Effect of Brick Powder and Stone Dust on Mechanical Properties of Self-Compacting Concrete

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Abstract

In past few decades, industrial waste and cement production on a huge scale has presented a serious problem worldwide. Adequate actions should be taken to control air and land contamination resulting from cement manufacturing and waste material on a huge scale by industries. The purpose of this study is to use brick powder and stone dust, which are waste products, in self-compacting concrete (SSC) and analyze their effects on concrete's mechanical properties. For this purpose, 5 %, 10 % and 15 % cement was replaced by brick powder and 10 % and 20 % sand was replaced by stone dust. Workability, air content and density of fresh concrete were investigated along with compressive strength, splitting tensile strength, and flexural strength for hardened concrete. Results showed that brick powder and stone dust addition led to the decreased workability of concrete. Compressive, flexural and split tensile strength increased with raising brick powder content at fixed proportion of stone dust with a maximum increase of 12.7 %, 11 % and 9 % respectively. It would prove to be cost- effective and eco sustainable solution to use industrial waste in concrete as substitute for cement and sand.

Keywords: *Self-compacting concrete, industrial waste, brick powder, stone dust, fresh properties, mechanical properties.*

Introduction

Cement acts as binder material and is the main ingredient of concrete. Pakistan produces 45 million tons of cement annually, despite being an important material for the development of country; it has several harmful effects on our environment. Huge amount of carbon dioxide (CO_2) is generated during cement manufacturing process (Bakhtyar et al., 2017), that is released in to our surroundings and adversely affect the nature. It is reported that cement industry accounts for around 6% of total CO_2 produced worldwide (Imbabi et al., 2012).

Industries produces products which are necessary for the healthy living, however industrial productions lead to production of waste

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materials, which are considered as a burden because of inadequate dumping locations, particularly in small cities and insufficient disposal system. They are the cause of land and air pollution. Efforts need to be made to utilize these waste materials (Fernandes et al., 2004, Berndt, 2009). To reduce these environmental contaminations, investigations are being carried out by researchers to utilize these wastes in concrete because of concrete's composite nature. Using brick powder as substitute of cement, it is concluded that with increasing percentage of substitution, fresh concrete density and slump of concrete decreases (Ge et al., 2015).

A previous research used brick waste in various proportions as replacement of coarse aggregate and observed slump to be decreasing with increasing replacement content (Khalil and Al-daebal, 2018). On the other side, when brick powder was used as sand substituent, air content increased (Nayel et al., 2018). Thus brick powder doesn't have desirable impacts on the workability and air content of concrete.

However, using grounded bricks in concrete up to 20 % increased its compressive and flexural strength (Rani and Jenifer, 2016). Another researcher replaced natural aggregates by crushed bricks. Results concluded that crushed bricks can be used as aggregate substitution without decreasing concrete strength up to 15% (Cachim, 2009). A previous study investigated the feasibility of utilizing waste brick powder. Cement was substituted with waste brick powder in various proportions up to 40% by weight. Compressive strength and pozzolanic properties of waste brick powder were investigated. Results revealed that brick powder shows pozzolanic qualities (Heidari and Hasanpour, 2013). Bricks are produced of clay that contains a good quantity of silica and aluminum, so finely powdered can be used as a replacement for some quantity of cement because they are pozzolanic in nature (Roger, 2011). This brick powder can be utilized in concrete for some strength improvements.

Self-compacting concrete (SSC) is highly workable concrete capable of flowing by its weight, without the need of compaction (ACI Committee Report 237R-07, 2007). As compared to normally vibrated concrete, SSC offers several benefits such as enhanced workability, less labor requirements, ease of placement, fast progress of concreting process etc. SSC mix design is different from normal concrete i.e. increased quantity of fine aggregates as compared to coarse aggregates (Diederich et al., 2013). SSC comprises of greater powder quantity acting as filler to enhance concrete workability. Other than being inexpensive, increased use of cement as powder negatively influence our environment. Because cement is major expensive ingredient, decreasing its amount by using industrial wastes e.g. fly ash, rice husk ash and blast furnace slag etc would result in decreasing concrete cost and adverse effect on environment (Bauzoubaa and Lachemi, 2001). Addition of fine powder in SSC such as lime stone powder, fly ash and glass powder results in better workability (Valcuende et al., 2012). Iqbal et. al. studied SSC characteristics by adding fly ash in various proportions and reported in achieving SSC with improved properties (Iqbal et al., 2017). By utilizing limestone and marble powder in SSC as filler, researchers reported improved concrete properties (Gesoglu et al., 2012).

