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Thermo-mechanical evaluation of hybrid basalt fiber aerodrome concrete pavement under dynamic impact

Qais, Qais Abdulrahman Ali[1*]
Kotlyarevskaya, Alena Valerevna[1]
Okolnikova, Galina Erikovna[1,2]
Al-muradi,Yunes Ali Ali[1]

[1] RUDN University Moscow, Russian Federation; qaiseng@gmail.com ; kays_k@rudn.ru (Q.A.A. Q.); kotlyarevskaya-av@rudn.ru (K.A.V.); okolnikova_ge@mail.ru (O.G.E.); almuradi5@mail.ru (Y.A.A.A.)
[2] Moscow State University of Civil Engineering, Moscow, Russian Federation; okolnikova_ge@mail.ru (O.G.E.)
Correspondence:* email qaiseng@gmail.com; contact phone +79014217848

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Abstract:

The object of research is the thermo-mechanical behaviour of hybrid basalt fibre-reinforced concrete used in aerodrome pavements. The subject of the research is the effect of hybrid fibre composition on impact resistance and thermal durability under dynamic loading. The purpose of the research was to develop and assess a hybrid basalt fibre mix capable of enhancing the mechanical and thermal stability of airfield pavements. **Method.** Three concrete mixes were selected: a control mix (K, 0% fibre), a micro-fibre mix (2A, 2% micro-fibre), and a macro-fibre mix (2B, 2% macro-fibre). The mechanical properties, specifically the Modulus of Elasticity**,** were modelled as a function of temperature and using reduction factors based on existing building standards (Eurocode 2: EN 1992-1-2). A linear static analysis was performed for 12 cases (3 mixes, 4 temperatures) using Autodesk Robot Structural Analysis software. The pavement was modelled as a slab with elastic soil supports (Winkler foundation). Two cumulative load cases were applied: a static uniform pressure of over an area and a uniform temperature increase. The primary output parameters were Total Displacement and Maximum Bending Moment. **Results**. The results indicate that high temperature is the most governing factor in the slab's structural behaviour, causing a varied reduction in material stiffness. This thermal degradation led to a gradual and dramatic increase in maximum vertical displacement, which rose from a baseline of at (Mix K) to at across all three mixes. Crucially, at high temperatures, the reinforcing action of both micro- and macro-basalt fibres was rendered insignificant because the failure mode was completely governed by the thermal degradation of the cement matrix itself. The maximum bending moment exhibited a non-linear relationship with temperature, initially decreasing due to stiffness loss, but then increasing sharply at (to for Mix K) due to significant thermal stresses and warping effects, indicating a state of critical distress.

1 Introduction

The performance of airfield pavements is greatly subject to their ability to withstand severe thermo-mechanical stresses resulting from numerous aircraft touchdowns, adverse weather cycles, and chemical exposures. Conventional rigid pavements, although resilient, are prone to exhibit premature distress under such cumulative loading conditions, necessitating the development of advanced material innovations. Studies aim at the role of constituent materials in improving the durability of military and civilian aerodrome pavements. Fibre-reinforced highly bonded cementitious composites have shown to improve fatigue resistance and reduce thermal cracking in rigid pavements under severe operating conditions [1], highlights the growing demand for novel fibre-reinforced composites that not only improve structural performance but also resist degradation due to mechanical and thermal loads [1].

Adding fibres to pavement structures have shown to significantly improve geotechnical and structural toughness. Laboratory modelling of fibre-reinforced subgrade pavement demonstrated that fibres contribute to increased load-carrying capacity, ductility, and reduced deformation under cyclic traffic loads [2]. These properties align with the findings of hybrid fibre reinforcement studies showing that the combined use of different fibres synergistically enhances toughness, crack resistance, and energy absorption of concrete materials [3]. These developments complement the need to optimize subgrade and pavement layers to achieve reliable long-term response to dynamic impact loads characteristic of aerodrome operations [3].

Aside from mechanical strength, thermal and chemical resistance remain pressing concerns for airfield concretes. Research on concretes with diversified coarse aggregates has shown that exposure to thermal shocks and chemicals accelerates deterioration, highlighting the increasing relevance of fibre reinforcement measures [4]. Similarly, investigations into fibre-reinforced natural perlite aggregate concretes revealed improved thermal insulation and mechanical stability, demonstrating the ability of fibres to enhance multifunctional performance [5]. This ability of fibres to enhance multifunctional performance underscores the importance of tailoring fibre types to specific durability requirements in pavement applications [5].

Particularly, hybrid fibre structures have emerged as a major focus for pavement engineering, as they combine the distinct advantages of different fibre types. Studies on hybrid fibre-reinforced geopolymer composites indicate superior toughness, cracking resistance, and long-term durability under simulated pavement loading [6]. When hybrid basalt fibre reinforcement is applied to aerodrome pavements, it presents a feasible path for mitigating simultaneous mechanical impacts and thermal stresses, thereby improving structural integrity and serviceability under extreme operating conditions [6]. Furthermore, investigations into the high-temperature behaviour of plant-based fibre-reinforced concretes revealed that fibres enhance toughness and cracking resistance at moderate heat but deteriorate at high temperatures, emphasizing the need for fibre treatment, hybridization, and matrix optimization to enhance thermal durability [7].

