



DOI: 10.58224/2618-7183-2026-9-2-9



Impact of aircraft landing load on the crack resistance of hybrid basalt fibre-reinforced aerodrome concrete pavements

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Abstract. Hybrid basalt fibre-reinforced concrete (HBFRC) has emerged as a high-performance material capable of addressing the severe mechanical demands placed on aerodrome pavement systems. By integrating basalt micro and macro fibres, the composite gains improved stiffness, enhanced crack-arrest capacity, and greater resistance to repeated aircraft-induced loads. This study develops and analyses 25 hybrid concrete mixes using both laboratory testing and a detailed finite element simulation in Ansys Workbench to quantify how different fibre proportions influence compressive strength, stiffness, and deformation under an Airbus A321neo load. A 3D fracture-based pavement model incorporating predefined semi-elliptical crack geometry was used to evaluate the deformation response across 7-, 14-, and 28-day curing periods. Results show a clear improvement in mechanical performance with hybridisation, with the mix containing 2% basalt microfibres and 1% macrofibres consistently yielding the lowest deformation values (0.0054353mm, 0.005815mm and 0.0057363mm) for 7 days, 14days and 28 days respectively, indicating superior crack-resistance and load-bearing capacity throughout the curing stages. While the mix containing 0.5% basalt microfibres and 0.5% macrofibres yielded the highest deformation values (0.0059277mm and 0.0058474mm) for 14 and 28 days respectively. The findings demonstrate that optimal hybrid fibre combinations significantly reduce pavement vulnerability to its risk of being susceptible to damage from changing aircraft loads like heaving traffic and can serve as practical reinforcement strategies for strengthening modern airfield infrastructure. The study further highlights the importance of micro–macro fibre synergy in improving fracture behaviour and offers valuable guidance for developing next-generation high-durability airport pavement materials.

Keywords: airfield pavement performance, finite element modelling, fracture resistance, pavement deformation, high-performance concrete, micro-macro fibre synergy, ansys workbench analysis

Please cite this article as: Qais Abdulrahman Ali Qais, Okolnikova G.E. Impact of aircraft landing load on the crack resistance of hybrid basalt fibre-reinforced aerodrome concrete pavements. *Construction Materials and Products*. 2026. 9 (2). 9. DOI: 10.58224/2618-7183-2026-9-2-9

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1. INTRODUCTION

Hybrid basalt fibre-reinforced concrete (HBFRC) improves the performance of structures by combining basalt fibres with other fibres, usually polypropylene, to make them more resistant to cracking, tougher, and better at handling cracks. Basalt fibres add stiffness and the ability to carry more weight, while polypropylene fibres stop micro-cracks and slow down the start of cracks. This makes them work better than single-fibre systems [1-2]. This hybridisation also improves the pore structure, making the matrix denser with fewer voids that are connected. This makes it more durable and less likely to break down [3-4]. Hybrid fibre systems also show stronger bonding between the fibres and the cement matrix, especially when there is dynamic loading. This makes energy absorption and load transfer more efficient [5]. Overall, experimental studies consistently demonstrate that hybrid combinations, such as basalt–polypropylene systems, substantially enhance compressive, tensile, and flexural properties, thereby confirming the evident synergistic effect of incorporating multiple fibres in concrete [6].

Because aircraft landings put extreme loads and repetitive dynamic stresses on aerodrome pavements, their structural integrity and durability are very important. Airfield pavements are subjected to much higher wheel loads, impact forces, and vibration-induced stresses than regular road pavements. This can speed up the formation and spread of cracks in the concrete layers [7]. When airfield pavements fail, it not only puts safety at risk, but it also costs a lot of money to fix and causes service interruptions. Researchers and engineers are therefore focusing more and more on new materials, especially fibre-reinforced concretes, to make aerodrome pavements more resistant to cracks, impacts, and wear and tear [8].

Hybrid fibre reinforcement has become a very promising way to fix the problems with traditional cementitious composites in high-stress situations like runways. Hybrid fibre-reinforced concrete (HFRC) uses the unique mechanical properties of each type of fibre to create synergistic effects that make the concrete more resistant to cracking, better at absorbing energy, and better at carrying loads. Basalt fibres have been extensively studied in this regard due to their excellent tensile strength, chemical stability, and compatibility with cementitious matrices. HFRC shows better ductility, fracture resistance, and impact toughness when mixed with synthetic or polymeric fibres like polypropylene [9]. This makes hybrid basalt fibre reinforcement a smart new way to design aerodrome pavements that can handle the heavy loads that come with aircraft landings.

In recent years, there has been a lot of progress in figuring out how basalt fibre-reinforced concrete breaks and gets tired when used on airfields. The authors [10] conducted experimental investigations on the fracture properties of basalt fibre-reinforced pavement concrete subjected to varying strain rates, illustrating that the incorporation of fibres markedly improved crack resistance by bridging microcracks and postponing crack propagation under dynamic loading conditions. Scientists in [11] emphasized the flexural fatigue characteristics of fibre-reinforced airport pavement concrete, noting that polymeric fibres enhance fatigue resistance during repetitive stress cycles. Fibres can help dissipate energy and stop cracks from spreading, which is especially important for runways. Landing gears put short but very high-impact forces on runways, which can shorten the life of concrete pavements.

Using hybrid basalt fibres has also shown great promise for speeding up construction and repair work on airfield infrastructure. The authors of the study [12] found that adding basalt macro-fibres to high-early-strength concrete made it work much better mechanically, which made it possible to fix damaged runway sections more quickly without weakening the structure. This discovery is especially pertinent to the military and civil aviation industries, where swift pavement restoration is essential for reducing operational interruptions. The researcher [13] also noted that durability is just as important for military airfield pavements. He stated that optimizing the constituent materials in cementitious composites directly affects how well they can withstand environmental damage and how long they can last with heavy aircraft traffic.

The development of fiber-reinforced polymer composites is driving the evolution of hybrid reinforcement strategies for high-performance pavements. The authors of [14] conducted an extensive study of modern fiber-reinforced composites, highlighting their exceptional mechanical and thermal

properties. In contrast, researchers in [15] demonstrated the effectiveness of glass fiber reinforcement under impact loading. These broader advances in materials science demonstrate how hybrid fiber reinforcement can be used in airfield pavements, where increased strength and impact resistance are critical.

Further supporting this direction, the authors of the work [16] conducted a numerical investigation into the dynamic impact performance of reinforced concrete aerodrome pavement incorporating hybrid basalt fibres. The study demonstrated that hybrid basalt fibre reinforcement significantly enhanced damage resistance, reduced crack propagation intensity, and improved split-way resistance under dynamic loading conditions. The findings confirmed that the synergistic interaction between macro- and micro-basalt fibres contributes to improved stress redistribution and impact energy dissipation, thereby strengthening the structural resilience of aerodrome pavements subjected to aircraft-induced dynamic loads.

Finite Element Analysis (FEA) is now an important computer program for studying how aerodrome pavements react to the weight of landing aircraft. FEA allows researchers to predict how pavement will perform under different operating conditions by simulating stress distribution, crack propagation, and the interaction between fibres and cementitious matrices. This means they don't have to rely only on expensive and time-consuming experiments. Research conducted by [7] has illustrated the efficacy of parametric finite element analysis (FEA) in evaluating pavement depression and load-induced stresses, establishing a foundation for more sophisticated simulations incorporating hybrid fibre reinforcements. When combined with experimental data, FEA offers a robust framework for optimising hybrid basalt fibre-reinforced concrete mixtures, pinpointing critical stress thresholds, and forecasting the service life of airfield pavements subjected to dynamic aircraft loading.