Numerous scientific studies have already been performed previously to study the influence of substitution of River sand with stone dust. A previous study reported that partial substitution of sand by stone dust contributes in declining slump, though, a considerable betterment in mechanical properties (Celik and Marar, 1996). There is substantial decrease in concrete expenditure without compromising on its properties (Ilangovan, 2010). It was concluded that concrete produced with the inclusion of rock dust gained mechanical and durability properties almost 14% higher than reference concrete (Shahul and Sekar, 2009).

Replacing sand by stone dust in various proportions, it is reported that 5% stone dust achieved highest compressive strength and split tensile strength, further stone dust can be used up to 15% without major loss in strength (Almeida et al., 2007). Another researcher replaced sand and cement with quarry dust and marble powder in various proportions and stated that improvement in compressive, flexural and split tensile strength was observed at 10% marble powder and 10% stone dust replacement (N. Bheel et al., 2020). Replacing sand by rock dust by 3.5%, 7%, 10.5%, and 14%, there is increase in compressive strength up to 7% replacement levels and then strength decreases (Zhuo et al., 2008). As, there are some beneficial and undesirable impacts of brick powder and stone dust addition into concrete as cement and sand replacements, it would be desirable to develop SCC using these waste materials and investigate their impacts on SCC properties.

Objectives

Cement is the major ingredient in producing concrete and is immensely used due to vast construction happening all around the world. However, cement production is energy and natural resources consuming process and during its production, large amount of carbon dioxide and other toxic gases are produced and emitted in to the environment (Imbabi et al., 2012)). On the other hand SCC consists of higher powder content to achieve required workability. For this purpose higher cement content is used, consequently resulting in costly concrete (Bouzoubaa and Lachemi, 2001). Similarly, concrete composition consist of large volume of aggregates, but because of risk of depletion and costly natural materials, construction industries needs to figure out ways to avoid these problems (Wu et al., 2010), one of which is utilization of industrial waste materials in concrete as replacement material.

Industries produce large amounts of waste materials which are mainly dumped and occupy valuable lands. These waste materials are readily available in large quantities and free of cost. Utilizing these wastes in concrete would lead to less costly concrete and reducing environmental contamination. The aim of this research study is to develop SCC using industrial waste materials like brick powder and stone dust as cement and sand replacements and to investigate their impacts on fresh and mechanical properties of resulting concrete. Objectives of this study are:

1. To examine the combined impact of brick powder and stone dust on air content, workability, and fresh concrete density.
2. To examine the combined impact of brick powder and stone dust on compressive, splitting tensile and flexural strength.

The mix design of SCC was finalized using EFNARC guidelines (EFNARC, 2002) and performing trial mixes. Total of 7 numbers of concrete mixtures were developed comprising 5%, 10% and 15% brick powder and 10%, 20% stone dust substituting cement and fine aggregate.

Materials

Coarse aggregate having maximum size of 16mm and fine aggregates of size ranging from 0-4.75mm were bought from construction materials dealer situated locally. Brick powder was collected from brick kiln and was ball grinded to size of cement. Aggregates and stone dust physical characteristics are provided in table 1. Cement of strength class CEM-I 42.5N was used. Superplasticizer known by the name of "Sika Viscocrete 3110" was used. Brick powder and stone dust used are shown in fig. 1. Chemical properties of brick powder and stone dust are provided in table 2.