Thus, thermo-mechanical evaluation of hybrid basalt fibre-reinforced aerodrome pavements becomes an essential research frontier. It addresses the twin challenges of impact and thermal resistance while providing insights into optimizing material design for next-generation airfield pavement structures [7].

Aerodrome concrete surfaces are subjected to very harsh service environments and loading conditions like intense air traffic loading, strain rate, high impact, temperature gradients, water infiltration, and environmental effects. Traditional concrete rigid airfield surfaces commonly deteriorate prematurely due to cracking, delamination, and reduced carrying capacity under the above-mentioned combined loads. Hybrid fiber reinforcement of concrete airfield surfaces gained renewed attention as an effective approach to enhance durability and resistance. Qais et al. discussed the influence of fiber hybridization on permeability and porosity of aerodrome concrete surfaces and claimed that hybrid fiber content tends to reduce pore connectivity and water absorption capacity [8].

Based on this durability-oriented outlook, numerical analysis carried out by Qais et al. supported that the use of hybrid basalt fiber reinforcements importantly contributes to improving the resistance to impact, energy absorption, and resistance to split-way action of the aerodrome pavement reinforced with concrete under dynamic aircraft loading conditions [9]. These results are well supported by the results obtained related to fracture mechanics analysis related to hybrid fiber reinforcements of high-strength concrete, where experimental and numerical results obviously identified increased fracture toughness, resistance to crack initiation, and superior post-cracking response if subjected to concentrated load [10]. It is further identified by reviews specific to the durability aspect of aerodrome pavements that hybrid fibre structures are superior to mono-fiber concretes if the reduction and mitigation of fatigue damage (FAT), thermal stress cracking, and other environmental actions are considered [11].

Apart from research works conducted specifically on pavement applications, generic research carried out on high-strength fiber concrete applications has shown that hybridization of fibers exerted beneficial effects on cracking, ductility, and loading of large-scale structures under adverse loading conditions [12]. Among a number of materials that have been identified as prospects for use as reinforcing materials for concrete is basalt fiber. Research carried out on the use of basalt fibers revealed that they possess high tensile strength, excellent thermal stability, chemical inertness, resistance to fire, radiation, vibration, and aggressive environments [13]. Separate research work has also shown that basalt fiber length and dosage can make a positive contribution to improving the compressive strength and elastic modulus of concrete, but overdosing can affect workability and dispersibility [14].

Thermal effects also prove important from a performance viewpoint, and the performance importance of thermal effects becomes significant for higher-strength and fiber-reinforced concrete materials. In research studies for very high-strength durable concrete, higher temperatures contribute significantly towards a decrease in the elastic modulus and strength, besides modifying the failure modes, making them more prone to cracking due to mechanical loading [15]. Micro mechanistic modeling approaches for evaluating thermal spalling also provide conclusive evidence that restrained thermal expansion and pore pressures offer a decisive contribution to concrete damage, underlining the effectiveness of fibers for hindering crack propagation and spalling [16]. General overviews regarding construction fibers also provide insight into the presence of basalt fibers within the category of natural and other man-made fibers and simultaneously underscore the higher heat-resistant nature and durable characteristics of these fibers over other plant fibers [17]. Research contributions regarding lightweight and perlite aggregate fiber-reinforced concretes also confirmed enhanced thermal and strength performances due to variations in temperature [18].

In scaled pavement materials, thermo-mechanical behavior has been examined using experiments and computations. Random aggregate approaches have been used to identify effective thermo-mechanical material properties, and it has been found that inhomogeneity in material significantly affects stress and damage distribution under concurrent thermal and mechanical loading [19]. Thermo-mechanical material performance analysis in cold environments has indicated that temperature cycling contributes to stiffness damage and impact damage under cyclic temperature loading in cold environments [20]. Similar research carried out on cement-asphalt composite binders cycled under freeze and thaw has illustrated substantial damage to dynamic mechanical properties, emphasizing material sensitivity to thermo-mechanical effects [21].

Highly advanced numerical models incorporating both thermal and mechanical analysis have also proved successful for the assessment of concrete structure safety. Combined CFD-FE (Computational Fluid Dynamics - Finite Element) simulations of the thermo-mechanical behavior of concrete tunnel lining subjected to fires showed the efficiency of coupled simulations for critical temperature differences [22]. Investigations on coupled water, temperature, and wheel loadings pointed out an amplified rate of deformation and failure of rigid pavements [23].

Material innovations for the enhancement of thermo-mechanical properties have also been investigated. Hybridized high-performance fibers designed for cementitious composites have shown improvements in thermal stability, strain resistance, and durability against thermal and mechanical loads [24]. On the loading side, studies on static and dynamic loads generated by vehicles have reaffirmed that the influence of impact is crucial in pavement responses to thermal and mechanical loading conditions and in the accumulation of damages [25]. More experimental work has been conducted to establish that concrete has temperature-sensitive impact strength. According to experimental work conducted on concretes made from recycled aggregates, subjecting concrete to temperature cycles showed that there was a noticeable effect on its impact strength, while in the case of roller compacted concrete, the strength increased in a rate-sensitive manner in dynamic compression [26], [27]. In-depth analysis on the coupled thermal/mechanical responses of engineering structures has also revealed that reliable predictions of material responses cannot be made without taking into consideration sophisticated material models, rates of loading, and mechanisms of interactions [28]. Developments on materials related to pavements strongly suggest the role of structural geometry and material combinations in the design of composite rigid-flexible pavement structures if subjected to thermal and mechanical loads [29]. Other literature on the phenomenon of self-healing due to thermal influences on pavement materials also illustrates trends on the use of thermal protection strategies, which are virtually unknown for aerodrome concrete pavements [30].

