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Research Article

Statistical Analysis of the Effect of Waste Polymer and Carbon Additives on Porosity in Cementitious Composites

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***Abstract*- ** Concrete is a building material that has been used extensively throughout human history and has played a fundamental role in the formation of civilizations. The strength, durability, and longevity of concrete are affected by many factors, and among these factors, porosity plays a critical role in determining concrete quality. In recent years, advances in nanotechnology have highlighted the use of nanomaterials, which impart different properties to building materials, particularly in the construction industry. However, improper disposal of waste polymers poses a serious problem for the ecosystem. Therefore, the use of waste polymers as aggregates in cement composites is considered an environmentally friendly approach. However, considering that the use of polymer alone can lead to a loss of mechanical properties, this study aimed to achieve synergistic effects by using graphene oxide, reduced graphene oxide, and graphene nanopellet additives. A total of nine experiments were conducted using the Taguchi method using a statistical experimental design and an $L_9(3^4)$ orthogonal array. The experimental plan specified the type and amount of nanomaterial, and the type and amount of polymer as parameters. It was determined that all parameters had an impact on the porosity of the cement composite, with the polymer type being the most influential parameter.

Keywords- Cement, Concrete Composite, Carbon-Based Materials, Waste Polymer, Taguchi.

I. INTRODUCTION

Concrete remains one of the most widely used construction materials due to its high compressive strength, durability, and affordability. However, its performance is largely dependent on factors such as raw material composition, water-cement ratio, and internal pore structure. Among these, porosity plays a critical role in determining the long-term durability and mechanical properties of cement-based composites. Increased porosity generally leads to higher permeability, lower strength, and greater susceptibility to environmental degradation such as freeze-thaw damage and chemical attack [1, 2].

Advances in nanotechnology have provided new opportunities to enhance the performance of cement-based materials through nanoscale additives [3]. Carbon-based nanomaterials such as graphene oxide (GO), reduced graphene oxide (rGO), and graphene nanoplatelets have attracted considerable attention due to their exceptional surface area, mechanical strength, and chemical stability. These properties allow them to improve the microstructure, reduce pore connectivity, and enhance the mechanical performance of cement composites [4, 5]. Recent studies have shown that adding a small amount of GO can significantly increase

compressive strength, elasticity, and microcracking resistance, particularly through its ability to increase matrix density and interfacial bonding [6].
Meanwhile, plastic waste management remains a significant global environmental problem. Incorporating recycled polymers such as polyethylene terephthalate (PET), acrylonitrile butadiene styrene (ABS), and PC/ABS into cement composites offers an environmentally friendly solution by reducing landfill waste and lowering the total weight of concrete [7]. However, adding polymers alone often leads to reductions in mechanical strength due to poor interfacial bonding within the cement matrix [8]. To offset this effect, combining polymer waste with nanoadditives has been proposed as a promising strategy to achieve a synergistic effect that increases microstructural compactness while maintaining environmental sustainability [9].
This study investigates the combined effect of waste polymers and carbon-based nanomaterials on the porosity of cement composites. An experimental design based on the Taguchi method was employed, utilizing an $L_9(3^4)$ orthogonal array to systematically analyze the influence of four parameters: polymer type, polymer content, nanomaterial type, and nanomaterial content.

II. MATERIALS AND METHOD

The graphene oxide used in the experiment, the chemicals used for the production of reduced graphene oxide, and the graphene nanopellets were of analytical grade. CEM II/A-LL grade Portland cement (42.5R) and MasterGlenium 608 superplasticizer, both conforming to the ASTM C150 standard, were used. Waste polymers were supplied by various companies. Graphene oxide was produced using the Hummers method [10, 11], while reduced graphene oxide was obtained by reducing graphene oxide (produced via the Hummers method) using an ascorbic acid-based reducing agent [12].

The Taguchi method was employed as an effective experimental design approach that utilizes orthogonal arrays to determine the optimal combinations of factor levels, aiming to reduce the number of experiments and associated costs while improving product quality and accelerating the development process. An $L_9(3^4)$ orthogonal array was prepared according to the conditions designed based on the Taguchi experimental design. The nanomaterial type (graphene oxide, reduced graphene oxide, and graphene nanopellet) and amount, as well as the polymer type (PET, ABS, PC/ABS) and amount, were considered as parameters. The parameters and their levels are presented in Table 1, while the experimental plan is provided in Table 2. The experimental steps performed according to these parameters are illustrated in Figure 1.