Table 1
Physical characteristics of aggregates and stone dust

Material	**Size (mm)**	**Water absorption (%)**	**Specific gravity**
Coarse aggregate (CA)	4.75–16	0.81	2.66
Fine aggregate (FA)	0–4.75	0.82	2.86
Stone dust	0–4.75	1.0	2.63

Table 2
Chemical properties of cement and brick powder

Constituents	Chemical composition							
	Na_2O	**K_2O**	**SO_3**	**MgO**	**Fe_2O_3**	**Al_2O_3**	**SiO_2**	**CaO**
Cement	0.9	0.4	2.9	1.5	3.7	3.4	21.9	65.7
Clay-brick powder	0.01	2.11	13.75	3.29	13.28	14.80	41.30	12.24

Fig. 1: (a) brick powder (b) stone dust

Experimental program

In order to select control mix, trial mixes were performed. Brick powder along with stone dust were used in several proportions, cement substitution of 5%, 10% and 15% whereas 10%, 20% of fine aggregate replacement. The evaluated fresh concrete properties consisted of workability, air content and density. Slump flow test, J-ring test, L-box test and V-funnel test were included in workability properties following ASTM and EFNARC standards. ASTM C138/C138M was used for finding air content and fresh concrete density.

In order to determine the hardened properties, cylindrical concrete specimens of dia 75mm and 150 mm height were casted and cured following ASTM C192/C192M. For conducting compressive strength and split tensile strength tests ASTM C39/C39M and ASTM C496/C496M were followed respectively. At the concrete age of 7 and 28 days, three cylindrical concrete samples were tested for compressive and splitting tensile strength for each concrete mix. Three prism specimens were casted from each concrete mix of dimensions 100 mm x 100 mm x 350 mm and cured as per ASTM C192/C192M for evaluation of flexural strength. Prism specimens were evaluated in four point bending test as specified by ASTM C78/C78M at 7 and 28 days. X-ray diffraction test was carried for determination of various phases in concrete with substituting waste materials. For operating x-ray diffraction analysis current and tube voltage was fixed at 30mA and 40 kV. Scanning electron microscopy was performed to study morphology of concrete sample by generating microscopic pictures of structure.

After finalizing reference mix, brick powder and stone dust was added in different proportions as substituting material for ascertaining their influence on fresh and hardened properties of concrete. Table 3 provides concrete mix designs of all mixtures.

Table 3
Mix design

Mix	w/b ratio	Filler (kg/m^3)	Cement (kg/m^3)	Clay-brick powder (kg/m^3)	Fine aggregate (kg/m^3)	Stone dust (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)	Super plasticizer (kg/m^3)
CM	0.46	100	430	0	960	0	720	243.8	7.95
B5S10	0.46	100	408.5	21.5	864	96	720	243.8	7.95
B5S20	0.46	100	408.5	21.5	768	192	720	243.8	7.95
B10S10	0.46	100	387	43	864	96	720	243.8	7.95
B10S20	0.46	100	387	43	768	192	720	243.8	7.95
B15S10	0.46	100	365.5	64.5	864	96	720	243.8	7.95
B15S20	0.46	100	365.5	64.5	768	192	720	243.8	7.95

Results and discussion

Fresh Concrete Properties

Table 4 provides the results of workability, air content and fresh density. Without any significant difference, density of concrete stayed nearly identical. Brick powder and stone dust has inverse impact on air content of concrete. Higher brick powder quantity led to higher air content of concrete which may because of material’s porous nature while increasing stone dust content caused lowering air content which may be attributed to its ability of filling the gaps within fresh concrete and the results are in agreement with the previous research (Celik and Marar, 1996). Slump flow and J-ring tests are shown in fig. 2. Brick powder and stone dust both contributed in decreasing workability properties of concrete. Decrease in slump flow was proportional to increasing substitution amount, it can be ascribed to porousness and increased water absorption of brick powder as concluded in previous research (Ge et al., 2015) and rough texture as well as presence of greater amount of fines in stone dust because crushing and cutting process with extra water requirement (Mir, 2015). Identical results were obtained in J-ring, V-funnel and L-box test.

Fig. 2: (a) slump flow (b) j-ring test

Table 4
Fresh Properties

Mix	Slump flow (mm)	J-ring value (mm)	V-funnel time (Sec)	L-box value	Density (kg/m^3)	Air content (%)
CM	726	718	8	1	2375	3.28
BP5S10	716	707	8.6	0.94	2369	3.05
BP5S20	694	682	9.3	0.87	2365	2.91
BP10S10	682	670	10.4	0.84	2362	3.42
BP10S20	690	674	10.2	0.86	2357	3.36
BP15S10	671	662	10.7	0.83	2354	3.61
BP15S20	665	658	11.2	0.81	2347	3.75

Hardened properties

Results of hardened properties of concrete on 7 and 28 days of curing are provided in table 5.