Fiber-reinforced concrete properties can be tailored through fiber type, length, and dosage to improve tensile strength, ductility, and impact resistance, emphasizing hybridization strategies for optimal crack control and structural performance [31]. In addition, fibers help reduce thermal spallation by bridging micro-cracks and redistributing stresses under rapid thermal loading [32]. Together, these findings highlight the importance of hybrid fibers, such as basalt combined with polypropylene, in enhancing both mechanical toughness and thermal resilience of aerodrome pavements subjected to dynamic and thermal stresses.

The object of the study is the thermo-mechanical behaviour of hybrid basalt fibre-reinforced concrete used in aerodrome pavements, while the subject of the research was the effect of hybrid fibre composition on impact resistance and thermal durability under dynamic loading. The purpose of the research is to develop and assess a hybrid basalt fibre mix capable of enhancing the mechanical and thermal stability of airfield pavements. The main tasks included analysing the mechanical and thermal responses of hybrid fibre-reinforced specimens, comparing their performance with conventional concrete, and evaluating their suitability for pavement applications.

Although numerous studies have examined fiber-reinforced concrete and aerodrome pavement performance, a clear scientific gap remains in the understanding of the thermo-mechanical behavior of hybrid basalt fiber aerodrome concrete under elevated temperatures. Existing research has largely focused on mechanical or durability performance at ambient conditions, impact resistance under dynamic loading, or high-temperature behavior of conventional concretes, without providing a coupled pavement-level thermo-mechanical evaluation that accounts for temperature-dependent material degradation and pavement subgrade interaction. In particular, it remains unclear whether the reported thermal stability of basalt fibers translates into effective control of deformation and internal stresses once the cement matrix is severely degraded by heat. This absence of a comprehensive solution motivates the present study, which applies finite element-based thermo-mechanical analysis to quantify the structural response of hybrid basalt fiber-reinforced aerodrome pavements under elevated temperature conditions.

2 Materials and Methods

The materials used in the production of the concrete mix series are discussed in this section.

Cement M600 CEM I 52.5 (for D0) (Fig. 1), Portland cement of type CEM I, strength class 52.5, normal hardening (Portland cement CEM I 52.5 N, Russian State Standard GOST 31108-2020) [33], manufactured according to Russian State Standard GOST 31108-2020[33] Common Construction Cements. Technical Specifications.

Fig. 1 - M600 - Akkermann Cement

Potable water. In this study, the water used for mixing the fibre-reinforced concrete mixture must comply with the requirements of Russian State Standard GOST 23732-79 [34]. Drinking water according to Russian State Standard GOST 2874-82[35] is permitted for use in the mixture without a quality analysis.

Superplasticizer. The superplasticizer used is a mixture of polycarboxylate esters, accelerating and structure-regulating components that impart special technological and physical-mechanical properties to concrete mixtures and concrete. This additive is a Polyplast Target type 2 meeting the requirements for super plasticizing additives according to Russian State Standard GOST 30459 [36], as well as technical specifications multifunctional concrete additive "Polyplast TARGET TU 5745-081-58042865-2015 with amendment No. 1.[37]

Fine aggregate. Fractionated quartz sand 0.63–1.25 mm (Fig. 2) is a natural medium sand according to Russian State Standard GOST 8736-93 [38]. The fineness modulus (FM) from over 2.0 to

2.5 corresponds to Russian State Standard GOST 8736-93[37]. Fractions from over 0.63 mm to 1.25 mm were used.

Fig. 2 - Fractionated quartz sand

Coarse aggregate. Crushed white quartz stone 10–20 mm (Fig. 3) is crushed stone from igneous and metamorphic rocks, meeting the requirements of Russian State Standard GOST 8267-93[38] and Russian State Standard GOST 26633-91[39], is used in the 20 mm fraction. The crushability grade of the crushed stone from igneous and metamorphic rocks shall be no less than 1200.

Fig. 3 - Crushed white quartz stone

Basalt macrofibres. Basalt macrofibres (Figure 4) with a fibre length of 50 mm and a diameter of 1 mm were used.

Fig. 4 - Basalt macrofibres

Basalt microfibres. Basalt microfibres (Fig. 5) with a fibre length of 18.2 mm and a diameter 17 μm.

Fig. 5 - Basalt microfibres

The foundation of this thermal analysis is the modelling of the degradation of the mechanical properties of concrete with increasing temperature. The three mixes selected for the present study were the control mix (M1, denoted as K), the mix with the highest proportion of micro-fibres (M2, denoted as 2A), and the mix with the highest proportion of macro-fibres (M7, denoted as 2B). Their mechanical properties at room temperature (20°C) were borrowed from the laboratory conditions outlined in the previous study.

