastic behaviour.
- The most common type of damage to the old and new conditions of the Cizre-Silopi Road is wheel rutting

damage. The HMA samples became more fluid and viscous with increasing temperature. Therefore, considering the temperature reaching up to 50 °C throughout the year and the fact that 40 % of the traffic on the relevant road consists of heavy vehicles, these factors play a significant role in the formation of wheel ruts.

- Concrete (C25) was not affected by the temperature changes, and its mechanical performance remained stable in the 20 to 50 °C temperature range.
- The compressive strength and load capacity of the RCC materials increased with the temperature.
- In addition to exhibiting a better temperature performance than HMA, both C25 and RCC had significantly higher compressive strengths. The compressive strength of HMA decreases by 52 % from 5.23 MPa to 2.53 MPa with an increase in temperature. In contrast, C25 maintained a compressive strength of 36 MPa, and RCC showed an increase in compressive strength, reaching 15 MPa with increasing temperature. Therefore, considering heavy traffic, C25 and RCC will better withstand axle loads and pressures than HMA.
- High temperatures in the region and heavy vehicle traffic are the main causes of damage to the HMA pavement. While asphalt is sensitive to temperature and experiences a loss of strength, C25 concrete, which does not lose strength and even exhibits increased strength in the case of RCC, is a better solution for road surfacing.
- Using concrete (C25) or RCC instead of HMA pavements significantly reduces the damage caused by temperature and heavy traffic, which require continuous maintenance and repair, thus providing significant advantages in terms of cost reduction and sustainability.

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