International Journal of Multidisciplinary Academic Studies and Research (IJMASR)
Registered with MSME, Govt. of India: UDYAM-MH-20-0329275
Available at https://ijmasr.org Volume-1, Issue-4, April 2026, Page-249-258.

To Cite This Article
Manish R. Polampalli, & Mr. Shriniwas V. Rayadu. (2026). Experimental Study on the Development of Optimum Concrete Mix Proportion using Ultrafine Materials. International Journal of Multidisciplinary Academic Studies and Research (IJMASR), 1(4), 249–258. https://doi.org/10.5281/zenodo.20260892

Article Info
Received: 20th April 2026, Accepted: 23rd April 2026, Published: 24th April 2026.

Experimental Study on the Development of Optimum Concrete Mix Proportion using Ultrafine Materials

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Abstract- The present study focuses on the "Experimental Study on the Development of Optimum Concrete Mix Proportion using Ultrafine Materials" for M30 grade concrete. The main objective of the research work was to investigate the effect of ultrafine materials such as Ultrafine Material (UF), UF100 and Microsilica on the compressive strength characteristics of concrete and to identify the optimum replacement percentage for achieving maximum strength and economy. Cement was partially replaced with ultrafine materials at different replacement levels of 2.5%, 5%, 7.5% and 10%. The experimental investigation included material testing, mix design as per IS 10262:2019, preparation of concrete specimens, casting, curing and compressive strength testing at 7 days and 28 days. Concrete cube specimens of size 150 mm × 150 mm × 150 mm were tested using Compression Testing Machine (CTM) as per IS 516 recommendations. The results obtained from the experimental investigation indicated that ultrafine materials significantly improved the compressive strength of M30 grade concrete. The improvement in strength was mainly due to better particle packing, reduction of internal voids and enhanced pozzolanic reaction. Among all ultrafine materials, Microsilica showed the best performance. Microsilica at 2.5% replacement achieved maximum average compressive strength of 55.32 MPa at 28 days, which represented 24.39% increase compared to conventional concrete. UF100 at 2.5% replacement also showed excellent performance with comparatively lower cost increase. The study concluded that lower replacement percentages such as 2.5% and 5% produced better results, whereas higher replacement percentages reduced compressive strength due to excessive ultrafine content.

Keywords: Ultrafine materials, High Performance Concrete (HPC), High Strength Concrete (HSC), Optimum mix proportion, Particle packing, Alccofine, Ultrafine GGBS, Fly ash, Silica fume.

I. INTRODUCTION

Concrete is the most widely used construction material in the world due to its excellent engineering properties, versatility, economy and durability. It is used extensively in buildings, bridges, roads, pavements, dams, tunnels, industrial structures and marine structures. Concrete has become an essential material for infrastructure development because of its ability to withstand compressive loads and its suitability for different environmental conditions. In recent years, the construction industry has experienced rapid growth due to urbanization and industrialization. The demand for high-strength, durable and sustainable concrete has increased significantly. Conventional concrete sometimes fails to meet modern performance requirements due to problems such as low tensile strength, permeability, shrinkage cracking and environmental concerns related to excessive cement consumption. The use of ultrafine materials in concrete technology has emerged as an effective solution for improving concrete properties. Ultrafine materials are extremely fine particles having high surface area which improve particle packing density, fill microscopic voids and enhance the microstructure of concrete. The present research focuses on the development of optimum concrete mix proportion using ultrafine materials for M30 grade concrete. The study investigates the effect of Ultrafine Materials, UF100 and Microsilica at different replacement levels on compressive strength and cost effectiveness.

II. RESEARCH METHODOLOGY

The methodology adopted in the present investigation includes:

1. Selection of materials
2. Testing of materials
3. Concrete mix design as per IS 10262:2019
4. Preparation of trial mixes
5. Replacement of cement using ultrafine materials
6. Casting of concrete cubes
7. Curing of specimens
8. Compressive strength testing
9. Analysis of experimental results

The concrete mixes were prepared by partially replacing cement with ultrafine materials at different percentages such as 2.5%, 5%, 7.5% and 10%.

