International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-05, Issue-01, April 2019

Thermal Expansion Coefficient Of Basalt Fibre Reinforced Polymer Bars

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Abstract: The use of non-metallic basalt fibre reinforced polymer (BFRP) bars in concrete structures has widely increased in the construction sector due to their high mechanical performance. However, BFRP bars have not been included in most design standards and specifications. This is due to lack of investigation on the performance of BFRP bars, in particular, their thermal stability when exposed to high temperature. In this paper, the thermal expansion coefficients of sand-coated basalt fibre reinforced polymer bars were investigated. The thermal stability of sand-coated BFRP bars were determined in the temperature ranging from room temperature to 350^{0}C as per ASTM E228-11.The deterioration of fibre/matrix interface of sand-coated BFRP bars due to extreme temperature were observed using scanning electron microscopy. The experimental test results showed that the sand -coated BFRP bars were treated at extreme temperature, the deterioration of the interface between fibre and resin matrix bring significant reduction of the thermal properties.

Keywords: ASTM standards, BFRP bars, Thermal expansion coefficient

I. INTRODUCTION

Structural deterioration owing to corrosion of conventional steel reinforcement is one of the prominent challenges facing the civil engineering industry. The use of fibre reinforced polymer (FRP) reinforcement in concrete structures escalates the resistance to corrosion when compared to conventional reinforcement and thereby enhances the service life of concrete structures for the last two decades. Carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP) are the most popular FRPs used in civil engineering components. Recently, basalt fibre reinforced polymer (BFRP) has been developed as one of alternatives of glass and even carbon FRP in many engineering fields. Comparatively, the BFRP is considered as one of the environmental friendly and non-hazardous materials because it is produced directly from volcanic rocks .This great environmental friendly aspect creates the composite materials very attractive in engineering markets such as automotive and civil engineering industry. Nevertheless, the thermal expansion coefficient is an important property to understand the flexural behavior of any new material before its application with concrete.

Only few studies have been found in the literature related to thermal expansion coefficient of basalt fibre reinforced polymer (BFRP) bars. Chaalal *et al.*(1993) investigated the coefficient of thermal expansion of GFRP bars under ASTM D696-91 standards. The coefficient of transverse thermal expansion (α^T) varied from 50.2x 10^{-6}/^{o}C for 15.9 mm-diameter bars to 55.6x10^{-6}/^{o}C for 19.1 mm -diameter bars, with an overall average value of 52.9x10^{-6}/^{o}C. The average coefficient of longitudinal thermal expansion (α^L) is equal to 9.0 x 10^{-6}/^{o}C. This value is similar to that of hardened concrete and steel reinforcement.In addition, α^T is five times greater than α^L, due to the characteristic anisotropy of GFRP bars. Sivagamsundari and Kumaran (2008) observed that the CTE values of GFRP bars range between 5 - 7 x 10^{-6}/^{0}C in longitudinal directions and 14 -17 x 10^{-6}/^{0}C in transverse directions from the experimental investigations. Zaidi *et al.*(2009) examined the thermal expansion of FRP bars using strain gauges and thermo mechanical analysis (TMA) methods. The experimental results show that the transverse and longitudinal CTE of GFRP bars obtained from TMA and strain gauge methods are similar. Elgabbas *et al.*(2015) concluded that the transverse coefficient of thermal expansion of BFRP specimens ranging from 18.4 x 10^{-6} /^{o}C to 26.8 x 10^{-6}/^{o}C, which is less than 40 x 10^{-6}/^{o}C as stated by Canadian standards association(CSA). Ayadin (2018) examined the thermal expansion coefficient of Glass FRP, Carbon FRP, Aramid FRP and Basalt FRP bars and concrete. The longitudinal coefficients of thermal expansion values of GFRP, CFRP, AFRP, BFRP bars were 4.43 x 10^{-6}/^{o}C, 1.05 x 10^{-6}/^{o}C,-5.18 x 10^{-6}/^{o}C and 1.92 x 10^{-6}/^{o}C. The transverse coefficients of thermal expansion values of FRP bars were 22.5 x 10^{-6}/^{o}C, 93 x 10^{-6}/^{o}C, 51 x 10^{-6}/^{o}C and 17.1 x 10^{-6}/^{o}C, respectively. The longitudinal coefficients of thermal expansion of concrete were 6-8 x 10^{-6}/^{o}C in

 DOI : 10.18231/2454-9150.2019.0333

different strengths. GFRP bar has been identified as the most stable material in its thermal behaviour whereas AFRP bar as the most unstable one.