Finite Element Analysis (FEA) has thus emerged as a significant computer program used to study the impact of the aerodrome pavement under the weight of landing aircraft. This has enabled researchers to predict the performance of the pavement under varying conditions using a simulation technique, studying the distribution of stress, crack development, and the interrelation of fibers with the cement matrix [17]. This has enabled researchers to avoid depending solely on experimental techniques, which are costly and time-consuming. Research has thus demonstrated the effectiveness of parametric FEA in assessing pavement depression and stress, paving the way for sophisticated simulations using high-strength eco-friendly binders along with basalt fiber reinforcements [18]. When experimental results are integrated, FEA has provided a strong basis to optimize hybrid mixtures, especially using technogenic wastes containing fiber, which enhances the overall performance of the material [19]. This has been critical in assessing the mechanical performance of fiber-reinforced concretes intended for industrial and civil engineering applications [20]. Moreover, FEA has enabled researchers to identify critical stress thresholds using experimental results, especially when data regarding the impact of fiber hybridization on the permeability and porosity of aerodrome pavements is integrated [21]. With the integration of information about the compressive strength of specialized basalt fiber mixtures [22], as well as the benefits of using combined reinforcement techniques [23], highly precise models can be developed. These simulations are of critical importance for forecasting the service life of airfield pavements and heavily loaded floor structures under the intense dynamic aircraft loading and pressures, which characterize the operations of contemporary aerodromes [24].

Given these advancements, the current study intends to perform a Finite Element Analysis regarding the influence of aircraft landing loads on the crack resistance of hybrid basalt fibre-reinforced aerodrome pavements. This research aims to elucidate the mechanisms by which hybrid basalt fibres enhance fracture resistance, energy absorption, and fatigue life in pavement structures exposed to extreme impact forces, drawing on recent experimental and numerical findings. The results are anticipated to aid in the formulation of more resilient, economical, and sustainable solutions for airfield infrastructure, thereby improving safety, performance, and operational efficiency in aviation contexts

2. METHODS AND MATERIALS

Experimental Materials

The materials used in the production of the fibre-reinforced concrete mixtures included Portland cement, potable water, superplasticizer, fine aggregate, coarse aggregate, and basalt fibres (macro and micro). All materials conformed to the relevant Russian State Standards (GOST) specifications to ensure consistency, reliability, and compliance with established construction material requirements.

Binder

Portland cement type CEM I 52.5 N (M600) was used as the primary binder in the preparation of the concrete mixtures, including the control mix (D0). The cement conforms to the requirements of GOST 31108-2020, which specifies technical standards for common construction cements. CEM I 52.5 N is a normal-hardening Portland cement characterized by high early and ultimate strength development, making it suitable for structural and high-performance concrete applications. The use of this cement ensured adequate hydration kinetics, mechanical strength development, and dimensional stability in the hardened concrete matrix.

Mixing Water

Potable water was used for mixing and curing the fibre-reinforced concrete specimens. The water complied with the requirements of GOST 23732-79, which regulates water quality for concrete and mortar production. In addition, drinking water conforming to GOST 2874-82 was permitted for use without additional chemical quality analysis. The use of clean water ensured proper cement hydration, improved workability of the fresh concrete mixture, and prevented deleterious chemical reactions that could negatively affect the mechanical and durability properties of the hardened concrete.

Chemical Admixture (Superplasticizer)

A high-range water-reducing admixture based on polycarboxylate ester technology was incorporated into the concrete mixtures to enhance workability and reduce water demand. The superplasticizer used was Polyplast Target Type 2, a complex additive composed of polycarboxylate esters, accelerating components, and structure-regulating modifiers. The admixture satisfies the requirements of GOST 30459 for super plasticizing additives, as well as TU 5745-081-58042865-2015 with Amendment No. 1. The incorporation of this admixture improved dispersion of cement particles, enhanced rheological behavior of the fresh mixture, reduced the water-to-cement ratio, and contributed to improved strength and structural density of the hardened concrete.

Fine Aggregate

Fractionated quartz sand with a particle size range of 0.63–1.2 mm was used as the fine aggregate. The sand is classified as natural medium sand in accordance with GOST 8736-93. The fineness modulus ranged from 2.0 to 2.5, meeting the grading requirements specified by the standard. The selected fraction (>0.63 mm to 1.25 mm) provided appropriate particle packing density and reduced internal voids within the concrete matrix. Proper grading of the fine aggregate enhanced workability, improved interfacial bonding between the cement paste and aggregate particles, and contributed to the overall mechanical performance of the hardened concrete.

Coarse Aggregate

Crushed white quartz stone with a nominal particle size of 10–20 mm was used as the coarse aggregate. The aggregate, derived from igneous and metamorphic rocks, complied with the requirements of GOST 8267-93 and GOST 26633-91. The crushability grade of the aggregate was not less than 1200, ensuring high resistance to mechanical degradation under load. The selected aggregate fraction provided adequate mechanical interlock, improved compressive strength, and enhanced structural stability in the hardened fibre-reinforced concrete.

Reinforcement Materials

Basalt fibres were incorporated as dispersed reinforcement within the concrete matrix to improve crack resistance, toughness, and post-cracking behavior. Two types of fibres were used: basalt macrofibres and basalt microfibres.

The basalt macrofibres had a length of 50 mm and a diameter of 1 mm. These fibres function primarily as crack-bridging elements, enhancing flexural strength, impact resistance, and residual load-carrying capacity after cracking.

The basalt microfibres had a length of 18.2 mm and a diameter of 17 μm . These fibres were introduced to control plastic shrinkage cracking and refine the microstructure of the cementitious matrix. The inclusion of microfibres improved crack distribution at the micro-scale, reduced crack width development, and enhanced durability-related performance.

Numerical Modeling and Analysis

The research utilized a 3D model of an individual aerodrome concrete pavement slab created in Ansys Workbench 2023 R1. The slab was modelled to be 5 m long, 5 m wide, and 0.5 m thick, which is about the size of a single concrete panel on an airfield. This study defined 25 different hybrid basalt fibre-reinforced concrete mixes. For each mix, the compressive strength was measured after three different curing times: 7, 14, and 28 days. The main properties used as input in the Ansys material model (Table 1) were Compressive Strength (f_c), Young's Modulus (E_c), Poisson's Ratio (ν) and Density (ρ), which were obtained from laboratory procedures as shown below.

Table 1. Input Data for Ansys Calculations.

Mix	Percentage of Basalt Micro Fibre (A)	Percentage of Basalt Macro Fibre (B)	Name	Compressive Strength (MPa)			Modulus of Elasticity (GPa)	Saturated Density (kg/m^3)
				7	14	28		
M1	0	0	K	51.67	58.33	63.6	51.5	2429.7
M2	2	0	2A	47.45	52.8	58.4	50.4	2458.53
M3	1.5	0	1.5A	50.18	54.36	60.76	51.96	2459.31
M4	1	0	1A	54.9	62.5	70.86	53.57	2447.2
M5	0.5	0	0.5A	53.152	60.5	67.7	50.98	2447.93
M6	0.25	0	0.25A	49.4	53.5	60.5	49.3	2441.4
M7	0	2	2B	51.53	57.55	66.67	51.7	2447.9
M8	0	1.5	1.5B	49.9	56.37	63.03	51.85	2459.46
M9	0	1	1B	52.72	58.42	68.5	52.73	2434.03
M10	0	0.5	0.5B	46.66	52.71	58.67	50.3	2430.11
M11	2	1	2A1B	52.7	57.5	64.15	52.7	2463.15
M12	2	0.5	2A0.5B	48.6	52.3	58.8	51.8	2457.31
M13	1.5	2	1.5A2B	48.4	53.8	59.28	52.2	2468.83
M14	1.5	1.5	1.5A1.5B	51.3	57.63	63.87	53.3	2468.96
M15	1.5	1	1.5A1B	52.1	57.04	63.74	52.97	2458.6
M16	1.5	0.5	1.5A0.5B	56.8	63.87	72.8	53.65	2448.76
M17	1.5	0.25	1.5A0.25B	52.8	59.18	67.13	52.4	2443.13
M18	1	2	1A2B	53.96	59.76	67.46	52.13	2437.7
M19	1	1.5	1A1.5B	49.34	54.65	60.2	52.7	2436.67
M20	1	1	1A1B	51.52	58.4	66.156	51.3	2433.6
M21	1	0.5	1A0.5B	49.34	57.3	63.71	51.05	2436.93
M22	0.5	2	0.5A2B	51.34	56.99	64.8	51.3	2444.2
M23	0.5	1.5	0.5A1.5B	52.23	57.4	64.42	51.92	2443.6
M24	0.5	1	0.5A1B	50.6	56.5	65.47	51.37	2439.6
M25	0.5	0.5	0.5A0.5B	49.813	54.2	62.02	50.52	2434.83