Materials Used in Investigation:

The following materials were used for preparation of M30 grade concrete:

1. Ordinary Portland Cement (OPC 53 Grade)
2. Fly Ash
3. Ultrafine Material
4. Fine Aggregate
5. Coarse Aggregate
6. Water
7. Superplasticizer

Concrete Mix Design:

Concrete mix design for M30 grade concrete was carried out as per IS 10262:2019 guidelines. The mix design process included selection of target strength, water cement ratio, water content and aggregate proportions.

Table 3.1 Stipulations for Mix Design

Parameter	Value
Grade of Concrete	M30
Type of Cement	OPC 53 Grade
Maximum Aggregate Size	20 mm
Exposure Condition	Moderate
Workability	125 ± 25 mm
Method of Placement	Manual/Pumping
Type of Aggregate	Crushed Angular
Degree of Control	Good
Admixture Type	Superplasticizer

The target mean compressive strength was calculated using IS 10262:2019.
The target strength equation is:

$$f'_{ck} = f_{ck} + 1.65S$$

Where:

- f'_{ck}= Target Mean Strength
- f_{ck}= Characteristic Strength

- *S*= Standard Deviation

For M30 grade concrete:

- Characteristic strength = 30 MPa
- Standard deviation = 5 MPa

Therefore,
Target Mean Strength = 38.25 MPa.

Table 3.2 Target Strength Calculation

Parameter	Value
Characteristic Strength	30 MPa
Standard Deviation	5 MPa
Target Mean Strength	38.25 MPa

Table 3.3 Water Cement Ratio Details

Parameter	Value
Maximum W/C Ratio	0.50
Selected W/C Ratio	0.363

Table 3.4 Water Content Calculation

Parameter	Value
Initial Water Content	186 kg
Estimated Water Content	203 kg
Water Reduction	23%
Final Water Content	156 kg

Trial Mix Proportions:
Different trial mixes were prepared using ultrafine materials.

Table 3.5 Mix Proportion for Traditional Mix

Material	Quantity (kg/m³)
Cement	323
Fly Ash	108
Ultrafine	0
20 mm Aggregate	691
10 mm Aggregate	436
Crushed Sand	547
River Sand	230
Water	156

Table 3.6 Mix Proportion for 2.5% Ultrafine Replacement

Material	Quantity (kg/m³)
Cement	312
Fly Ash	108
Ultrafine	11
20 mm Aggregate	690
10 mm Aggregate	436
Crushed Sand	546
River Sand	230
Water	156

Table 3.7 Mix Proportion for 5% Ultrafine Replacement

Material	Quantity (kg/m³)
Cement	301
Fly Ash	108
Ultrafine	22
20 mm Aggregate	689
10 mm Aggregate	435
Crushed Sand	546
River Sand	230
Water	156

Table 3.8 Mix Proportion for 7.5% Ultrafine Replacement

Material	Quantity (kg/m³)
Cement	290
Fly Ash	108
Ultrafine	32
20 mm Aggregate	688
10 mm Aggregate	434
Crushed Sand	545
River Sand	229
Water	156

Table 3.9 Mix Proportion for 10% Ultrafine Replacement

Material	Quantity (kg/m³)

Cement	280
Fly Ash	108
Ultrafine	43
20 mm Aggregate	687
10 mm Aggregate	434
Crushed Sand	544
River Sand	229
Water	156

III. RESULTS AND DISCUSSION

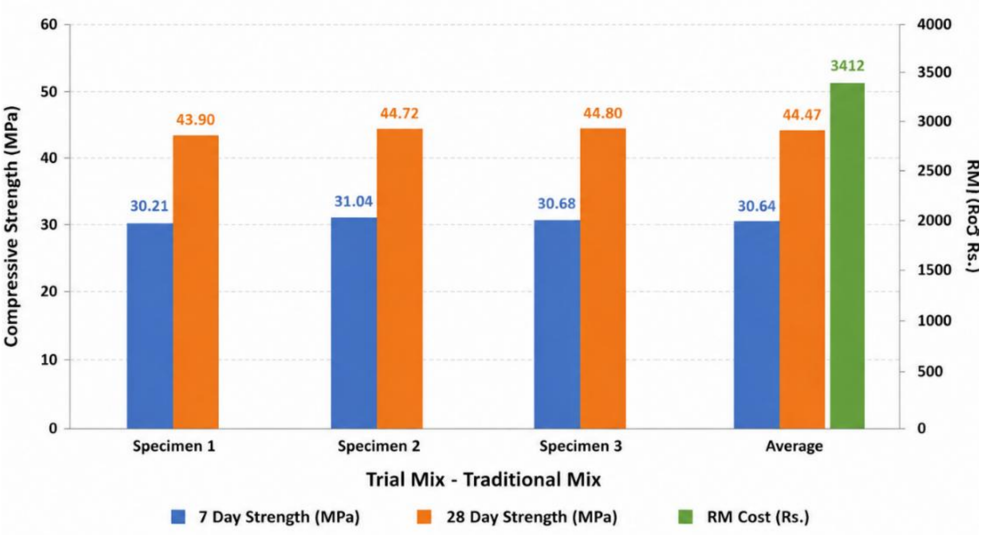
Compressive Strength Results:

The compressive strength results obtained from the present experimental investigation are presented and discussed in this section. Compressive strength is one of the most important properties of concrete because it indicates the load carrying capacity and overall quality of hardened concrete. In the present study, compressive strength testing was carried out on concrete cube specimens of size 150 mm × 150 mm × 150 mm using Compression Testing Machine (CTM) as per IS 516 guidelines. The concrete specimens were tested after 7 days and 28 days of water curing to evaluate both early-age strength and final compressive strength characteristics of M30 grade concrete containing ultrafine materials.The experimental program included preparation of conventional concrete mix and modified concrete mixes containing Ultrafine Material (UF), UF100 and Microsilica at different replacement percentages such as 2.5%, 5%, 7.5% and 10% by weight of cement. Three specimens were tested for each mix proportion and average compressive strength values were calculated to obtain accurate and reliable results. The compressive strength results obtained from different trial mixes clearly indicated that the addition of ultrafine materials significantly affected the strength characteristics of concrete.The conventional concrete mix without ultrafine materials achieved an average compressive strength of 30.64 MPa at 7 days and 44.47 MPa at 28 days. These values satisfied the target strength requirement for M30 grade concrete and were considered as reference values for comparison with modified concrete mixes. The inclusion of ultrafine materials improved the particle packing density and reduced the internal voids within the concrete matrix, resulting in higher compressive strength compared to traditional concrete.Among all ultrafine concrete mixes, lower replacement percentages such as 2.5% and 5% showed significant improvement in compressive strength. The ultrafine material concrete with 2.5% replacement achieved an average 28-day compressive strength of 52.69 MPa which represented 18.48% increase over conventional concrete. Similarly, UF100 with 2.5% replacement achieved an average strength of 52.18 MPa, showing considerable improvement in strength characteristics with relatively lower cost increase.The best performance among all trial mixes was observed in Microsilica concrete. Microsilica at 2.5% replacement achieved the maximum average 28-day compressive strength of 55.32 MPa which represented 24.39% increase over traditional concrete.

The superior performance of microsilica concrete was mainly due to its extremely fine particle size and high pozzolanic activity. The ultrafine microsilica particles effectively filled microscopic voids between cement particles and aggregates, producing a dense and compact concrete structure. Additionally, the pozzolanic reaction between microsilica and calcium hydroxide generated additional calcium silicate hydrate gel which further enhanced the strength of concrete.The compressive strength results also indicated that excessive replacement of cement using ultrafine materials adversely affected concrete strength. At higher replacement levels such as 7.5% and 10%, the compressive strength values gradually decreased. This reduction in strength occurred because excessive ultrafine content reduced effective cementitious material available for hydration and also affected workability and compaction of concrete. In UF100 concrete, the 10% replacement level showed significant reduction in strength and produced lower compressive strength than conventional concrete.

Table 4.1 Compressive Strength Results of Traditional Mix

Trial Mix	7 Day Strength (MPa)	7 Day Average (MPa)	28 Day Strength (MPa)	28 Day Average (MPa)	RM Cost	% Strength Change	% Cost Increase
Traditional Mix	30.21		43.90				
	31.04	30.64	44.72	44.47	3412	0.00	0.00
	30.68		44.80				



Graph 4.1 Compressive Strength Results of Traditional Mix

Discussion:

1. The conventional M30 concrete achieved an average compressive strength of 30.64 MPa at 7 days and 44.47 MPa at 28 days.
2. These results satisfied the target strength requirements for M30 grade concrete and were used as reference values for comparison with ultrafine concrete mixes.