The present research paper is focused on the thermal expansion studies of sand-coated basalt fibre reinforced polymer (BFRP) bars of 8mm-diameter.The thermal expansion coefficient of sand-coated BFRP bars of 8mm-diameter were measured according to ASTM E228 using a computer controlled push-rod dilatometer.

II. EXPERIMENTAL PROGRAM

2.1 Materials

The sand coated BFRP bars of 8mm- diameter were purchased from Arrow technical textile private limited, Mumbai, India which were manufactured using pultrusion process. The bars were applied with standard epoxy resin and braided with nylon wire and then finally the quartz sand was coated on the bars as shown in Fig 1.

Fig. 1 Sand-coated BFRP bars

2.2 Specimen Preparation

The specimens for thermal expansion test were carried out in accordance with American Society for Testing and Materials (ASTM) standards. The specimens were cut from the sand-coated BFRP bars using saw blade. Three specimens were prepared for this test.

2.3 Thermal Expansion Coefficient Measurement

Thermal expansion test specimens had length and diameter 30mm and 8mm respectively. The thermal expansion test was performed using pushrod dilatometer at high temperature laboratory as shown in Fig.2.This pushrod dilatometer consists of furnace, inductive transducer, temperature sensor, and specimen holder. The initial length of the specimen was noted at room temperature. Then, the specimen was placed into a holder of the pushrod dilatometer (Fig 3). A spring- loaded pushrod was positioned against the specimen. The opposite end of the push rod was connected to a displacement sensor. The specimen and holder were then enclosed within a furnace where the specimen was heated at a constant rate 2^0C/min up to a temperature of 350^0C (Fig.4). During the experiment, the linear thermal expansion of the specimen was measured at every 50^0C by a highly accurate displacement sensing system. The thermal expansion coefficient (α) was determined by the following equation,

$$\alpha = \frac{1}{L_o}\frac{\Delta L}{\Delta T} \qquad (1)$$

Where L_o is the initial length of the specimen at room temperature (^{o}C) ΔL is the change in length of the specimen(mm) and ΔT is the temperature difference between any two temperatures T_o and T_1(^{o}C).

Fig.2 Opened pushrod dilatometer

Fig.3 Specimen installed in a holder

Fig.4 Closed pushrod dilatometer

2.4 Scanning Electron Microscopy (SEM)

Scanning electron microscopy (SEM) is an outstanding technique to examine the surface morphology of fibres and damaged portion of fibre composites. A scanning electron microscopy (SEM) JEOL-JSM-5610LV model was used for this test. Three BFRP samples were cut in an approximate thickness of 5 mm. Then, the samples were properly cleaned using an air-blower which also saved the SEM chamber from being contaminated and provided higher quality images. An ion sputtering device was used to coat the samples with gold prior to SEM examination. The accelerating voltage used in this study was 5KV.

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ISSN : 2454-9150 Vol-05, Issue-01, April 2019

III. TEST RESULTS AND DISCUSSION

3.1 Thermal Expansion Coefficient

The thermal expansion coefficient of sand-coated BFRP bars of 8mm-diameter as shown in Table1.From the experimental test results, it was observed that the thermal expansion coefficient of sand-coated BFRP bars was about 2.74x 10^{-6} at 100^0C and this value increases upto 4.65 x 10^{-6} at 300^0C. At 350^0C, the amount of expansion decreases thereby decreasing its TEC due to the oxidation of the resin and thus possible deterioration of the interfaces starts between fibre and resin matrix. When the sand-coated BFRP bars was heated to the temperature above 300^0C (Fig.5), a smoke was raised from the pushrod dilatometer. The change in the thermal expansion coefficient (/^{0}C) for sand-coated BFRP bars at various temperatures is shown in Fig.6.