As experimental information for these particular mixes at elevated temperatures was not easily found, material property degradation was modeled from existing building standards (Eurocode 2: EN 1992-1-2) using reduction factors. This is a standard technique for modeling concrete structure behavior under fire and at elevated temperatures. The most significant property impacted by this is the Modulus of Elasticity (Ec), which determines the stiffness of the material and influences displacement and stress distribution. Values of the Young's Modulus of all mixes, calculated depending on temperature, are presented in Table 1. The thermal expansion coefficient (α) and Poisson's Ratio (v) were taken as constant, i.e., 0.2 and 1.0 × 10 −5/K, respectively.

Table 1. Temperature-Dependent Modulus of Elasticity for Selected Concrete Mixes

Mix	Percentage of Basalt Micro Fibre (A)	Percentage of Basalt Macro Fibre (B)	Name	Modulus of Elasticity (GPa) at different temperatures			
				20°C	100°C	300°C	600°C
M1	0	0	K	51.50	43.78	23.18	5.15
M2	2	0	2A	50.40	42.84	22.68	5.04
M3	0	2	2B	51.70	43.95	23.27	5.17

The numerical study was performed using Autodesk Robot Structural Analysis (https://www.autodesk.com) a robust software for advanced structural engineering simulations. The concrete slab was modelled with the dimensions of 2m by length, 2m by width, and 0.3m of thickness, in accordance with the geometry used in the first dynamic impact study. The volume of the slab was discretized by four-noded quadrilateral shell elements. There was a mesh convergence study to ensure that the results were independent of mesh density, trading off computational accuracy with efficiency. The resultant mesh had around 400 elements.

Boundary conditions were defined to replicate the interaction of the pavement and the supporting subgrade. Unlike the fixed support used in the short-duration dynamic analysis, elastic soil supports (Winkler foundation) with a subgrade modulus k=50,000 kN/m3 were used in this model. The Winkler foundation represents the continuous ground support and is crucial for accurately modelling thermally induced stresses and deformations.

The experiment involved two principal load cases cumulatively applied: a static uniform pressure of 500kPa over a 0.4m x 0.4m area at the center of the slab to represent the weight of a parked aircraft wheel, and a uniform temperature increase (ΔT) was applied to the entire volume of the slab for all thermal cases. Separate analyses were conducted at 100°C, 300°C, and 600°C temperatures, with the 20°C case (with no more than the static load) being the reference case.

Linear static analysis was performed for all 12 cases (3 mixes × 4 temperatures). The primary output parameters that were used to examine the performance of the pavement were Total Displacement (Uz) and Maximum Bending Moment (Mxy).

3 Results and Discussion

The simulation was able to effectively reproduce the thermo-mechanical response of the pavement, with clear results indicating that displacement is greatly affected by both temperature and the make-up of the concrete. The maximum vertical displacement values for all conditions are tabulated in Table 2 below.

Table 2. Maximum Deformation of the hybrid concrete mixes after curing

Mix	Percentage of Basalt Micro Fibre (A)	Percentage of Basalt Macro Fibre (B)	Name	Maximum Displacement (cm) at different temperatures			
				20°C	100°C	300°C	600°C
M1	0	0	K	1.1	1.3	1.7	2.5
M2	2	0	2A	1.2	1.3	1.7	2.5
M3	0	2	2B	1.1	1.3	1.7	2.5

The mathematical calculation performed in Autodesk Robot brings into the limelight an explicit and unambiguous comprehension of the thermo-mechanical performance of the basalt fiber-reinforced concrete pavement. The results strongly suggest that high temperature is the most governing factor governing the slab's structural behavior. If the temperature increased from 20°C to 600°C, the road surface suffered a severe reduction of its material stiffness (Modulus of Elasticity), leading to a gradual and varied vertical settlement under continuous 500 kPa stress. One of the primary and actually surprising results was that under these high-temperature regimes, the reinforcing action of both micro (2A) and macro (2B) basalt fibers was rendered insignificant due to the fact that the failure mode was completely governed by thermal degradation of the cement matrix itself.

