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Effect of Atmospheric Pressure Oxygen Plasma treatment on Bonding Characteristics of Basalt Fibre Reinforced Concrete

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Abstract

In this research work, the bonding characteristics of plasma treated basalt fibres were analysed by employing the fibre pull-out test. 80 samples were prepared with two different spans of basalt fibres (such as 25 mm and 50 mm) and four levels of embedded length (10, 15, 20 and 25) inside standard M20 grade concrete. Debonding and bonding characteristics of the plasma treated fibres were compared with raw basalt fibres through the fibre pull-out test. The plasma treated and raw basalt fibres were characterised through Field emission scanning electron microscope (FESEM) and Fourier transform infrared (FTIR) analysis. It was observed that confirmation of the presence of hydroxyl groups on the basalt fibre surface was realised through the FTIR test and that there was higher adsorption of concrete particles by the plasma treated basalt fibres through FESEM. The de bonding and fibre pull-out energy of the plasma treated basalt fibres were improved by about 9% and 10% compared with 25 mm and 50 mm raw basalt fibres. From the observation above, it can be stated that the surface modification of basalt fibre may lead to a change in the debonding and pull-out energy level.

Key words: *basalt fibre, plasma treatment, pull-out Strength, debonding energy.*

Introduction

Improving concrete properties has been the focus of many researchers globally [1, 2] since 1910, including steel fibres, nails and clips. However, corrosion proves to be one of the major drawbacks. Textile fibres such as polypropylene, polyvinylchloride and polyvinyl alcohol were introduced as probable alternatives. After 1960, extensive work was carried out to investigate the effect of reinforcement materials on tensile, compressive, flexure and shear properties of concrete. Fibre reinforcement was shown to improve and increase the toughness of concrete and mortar. The maximum fibre content was identified as 2% of the volume fraction, which led to an improvement of up to 3% in tensile properties [4-7].

The Association Française de Génie Civil (AFGC) [8] determined that a) UHPC Ultra high performance concrete has a compressive strength greater than 150 MPa; b) internal fibre reinforcement ensures ductile behavior, and c) there are high bonding properties with special aggregates. The inclusion of reinforcement fibres does not affect rheological properties like the uniform flow and viscosity of concrete composites.

Normally, 0.2 mm diameter steel fibre is used in UHPC. The strength of UHPC reaches around 12.0 to 22 MPa, meanwhile the tensile strain capacity ranges from 0.3% to 0.79% after water curing for 28 days. ***Table 1*** shows physical properties of the steel, synthetic and basalt fibres used [6, 10-12].

Table 1. Physical properties of fibres used in UHPC.

Type of fibre	Tensile strength, MPa	Density, G/cm^3	Corrosive
Steel	2500	7.5	High possibility
Poly vinyl Alcohol (PVA)	1620	1.3	Little possibility
Polyethylene (PE)	3000	0.97	Little possibility
Basalt	3000-4840	2.65	Little possibility

The steel fibre used in UHPC has a high aspect ratio of above 100 and high strength range of 2500 MPa. Steel fibres have the drawbacks of a) being corrosive, b) 3 times denser than concrete, and c) the sinking of fibres during mixing and casting. In combination this leads to poor fibre dispersion in concrete. Textile fibres offer a viable alternative to the corrosion problem. However, the low density does not address the dispersion issue. Furthermore, there is additional cost involved. Several researchers have reported the poor performance of textile fibre reinforcement in terms of accelerated aging and exposure to adverse environments. Mineral fibres such as asbestos and basalt have been considered as concrete reinforcement material and fibre are reported to yield better results. However, asbestos has been identified as a carcinogen and is no longer recommended. Basalt has the additional advantage of retaining strength in a high temperature environment up to 600 °C [13]. Several researchers reported that basalt fibre increases the strength and fracture behaviour of concrete composites [13-15]. However, these studies only researched properties like the compressive, tensile, flexure and shear strength of concrete composites. Meanwhile, the bonding and pull-out properties of fibres in concrete fibre play an important role in improving the ductile behaviour of concrete composites [21]. However, there is a necessity to study the bonding properties of fibres in concrete.

