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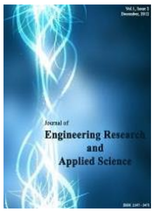

Freeze-thaw resistance of light-coloured basalt fibre reinforced concrete used for concrete paving

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Abstract
Significant amount of research has been conducted in Turkey regarding concrete paving since 1990s. The service life of pavement should be planned for short, medium and long terms when concrete is selected for the pavement type. Factors like mix ratios, vehicle load, chemical degradation, energy damping, temperature effects, regional conditions, application type, freeze and thaw and gritting should be considered during the concrete planning phase. Furthermore, concrete roads provide improved night vision. Concrete roads are inherently light-coloured and they provide improved night vision absorbing less light when compared to darker asphalt paving. Concrete roads eliminate the risk of headlight reflection in wet conditions. This study investigates the strength and resistance properties of white, basalt fibre reinforced concrete. Basalt fibres of 6mm, 12mm and 24mm in length were added to the mixture, 2% by volume. Fibre lengths of 6mm and 12mm were found to be the most suitable as a result of strength and resistance tests. Samples produced using 24mm basalt fibres provided minimum loss of compressive strength after 100 f-t cycles.

Keywords: Basalt fibre; concrete roads; durability; white cement; silica aggregate

1. Introduction

Road pavements can be categorized in two groups namely; flexible pavements (asphalt paving) and rigid pavements (concrete paving) [3].It is widely known that concrete roads as a rigid pavement structure offer a better performance when compared to asphalt roads in many respects [18] Nevertheless, concrete roads prove to be advantageous as light-coloured concrete surfaces provide improved night vision for drivers. Even if the manufacturing procedure of the concrete complies with the standards, the production method may vary due to environmental conditions and applications [9].

Concrete and cement based composites are combined with many materials such as steel and organic fibres. Today, steel fibres are most widely preferred for the advantages they offer with their high elasticity module. Yet, it is also known that steel fibre is a building material susceptible to corrosion. Moreover, steel fibres lead to an increase in the dead load therefore causing a loss of workability in fresh concrete [13].. Glass fibre, on the other hand, is a fibre type which is highly susceptible to alkaline conditions. The most significant drawback of carbon fibres is its high cost and its anisotropic feature. Synthetic fibres (especially polymer based), on the other hand, offer a limited area of use due to its low elasticity module, low melting point, and poor adherence properties. Therefore, use of new fibre types in concrete and cement based composites were prioritized and basalt fibre was developed for this purpose [8,11,7] Basalt fibre offers high strength and elasticity module, high chemical durability and favorable adherence feature while providing manufacturing opportunities without the need for high technology use. Plus, basalt fibre production does not involve any additives. Therefore, the cost of basalt fibre is relatively low. Basalt fibre offers a higher thaw resistance when compared to glass fibre; and a higher tensile deformation when compared to carbon fibre [5]. Thus, basalt fibre is commonly used in automobile industry, chemicals industry, military

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facilities, refractory component production and as a reinforcing component for structures [5, 12,17,21,20]. Materials possess a porous structure. The water available in the pores of a material if freezes due to minus degrees may lead to reduced material strength and even breakage of the material. This is caused by the increasing volume of the water when it is frozen [16]. The volume of the water increases by 9% when it is frozen. So, it is clear that freezing phenomenon leads to a thermal expansion in materials. Pore structure is significantly affected by the thermal expansion. Due to repeated freeze-thaw phenomenon the pores expand a little more each time resulting in significant fractures and even debris [14]. A cross-sectional fracture in concrete is caused by a severe and lasting freeze-thaw effect while surface damage is the most common occurrence in the daily life [1]. This study involves light-coloured concretes obtained using basalt fibre in different sizes (6-12-24mm) and white cement. The feasibility of this application was investigated through the analysis of the strength and resistance features of the concretes obtained.