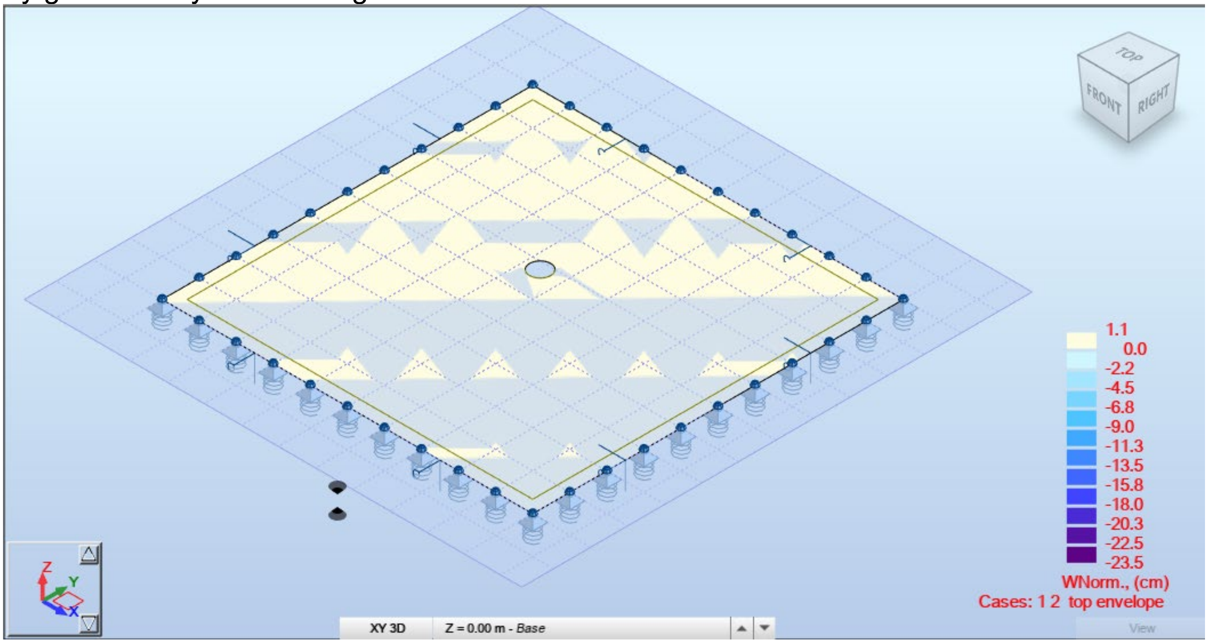

Fig. 6 - Baseline Displacement of Control Mix (K) at 20°C

The above contour diagram (Fig. 6) is the fundamental baseline for the entire study. It illustrates the pavement's purely mechanical deformation under the 500 kPa load, free from any thermal stress. The map would show a localized and minimal displacement pattern, with a peak value of 1.1 cm. The peak value of 1.1cm represents the best-case performance of the unreinforced pavement and serves as the essential benchmark against which all subsequent thermal effects are measured.

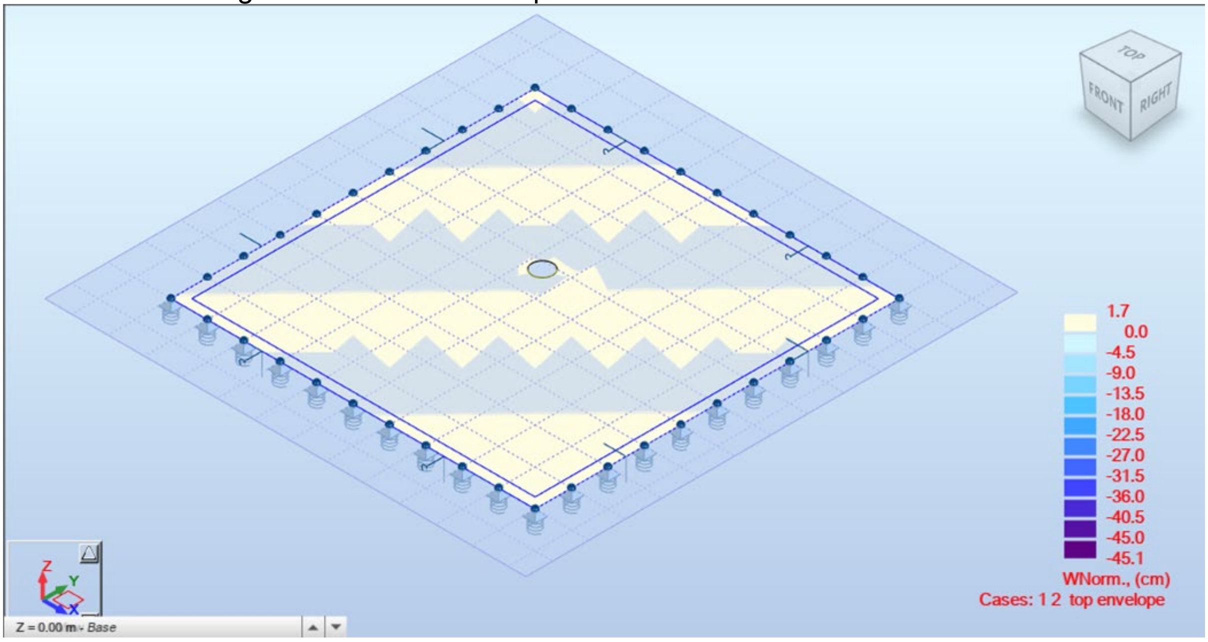

Fig. 7 - Displacement Under Significant Thermal Degradation (Mix K at 300°C)

Fig.7 provides a visual representation of the pavement's compromised state at a critical temperature. At 300°C, the concrete has lost over half of its original stiffness, which is clearly visible in the contour plot, which would depict a significantly deeper deformation compared to the 20°C case, with the maximum displacement having increased by over 50% to 1.7 cm. This figure effectively demonstrates how moderate-to-high temperatures severely impair the pavement's load-bearing capacity and structural integrity.