In this research work, novel basalt staple fibres were identified and used as reinforcement material in cement matrix due to their unique mechanical properties. In this case, the fibre to cement bonding properties were analysed through destructive tests. In addition, the surface properties of basalt fibres were enhanced by employing plasma treatment to improve the fibre bonding strength.

Material and methodology

Materials

Basalt staple fibres of various length, such as 25 mm and 50 mm, were procured from Techno Basalt Limited, Ukraine. The average diameter of the fibres was in the range of 13-20 microns.

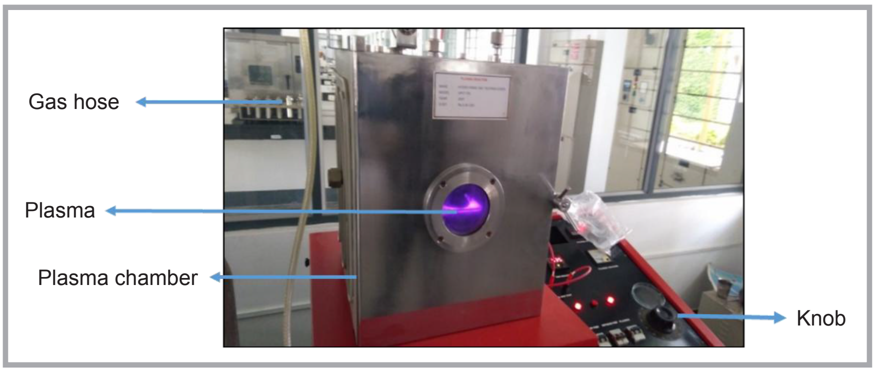

Figure 2. *Plasma chamber.*

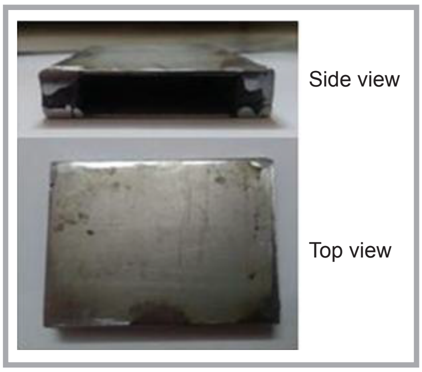

Figure 3. *Steel mould.*

Methods

Plasma treatment

A predetermined quantity of basalt staple fibres were treated in plasma generated through atmospheric oxygen. The fibres were scattered uniformly on a plate and exposed in a plasma chamber (refer to ***Figure 2***) for 2 minutes.

Characterisation

The microstructure of the raw basalt and plasma treated fibres was studied by employing FESEM (Carl Zeiss-Supra 55vp) in the secondary electron (SE) mode. Analysis of the elemental composition was made using energy dispersive spectroscopy (EDS). The presence of hydroxyl groups was observed by employing the FTIR test for the plasma treated fibres.

Pull-out test

Sample preparation

A mould (refer the ***Figure 3***) was made using a steel plate with dimensions of 70 mm (L) X 50 mm (W) X 10 mm (H) for sample preparation. Basalt staple fibres were embedded into M20 concrete using the steel mould. About 120 samples of varying embedded fibre length were prepared for the pull-out test. The fibres were embedded into the cement filled mould and cured for 28 days as per standard IS 456. Then the pull-out test was carried out using a tensile tester.

In pull-out testing, the projected fibre length is firmly fixed in the top movable jaw and the embedded fibre concreate is held by the fixed jaw, as shown in ***Figure 4***. The movable jaw works on the principle of a constant rate of elongation. The debonding energy was measured at the point which the embedded fibre begins to slip. Debonding energy is defined as the energy required to slip the fibre from the concrete during the pull-out test.

The debonding energy may influence several variables, such as the embedded length, type of fibre, surface properties of the fibres, type of matrix etc. Hence, analysis of the debonding energy of the plasma treated and raw basalt fibres was inevitable in this research work.