Table 1. Parameters and levels determined for concrete mortar

SYMBOL	**PARAMETER**	**LEVELS**		
		1	**2**	**3**
A	Polymer Type	PET	ABS	PC/ABS
B	Polymer Amount (%)	0.5	1	1.5
C	Nano material Type (%)	GO	rGO	GNPs
D	Nano materials amount (%)	0.01	0.05	0.1

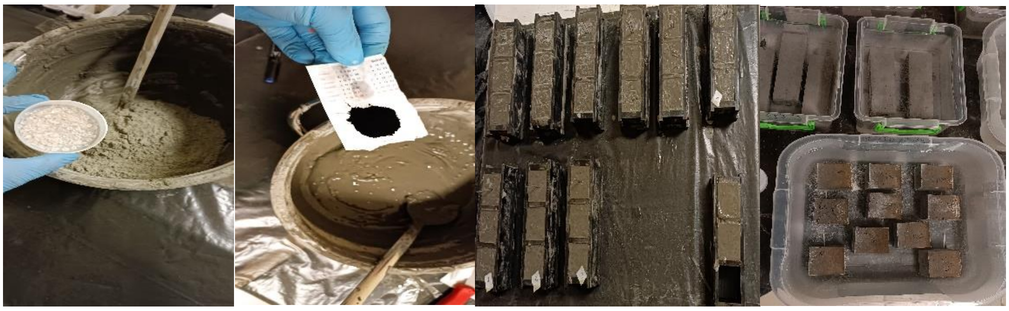

Fig. 1 Images of concrete mortar tests

III. RESULTS AND DISCUSSION

The experiments were conducted using the Taguchi optimization technique, following a four-parameter, three-level, nine-trial experimental plan. The experimental plan, prepared according to the $L_9(3^4)$ Taguchi orthogonal array design, along with the 28-day porosity results for the concrete samples (tested in duplicates), is presented in Table 2. Analysis of variance (ANOVA) was performed on the porosity results in Table 2, applying the "smaller-the-better" criterion to evaluate the effectiveness of the parameters on porosity.

Table 2. Experimental plan and 28-day porosity results in duplicate concrete samples

	Parameter Levels				**% Porosity Values**		
Exp. No	**Polymer Type**	**Polymer Amount**	**Nanomateri al Type**	**Nanoma terial Amount**	**%Porosity 1st Series**	**%Porosity 2nd Series**	**Average % Porosity**
1	PET	0.5	GO	0.01	28,1	28	28,1
2	PET	1	rGO	0.05	28,1	28,2	28,15
3	**PET**	**1.5**	**GNPs**	**0.1**	**27,8**	**27,9**	**27,85**
4	ABS	0.5	rGO	0.1	28,4	28,4	28,4
5	ABS	1	GNPs	0.01	28,1	28	28,05
6	ABS	1.5	GO	0.05	28,9	28,8	28,85
7	PC/ABS	0.5	GNPs	0.05	30,1	30,2	30,15
8	PC/ABS	1	GO	0.1	28,4	28,5	28,45
9	PC/ABS	1.5	rGO	0.01	29,4	29,4	29,4

In the analysis of variance (ANOVA) table (Table 3), the p-value indicates the level of statistical significance. A p-value less than 0.005 suggests that the effect of a factor or parameter on the dependent variable is statistically significant. Since all our parameters have p-values below 0.005, they are considered statistically significant. The highest contribution to porosity was observed for the polymer type at 59.66%, followed by the nanomaterial amount at 22.85%, the polymer amount at 15.10%, and the nanomaterial type at 2.10%. As the aim was to achieve low porosity in cement composites, the "smaller-the-better" principle was applied in the Taguchi design. Under this criterion, experimental condition number 3 (PET polymer, 1.5% polymer amount, GNP nanomaterial type, and 0.1% GNP amount) yielded the best results.