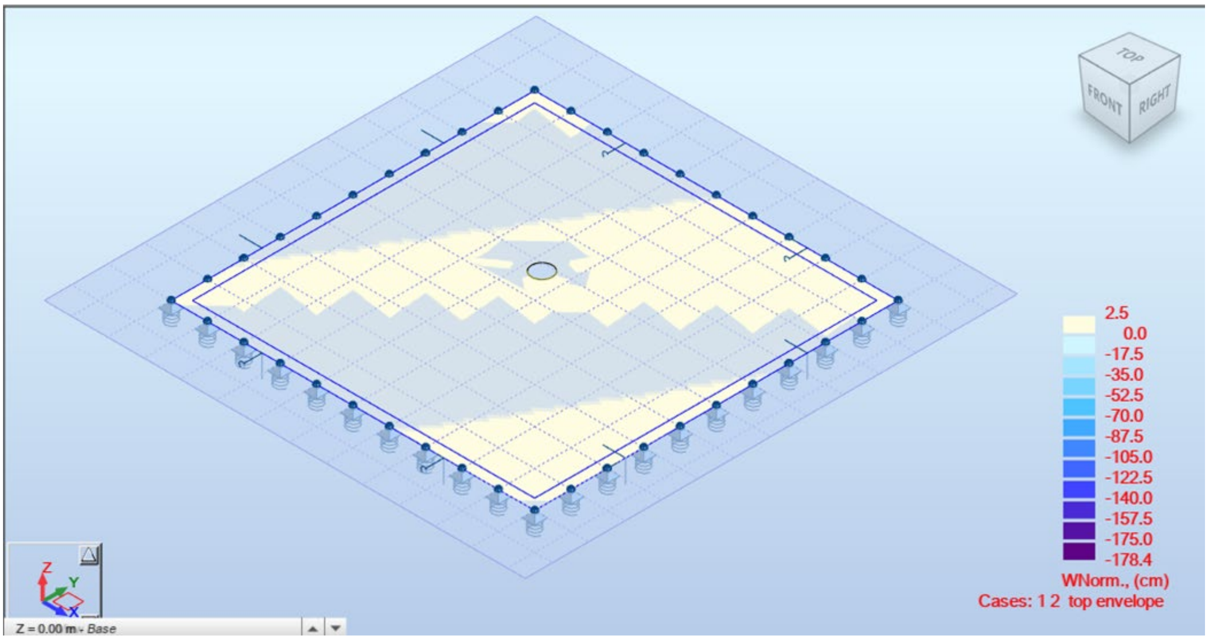

Fig. 8 - Displacement at Near-Failure Temperature (Mix 2B at 600°C)

This diagram (Fig. 8) shows the pavement in a state of near-catastrophic failure. At 600°C, the material has lost approximately 90% of its stiffness, resulting in an extreme maximum displacement of 2.5 cm. The key analytical point is that even with the inclusion of macrofibres (which are expected to provide the most robust structural reinforcement), the performance is identical to the unreinforced control mix. This contour map displays that at extreme temperatures, the failure of the cement matrix is absolute and completely overwhelms any potential benefits from the fibre reinforcement structure.

Bending moments are a measure of the internal flexural forces within the slab and are a primary indicator of the tensile stresses that lead to cracking. The maximum bending moments for each scenario are presented in Table 3.

Table 3. Maximum Bending Moment of the Concrete Mixes at Different Temperatures

Mix	Percentage of Basalt Micro Fibre (A)	Percentage of Basalt Macro Fibre (B)	Name	Maximum Bending Moment (kN.m/m) at different temperatures			
				20°C	100°C	300°C	600°C
M1	0	0	K	1380.41	1335.51	1257.04	1531.17
M2	2	0	2A	1362.52	1344.91	1261.49	1534.98
M3	0	2	2B	1367.42	1336.41	1256.43	1530.27

The analysis of maximum bending moments provides useful information regarding internal flexural stresses within the pavement, and these are responsible for cracking. The result portrays a non-linear temperature vs. internal stress relationship that is highly complicated. The maximum bending moment decreases as the temperature rises from 20°C to 300°C. This reduction is because the high material stiffness loss (Modulus of Elasticity) reduces the ability of the slab to resist many internal forces, deforming with greater ease instead. With an increase in temperature to a critical point of 600°C, however, the trend is extremely reversed, with the bending moment increasing to its maximum level. This rise is caused by significant thermal stresses and warping effects, which induce enormous internal stresses throughout the deteriorated slab, a state of critical distress and failure on the horizon. These mixes vary slightly, but this general trend is consistent, demonstrating that the global thermo-mechanical behavior of the concrete dictates the results.