Finite Element Model Generation

3D 20-node solid structural elements (SOLID186) were used to mesh the volume of the concrete slab. A Tetrahedron meshing scheme was used to find a good balance between speed and accuracy in calculations. A mesh convergence study was done to make sure that the results didn't depend on the mesh density. The last mesh had 8474 elements and 12671 nodes. The meshed model is shown in Fig. 1. The slab was analysed with a predefined Semi-Elliptical crack with a minor radius of 0.5m, a major radius of 1m, a largest contour radius of 0.5m and 4 mesh contours to ensure the crack analysis is more realistic (Fig. 1).

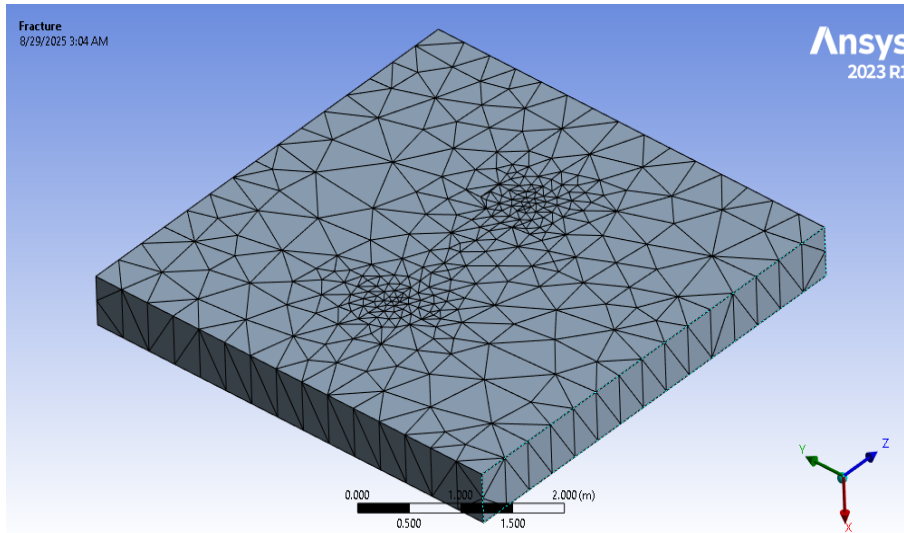


Fig. 1. Meshing and Predefined fracture of the model.

Contact pressure was used to simulate the load of an Airbus A321neo. The load was put on a specific spot in the middle of the slab, which was where the aircraft's tyre made contact (Fig. 2). The pressure value of [1.4] MPa was determined from the aircraft's maximum take-off weight and the way its main landing gear tires were set up [25]. A fixed support boundary condition was applied to the entire bottom surface of the pavement slab to make it act like a rigid subgrade. This limited the slab in all degrees of freedom. Fig. 2 shows the full setup of the FEA model, including the loading and boundary conditions.

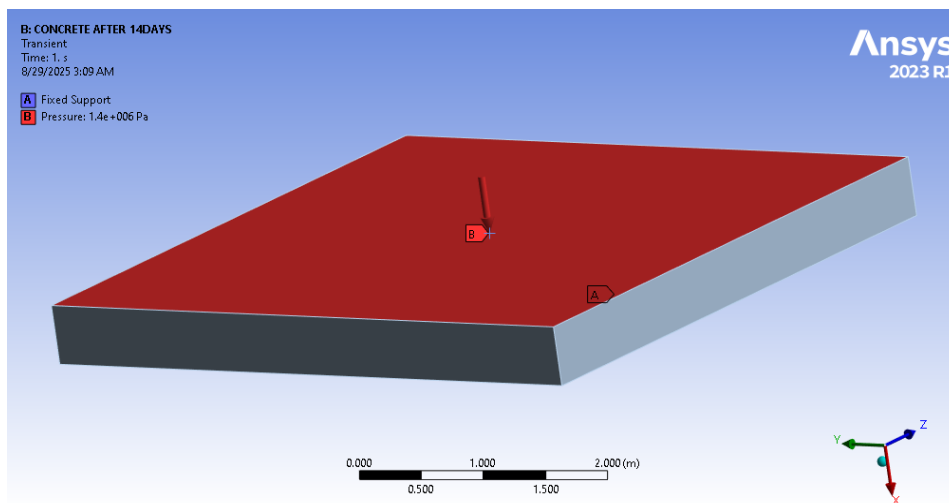


Fig. 2. Loading and boundary conditions of the model.

The Ansys Mechanical solver was used to do a Transient Structural Analysis to find out how the pavement would react to the aircraft load. The Total Deformation of the slab was the main output parameter used to test how well it could resist cracks.

3. RESULTS AND DISCUSSION

Pavement Deformation under Aircraft Load

Each of the 75 simulated scenarios 25 different concrete mixes under a fixed load for 7, 14, and 28 days had its maximum total deformation recorded. Table 2 shows the results, which show that the deformation of the pavement clearly depends on both the amount of time the concrete cures and the percentage of both micro and macro hybrid basalt fibre reinforcement.

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

Mix	Percentage of Basalt Microfibre (A)	Percentage of Basalt Macro Fibre (B)	Name	Maximum Deformation (mm)		
				7days	14days	28days
M1	0	0	K	0.0055208	0.0059065	0.0058265
M2	2	0	2A	0.0054531	0.0058341	0.0057551
M3	1.5	0	1.5A	0.0054579	0.0058392	0.0057601
M4	1	0	1A	0.0054626	0.0058442	0.0057651
M5	0.5	0	0.5A	0.0054639	0.0058456	0.0057664
M6	0.25	0	0.25A	0.0055034	0.0058879	0.0058081
M7	0	2	2B	0.0054601	0.0058415	0.0057624
M8	0	1.5	1.5B	0.0054433	0.0058236	0.0057447
M9	0	1	1B	0.0054871	0.0058704	0.0057909
M10	0	0.5	0.5B	0.0055209	0.0059066	0.0058266
M11	2	1	2A1B	0.0054353	0.005815	0.0057363
M12	2	0.5	2A0.5B	0.005454	0.005835	0.005756
M13	1.5	2	1.5A2B	0.0054475	0.0058281	0.0057491
M14	1.5	1.5	1.5A1.5B	0.0054393	0.0058193	0.0057405
M15	1.5	1	1.5A1B	0.0054644	0.0058461	0.005767
M16	1.5	0.5	1.5A0.5B	0.0054658	0.0058477	0.0057685
M17	1.5	0.25	1.5A0.25B	0.0054947	0.0058786	0.005799
M18	1	2	1A2B	0.005511	0.0058959	0.0058161
M19	1	1.5	1A1.5B	0.0055034	0.0058879	0.0058082
M20	1	1	1A1B	0.005521	0.0059067	0.0058267
M21	1	0.5	1A0.5B	0.0055215	0.0059072	0.0058272
M22	0.5	2	0.5A2B	0.0054912	0.0058748	0.0057953
M23	0.5	1.5	0.5A1.5B	0.0054804	0.0058632	0.0057838
M24	0.5	1	0.5A1B	0.005499	0.0058831	0.0058034
M25	0.5	0.5	0.5A0.5B	0.0055407	0.0059277	0.0058474