Table 5
Mechanical properties of concrete

Mix	Compression strength MPA		Splitting tensile strength MPA		Flexural strength MPA	
	7 days	28 days	7 days	28 days	7 days	28 days
CM	17.4	26.34	2.32	3.7	3.42	4.79
B5S10	18.2	29.15	2.43	3.96	3.65	5.31
B5S20	16.54	26.96	2.34	3.74	3.5	4.98
B10S10	19.14	30.17	2.48	4.16	3.56	5.14
B10S20	17.67	27.78	2.36	3.84	3.33	4.93
B15S10	18.1	27.41	2.37	3.89	3.54	5.07
B15S20	15.48	24.33	2.11	3.44	3.12	4.48

Compressive strength

Compressive strength results are graphically presented in fig. 3. At early age i.e. 7 days, results showed improved compressive strength with all substitute proportions of brick powder at steady amount of stone dust of 10%, and compressive strength reduction was noted while raising stone dust content to 20%. Concrete mix B10S10 presented maximum gain in strength by 9 %. The strength gain pattern changes for longer curing days. At 28 days, all concrete mixes with the presence of brick powder presented improved strength than at early age. Almost all concrete specimens attained improved strength as compared to control mix other than mix B15S20. The highest increase in strength was recorded at B10S10 by 12.7%. A previous researcher commented that brick powder contains silicates that react with calcium hydroxide resulting in extra calcium silicate hydrate (CSH) production which causes decreasing porosity, hence this factor helps in attaining improved strength in later days (Farrell et al., 2001). Another researcher substituted cement by grounded brick up to 30% in SSC and reported that SSC with 10% brick powder showed maximum compressive strength gain (Kartini et al., 2012). A previous study utilized brick powder as replacement of cement up to 15% and recycled aggregate with natural aggregates up to 30%. Results indicated that brick powder can be used up to 15% in the absence of natural aggregates substitution. Where as in combination, 30% aggregate and 5% cement replacement is suggested (Letelier et al., 2017). However, in this research study concrete mix containing 10% brick powder and 10% stone dust content attained highest strength increase.

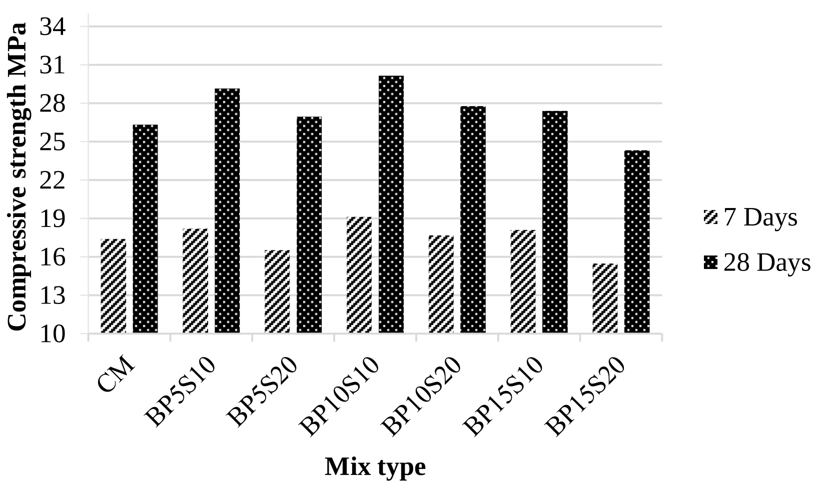

Fig. 3: Compressive strength

Split tensile strength

Splitting tensile strength test results are summarized in fig. 4. Identical strength gain pattern was observed to be in split tensile strength as of compression strength. Results demonstrated improved splitting tensile strength with all replacement proportions of brick powder at steady amount of dust content. However, here is reduction in splitting tensile strength by raising stone dust content.

Maximum gain in splitting tensile strength was obtained by concrete mix B10S10 by 11%. And minimum splitting tensile strength was observed to be of concrete mix B15S20, which was 7% lower than control mix. A study concluded that replacement level of 15% of cement by brick dust resulted in gaining highest splitting tensile strength (Khan et al., 2018). Another research reported increase in split tensile strength up to 10% brick powder replaced with cement (Preeti et al., 2018). In this research study maximum gain in split tensile strength was achieved by concrete mix with 10% brick powder and 10% stone dust.