In addition, the pull-out energy was measured after complete removal of embedded fibres in the concrete. The debonding and pull-out energy were studied for all samples prepared and the test results analysed.

Result and discussion

Surface characterisation

The microstructures of the raw basalt and plasma treated fibres were observed by FESEM (***Figure 5.a*** and ***5.b***). It can be seen from the images that surface modification of the plasma treated basalt fibre is clearly visible as compared to the raw basalt fibres. The presence of hydroxyl groups was confirmed through FTIR analysis, shown in ***Figure 6***.

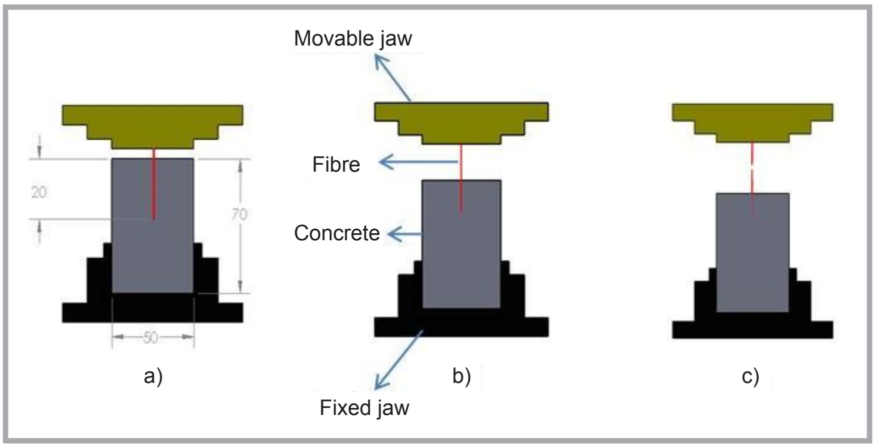

Figure 4. *Schematic diagram of fibre pull-out test: a) concrete is clamped by the fixed jaw and fibres were clamped by the movable jaw; b) fibre elongation due to pulling by the movable jaw and; c) fibres broken stage.*

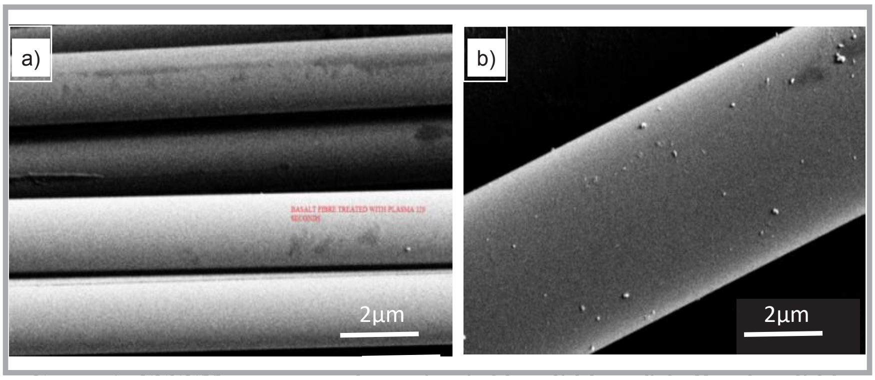

Figure 5. *FESEM images: a) plasma treated basalt fibres and b) raw basalt fibres.*