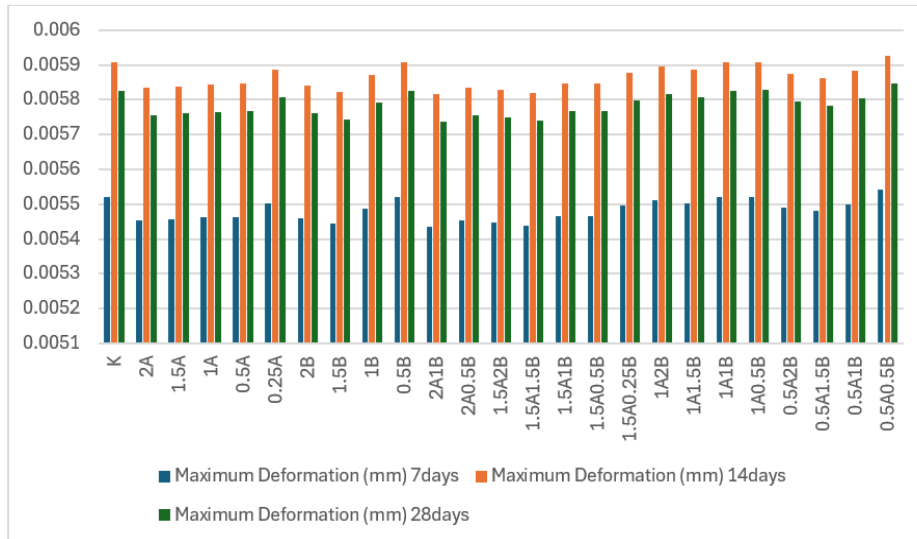


Fig. 3. Maximum deformation after curing for different hybrid basalt fibre concrete mixes.

Fig. 3 shows the maximum total deformation plotted against hybrid basalt fibre content for each curing period and how they are represented in hybrid fibre mixtures, for instance, K represents no fibre addition at all, A shows Microfibre addition, and B shows macrofibre addition (Table 2). The data shows that deformation usually increases from 7 to 28 days for most mixes. This is what was expected to happen because of the predefined crack, which causes possible disintegration of fibres making the concrete likely to bend when a load is put on it. Adding hybrid basalt fibres also made the total deformation much lower than the control mix K (0% fibre), the best-performing percentage is concrete overall is mix 2A1B (M11 from Table 2), which contains 2% Bas-alt Microfibre and 1% Basalt Macro Fibre (at 7 days M11 has the lowest deformation at 0.0054353 mm, at 14 days M11 has the lowest deformation at 0.005815 mm., 28 days M11 has the lowest deformation at 0.0057363 mm).

Deformation Contour Plots

The total deformation contour plots below show 3 different representative cases, each at 7 days, 14 days and 28 days of curing, respectively.

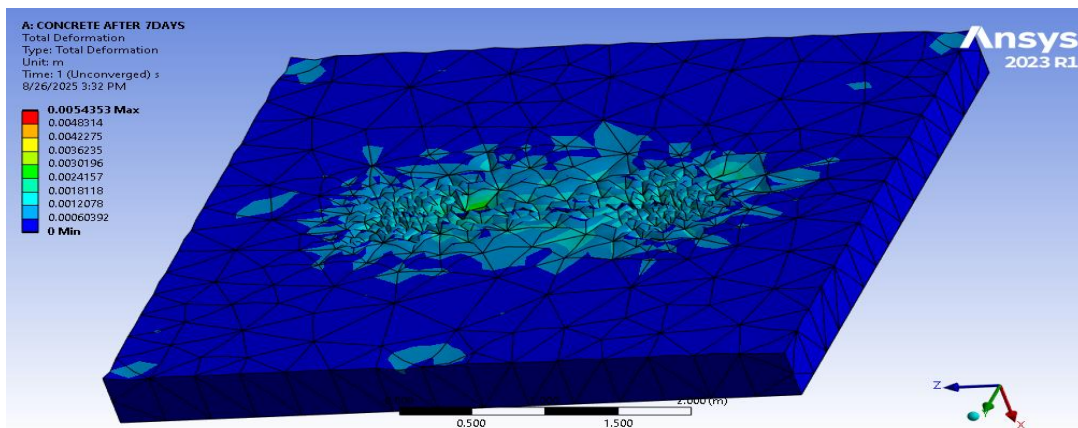


Fig. 4. Concrete Mix 2% Microfibre and 1% Macro Fibre, total deformation after 7 days curing.

The contour plot below (Fig. 4) displays the best performing concrete mix, M11 (2% Microfibre, 1% Macro Fibre) after 7 days of curing with a deformation of 0.0054353 mm. This mix shows the lowest deformation of all 25 mixes at the 7-day mark, demonstrating its superior initial stiffness and load resistance. The combination of both fibre types provides early reinforcement.

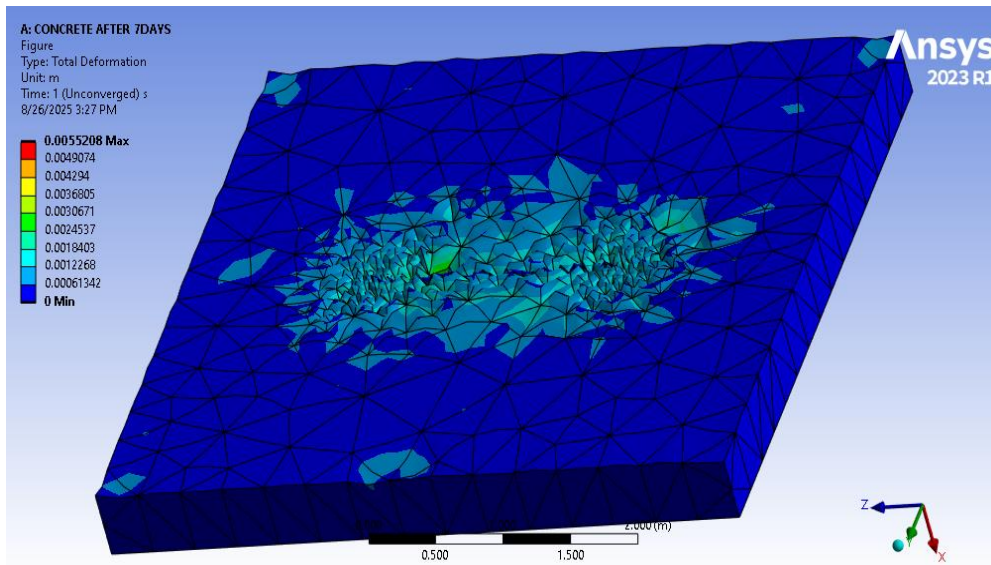


Fig. 5. Concrete Mix 0% Microfibre and 0% Macro Fibre total deformation after 7 days curing.

Fig. 5 above shows the worst-performing concrete mix, M1 (0% Microfibre, 0% Macro Fibre), after 7 days of curing with a deformation of 0.0055208 mm. This is the control mix with no fibres. Its high deformation value serves as the reference for comparison, highlighting the significant improvement gained by adding fibres.