Table 3. Analysis of variance (ANOVA) of porosity percentage values

	Parameters	Segq SS (SDi)	Adj. SS (SSi)	Adj. MS (MSi)	Contribution (%)	p-Value	F-Value
A	Polymer Type	2	5,43444	2,71722	59,66	0,000	698,71
B	Polymer Amount	2	1,36778	0,68389	15,01	0,000	175,86
C	Nanomaterial Type	2	0,191111	0,09556	2,10	0,0000	24,57
D	Nanomaterial Amount	2	2,08111	1,04056	22,85	0,000	267,57
	Error	9	0,035000	0,00389	0,38		
	Total	17	9,10944		100		

According to the Main Effects Plot in Figure 2, the optimal points were identified as PET for the polymer type, 1% for the polymer amount, GO for the nanomaterial type, and 0.1% for the nanomaterial amount. However, since these optimal conditions were not included in the experimental plan, an additional verification experiment was conducted under the specified conditions. As a result of the verification experiment, the porosity value decreased as expected and was measured as 27.3%, and this value was found to be lower than the results obtained in the experimental plan.

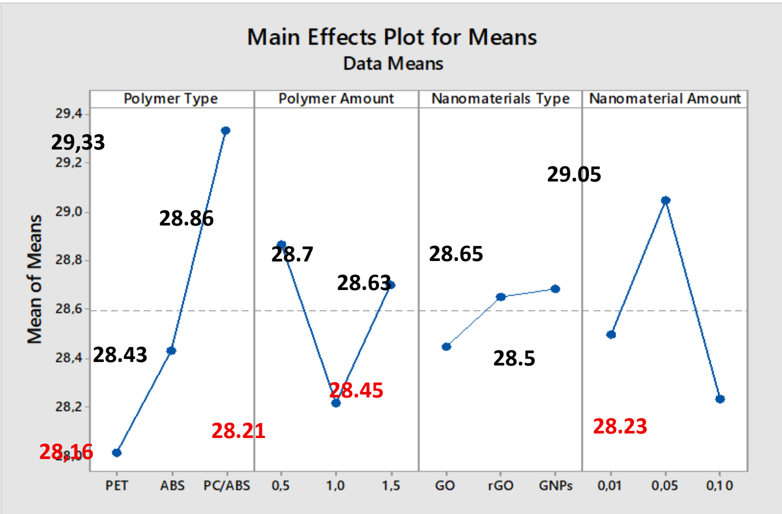

Fig. 2 Effect of waste polymer and nanomaterials on porosity in concrete composites and performance statistics of parameters

The recovery rates for the nine experiments compared to the reference sample are presented in Table 4. Among these results, the highest recovery rate, 10.73%, was observed in experiment 3. Furthermore, the verification experiment revealed that the recovery rate increased to 12.5%.

Table 4. Improvement rates between optimum and reference material properties in concrete composite experiments of waste polymer and nanomaterials

Experiment Number		Reference Concrete	*Results	Recovery Rate (%)
Concrete tests and recovery rates of waste polymers and nanomaterials	Experiment 1	31.2	28,1	9,93[a]
	Experiment 2	31.2	28,15	9,77
	Experiment 3	31.2	27,85	10,73
	Experiment 4	31.2	28,4	8,97
	Experiment 5	31.2	28,05	10,09
	Experiment 6	31.2	28,85	7,53
	Experiment 7	31.2	30,15	3,36
	Experiment 8	31.2	28,45	8,81
	Experiment 9	31.2	29,4	5,76

Calculation of the % recovery rate for the experiment conducted under optimum conditions
Reference experiment
[a]((31,2-28,1) / 31,2)*100 = -9,93

IV. CONCLUSION

This study investigated the effects of waste polymers and carbon-based nanomaterials on the porosity of cement composites. Experiments were conducted using the Taguchi $L_9(3^4)$ orthogonal array, and the following findings were obtained:

- All parameters (polymer type and amount, nanomaterial type and amount) influenced the porosity of cement composites.
- According to the ANOVA results, polymer type was the most significant factor, accounting for 59.66% of the variation, followed by nanomaterial amount and polymer amount.
- Based on the "smaller-the-better" principle, the optimal conditions were identified as PET polymer, 1% polymer content, GO nanomaterial, and 0.1% nanomaterial content.
- As a result of the verification experiment, the porosity value decreased to 27.3%, providing a 12.5% improvement compared to the reference sample.
- Carbon-based nanomaterials effectively mitigated the potential increase in porosity caused by polymer addition by filling the pore structure within the cement matrix and enhancing the microstructure. This indicates a synergistic effect in counteracting the negative impact of polymer incorporation.

The results demonstrate that combining waste polymers with nanomaterials is a significant approach for achieving both environmental sustainability and optimizing the performance of cement composites.

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