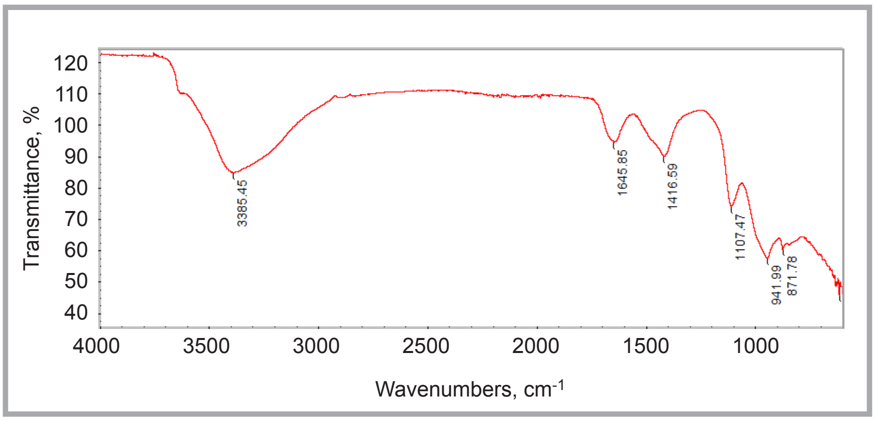

Figure 6. *FTIR Analysis: Plasma treated basalt fibre.*

The elemental compositions of the basalt fibres were examined by EDS. The primary elements in the fibres are listed in ***Table 2***.

Pull-out test

80 samples were prepared with four different levels of embedded length and two different span lengths of basalt fibre.

The debonding energy were measured by considering the initial fibre slip during the pull-out test, the results of which are shown in ***Table 3***. It was observed that the plasma treated fibres showed significant improvement in attaining debonding energy regardless of the embedded length and staple length of basalt fibres. This is due to the surface modification of basalt fibres.

Table 2. *EDS analysis of raw basalt fibres.*

Elements	Weight percentage, %	Atomic percentage, %
KO_2	45.79	62.04
NaO_2	1.78	1.68
MgO_3	2.18	1.94
Al_2O_3	8.77	7.04
SiO_2	26.19	20.21
KiO_2	1.32	0.73
CaO_2	5.79	3.13
TiO_2	0.73	0.33
MgO_2	7.45	2.89
Total	100.00	100.00

The pull-out energy was measured after the complete removal of embedded fibres from the concrete matrix. It was observed that the pull-out energy of plasma treated basalt fibres are improved significantly compared to the raw fibres.

Conclusions

In this research work, the following observations were made.

In the concrete sample with 25 mm basalt fibres, the debonding and pull-out energy of the plasma treated basalt fibre reinforced concrete increased by about 9% compared to the untreated basalt fibre with an embedded fibre length of 10 and 15 mm.

In the concrete sample with 50 mm basalt fibre, the debonding and pull-out energy of the plasma treated basalt fibre reinforced concrete increased by about 10% compared to the untreated basalt fibre with an embedded fibre length of 20 and 25 mm.

From the test results, the debonding energy gradually increases up to a 20 mm embedded length and then starts decreasing. The pull-out energy gradually increases from the minimum to maximum span of fibres (i.e., 10 mm, 15 mm, 20 mm and 25 mm). These changes may be due to the wettability and adhesive nature of the modified basalt fibres through plasma treatment, and the results above are in line with earlier research reports.

Table 3. *Results of de-boning energy during pull-out test.*

Sample's fibre length	Embedded length	Debonding energy in joules						Percentage improvement
		Untreated			Plasma treated			
		Mean	Standard deviation	Standard error	Mean	Standard deviation	Standard error	
25 mm	10 mm	91.6	0.65	0.14	100.1	0.62	0.14	8
	15 mm	94.7	1.36	0.31	104.9	1.63	0.36	10
50 mm	20 mm	94.8	1.87	0.42	106.8	1.96	0.44	11
	25 mm	96.6	2.27	0.51	106.1	1.88	0.42	9

Table 4. *Pull-out test.*

Sample's fibre length	Embedded length	Pull-out energy in Joule						Percentage improvement
		Untreated			Plasma treated			
		Mean	Standard deviation	Standard error	Mean	Standard deviation	Standard error	
25 mm	10 mm	148.88	0.65	0.14	164.33	0.78	0.17	9
	15 mm	153.43	2.04	0.46	168.65	2.04	0.46	9
50 mm	20 mm	268.1	2.84	0.64	294.01	5.21	1.16	9
	25 mm	284.06	5.29	1.18	317.23	4.14	0.93	10

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