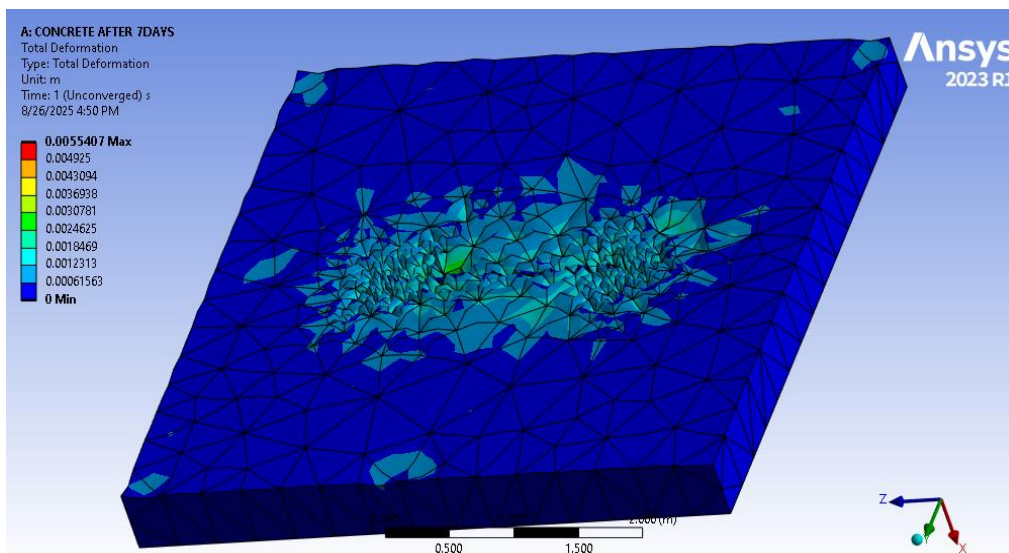


Fig. 6. Concrete Mix 0.5% Microfibre and 0.5% Macro Fibre, total deformation after 7 days curing.

The above contour plot (Fig. 6) represents a mid-range hybrid concrete mix, M25 (0.5% Microfibre, 0.5% Macro Fibre) after 7 days of curing with a deformation of 0.0055407 mm. This mix represents a low-percentage hybrid, showing that even small amounts of fibres can result in increased deformation compared to the best mix, but still provide some benefit over the original control mix with no fibres.

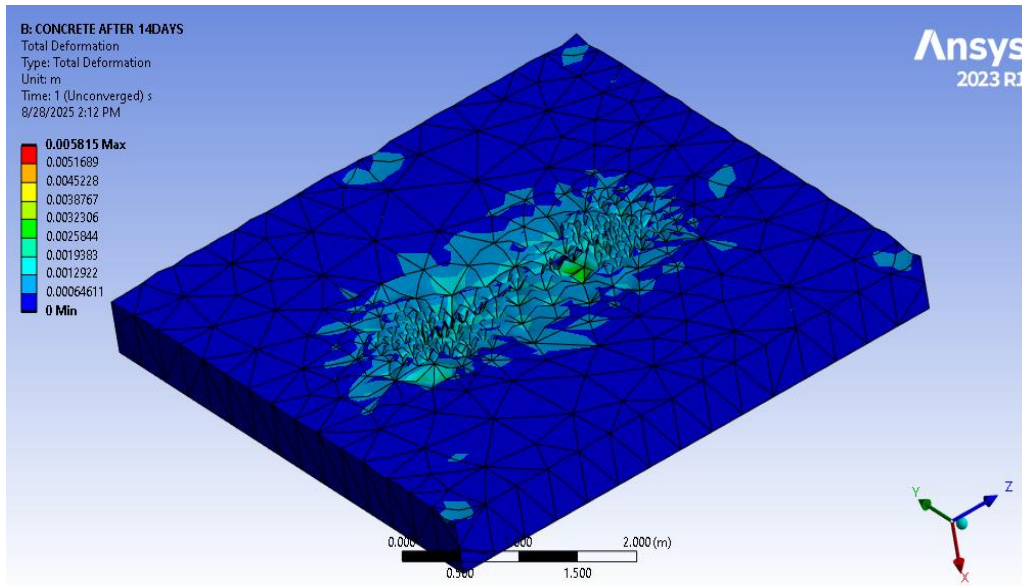


Fig. 7. Concrete Mix 2% Microfibre and 1% Macro Fibre, total deformation after 14 days curing.

The above contour plot (Fig. 7) represents the best performing concrete mix, M11 (2% Microfibre, 1% Macro Fibre), after 14 days of curing with a deformation of 0.005815 mm. Mix M11 continues to be the most effective mix, maintaining the lowest deformation value as the concrete gains strength over time. This indicates a consistent and reliable reinforcing effect.

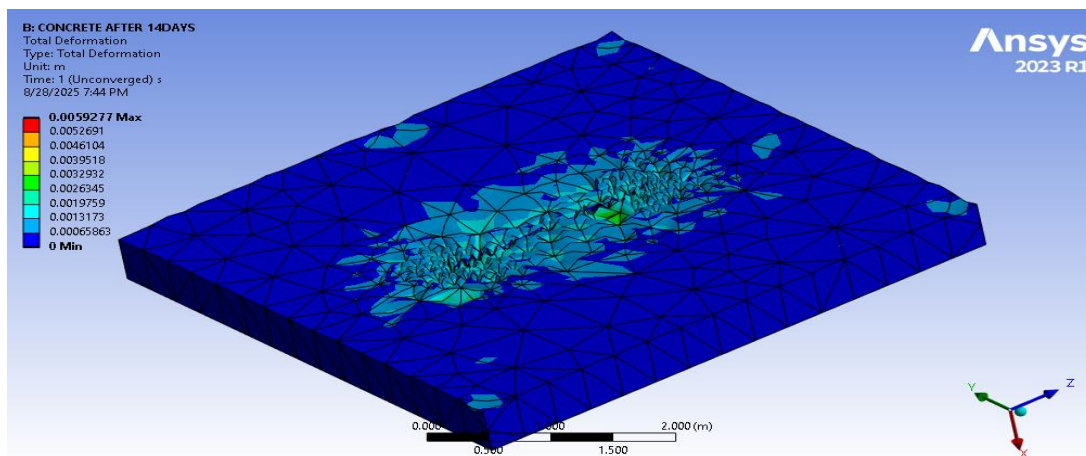


Fig. 8. Concrete Mix 0.5% Microfibre and 0.5% Macro Fibre, total deformation after 14 days curing.

Fig. 8 represents the worst-performing concrete mix, M25 (0.5% Microfibre, 0.5% Macro Fibre), after 14 days of curing with a deformation of 0.0059277 mm. While not the worst performer overall, its deformation value is the highest among all mixes at 14 days, making it a good representative of a mix.

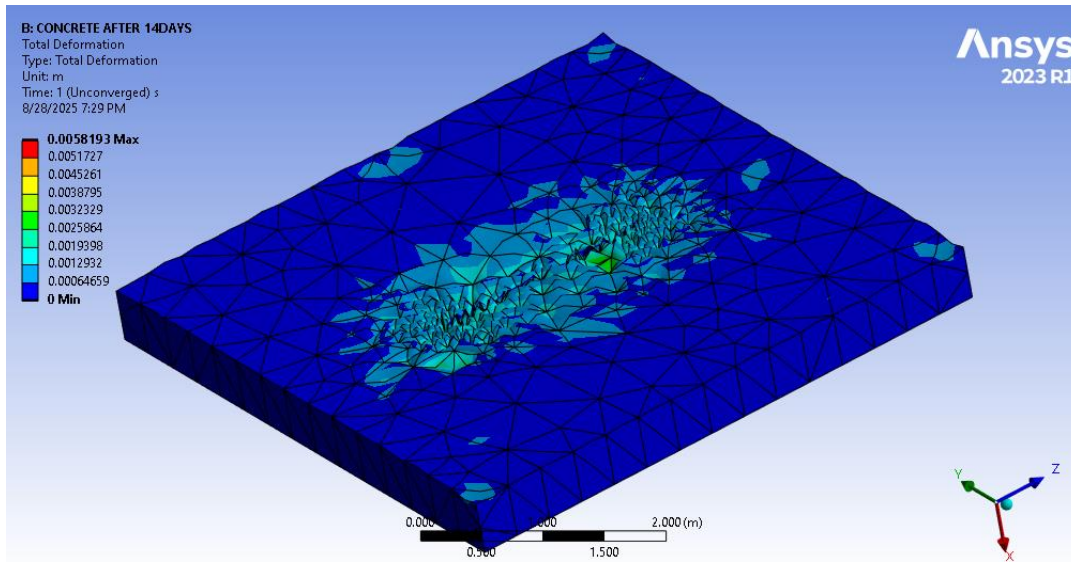


Fig. 9. Concrete Mix 1.5% Microfibre and 1.5% Macro Fibre, total deformation after 14 days curing.