Table 1 Experimental test results of Sand coated BFRP bars

Specimen ID	Temperature (^{0}C)	Thermal Expansion (mm)	Thermal Expansion Coefficient (/^{0}C)
BFRP8-1	100	0.004	2.74 x 10^{-6}
BFRP8-2	150	0.008	3.09 x 10^{-6}
BFRP8-3	200	0.016	3.94 x 10^{-6}
BFRP8-4	250	0.024	4.45 x 10^{-6}
BFRP8-5	300	0.031	4.65 x 10^{-6}
BFRP8-6	350	0.027	3.66 x 10^{-6}

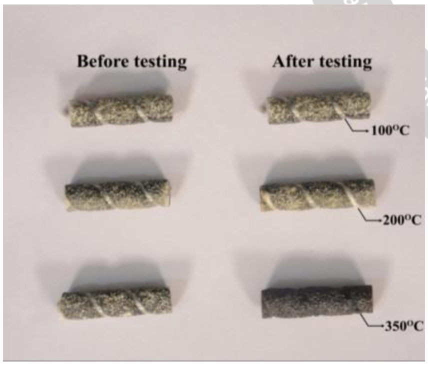
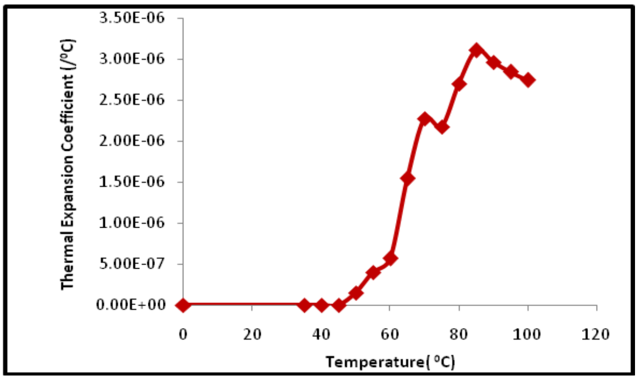
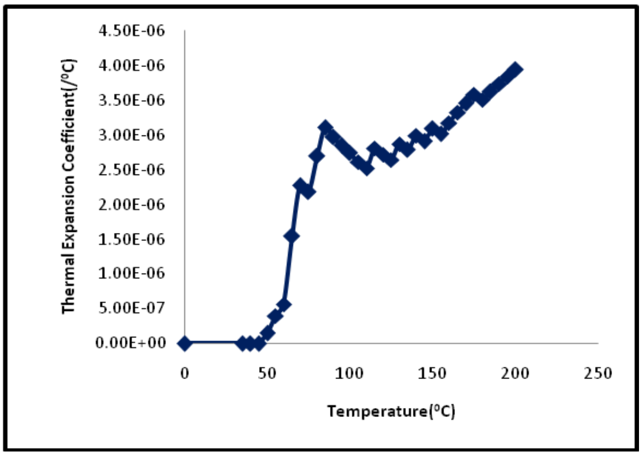


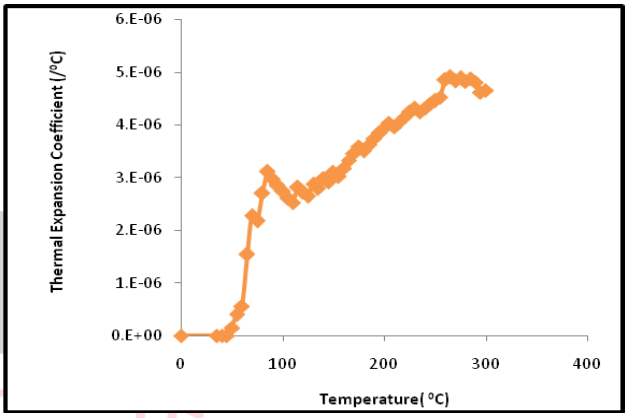
Fig.5. Specimens before and after testing