Table 4.2 Compressive Strength Results for 2.5% Ultrafine Replacement

Trial Mix	7 Day Strength (MPa)	7 Day Average	28 Day Strength (MPa)	28 Day Average	RM Cost	% Strength Increase	% Cost Increase
UF 2.5%	39.18		53.35				
	38.39	38.83	52.15	52.69	3518	18.48	3.11
	38.92		52.57				

Discussion:

1. The concrete mix containing 2.5% ultrafine replacement showed significant improvement in compressive strength compared to conventional concrete.
2. The average 28-day compressive strength increased to 52.69 MPa which represents 18.48% increase over traditional concrete.
3. This improvement occurred due to better particle packing and void filling action of ultrafine particles.

Table 4.3 Compressive Strength Results for 5% Ultrafine Replacement

Trial Mix	7 Day Strength	7 Day Average	28 Day Strength	28 Day Average	RM Cost	% Strength Increase	% Cost Increase
UF 5%	37.88		51.44				
	38.85	37.51	50.38	50.87	3626	14.39	6.27
	35.80		50.80				

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Discussion:

1. At 5% replacement level, the ultrafine concrete showed average 28-day compressive strength of 50.87 MPa.
2. Although strength improvement was observed, it was slightly lower than the 2.5% replacement mix. The percentage strength increase was 14.39%.

Table 4.4 Compressive Strength Results for 7.5% Ultrafine Replacement

Trial Mix	7 Day Strength	7 Day Average	28 Day Strength	28 Day Average	RM Cost	% Strength Increase	% Cost Increase
UF 7.5%	28.90		47.69				
	26.00	27.85	48.98	48.30	3716	8.60	8.91
	28.65		48.23				

Discussion:

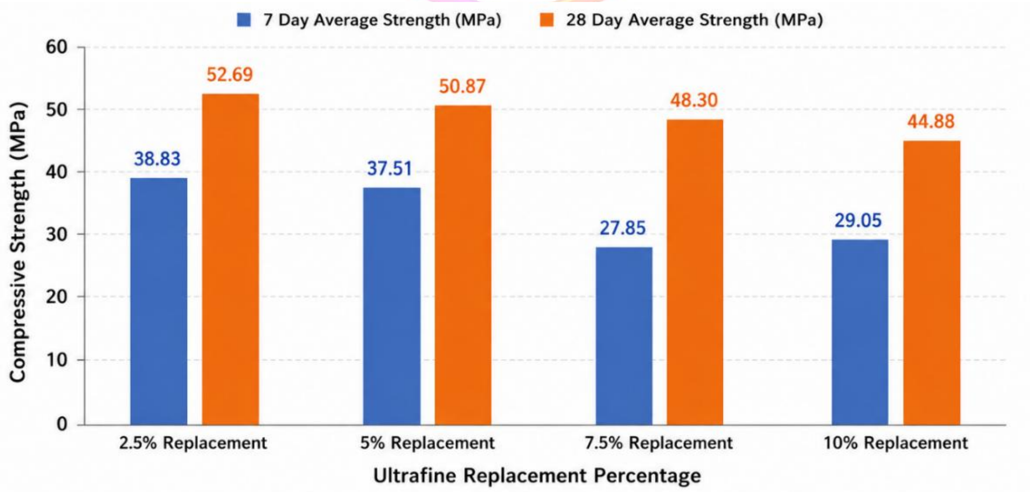
1. The strength values reduced at 7.5% replacement due to excessive ultrafine content.
2. Higher replacement reduced effective cementitious material and affected hydration process.

Table 4.5 Compressive Strength Results for 10% Ultrafine Replacement

Trial Mix	7 Day Strength	7 Day Average	28 Day Strength	28 Day Average	RM Cost	% Strength Increase	% Cost Increase
UF 10%	29.97		45.96				
	27.04	29.05	43.80	44.88	3814	0.91	11.78
	30.14		44.87				

Discussion:

1. At 10% replacement, compressive strength was almost similar to conventional concrete.
2. Excessive ultrafine material negatively affected workability and hydration efficiency.