The above contour plot (Fig. 9) represents a mid-range hybrid concrete mix, M14 (1.5% Microfibre, 1.5% Macro Fibre), after 14 days of curing with a deformation of 0.0058193 mm. This mix represents a solid mid-range performance, demonstrating that a well-balanced hybrid mix can achieve results close to the best-performing one.

The contour plot below (Fig. 10) represents the best performing concrete mix, M11 (2% Microfibre, 1% Macro Fibre), after 28 days of curing with a deformation of 0.0057363 mm. Even at 28 days, when the concrete has reached its full compressive strength, this hybrid mix maintains its position as the best performer, solidifying the conclusion that this specific combination is ideal for reducing deformation and increasing crack resistance.

Fig. 11 below represents the worst-performing concrete mix, M25 (0.5% Microfibre, 0.5% Macro Fibre) after 28 days of curing with a deformation of 0.0058474 mm. This mix again represents the highest deformation, indicating that this specific combination is not as effective as others, even after the concrete has fully cured.

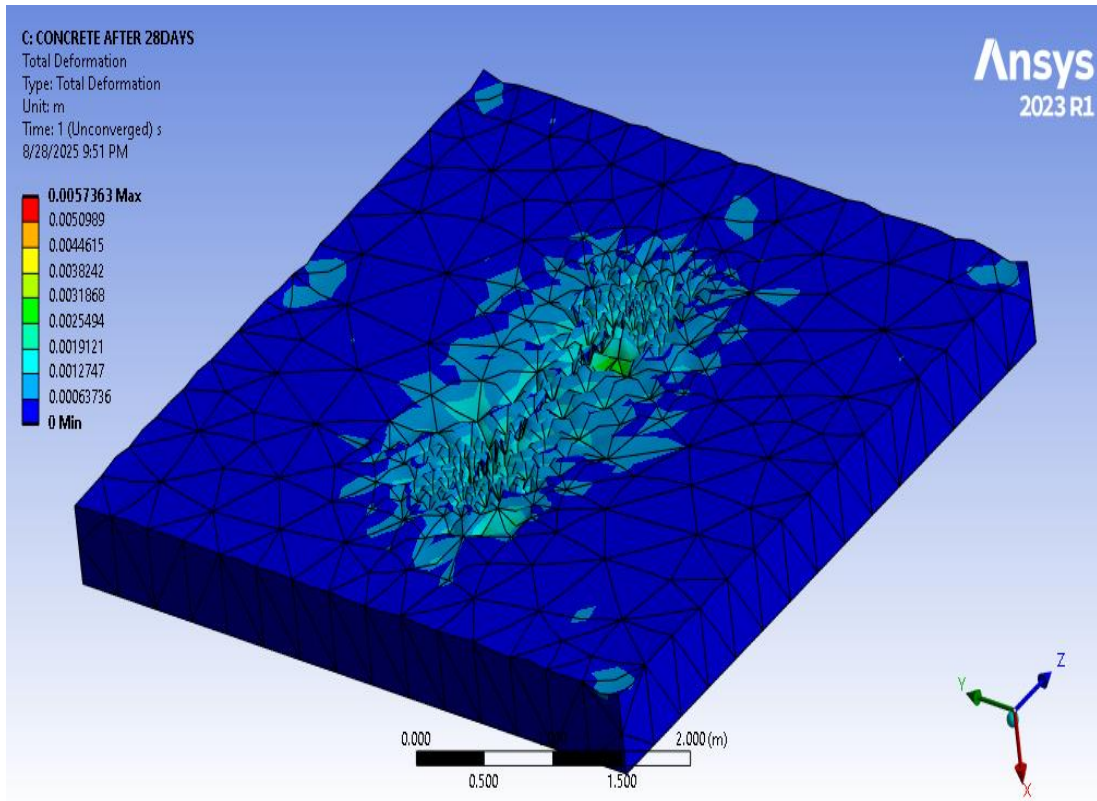


Fig. 10. Concrete Mix 2% Microfibre and 1% Macro Fibre total deformation after 28 days curing.

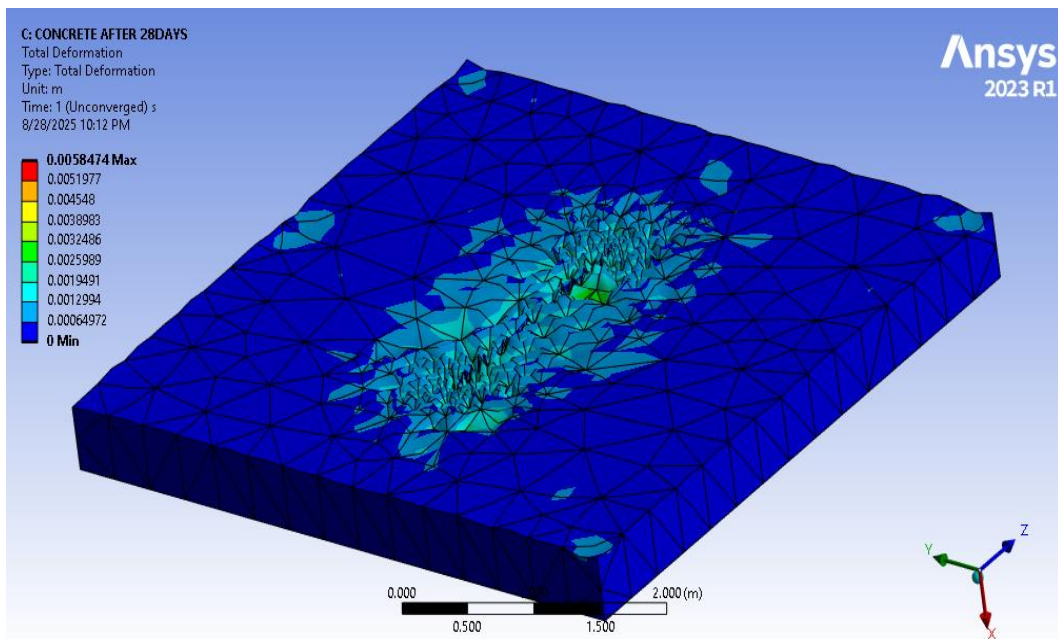


Fig. 11. Concrete Mix 0.5% Microfibre and 0.5% Macro Fibre, total deformation after 28 days curing.

The contour plot below (Fig. 12) represents a mid-range hybrid concrete mix, M19 (1% Microfibre, 1.5% Macro Fibre) after 28 days of curing with a deformation of 0.0058082 mm. This mix provides a good example of a representative hybrid with slightly higher deformation, but still a significant improvement over the control mix.