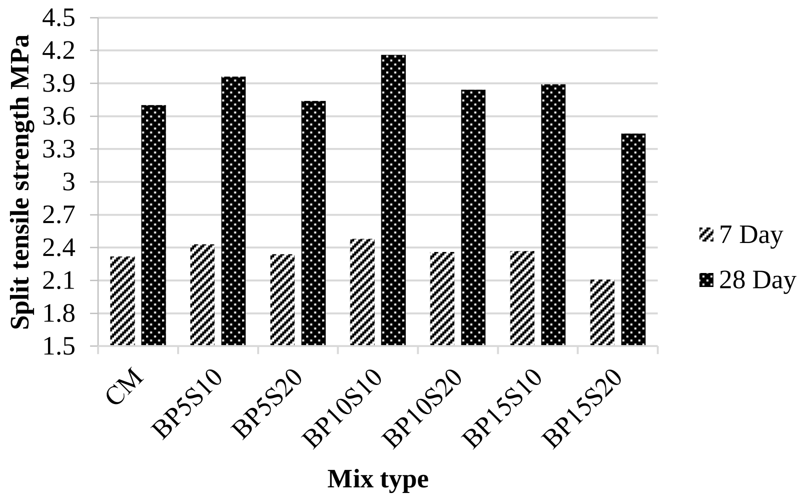

Fig. 4: Splitting tensile strength

Flexural strength

Flexural strength test results are shown in fig. 5. Flexural strength increased by increasing brick powder content at constant stone dust content. Decrease in flexural strength was noted by increasing stone dust content.

The maximum gain in flexural strength was observed for concrete mix B5S10, which was 9% higher than reference concrete at 28 days. And minimum flexural strength was noted for concrete mix B15S20, which was 6.5% lower than control mix. A study reported improvement in flexural strength by 10% cement and 30% natural aggregates replacement by powdered brick and recycled aggregates (Letelier et al., 2017). There is loss in flexural strength with increasing amount of brick powder as replacement of cement (Letelier et al., 2018). In this research work maximum increase in flexural strength was attained by concrete mix with 5% brick powder and 10% stone dust content.

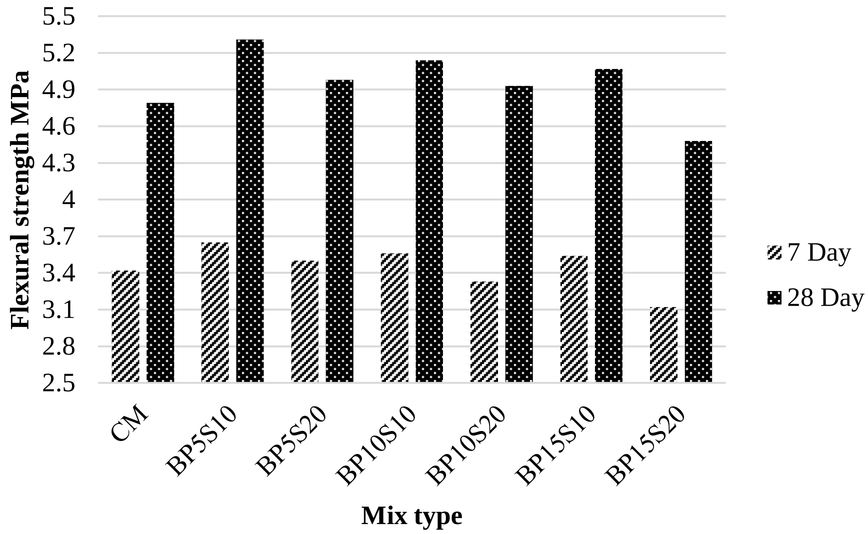

Figure 5: Flexural Strength

Microstructure

Analysis of XRD was carried out to differentiate the stages in concrete. The XRD assessment was conducted on 28 days of curing on reference concrete and B10S10 is shown in fig 6. Control mix (CM) and B10S10 clearly displayed same peaks with distinct intensity levels. The pronounced peaks at 2θ degrees of 18.07, 34.12, 47.09, 50.66, 54.29, and 64.09 due to portlandite (P) (Yousuf et al., 1999). The peaks at 2θ degree ranges of 26.63, 59.85, 67.73, and 68.21 due to quartz (Q). CSH in the graph can be detected by peaks at 31.92˚ and 49.76˚. From the XRD graph it is visible that B10S10 has intense portlandite (CH) and CSH peaks compared to reference mix, demonstrating an enhanced degree of hydrated products.