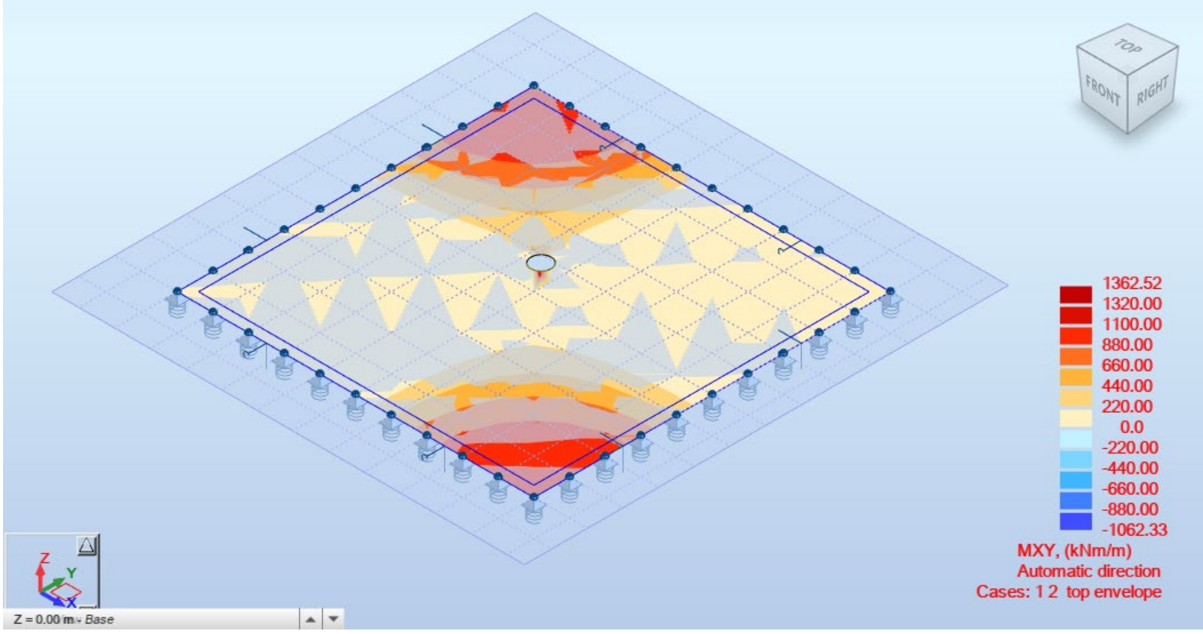

Fig. 9 - Baseline Bending Moment of Microfiber Mix (2A) at 20°C

This contour diagram (Fig. 9) establishes the baseline internal stress state of the reinforced pavement under purely mechanical loading. The Mix 2A has a moment of 1362.52 kNm/m, which is slightly lower than the control mix, showing the initial benefit of fiber reinforcement in distributing stress. The above map (Fig. 9) shows predictable stress concentration under the load and represents the pavement's optimal condition for resisting flexural forces.

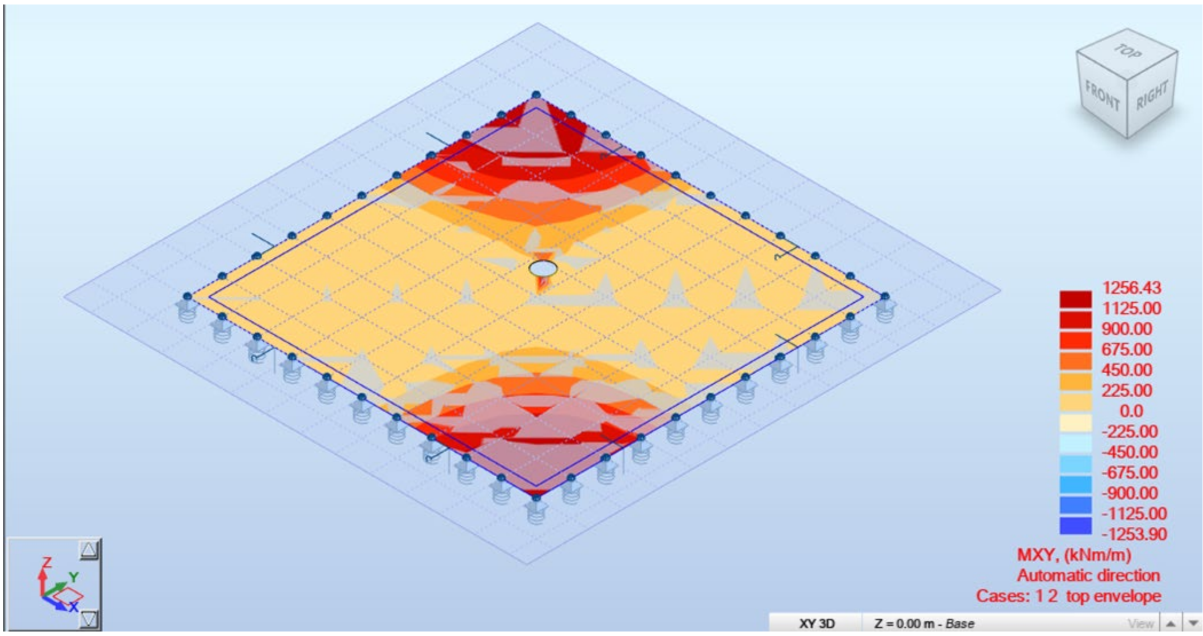

Fig. 10 - Bending Moment at Minimum Stress Point (Mix 2B at 300°C)

Fig.10 above is crucial as it visualizes the pavement at its point of lowest internal stress. At 300°C, the material has lost significant stiffness, and for Mix 2B, the moment drops to 1256.43 kN.m/m. This contour map would show a reduced peak stress compared to the 0°C case. It illustrates a critical transitional state where the pavement is deforming significantly rather than resisting the load with high internal forces, a key behavior preceding ultimate failure.