Graph 4.2 Compressive Strength Results for 2.5%, 5%, 7.5% and 10% Ultrafine Replacement

Table 4.6 Compressive Strength Results for UF100 2.5%

Trial Mix	7 Day Avg	28 Day Avg	RM Cost	% Strength Increase	% Cost Increase
UF100 2.5%	39.69	52.18	3463	17.33	1.49

Discussion:

1. UF100 at 2.5% replacement showed excellent strength improvement with comparatively low-cost increase.
2. The average 28-day strength reached 52.18 MPa.

Table 4.7 Compressive Strength Results for UF100 5%

Trial Mix	7 Day Avg	28 Day Avg	RM Cost	% Strength Increase	% Cost Increase
UF100 5%	35.63	49.19	3516	10.61	3.05

Discussion:

1. The strength decreased compared to 2.5% replacement but remained higher than conventional concrete.

Table 4.8 Compressive Strength Results for UF100 7.5%

Trial Mix	7 Day Avg	28 Day Avg	RM Cost	% Strength Change	% Cost Increase
UF100 7.5%	31.80	42.83	3556	-3.70	4.22

Discussion:

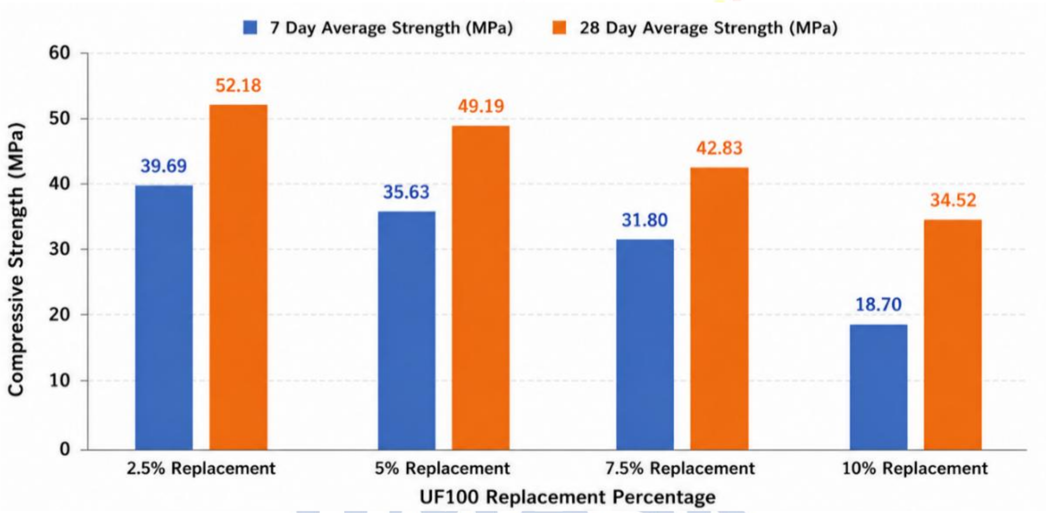
1. The strength reduced below conventional concrete indicating excessive replacement.

Table 4.9 Compressive Strength Results for UF100 10%

Trial Mix	7 Day Avg	28 Day Avg	RM Cost	% Strength Change	% Cost Increase
UF100 10%	18.70	34.52	3604	-22.38	5.63

Discussion:

1. Significant reduction in strength was observed at 10% replacement due to inadequate cement hydration and excessive ultrafine content.



Graph 4.3 Compressive Strength Results for 2.5%, 5%, 7.5% and 10% UF100 replacement

Table 4.10 Compressive Strength Results for Microsilica 2.5%

Trial Mix	7 Day Avg	28 Day Avg	RM Cost	% Strength Increase	% Cost Increase
Microsilica 2.5%	37.70	55.32	3551	24.39	4.07

Discussion:

1. Microsilica at 2.5% replacement showed maximum compressive strength among all mixes. The average 28-day strength reached 55.32 MPa which represents 24.39% increase over conventional concrete.
2. The improved strength was mainly due to high pozzolanic activity and excellent particle packing of microsilica.