(a)



(b)



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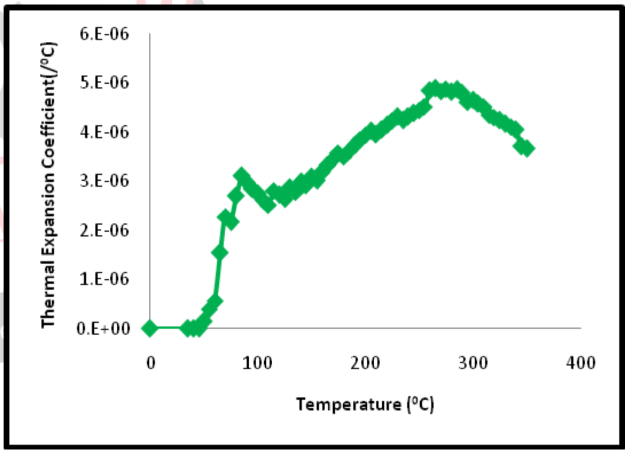


(d)

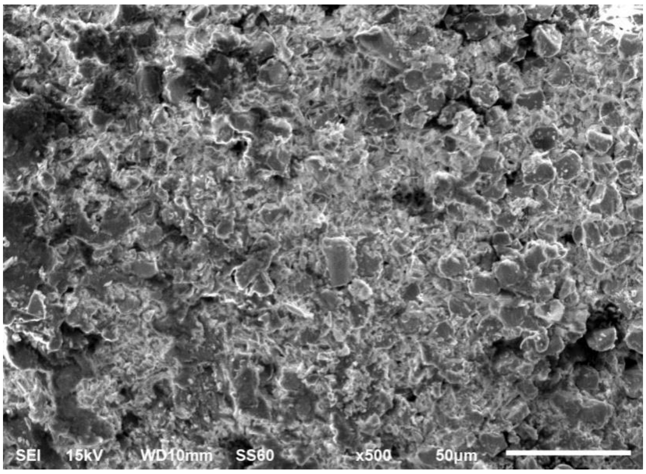
Fig.6 Thermal expansion coefficient Vs Temperature (a) at 100^0C (b) at 200^0C(c) at 300^0C (d) at 350^0C

3.2 Scanning Electron Microscopy (SEM)

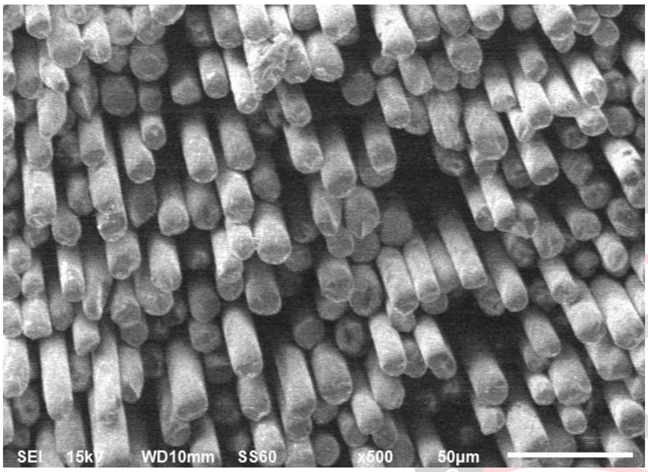
The main structural changes were examined using scanning electron microscopy (SEM). SEM was conducted at medium (200-1000x) magnification level. The medium level magnification images provided a more detailed view of the section. Fig.7 shows the differences in the SEM images of thermal BFRP specimens treated at room temperature and extreme temperature. The SEM images clearly noted that lot of resin properly wets the basalt fibres, which indicates a good bonding of the fibre to the resin matrix. (Fig7a). The SEM image, in Fig 7b, viewed that there was more separation of fibres and less resin on the

DOI : 10.18231/2454-9150.2019.0333

fibre surfaces, which shows reduced fibre bonding to the resin matrix.