2. Experimental study

2.1. Materials

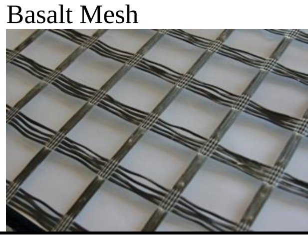
2 different types of silica aggregate with the grain size of 0-5mm and 5-12mm were used in the study. CEM I 52.5 R (White Portland Cement) manufactured by Çimsa Inc. which complies with the TS EN 197-1 and ASTM C150 standards was preferred for the cement applications. The chemical and physical properties of CEM I 52.5 R cement are shown in Table 1. 3rd generation polycarboxylate based water reducer and air entrainer admixtures were used as chemical additives. Polyacrylic based polymer was used in order to minimalize the durability problem.

Table 1. The chemical and physical properties of CEM I 52.5 R cement

Chemical Properties (%)		Physical and Mechanical Properties	
SiO_2	21,6	Specific Weight	3,06
Al_2O_3	4,05	Specific Surface (cm2/gr)	4600
Fe_2O_3	0,26	Whiteness (%)	85,5
CaO	65,7	Initial Set (min.)	100
MgO	1,30	Final Set (min.)	130
Na_2O	0,30	Water Used for Consistency (%)	30
K_20	0,35	Volume Constancy (mm)	1,0
SO_3	3,30	Remnants Obtained Using 0.045 Sieve (%)	1,0
Free CaO	1,60	Remnants Obtained Using 0.090 Sieve (%)	0,1
Chloride (Cl)	0,01	Compressive Strength for 2 days (MPa)	37,0
Insolubles	0,18	Compressive Strength for 7 days (MPa)	50,0
Loss on Ignition	3,20	Compressive Strength for 28 days (MPa)	60,0

Technical properties of the basalt fibre are shown in Table 2. Fibres of different sizes were used 2% by volume in the preparation of the samples. Moreover, basalt mesh was used in order to increase the flexural strength of each concrete mix. Basalt mesh used has the same technical properties as the basalt fibre.

Table 2. Technical properties of the basalt fibre

Tensile Strength (MPa)	4840	Basalt Fibre
Elasticity Module (GPa)	89	
Range of Application Temperature (ºC)	-260/+982	
Melting Point (ºC)	1450	
Specific Weight	2,60	Basalt Mesh
Fibre Diameter (mm)	0,01 (10 micron)	
Fibre Length (mm)	6-12-24	
Range of Mesh (For Basalt Mesh)	10x10	

Mixture percentages of the materials used in concrete preparation are shown in Table 3. Samples were prepared in a cubical form of 150x150x150mm dimensions for compressive strength test and in a prism form of 150x15x750mm dimensions for flexural strength test.

Table 3 Material quantity available in a 1 m^3 concrete mix

Concrete Ingredients (kg)					
Cement	Aggregate 0-5	Aggregate 5-15	Water	Chemical Additives Plasticizer + Air Entrainer + Polymer	Basalt Fibre
760	510	420	260	34	54

2.2. Experimental method

Fresh concrete was cast into the cubical and prism molds using a spray machine. 36 cubical and 36 prism molds were produced for compressive strength and flexural strength tests separately. Samples prepared for the experimental study were removed from their molds after 24 hours. Samples were then kept in a (lime saturated) water bath until the testing time. Uniaxial compression tests and 3-point flexural tests were conducted on the concrete samples on the 1st, 7th and the 28th day. Freeze thaw tests were conducted according to the guidelines specified in the TS EN 12467 standard. Freeze thaw cycles were commenced after the samples were kept in the water for 48 hours. The cycle for freeze thaw test is shown in Figure 1. Compression and flexural strength tests were then commenced following the freeze-thaw cycle.