Table 4.11 Compressive Strength Results for Microsilica 5%

Trial Mix	7 Day Avg	28 Day Avg	RM Cost	% Strength Increase	% Cost Increase
Microsilica 5%	39.49	53.03	3692	19.24	8.21

Discussion:

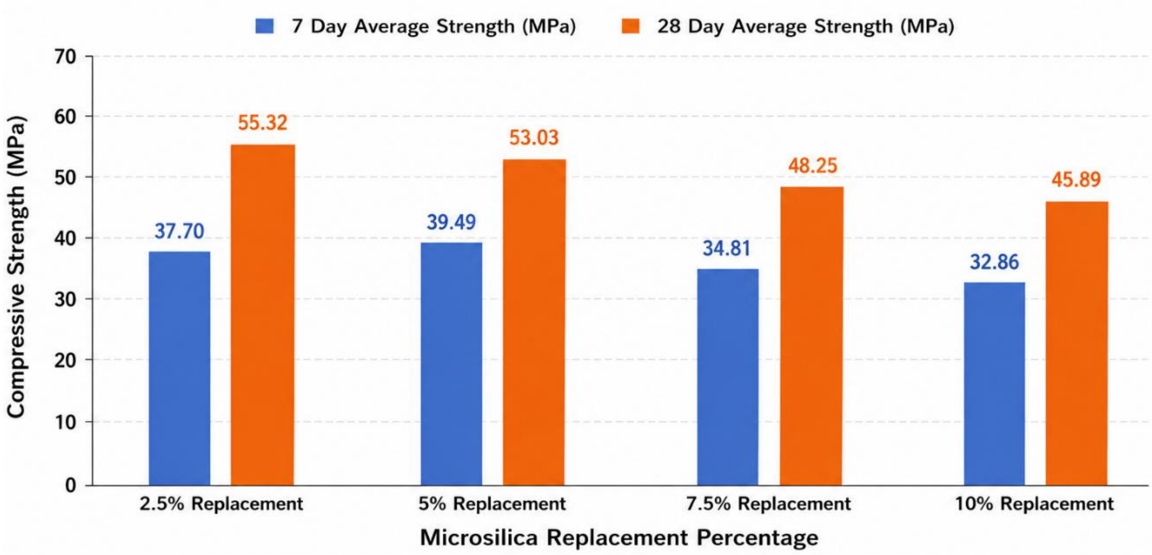
1. Excellent strength improvement was observed at 5% replacement. However, strength was slightly lower than 2.5% replacement.

Table 4.12 Compressive Strength Results for Microsilica 7.5%

Trial Mix	7 Day Avg	28 Day Avg	RM Cost	% Strength Increase	% Cost Increase
Microsilica 7.5%	34.81	48.25	3812	8.49	11.72

Table 4.13 Compressive Strength Results for Microsilica 10%

Trial Mix	7 Day Avg	28 Day Avg	RM Cost	% Strength Increase	% Cost Increase
Microsilica 10%	32.86	45.89	3940	3.18	15.47



Graph 4.4 Compressive Strength Results for 2.5%, 5%, 7.5% and 10% Microsilica replacement

CONCLUSION

Based on the experimental investigation carried out on M30 grade concrete using ultrafine materials such as Ultrafine Material (UF), UF100 and Microsilica, the following conclusions are drawn:

1. The use of ultrafine materials significantly improved the compressive strength characteristics of M30 grade concrete.
2. Ultrafine particles improved particle packing density and reduced microvoids present inside the concrete matrix.
3. The conventional concrete mix achieved average compressive strengths of 30.64 MPa at 7 days and 44.47 MPa at 28 days.
4. Ultrafine Material (UF) at 2.5% replacement showed considerable strength improvement and achieved 52.69 MPa average compressive strength at 28 days.
5. UF100 at 2.5% replacement achieved 52.18 MPa compressive strength with comparatively lower cost increase.
6. Microsilica showed the best performance among all ultrafine materials used in the investigation.
7. Microsilica at 2.5% replacement achieved maximum average compressive strength of 55.32 MPa at 28 days.
8. The percentage strength increase for Microsilica 2.5% replacement was found to be 24.39% compared to conventional concrete.
9. Lower replacement percentages such as 2.5% and 5% produced better compressive strength results than higher replacement percentages.
10. Higher replacement percentages such as 7.5% and 10% reduced concrete strength due to excessive ultrafine content and reduction in effective cementitious material.
11. The addition of ultrafine materials slightly increased the material cost of concrete, but the strength improvement obtained was much higher than the percentage cost increase.

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