(a)



(b)

Fig.7 SEM images of BFRP specimens treated: (a) at room temperature (b) at 350^{0}C

IV. CONCLUSION

In this study, the sand-coated BFRP bars of 8mm -diameter were tested to exhibit their thermal properties. The following conclusions can be drawn on the basis of the experimental results:

The thermal expansion coefficient of sand-coated BFRP bars was about 2.74 x 10^{-6} at 100^{0}C and this valve increases up to 4.65 x 10^{-6} at 300^{0}C. At high temperature (350°C), the degradation of the polymer matrix was observed and they led to a decrease of the TEC. The SEM images confirmed that no damage occurred in the BFRP specimen at room temperature. Nevertheless, the significant damage was clearly viewed in the BFRP specimen at 350°C.

ACKNOWLEDGEMENT

The authors wish to thank Arrow technical textiles private limited and High Temperature laboratory, Department of Manufacturing Engineering, Annamalai University for their assistance in testing the BFRP specimens.

REFERENCES

[1] Herbert. W.M, “Progress in polymer degradation and stability research,” *Nova science publishers*, New york, 2007.

[2] Mouritz.A.P, Gibson A.G, “Fire properties of polymer composites materials,”*Springer*, Netherland,143, 2006.

[3] Challal.O and Benmokrane.B. “Physical and mechanical performance of an innovative glass-fiber-reinforced plastic rod for concrete and grouted anchorages,” *Canadian Journal of Civil Engineering*, 20(2), 1993.

[4] Sivagamasundari.R. and Kumaran.G , “A Comparative Study On The Flexural Behaviour Of One-Way Concrete Slabs Reinforced With GFRP Reinforcements And Conventional Reinforcements When Subjected To Monotonic And Repeated Loading,” *International open civil engineering Journal*, vol 2, pp.24-34,2008.

[5] Zaidi. A, Masmoudi. R, “Thermal expansion of fiber reinforced polymer (FRP) bars,” *Canadian Journal of Civil Engineering*, 7,2009.

[6] Elgabbas.F , Ahmed.E.A, Benmokrane.B , “Physical and mechanical characteristics of new basalt-FRP bars for reinforced concrete structures,” *Construction and building materials*,95,623-635,2015.

[7] Ayadin.F, “Experimental investigation of thermal expansion and concrete strength effects on FRP bars behavior embedded in concrete,” *Construction and Building Materials*, 163, 1-8, 2018.

[8] Masmoudi. A, Masmoudi. R, Ouezdou. M.B, “Thermal effects on GFRP rebars: experimental study and analytical analysis,” *Materials and structures*, 43,775–788, 2010.

[9] Masmoudi.R, Zaidi.A, Patrick Gerard.P, “Transverse thermal expansion of FRP bars embedded in concrete,” *Journal of. Composites for Construction*, 9 (5), 377,2005..

[10] McEloy. D.L, Weaver.F.J, “Thermal expansion of epoxy-fibre glass composite specimens,” *Proceeding of the nineth international thermal expansion symposium*, Pittsburgh, Pennsylvania, December 8-10, 1986.

[11] Sivagamasundari. R , “Experimental and analytical investigations on the behavior of concrete slabs reinforced with fibre based rods as flexural reinforcements,” *Ph.D Thesis*, Dept. of structural engineering, Annamalai university,September,2008.

[12] ASTM: E228, “Standard test method for Linear thermal expansion of solid materials with a push-rod

 DOI : 10.18231/2454-9150.2019.0333

dilatometer," *ASTM International*, United states, 2011.

[13] ISIS: M03, "Reinforcing concrete structures with fibre reinforced polymers," *ISIS Canada Research Network*, 2007.

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 DOI : 10.18231/2454-9150.2019.0333