Scanning electron microscopy analysis of the SSC was conducted at 28 curing days to shows its microstructure. The inner structures which are displayed in SEM micrographs, considerably affect the characteristics of concrete. Figure 7 displays microstructure of control mix and B10S10.

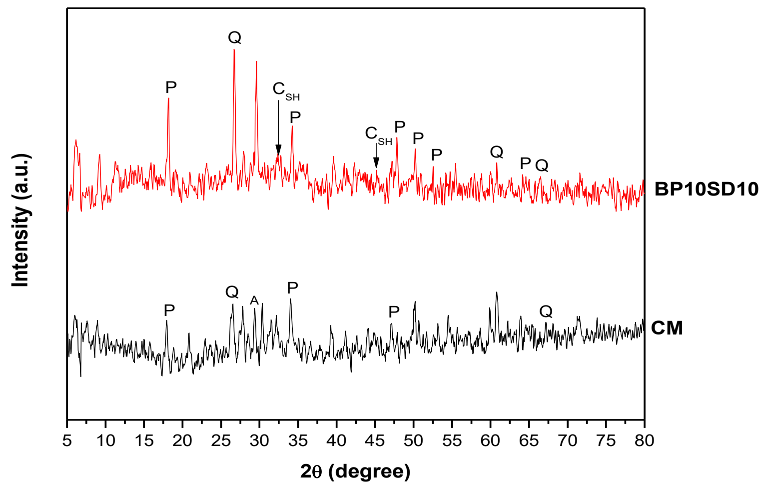

Figure 6: XRD Analysis

It is apparent that mix B10S10 provides more packed, dense and generally improved microstructure showing presence of CSH, crystalline CH, relative with CM. B10S10 gains its enhanced mechanical efficiency by greater quantity of hydrates. Concrete properties are highly dependent on their microstructure; therefore, CSH development and advancement are a significant variable in concrete properties.

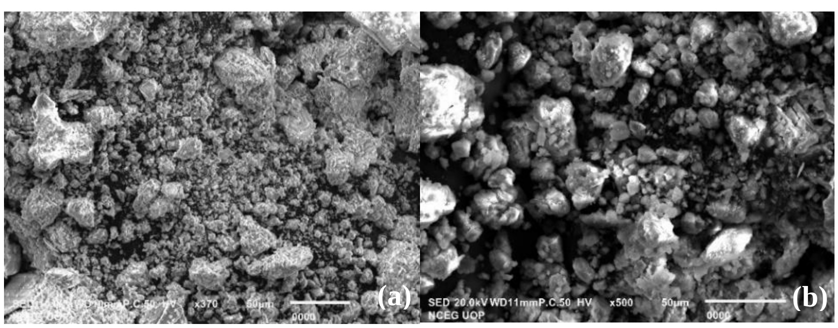

Figure 7: (a) SEM for control mix (b) SEM of BP10SD10

Conclusion

This research study was conducted to evaluate the feasibility of using powdered brick and stone dust in concrete and investigate its influence on fresh and hardened properties of SSC as replacement of cement and fine aggregate. Following are the conclusions of this research work.

- SSC can be produced by utilizing powdered brick and stone dust without undermining mechanical properties of concrete.
- Both powdered brick and stone dust contributed in reducing workability of concrete because of porous nature, high water absorption and rough texture of waste material.
- Compressive strength, flexural strength and splitting tensile strength increased with increasing brick powder content while keeping stone dust content fixed. In later curing days, almost all concrete mixes achieved improved strength because of occurrence of pozzolanic reaction at later stage.
- Compressive strength, flexural strength and splitting tensile strength decreased with increasing stone dust content up to 20%.
- Powdered brick and stone dust can be used in concrete for producing SSC, therefore reducing cement and natural material consumption. This could result in controlling air pollution caused by cement production and land pollution caused by industrial waste materials.

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