The Influence of Various Factors on the Drying Shrinkage of Basalt Fibre Reinforced Cement-Based Composites Designed by the Taguchi Method

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Abstract. Cement-based composites are widely used for various construction applications due to their outstanding mechanical and durability performance. However, the high drying shrinkage of cement-based composites has resulted in detrimental effects on its long-term performance. Drying shrinkage in cement-based composites causes cracks that serve as a pathway for the ingress of deleterious materials into the composites. Therefore, improving the drying shrinkage resistance of cement-based composites will result in an enhancement of the overall performance of the composites. The incorporation of short fibres and supplementary cementitious materials are some of the effective ways to improve the resistance of cement-based composites against drying shrinkage. Therefore, this study aims to evaluate the effect of the incorporation of basalt fibres and fly ash on the drying shrinkage of cement-based composites. This paper presents the results from the experimental and numerical investigation on the influence of various factors on the drying shrinkage of basalt fibre reinforced cement-based composites. The mixtures evaluated in this study were designed using the Taguchi method and a total of nine mixtures were made. The influence of the fly ash, water, sand and basalt content on the drying shrinkage of the mixtures were investigated. The findings from this study showed that the use of fly ash to cement ratio of 4, sand to binder ratio of 1, water to binder ratio of 0.25 and basalt fibre dosage of 2% is optimum to reduce drying shrinkage.

Keywords: Cement-based Composites; drying shrinkage; Fly Ash; Basalt fibre; Taguchi method.

1. Introduction
Cement-based composites are the most used building material for various construction purposes (Han, Yu and Ou, 2014). The preference in cement-based composites for construction is due to its excellent strength
performance, versatility and availability of materials locally (Neville and Brooks, 2010). However, the application of cement-based composites is plagued by its shrinkage which is consequential to its performance and service life. One of the common shrinkages that occur in cement-based composites is drying shrinkage with is caused by the rapid loss of moisture from the composites.

In order to mitigate the shrinkage in cement-based composites, several materials can be incorporated. It has been found out the use of supplementary cementitious materials (SCMs), short fibres, low water content can be used to mitigate the drying shrinkage in cement-based composites. The presence of coarse aggregates in cement-based composites is also known to reduce drying shrinkage as a result of the restraint they provide within the matrix. However, the majority of the current studies have only explored the effect of fibres such as polyvinyl alcohol (Adesina and Das, 2020c), carbon (Alcaide et al., 2007), natural fibres (Booya et al., 2018) on the drying shrinkage. The use of basalt fibres which is a sustainable alternative in cement-based composites made without coarse aggregate is limited creating a huge knowledge gap (Duic et al. 2020; Branston et al., 2019).

Hence, it is critical and imminent to determine the effect of various factors alongside basalt fibre dosage on the drying shrinkage of cement-based composites. Due to the high level of various factors required in order to effectively evaluate the effect of various factors; the design of experiments was made using the Taguchi method. Taguchi method eliminates the need to prepare a high number of mixtures thereby reducing the time and cost of experimental studies (Manjunath and Narasimhan, 2018).

Taguchi method was used recently to assess the influence of various factors on the mechanical performance of basalt fibre-reinforced composites (Adesina and Das, 2020a). However, there exists no use of this method to investigate the influence of various factors on the drying shrinkage of the composites. Hence, in this study; the Taguchi method was used to design the experiments and assess the impact of various factors on the drying shrinkage of the basalt fibre reinforced composites. Fly ash and basalt fibres which are environmentally friendly materials were used as SCM and reinforcement, respectively in all mixtures. The factors investigated in this study are the ratio of FA to PC, sand to binder, water to binder. The impact of three different dosages of basalt fibres was also considered as one of the factors.

2. Experimental Program

2.1 Materials

Fly ash and Portland cement satisfying the requirements of ASTM C 618 (2010) and ASTM C 150 (2012), respectively were used as the binder in this study. Fine aggregates with a specific gravity of 2.64. Basalt fibre with a diameter and length of 16 μm and 18 mm, respectively were used.

2.2 Mixture design

In order to assess the influence of different factors effectively, the design of the experiment was developed using three levels of each factor based on the practical composition of conventional cement-based composites. The factors and corresponding levels are presented in Table 1. Nine mixtures were developed based on the Taguchi method and the composition presented in Table 2.

| Factor ID | Factor                  | Levels |
|-----------|-------------------------|--------|
| A         | FA to cement ratio      | 1      |
|           |                         | 2      |
|           |                         | 4      |
| B         | Sand to Binder ratio    | 0.25   |
|           |                         | 0.45   |
|           |                         | 0.35   |
| C         | Water to binder ratio   | 0.25   |
|           |                         | 0.30   |
|           |                         | 0.35   |
| D         | Fibre dosage (%)        | 1      |
|           |                         | 2      |
|           |                         | 5      |

Table 1. Factors and levels used
Table 2. Composition of mixtures

| Run | Factor A | Factor B | Factor C | Factor D |
|-----|----------|----------|----------|----------|
| 1   | 1        | 0.25     | 0.25     | 1        |
| 2   | 2        | 0.25     | 0.35     | 9        |
| 3   | 2        | 1        | 0.25     | 2        |
| 4   | 4        | 0.45     | 0.25     | 5        |
| 5   | 4        | 0.45     | 0.35     | 1        |
| 6   | 1        | 1        | 0.30     | 2        |
| 7   | 1        | 1        | 0.30     | 5        |
| 8   | 4        | 0.25     | 0.30     | 2        |
| 9   | 2        | 0.45     | 0.35     | 1        |

2.3 Sample preparation and curing
For each mixture presented in Table 2, the binder and aggregates were mixed initially before adding water to the mixtures while the mixing continued. This process was followed by the slow addition of the basalt fibres. The mixture was mixed for an additional two minutes after all the fibres were added to achieve a homogenous mixture. The fresh mixture was poured into bar moulds after mixing was completed and samples demoulded after 24 hours. After demoulding the samples were left open in laboratory conditions to allow drying of the samples to progress.