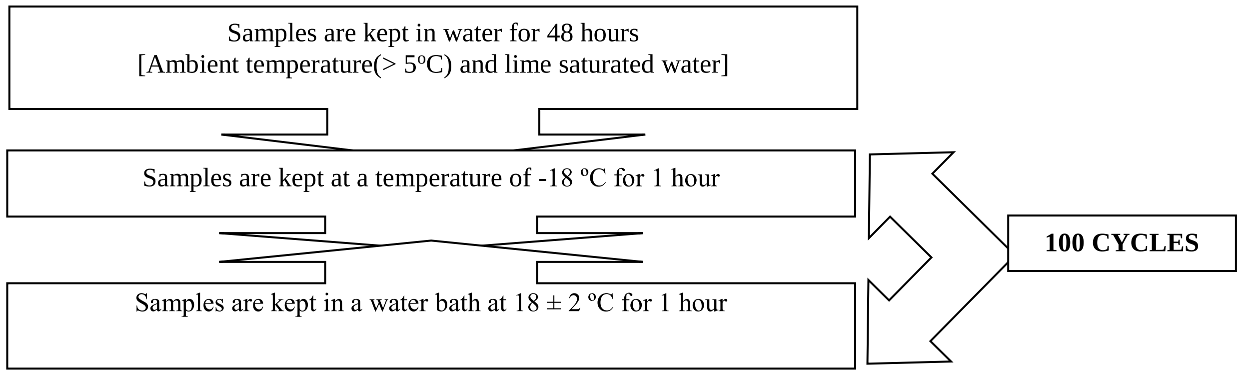


Figure 1. Procedural steps carried out for the freeze-thaw cycle

3. Results and discussion

3.1. Fresh concrete test (flow diameter)

Fresh concrete properties for the composites reinforced with basalt fibre are shown in Table 4. Flow diameters were identified for fresh concrete samples. Flow diameter was decreased due to the adverse effect of increased fibre length on workability. Flow diameters were decreased by 6.5% to 13.7% as a result of increased fibre length.

Table 4. Fresh concrete properties of composites reinforced with basalt fibre

Fibre length (mm)	6	12	24
Flow diameter (cm)	16,8	15,7	14,5

3.2. Compressive strength test

The results of the uniaxial compression tests conducted for the samples obtained using basalt fibre with different lengths on 1st, 7th and 28th days are shown in Figure 2. An increase was observed in the compressive strength due to a limited increase in the slenderness of the basalt fibre. Yet, a decrease in the compressive strength was observed when the fibre length was more than 12mm.

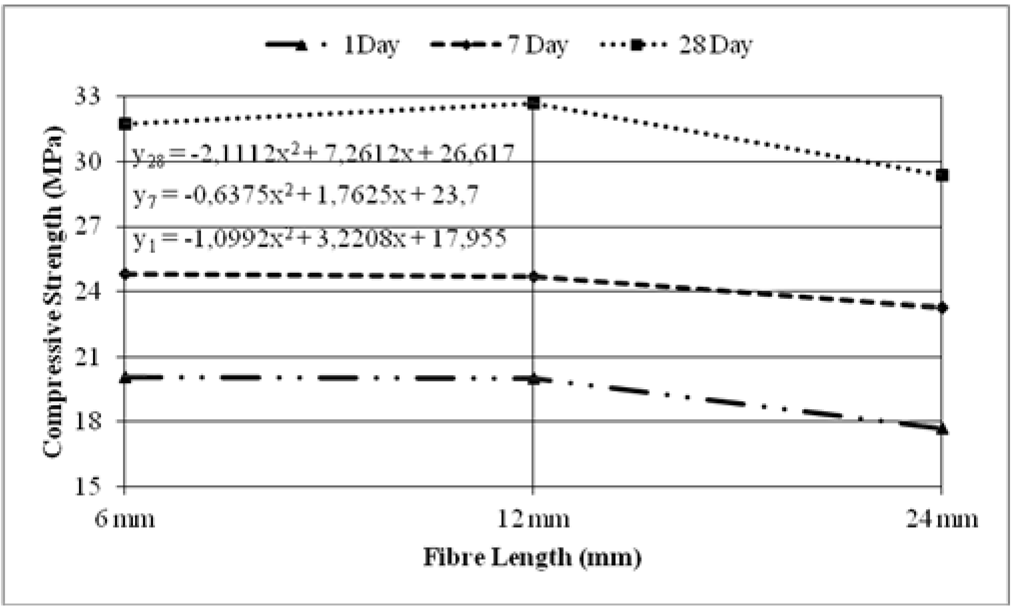


Figure 2.The effect of fibre length on compressive strength.