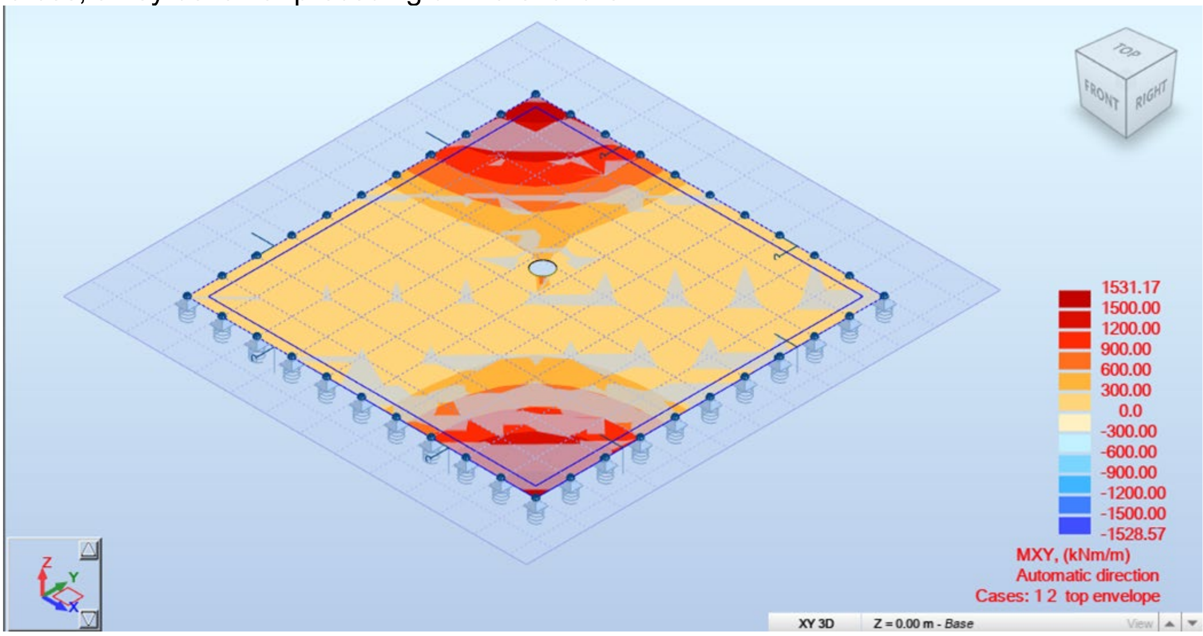

Fig. 11 - Bending Moment at Minimum Stress Point (Mix 2B at 300°C)

This contour diagram (Fig.11) illustrates the pavement in a state of critical failure. At 600°C, severe thermal gradients induce catastrophic internal forces, causing the moment in the control mix K to spike to 1531.17 kN.m, the highest value recorded. The map would show large areas of intense stress concentration (indicated by the color scale), visually representing a slab that is tearing itself apart internally. The map (Fig.11) confirms that at extreme temperatures, the failure is driven by overwhelming thermal strains that induce stresses far beyond the material's residual capacity.

4 Conclusions

The research object is an aerodrome concrete pavement slab made of hybrid basalt fibre-reinforced concrete subjected to combined mechanical loading and elevated temperature conditions representative of extreme service and accidental scenarios.

A thermo-mechanical numerical analysis was carried out using the finite element method implemented in Autodesk Robot Structural Analysis. Temperature-dependent degradation of mechanical properties was modelled using Eurocode 2 reduction factors, and the pavement–subgrade interaction was represented by a Winkler elastic foundation model.

Three concrete mixes were investigated: a control mix without fibres (K), a micro-basalt fibre mix (2A), and a macro-basalt fibre mix (2B). Linear static analyses were performed for four temperature levels (0°C, 100°C, 300°C, and 600°C) under a combined uniform mechanical load and uniform temperature increase. The thermo-mechanical response was evaluated in terms of maximum vertical displacement and maximum bending moment.

1. It was quantitatively established that temperature increase is the dominant governing factor in the thermo-mechanical behaviour of aerodrome concrete pavements, overriding the influence of fibre reinforcement under elevated temperature conditions.
2. A critical loss of stiffness (up to approximately 90%) was identified at 600°C for all concrete mixes, resulting in a nearly identical maximum displacement response (≈2.5 cm), regardless of fibre type or presence.
3. It was shown that both micro- and macro-basalt fibres lose structural effectiveness at high temperatures, as the governing failure mechanism shifts from crack control to cement matrix thermal degradation.
4. A non-linear temperature–bending moment relationship was revealed: bending moments decrease up to 300°C due to stiffness degradation, followed by a sharp increase at 600°C caused by dominant thermal stresses and slab warping effects.
5. The study confirms that fibre reinforcement alone cannot ensure thermo-mechanical stability of aerodrome pavements under extreme thermal exposure, highlighting the need for matrix-level material innovations.
   6. From a design perspective, the results provide evidence that future high-performance aerodrome pavements must prioritise enhancement of the intrinsic thermal resistance of the cementitious matrix, in combination with fibre reinforcement, rather than relying on fibres as the primary mitigation strategy

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6 Conflict of Interests

The authors declared no potential conflicts of interest concerning the research, authorship, and publication of this article.

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