2.4 Test method
The drying shrinkage of each mixture was measured up to 28 days by measuring the length change of the samples per ASTM C 157 (2016). For each mixture, a total of four samples were made and measured. The average drying shrinkage obtained from four samples for each mixture was used to obtain the effect of each factor on the drying shrinkage.

3. Results and Discussion
The results and discussion made in this section are based on the drying shrinkage of the composites after 28 days of subjecting to drying conditions. Based on the results, Equation 1 was formulated to predict the drying shrinkage (DS) of the mixtures. From the analysis of the results, the influence of different factors on the drying shrinkage of the cement-based composites are presented in Figure 1 to Figure 4.

\[ DS = 0.45 + 0.082A + 0.029B - 0.064C - 0.14D \] (1)

3.1 Effect of fly ash to cement ratio
It is evident from Figure 1 that increasing the content of FA as replacement of the PC resulted in a decrease in the drying shrinkage with a more significant reduction made at FA to PC ratio greater than 2. The reduction in the drying shrinkage with a higher content of FA can be ascribed to the pore filling effect of FA particles and the formation of pozzolanic products which results in the densification of the microstructure. This observation corresponds to other studies where FA was used to replace PC in cement-based composites (Yang, Yang, and Li 2007; Adesina and Awoyera 2019; Awoyera et al. 2019).
3.2 Effect of sand to binder ratio

Figure 2 presents the effect of drying shrinkage of the cement-based composites. The results obtained are anticipated as the increase in the sand content is expected to provide more restraint in the matrix, hence, lower change in the length of the composites. The results showed that there is no considerable effect on the drying shrinkage when the sand to binder was increased from 0.25 to 0.45. However, a considerable reduction in the drying shrinkage ensued when the sand to binder increase to 1. These results agree with the observation made by Ye et al. (2019) where it was observed that increasing the sand to binder ratio results in lower drying shrinkage of engineered cement-based composites. Hence, it can be deduced that increasing the content of aggregates in cement-based composites will mitigate drying shrinkage. Nonetheless, it is worth mentioning that increasing the sand to binder content will result in more reduction in the strength capacity. Hence, it is recommended to ensure that other requirements such as strength and durability are within acceptable limits when higher sand to binder ratio is employed to mitigate drying shrinkage.

Figure 1. Effect of fly ash to cement ratio on drying shrinkage
3.3 Effect of water to binder ratio

Generally, increasing the water to binder ratio is detrimental to the performance of cement-based composites. A similar effect on drying shrinkage was observed when the water to binder ratio in cement-based composites was increased from 0.25 to 0.30. However, a slight reduction (i.e. less than 0.05%) was observed when the water to binder ratio was further increased to 0.35. These results confirm the observation made by other studies where the use of lower water to binder ratio in cement-based composites was found to yield lower drying shrinkage (Adesina and Das, 2020c, 2020b, 2020d).

Figure 2. Effect of sand to binder ratio on drying shrinkage

Figure 3. Effect of fly ash to cement ratio on drying shrinkage
3.4 Effect of basalt fibre dosage

The incorporation of fibres into cement-based composites is expected to mitigate drying shrinkage as the fibres provide restraints within the matrix. Figure 4 presents the effect of basalt fibre dosage. It is clear from Figure 4 that 2% is the optimum basalt fibre dosage to reduce drying shrinkage. At higher content of basalt fibre (i.e. 5%), the drying shrinkage of the composites was higher (i.e. greater than when 2% was used). The reduction in the drying shrinkage at 2% basalt fibre can be ascribed to the effective bridging effect of the basalt fibres in the matrix. The increase in the drying shrinkage when the fibre dosage was increased to 5% can be attributed to the agglomeration of the fibres due to improper dispersion in the mixture (Branston et al., 2016). These accumulated fibres create a weak point and void in the matrix resulting in higher drying shrinkage due to their inability to offer restraint within the matrix. It is worth mentioning that the presence of fibres has been found to reduce the compressive strength of cement-based composites. Hence, it is critical to ensure that there is no significant deterioration in the strength capacity when basalt fibres are used to mitigate drying shrinkage. Also, this optimum dosage is applicable to these mixtures without coarse aggregate. Therefore, a different behaviour or optimum dosage might be applicable to concrete mixtures.

![Figure 4. Effect of basalt fibre dosage on drying shrinkage](image)

4. Conclusions

The effect of various factors on the drying shrinkage of cement-based composites reinforced with basalt fibre was investigated in this study. Based on the outcome from this experimental and numerical investigation it was found out that replacing Portland cement with fly ash results in lower drying shrinkage. Similarly, increasing the sand content of the mixture reduces the drying shrinkage of the composites as more restraints are provided. In terms of the basalt fibre dosage, the optimum was found to be 2% as a higher content of the basalt fibre resulted in higher drying shrinkage.

In general, the drying shrinkage of cement-based composites can be reduced with the use of basalt fibre at a dosage of 2% alongside higher content of fly ash and sand in the mixtures. However, the use of fly ash
and basalt fibres are more effective in mitigating drying shrinkage compared to higher sand to binder ratio and lower water to binder ratio. The use of fly ash and basalt fibres in cement-based composites not only help to mitigate the drying shrinkage but also improves the sustainability of the composites.

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