Samples obtained using 6mm basalt fibre gave relatively higher compressive strength values for the tests conducted on the 1st and 7th days while the compressive strength value for the test conducted on the 28th day was decreased (by 3.2%) when compared to the values obtained for the samples obtained using 12mm basalt fibre. Samples obtained using 12mm basalt fibre gave similar results with the samples obtained using 6mm basalt fibre for the tests conducted on the 1st and 7th days. However, samples obtained using 6mm basalt fibre gave relatively higher compressive strength values for the tests obtained on the 28th day. Samples obtained using 24mm basalt fibre gave the lowest compressive strength values for the tests obtained on the 1st, 7th and 28th days. When the compressive strength values obtained for the 28th day analyzed a loss in strength by 8.10-11.2% was observed in the samples obtained using 24mm basalt fibres when compared to the ones obtained using 12mm and 6mm basalt fibres. Samples obtained using 12mm basalt fibres were proved to perform best when the compressive strength values obtained for all the test days (1st, 7th and 28th) were analyzed.

3.3. Fresh concrete test (flow diameter)

The results of the 3-point flexural strength tests conducted for the samples obtained using basalt fibre with different lengths on 1st, 7th and 28th days are shown in Figure 3. Strength values were decreased when the fibre length was more than 12mm as it was the case with the compressive effect.

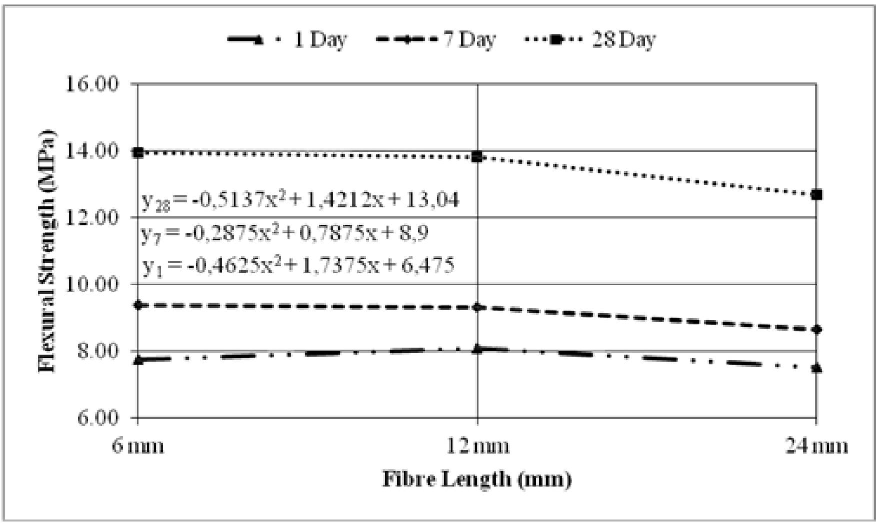


Figure 3. The effect of fibre length on flexural strength

Flexural strength values of the samples obtained using 6mm basalt fibre for the tests conducted on the 7th and 28th days were higher than the ones obtained using 12mm and 24mm basalt fibres. Even though the samples obtained using 12mm basalt fibre gave the highest values for 1 day flexural strength they fail to sustain this feature for the 7th and 28th days. Samples obtained using 24mm basalt fibre gave the lowest flexural strength values for the tests conducted on the 1st, 7th and 28th days as it was the case for compressive strength. The flexural strength of the samples obtained using 24mm basalt fibre were decreased by 10.0% and 9.30% when compared to the samples obtained using 6mm and 12mm basalt fibres respectively.

3.4. Freeze-thaw resistance test

The results obtained from the uniaxial compressive strength tests conducted on the samples procured using basalt fibre before and after 100 freeze-thaw cycle are shown in Figure 4.

The compressive strength values of the samples obtained using 6mm and 12mm basalt fibre range between 19.0 and 19.5 MPa after 100 f-t cycles. However, compressive strength values of the samples obtained using 24mm basalt fibre were decreased to a level of 17 MPa. Compressive strength value of the samples obtained using 24mm basalt fibre is lower than the compressive strength values of the samples obtained using 6mm and 12mm basalt fibre by 11.8%.