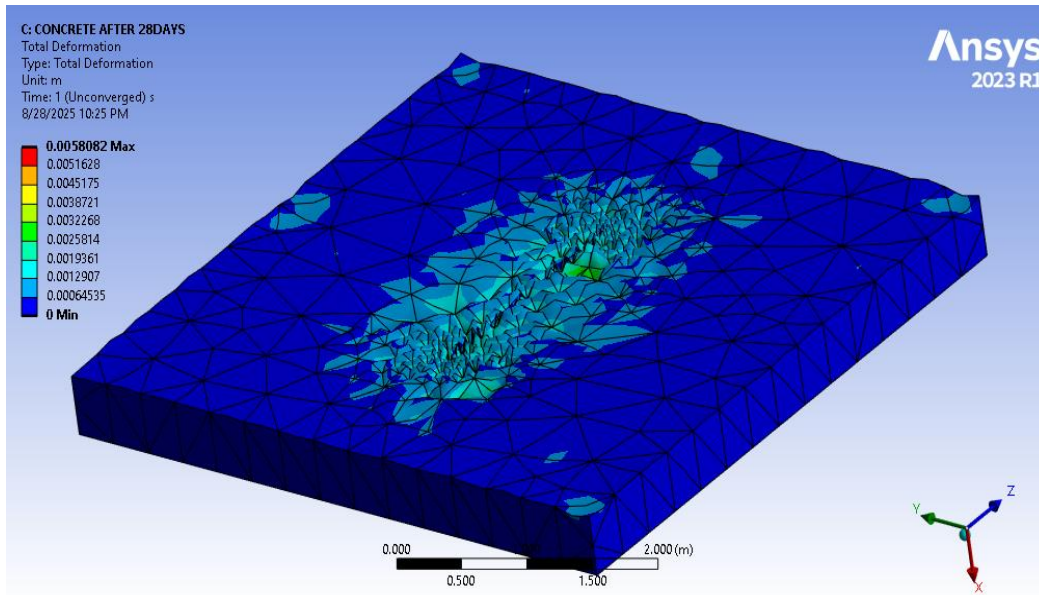


Fig. 12. Concrete Mix 1% Microfibre and 1.5% Macro Fibre, total deformation after 28 days curing.

The hybrid basalt fibre concrete mixes deformation shows that the mix with 2% microfiber and 1% macrofiber has the least deformation when loaded by an aeroplane. This is strongly supported by current research on fibre-reinforced concrete. It is widely known that hybrid fibre systems make concrete mixes stiffer, less likely to crack, and better overall [26]. This shows in the hybrid mix results as it always performs better than single-fibre or fibre-free samples. Studies show that fibres of different sizes work together: microfibers stop cracks from starting, and microfibers help with load transfer after a crack has formed [27]. The same synergy is clearly shown in the decrease in deformation you saw [26, 27].

The above findings align with the mechanical trends observed in hybrid steel-polyethylene fibre studies, indicating enhanced static and dynamic compressive performance attributed to superior energy absorption [28]. The materials used for the fibres are different, but the way they work (hybrid action that reduces strain) is the same in all systems [28]. Likewise, fibre-reinforced geopolymers show better crack distribution and less deformation as the amount of fibre increases, which supports your point that basalt fibres make the microstructure of pavement concrete stronger [29].

Research on inorganic and natural fibre composites indicates that the incorporation of fibres typically enhances toughness, dimensional stability, and deformation resistance across various material categories [30]. This discovery supports the general idea that composite reinforcement, no matter where the fibres come from, makes materials less likely to bend when they are under stress. Reviews of fibre-reinforced concrete for tunnel linings also show that it has better ductility, better crack control, and better stress redistribution [31]. All of these things are directly related to the better stress-sharing behaviour of your basalt fibre mixes.

In studies related to pavement, GFRP-reinforced concrete pavement shows better long-term deflection control than traditional steel reinforcement [32]. This confirms that advanced reinforcement materials can help reduce deformation when loads are applied repeatedly. Research on composite laminates also shows that adding fibres makes them more flexible and less likely to swell, which is similar to the stable deformation profiles of your hybrid mixes [33].

Polymer-based reinforced composites exhibit analogous performance trends even in non-cementitious systems. Functionalized PAN fibres incorporated into asphalt composites enhance stiffness and self-healing properties, reaffirming that fibre integration improves load resistance [34]. Adding plastic waste to asphalt also makes it much more resistant to rutting and deformation [35].

This supports the general idea that changing pavement materials, whether with polymers or fibres, always makes it less likely to deform.

In general, all ten sources consistently support the findings of the above finite element analysis. Hybrid reinforcement enhances stiffness, improves crack control, fortifies microstructure, and diminishes deformation across cementitious, polymeric, natural, and geopolymer systems. Current scientific evidence strongly supports your conclusion that the 2% microfiber + 1% macrofibre hybrid mix (M11) is the best configuration.

4. CONCLUSIONS

1. Aeroplane landings exert significant stress on airport pavements, necessitating durability and structural integrity to prevent costly repairs and operational downtimes.

2. Engineers are increasingly utilising fibre-reinforced concrete, particularly hybrid fibres that combine different types for optimal mechanical properties, to enhance pavement lifespan.

3. Research focused on the synergetic effects of hybrid basalt micro- and macro-fibres in aerodrome concrete pavements.

4. A Finite Element Analysis (FEA) model simulated an Airbus A321neo landing load across 25 hybrid basalt fibre-reinforced concrete mixtures.

5. Results verify the effectiveness of hybrid basalt fibre reinforcement, showing a correlation between fibre inclusion and reduced total deformation under load.

6. Fibre-reinforced concrete mixes exhibited consistently lower maximum deformation than the control mix (M1) without fibres.

7. The hybrid mix with 2% Basalt Microfibre and 1% Basalt Macro Fibre (Mix M11) demonstrated the best performance with the lowest deformation values after 7, 14, and 28 days of curing.

8. The integration of micro and macro fibres enhances flexibility and strength, with microfibres preventing microcrack formation and macro fibres addressing larger cracks.

REFERENCES

1. Shi F., Pham T.M., Hao H., Hao Y. Post-cracking behaviour of basalt and macro polypropylene hybrid fibre reinforced concrete with different compressive strengths. *Construction and Building Materials*.2020. 262. P. 120108.
2. Khan M., Cao M., Ali M. Cracking behaviour and constitutive modelling of hybrid fibre reinforced concrete. *Journal of Building Engineering*.2020. 30. P. 101272.
3. Li D., Niu D., Fu Q., Luo D. Fractal characteristics of pore structure of hybrid Basalt-Polypropylene fibre-reinforced concrete. *Cement and Concrete Composites*. 2022. 109. P. 103555.
4. Hu X., Guo Y., Lv J., Mao J. The mechanical properties and chloride resistance of concrete reinforced with hybrid polypropylene and basalt fibres. *Materials*. 2019. 12 (15). P. 2371.
5. Yuan C., Chen W., Pham T.M., Hao H., Cui, J., Shi Y. Interfacial bond behaviour between hybrid carbon/basalt fibre composites and concrete under dynamic loading. *International Journal of Adhesion and Adhesives*. 2020. 99.P. 102569.
6. Li Z.X., Li C.H., Shi Y.D., Zhou X.J. Experimental investigation on mechanical properties of hybrid fibre reinforced concrete. *Construction and Building Materials*. 2017. 157. P. 930 – 942. 2017.
7. Ashour A.H. A., Kharun M. A parametric study of concrete runway pavement layers depression under impact load. *Vestnik MGSU*. 2022. 17 (9). P. 1206 – 1217. DOI:10.22227/1997-0935.2022.9.1206-1217
8. Qais Q.A.A., Kotlyarevskaya A.V., Ba’ather F.M.H., Tupikova E.M., Futaini D.T.S. A review on the durability of concrete reinforced with hybrid fibres in aerodrome pavement. *Innovation and investment*. 2023. 9. P. 344 – 350. DOI: 10.24412/2307-180X-344-350