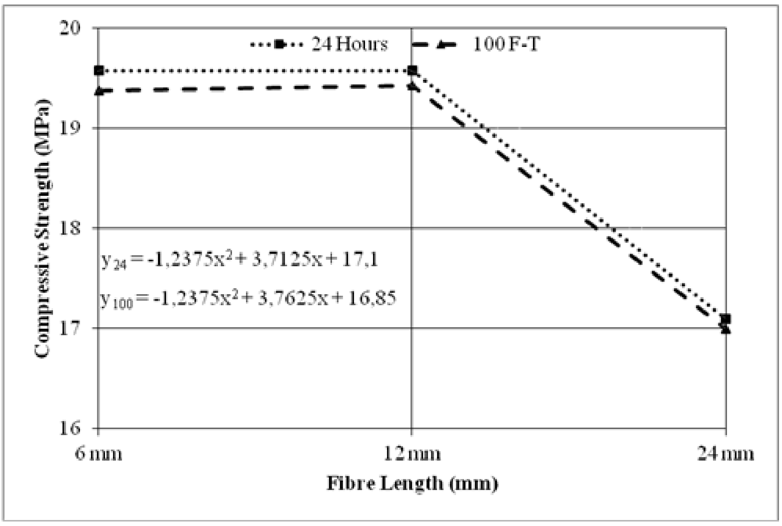


Figure 4. The effect of 100 freeze-thaw cycles on compressive strength

The effects of 100 freeze-thaw cycles on flexural strength are shown in Figure 5. It can be observed from Figure 5 that the flexural strength value of the samples procured using 24mm basalt fibre cannot go above 8 MPa. Flexural strength value of the samples obtained using 24mm basalt fibre is 1.1 fold lower than the compressive strength values of the samples obtained using 6mm and 12mm basalt fibre.

The strength loss as a result of 100 freeze thaw cycles obtained from the samples procured using different fibre lengths are shown in Figure 6. The highest loss in terms of compression strength was obtained from the samples procured using 6mm basalt fibre. The least strength loss, on the other hand, was obtained from the samples procured using 24mm basalt fibre. Increased fibre length has an effect –even though it is limited- on the strength loss originating from freeze-thaw cycles. Yet this situation proves to be the total opposite for the strength loss in the flexural aspect. A slight strength loss was observed following the freeze-thaw cycle as a result of increased fibre length.

As a result of these studies it was obvious that steel fibres do not have a significant effect on freeze-thaw phenomenon [6,4,2,19]. Steel fibres are only able to slow down the collapse and damage of the concrete during freeze-thaw cycle [6].

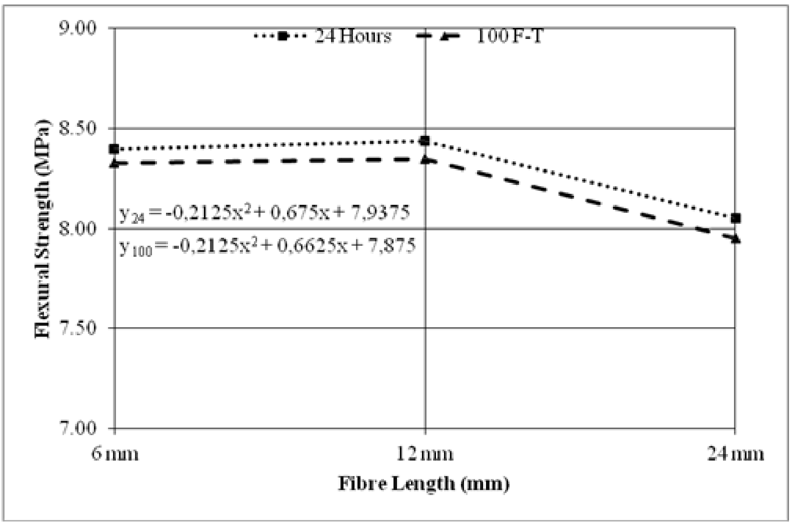


Figure 5. The effect of 100 freeze-thaw cycles on flexural strength

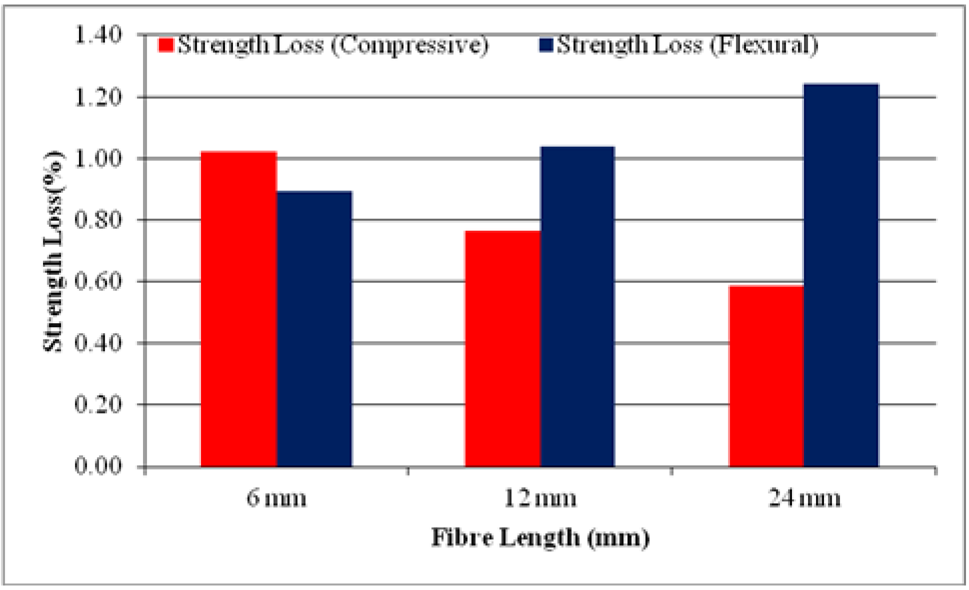


Figure 6. Strength loss as a result of freeze-thaw cycles

4. Conclusion

The results obtained from the strength tests conducted on the samples procured using basalt fibres of different lengths and white cement are summarized below.

A strength loss is observed in case of the use of fibre lengths above 12mm in terms of compressive and flexural strength. This is caused by the weakened adherence between fibre and cement as a result of increased fibre length.

Nevertheless, workability was also decreased as a result of increased fibre length leading to wider pore structures in the concrete. Increased porous area has an adverse effect on the strength properties of the concrete samples.

An increase in the flexural strength was observed as slenderness was increased for the basalt fibre reinforced concrete as it is the case for steel fibre reinforced concrete. However, increased slenderness has an adverse effect on the workability as it is the case for mixtures with steel fibre.

The samples obtained using 6mm and 12 mm basalt fibres give higher strength values in terms of freeze-thaw strength. Workability was adversely affected for the samples obtained using 24mm basalt fibres and these samples showed a porous structure. Thus, leading to decreased compressive and flexural strength values.

No similarity has been observed when the strength losses based on compression and flexural impacts were analyzed. The samples obtained using 24mm basalt fibre which gave the least compressive strength loss proved to have the total opposite effect on the flexural strength.

It was found that steel and glass fibres had no effect on the freeze-thaw resistance as a result of the literature review made based on the experimental studies available. However, freeze-thaw resistance of the concrete is increased with the basalt fibre reinforcement.

The freeze-thaw effect which causes significant damage on the concrete roads is minimalized with the use of basalt fibre. Thus, it is possible to reduce maintenance costs of the concrete roads and therefore to contribute to the economy.

Light-coloured concrete pavements which are manufactured using white concrete will improve the night vision.

Rigid pavements produced using 6mm – 12mm basalt fibres and white cement both increases the freeze-thaw resistance and driving safety (visibility).

Further research in the freeze-thaw resistance of the concrete involving basalt, glass, and steel fibres will lead to significant developments in this field.

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