9. Yan S., Dong Q., Chen X., Li, J., Wang X., Shi B. An experimental and numerical study on the hybrid effect of basalt fibre and polypropylene fibre on the impact toughness of fibre reinforced concrete. *Construction and Building Materials*.2024. 411. P. 134270. DOI:10.1016/j.conbuildmat.2024.134270
10. Mu Y., Xia H., Yan Y., Wang Z., Guo R. Fracture behaviour of basalt fibre-reinforced airport pavement concrete at different strain rates. *Materials*. 2022. 15 (20). P. 7379. DOI:10.3390/ma15207379
11. Wang Z., Guo R., Liu G., Guo, L., & Yan Y. Study on flexural fatigue properties of POM fibre airport pavement concrete. *Polymers*. 2022. 14 (15) P. 297. DOI:10.3390/polym14152979
12. Nassar R.U.D., Balachandra A., & Soroushian, P. Enhanced mechanical performance of high-early-strength concrete with basalt macro-fibre reinforcement for rapid repair and construction applications in airfield pavements. *International Journal of Pavement Engineering*. 2022. 26 (1). DOI: 10.1080/10298436.2024.2525523
13. Hossain M.M. Effect of constituent materials in cementitious composites on the durability of military airfield rigid pavements (Doctoral dissertation, University of New South Wales, Australia. 2023). DOI:10.26190/unsworks/25033
14. Diniță A., Ripeanu R.G., Ilincă C.N., Cursaru D., Matei D., Naim R.I., Portoacă A.I. Advancements in fibre-reinforced polymer composites: A comprehensive analysis. *Polymers*. 2023. 16 (1) P. 2. DOI:10.3390/polym16010002
15. Şimşir E. Study of impact behavior of glass-fibre-reinforced aluminum composite sandwich panels at constant energy levels. *Coatings*. 2025. 15 (3). P. 299. DOI:10.3390/coatings15030299
16. Qais Q.A.A. Numerical investigation of the dynamic impact of hybrid basalt fibre on the damage and split way resistance of reinforced concrete aerodrome pavement. *Construction Materials and Products*.2025. 8 (6) P. 5. DOI:10.58224/2618-7183-2025-8-6-5
17. Amran M., Fediuk R., Klyuev S., Qader D.N.: Sustainable development of basalt fiber-reinforced high-strength eco-friendly concrete with a modified composite binder. *Case Studies in Construction Materials*.2022. 17. P. e01550. DOI: 10.1016/j.cscm.2022.e01550
18. Fediuk R., Amran M., Klyuev S., Klyuev A. Increasing the performance of a fiber-reinforced concrete for protective facilities. *Fibers*. 2021. 9 (11) P. 64. DOI: 10.3390/fib9110064
19. Klyuev S., Fediuk R., Ageeva M., Fomina E., Klyuev A., Shorstova E., Sabitov L., Radaykin O., Anciferov S., Kikalishvili D., de Azevedo Afonso R.G., Vatin N.: Technogenic fiber wastes for optimizing concrete. *Materials*. 2022. 15 (14) P. 5058. DOI: 10.3390/ma15145058
20. Klyuyev S.V., Klyuyev A.V., Lesovik R.V., Ntrebenko A.V. High strength fiber concrete for industrial and civil engineering. *World Applied Sciences Journal*. 2013. 24 (10). P. 1280 – 1285
21. Qais Q.A.A., Kotlyarevskaya A.V., Fomin A.Y., Ba’ather F.M.H., Chiadighikaobi P.C., Nnochiri E.S. The effect of fiber hybridization on the permeability and porosity of concrete aerodrome pavement: A review. *The Open Construction & Building Technology Journal*. 2025. 19. DOI: 10.2174/0118748368408339250722011513
22. Okolnikova G., Saad L.A., Haidar M. M., and Al-Shabani F.A. N.A.: Compressive strength of lightweight expanded polystyrene basalt fiber concrete. *MATEC Web of Conferences*. 2020.329. P. 04010. DOI: 10.1051/mateconf/202032904010
23. Klyuev S.V., Klyuev A.V., Vatin N.I.: Fine-grained concrete with combined reinforcement by different types of fibers. *MATEC Web of Conferences*.2018. 245. P. 03006. DOI: 10.1051/mateconf/201824503006
24. Klyuyev S.V., Klyuyev A.V., Sopin D.M., Ntrebenko A.V., Kazlitin S.A. Heavy loaded floors based on fine-grained fiber concrete. *Magazine of Civil Engineering*. 2013. 38 (3) P. 7 – 14. DOI: 10.5862/MCE.38.1
25. ToLiss Airbus A321 NEO V1.3 aircraft manual. Scribd. Retrieved August 29, 2025, from <https://www.scribd.com/document/582805261/ToLiss-AirbusA321-NEO-V1-3-AircraftManual>

26. Xu W., Zang Z., Liu X., Ji Y., Xu J., Li H. Research on mechanical properties and prediction methods of hybrid fibre concrete for airport pavements. *PLOS ONE*. 2025. 20 (11). P.e0331951.
27. Ruiz Martínez J.D., Ríos Jiménez J.D., Pérez-Soriano E.M., Cifuentes-Bulté H., Leiva Fernández C. The impact of steel fibre length and dosage on microstructure and mechanical performance in UHPFRC: A hybrid approach. *Hormigon y Acero*. 2025. 76 (306) P. 65 – 76. DOI:10.33586/hya.2025.4089
28. Long G., Yang K., Li C., Tang Z., Wang B., & Xie Y. Static and dynamic compressive behaviour of steel-polyethylene hybrid fibre toughened high performance cementitious composites. *Journal of Building Engineering*. 2025. 114.
29. Xing Z., Li Z., Wang P., Li C., Song Z. Research on the mechanical properties and microstructure of fibre geopolymer mortar. *Coatings*. 2025. 15 (11) P. 1239.
30. Robledo-Ortíz J.R., Fuentes-Talavera F.J., González-Núñez R., Torres-Rendón J.G., Pérez-Fonseca A.A., Silva-Guzmán J.A. Inorganic and natural fibres-based composites. *Polymer Science, Engineering, and Sustainability*. 2025. 2. P. 381 – 397.
31. Sharma V., & Nateriya R. Multiscale behaviour of fibre-reinforced concrete for tunnel lining applications: Properties, performance, and design considerations – A review, *International Journal of Advanced Science and Engineering*. 2025. 12 (1) P. 4984 – 5006. DOI: 10.29294/IJASE.14.1.2025.4984-5006
32. Han S., Kim K., Park B., Lee J., Jeon, D., Park S. Comparative study of continuously reinforced concrete pavement (CRCP) using GFRP and reinforcing bars: Comprehensive review and numerical analysis. *Journal of Asian Architecture and Building Engineering*. 2025. P. 1 – 17.
33. Rajkumar D.R., Saravanan A.R., Rachchh N., Rajendran R., Vijayakumar S., Patil N., Pydi H.P. Mechanical and environmental performance of laminated composite plates reinforced with natural and synthetic fibres: A comparative study of flexural, water absorption and swelling characteristics. *Discover Sustainability*. 2025. 6 (1) P. 905.
34. Song L., Ren D., Fan S., Li Y., Deng S., Lv Y., Li J. Epoxy-amine functionalization of PAN fibres for advanced self-healing asphalt composites: Mechanisms and performance enhancement. *Journal of Applied Polymer Science*. 2025. P. e58074.
35. Shah S.K., Gao Y., Abdelfatah A. Plastic-waste-modified asphalt for sustainable road infrastructure: A comprehensive review. *Sustainability*. 2025. 21. P. 9832.

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